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2018 Lower Fraser Valley Air Quality Monitoring Report

SERVICES AND SOLUTIONS FOR A LIVABLE REGION

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Summary

This annual report summarizes the air quality monitoring data collected by the Lower Fraser Valley (LFV) Air Quality Monitoring Network in 2018 and describes the air quality monitoring activities and programs conducted during the year. The main focus is to report on the state of ambient (outdoor) air quality in the LFV.

LFV Air Quality Monitoring Network

The LFV Air Quality Monitoring Network includes 31 air quality monitoring stations located from Horseshoe Bay in West Vancouver to Hope. Metro Vancouver operates 25 stations in Metro Vancouver, as well as 6 stations in the Fraser Valley Regional District (FVRD) in partnership with the FVRD.

Air quality and weather data from all but one station are collected automatically on a continuous basis, transmitted to Metro Vancouver's Head Office in Burnaby, and stored in an electronic database. The data are then used to communicate air pollutant information to the public, such as through air quality health index (AQHI) values and on airmap.ca.

Air quality monitoring stations are located throughout the LFV to provide an understanding of the air quality levels that residents are exposed to most of the time. This report shows how these levels have varied throughout the region in 2018 and how these levels have changed over time. Trends in air quality measured by the Air Quality Monitoring Network are used to evaluate the effectiveness of pollutant emission reduction actions undertaken as part of Metro Vancouver's Clean Air Plan.

Specialized Air Quality Monitoring

In addition to the monitoring network stations, Metro Vancouver deploys portable air quality stations and instruments to conduct specialized monitoring studies. Specialized studies can target suspected problem areas (or "hot spots") at the local, neighbourhood or community level. Specialized studies in 2018 included the initiation of a study at Tsleil-Waututh Reserve Lands in North Vancouver. The purpose of the study is to compare air quality levels to Metro Vancouver's ambient air quality objectives, compare air quality levels to other areas monitored by Metro Vancouver in the region and specifically the Burrard Inlet Area.

Visual Air Quality

Visual air quality (sometimes referred to as visibility or haze) can become degraded in the LFV, causing local views to become partially or fully obscured. Haze may have different characteristics depending on the underlying cause. In parts of Metro Vancouver, especially more urbanized areas to the west, haze can have a brownish appearance due to nitrogen dioxide from transportation emissions. Further east in the LFV, impaired visual air quality can be more associated with a white haze caused by small particles ($PM_{2.5}$) in the air that scatter light.

Monitoring is conducted to assess how and by how much visual air quality has become impaired. Measurements of $PM_{2.5}$, particle constituents (for example, particulate nitrate, particulate sulphate, elemental carbon and organic carbon), nitrogen dioxide and other air contaminants as well as light scattering provide important data for visual air quality management activities. Automated digital cameras operated in seven locations in the LFV record views along specific lines-of-sight. By examining photographs alongside data from monitoring equipment, visual air quality impairment can be related to pollutant concentrations and relevant emissions sources. These activities conducted through a multi-agency collaboration (BC Visibility Coordinating Committee) inform the development of policy options for improving visual air quality.

Pollutants Monitored

Pollutants are emitted to the air from a variety of human activities and natural phenomena. Once airborne, the resulting pollutant concentrations are dependent on several factors, including the weather, topography and chemical reactions in the atmosphere.

Common air contaminants, including ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter are widely monitored throughout the network. Particulate matter is composed of very small particles that remain suspended in the air. They are further distinguished by their size, which is measured in units of a millionth of a metre (or micrometre).

Particles with a diameter smaller than 10 micrometres are referred to as inhalable particulate (PM_{10}), while those smaller than 2.5 micrometres are termed fine particulate ($PM_{2.5}$). Both PM_{10} and $PM_{2.5}$ concentrations are monitored at stations throughout the LFV.

Other pollutants less widely monitored in the network include black carbon (BC), ultrafine particles (UFP), ammonia (NH_3), volatile organic compounds (VOC), and total reduced sulphur compounds (TRS).

Air Quality Health Index (AQHI)

Developed by Environment and Climate Change Canada and Health Canada, the Air Quality Health Index (AQHI) communicates the health risks associated with a mix of air pollutants to the public and provides guidance on how individuals can adjust their exposure and physical activities as air pollution levels change. The AQHI is calculated every hour using monitoring data from stations in the LFV.

Current AQHI levels in the LFV as well as the AQHI forecasts and additional information about the AQHI are available at:

www.airmap.ca
www.env.gov.bc.ca/epd/bcairquality/readings/aqhi-table.xml

Air Quality Objectives and Standards

Several pollutant-specific air quality objectives and standards are used as benchmarks to characterize air quality. They include Metro Vancouver and provincial ambient air quality objectives, and the federal Canadian Ambient Air Quality Standards (for ozone, particulate matter, sulphur dioxide and nitrogen dioxide).

The federal Canadian Ambient Air Quality Standards (CAAQS) have been established as objectives under the Canadian Environmental Protection Act, and replaced Canada-Wide Standards. In 2015, Metro Vancouver adopted a 1-hour interim ambient air quality objective for SO_2 of 75 parts per billion (ppb) prior to establishment of the federal SO_2 CAAQS. After establishment of the federal SO_2 CAAQS, Metro Vancouver's SO_2 objectives were revised in November 2017, with a more stringent 1-hour objective of 70 ppb not to be exceeded and an annual objective of 5 ppb.

In 2019, Metro Vancouver aligned its objectives for CO, NO_2 and O_3 with federal and provincial standards. Metro Vancouver adopted a 1-hour and annual ambient air quality objective for NO_2 that is the same as the federal 2020 CAAQS. Similarly, the 8-hour O_3 objective was made the same as the 2020 CAAQS. The 1-hour and 8-hour CO objectives were set to 13,000 ppb and 5,000 ppb respectively, to match the more stringent Provincial objectives.

Priority Pollutants

Research indicates that adverse health effects can occur at the air contaminant concentrations measured in the LFV. Health experts have identified exposure to ozone and particulate matter as being associated with the most serious health effects. Ozone is a strong oxidant that can irritate the eyes, nose and throat, and reduce lung function. $PM_{2.5}$ particles are small enough to be breathed deeply into the lungs, resulting in impacts to both respiratory and cardiovascular systems. Long-term exposure to these pollutants can aggravate existing heart and lung diseases and lead to premature mortality.

Of particular concern is $PM_{2.5}$ that is emitted from diesel fuel combustion in car, truck, marine, rail and non-road engines. These particles ("diesel PM") are carcinogenic and are believed to contribute significantly to the health effects described above. Instrumentation installed in some air quality monitoring stations in the LFV can be used to estimate the proportion of particles that originate from diesel engines.

Wildfire Impacts

Wildfire activity in the Pacific Northwest has increased in severity in recent years. Wildfire smoke can be transported long distances and impact Metro Vancouver. The wildfire season in 2018 was one of the worst in British Columbia's history and included significant smoke-related air quality impacts which occurred due to wildfires burning in British Columbia, and the west coast of the US. These impacts led to the most air quality advisories issued by Metro Vancouver in a single year and the highest concentrations of $PM_{2.5}$ measured in the region on record.

Air Quality Advisories

In 2018, air quality advisories were in effect for a total of twenty-two days in July, August and September. A four-day advisory was issued in July due to elevated ground-level ozone and $PM_{2.5}$, a three-day advisory in

August due to elevated ground-level ozone and $PM_{2.5}$ as a result of wildfire smoke and a barge fire, a 14-day advisory due to wildfire smoke with elevated ozone for parts of the advisory, and a single day advisory for wildfire smoke in September.

The 14-day advisory in August was the longest continuous Metro Vancouver advisory on record and was caused by extensive wildfires burning in British Columbia and Washington state.

Periods of degraded air quality can occur in the LFV for several reasons, such as smoke from wildfires or summertime smog during hot weather. Air quality advisories are issued to the public when air quality has deteriorated or is predicted to deteriorate. In the last ten years, the number of days when air quality advisories were in place ranged from zero to 22 days annually.

Regional Long-Term Trends

Long-term regional trends in air quality are the trends observed within the LFV as a whole. They are determined by averaging measurements from several stations distributed throughout the LFV.

Figures S1 to S4 show the average concentrations and the short-term peak concentrations of four common air contaminants for the last two decades. Average concentrations represent the ambient concentrations that the region experiences most of the time. Short-term peak concentrations show the relatively infrequent higher concentrations experienced for short periods (on the scale of one hour to one day). Specific locations may have experienced trends that differ slightly from the regional picture.

Improvements have been made over the last two decades for most pollutants, including carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and fine particulate matter ($PM_{2.5}$). Both short-term peak and average concentrations have declined since the mid- nineties for all these pollutants with the exception of $PM_{2.5}$ which has been influenced in recent years due to wildfires.

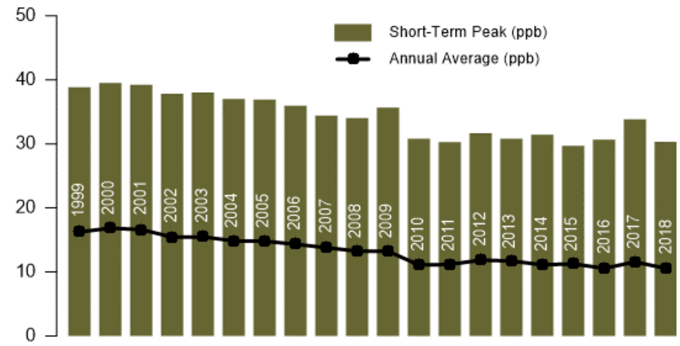


Figure S1: Nitrogen Dioxide Trend.

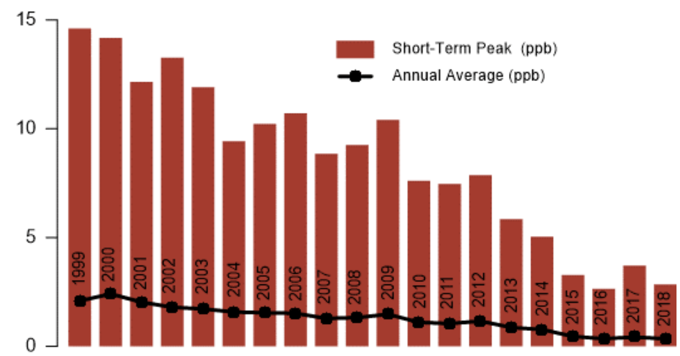


Figure S2: Sulphur Dioxide Trend.

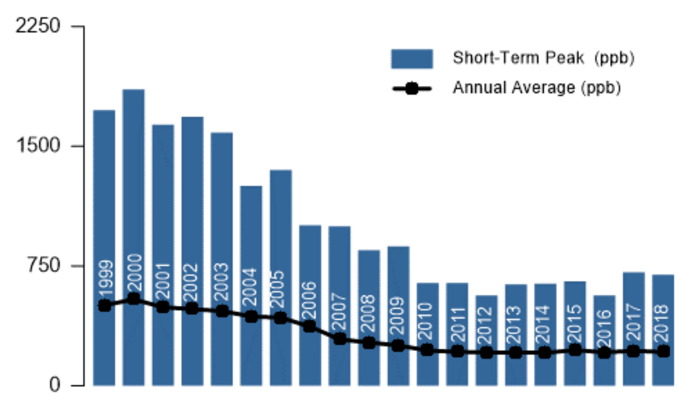


Figure S3: Carbon Monoxide Trend.

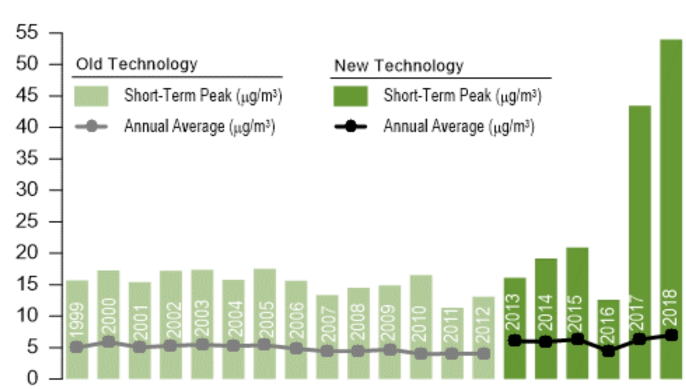


Figure S4: Fine Particulate Matter ($PM_{2.5}$) Trend.

Despite significant population growth in the region over the same time period, actions to reduce emissions across a variety of sectors have brought about these improvements in air quality. Stricter vehicle emission standards and the AirCare program (1992 – 2014) are largely responsible for lower carbon monoxide (CO) and nitrogen dioxide (NO_2) levels.

Requirements for reduced sulphur content in marine, on-road and off-road fuels, and reduced emissions from the petroleum refining and cement industries have led to the considerable improvements in sulphur dioxide (SO_2) levels. Emission reductions from light duty and heavy duty vehicles, wood products sectors, and petroleum refining have contributed to the decline in $PM_{2.5}$ emissions.

The regional $PM_{2.5}$ trends are illustrated in Figure S4. Fine particulate matter monitoring technology was upgraded in 2013 to continuous particulate monitors that met the U.S. Environmental Protection Agency $PM_{2.5}$ Federal Equivalent Method (FEM). The FEM monitors have the ability to measure a portion of particulate matter not previously measured. Wildfire effects are evident in 2017 and 2018.

For ozone, the same improvements seen for other pollutants have not been observed. In contrast, average regional ozone levels (Figure S5) have shown a slight increasing trend. Research suggests that background ozone concentrations are rising and one reason for the observed increase in average levels.

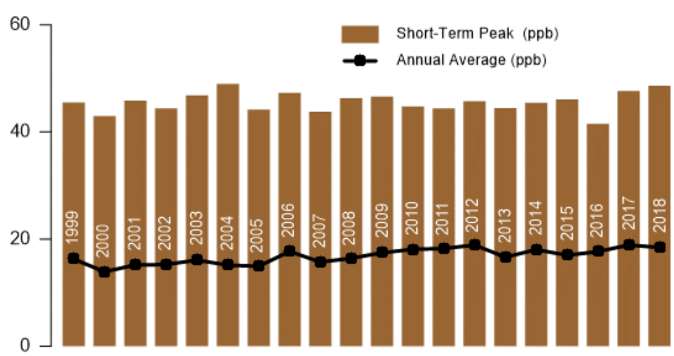


Figure S5: Ozone Trend.

Regionally averaged short-term peak ozone trends are also shown in Figure S5. The severity of peak ozone episodes greatly diminished in the 1980s, however short-term peak ozone levels have been mainly unchanged during the last two decades, despite large reductions in emissions of pollutants that contribute to ozone formation.

Metro Vancouver and the Fraser Valley Regional District adopted the Regional Ground-Level Ozone Strategy in 2014, which provides strategic policy direction for ozone management in the LFV based on local scientific research. Research indicates that a spatial understanding of the ratio of concentrations of nitrogen oxides (NO_X) and volatile organic compounds (VOC), two precursor pollutants that react to form ozone, is key to determining which precursors to reduce in order to maintain and improve air quality in our region.

Ground-Level Ozone – 2018

Monitoring results for all ozone monitoring stations with sufficient data coverage during 2018 are shown in Figure S6. The data show that peak ozone levels, as measured by the Canadian Ambient Air Quality Standard value and maximum 1-hour average, generally occurred in the eastern parts of Metro Vancouver and in the FVRD during sunny and hot weather.

In 2018, the Canadian Ambient Air Quality Standard for ozone was met at all monitoring stations with the exception of Mission and Hope. Metro Vancouver's 1-hour objective was exceeded at more than half of the monitoring stations on a combination of five days (July 16, 29, 30, August 8 and 21). The 8-hour Metro Vancouver objective was exceeded on eleven days (July 16, 25, 26, 27, 28, 29, 30 and August 7, 8, 21, and 22) at a combination of 17 stations (not shown). Air quality advisories were issued due to ground-level ozone on seven days in 2018. Ozone production was significantly enhanced by wildfire smoke in 2018 with levels not typically seen in Metro Vancouver.

Ground-level ozone is a secondary pollutant formed in the air from other contaminants such as nitrogen oxides (NO_X) and volatile organic compounds (VOC). The highest concentrations of ozone occur during hot sunny weather and can be enhanced by wildfire smoke.

NO_X emissions are dominated by transportation sources, with nearly 77% of emissions coming from cars, trucks, ships, rail, planes, and non-road engines. VOC are emitted from natural sources (e.g., trees), cars, light trucks, and solvents found in industrial, commercial and consumer products.

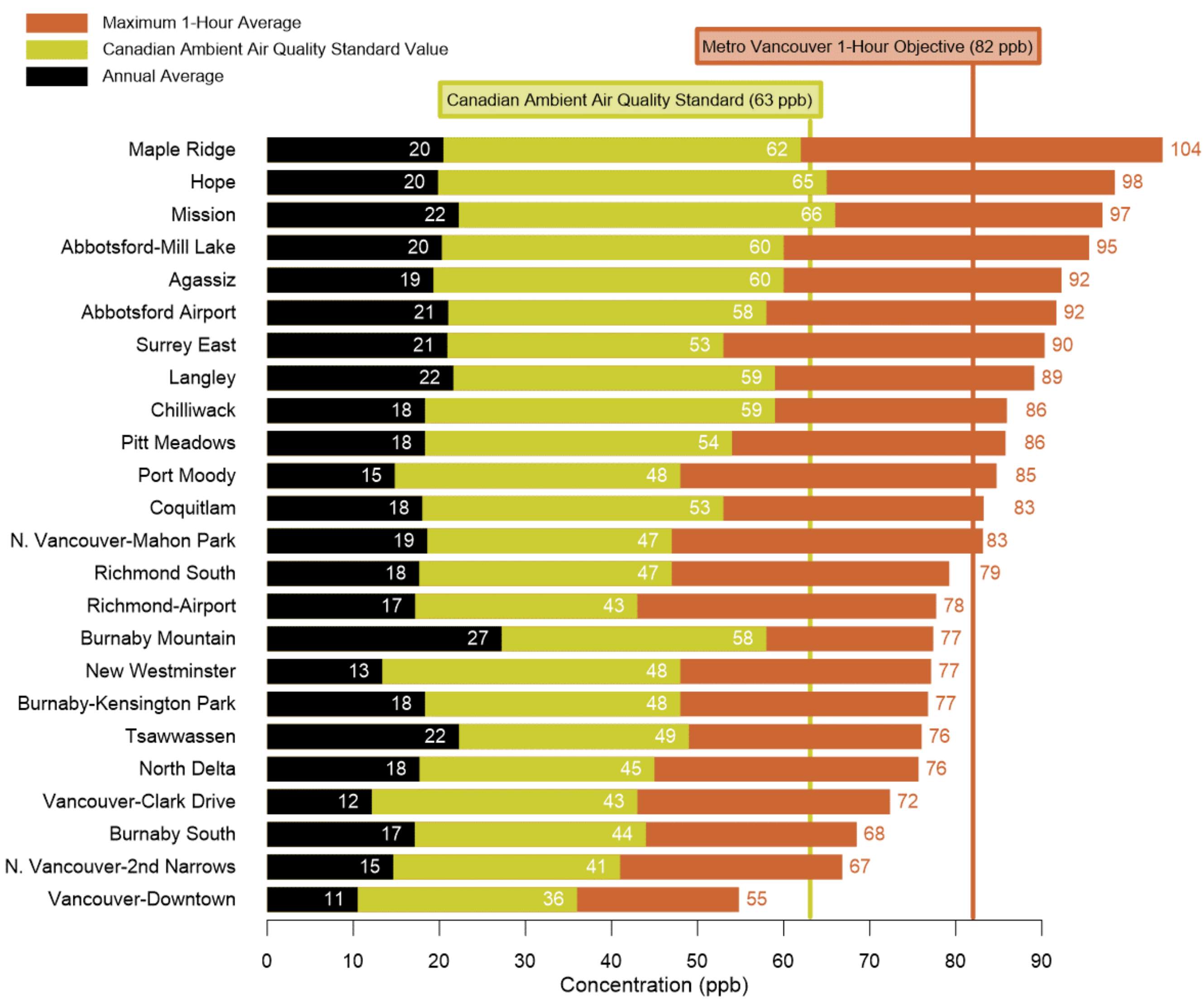


Figure S6: Ground-Level Ozone (O_3) 2018.

Fine Particulate Matter ($PM_{2.5}$) – 2018

Results for all $PM_{2.5}$ monitoring stations in 2018 are shown in Figure S7. Nearly half of the stations exceeded the 24-hour Canadian Ambient Air Quality Standard and only two stations (Vancouver-Clark Drive and Hope) exceeded the Metro Vancouver annual objective of 8 μg/m³. Exceedances of Metro Vancouver's 24-hour $PM_{2.5}$ objective were unprecedented in 2018 occurring at all monitoring stations in the region on a combination of twenty-nine days.

> Fine particulate matter ($PM_{2.5}$) emissions are typically dominated by residential wood burning, non-road engines and equipment, and industrial sources. However, in 2018 the impact of wildfires outside the region was apparent with the Province experiencing one of the most severe wildfire seasons.

The 24-hour objective was exceeded in July due to a local bog fire in Richmond and in August and September due to extensive smoke from wildfires burning inside and outside the region. On August 9th a $PM_{2.5}$ advisory was issued due to wildfires burning in Agassiz, Chilliwack and east of Manning Park. The following day the advisory was expanded when several municipalities were blanketed with smoke from a large barge fire in Surrey.

On August 13th an unprecedented fourteen-day advisory was issued due to wildfire smoke from fires burning throughout the Pacific Northwest. The advisory was the longest continuous advisory in Metro Vancouver history. The highest 24-hour $PM_{2.5}$ measurement on record was measured at Hope with a concentration of 247 μg/m³.

Exceedances were experienced at several stations over eight days in October and November which were thought to be a result of open burning, residential wood burning and/or Halloween fireworks.

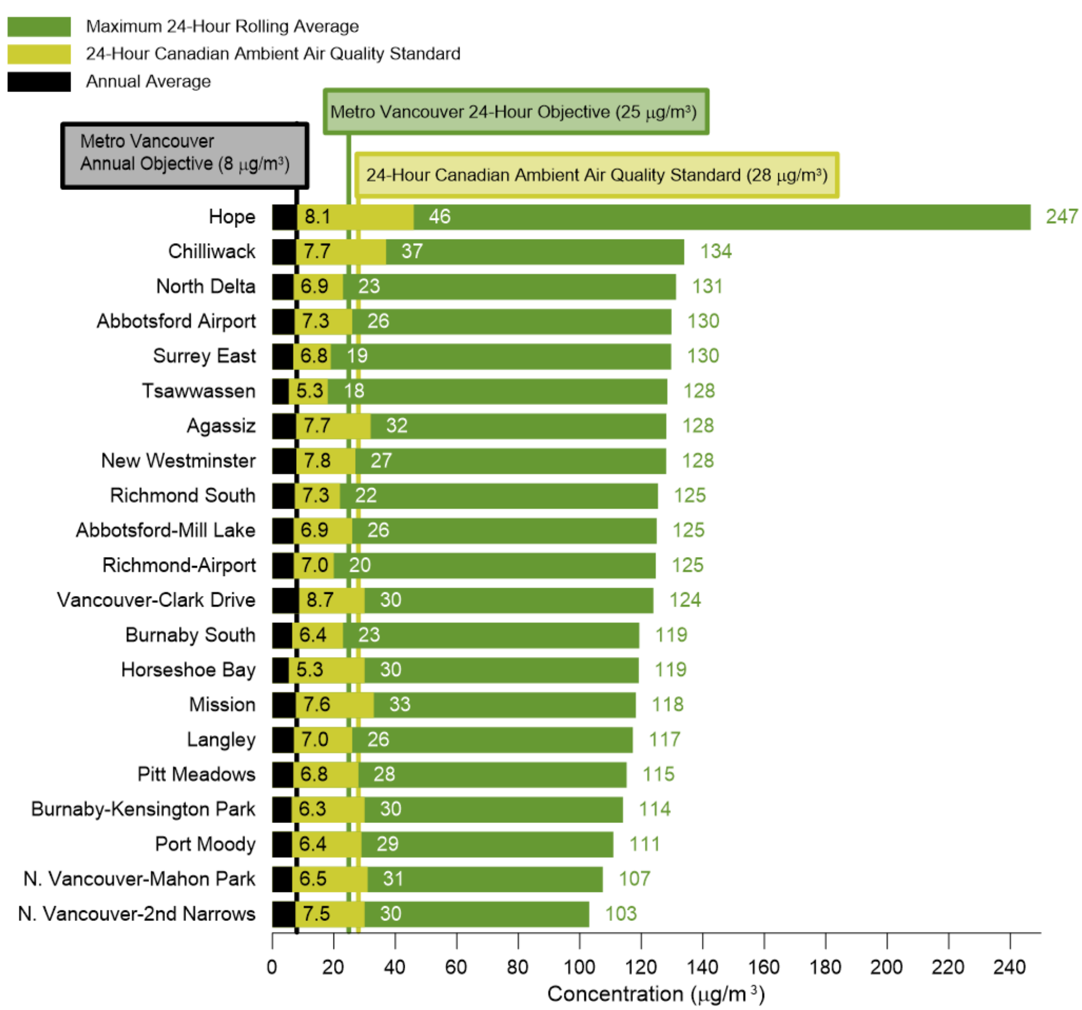


Figure S7: Fine Particulate Matter ($PM_{2.5}$) 2018.

Nitrogen Dioxide – 2018

Results for nitrogen dioxide (NO_2) monitoring in 2018 are shown in Figure S8. All stations experienced nitrogen dioxide levels that were below Metro Vancouver's 1-hour and annual objective. In 2018, the highest average nitrogen dioxide levels were measured near major roadways including at the Vancouver-Clark Drive and Vancouver-Downtown stations.

As nitrogen dioxide emissions are dominated by transportation sources, the highest average nitrogen dioxide concentrations are measured in the more densely trafficked areas and near busy roads. Lower concentrations are observed where these influences are less pronounced, such as the eastern parts of Metro Vancouver and in the FVRD.

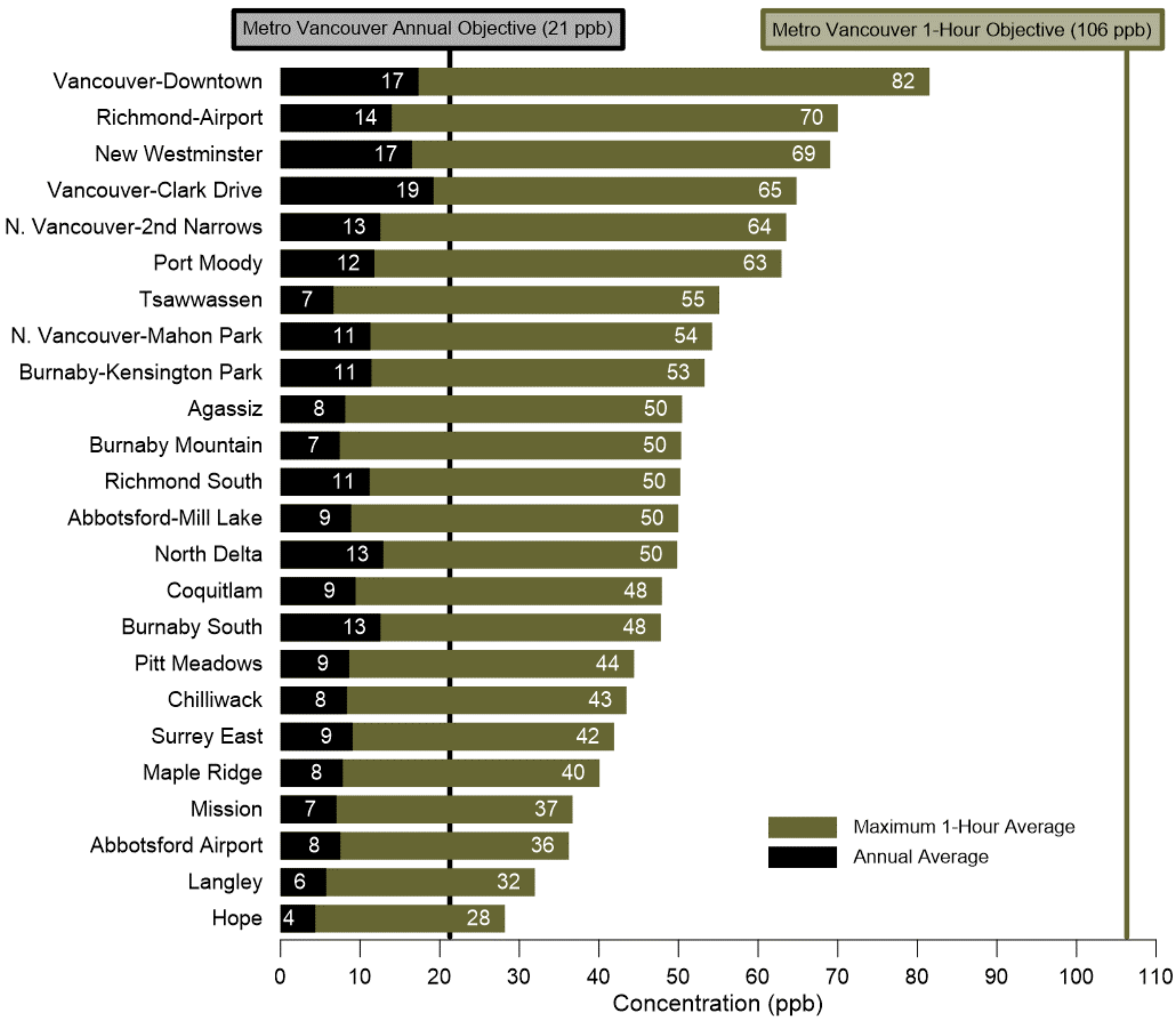


Figure S8: Nitrogen Dioxide (NO_2) 2018.

Sulphur Dioxide – 2018

Monitoring results for sulphur dioxide (SO_2) monitoring stations are shown in Figure S9. Sulphur dioxide levels were below the annual objective at all stations in 2018.

Average concentrations of sulphur dioxide in 2018 were less than 1 ppb at all stations. Average levels remain low in 2018 compared with previous years which can be attributed to stricter marine fuel requirements that came into effect at the beginning of 2015.

With the exception of Burnaby-Capitol Hill and Vancouver-Clark Drive all stations were below Metro Vancouver's 1-Hour objective of 70 ppb in 2018. The 1-hour objective was exceeded at the Burnaby-Capitol Hill station during one hour on the evening of January 1 and at the Vancouver-Clark Drive station during two hours on the evening of April 3. These exceedances were measured when winds were blowing from the direction of the petroleum refinery in Burnaby.

Sulphur dioxide is formed primarily by the combustion of fossil fuels containing sulphur. Within the LFV the major sources of SO_2 are an oil refinery, marine vessels, a waste to energy facility and two cement plants. The geographical distribution of sulphur dioxide emissions is influenced mainly by the refinery in Burnaby and ocean-going vessels in the marine areas of Burrard Inlet, although in recent years, marine emissions have been reduced substantially. The highest sulphur dioxide levels are typically measured near the Burrard Inlet area. Away from the Burrard Inlet area, sulphur dioxide levels are considerably lower.

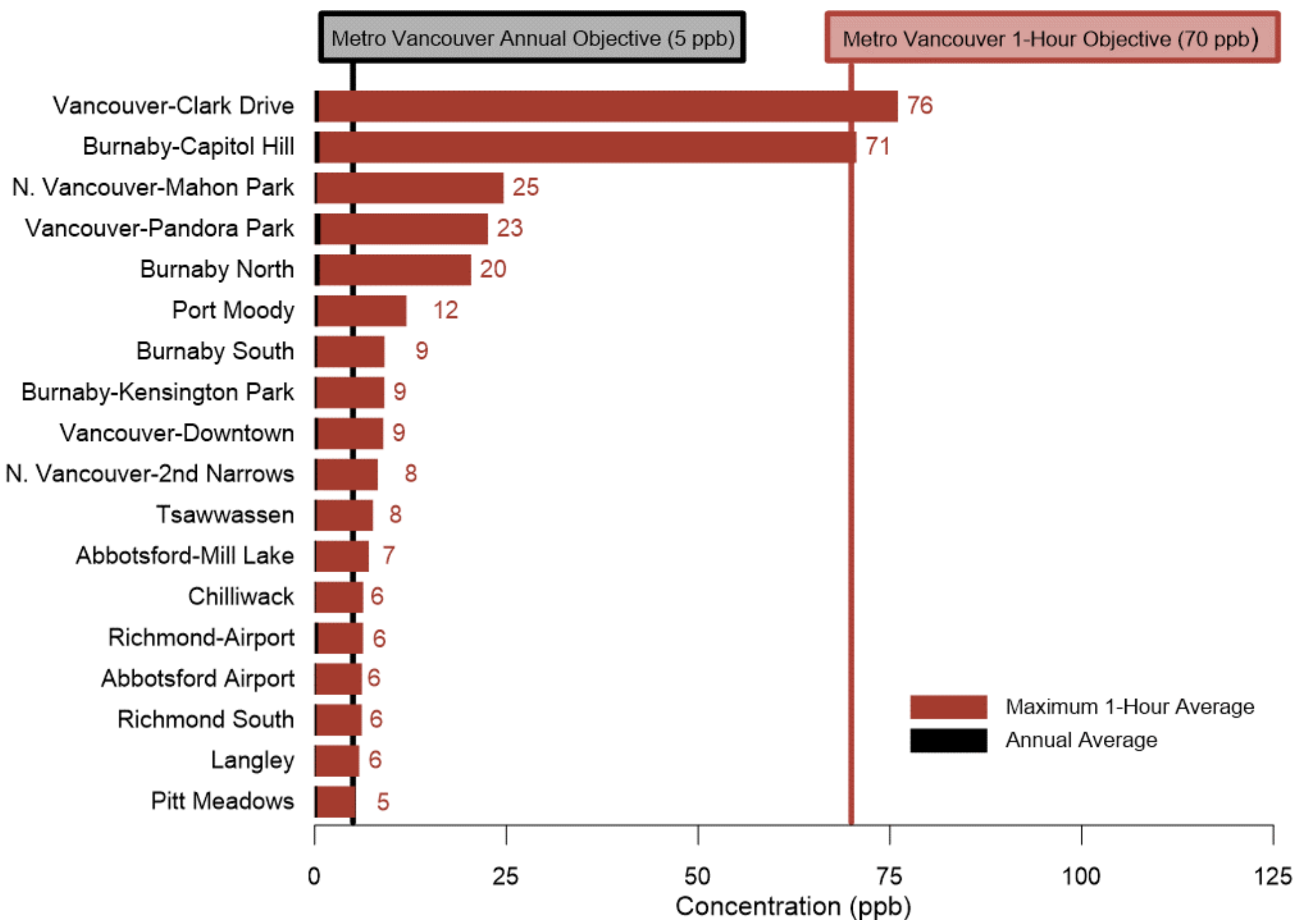
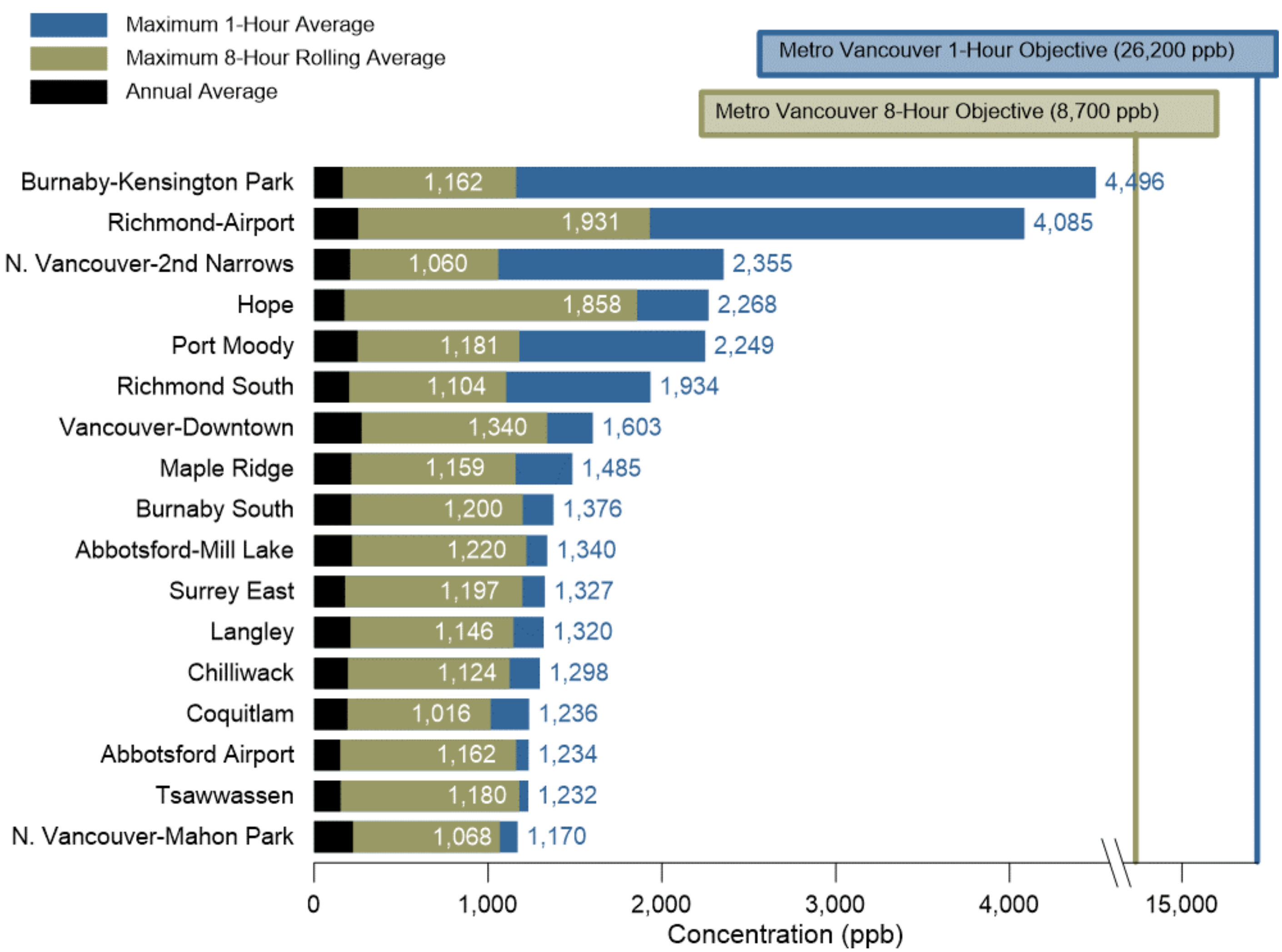


Figure S9: Sulphur Dioxide (SO_2) 2018.

Carbon Monoxide – 2018

Carbon monoxide (CO) monitoring results for 2018 are shown in Figure S10. Carbon monoxide levels were all well below the relevant Metro Vancouver air quality objectives at all stations throughout the LFV. The principal source of carbon monoxide continues to be emissions from motor vehicles.

Higher concentrations generally occur close to major roads during peak traffic periods. Like nitrogen dioxide, the highest average carbon monoxide concentrations are measured in the more densely trafficked areas and near busy roads. Lower concentrations are observed where these influences are less pronounced, such as the suburban and rural parts of Metro Vancouver and the FVRD.



Notes:

- The scale is broken in the x-axis between 4,500 and 8,000 ppb. The highest concentrations measured are five times less than the objective.
- Vancouver-Clark Drive and Horseshoe Bay did not meet the data completeness threshold and thus are not shown here.

Figure S10: Carbon Monoxide (CO) 2018.

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List of Acronyms

AQHI	Air Quality Health Index
BC	Black Carbon
BCVCC	BC Visibility Coordinating Committee
CCME	Canadian Council of Ministers of the Environment
CAAQS	Canadian Ambient Air Quality Standard
CO	Carbon Monoxide
FEM	Federal Equivalent Method
FVRD	Fraser Valley Regional District
LFV	Lower Fraser Valley
MAMU	Mobile Air Monitoring Unit
NAPS	National Air Pollution Surveillance
NO_X	Nitrogen oxides
NO_2	Nitrogen dioxide
NO	Nitric oxide
NH_3	Ammonia
O_3	Ozone
PM	Particulate matter
PM_{10}	Inhalable particulate matter (particles smaller than 10 micrometres in diameter)
$PM_{2.5}$	Fine particulate matter (particles smaller than 2.5 micrometres in diameter)
SO_X	Sulphur oxides
SO_2	Sulphur dioxide
THC	Total hydrocarbons
TRS	Total reduced sulphur compounds
UFP	Ultrafine particles
VOC	Volatile organic compounds

Section A – Introduction

This report summarizes data collected from air quality stations in the Lower Fraser Valley (LFV) Air Quality Monitoring Network in 2018 and describes the air quality monitoring activities and programs conducted during the year. The focus is to report on the state of ambient (outdoor) air quality in the LFV.

Metro Vancouver maintains one of the most comprehensive air quality networks in North America serving a population of 2.8 million with 31 air quality stations located from Horseshoe Bay in West Vancouver to Hope in 2018. Pollutants monitored by the network include both gases and particulate matter. Common air contaminants include ozone (O_3), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter. These are all widely monitored throughout the network.

Particulate matter consists of very small solid and liquid material suspended in the air. This air pollutant is characterized by size and measured in units of a millionth of a metre, or micrometre (µm). Particles with a diameter smaller than 10 micrometres are referred to as inhalable particulate (PM_{10}), while those smaller than 2.5 micrometres are termed fine particulate ($PM_{2.5}$). Both PM_{10} and $PM_{2.5}$ concentrations are monitored throughout the LFV.

Other pollutants monitored by the network include ammonia, volatile organic compounds (VOC), black carbon, ultrafine particles (UFP) and odourous total reduced sulphur compounds (TRS). Additional information Metro Vancouver collects to help monitor air quality conditions includes weather (meteorological) data and images recording visual air quality conditions (visibility).

Priority Pollutants

Research indicates that adverse health effects can occur at air quality levels commonly measured in the LFV. Health experts have identified exposure to ozone and particulate matter as being associated with serious health effects. Ozone is a strong oxidant that can irritate the eyes, nose and throat, and reduce lung function. Fine particulate ($PM_{2.5}$) is small enough to be breathed deeply into the lungs, resulting in impacts to both respiratory and cardiovascular systems. Long-term exposure to these pollutants can aggravate existing heart and lung diseases and lead to premature mortality.

Of particular concern is $PM_{2.5}$ that is emitted from diesel fuel combustion in car, truck, marine, rail and non-road engines. These particles ("diesel PM") are carcinogenic and are believed to contribute significantly to the health effects described above. Instrumentation installed in some air quality monitoring stations in the LFV can be used to estimate the proportion of particles that originate from diesel engines.

Air Quality Trends

Improvements have been made in air quality over the last two decades for most pollutants, including nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), volatile organic compounds (VOC) and fine particulate matter ($PM_{2.5}$). Despite significant population growth in the region over the same time period, emission reductions across a variety of sectors have brought about these improvements. The population increased in Metro Vancouver and the FVRD by about 50% from 1991 to 2016, from approximately 1.8 million to 2.8 million residents.

The long-term regional trends for ground-level ozone show a different story. Long-term trends of peak ozone concentrations show levels currently lower than those experienced in the 1980s, but peak levels have been largely unchanged over the last fifteen to twenty years. Average concentrations of ground-level ozone however have increased over the same period.

Metro Vancouver and the Fraser Valley Regional District adopted the Regional Ground-Level Ozone Strategy in 2014, which provides strategic policy direction for ozone management in the LFV based on local scientific research. Research indicates that a spatial understanding of the ratio of concentrations of nitrogen oxides (NO_X) and volatile organic compounds (VOC), two precursor pollutants that react to form ozone, is key to determining which precursors to reduce in order to maintain and improve air quality in our region.

Trends in air pollutants are discussed further by pollutant in Section D.

Wildfires and Air Quality Events

In recent years, wildfires in the Pacific Northwest have increased in severity and become more widespread. Wildfires can produce considerable amounts of smoke that can be transported great distances. The 2018 wildfire season was one of the worst in British Columbia's history, with the largest area burned.

In 2018, significant and lengthy smoke-related air quality impacts occurred due to wildfires burning in the BC Interior, and the west coast of the US. These impacts led to the most air quality advisories issued by Metro Vancouver in a single year.

Wildfires and other air quality events experienced in 2018 are discussed further in Section J.

Air Quality Advisories

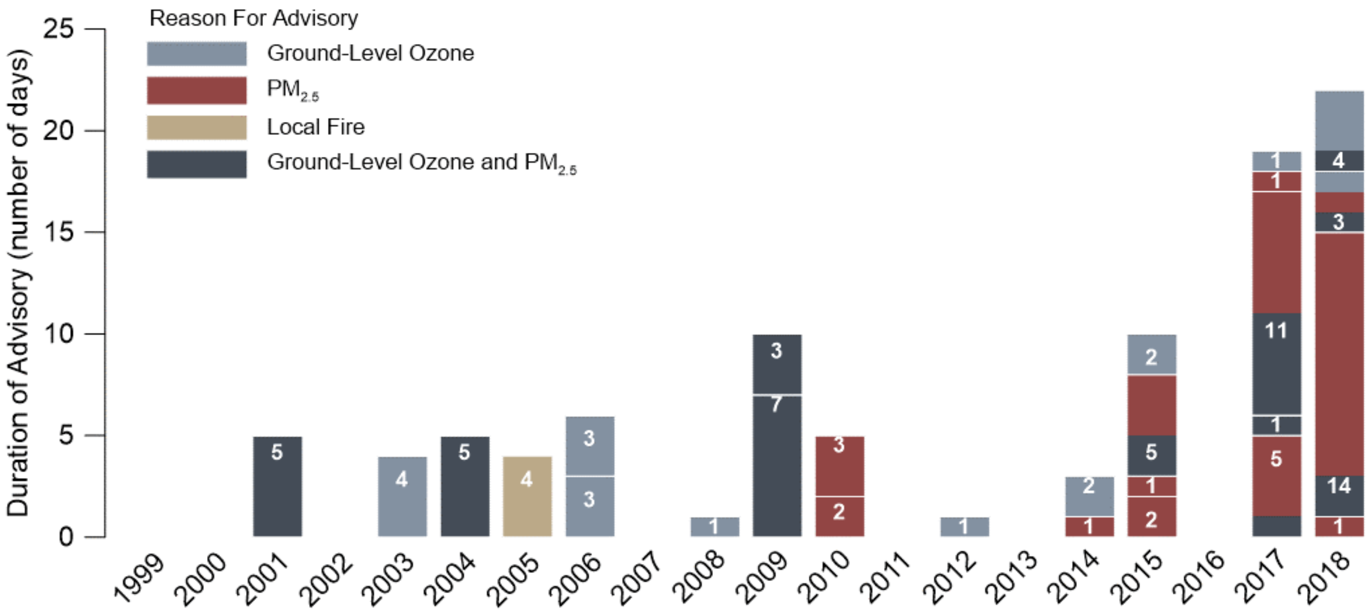
Periods of degraded air quality can occur in the LFV for several reasons, such as summertime smog during hot weather, smoke from forest fires and winter inversions preventing dispersion of emitted air contaminants. In cooperation with partner agencies, including the Fraser Valley Regional District, Vancouver Coastal Health Authority, Fraser Health Authority, Environment Canada and the B.C. Ministry of Environment, Metro Vancouver operates an air quality advisory program.

In 2018, air quality advisories were issued during four separate periods for a total of twenty-two days in summer, the most in Metro Vancouver's history. The first advisory of the year was initiated during hot weather, on July 28 due to high concentrations of ground-level ozone in the eastern parts of Metro Vancouver and the Fraser Valley and continued for four days. On July 30th the advisory was expanded to include elevated levels of fine particulate matter for a single day due to wildfires in Eurasia and Alaska as well as a local bog fire in Richmond.

On August 8th a ground-level ozone advisory was issued for the eastern parts of Metro Vancouver and the Fraser Valley. On August 9th the ozone advisory was continued and a fine particulate matter advisory was added for the eastern Fraser Valley due to wildfires burning in Agassiz, Chilliwack, and east of Manning Park. On August 10th, the ozone advisory was ended, but the $PM_{2.5}$ advisory continued for the Fraser Valley, and all of Metro Vancouver was added to the $PM_{2.5}$ advisory due to considerable smoke that was produced from a large barge fire that started in the early morning hours in Surrey. The advisory was cancelled the following day.

On August 13, widespread smoke was experienced due to wildfire smoke from fires burning throughout the Pacific Northwest. An unprecedented fourteen-day advisory was issued whereby all monitoring stations in the region experienced exceedances of the $PM_{2.5}$ objective. The smoke was the result of wildfires burning in BC and Washington state. During the advisory, two of the days also included a ground-level ozone advisory on August 21st and 22nd. The 14-day advisory was lifted on August 27 making it longest and most severe air quality advisory in Metro Vancouver history.

Smoke returned to the region in the afternoon of September 5 and a one-day advisory was issued on September 6 when several monitoring stations exceeded the 24-hour $PM_{2.5}$ objective. The smoke likely originated from wildfires burning east of Manning Park.



Notes:

- Trigger levels for advisories have changed over the years; care must be taken when interpreting advisory trends.
- The advisory in 2005 was the result of a large fire in Burns Bog.

Figure 1: Number of days of air quality advisories in the LFV.

In the last ten years, the number of days on which air quality advisories were in place has ranged from zero to twenty-two days annually. Shown in Figure 1 is the historical trend of the number of days the LFV was under an advisory. The total number of advisory days is shown as a bar while the number of consecutive days of an advisory period is given by the number in white.

Air quality bulletins are used to advise the public of the occurrence of localized degraded air quality during cool weather months and actions that may be taken to reduce the emissions contributing to degraded air quality conditions.

Visual Air Quality

Degraded air quality can cause views to be partially or fully obscured by haze at times in the LFV. This is referred to as visual air quality impairment.

Throughout the LFV, the contaminant with the greatest impact on visual air quality is $PM_{2.5}$. However, the appearance of haze can be affected by the presence of a number of different air contaminants. In more urbanized areas in the west, haze may have a brownish colour. Nitrogen dioxide emissions from transportation sources contribute to this brown appearance. Further east in the LFV, a white haze can sometimes be observed as a result of small particles in the air ($PM_{2.5}$) scattering light. Secondary $PM_{2.5}$, such as that formed by reactions of NO_X and SO_2 with ammonia, as well as directly emitted (or primary) $PM_{2.5}$ contribute to this haze. Smoke, windblown dust and soil particles, as well as moisture levels in the air can also affect visibility.

Analysis of the air contaminants present under different visual air quality conditions is being used to understand the factors contributing to visual air quality impairment in the LFV and to develop tools to evaluate visual air quality quantitatively. Data collected as part of the visual air quality monitoring program include measurements of nitrogen dioxide and $PM_{2.5}$, measurements of the constituents of particulate matter (for example particulate nitrate, particulate sulphate, elemental carbon and organic carbon) and the optical (light scattering) characteristics of ambient air samples.

In 2018, automated digital cameras were used to record visual air quality conditions in seven locations. Images from the cameras show views along specific lines-of-sight with recognizable topographical features at known distances. The images are archived for various uses, including:

- relating air contaminant measurements to visual range and visual air quality degradation under a variety of air quality and meteorological conditions;

- assessing public perceptions of the different visual air quality conditions found in the LFV; and
- developing visual air quality measurement metrics.

Images from each of the seven monitoring locations are shown on [www.clearairbc.ca.](http://www.clearairbc.ca)

The monitoring data and images collected provide important input to a collaborative multi-agency initiative to develop a visual air quality management strategy for the LFV. Visual air quality is further discussed in Section F.

Air Quality Health Index (AQHI)

The national health-based Air Quality Health Index (AQHI), developed by Environment Canada and Health Canada, has been in use since 2008. The AQHI communicates the health risks associated with a mix of air pollutants to the public and provides guidance on how individuals can adjust their exposure and physical activities as air pollution levels change.

The AQHI is calculated every hour using monitoring data from stations in the LFV. Current AQHI levels in the LFV, AQHI forecasts (for *today*, *tonight*, *tomorrow, and tomorrow night*) and additional information about the AQHI are available at:

www.airmap.ca
www.env.gov.bc.ca/epd/bcairquality/readings/aqhi-table.xml

Environment Canada's Weather Website also publishes the AQHI.

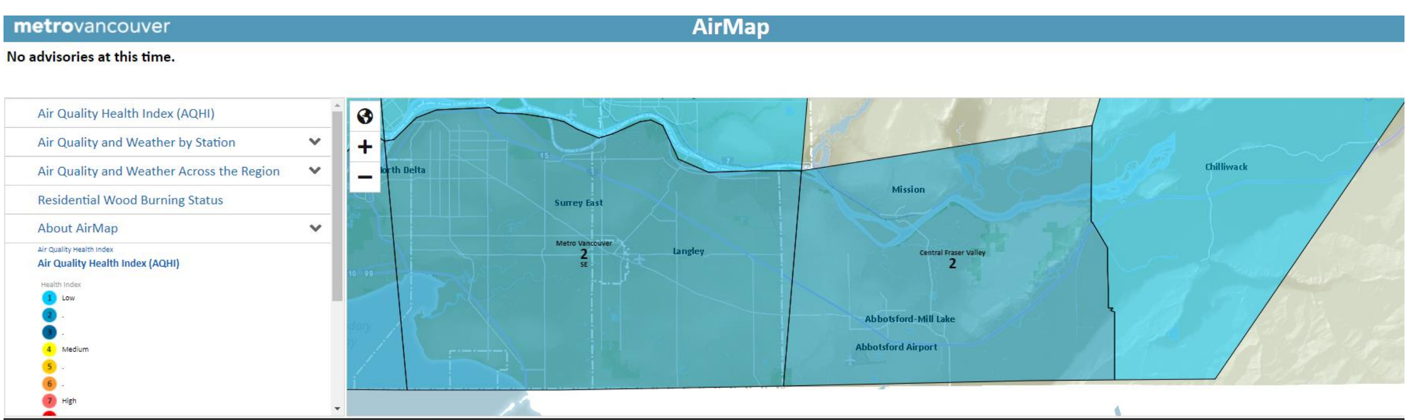
Air Quality Measurements

The LFV Air Quality Monitoring Network primarily employs continuous monitors which provide data in real-time every minute of the day. The network also contains specialized air quality monitors that sample the air non-continuously. Non-continuous 24-hour (daily) samples are collected on filters and/or in canisters every sixth or twelfth day depending on the site. The sampling is scheduled in accordance with the National Air Pollution Surveillance (NAPS) program. After sample collection, filters and canisters are analyzed in a federal laboratory to determine pollutant concentrations. Non-continuous samples of volatile organic compounds (VOC) are collected at seven sites throughout the LFV. VOC refers to a group of organic chemicals. A large number of chemicals are included in this group but each individual chemical is generally present at relatively low concentrations in air compared to other common air contaminants.

Non-continuous particulate samples are collected at five monitoring stations in the LFV where pollutant concentrations are determined. A detailed analysis is conducted by the federal laboratory for four of these stations (Port Moody, Burnaby South, Abbotsford Airport and Vancouver-Clark Drive).

Chemicals contained in $PM_{2.5}$ and VOC samples are identified and quantified at a federal laboratory. These data can then be used to help determine the emission sources contributing to the contaminants in the air.

Non-continuous measurements are discussed in Section E.



Section B – Air Quality Objectives and Standards

Several air quality objectives and standards are used as benchmarks to characterize air quality including the federal Canadian Ambient Air Quality Standards (CAAQS), and Metro Vancouver's ambient air quality objectives. Metro Vancouver's ambient air quality objectives are shown in Table 1. The objective or standard is achieved if the ambient concentration is at or lower than (i.e., better than) the objective.

The federal Canadian Ambient Air Quality Standards (CAAQS) have been established as objectives under Canadian Environmental Protection Act 1999, and replaced the Canada-Wide Standards for fine particulate matter and ground-level ozone. The CAAQS were implemented in 2015 for particulate matter (PM) and ozone (O_3). In 2020, the numerical value of the CAAQS became more stringent for $PM_{2.5}$ and O_3 and nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) were also added. These set specific limits for $PM_{2.5}$, O_3, NO_2, and SO_2 based on concentrations averaged over a three-year period with the exception of the annual metric which are averaged over one year.

The CAAQS for $PM_{2.5}$ is a value that is calculated by taking an annual 98th percentile value using daily averages, averaged over three consecutive years. Achievement of the $PM_{2.5}$ CAAQS is attained when the CAAQS value is less than or equal to 27 µg/m^3.

The CAAQS for ozone is a value that is calculated by the 4th highest annual 8-hour daily maximum, averaged over three consecutive years. Achievement of the ozone CAAQS is attained when the CAAQS value is less than or equal to 62 ppb.

The NO_2 CAAQS include metrics for both 1-hour and annual averages. The 1-hour CAAQS for NO_2 is a value that is calculated by taking an annual 98th percentile value using daily maximum 1-hour measurements, averaged over three consecutive years. Achievement of the 1-hour NO_2 CAAQS is attained when the CAAQS value is less than or equal to 60 ppb. The annual CAAQS for NO_2 is a value of 17 ppb that is compared to the average of all 1-hour concentrations collected within the year.

In 2005, as part of the Air Quality Management Plan, Metro Vancouver adopted health-based ambient air quality objectives for ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO).

In 2009 the provincial government established air quality objectives for $PM_{2.5}$. The province's annual objective is eight micrograms per cubic metre (µg/m^3) and annual planning goal is six micrograms per cubic metre for $PM_{2.5}$.

An objective or standard is achieved if the ambient concentration is at or lower than (i.e., better than) the objective.

Metro Vancouver aligned its annual objectives for $PM_{2.5}$ in the 2011 Integrated Air Quality and Greenhouse Gas Management Plan, as well as adopting a one-hour ozone objective of 82 parts per billion.

Metro Vancouver's 24-hour $PM_{2.5}$ objective of 25 µg/m^3 is numerically the same as the province, but compliance with Metro Vancouver's objective requires that there are no exceedances and is applied as a rolling average.

In 2015, Metro Vancouver adopted a 1-hour interim ambient air quality objective for SO_2 of 75 parts per billion (ppb) prior to establishment of the federal SO_2 CAAQS. After establishment of the federal SO_2 CAAQS, Metro Vancouver's SO_2 objectives were revised in November 2017, with a more stringent 1-hour objective of 70 ppb not to be exceeded and an annual objective of 5 ppb.

In 2019, Metro Vancouver aligned its objectives for CO, NO_2 and O_3 with federal and provincial standards. Metro Vancouver adopted a 1-hour and annual ambient air quality objective for NO_2 that is the same as the federal 2020 CAAQS. Similarly, the 8-hour O_3 objective was made the same as the 2020 CAAQS. The 1-hour and 8-hour CO objectives were set to 13,000 ppb and 5,000 ppb respectively, to match the more stringent Provincial objectives.

Several of Metro Vancouver's objectives are intended to be compared with *rolling averages*. A *rolling average* is an average that is calculated by averaging the concentrations from a number of previous consecutive hours. For example, a 24-hour rolling average is calculated by averaging the concentrations measured during the previous 24 hours. A 24-hour rolling average is calculated for each hour of the day. Similarly, an 8-hour rolling average is calculated by averaging the concentrations from the previous 8 hours.

Table 1: Metro Vancouver's ambient air quality objectives.

Air Contaminant	Averaging Period	Ambient Air Quality Objective[a]	
		μg/m³	ppb
Carbon monoxide (CO)	1-hour	30,000 (14,900*)	26,200 (13,000*)
	8-hour[b]	10,000 (5,700*)	8,700 (5,000*)
Nitrogen dioxide (NO_2)	1-hour	200 (113*[c])	106 (60*[c])
	Annual	40 (32*)	21 (17*)
Sulphur dioxide (SO_2)	1-hour	183	70
	Annual	13	5
Ozone (O_3)	1-hour	161	82
	8-hour	128[b] (122*[d])	65 (62*[d])
Inhalable particulate matter (PM_{10})	24-hour	50[b]	
	Annual	20	
Fine particulate matter ($PM_{2.5}$)	24-hour	25[b]	
	Annual	8 (6[e])	
Total reduced Sulphur (TRS)	1-hour (acceptable)	14	10
	1-hour (desirable)	7	5

*Metro Vancouver's Board adopted more stringent air quality objectives in November of 2019.

[a] Except where noted, Metro Vancouver objectives are "not to be exceeded", meaning the objective is achieved if 100% of the validated measurements are at or below the objective level.

[b] Achievement based on rolling average.

[c] Achievement based on annual 98th percentile of the daily maximum 1-hour concentration, averaged over three consecutive years.

[d] Achievement based on annual 4th highest daily maximum 8-hour average concentration, averaged over three consecutive years.

[e] Metro Vancouver's annual $PM_{2.5}$ planning goal of 6 μg/m³ is a longer term aspirational target to support continuous improvement.

Section C – Lower Fraser Valley Air Quality Monitoring Network

Metro Vancouver operates the LFV Air Quality Monitoring Network which consists of air quality monitoring sites located between Horseshoe Bay in West Vancouver and Hope. The locations of the monitoring stations operated in 2018 are shown in Figure 2 while the pollutants and meteorology measured at each station are identified in Table 2.

In 2018, there were 31 air quality monitoring stations in the network which includes 25 stations located in Metro Vancouver and 6 stations located in the FVRD. There are also 3 stations in Metro Vancouver that provide only weather data. Air quality and weather data are collected automatically on a continuous basis, transmitted to Metro Vancouver's head office in Burnaby, and stored in a database. The data are then used to provide information to the public through the AQHI, Metro Vancouver's website, the BC air quality website, and reports. At one of the stations (White Rock) particulate matter is sampled throughout the year on a defined periodic schedule. These non-continuous data are not collected automatically to the database.

Many pollutants measured are discussed in this report with a focus on common air contaminants: particulate matter (PM_{10} and $PM_{2.5}$), ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2).

Comparisons of measured levels of these air contaminants with federal, provincial and Metro Vancouver air quality objectives and standards and an assessment of regional trends are provided in Section D. The locations of SO_2, O_3, NO_2 and $PM_{2.5}$ monitoring in 2018 are shown in Figures 3 to 6.

Portable equipment was used to carry out short-term air quality monitoring studies (specialized studies) in 2018. The equipment employed in specialized studies includes Metro Vancouver's Mobile Air Monitoring Unit (MAMU) which is capable of monitoring gaseous and particulate pollutants in the same way as other monitoring stations in the network. Specialized studies and other monitoring activities undertaken are described in Sections G, H and I.

Real-time data from the LFV Air Quality Monitoring Network can be accessed on Metro Vancouver's website at: www.airmap.ca

Additional information on the LFV Air Quality Monitoring Network is available in the 2012 report "Station Information: Lower Fraser Valley Air Quality Monitoring Network". This report is available at: www.metrovancouver.org

Data completeness for the year 2018 is shown in Table 3. In Table 3 the annual completeness is provided numerically while each quarter is shown as green if completeness for that quarter is greater than or equal to 75%, red if below 75% and white if no data exists.

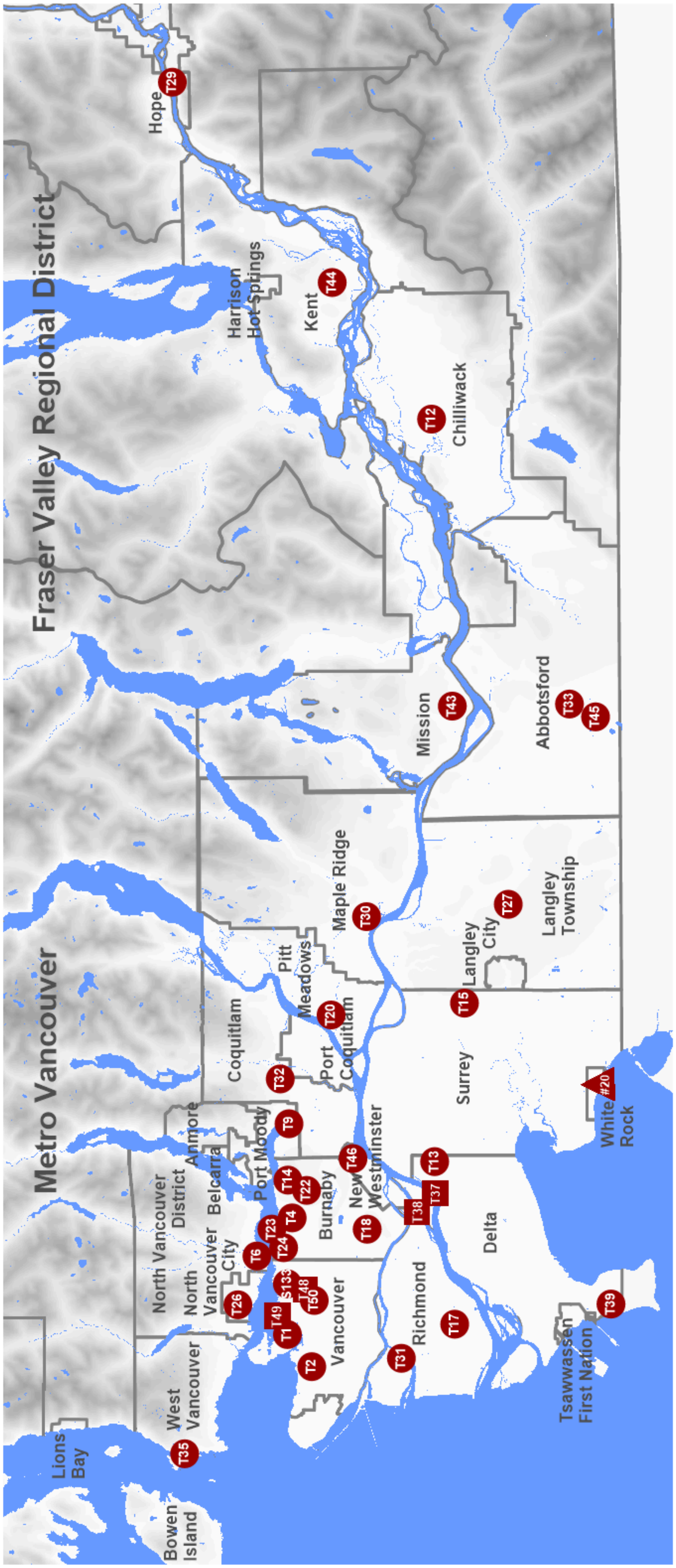
Network Changes

There are ongoing enhancements to stations and equipment that occur throughout the air quality monitoring network.

Minimal changes were made to the network in 2018.

Changes to the network in 2018 include:

- A two-channel aetholometer was replaced with a 7-channel aetholometer at three stations: North Vancouver – Second Narrows, Burnaby South and Pitt Meadows.
- Visual air quality monitoring cameras located in Burnaby were moved from 4330 Kingsway approximately 750 metres southeast to 4515 Central Boulevard, concurrent with the move of Metro Vancouver's Head Office.



T1	Vancouver-Downtown	T18	Burnaby South	T32	Coquitlam
T2	Vancouver-Kitsilano	T20	Pitt Meadows	T33	Abbotsford-Mill Lake
T4	Burnaby-Kensington Park	T22	Burnaby-Burmount	T35	Horseshoe Bay
T6	N. Vancouver-2nd Narrows	T23	Burnaby-Capitol Hill	T37	Alex Fraser Bridge
T9	Port Moody	T24	Burnaby North	T38	Annacis Island
T12	Chilliwack	T26	N. Vancouver-Mahon Park	T39	Tsawwassen
T13	North Delta	T27	Langley	T43	Mission
T14	Burnaby Mountain	T29	Hope	T44	Agassiz
T15	Surrey East	T30	Maple Ridge	T45	Abbotsford Airport
T17	Richmond South	T31	Richmond-Airport	T46	New Westminster

T48	Vancouver-Templeton
T49	Vancouver-Portside
T50	Vancouver-Clark Drive
S133	Vancouver-Pandora Park
#20	White Rock

● Continuous Station
▲ Non-Continuous Station
■ Meteorological Station Only

Figure 2: Lower Fraser Valley air quality monitoring network, 2018.

Table 2: Air quality monitoring network, 2018.

Stations		Air Quality Monitors														Meteorology					
		Continuous										Non-Continuous								
		Gases							Particulate Matter											
ID	Name	SO_2	TRS	NO_2	CO	O_3	THC	NH_3	PM_{10}	$PM_{2.5}$	BC	NEPH	VOC	SP	D	Wind	T_{air}	SR	RH	BP	Precip
T1	Vancouver-Downtown	√		√	√	√															
T2	Vancouver-Kitsilano	Station temporarily out of service																			
T4	Burnaby-Kensington Park	√	√	√	√	√			√	√						√	√		√		
T6	N. Vancouver-2nd Narrows	√		√	√	√				√	√					√	√		√		√
T9	Port Moody	√	√	√	√	√			√	√	√		√		√	√	√	√	√		√
T12	Chilliwack	√		√	√	√		√	√	√	√	√	√			√	√	√	√	√	√
T13	North Delta			√		√				√						√	√		√		√
T14	Burnaby Mountain			√		√										√	√		√		√
T15	Surrey East			√	√	√				√						√	√				√
T17	Richmond South	√		√	√	√				√						√	√		√		√
T18	Burnaby South	√		√	√	√			√	√	√	√	√	√	√	√	√		√	√	√
T20	Pitt Meadows	√		√		√				√	√	√				√	√		√	√	√
T22	Burnaby-Burmount		√				√						√			√	√				
T23	Burnaby-Capitol Hill	√	√													√	√		√		
T24	Burnaby North	√	√				√		√				√			√	√	√	√		√
T26	N. Vancouver-Mahon Park	√		√	√	√				√						√	√		√	√	√
T27	Langley	√		√	√	√			√	√						√	√		√	√	√
T29	Hope			√	√	√			√	√						√	√		√		√
T30	Maple Ridge			√	√	√										√	√		√		√
T31	Richmond-Airport	√		√	√	√			√	√	√	√	√			√	√	√	√	√	√
T32	Coquitlam			√	√	√										√	√		√	√	√
T33	Abbotsford-Mill Lake	√		√	√	√		√	√	√						√	√		√		√
T35	Horseshoe Bay				√					√						√	√		√		√
T37	Alex Fraser Bridge	Station temporarily out of service																			
T38	Annacis Island															√	√		√		√
T39	Tsawwassen	√		√	√	√				√						√	√		√		√
T43	Mission			√		√				√						√	√		√		√
T44	Agassiz			√		√				√						√	√		√		√
T45	Abbotsford Airport	√		√	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√
T46	New Westminster			√		√				√						√					
T48	Vancouver-Templeton															√	√		√		
T49	Vancouver-Portside															√	√		√		√
T50	Vancouver-Near-Road	√		√	√	√				√	√		√	√	√	√	√		√		
S133	Vancouver-Pandora	√																			
#20	White Rock	Station temporarily out of service																			
Total Monitoring Units		**18**	**5**	**24**	**19**	**24**	**2**	**3**	**11**	**21**	**8**	**5**	**8**	**3**	**4**	**30**	**29**	**5**	**27**	**8**	**24**

SO_2 = sulphur dioxide; TRS = total reduced sulphur; NO_2 = nitrogen dioxide; CO = carbon monoxide; O_3 = ozone; THC = total hydrocarbon; NH_3 = ammonia;

PM10 = inhalable particulate matter; $PM_{2.5}$ = fine particulate matter; NEPH = particulate light scattering; VOC = volatile organic compounds; SP = particulate speciation;

D = dichotomous particulate; BC = Black Carbon; Wind = wind speed and direction; T_{air} = air temperature; SR = incoming solar radiation; RH = relative humidity;

BP = barometric pressure; Precip = precipitation; √ = monitored at this location.

Table 3: Annual and quarterly data completeness, 2018.

Stations		Air Quality Monitors											Meteorology						
		Gases							Particulate Matter										
ID	Name	SO_2	TRS	NO_2	CO	O_3	THC	NH_3	PM_{10}	$PM_{2.5}$	BC	UFP	Wind Spd	Wind Dir	Tair	SR	RH	BP	Precip
T01	Vancouver-Downtown	99		98	99	99													
T02	Vancouver-Kitsilano																		
T04	Burnaby-Kensington Park	99	99	100	90	100			98	97			100	100	100		100		
T06	N. Vancouver-2nd Narrows	98		99	99	99				97	96		100	100	100		100		98
T09	Port Moody	95	93	99	96	99			86	99	99		99	99	100	100	100		100
T12	Chilliwack	95		98	95	99		98	99	96	95		99	99	99	99	99	99	100
T13	North Delta			99		99				99			100	100	100		100		100
T14	Burnaby Mountain			100		99							100	100	100		100		100
T15	Surrey East			99	99	99				98			100	100	100		100		100
T17	Richmond South	99		99	99	100				89			100	100	100		100		100
T18	Burnaby South	96		99	96	100			99	99	92		100	100	100		100	100	100
T20	Pitt Meadows	95		99		99				98	45		99	99	99		99	99	99
T22	Burnaby-Burmount		99				82						100	100	100				
T23	Burnaby-Capitol Hill	100	96										100	100	100		100		
T24	Burnaby North	100	100				98		99				98	98	98	98	98		98
T26	N. Vancouver-Mahon Park	100		99	98	100				99			81	98	99		99	100	99
T27	Langley	95		98	96	99			99	99			99	99	99		99	98	99
T29	Hope			99	98	99			99	99			98	100	100		100		100
T30	Maple Ridge			100	99	99							99	99	100		100		100
T31	Richmond-Airport	95		99	96	99			92	99	100		100	98	100	100	100	100	100
T32	Coquitlam			100	100	99							100	99	100		100	100	100
T33	Abbotsford-Mill Lake	96		98	97	99		98	95	99			100	100	100		100		100
T35	Horseshoe Bay				65					94			76	77	100		100		93
T38	Annacis Island												92	92	91		91		92
T39	Tsawwassen	92		99	94	99				99			99	99	99		99		99
T43	Mission			99		99				98			99	99	99		99		99
T44	Agassiz			99		100				98			99	99	99		99		99
T45	Abbotsford Airport	96		98	94	98		97	98	99	97		98	97	99	99	99	99	99
T46	New Westminster			99		99				98			100	100					
T48	Vancouver-Templeton												100	100	100		100		
T49	Vancouver-Portside												100	100	100		100		95
T50	Vancouver-Clark Drive	94		96	67	96				96	95	72	100	100	100		100		
S133	Vancouver-Pandora Park	91											100	100	100		100	100	

Note: Quarterly completeness ≥ 75% is shown in green, < 75% is shown in red, and no data is white, while annual completeness is shown numerically.

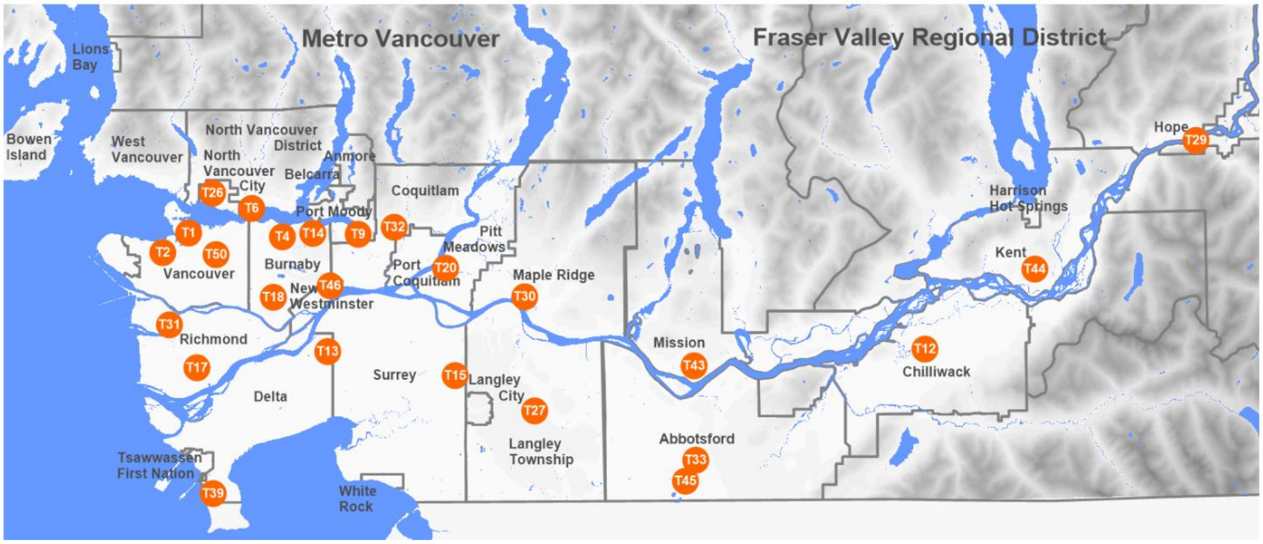


Figure 3: Ground-level ozone and nitrogen dioxide monitoring stations, 2018.

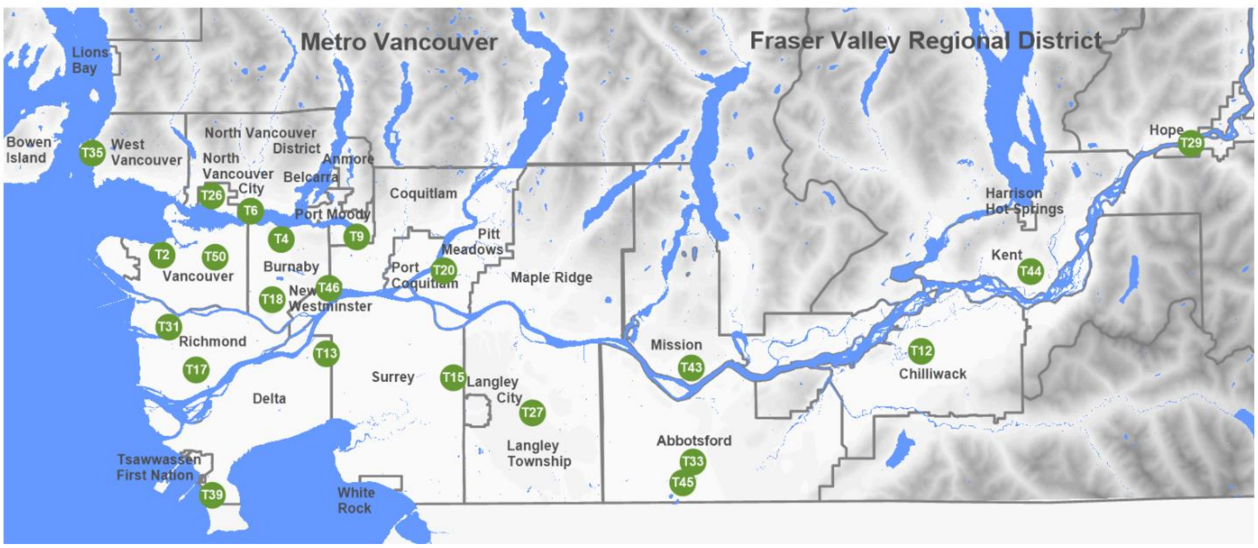


Figure 4: Fine particulate matter ($PM_{2.5}$) monitoring stations, 2018.

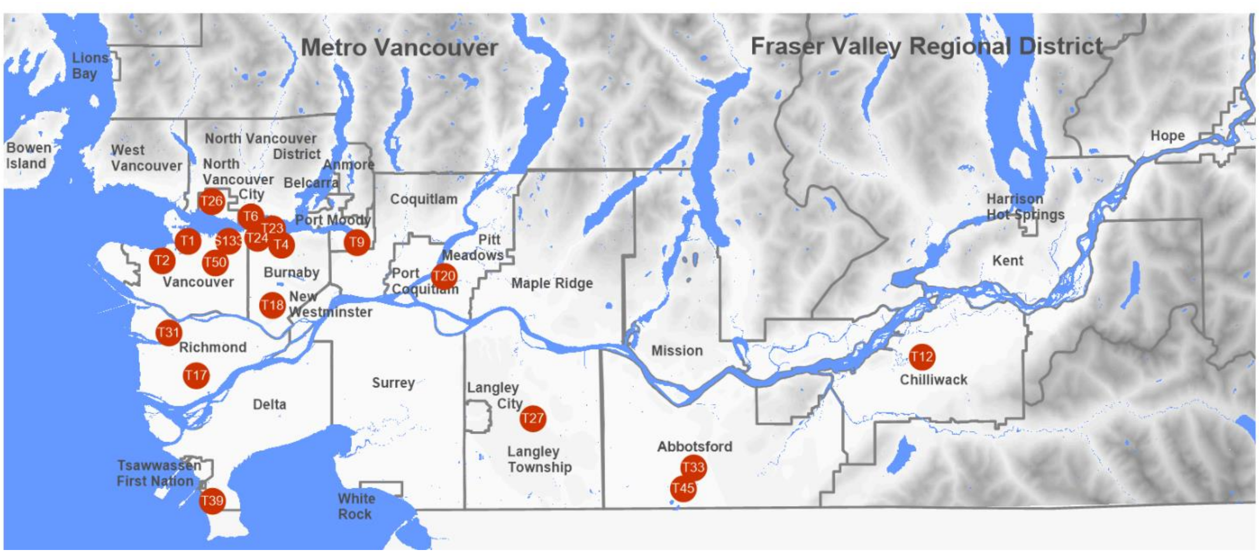


Figure 5: Sulphur dioxide monitoring stations, 2018.

Section D – Continuous Pollutant Measurements

Ozone (O_3)

Characteristics

Ozone (O_3) is a reactive form of oxygen. It is a major pollutant formed when NO_X and reactive volatile organic compounds (VOC) react chemically in the presence of heat and sunlight. Sunlight plays a significant role in O_3 production and as such, local maximum O_3 concentrations are usually experienced during the summer in the LFV.

Naturally occurring O_3 in the upper level of the atmosphere, known as the stratosphere, shields the surface from harmful ultraviolet radiation. However, at ground level, O_3 is a major environmental and health concern. Ozone is a significant oxidant and can irritate the eyes, nose and throat as well as reduce lung function. High concentrations can also increase the susceptibility to respiratory disease and reduce crop yields.

Sources

Ozone is termed a secondary pollutant because it is not usually emitted directly into the air. Instead, it is formed from chemical reactions involving pollutants identified as precursors, including NO_X and reactive VOC. The levels of O_3 measured depend on the emissions of these precursor pollutants.

Nitrogen oxide (NO_X) emissions are dominated by transportation sources. About 60% of the emissions come from cars, trucks, ships, rail and planes. Other sources include non-road engines, boilers and building heating systems.

The main contributors to VOC emissions are chemical products use (industrial, commercial and consumer products such as paints, varnishes and solvents), cannabis production, natural sources (trees and vegetation), cars and light trucks and non-road engines.

The formation of O_3 occurs readily during hot and sunny weather conditions with peak levels observed in the summer. Under these conditions, the highest levels generally occur downwind of major precursor emissions such as in eastern parts of Metro Vancouver and in the FVRD. The presence of wildfire smoke can also enhance ozone production which is discussed further in Section J.

Monitoring Results

Figures S6 and 6 illustrate the results of O_3 monitoring in 2018. Figure 6 represents a bubble plot which shows three types of information: maximum 1-hour, maximum 8-hour and annual average concentrations for each ozone monitoring station. In Figure 6 the bubble position on the x-axis denotes the maximum 1-hour average, the position on the y-axis denotes the maximum 8-hour rolling average and the size of the bubble is proportional to the annual average. The Metro Vancouver 1-hour and 8-hour objectives are also provided on the plot as lines and areas of exceedance are shaded grey. The stations plotted above the 8-hour objective (65 ppb) all exceeded the objective while the stations to the right of the 1-hour objective (82 ppb) exceeded both objectives. The same values are represented spatially in Figures 7 to 9 while the Canadian Ambient Air Quality Standard (CAAQS) is shown in Figure 10.

Summer ozone exceedances were widespread throughout the region and thought to be influenced by the presence of wildfire smoke. Smoke from wildfires enhanced ozone production.

In 2018, the Canadian Ambient Air Quality Standard (CAAQS) was exceeded at Mission and Hope. The CAAQS value is calculated by the annual 4^{th} highest 8-hour daily maximum, averaged over three consecutive years. The 2018 year included two wildfire years (2017 and 2018). In both summers smoke from wildfires acted to enhance ozone production resulting in higher than typical concentrations.

The Burnaby Mountain station measured the highest average ozone level which is typical given the station's high elevation on the top of Burnaby Mountain.

There were periods during the summer of 2018 when conditions were conducive for ozone formation resulting in elevated O_3 levels in the LFV. The 1-hour Metro Vancouver objective was exceeded at twelve stations on a combination of five days with the highest concentration of 104 ppb measured in Maple Ridge. Exceedances occurred on July 16 at Hope; July 29 at Hope, Maple Ridge and Mission; July 30 at Hope, Maple Ridge, Coquitlam, Mission and Agassiz; August 8 at Chilliwack, Langley, Hope, Abbotsford-Mill Lake, Mission, Agassiz and Abbotsford-Airport; and August 21 at Port Moody, Surrey East, North Vancouver-Mahon Park, Langley, Maple Ridge, Abbotsford-Mill Lake, Mission, and Abbotsford-Airport.

Exceedances in the western portion of Metro Vancouver (i.e., North Vancouver) are not common and it is likely that ozone formation was enhanced on August 21 due to wildfire smoke that was prevalent throughout the region.

The 8-hour Metro Vancouver objective was exceeded on twelve days including July 16, 25, 26, 27, 28, 29, and 30, and August 7, 8, 9, 21, and 22 at a combination of 17 stations with the highest concentration of 86.7 ppb measured in Maple Ridge on July 30.

Air quality advisories were issued in 2018 for a combination of elevated ground-level ozone and/or fine particulate matter. In 2018, air quality advisories were issued due to O_3 on eight days. On several of these days O_3 was thought to be enhanced by the presence of wildfire smoke. The enhancement of O_3 due to wildfire smoke is further discussed in Section J.

The highest short-term concentrations occur in the eastern parts of Metro Vancouver and in the FVRD (Figures 7 and 8). The lowest annual O_3 averages (Figure 9) occur in highly urbanized areas due to O_3 scavenging. Ozone scavenging occurs in locations where higher levels of NO_x are found (e.g. urban areas or near busy roadways). In these areas, emissions containing NO_x, react quickly with O_3 to form NO_2 (nitrogen dioxide) and O_2 (oxygen) thus decreasing O_3 concentrations.

Figure 11 shows the seasonal trend of O_3 with the monthly average provided with highest 1-hour concentrations from each month. In both figures, concentrations from selected stations are shown alongside the range of concentrations measured at all stations (shown as a grey band). The seasonal variation evident in Figure 11 is typical of historical ozone trends in the LFV with higher values in spring and summer, and lower values during fall and winter. Since O_3 is produced by photochemical reactions there is greater production in spring and summer with the presence of sunlight and land- and sea-breeze wind patterns. Spring exhibits the highest average O_3 concentrations (Figure 11 left) while the highest short-term hourly concentrations (Figure 11 right) occur in the summer.

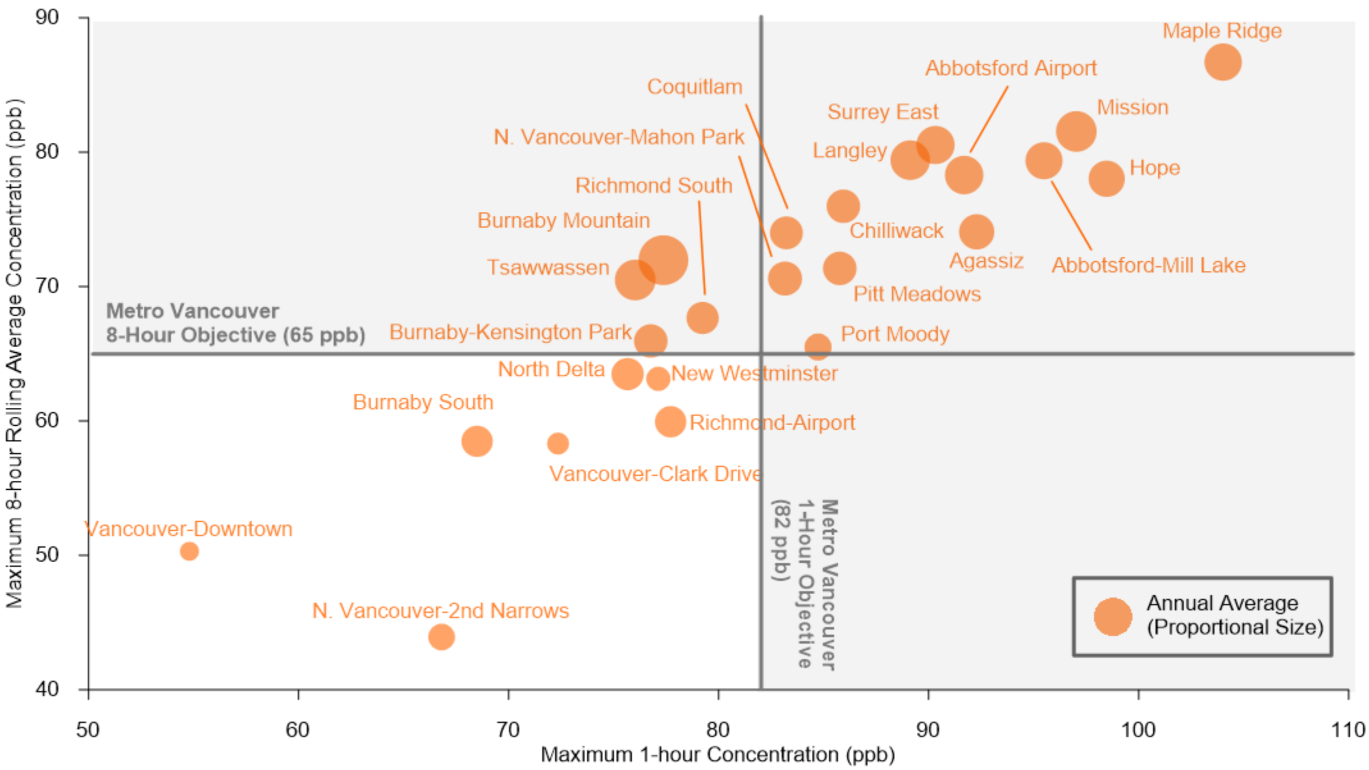
Figure 12 illustrates the long-term annual average O_3 trend in the LFV. The annual average trend is given in the left plot with the short-term peak trend given in right plot for the last two decades. Annual O_3 levels have shown an upward trend since the mid-90s. Research indicates that background ozone concentrations are rising and is one factor for observed increases in average levels.

A trend in short-term peak O_3 concentrations (Figure 12) is less apparent. Yearly differences are likely related to variability in meteorology, however there doesn't appear to be a trend in peak concentrations. Peak ozone levels have been mostly unchanged during the last fifteen to twenty years, despite significant reductions in ozone precursor pollutants over the same time period.

Metro Vancouver and the Fraser Valley Regional District adopted the Regional Ground-Level Ozone Strategy in 2014, which provides strategic policy direction for ozone management in the LFV based on local scientific research. Research indicates that a spatial understanding of the ratio of concentrations of nitrogen oxides (NO_X) and volatile organic compounds (VOC), two precursor pollutants that react to form ozone, is key to determining which precursors to reduce in order to maintain and improve air quality in our region.

The values in Tables 4 and 5 represent the frequency distribution (or count) of how many hourly and 8-hour rolling average measurements were in the specified ranges, respectively. The frequency distributions in these tables show how often various O_3 levels are reached. It can be seen that stations located in the eastern parts of Metro Vancouver and in the FVRD measured the greatest frequency of high O_3 concentrations.

A series of diurnal plots are shown in Figure 13 for each O_3 monitoring station. The plots demonstrate the differences between weekdays and weekends along with differences between summer and winter. Most of the stations exhibit similar diurnal trends. In the summer, O_3 concentrations are low through the night and begin increasing near sunrise with the highest (peak) concentration occurring in the afternoon. Examining the timing of the peak shows in general the stations in the west peak first while the stations in the east peak a few hours later with Hope typically experiencing the latest peak in the day. Noon is marked on the figure as a black vertical line for reference. On very hot sunny days, typically during a summertime episode, the O_3 peak occurs later in the day. Winter shows a similar trend of an afternoon peak. Ozone peaks in the winter are greatly attenuated compared with the summer.



Note: Stations contained within the grey area denote an exceedance of an objective.

Figure 6: Ground-level ozone monitoring, 2018.

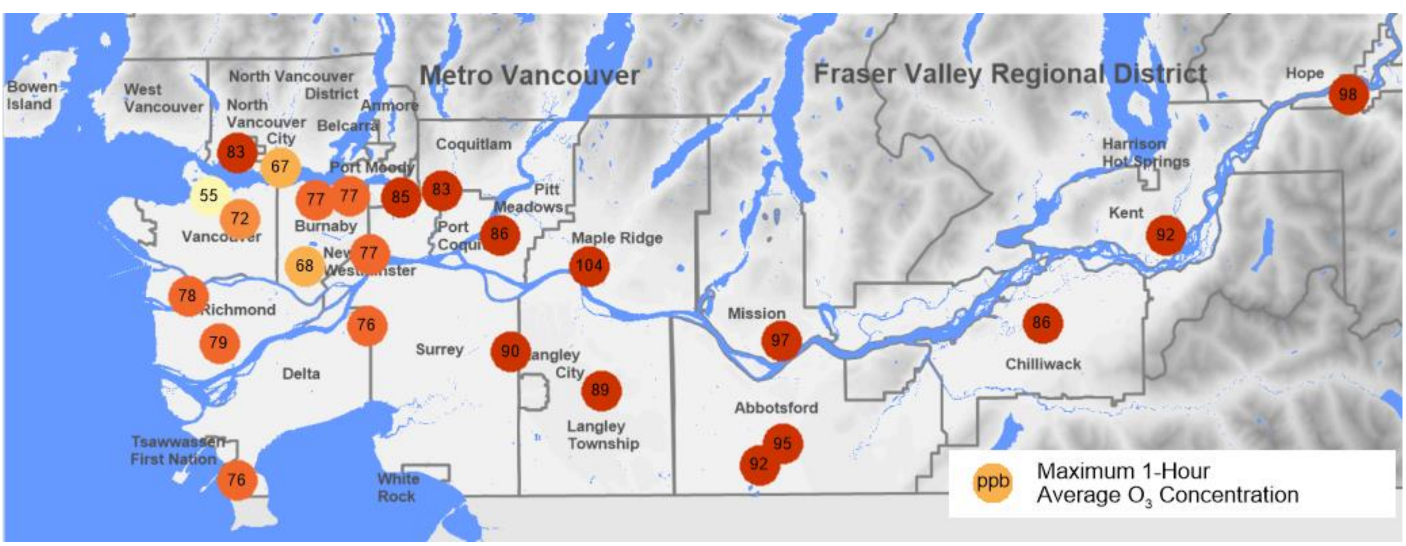


Figure 7: Short-term peak (maximum 1-hour) ozone in the LFV, 2018.

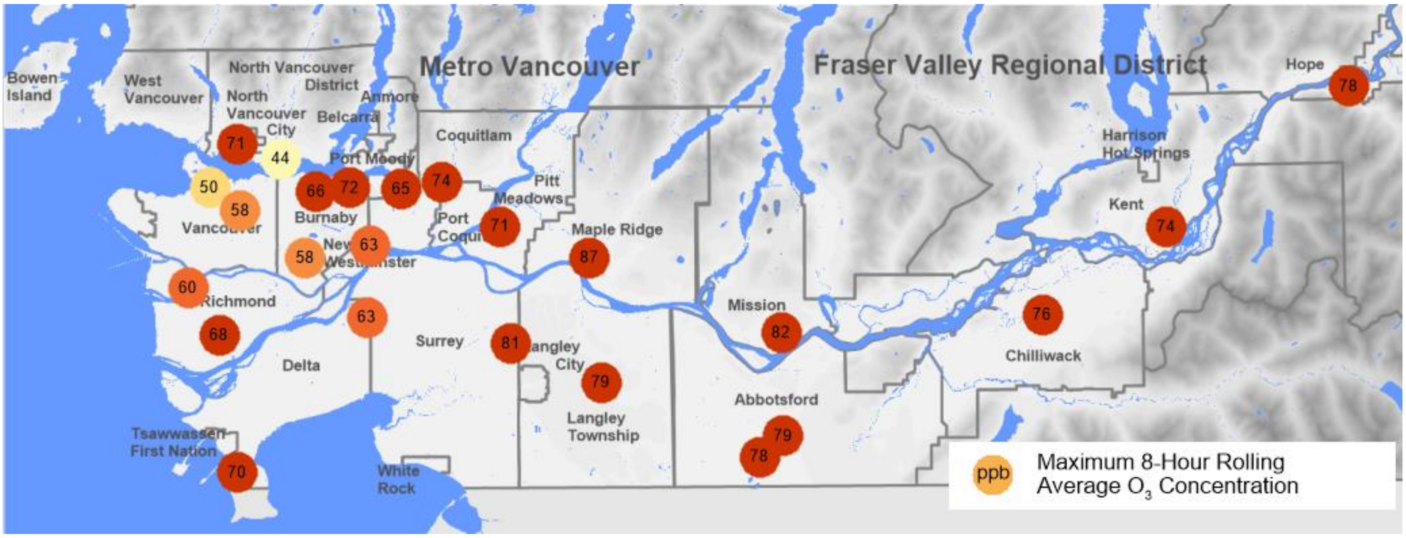


Figure 8: Short-term peak (maximum 8-hour) ozone in the LFV, 2018.

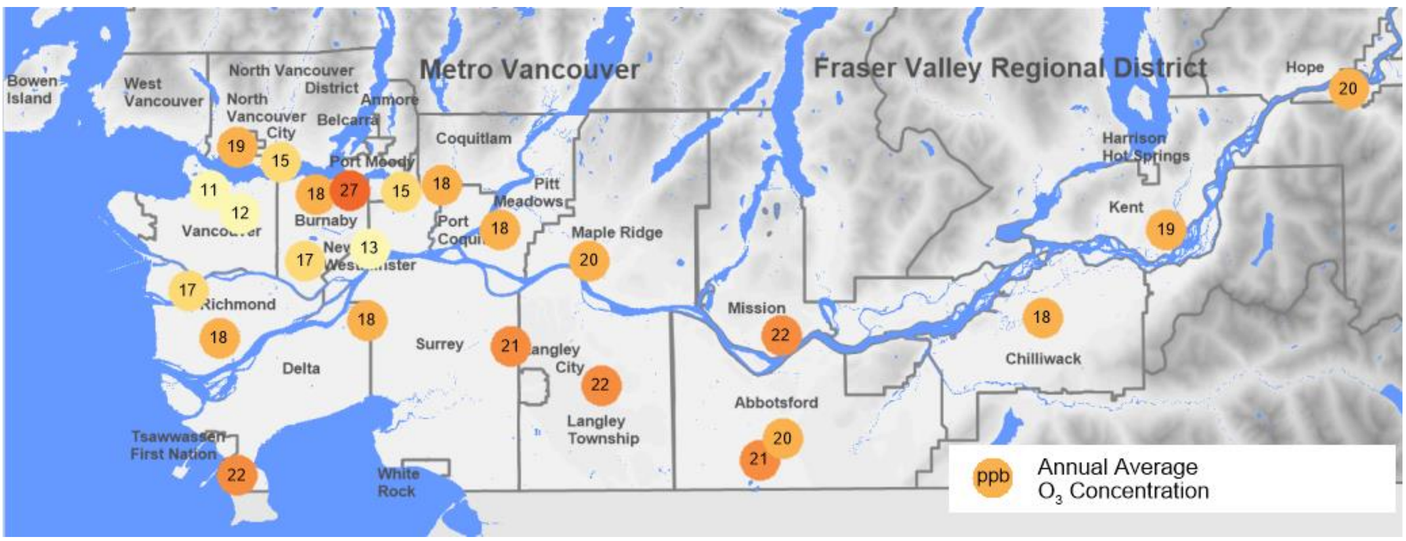


Figure 9: Annual average ozone in the LFV, 2018.

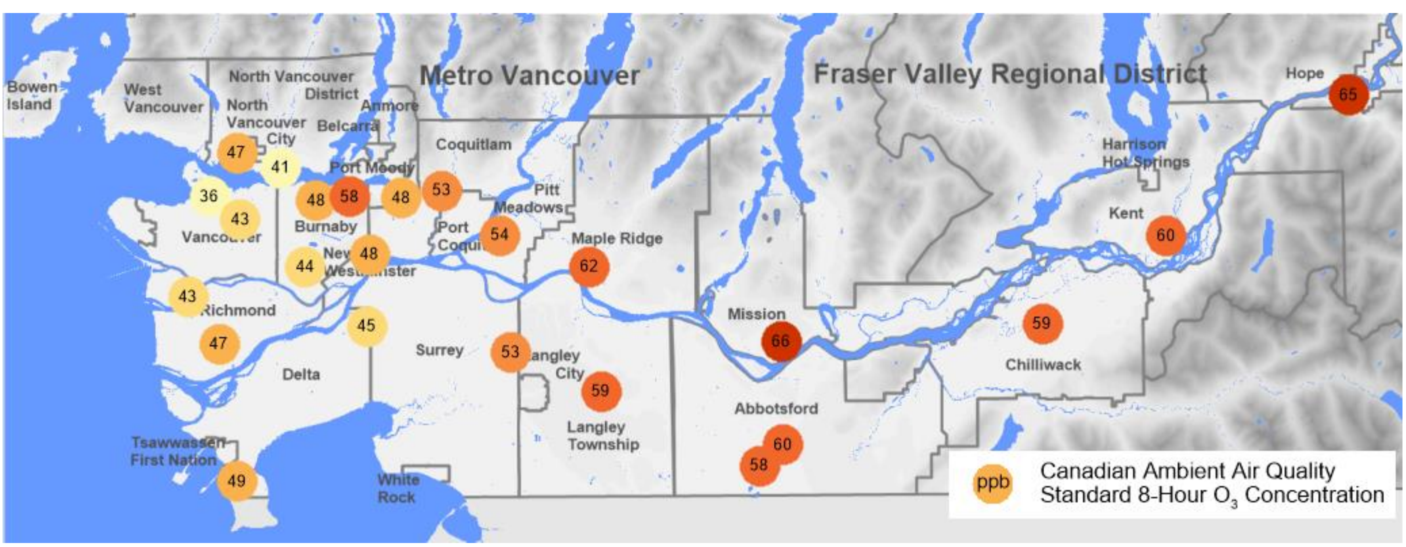


Figure 10: Canadian Ambient Air Quality Standard value for ozone in the LFV, 2018.

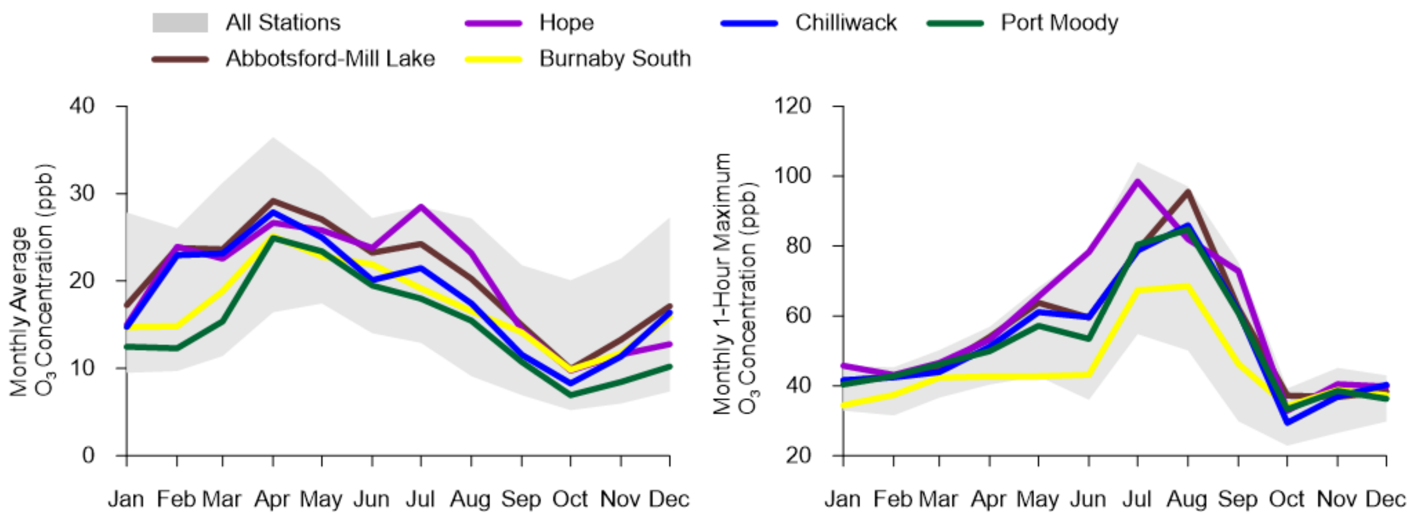


Figure 11: Monthly average (left) and short term peak (right) ozone, 2018.

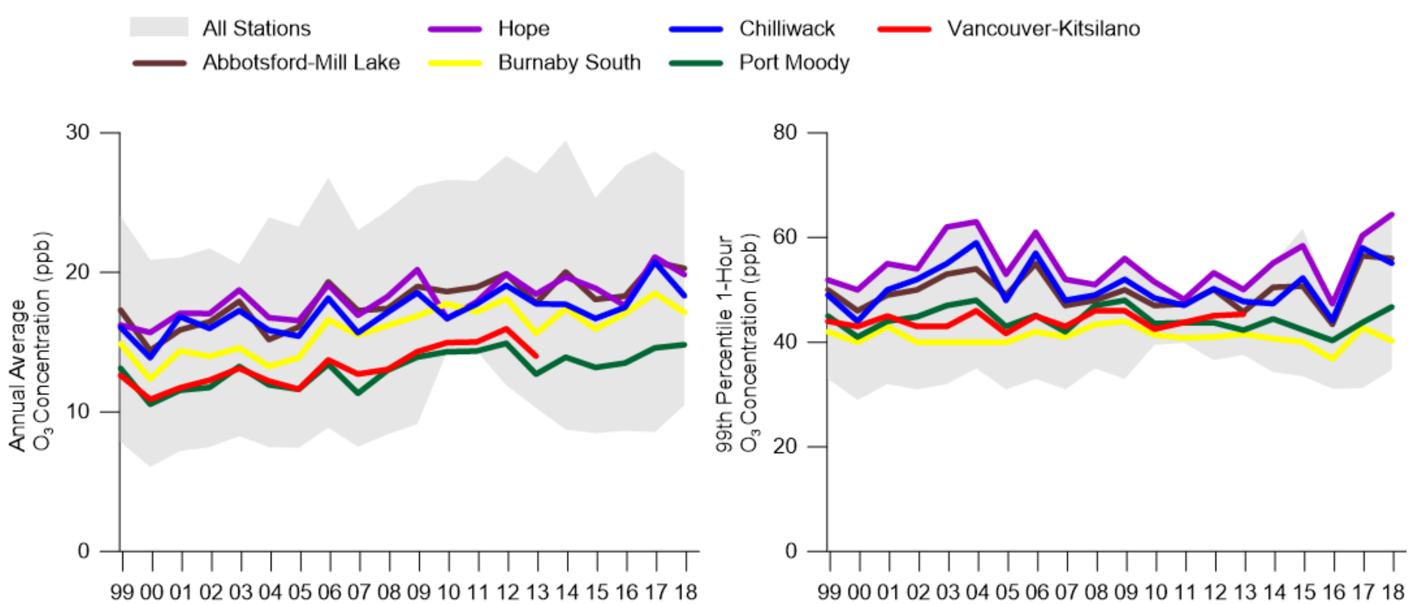


Figure 12: Annual (left) and short term peak (right) ozone trend, 1999 to 2018.

Table 4: Frequency distribution of hourly ozone, 2018.

O_3 Conc. (ppb)	Vancouver-Downtown	Burnaby-Kensington Park	N. Vancouver-2nd Narrows	Port Moody	Chilliwack	North Delta	Burnaby Mountain	Surrey East	Richmond South	Burnaby South	Pitt Meadows	N. Vancouver-Mahon Park	Langley	Hope	Maple Ridge	Richmond-Airport	Coquitlam	Abbotsford-Mill Lake	Tsawwassen	Mission	Agassiz	Abbotsford Airport	New Westminster	Vancouver-Clark Drive
0 to 5	3279	1265	1820	2595	1723	1578	87	994	2208	1343	1975	1369	1187	1537	1295	1967	1701	1287	705	747	1430	1223	3062	3110
5 to 10	1548	1177	1518	1160	1027	1051	202	811	802	1078	818	1082	690	979	804	953	1067	946	594	722	1019	968	1116	1249
10 to 15	1339	1316	1422	1076	1130	1170	678	1103	915	1343	950	1173	888	1067	1079	1051	1170	1068	981	1064	1123	919	1062	1071
15 to 20	1048	1162	1296	969	1127	1238	1102	1272	1016	1460	953	1183	1056	1113	1188	1120	1132	1142	1368	1396	1196	1049	941	905
20 to 25	720	1280	1068	906	1021	1201	1472	1204	956	1368	1090	1213	1197	1038	1167	1078	985	1092	1387	1294	1162	997	777	760
25 to 30	447	1042	789	784	820	1063	1756	1234	974	1083	1039	1100	1234	870	1102	1025	1007	1031	1320	1274	982	1087	670	594
30 to 35	193	742	432	536	747	757	1611	937	896	696	879	769	1114	771	920	770	716	979	1101	1010	760	1010	480	399
35 to 40	52	441	216	354	529	399	1048	643	537	246	535	476	702	628	572	500	463	630	770	601	548	757	324	201
40 to 45	13	196	54	170	311	172	432	280	290	59	245	186	330	320	299	168	206	299	340	292	264	345	125	78
45 to 50	7	67	15	65	86	42	168	89	79	18	90	91	114	106	139	53	120	94	54	108	79	134	53	20
50 to 55	8	17	1	29	43	11	76	40	22	7	31	39	40	64	49	6	42	43	12	47	51	49	16	8
55 to 60		8		8	40	16	32	21	3	7	17	9	34	54	29	4	25	35	8	40	23	28	6	10
60 to 65		4	2	7	21	1	16	13	6	4	9	9	13	35	19	2	13	25	3	28	35	19	5	2
65 to 70		4	1	6	8	4	5	10	4	3	7	3	7	24	12		9	10	1	28	21	10	5	2
70 to 75		2		2	11	1	7	5	1		5	3	7	30	8	1	9	13	3	16	19	5	1	1
75 to 80		3		1	6	1	3	7	3		5	1	8	20	4	1	2	7	2	5	5	4	2	
80 to 85				2	2			1			2	2	5	3	5		3	1		4	3	3		
85 to 90					1			2			1		4	3	6			2		6	2	2		
>=90								1						2	4			2		7	3	1		
Missing	100	34	116	75	96	55	65	87	48	39	101	44	129	93	51	59	86	53	104	71	26	147	97	349
Data Completeness	99%	100%	99%	99%	99%	99%	99%	99%	100%	100%	99%	100%	99%	99%	99%	99%	99%	99%	99%	99%	100%	98%	99%	96%

Table 5: Frequency distribution of 8-hour rolling average ozone, 2018.

O_3 Conc. (ppb)	Vancouver-Downtown	Burnaby-Kensington Park	N. Vancouver-2nd Narrows	Port Moody	Chilliwack	North Delta	Burnaby Mountain	Surrey East	Richmond South	Burnaby South	Pitt Meadows	N. Vancouver-Mahon Park	Langley	Hope	Maple Ridge	Richmond-Airport	Coquitlam	Abbotsford-Mill Lake	Tsawwassen	Mission	Agassiz	Abbotsford Airport	New Westminster	Vancouver-Clark Drive
0 to 4	2183	712	1108	1777	968	938	7	561	1389	832	1255	800	646	976	776	1224	1086	641	401	287	726	571	2078	2118
4 to 8	1793	888	1228	1145	995	856	55	593	831	809	797	783	584	739	603	904	877	853	423	474	917	845	1288	1400
8 to 12	1393	1107	1352	1075	1060	1041	250	812	934	1121	897	1037	789	926	838	993	966	877	624	768	989	892	1126	1196
12 to 16	1200	1138	1309	1017	1089	1167	702	1054	1031	1245	863	1133	834	1019	1067	1102	1100	1014	935	1114	1095	900	1000	1025
16 to 20	945	1105	1216	905	1007	1146	929	1109	864	1329	891	1140	955	1036	1088	975	1012	1048	1244	1245	1116	944	882	893
20 to 24	558	1195	926	891	908	1078	1178	1078	866	1218	1023	1118	1050	933	987	987	971	988	1214	1147	1001	971	731	671
24 to 28	318	1006	738	722	744	944	1478	1152	878	1045	942	981	1083	757	1055	941	929	956	1169	1101	886	925	595	522
28 to 32	178	671	428	476	677	748	1496	933	777	699	852	709	1041	747	869	688	724	897	1045	1013	721	934	399	285
32 to 36	49	484	212	363	497	458	1276	669	597	334	588	513	792	613	651	526	467	674	802	722	584	765	296	195
36 to 40	14	297	90	189	394	210	753	415	356	69	302	290	480	437	383	240	283	410	523	409	371	529	160	75
40 to 44	7	81	23	88	164	83	315	160	118	10	136	126	226	175	183	105	134	185	243	187	141	228	53	32
44 to 48	3	33		22	70	25	124	48	55	14	52	49	67	87	91	20	64	59	30	68	67	102	15	8
48 to 52	2	7		9	41	2	66	38	12	6	13	20	24	50	34	2	26	43	8	34	36	28	7	4
52 to 56		7		5	19	3	19	17	4	6	6	4	30	44	34	1	12	25	2	43	32	20	4	4
56 to 60		7		5	17	3	30	13	3	3	8	2	9	40	7	3	8	14	1	24	27	10	5	1
60 to 64		4		5	7	8	8	4	2		5	3	9	26	7		8	11	2	18	16	8	3	
64 to 68		1		4	10		6	3	3		5	2	6	20	8		5	6	1	12	7	6		
68 to 72					2		4	3			5	2	8	26	5		3	6	3	6	7	3		
72 to 76					3			5					5	3	6		3	5		9	4	3		
>=76								3					3	2	9			3		8		3		
Missing Data	117	17	129	62	88	50	64	90	40	20	120	48	119	104	59	49	82	45	90	71	17	73	118	331
Completeness	99%	100%	99%	99%	99%	99%	99%	99%	100%	100%	99%	100%	99%	99%	99%	99%	99%	100%	99%	99%	100%	99%	99%	96%

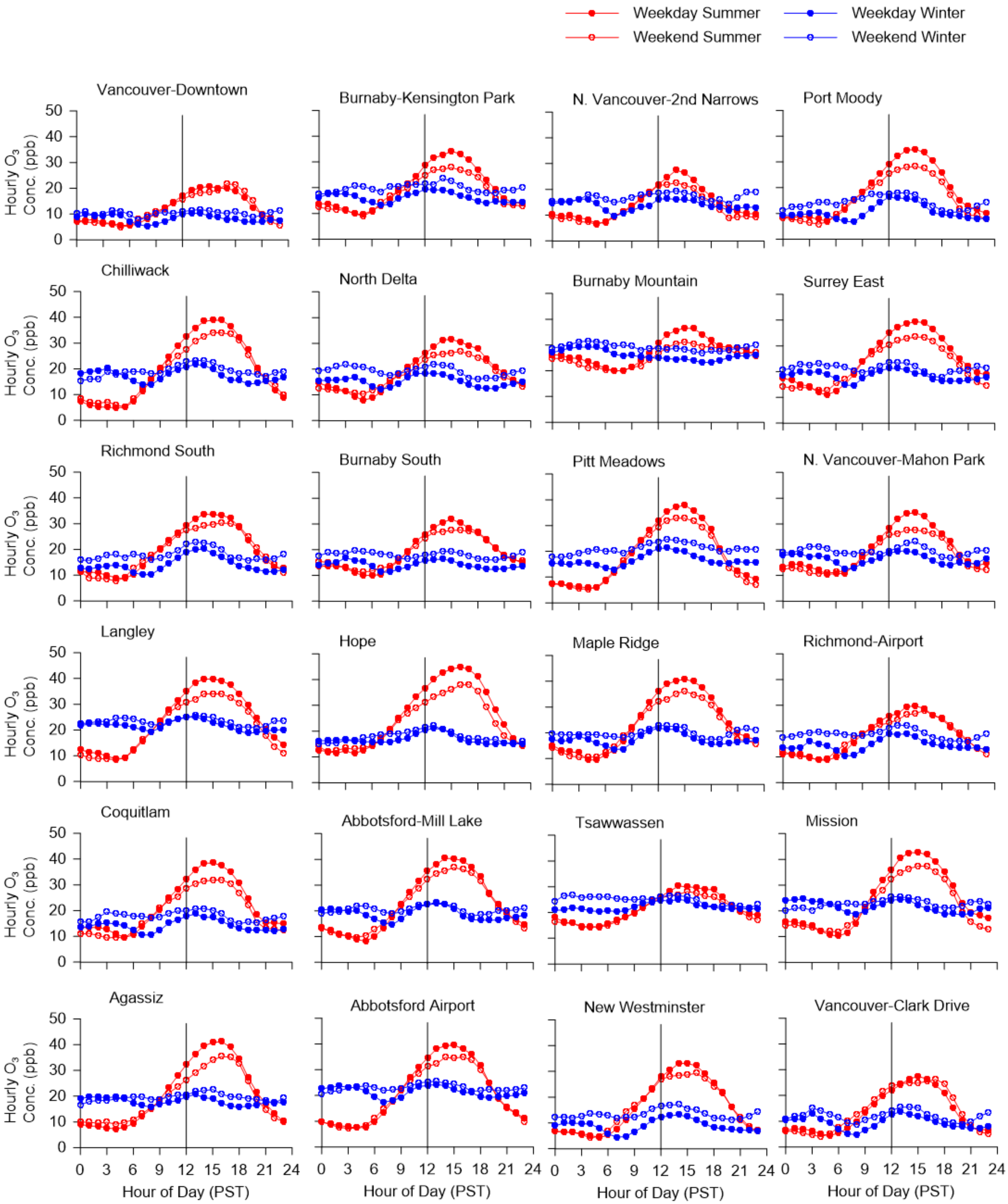


Figure 13: Diurnal trends ozone, 2018.

Fine Particulate ($PM_{2.5}$)

Characteristics

The term '$PM_{2.5}$' has been given to airborne particles with a diameter of 2.5 micrometres (μm) or less, also known as fine particulate matter. Given the very small size of these particles, they can penetrate into the finer structures of the lungs. Exposure to fine particulate ($PM_{2.5}$) can lead to both chronic and acute human health impacts, aggravate pulmonary or cardiovascular disease, increase symptoms in asthmatics and increase mortality. Fine particulate matter is considered by health experts to be an air pollutant of serious concern because of these health effects.

Fine particulate is also effective at scattering and absorbing visible light. In this role $PM_{2.5}$ contributes to regional haze and impaired visual air quality.

Sources

Emissions of $PM_{2.5}$ are dominated by residential wood burning (32%), non-road engines and equipment (15%), and industrial sources (15%). In addition to local sources, $PM_{2.5}$ can be transported long distances from sources such as large forest fires in other parts of western Canada, the US or more distant.

Scientific investigations in the LFV indicate that a considerable proportion of ambient $PM_{2.5}$ is also formed by reactions of NO_X and SO_2 with ammonia in the air (mainly from agricultural sources in the LFV). Fine particulate produced in this manner is called secondary $PM_{2.5}$ and accounts for a significant percentage of $PM_{2.5}$ in summer. Therefore, emissions of precursor gases of secondary $PM_{2.5}$ are also important sources in the region.

Monitoring Results

The $PM_{2.5}$ annual average, maximum 24-hour rolling average and Canadian Ambient Air Quality Standard (CAAQS) values are shown in Figures S7 and 14 for 2018. The same values are shown spatially in Figures 15, 16 and 17, respectively.

Nearly half of all stations with sufficient data available to calculate a CAAQS value were found to exceed the Standard. Canadian Ambient Air Quality Standard values for 2018 ranged from 18 to 46 $\mu g/m^3$.

Exceedances of Metro Vancouver's 24-hour $PM_{2.5}$ objective were widespread in 2018 due to smoke from wildfires. Unprecedented levels of $PM_{2.5}$ were measured throughout the region and led to the highest concentration and longest advisory in Metro Vancouver's history.

All but two stations (Vancouver-Clark Drive and Hope) were below the Metro Vancouver annual objective of 8 $\mu g/m^3$ and most stations were above the planning goal of 6 $\mu g/m^3$. Metro Vancouver's planning goal is a longer term aspirational target to support continuous improvement.

Exceedances of Metro Vancouver's 24-hour $PM_{2.5}$ objective were widespread in 2018. The region was impacted by extensive wildfires burning throughout the Pacific Northwest as well as in-region wildfires, a bog fire and a large barge fire.

The $PM_{2.5}$ objective was exceeded on July 27 and 28 at the Richmond-Airport station due to a bog fire in Richmond. On July 30, a one-day $PM_{2.5}$ advisory was issued as a precautionary measure because of possible wildfire smoke, however no exceedances of $PM_{2.5}$ were recorded on the day.

On August 9, $PM_{2.5}$ was exceeded at Hope and an advisory was issued for the Eastern Fraser Valley due to wildfires burning near Agassiz, Chilliwack and Manning Park.

The following day the $PM_{2.5}$ advisory was expanded to include all of Metro Vancouver when several municipalities were affected by smoke from a large barge fire (at a metal recycling depot) in Surrey (picture below). On August 10 and 11, $PM_{2.5}$ was exceeded at Hope due to wildfire smoke and New Westminster due to smoke from the barge fire.

On August 13, widespread smoke was experienced due to wildfire smoke from fires burning throughout the Pacific Northwest. An unprecedented fourteen-day advisory was issued whereby all monitoring stations in the region experienced exceedances of the $PM_{2.5}$ objective. The advisory was the longest continuous advisory in Metro Vancouver history. For three continuous days (August 13, 14, and 15) the $PM_{2.5}$ objective was exceeded at every monitoring station in the LFV.

On August 17 air quality improved for two days at all monitoring stations with the exception of Hope which exceeded the objective on both days.

Widespread smoke returned to the region on August 19 due to wildfires burning in BC and Washington state. Hope measured Metro Vancouver's highest 24-hour rolling average $PM_{2.5}$ concentration on record with a concentration of 257 $\mu g/m^3$. As the smoke continued to persist, every monitoring station was in exceedance on August 20 and continued to be for five days straight. August 23 was perhaps the most severe day across the region when the 24-hour $PM_{2.5}$ average was greater than 100 $\mu g/m^3$ at all monitoring stations.

On August 26 hourly $PM_{2.5}$ concentrations improved to below 25 $\mu g/m^3$. The 14-day advisory was lifted on August 27 making it longest and most severe air quality advisory in Metro Vancouver history.

On September 6, a one-day advisory was issued and $PM_{2.5}$ exceeded the objective at Chilliwack, North Delta, Hope, Mission and Vancouver-Clark Drive due to smoke from wildfires burning in BC and Washington state. On September 7 the $PM_{2.5}$ objective was exceeded at Chilliwack and Hope.

Results of the wildfire smoke influence are discussed further in Section J.

In addition to the wildfire influences there were other $PM_{2.5}$ exceedances that occurred throughout the year. Exceedances were experienced in Chilliwack on October 24, Langley on October 20, 21, and 22, November 18 and 19, Pitt Meadows on November 1, Abbotsford-Mill Lake and Mission on October 20 and 21, and Abbotsford-Airport and Vancouver-Clark Drive on October 20. These exceedances were thought to be a result of a combination of fireworks, residential wood burning and/or open burning.

Table 6 gives the frequency distribution of $PM_{2.5}$ concentrations for the year. In 2018, Hope experienced the highest frequency of elevated $PM_{2.5}$ concentrations (> 25 $\mu g/m^3$), which occurred due to its proximity to the Fraser Canyon where outflow winds transported heavy smoke into the region.

Seasonally, $PM_{2.5}$ levels are usually higher in the summer with the highest values typically experienced during the dry summer months (Figure 18), due to the secondary formation of $PM_{2.5}$ and smoke from wildfire activity. In 2018, the highest average and peak $PM_{2.5}$ levels were experienced in August.

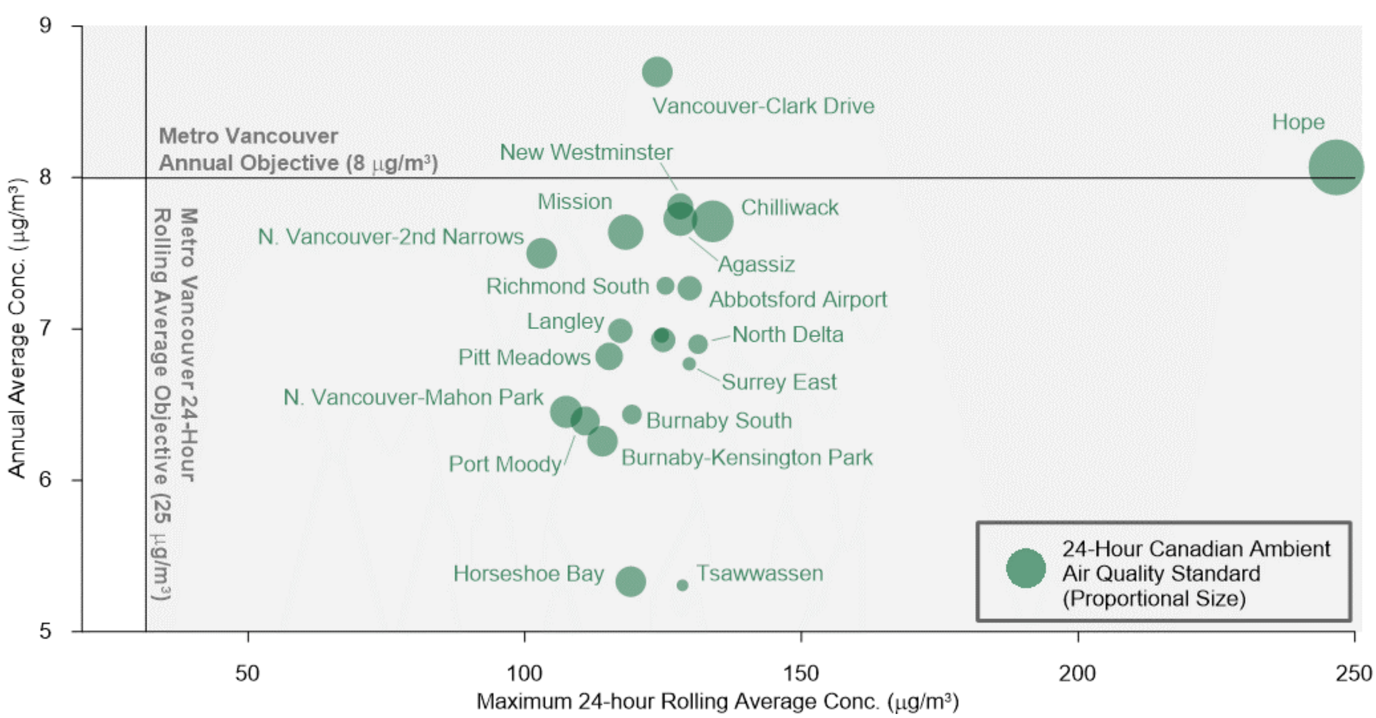
Figure 19 illustrates the long-term $PM_{2.5}$ trends in the LFV with annual average and peak concentrations shown respectively. Monitoring technology was upgraded in 2013 to continuous particulate monitors that met the U.S. Environmental Protection Agency $PM_{2.5}$ Federal Equivalent Method (FEM). The FEM monitors have the ability to measure a portion of particulate matter not previously measured. The short-term peak concentrations reflect the highest levels that occur, represented by the 99th percentile of the 24-hour rolling average for each year. Given that it will take numerous years to establish a long-term record of $PM_{2.5}$ with the FEM monitor, both the TEOM and FEM data are shown together.

In Figure 19 the TEOM data is shown as solid lines with a grey band displaying the range of values from all TEOM stations, while the FEM data is shown as dotted lines with an orange band showing the range from all FEM stations.

It is evident that the FEM monitor measures higher $PM_{2.5}$ concentrations compared to the TEOM monitor. Long-term average trends of the TEOM data show that 2015 was not appreciably different than previous years. However, the FEM data shows a step increase compared with the TEOM, which is a result of the FEM monitor's ability to measure some particles not previously measured by the TEOM monitor.

The differences in peak trends from year to year are driven by meteorological variability and wildfire activities. The long-term peak trend shows that 2017 and 2018 measured much higher peak concentrations compared with other years.

A series of diurnal plots are shown in Figure 20 for each $PM_{2.5}$ monitoring station. Typically, the summer exhibits little diurnal variation while the winter displayed higher $PM_{2.5}$ concentrations in the evenings compared with the daytime. The evenings in winter were likely elevated due to reduced atmospheric mixing depths coupled with regional and local emission sources.



Note: Stations contained within the grey area denote an exceedance of an objective.

Figure 14: Fine particulate ($PM_{2.5}$), 2018.

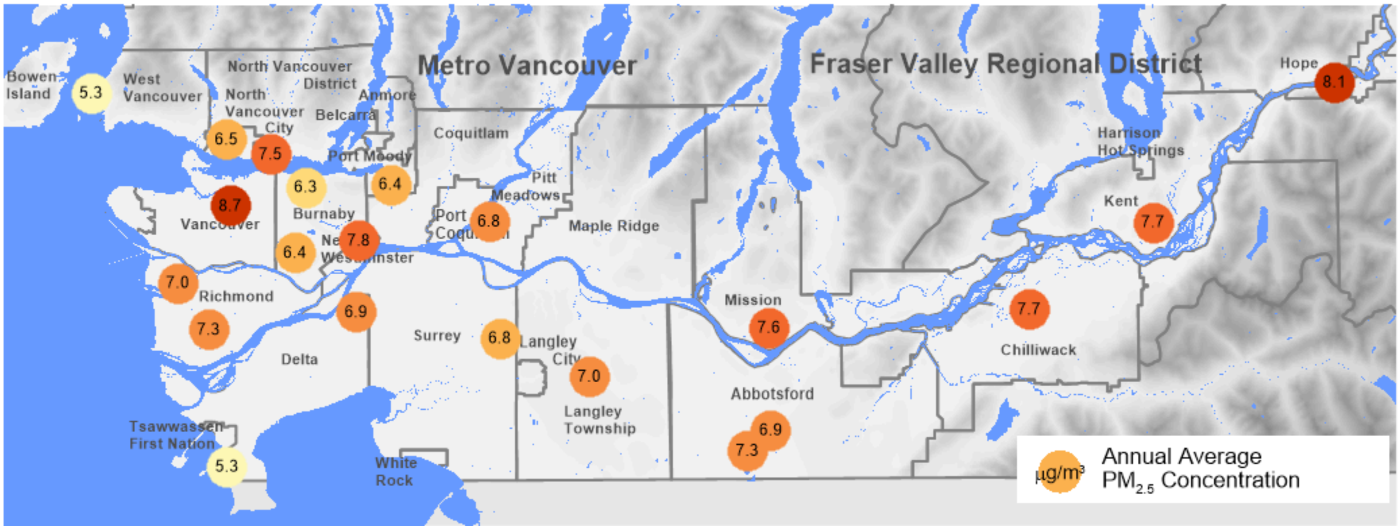


Figure 15: Annual average fine particulate ($PM_{2.5}$) in the LFV, 2018.

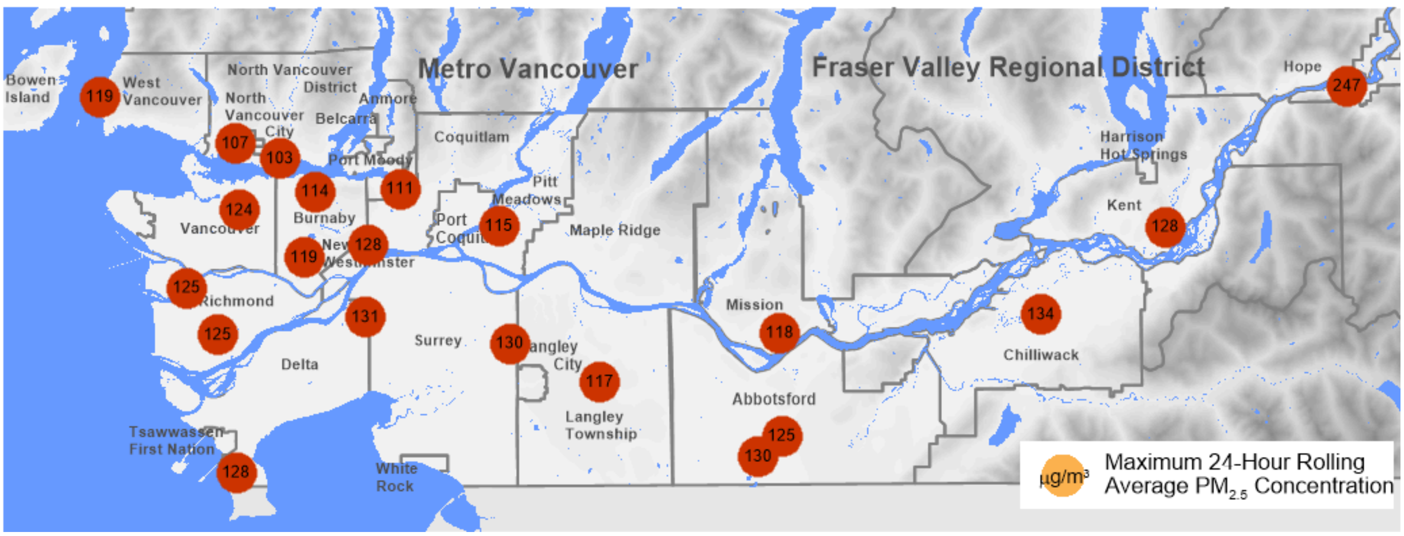


Figure 16: Short-term peak fine particulate ($PM_{2.5}$) in the LFV, 2018.

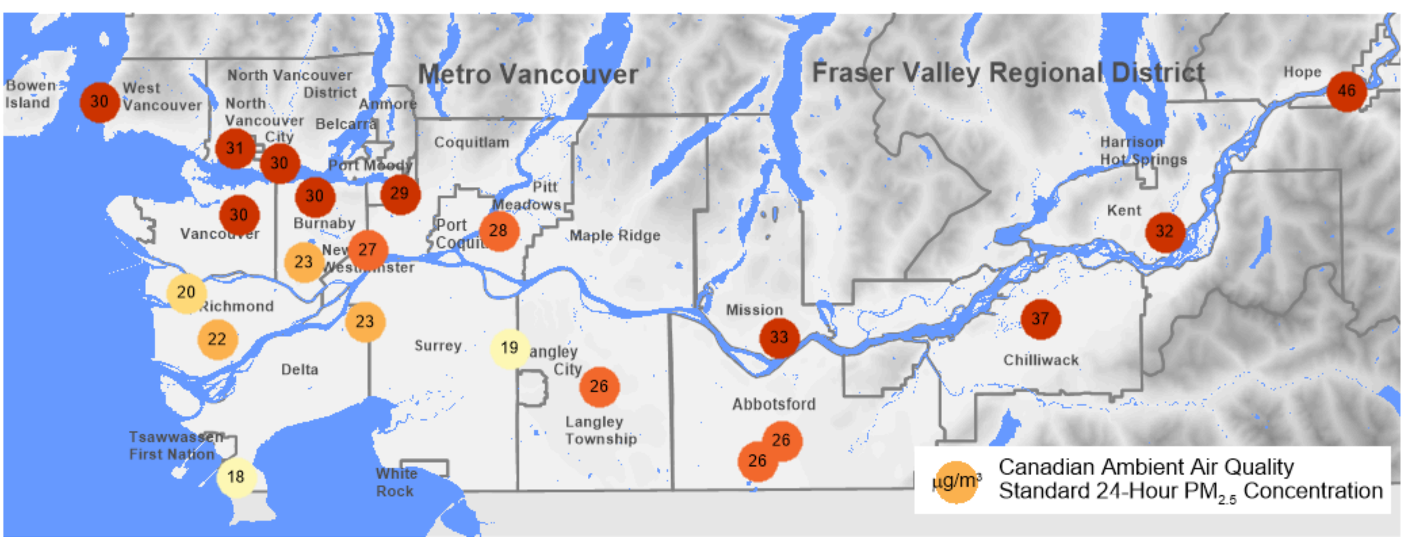


Figure 17: Canadian Ambient Air Quality Standard value for fine particulate ($PM_{2.5}$), 2018.

Table 6: Frequency distribution of 24-hour rolling average fine particulate ($PM_{2.5}$), 2018.

$PM_{2.5}$ Conc. ($\mu g/m^3$)	Burnaby-Kensington Park	N. Vancouver-2nd Narrows	Port Moody	Chilliwack	North Delta	Surrey East	Richmond South	Burnaby South	Pitt Meadows	N. Vancouver-Mahon Park	Langley	Hope	Richmond-Airport	Abbotsford-Mill Lake	Horseshoe Bay	Tsawwassen	Mission	Agassiz	Abbotsford Airport	New Westminster	Vancouver-Clark Drive
0 to 12	7955	7722	8033	7320	7936	7817	7021	8022	7721	8074	7603	7788	7834	7890	7744	8246	7423	7651	7724	7610	7156
12 to 24	363	530	414	772	464	543	620	462	521	394	796	452	621	524	265	255	824	685	778	739	963
24 to 36	54	74	62	88	73	63	40	43	80	63	136	94	46	77	37	31	92	97	88	89	101
36 to 48	25	24	20	17	29	40	38	30	38	26	40	44	55	65	27	28	69	20	43	31	30
48 to 60	42	33	44	53	29	26	13	31	41	40	9	34	7	15	58	6	38	34	17	36	35
60 to 72	43	55	40	57	6	6	7	29	25	43	6	51	6	5	32	6	21	36	5	23	21
72 to 84	15	13	20	12	15	4	4	25	12	14	13	22	6	12	15	6	10	8	4	24	21
84 to 96	15	14	10	14	20	26	13	6	12	15	30	12	27	29	5	30	15	10	15	7	14
96 to 108	7	17	10	7	18	17	26	7	11	19	12	13	24	7	6	19	11	32	29	6	8
108 to 120	8		6	7	9	9	22	12	7		6	7	9	13	11	7	13	14	11	9	10
120 to 132				9	10	7	7					10	5	5		11		9	9	7	6
132 to 144				3								9									
144 to 156												8									
156 to 168												9									
168 to 180												4									
180 to 192												2									
192 to 204												4									
204 to 216												3									
216 to 228												3									
228 to 240												4									
>=240												5									
Missing	233	278	101	401	151	202	949	93	292	72	109	182	120	118	560	115	244	164	37	179	395
Data Completeness	97%	97%	99%	95%	98%	98%	89%	99%	97%	99%	99%	98%	99%	99%	94%	99%	97%	98%	100%	98%	96%

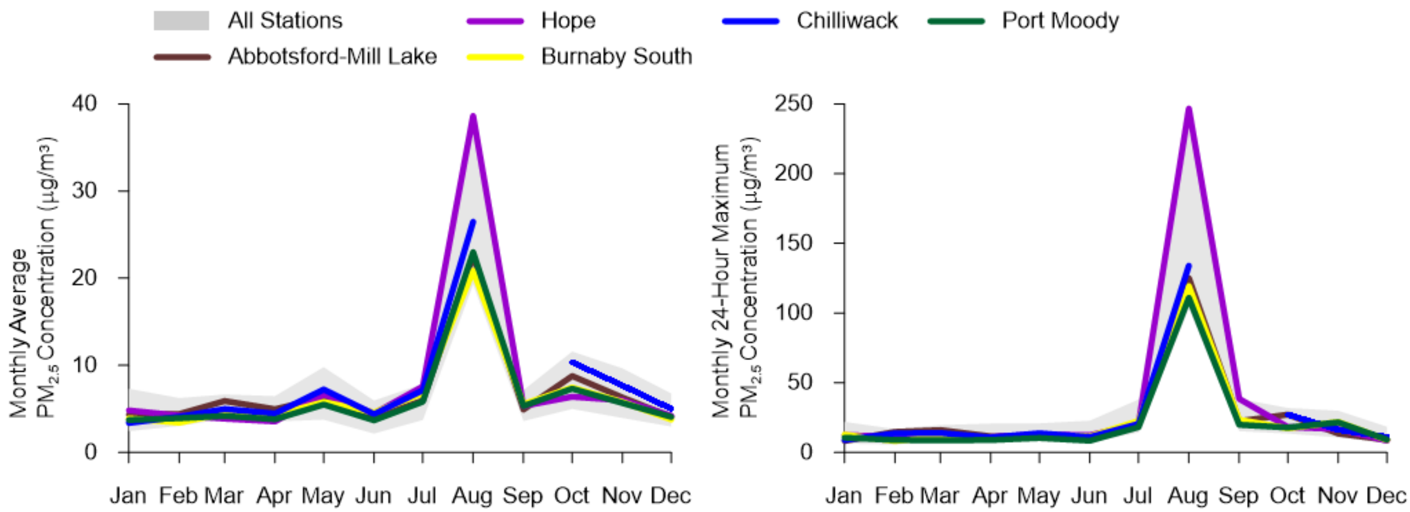


Figure 18: Monthly average (left) and short term peak (right) fine particulate ($PM_{2.5}$), 2018.

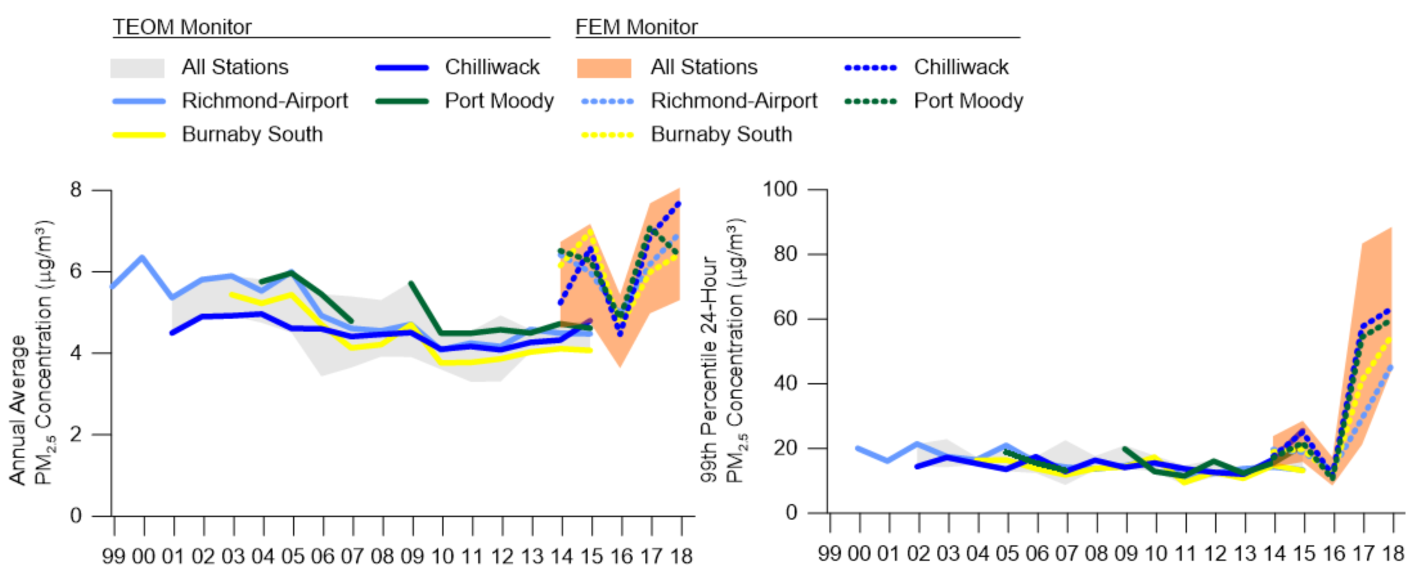
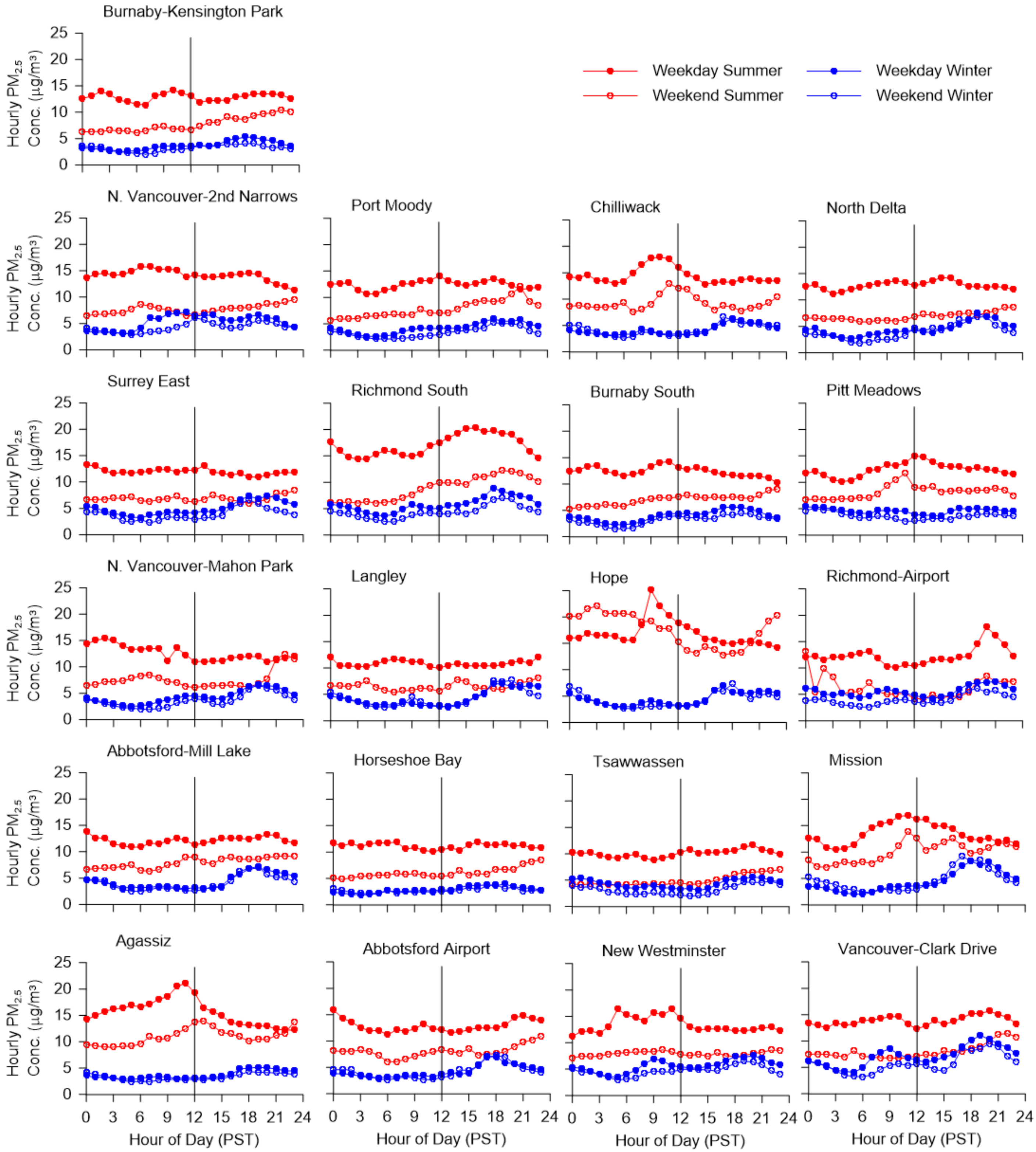


Figure 19: Annual (left) and short term peak (right) fine particulate ($PM_{2.5}$) trend, 1999 to 2018.



Note: These diurnal plots are heavily influenced by wildfire smoke events in summer and do not represent a typical annual trend.

Figure 20: Diurnal trends fine particulate ($PM_{2.5}$), 2018.

Nitrogen Dioxide (NO_2)

Characteristics

Of all the different oxides of nitrogen (NO_X), nitric oxide (NO) and nitrogen dioxide (NO_2) are of most concern in ambient air quality. Both are produced by the high temperature combustion of fossil fuels, and are collectively referred to as NO_X. Nitric oxide generally predominates in combustion emissions but rapidly undergoes chemical reactions in the atmosphere to produce NO_2.

Nitrogen dioxide is a reddish-brown gas with a pungent, irritating odour. It has been implicated in acute and chronic respiratory disease and in the creation of acid rain. It also plays a major role in ozone formation, and as a precursor to secondary particulate formation ($PM_{2.5}$), both of which can affect visual air quality in the region.

Sources

Common NO_X sources include boilers, building heating systems and internal combustion engines. In the LFV, transportation sources account for approximately 77% of NO_X emissions, with stationary and area sources contributing the remainder.

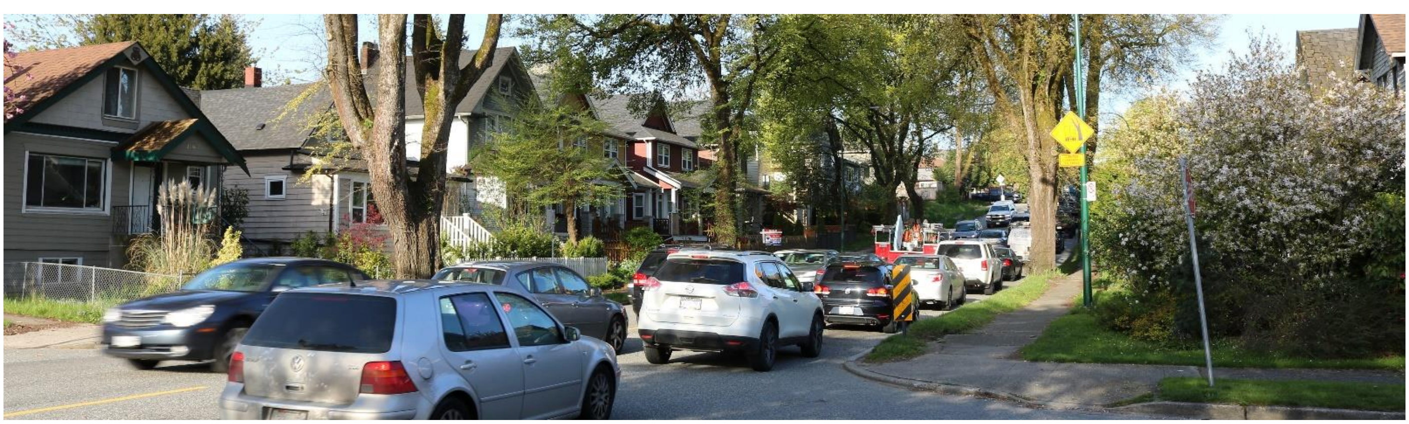
Monitoring Results

Figures S8 and 21 shows NO_2 monitoring levels in 2018, while Figures 22 and 23 shows the same values spatially. All 1-hour NO_2 concentrations continued to be below the Metro Vancouver objective at all times in 2018. Average levels for the year were also below Metro Vancouver's annual objective.

The majority of nitrogen oxides are from transportation sources such as cars, trucks, rail, planes and ships. These sources play a large role in ozone formation in the summer, which can lead to an air quality advisory.

Emissions affecting NO_2 concentrations are dominated by transportation sources, which is indicated by the locations of the highest concentrations. The highest concentrations are measured in more densely trafficked areas near busy roads. Lower concentrations were observed where traffic influences were less pronounced, such as the eastern parts of Metro Vancouver and in the FVRD.

The seasonal trend for NO_2 in 2018 is shown by monthly averages and the monthly maximum 1-hour concentrations in Figure 24. On average, NO_2 concentrations were higher in the winter and lower in the summer. This seasonal trend is typical of the region and is the result of lower atmospheric mixing heights in winter along with increased residential, commercial and industrial heating.



The long-term NO_2 trends are shown in Figure 25. The annual average and short-term peak trends are provided in Figure 25 for the last two decades.

The trend for average and peak (98th percentile of 1-hour) concentrations continued to decline, showing constant improvement in NO_2 levels since the mid 1990's. Long-term changes in air quality can be attributed to changes in emissions while the yearly variation is likely attributable to meteorological variability. The improvements in the long-term trends shown here are thought to be largely due to improved vehicle emission standards and the AirCare program, which was operated in BC from 1992 to 2014.

The frequency distribution of hourly concentrations measured in 2018 is given in Table 7.

A series of diurnal plots are shown in Figure 26 for each station that monitors NO_2. The plots demonstrate the differences between weekdays and weekends along with differences between summer and winter. Most stations exhibit higher concentrations on weekdays compared with weekends and show a peak in the morning along with a peak in the afternoon. Higher concentrations correspond relatively well with traffic volume patterns.

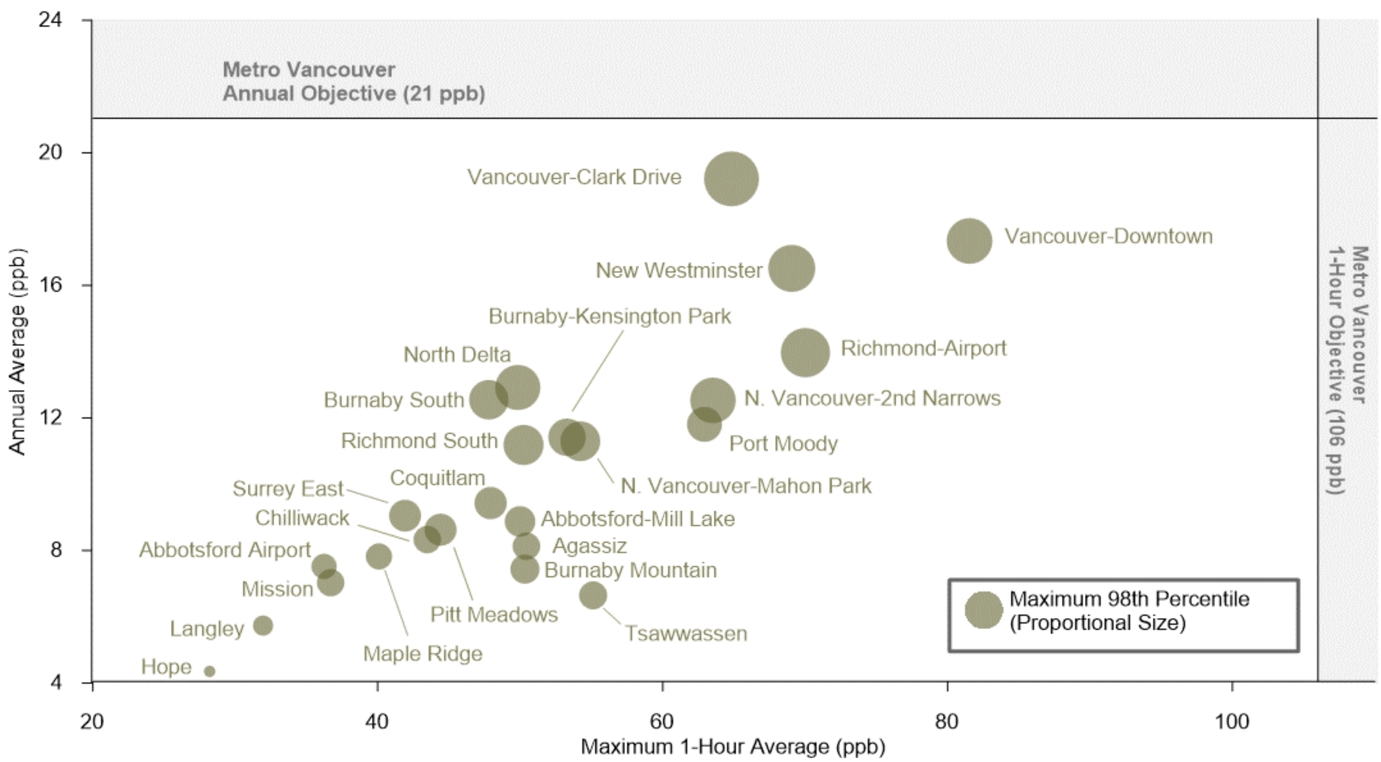


Figure 21: Nitrogen dioxide monitoring, 2018.

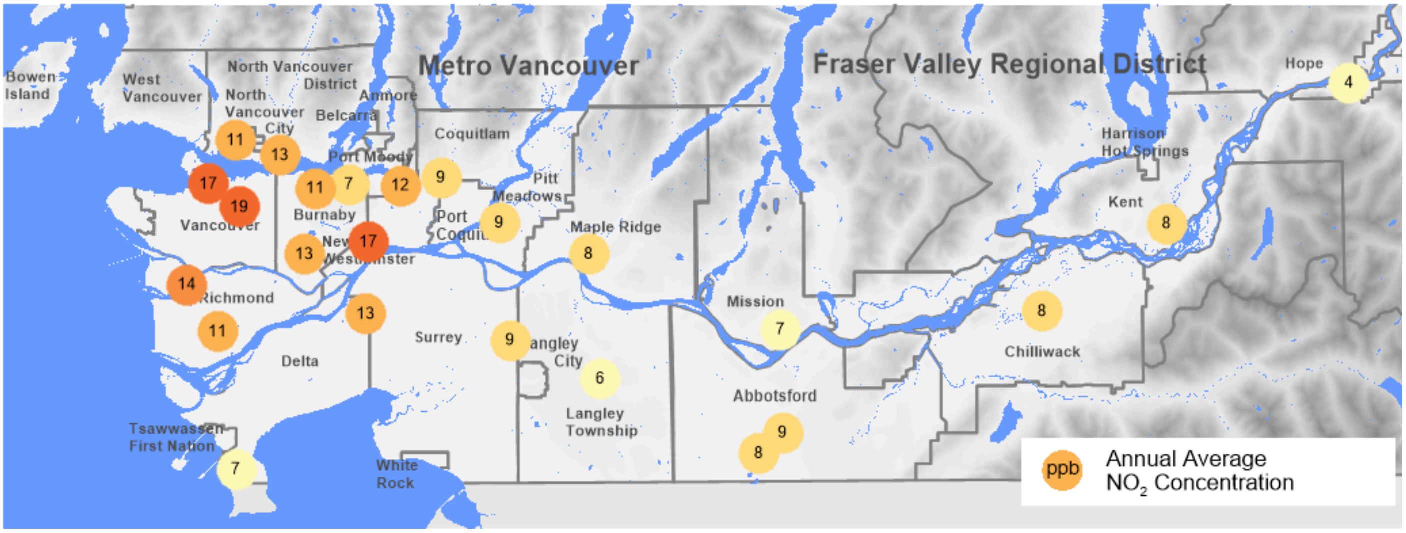


Figure 22: Annual average nitrogen dioxide in the LFV, 2018.

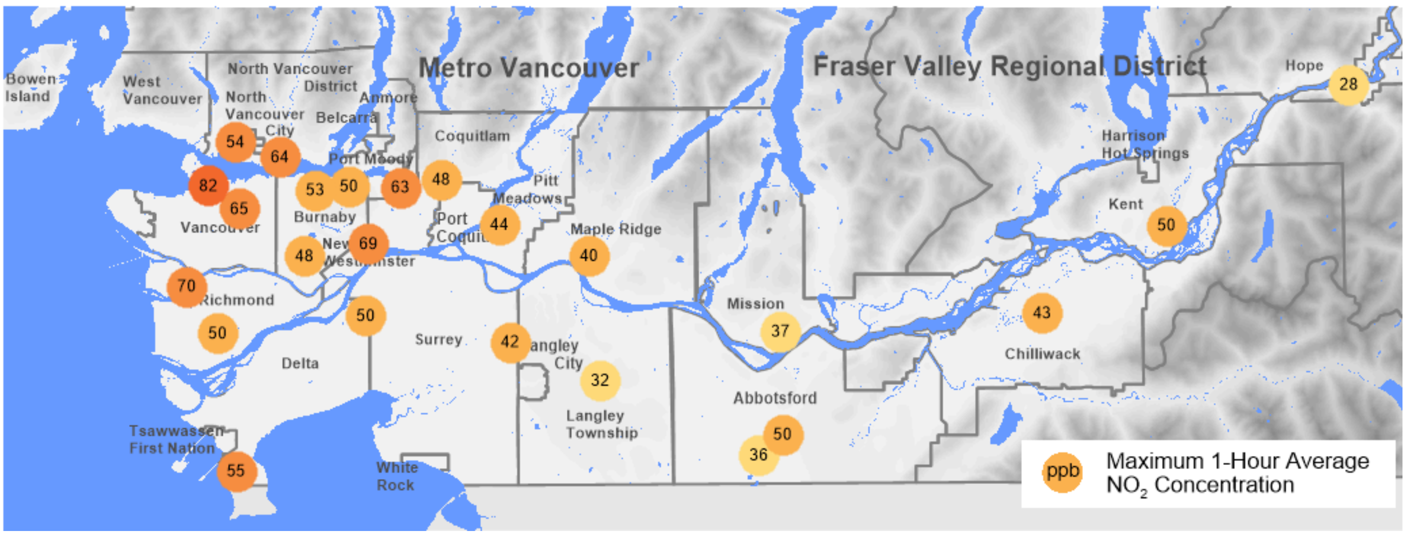


Figure 23: Short-term peak (maximum 1-hour) nitrogen dioxide in the LFV, 2018.

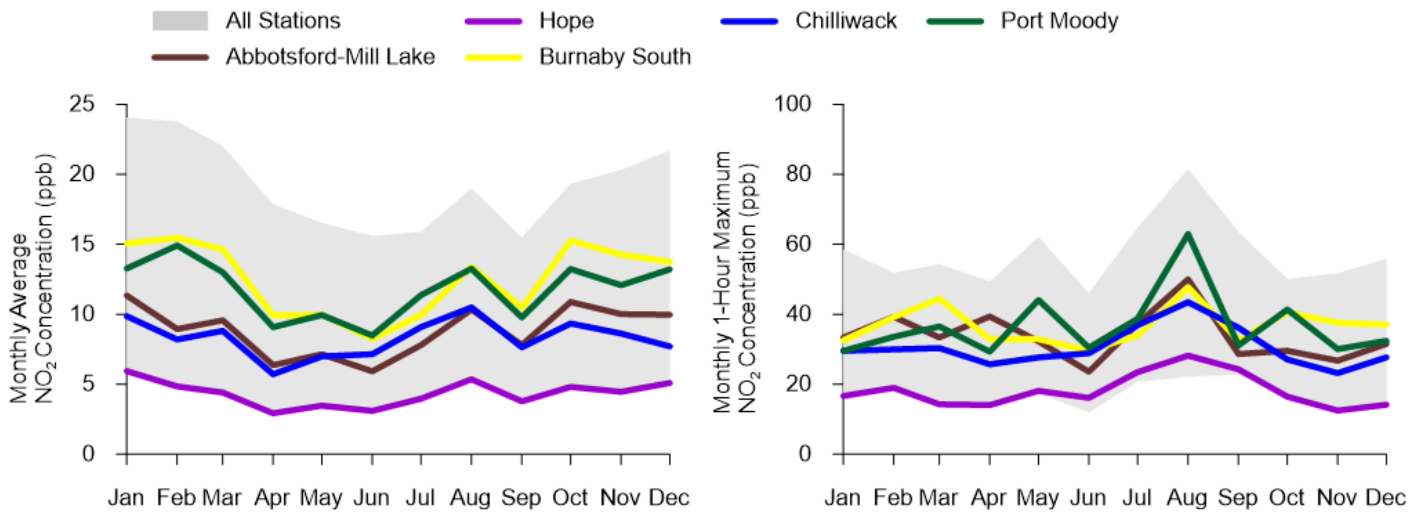


Figure 24: Monthly average (left) and short term peak (right) nitrogen dioxide, 2018.

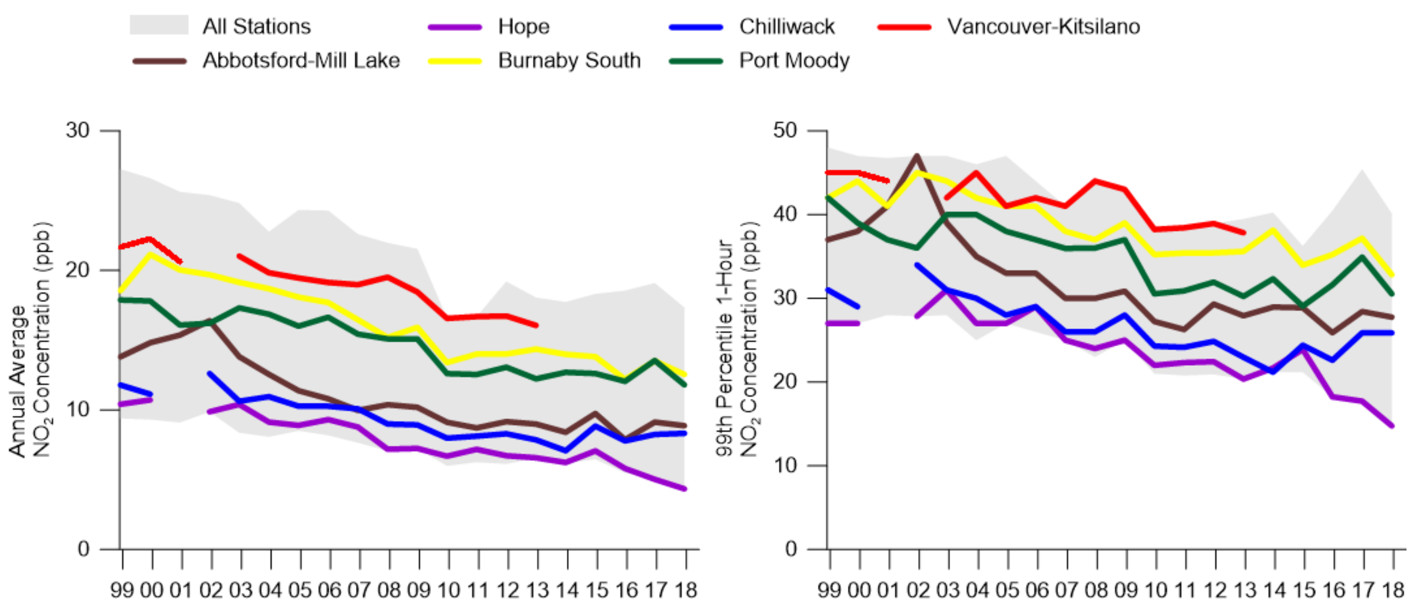


Figure 25: Annual (left) and short term peak (right) nitrogen dioxide trend, 1999 to 2018.

Table 7: Frequency distribution of hourly nitrogen dioxide, 2018.

NO_2 Conc. (ppb)	Vancouver-Downtown	Burnaby-Kensington Park	N. Vancouver-2nd Narrows	Port Moody	Chilliwack	North Delta	Burnaby Mountain	Surrey East	Richmond South	Burnaby South	Pitt Meadows	N. Vancouver-Mahon Park	Langley	Hope	Maple Ridge	Richmond-Airport	Coquitlam	Abbotsford-Mill Lake	Tsawwassen	Mission	Agassiz	Abbotsford Airport	New Westminster	Vancouver-Clark Drive
0 to 4	28	683	647	628	2046	934	2361	1905	2013	636	2458	1173	3886	4963	2364	1054	1701	1919	3878	3093	2519	3035	328	239
4 to 8	825	2502	2197	2216	2940	2270	3342	2798	1886	2143	2355	2317	2698	2564	2988	1880	2681	2894	2275	2943	2688	2306	1141	885
8 to 12	1546	2253	2158	2178	1760	1467	1729	1684	1354	1996	1640	1991	1234	903	1713	1366	1806	1593	1053	1296	1481	1456	1417	1081
12 to 16	1604	1488	1450	1620	974	1279	656	1060	1181	1495	1013	1210	483	195	862	1171	1224	1072	694	656	1029	969	1546	1153
16 to 20	1559	843	942	1073	516	1019	321	622	821	970	639	829	202	46	454	1013	681	588	371	373	590	528	1400	1256
20 to 24	1405	464	571	580	245	705	131	336	637	744	297	533	78	9	223	874	345	328	230	196	228	209	1171	1256
24 to 28	895	264	344	231	104	485	88	171	428	409	154	329	24	3	70	548	182	138	99	92	93	51	773	1023
28 to 32	426	137	164	99	20	266	43	61	229	166	63	166	11	1	20	370	71	53	25	35	42	16	479	689
32 to 36	169	50	82	36	11	167	20	26	92	94	36	91			10	204	17	20	12	3	3	7	245	405
36 to 40	57	20	60	15	3	70	10	9	29	19	11	25			5	120	4	7	8	1	1	1	89	267
40 to 44	26	8	32	5	2	13	5	2	4	7	4	11			1	37	3						27	100
44 to 48	14	4	29	2		11	3			4	1	3				13	2	1	1		3		9	45
48 to 52	9	1	17	2		2	3		2			1				11		1	4		1		4	10
52 to 56	5	3	5	1								1				2			1				2	8
56 to 60	1		4	1												2							1	3
60 to 64	1		3	1																			1	2
64 to 68																								2
68 to 72																2							1	
72 to 76																								
76 to 80																								
80 to 84	1																							
>=84																								
Missing	189	40	55	72	139	72	48	86	84	77	89	80	144	76	47	93	43	146	109	72	82	182	126	336
Data Completeness	98%	100%	99%	99%	98%	99%	100%	99%	99%	99%	99%	99%	98%	99%	100%	99%	100%	98%	99%	99%	99%	98%	99%	96%

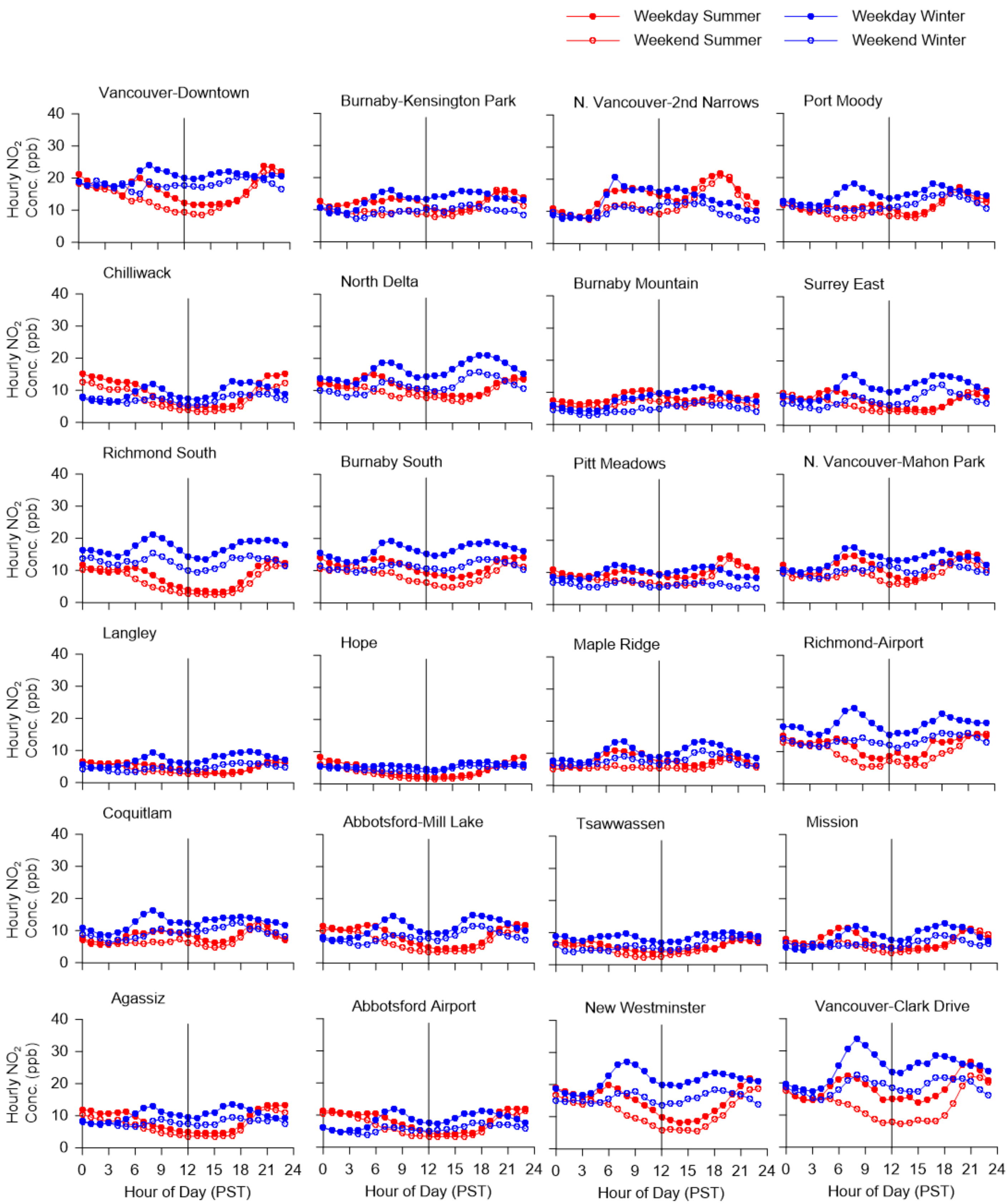


Figure 26: Diurnal trends nitrogen dioxide, 2018.

Sulphur Dioxide (SO_2)

Characteristics

Sulphur dioxide (SO_2) is a colourless gas with a pungent odour. It reacts in the air to form acidic substances such as sulphuric acid and sulphate particles.

Brief exposure to high concentrations of SO_2 and its by-products can irritate the upper respiratory tract and aggravate existing cardiac and respiratory disease in humans. Long-term exposure may increase the risk of developing chronic respiratory disease.

The environmental effects of SO_2 and its reactive products have been studied for many years. These compounds can cause damage to vegetation and buildings, they play a role in the formation of acid rain and they may affect the natural balance of waterways and soils. Sulphur oxides (SO_X) including SO_2 can also combine with other air contaminants to form the fine particulates ($PM_{2.5}$) that are thought to be one of the contributing factors in the degradation of visual air quality in the region.

Sources

Sulphur dioxide is emitted when fossil fuels containing sulphur are burned. The largest source of SO_2 emissions in the region an oil refinery, marine vessels, a waste to energy facility and two cement plants. The geographical distribution of sulphur dioxide emissions is influenced mainly by a petroleum refinery in Burnaby and ocean-going vessels in the marine areas of Burrard Inlet, although in recent years, marine emissions have been reduced substantially.

Local SO_2 emissions are low relative to other cities of similar size because natural gas, rather than coal or oil, is used in almost all residential, commercial and industrial heating in the region.

Monitoring Results

Sulphur dioxide levels measured in 2018 are shown in Figures S9 and 27. Figure 27 displays the maximum 1-hour and annual average concentrations for each SO_2 monitoring location with sufficient data completeness during 2018. The same values are represented spatially in Figures 28 and 29.

Sulphur dioxide levels were below the annual objective at all stations in 2018. The annual average SO_2 levels were less than 1 ppb at all stations. Average levels remained low in 2018 compared with previous years and can be attributed to stricter marine fuel requirements that came into effect at the beginning of 2015.

Average sulphur dioxide levels have improved significantly in recent years due to stricter requirements for lower sulphur content marine fuels.

With the exception of Vancouver-Clark Drive and Burnaby-Capitol Hill all stations were below Metro Vancouver's 1-Hour objective of 70 ppb in 2018. The 1-hour objective was exceeded for one hour at Burnaby-Capitol Hill in the evening of January 1 and two hours at Vancouver-Clark Drive in the evening of April 3. All of the exceedances were measured when winds were blowing from the direction of the petroleum refinery in Burnaby.

The highest levels of SO_2 are typically measured in the northwest (Figures 28 and 29), particularly close to the dominant sources of SO_2 emissions (i.e., the petroleum refinery, marine vessels, and port areas) in the Burrard Inlet area.

There is little or no discernible seasonal trend in SO_2 concentrations throughout the year (Figure 30). However, the effect of the refinery shutdown can be seen in February and March when it was undergoing maintenance for two months. The stations nearest to Burrard Inlet generally experienced the highest average concentrations through most of the year while the highest 1-hour measurements were recorded at Burnaby-Capitol Hill in January, April, May, and July.

The long-term SO_2 trends in the LFV are shown in Figure 31. Average sulphur dioxide levels have improved significantly in recent years due to stricter requirements for lower sulphur content marine fuels. Overall, the yearly variation can be attributed in part to meteorological variability while the major long-term changes in air quality are mainly a result of changes in emissions.

Long-term trends provide information to help assess the impact of emission reduction efforts, policy changes and technology advances. For example, emissions of SO_2 declined during the early 1990s due to reduced sulphur content in on-road fuels and reduced emissions from oil refining and cement industries. In recent years' measurements of both the annual short-term peak (99th percentile of the 1-hour values) and the annual average are markedly lower than they were in the 1990s.

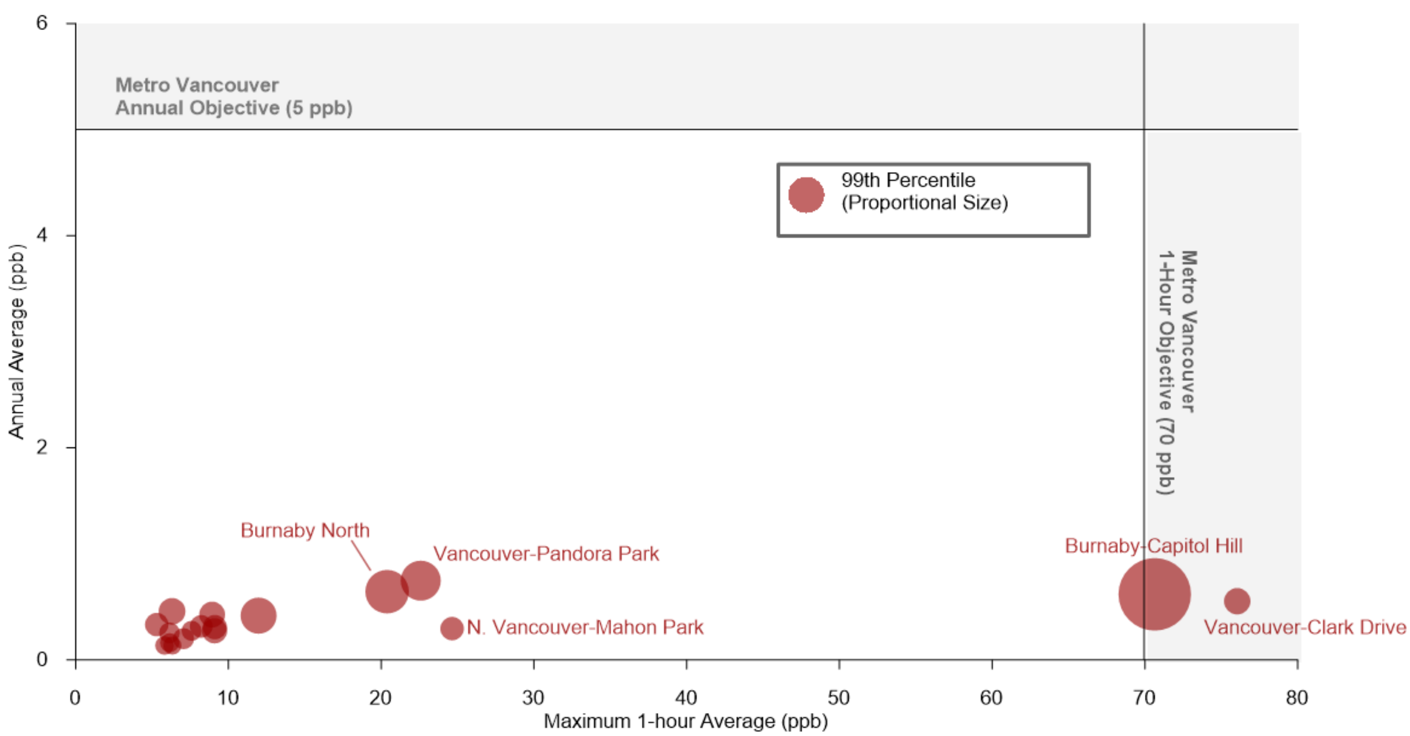
The values in Table 8 represent the frequency distribution (or count) of how many hourly average measurements were in the specified ranges, respectively. It is evident that stations located near the Burrard Inlet area experience a greater occurrence of higher concentrations compared with areas away from the Inlet.

A series of diurnal plots are shown in Figure 32 for each SO_2 monitoring station. The diurnal plots illustrate the weekday/weekend differences along with summer/winter differences. Stations located away from Burrard Inlet show little diurnal variation while stations located near the inlet show trends indicative of nearby emission sources.

The diurnal patterns of SO_2 measured near Burrard Inlet in the summer are mainly influenced by wind flow and marine and oil refinery emissions. Port Moody experiences higher concentrations during the middle of the day in summer when winds are blowing from marine areas and the oil refinery toward the station.

Stations historically influenced by marine vessel emissions such as North Vancouver-2nd Narrows and North Vancouver-Mahon Park show attenuated levels compared with previous years.

The Burnaby-Capitol Hill station and Burnaby North show diurnal variation with sporadic peak SO_2 concentrations during the morning and evening periods when mixing layer depth is reduced and dispersion is limited. Measurements of SO_2 at this station are influenced by its proximity to the oil refinery.



Note: Stations contained within the grey area denote an exceedance of an objective.

Figure 27: Sulphur dioxide monitoring, 2018.

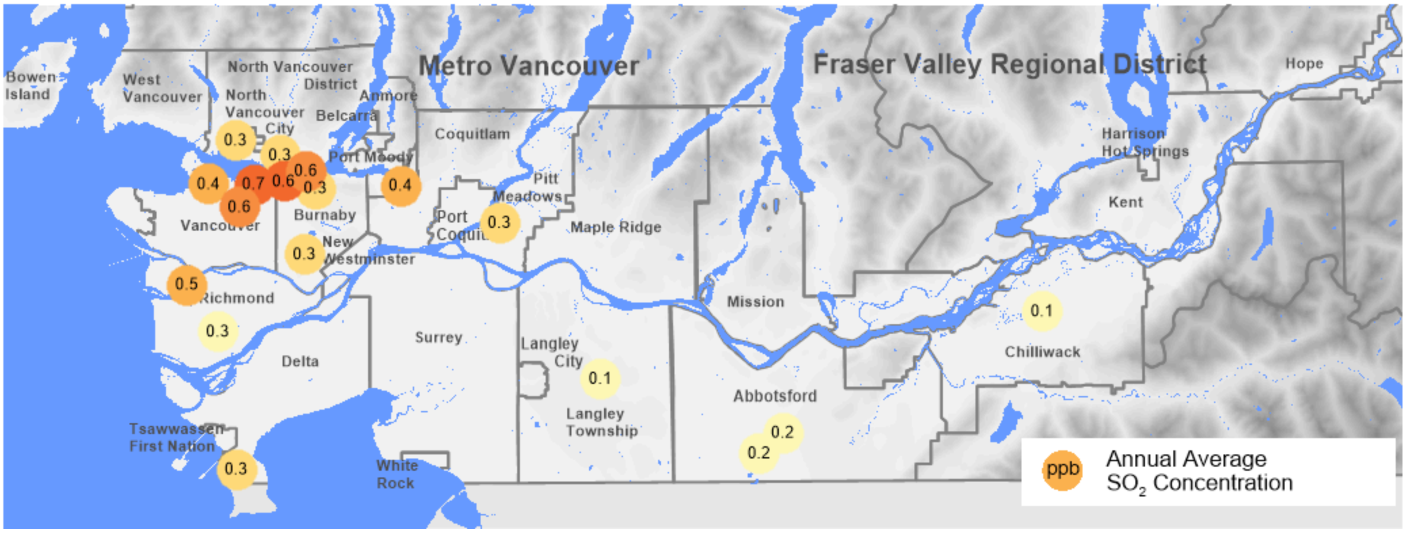


Figure 28: Annual average sulphur dioxide in the LFV, 2018.

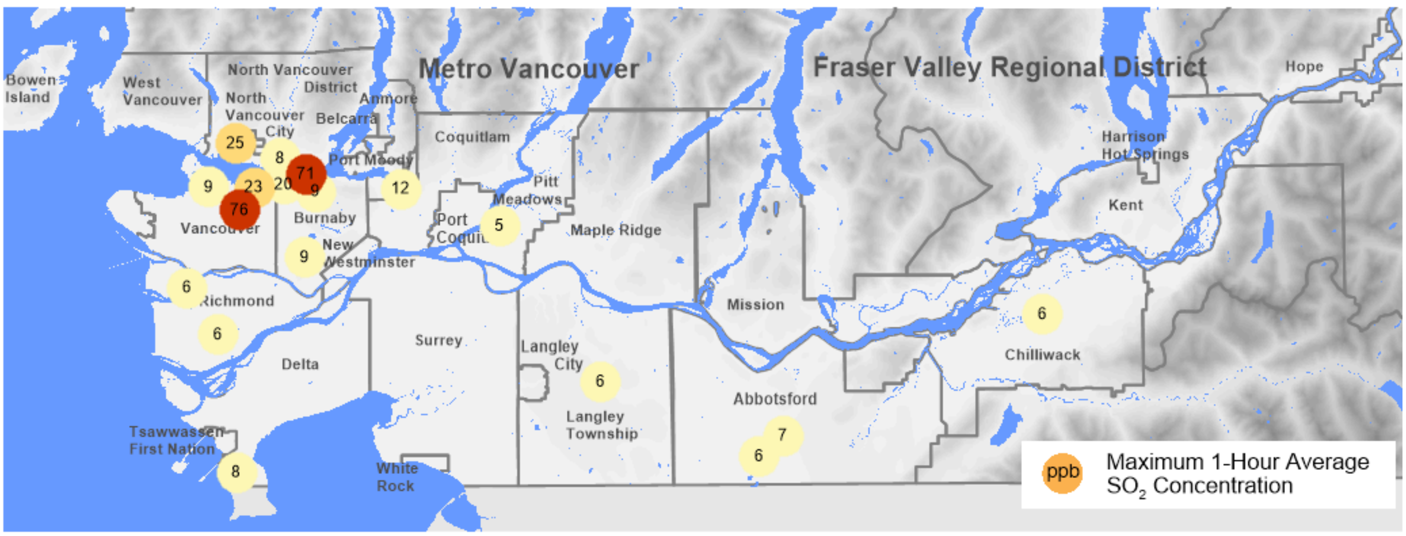


Figure 29: Short-term peak (maximum 1-hour) sulphur dioxide in the LFV, 2018.

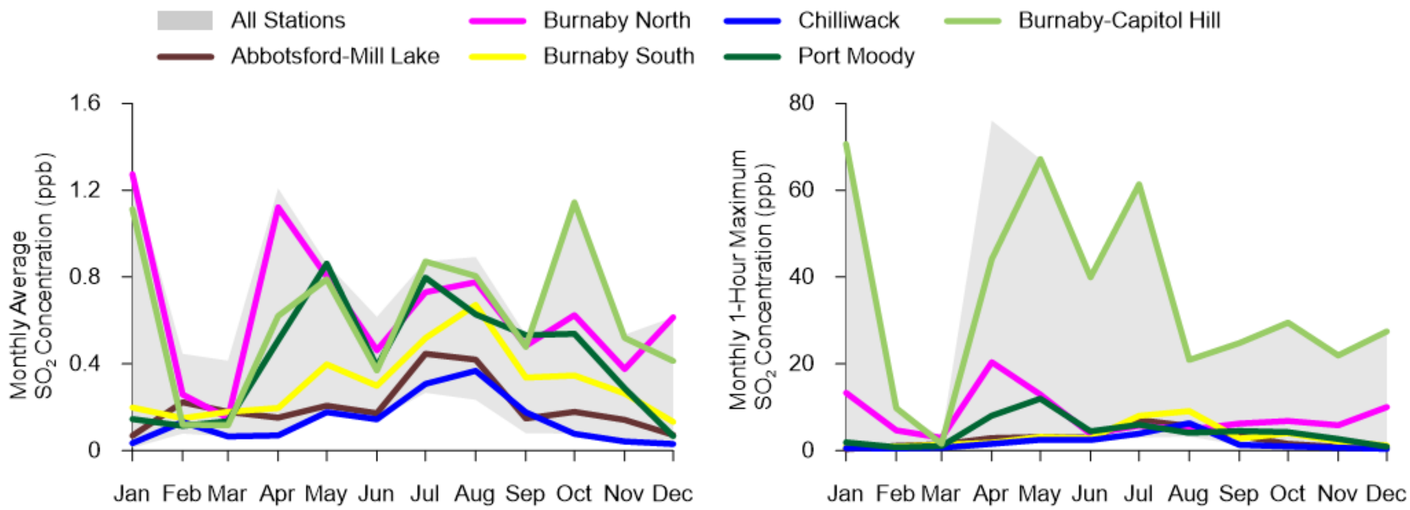


Figure 30: Monthly average (left) and short-term peak (right) sulphur dioxide, 2018.

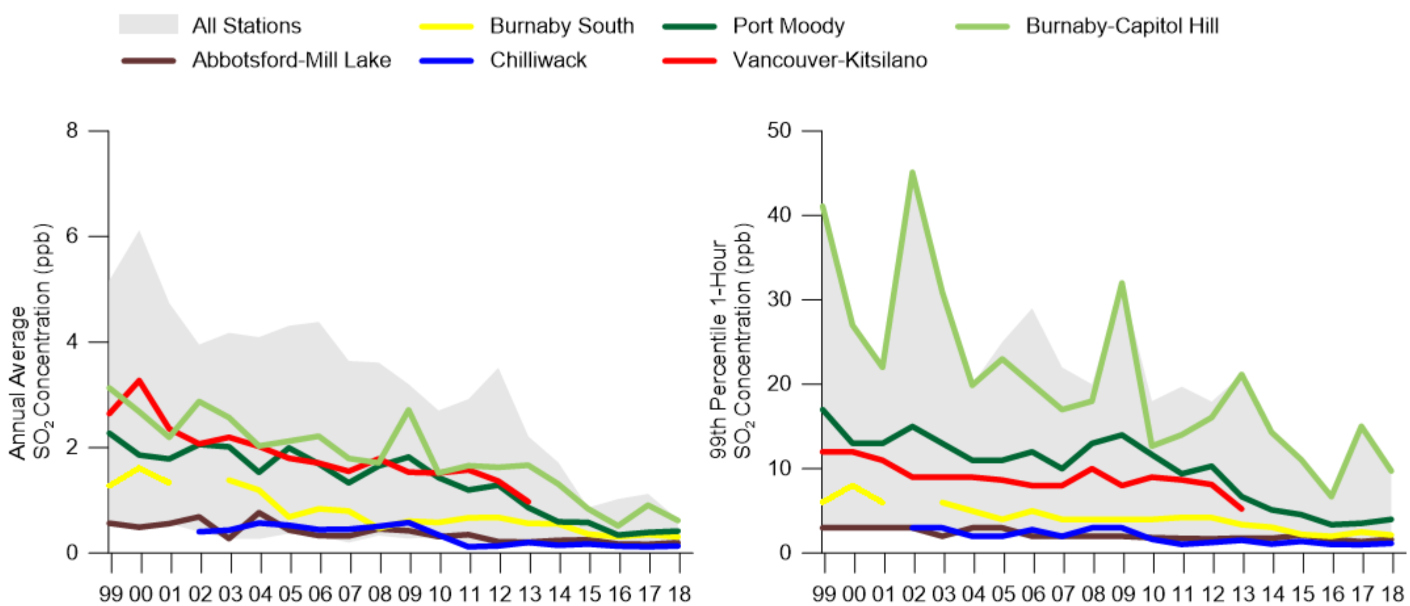


Figure 31: Annual (left) and short-term peak (right) sulphur dioxide trend, 1999 to 2018.

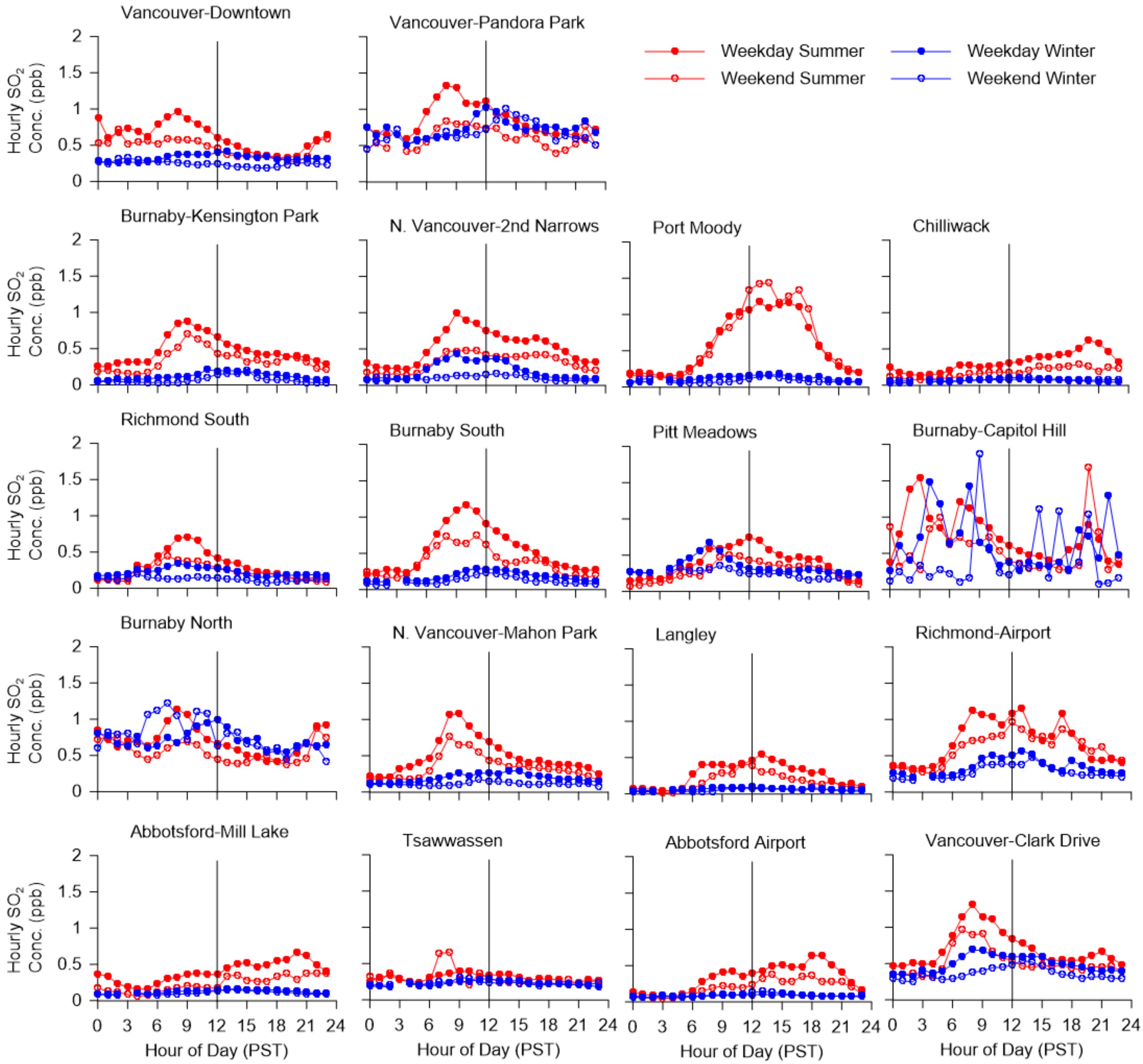


Figure 32: Diurnal trends sulphur dioxide, 2018.

Table 8: Frequency distribution of hourly sulphur dioxide, 2018.

SO_2 Conc. (ppb)	Vancouver-Downtown	Burnaby-Kensington Park	N. Vancouver-2nd Narrows	Port Moody	Chilliwack	Richmond South	Burnaby South	Pitt Meadows	Burnaby-Capitol Hill	Burnaby North	N. Vancouver-Mahon Park	Langley	Richmond-Airport	Abbotsford-Mill Lake	Tsawwassen	Abbotsford Airport	Vancouver-Clark Drive	Vancouver-Pandora Park
0 to 4	8621	8133	8290	7952	7401	8453	8218	8043	8041	8427	8259	7254	8313	8196	7913	7964	8145	7843
4 to 8	16	15	4	80	2	1	7	5	107	126	11	3	8	10	12	4	8	96
8 to 12	1	1	1	3			2		51	23							1	11
12 to 16									20	2							1	3
16 to 20									11	1	1						1	1
20 to 24									9	1							1	2
24 to 28									8		1							
28 to 32									4									
32 to 36									1									
36 to 40									2								1	
40 to 44																		
44 to 48									2									
48 to 52																	1	
52 to 56																		
56 to 60									1									
60 to 64									1									
64 to 68									1									
68 to 72									1								1	
72 to 76																		
>=76																	1	
Missing	50	77	222	447	435	90	396	447	16	35	39	446	430	347	702	385	550	770
Data Completeness	99%	99%	97%	95%	95%	99%	95%	95%	100%	100%	100%	94%	95%	96%	92%	95%	94%	91%

Carbon Monoxide (CO)

Characteristics

Carbon monoxide (CO) is a colourless, odourless and tasteless gas produced by the incomplete combustion of fuels containing carbon. It has a strong affinity for haemoglobin and thus reduces the ability of blood to transport oxygen. Long-term exposure to low concentrations may cause adverse effects in people suffering from cardiovascular disease.

Sources

Carbon monoxide is the most widely distributed and commonly occurring air pollutant. The principal sources are non-road engines and motor vehicles. In the LFV, over 91% comes from mobile sources which include cars, trucks, buses, planes, trains, ships and non-road engines. Other sources contributing to measured CO levels are building heating, commercial and industrial operations, and smoke from wildfires.

Monitoring Results

Figures S10 and 33 illustrate the results of CO monitoring for 2018 for stations with sufficient data completeness. Figure 33 displays the maximum 1-hour and 8-hour average as well as the annual average for each CO monitoring location. The same results are represented on maps in Figures 34, 35 and 36.

Measured carbon monoxide levels were well below Metro Vancouver's objectives at all stations throughout the LFV. Typically, the highest concentrations occur in the west where highly urbanized areas experience large volumes of traffic.

Average levels remained low throughout the LFV with the lowest readings recorded at stations away from heavily trafficked areas.

With the majority of CO released from cars, trucks, buses and non-road engines, dramatic improvements have occurred in the last two decades due to improved vehicle emission standards and vehicle emissions testing.

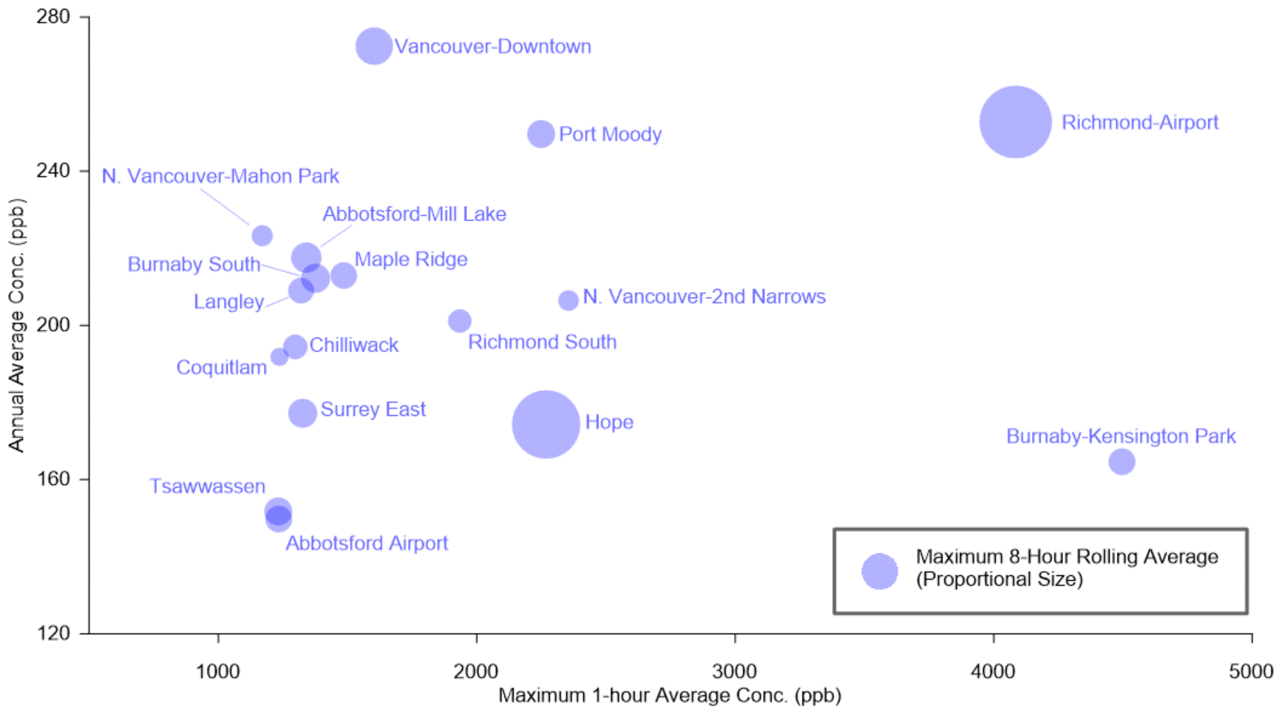
The seasonal trends for CO in 2018 are plotted as monthly average and maximum 1-hour concentrations in Figure 37. Typically average CO concentrations are higher in the winter compared with the summer which is a result of lower atmospheric mixing heights in winter along with increased residential, commercial and industrial heating. However, in 2018 some of the highest average concentrations occurred in August when CO contained in wildfire smoke was widespread.

Figure 38 illustrates the long-term average and peak CO trends in the LFV. Some year-to-year variation is evident in the peak trends, however long-term changes in air quality are mainly attributed to changes in emissions. Improvements in both the average and the short-term peak concentrations (99^{th} percentile of the 1-hour values) appear to be leveling off in recent years.

In the LFV average levels have decreased dramatically since the early nineties. Declining CO concentrations are largely due to improved vehicle emission standards and the AirCare program, which was operated in BC from 1992 to 2014.

A series of diurnal plots are shown in Figure 39 for each station that monitors CO. Most stations exhibit higher winter concentrations on weekdays compared with weekends, with many stations showing a large peak in the morning that corresponds relatively well with morning traffic patterns.

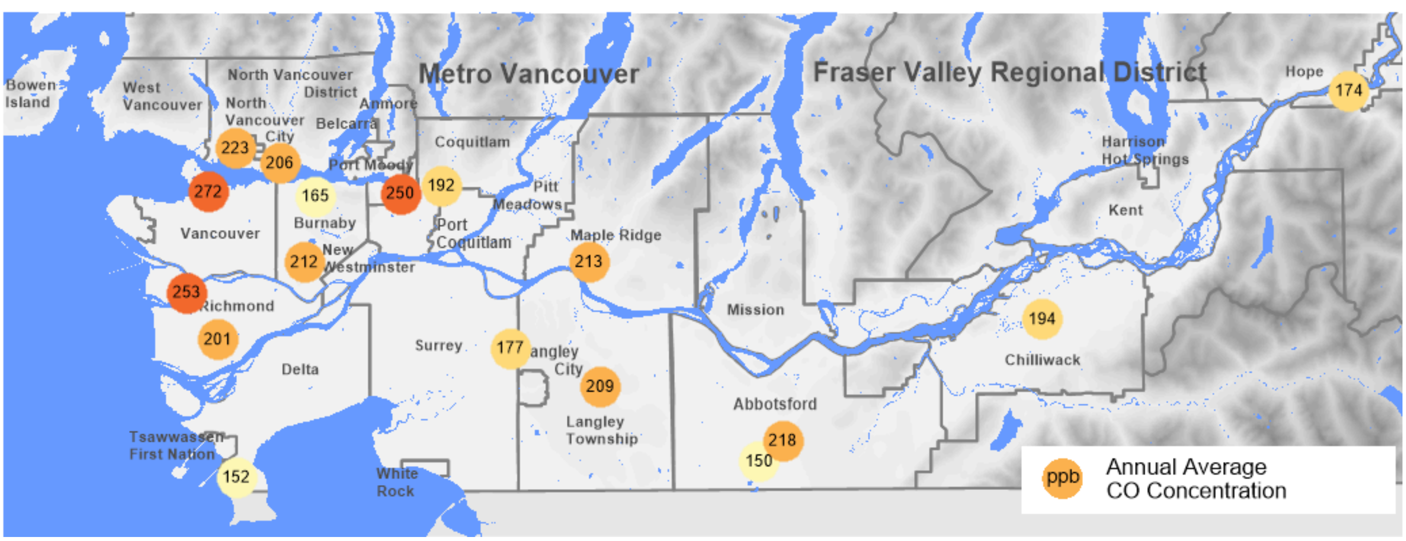
Stations that appear to be strongly influenced by CO emission sources such as traffic include Vancouver-Clark Drive where a well-defined peak is evident in the mornings on weekdays during the winter.



Notes:

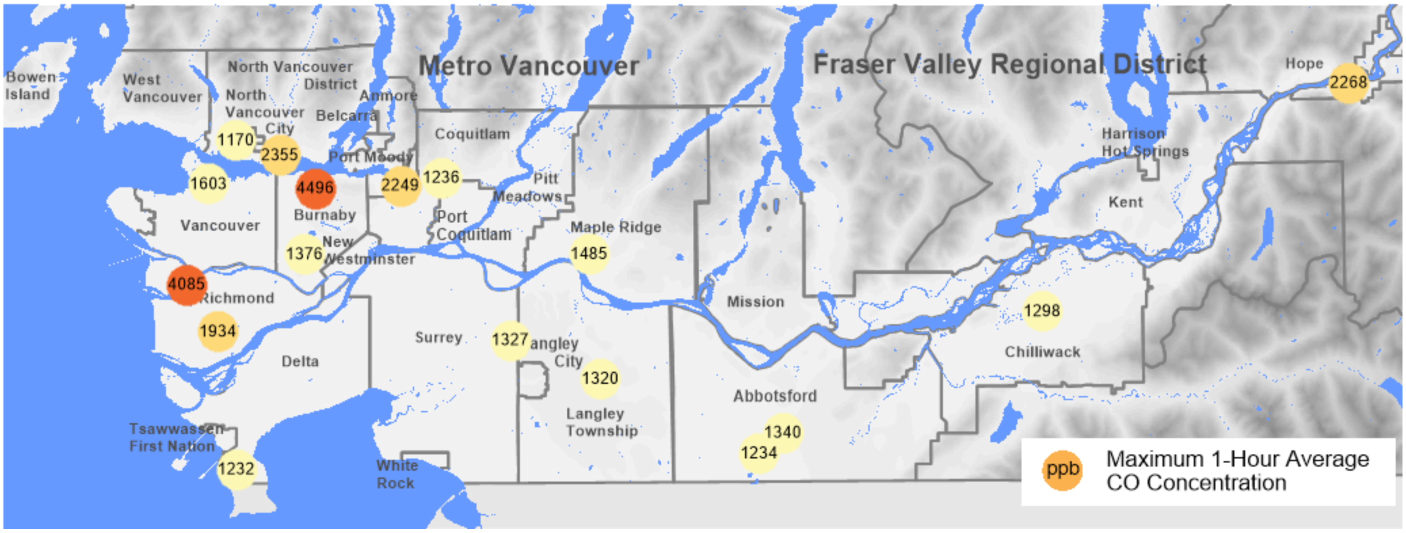
- Air contaminant levels shown here are well below (i.e., better than) air quality objectives.
- Vancouver-Clark Drive and Horseshoe Bay did not meet the data completeness threshold and thus are not shown here.

Figure 33: Carbon monoxide monitoring, 2018.



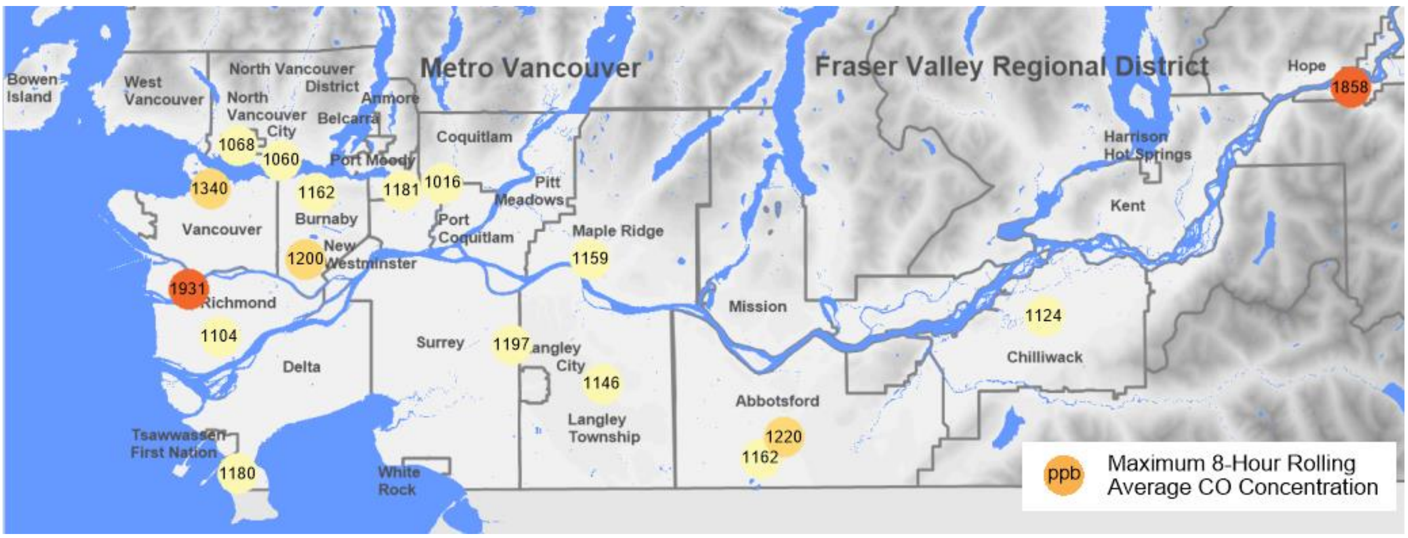
Note: Vancouver-Clark Drive and Horseshoe Bay did not meet the data completeness threshold and thus are not shown here.

Figure 34: Annual average carbon monoxide in the LFV, 2018.



Note: Vancouver-Clark Drive and Horseshoe Bay did not meet the data completeness threshold and thus are not shown here.

Figure 35: Short-term peak (maximum 1-hour) carbon monoxide in the LFV, 2018.



Note: Vancouver-Clark Drive and Horseshoe Bay did not meet the data completeness threshold and thus are not shown here.

Figure 36: Short-term peak (maximum 8-hour) carbon monoxide in the LFV, 2018.

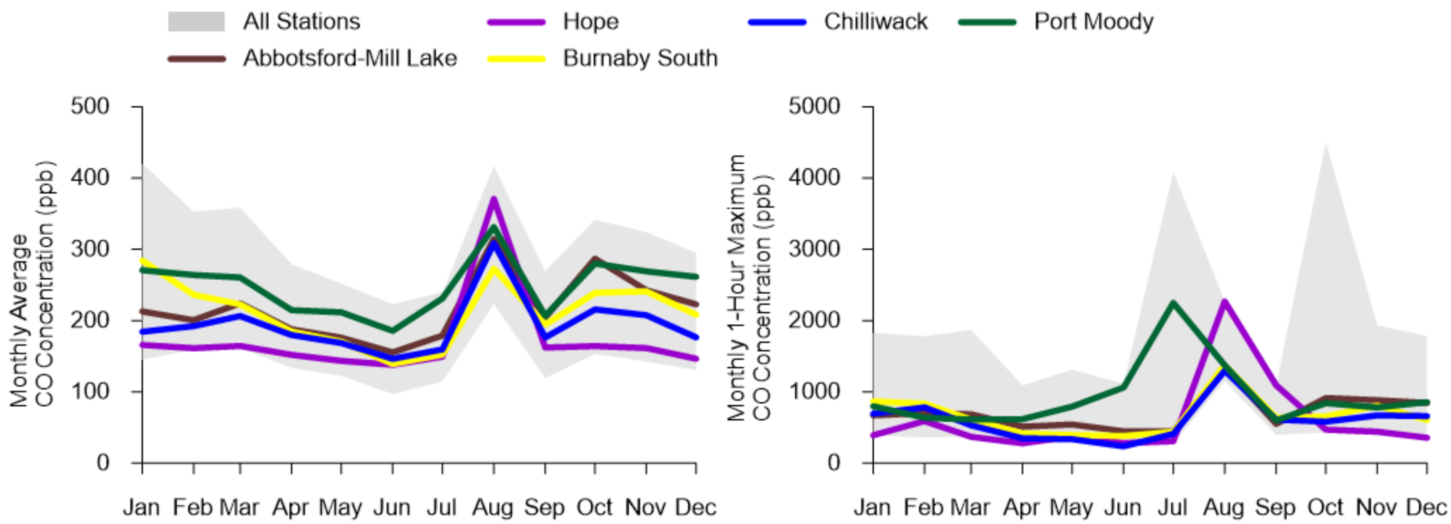


Figure 37: Monthly average (left) and short term peak (right) carbon monoxide, 2018.

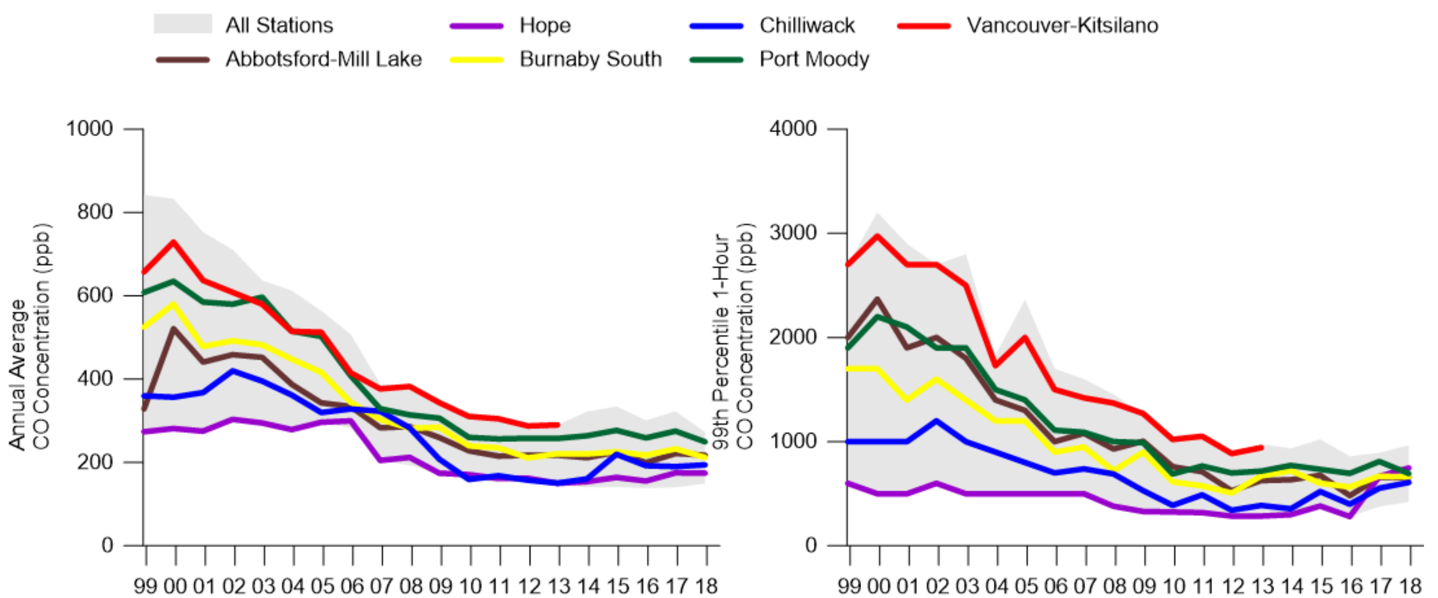
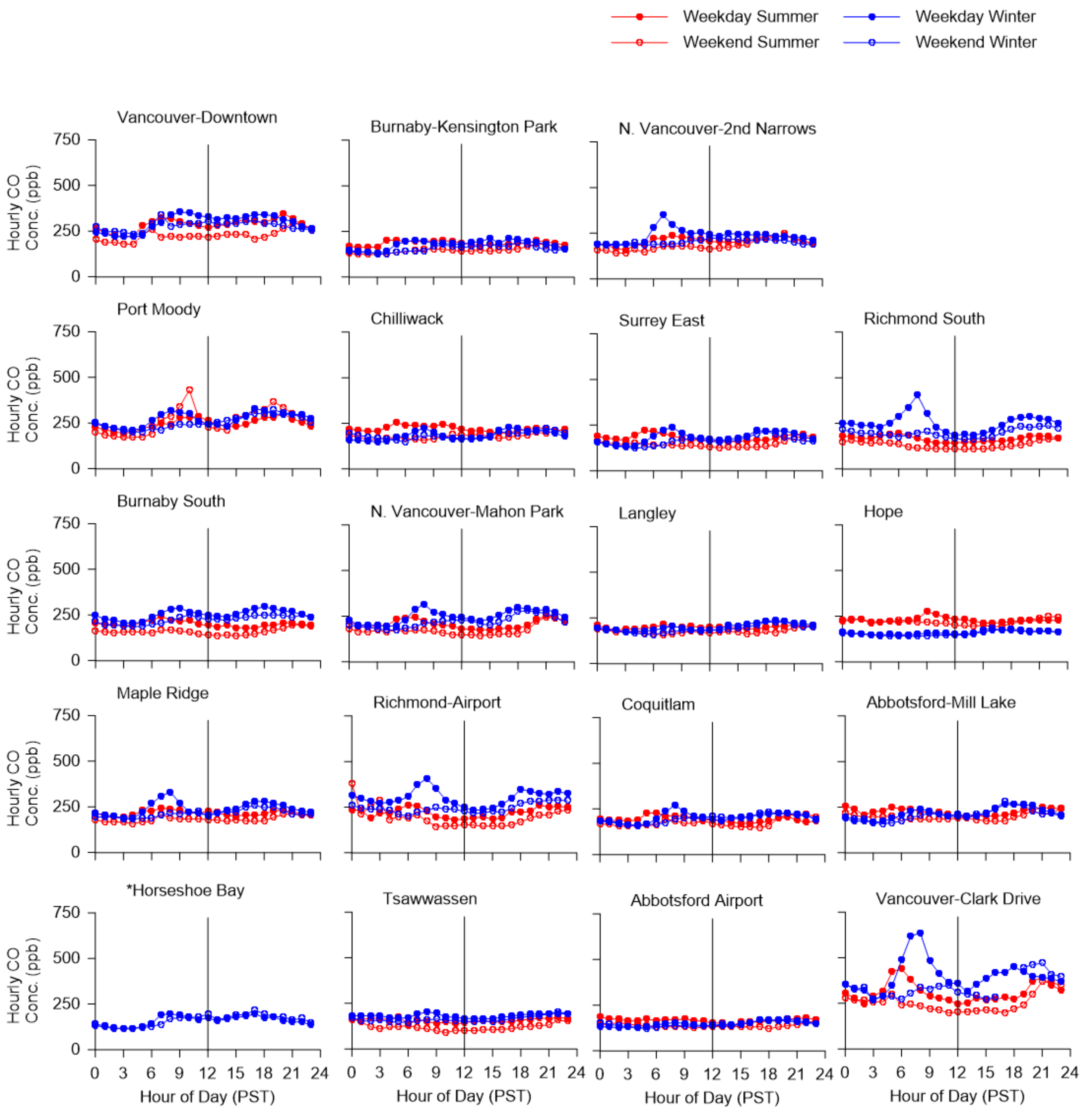


Figure 38: Annual (left) and short term peak (right) carbon monoxide trend, 1999 to 2018.



*Data completeness requirements were not met at this site in summer.

Figure 39: Diurnal trends carbon monoxide, 2018.

Inhalable Particulate (PM_{10})

Characteristics

The term 'PM_{10}' refers to airborne particles with a diameter of 10 micrometres (μm) or less. These particles are also known as inhalable particulate matter which, given their small size, can be inhaled and deposited in the lungs.

Exposure to PM_{10} can lead to both chronic and acute human health impacts, particularly pulmonary function. Inhalable particulate can aggravate existing pulmonary and cardiovascular disease, increase symptoms in asthmatics and increase mortality. High PM_{10} levels can also increase corrosion and soiling of materials, and may damage vegetation. The smaller particles also contribute to degraded visual air quality.

Sources

Inhalable particulate is emitted from a variety of sources with the largest contribution from construction and demolition activities (23%) followed by residential wood burning (21%). Other major contributors to PM_{10} are industrial sources, and non-road engines and equipment. There are also natural sources of PM_{10} such as wind-blown soil, forest fires, ocean spray and volcanic activity.

Monitoring Results

Figure 40 illustrates the PM_{10} monitoring in 2018, while Figures 41 and 42 shows the same values spatially. Annual averages ranged from 7 to 14 μg/m^3 which are all below Metro Vancouver's annual PM_{10} objective.

Widespread exceedances of Metro Vancouver's 24-hour PM_{10} objective were experienced in 2018. The Metro Vancouver 24-hour objective was exceeded on July 28th at Richmond-Airport and July 30th at Hope. Hope exceeded for two days on August 10 and 11 followed by a day without any exceedances. On August 13 to 24 most stations experienced exceedances of the PM_{10} objective with the exception of two days (August 17 and 18) with no exceedances at any stations. In 2018 there were fewer days of exceedance compared with 2017 during the summer, however 24-hour average concentrations were higher in 2018 with multiple days of >100 μg/m^3 at most stations. As discussed in the $PM_{2.5}$ section, the 2018 year was heavily impacted by extensive wildfires burning throughout the Pacific Northwest as well as three in-region wildfires, a bog fire and a large barge fire.

In September, the Richmond-Airport station exceeded the short-term PM_{10} objective for two days on September 4 and 5.

While improvements in PM_{10} concentrations have occurred in the last two decades, exceedances of Metro Vancouver's 24-hour PM_{10} objective were widespread in 2018 due to smoke from wildfires burning throughout the Pacific Northwest as well as three in-region wildfires, a bog fire and a large barge fire.

Table 9 gives the frequency distribution of PM_{10} concentrations for the year. In 2018, stations in Metro Vancouver experienced the greatest frequency of high PM_{10} concentrations due to heavy smoke transported from wildfires burning in July, August and September.

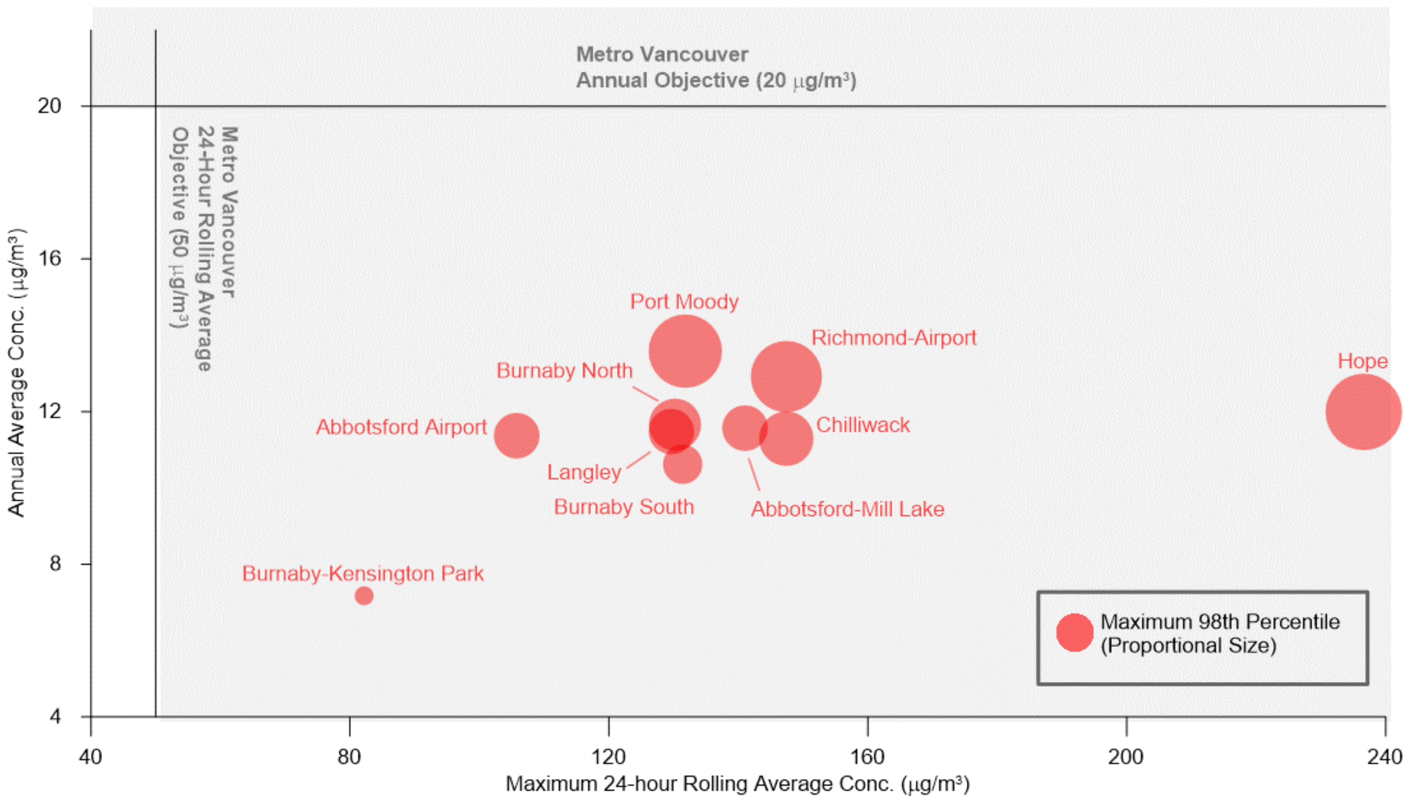
The seasonal trend of monthly average PM_{10} was similar to previous years, with the highest concentrations occurring during hot and dry periods of the summer (Figure 43). The highest average and peak level concentrations were experienced in the month of August. These trends were a result of wildfire smoke impacts to the region.

The long-term PM_{10} trends (1999 to 2018) are shown in Figure 44 with the annual average trend provided on the left and the short-term peak trend on the right. The annual average PM_{10} trend shows a general improvement in the last 20 years. The peak trend, represented by the 99th percentile of the 24-hour rolling average also shows a slight improvement with the exception of the last three wildfire years (2015, 2017 and 2018). The years 2017 and 2018 were influenced by unprecedented wildfire smoke that covered the region. The 2005 peak was the result of a large fire in Burns Bog in Delta. The 2015 peak was also a result of wildfire smoke that covered the region.

A series of diurnal plots are shown in Figure 45 for each PM_{10} monitoring station. The plots show the differences between weekdays and weekends along with differences between summer and winter.

Historically most stations exhibit higher concentrations on weekdays than weekends, likely the result of greater traffic volumes (road dust) and work related activities (outdoor burning, agricultural activities, industrial processes, etc.). In 2018 however, other factors including wildfires influenced concentrations.

Winter exhibits the least diurnal variation. The summer pattern was influenced by the wildfire events resulting in elevated levels on weekdays due to the timing of the smoke impacts.



Note: Stations contained within the grey area denote an exceedance of an objective.

Figure 40: Inhalable particulate (PM_{10}) monitoring, 2018.

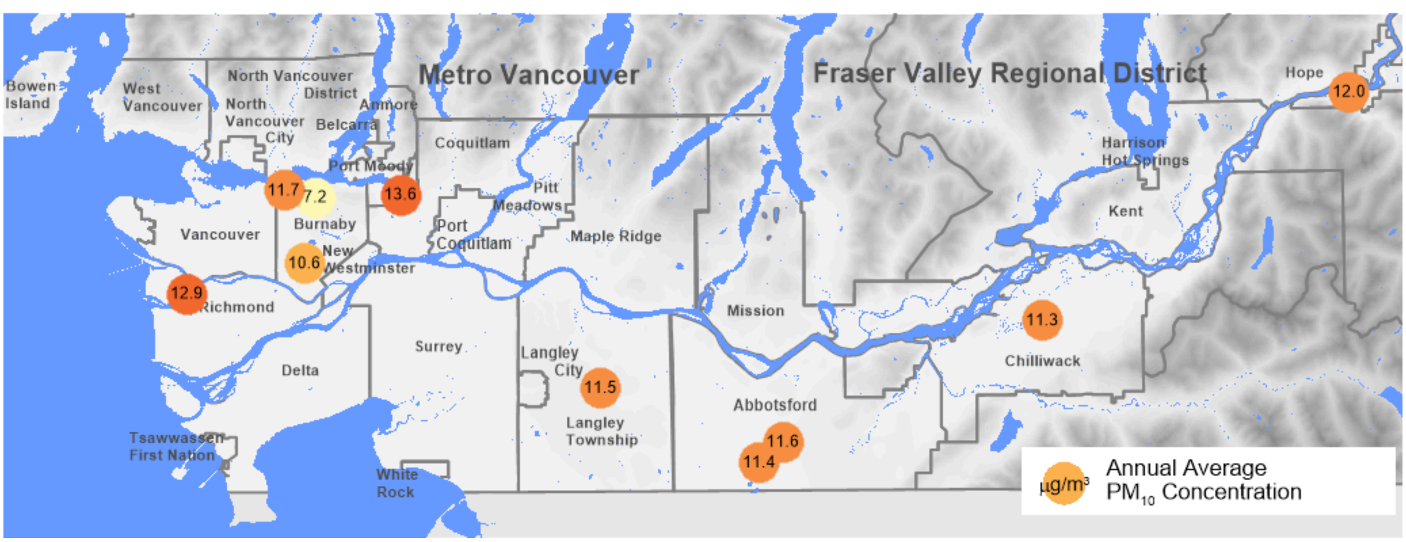


Figure 41: Annual average inhalable particulate (PM_{10}) in the LFV, 2018.

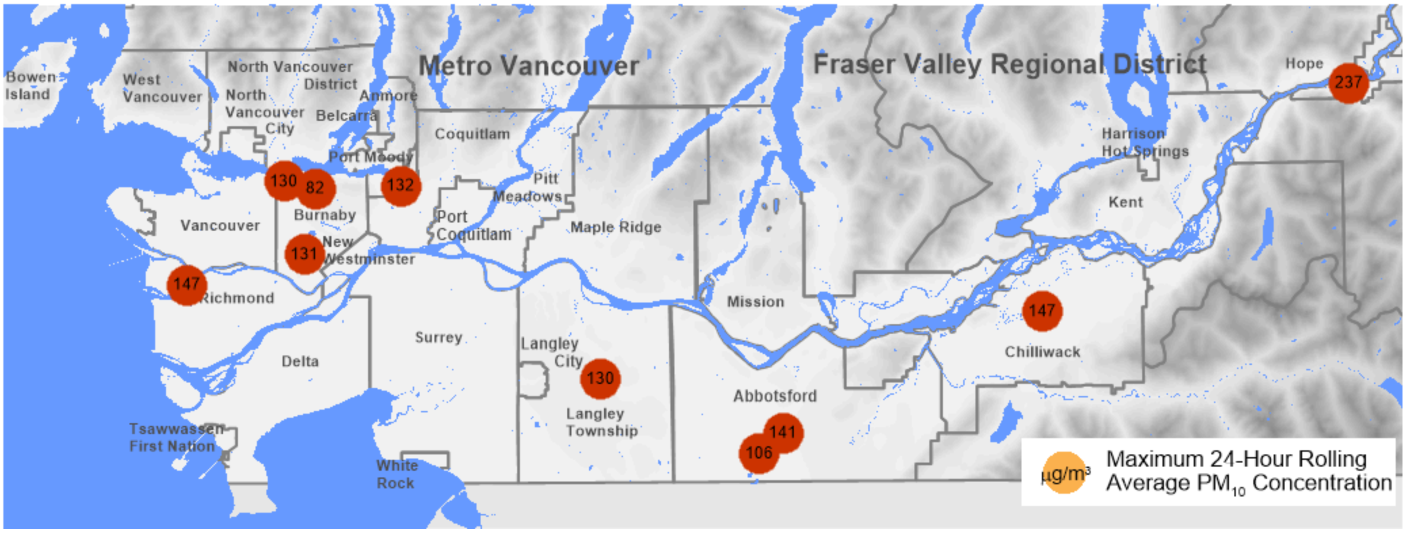


Figure 42: Short-term peak inhalable particulate (PM_{10}) in the LFV, 2018.

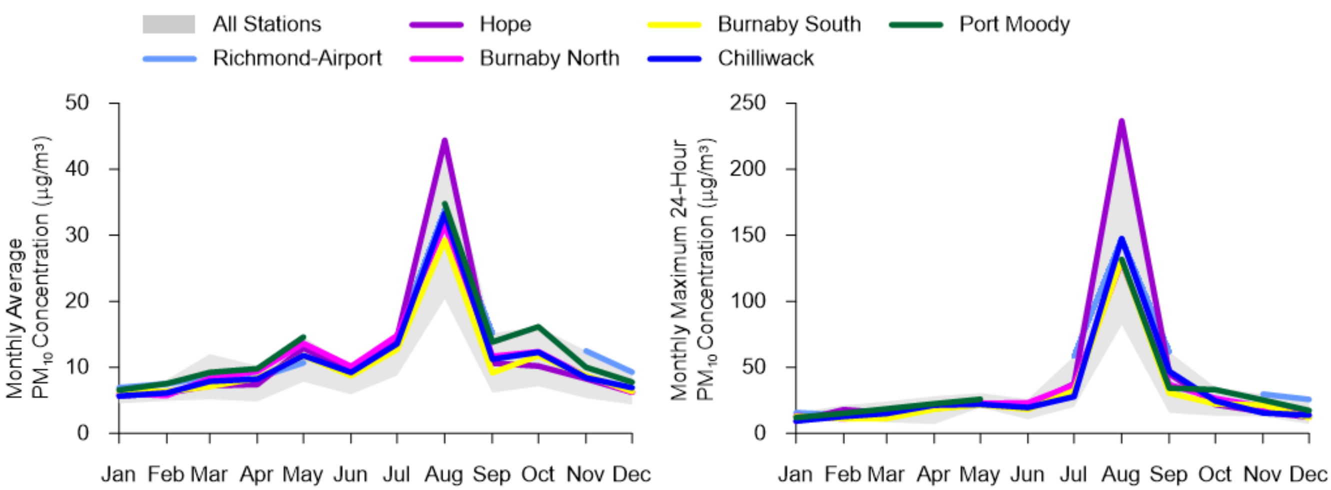


Figure 43: Monthly average (left) and short term peak (right) inhalable particulate (PM_{10}), 2018.

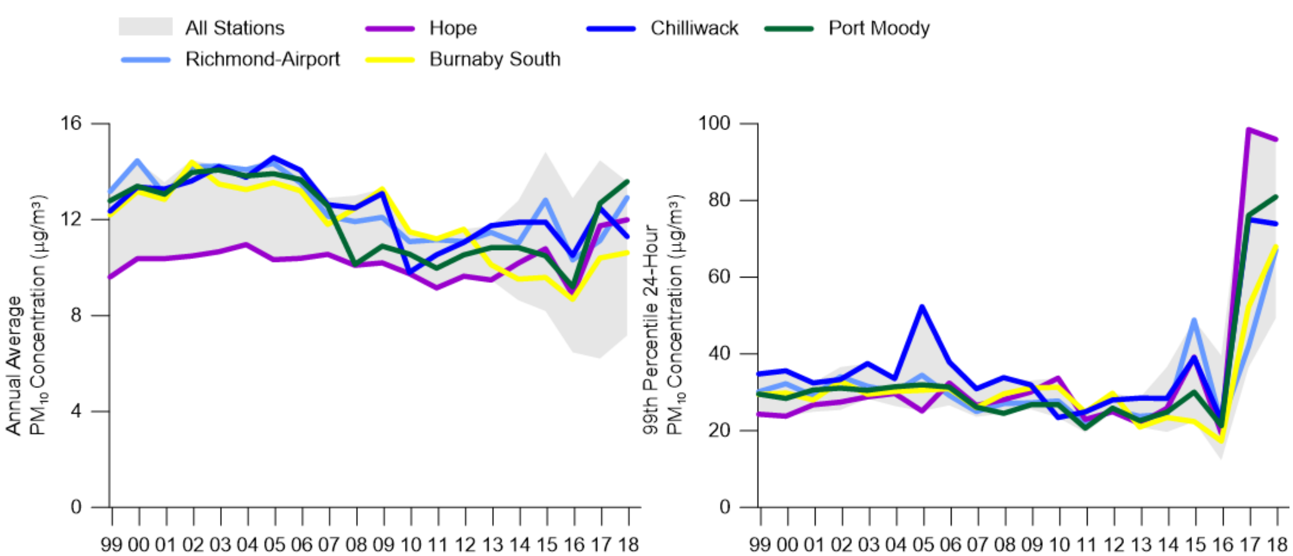
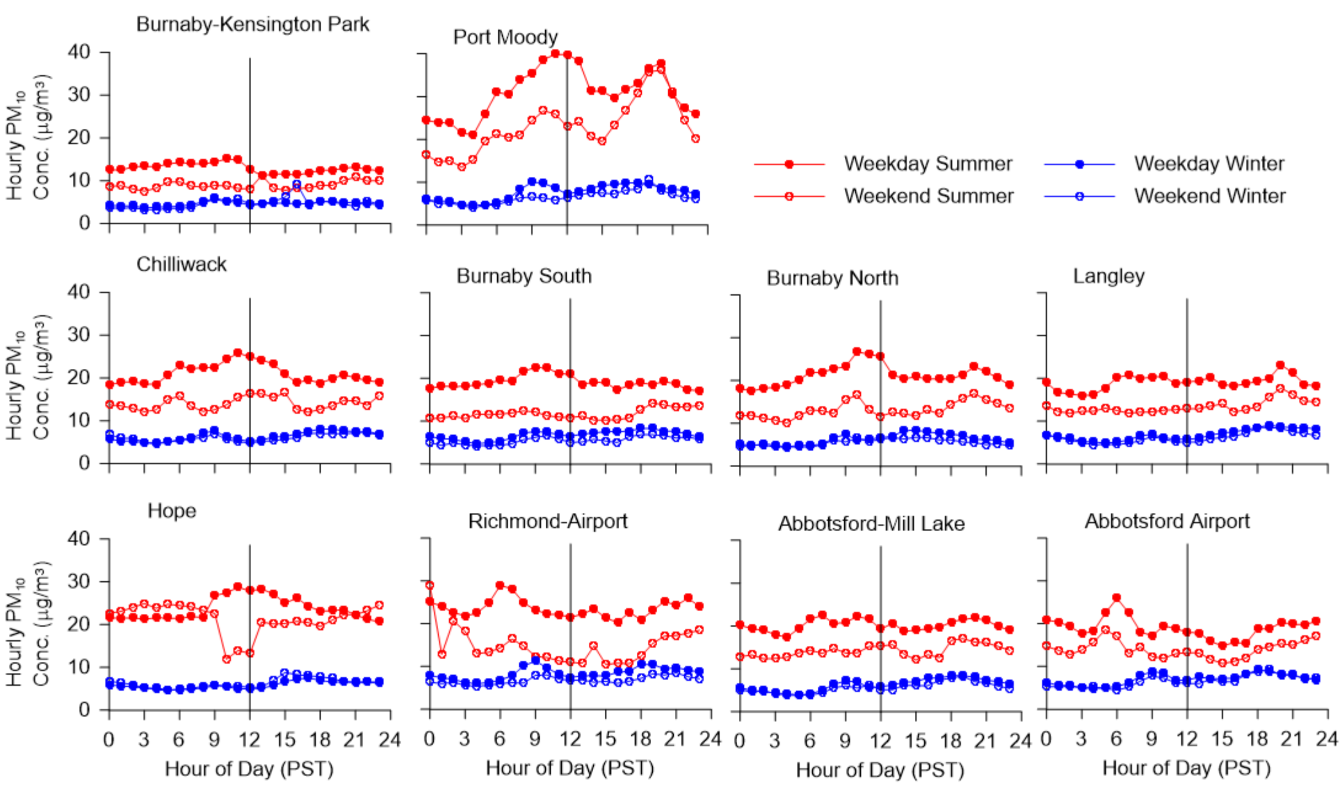


Figure 44: Annual average (left) and short term peak (right) inhalable particulate (PM_{10}) trend, 1999 to 2018.

Table 9: Frequency distribution of 24-hour rolling average inhalable particulate (PM_{10}), 2018.

PM10 Conc. (µg/m³)	Burnaby-Kensington Park	Port Moody	Chilliwack	Burnaby South	Burnaby North	Langley	Hope	Richmond-Airport	Abbotsford-Mill Lake	Abbotsford Airport
0 to 12	7901	4532	6425	6822	6066	6250	6444	5535	6002	6038
12 to 24	460	2345	1830	1498	2124	1952	1623	1833	1983	2194
24 to 36	51	466	219	191	229	292	229	330	235	276
36 to 48	49	74	49	26	52	44	84	128	54	36
48 to 60	54	18	22	24	20	26	31	90	36	33
60 to 72	25	20	49	36	24	25	49	9	24	6
72 to 84	14	52	53	19	39	6	33	6	3	7
84 to 96		24	9	17	28	6	22	5	5	23
96 to 108		17	11	20	18	34	9	6	9	37
108 to 120		8	9	7	7	16	14	8	31	
120 to 132		13	6	13	11	7	8	31	10	
132 to 144			9				14	16	12	
144 to 156			5				12	6		
156 to 168							8			
168 to 180							3			
180 to 192							3			
192 to 204							2			
204 to 216							3			
216 to 228							5			
228 to 240							5			
>=240										
Missing Data	206	1191	64	87	142	102	159	757	356	110
Completeness	98%	86%	99%	99%	98%	99%	98%	91%	96%	99%



Note: These diurnal plots are heavily influenced by wildfire smoke events in summer and do not represent a typical annual trend.

Figure 45: Diurnal trends inhalable particulate (PM_{10}), 2018.

Black Carbon (BC)

Characteristics

Black carbon (BC) is carbonaceous material formed by the incomplete combustion of fossil fuels, biofuels, and biomass, and is emitted directly in the form of fine particles ($PM_{2.5}$). BC is a major component of "soot", a complex light-absorbing mixture that also contains some organic carbon.

The terms black carbon and soot are sometimes used interchangeably. Although BC has a very short residence time in the atmosphere (about a week), it is a strong absorber of solar radiation and can absorb much more energy than carbon dioxide (CO_2). As a result, BC is considered a "short-lived climate forcer". Black carbon contributes to the adverse impacts on human health, ecosystems, and visibility associated with fine particulate matter ($PM_{2.5}$).

Sources

Mobile sources are the largest contributors of BC emissions in the LFV, emitting over 80% of the BC emissions in the region. Non-road engines (primarily diesel fuelled), heavy duty vehicles, rail and marine vessels are significant sources of BC emissions. Other significant sources in the region are biomass burning activities, including agricultural burning, open and prescribed burning, wildfires and residential heating.

Monitoring Results

Figures 46 and 47 illustrates the results of continuous BC monitoring for 2018. Figure 46 displays the value of the maximum 1-hour and 24-hour average as well as the annual average for each station with the same information shown in a bubble plot in Figure 47.

There are no provincial, federal or Metro Vancouver objectives for black carbon. The highest 1-hour average BC concentration occurred at Richmond-Airport, likely due to a local emission source for a short period of time.

In Figure 48 the seasonal trends for BC shows average values higher in August and October with the highest peak level occurring in June.

Black carbon is generally greater on weekdays compared with weekends, shown in Figure 49. This trend is especially evident at the Vancouver-Clark Drive station where greater amounts of BC are experience in the winter and on weekdays compared with weekends.

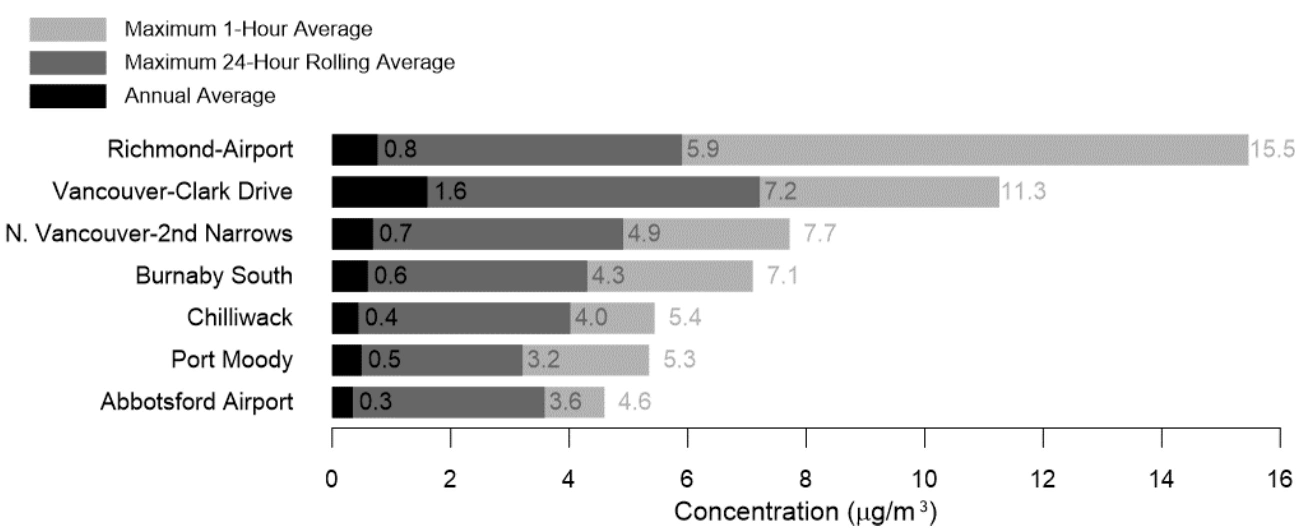


Figure 46: Black carbon monitoring, 2018.

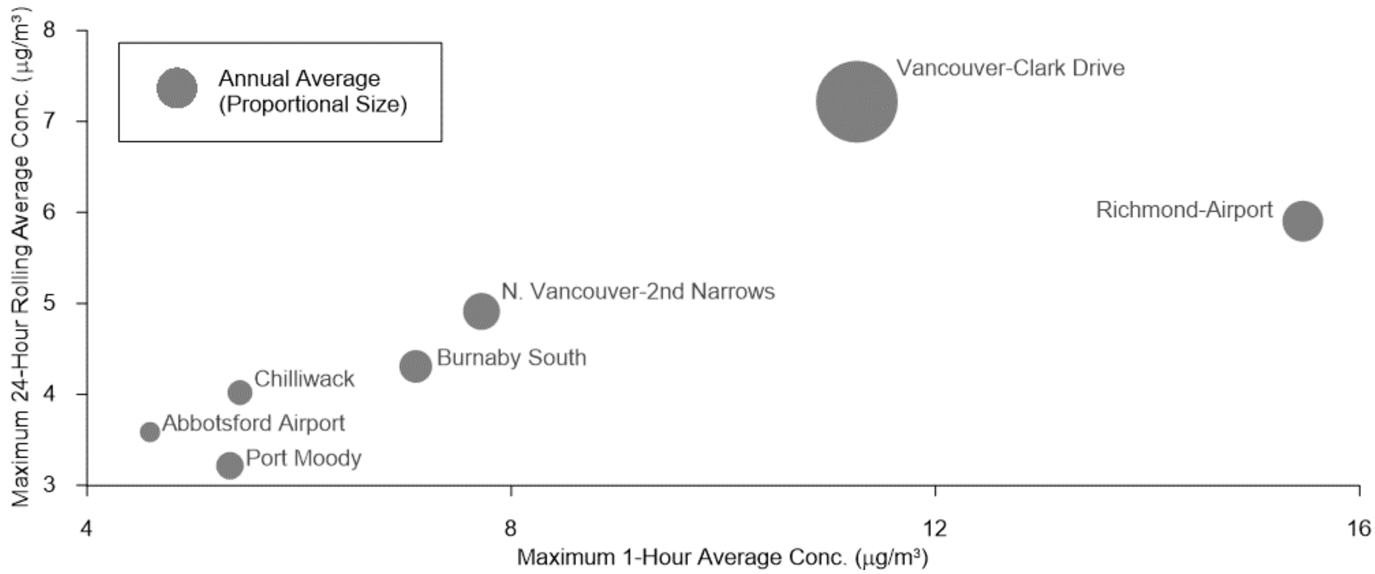


Figure 47: Black carbon monitoring, 2018.

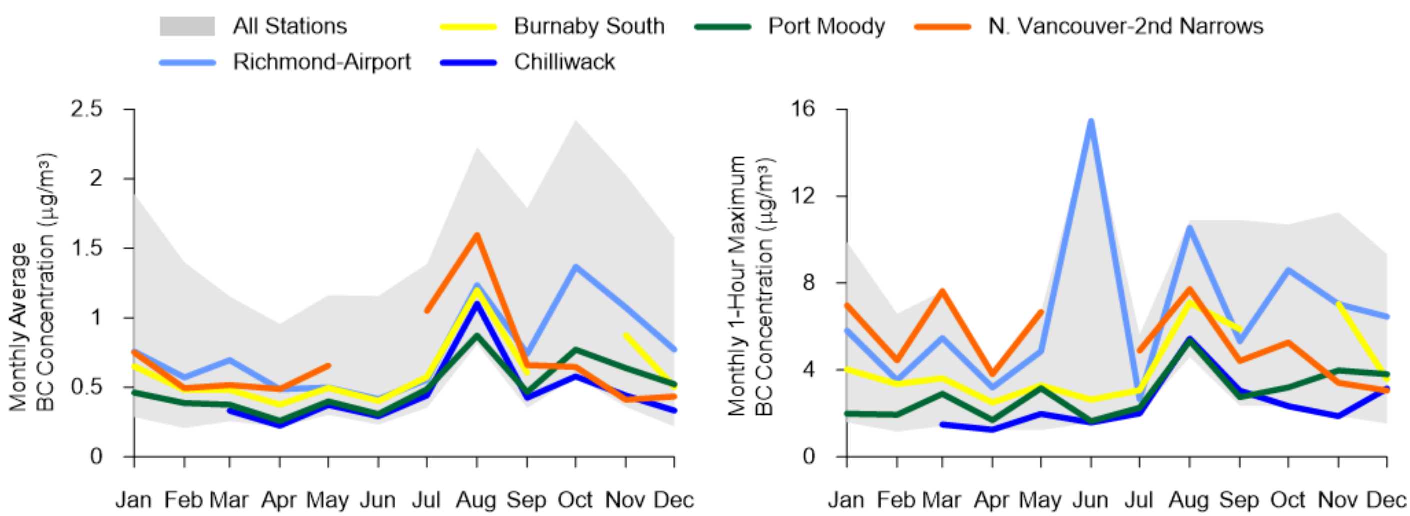
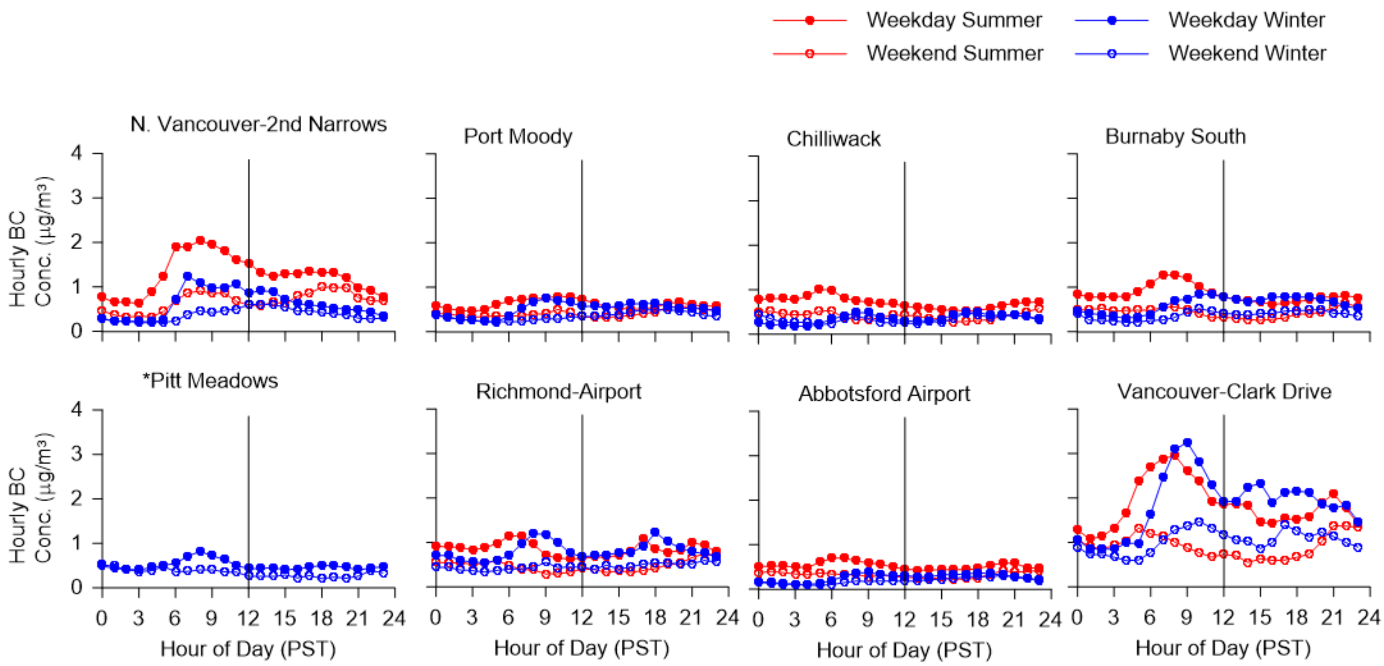


Figure 48: Monthly average (left) and short term peak (right) black carbon, 2018.



*Data completeness requirements were not met at this site in summer.

Figure 49: Diurnal trends black carbon, 2018.

Ultrafine Particles (UFP)

Characteristics

Ultrafine particles (UFP) consist of a combination of suspended solids and liquid droplets having aerodynamic diameters less than 0.1 microns (100 nanometers). These particles are measured based on their numbers (units of 10^3 #/cm^3) in the atmosphere rather than fine particulate matter that is measured based on its mass (μg/m^3).

Ultrafine particles are relatively short-lived, as compared to longer-lived $PM_{2.5}$ particles which may persist in the atmosphere for up to several weeks. The short lifetime for UFP results from their very high number concentrations upon emission. Levels may peak near strong UFP sources such as busy freeways. These exceptionally concentrated UFP rapidly agglomerate (stick together) with each other and with larger particles (e.g. $PM_{2.5}$) to yield particles with diameters larger than 0.1 microns. Agglomeration, dispersion, and advection are the dominant atmospheric processes determining the UFP spatial distribution. Deposition (settling onto surfaces) plays a minor role in the UFP spatial distribution because gravity does not have a strong influence on UFP. Typically, the UFP level decreases exponentially to reduced levels within 500 m of a strong source.

Sources

There are several sources of UFP, including manufacturing, combustion sources, and nucleation events. It is generally recognized that smaller particles are more harmful to human health. Unlike larger particles, UFP can penetrate pulmonary tissue, enter the bloodstream, and circulate throughout the body. Thereby, UFP can damage a number of internal systems that may be inaccessible to larger particles.

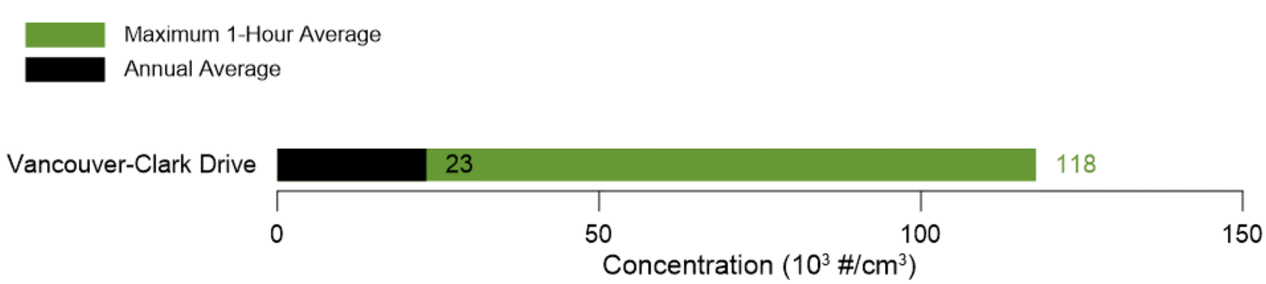
Monitoring Results

Ultrafine particle monitoring has not been conducted in the region prior to the near-road air quality monitoring study. The results from the near-road monitoring study are the first collected in the Metro Vancouver region due to availability of new monitoring technology and interest in these particles from a health perspective.

Figure 50 illustrates the results of continuous UFP monitoring for 2018. The figure displays the value of the maximum 1-hour and annual average for the single UFP station that operated in 2018 using all available data. There are currently no federal, provincial or regional air quality objectives for UFP.

In Figure 51 the seasonal trends for UFP shows average values higher in the winter months with the highest peak level occurring in February. Four months (September to December) are not shown due to data completeness requirements not being met.

Ultrafine particles are generally greater on weekdays compared with weekends, shown in Figure 52. The winter weekday trend is the most prominent with a peak count of ultrafine particles in the morning corresponding with traffic.



Note: Data completeness requirements were not met and data is shown with all available data.

Figure 50: Ultrafine particle monitoring, 2018.

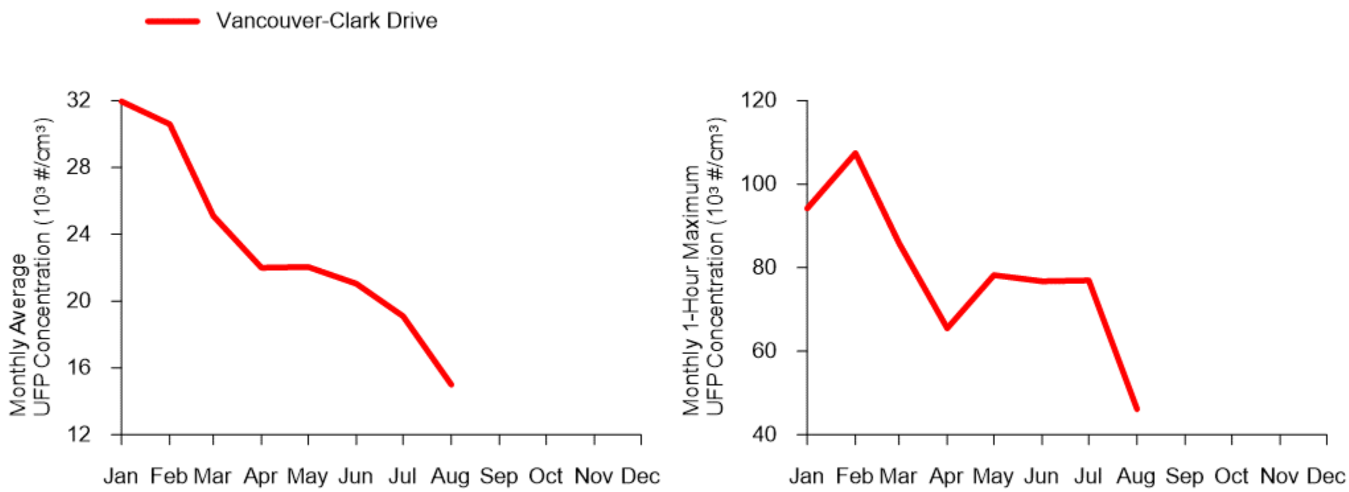


Figure 50: Monthly average (left) and short-term peak (right) ultrafine particles, 2018.

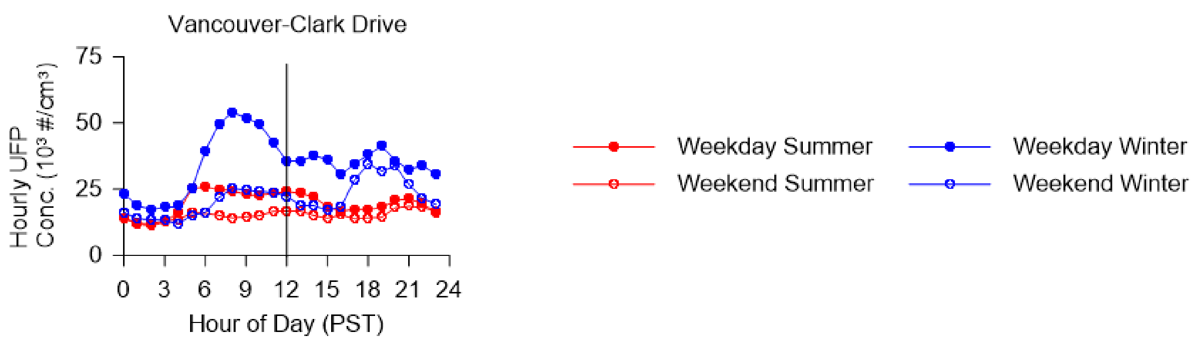


Figure 51: Diurnal trends ultrafine particles, 2018.

Total Reduced Sulphur (TRS)

Characteristics

Total reduced sulphur (TRS) compounds are a group of sulphurous compounds that occur naturally in swamps, bogs and marshes. They are also created by industrial sources such as pulp and paper mills, petroleum refineries and composting facilities. These compounds have offensive odours similar to rotten eggs or rotten cabbage, and at high concentrations can cause eye irritation and nausea in some people.

Sources

Most public complaints regarding these odours are associated with composting facilities and with the petroleum refining and distribution industry located along Burrard Inlet. A few periodic inquiries also occur as a result of natural emissions from such locations as Burns Bog in Delta.

Monitoring Results

Figure 53 illustrates the TRS measurements in 2018 for stations with sufficient data completeness. Average levels continued to be near or below detectable limits. Peak levels during 2018, indicated by the maximum 1-hour value, exceeded the Desirable Objective for a total of eight hours and were below the Acceptable Objective. The occurrences of elevated TRS are of short duration and generally during the night or early morning. The exceedances occurred in January, February, September and October.

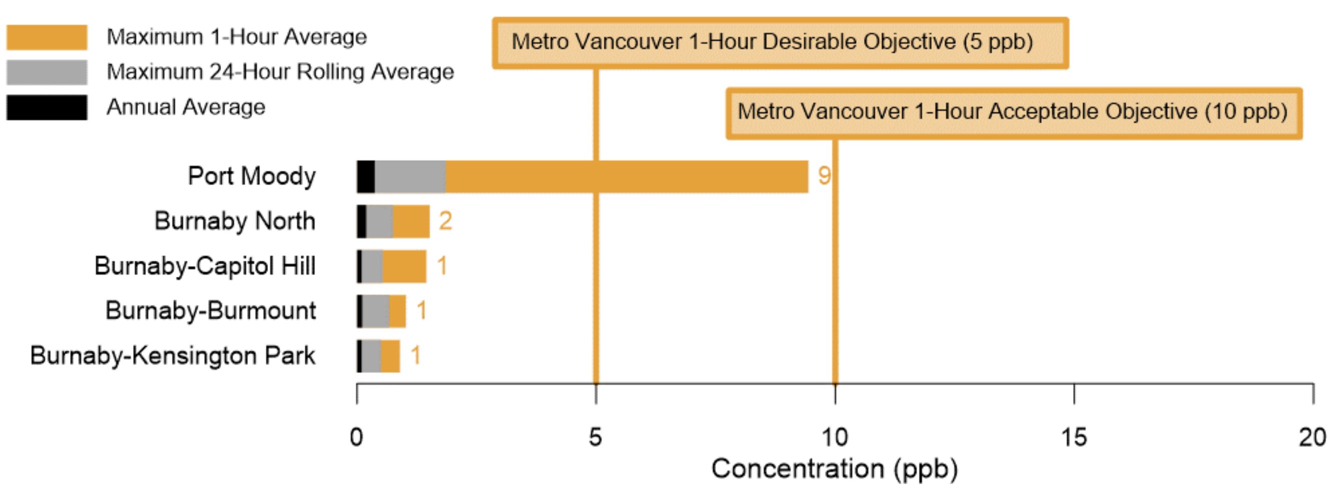


Figure 52: Total reduced sulphur monitoring, 2018.

Ammonia (NH_3)

Characteristics

Ammonia (NH_3) can contribute to the formation of fine particles when chemical reactions occur between ammonia and other gases in the atmosphere including sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). The resulting ammonium nitrate and ammonium sulphate particles are efficient at scattering light and can impair visual air quality with a white haze.

Sources

The largest contribution to ammonia in the LFV comes from the agriculture sector. The majority of ammonia emissions come from cattle, pig, and poultry housing, land spreading and storage of manure, and fertilizer application.

Monitoring Results

Continuous measurements of ammonia were made at three sites in the monitoring network in 2018. The 2018 data are presented in Figure 54, shown as the maximum 1-hour average, maximum 24-hour rolling average and annual average ammonia concentrations. There are no applicable objectives for ammonia.

Continuous measurements of ammonia began in 2005. Due to the relatively short period for which data are available, no clear long-term trend in ammonia is evident.

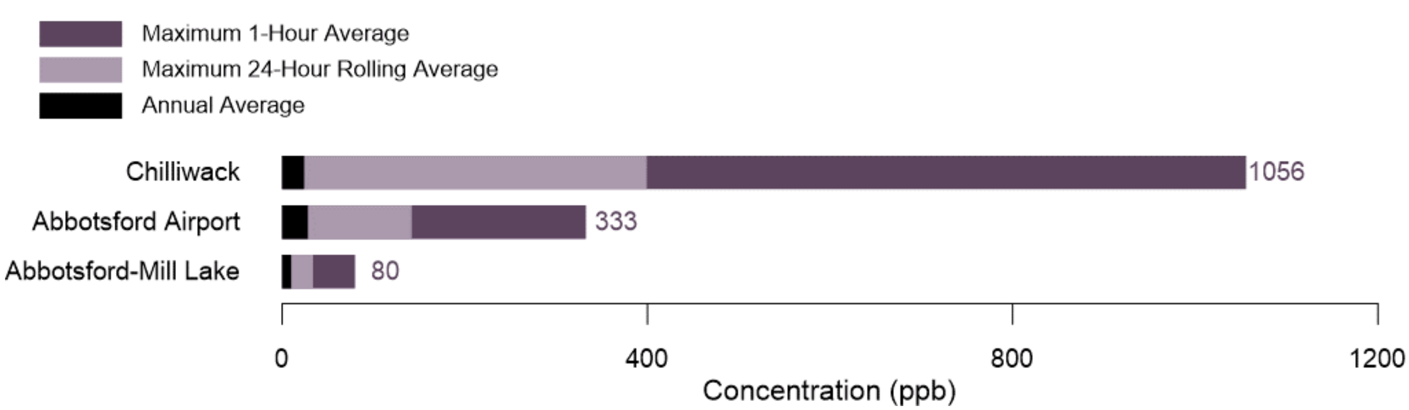


Figure 53: Ammonia monitoring, 2018.

Section E – Non-Continuous Pollutant Measurements

Non-continuous samples are collected in accordance with the National Air Pollution Surveillance (NAPS) program. After collection, samples are transported to and analyzed in a federal laboratory in Ottawa to determine pollutant concentrations.

Analysis results of non-continuous (integrated) sampling from the federal laboratory can take considerable time. Therefore, analysis of non-continuous results will be conducted when available and appended to this report.

Particulate Sampling

Non-continuous 24-hour (daily) $PM_{2.5}$ and PM_{10} samples are collected on filters every sixth day depending on the site. Non-continuous particulate samples are collected at five monitoring stations in the LFV and pollutant concentrations are determined. A detailed analysis is conducted by the federal laboratory for four of these stations (Port Moody, Burnaby South, Abbotsford Airport and Vancouver-Clark Drive).

Using specialized PM speciation instrumentation, additional detailed information about the chemical composition of $PM_{2.5}$ is obtained from three stations in the network (Burnaby South, Abbotsford Airport and Vancouver-Clark Drive) as a result of analyses carried out by the federal NAPS program. From the 24-hour samples collected at these two sites, the various compounds that form $PM_{2.5}$ are identified.

Volatile Organic Compounds (VOC)

Volatile Organic Compounds (VOC) refers to a combination of organic chemicals. A large number of chemicals are included in this group but each individual compound is generally present at relatively low concentrations in air compared to other common air contaminants. The gaseous VOC present in the air can originate from direct emissions and from volatilization (*i.e.* changing into the gas phase) of substances in the liquid or solid phase.

Locally, some VOC can be pollutants found in urban smog and are precursors of other contaminants present in smog such as ozone and fine particulates. Some materials in this class (*e.g.* carbon tetrachloride) can contribute to depletion of the stratospheric ozone layer and may contribute to climate change. Other VOC (*e.g.* benzene) can pose a human health risk.

Sources of VOC in Metro Vancouver include, but are not limited to emissions from the combustion of fossil fuels, industrial and residential solvents and paints, vegetation, agricultural activities, cannabis production, petroleum refineries, fuel-refilling facilities, the burning of wood and other vegetative materials, and large industrial facilities.

Under the Canadian Environmental Protection Act some VOC are included in the Toxic Substances List.

Emissions of some VOC are managed under permits and industry-specific regulations within Metro Vancouver.

Non-continuous 24-hour (daily) sampling of VOC is conducted every sixth or twelfth day on a national schedule. In 2018, VOC samples were collected at eight sites in the LFV. In cooperation with the federal National Air Pollution Surveillance (NAPS) program, canister sampling of VOC has been conducted in the LFV since 1988. Canisters sent to the federal laboratory are analyzed for up to 175 VOC. These data can then be used to help determine the emission sources contributing to contaminants in the air.

In addition to the canister sampling, continuous measurements of total hydrocarbons (THC) were made at two stations in 2018, Burnaby North and Burnaby-Burmount (results not shown). Both of these are adjacent to petroleum industry facilities.

Section F – Visual Air Quality Monitoring

Characteristics

When light between an object and the eye of an observer is scattered and/or absorbed by particles and gases in the air, views can look hazy or even be fully obscured. The term visual air quality refers to the impacts air contaminants have on our ability to see through the atmosphere, affecting the appearance of views including the distance at which the elements of a scene can be clearly seen. It does not refer to the direct effects of clouds, fog, rain or mist on a view.

Visual air quality studies conducted in the LFV have concluded that the major contributor to visual air quality impairment in the LFV is $PM_{2.5}$ and have shown that visual air quality degradation occurs at relatively low air contaminant concentrations, below Metro Vancouver's ambient air quality objectives for $PM_{2.5}$. However, the effects of visual air quality impairment can have different characteristics in different locations within the airshed due to the air contaminants present.

For example, in more urbanized areas of the western LFV, nitrogen dioxide emitted when fuels are burned contributes to the yellow-brown discolouration of the view. Further east in the LFV, visual air quality impairment usually occurs as white haze due to the presence of $PM_{2.5}$. Sources of particulate matter contributing to visual air quality impairment include anthropogenic activities as well as natural sources such as windblown dust, soil, sea salt and smoke.

Monitoring Program

To assess visual air quality in the LFV, Metro Vancouver, FVRD, BC Ministry of Environment and Climate Change Strategy (BC ENV) and Environment and Climate Change Canada (ECCC) jointly established a visual air quality monitoring network and reporting metrics. Continuous measurements of light scattering and the species responsible for light absorption are complemented by particulate speciation sampling, meteorological measurements and images of views along specific lines-of-sight. Measurements of views or both views and air contaminants are made at seven locations in the LFV (Figure 55).

Light scattering measurements are made for visual air quality analysis using nephelometers in five locations. Aethalometers and nitrogen dioxide analyzers are also located at these sites and are used to characterize light absorption.

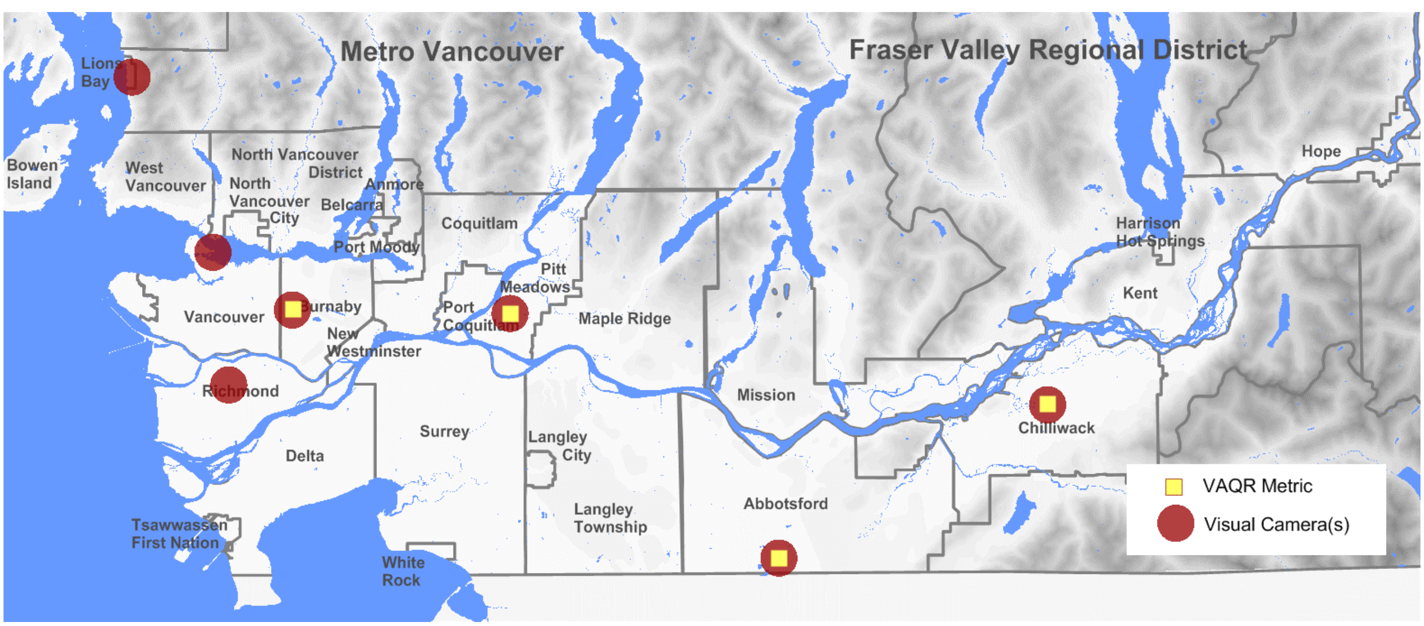


Figure 54: Visual air quality monitoring locations in the LFV, 2018.

Analysis of monitoring data to reconstruct light extinction has indicated that scattering by particles generally has the most influence on visual air quality in the LFV. Modelling work has determined that the highest contributions to extinction, and consequently visual air quality degradation, in the LFV on the most impaired visual air quality days are from particulate nitrate and organic matter. The extent of the influence of other species, such as particulate sulphate, on visual air quality degradation is dependent on meteorological conditions.

Automated digital cameras are operated in the seven locations shown in Figure 55: Chilliwack, Abbotsford, Pitt Meadows, Burnaby, Vancouver, Richmond and Lions Bay. The cameras in Burnaby were installed in a new location in 2018, capturing images on lines of sight that are similar to two of the lines of sight at the camera site operated in previous years. Images are captured at 10 or 30 minute intervals along specific lines-of-sight with recognizable topographical features at defined distances.

Visual Air Quality Pilot Project

A visual air quality pilot project was established in the LFV by the BC Visibility Coordinating Committee (BCVCC). The BCVCC was established in 2006 and is a collaborative venture between Metro Vancouver, FVRD, ECCC, Health Canada and BC ENV. An objective of the pilot project is to determine the actions necessary to protect and improve visual air quality in the LFV.

Key components of the pilot project include:

- The establishment and ongoing operation of a visual air quality monitoring network;
- The development of a visual air quality reporting tool and recommendations for a visual air quality goal;
- The identification of the causes and impacts of impaired visual air quality in the LFV;
- An improvement of our understanding of the economic drivers for visual air quality management; and
- The creation of a strategy to engage and inform stakeholders and members of the public about visual air quality issues.

Visual Air Quality Rating

A visual air quality rating (VAQR), with descriptors ranging from excellent, good, fair, poor to very poor, is the reporting metric developed by the BCVCC, to enhance outreach about visual air quality in the LFV and to provide mechanisms to track changes in visual air quality. The VAQR was launched in 2015 and was reported for four sites in 2018, as shown in Figure 55.

The VAQR reflects residents' perceptions of visual air quality conditions. Images from visual air quality monitoring network cameras were used to survey residents in Metro Vancouver and FVRD to relate perceived visual air quality to measured air contaminant concentrations and the estimated resulting optical characteristics of the atmosphere along the line-of-sights to the views. Visual air quality conditions recorded by the cameras in Chilliwack and Abbotsford in 2018 are shown in Figure 56.

Images from a selection of the visual air quality monitoring cameras can be viewed at: http://www.clearairbc.ca/community

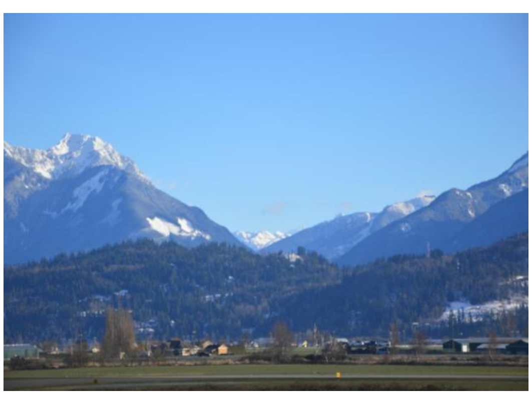
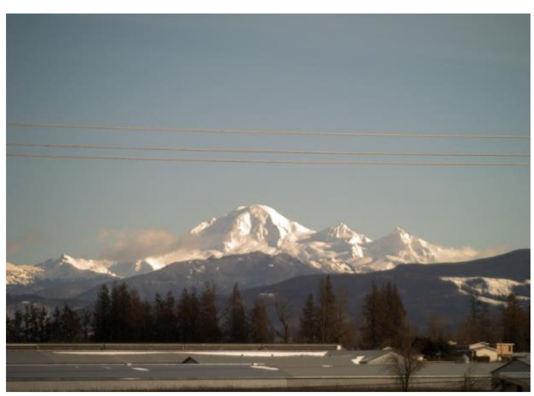



Figure 55: Images showing excellent visual air quality ratings at the Chilliwack and Abbotsford sites in February 2018.

Section G – Meteorological Measurements

Purpose

An understanding of meteorology is integral in understanding and forecasting air quality and visual air quality patterns. The state of the atmosphere determines pollutant dispersion and the resultant ground-level concentration. Meteorology is observed at LFV air quality monitoring network stations for several purposes:

- To allow for a characterization of meteorological patterns throughout the LFV.
- To assist with the linkage between pollutant emission sources and ambient concentrations.
- To provide data to be used as input in dispersion modelling.
- To provide real-time data to numerous agencies including Environment Canada, which are used for weather and air quality forecasting in the region.

It should be noted that the LFV network's primary purpose is for the collection of air quality measurements and secondary purpose is for meteorological observation. Attempts have been made to site meteorological instruments to provide representative observation, however due to restrictions at some stations, not all instruments are sited to capture spatially representative measurements.

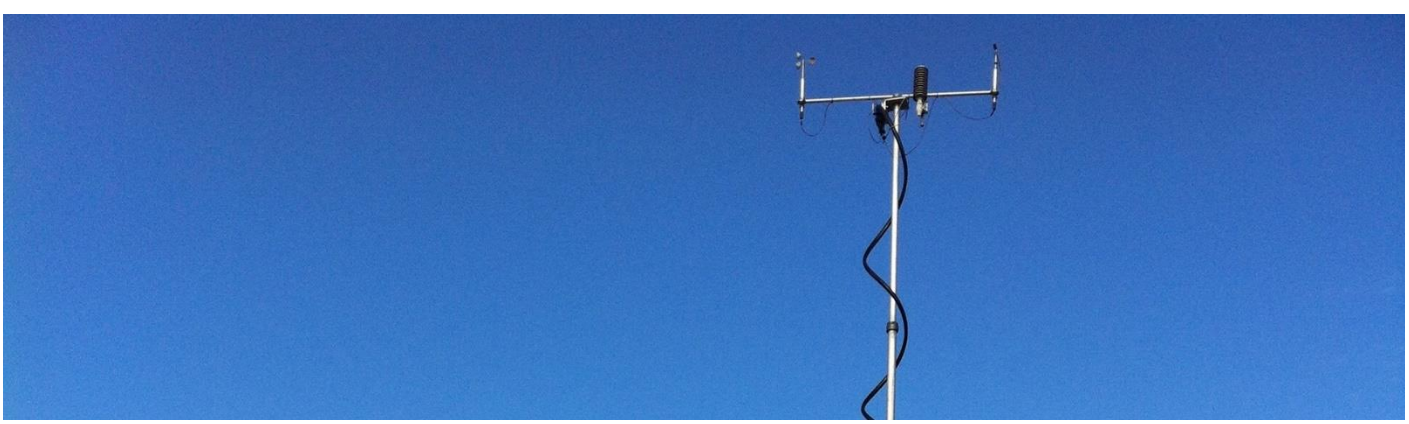
Monitoring Program

Various meteorological parameters are observed as part of the LFV air quality monitoring network (see Section C Table 2). Meteorological parameters observed in the network include:

- wind speed and direction
- air temperature
- relative humidity
- precipitation
- barometric pressure
- incoming solar radiation
- net radiation

Wind speed and direction observations allow for the characterization of pollutant transport and dispersion and are used to understand the relationships between pollutant sources and measurements at air quality monitoring stations.

Air temperature and incoming solar radiation measurements can be used to determine the potential for ozone formation during the summer. Ozone concentrations are dependent on sunshine to cause photochemical reactions among air pollutants. Higher air temperatures are necessary for these reactions to occur.



Humidity is important in the formation and growth of visibility reducing particles, and its measurement is a key to understanding the many factors responsible for visual air quality degradation.

Precipitation can remove particles from the atmosphere and may help explain differences in air quality from one part of the region to another. In addition, precipitation data are used by Metro Vancouver's Wastewater Collection and Watershed Management functions.

Meteorological Observations

Figure 57 shows the annual precipitation totals for 2018 at Lower Fraser Valley air quality monitoring network stations. The greatest precipitation was observed near the local mountains. Historical 30-year climate normals (1981-2010) obtained from Environment Canada are also shown in Figure 57 for several stations. Figure 57 displays the seasonal variation as observed by the LFV air quality network stations (shown as a blue band). Historical 30-year climate normals (1981-2010) obtained from Environment Canada are also shown in Figure 58 for Vancouver International Airport, Port Moody and Chilliwack.

Compared to climate normals, monthly precipitation in 2018 was drier in May, July and August, and was wetter in January, April, September, November and December.

Figure 59 illustrates the seasonal variation of air temperatures observed throughout the monitoring network stations. The hourly maximum and minimum, daily maximum and minimum, and average temperatures are given with the range in values shown as bands. Also shown in Figure 59 are the 30-year climate normals (1981-2010) for Environment Canada's Vancouver International Airport and Agassiz stations.

The data observed in 2018 indicate that average temperatures recorded in May, July, August, November and December were warmer than the 30-year average. During these months' higher averages and daily maximums were experienced compared with the climate normals. The highest air temperatures were measured in August. February, March and September was on average cooler than normal.

Table 10 provides the average temperature along with the lowest and highest hourly air temperatures observed throughout the year. Air temperatures are milder near the water and exhibit a greater range inland. The highest hourly temperature in 2018 was 34.7^{o}C observed at Chilliwack.

Table 11 gives the frequency distribution of hourly air temperature for the year. Stations located inland, such as those in eastern parts of Metro Vancouver and the Fraser Valley Regional District exhibit the greatest frequency of both very low and high air temperatures.

Wind patterns vary between stations as shown by the frequency distributions in Figure 60. The distributions are shown as a "wind rose", which is a bar chart in a polar format. The direction of the bar indicates the direction from which the wind is blowing, the colour indicates the wind speed class and the length of the bar indicates the frequency of occurrence.

Figure 60 shows observed annual wind roses for selected stations including (in order of west to east): Horseshoe Bay, Richmond-Airport, Burnaby North, Pitt Meadows, Abbotsford Airport, Chilliwack, and Hope. The patterns shown during 2018 reflect the predominant winds in those areas. Richmond exhibits a predominant easterly wind with a smaller component from the west, and very little wind from either the north or south. Horseshoe Bay shows wind patterns aligned with Howe Sound with a strong north-south component.

The year 2018 included a wetter than normal winter, dryer than normal spring and hot dry summer.

Burnaby North shows several northerly wind components along with a predominant east-north east component. This wind pattern is reflective of the North Shore mountain wind flows and drainage flow from Indian Arm. Pitt Meadows shows a somewhat similar pattern with predominant directions from the valleys of Pitt Lake and Alouette Lake. Abbotsford, Chilliwack and Hope experience similar wind flow patterns, with strong east-west components driven by the channelling of winds in the narrower portion of the Fraser Valley.

Figures 61 to 64 show wind roses for winter, summer, spring and fall, respectively. The contrast between winter and summer can be seen in Figures 61 and 62 with winds predominantly from the east in winter switching to southwest in summer. The more westerly flow seen in the summer is the development of a daytime sea breeze during anti-cyclonic (high pressure) weather.

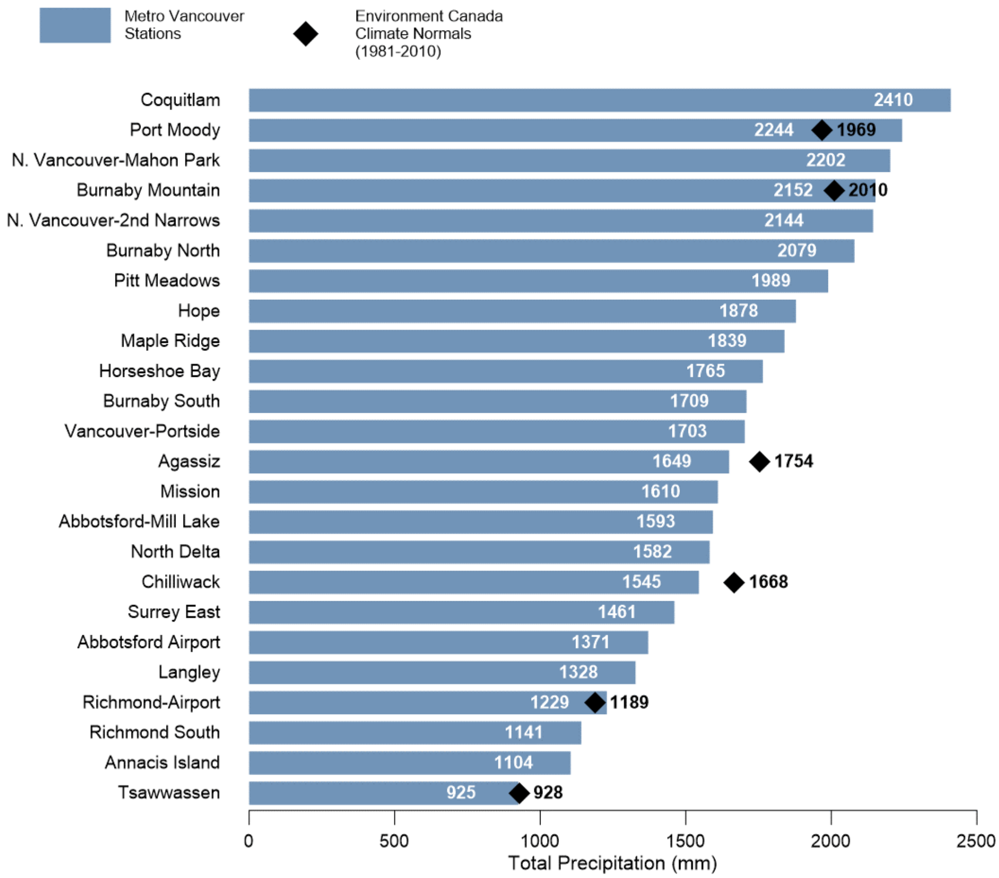
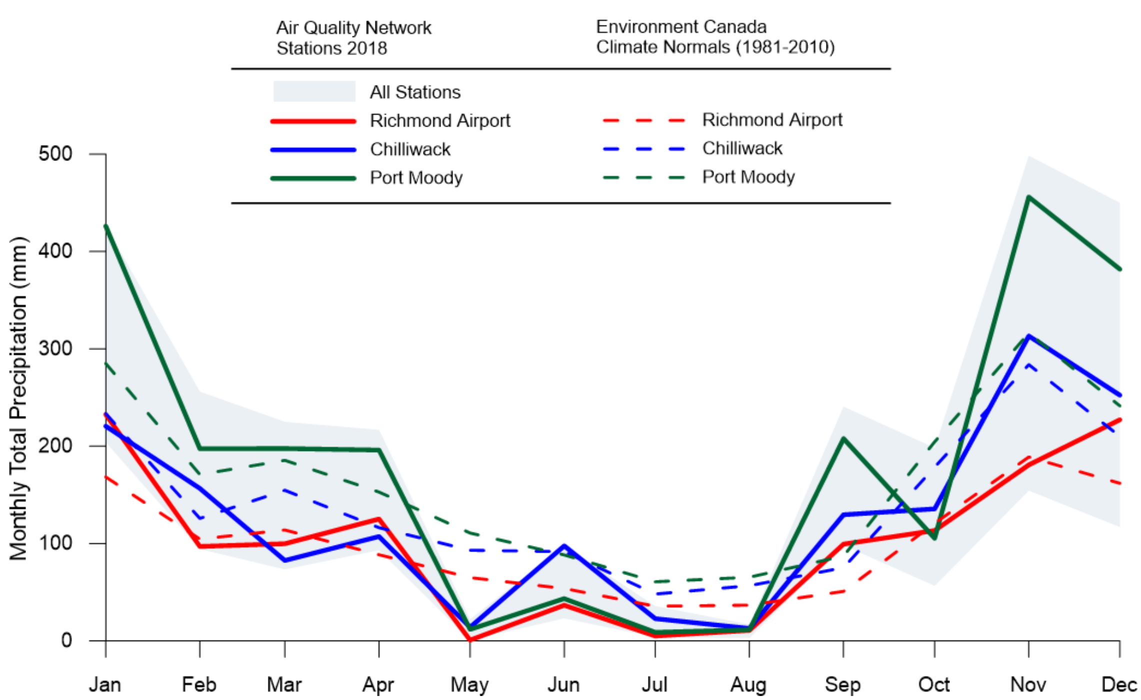
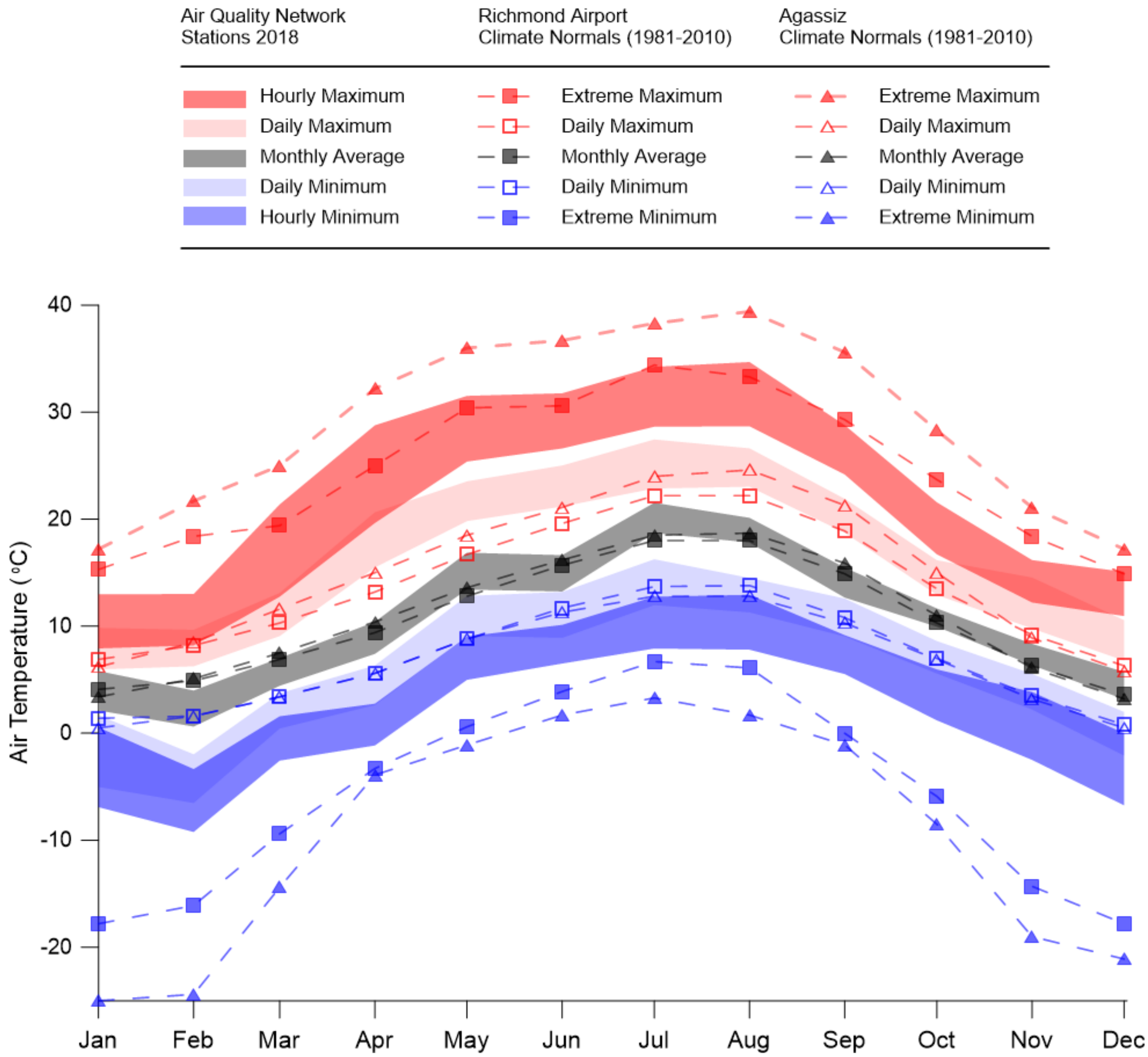


Figure 56: Annual precipitation totals in the LFV, 2018.



Note: The range of values observed at LFV air quality network stations are shown as a blue band and Environment Canada climate normals are shown as dotted lines.

Figure 57: Total monthly precipitation in the LFV, 2018.



Note: LFV air quality network stations are shown as colour bands and Environment Canada 30-year climate normals are shown as dotted lines.

Figure 58: Monthly air temperatures in the LFV, 2018.

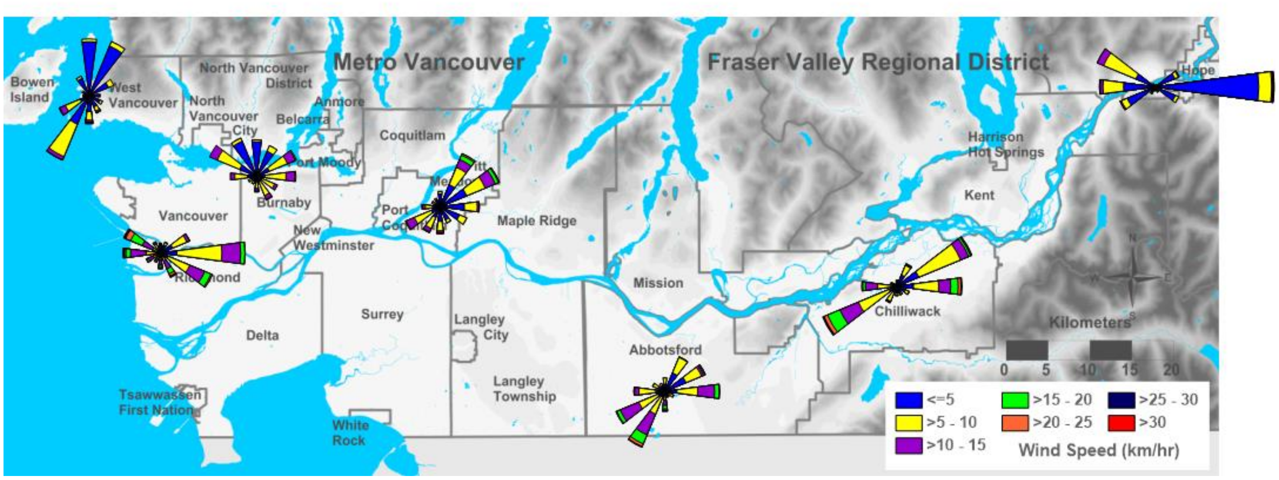


Figure 60: Selected annual wind roses throughout the LFV, 2018.

Table 10: Air temperature in LFV, 2018.

Station	Hourly Maximum (ºC)	Hourly Minimum (ºC)	Annual Average (ºC)
Chilliwack	34.7	-6.3	11.3
Abbotsford-Mill Lake	34.5	-6.1	11.1
Hope	34.2	-9.1	10.7
Maple Ridge	34.1	-6.7	11.0
Agassiz	34.1	-6.8	11.5
Mission	33.8	-6.4	11.1
Pitt Meadows	33.6	-9.2	10.9
Abbotsford Airport	33.4	-5.8	10.9
Langley	33.3	-7.9	10.7
Burnaby-Burmount	33.0	-5.2	11.6
Surrey East	32.9	-5.8	11.1
Coquitlam	32.9	-6.0	11.0
Annacis Island	32.5	-4.5	12.1
Burnaby South	32.3	-3.3	11.4
Port Moody	32.2	-6.8	11.0
North Delta	31.8	-6.7	10.3
Burnaby-Kensington Park	31.7	-4.7	10.9
Vancouver-Clark Drive	31.5	-6.0	11.5
Horseshoe Bay	30.9	-4.5	10.9
Richmond South	30.8	-6.3	11.1
Burnaby North	30.7	-5.5	11.2
Burnaby-Capitol Hill	30.5	-5.7	10.3
N. Vancouver-Mahon Park	30.0	-6.1	11.0
Vancouver-Templeton	29.8	-5.7	10.9
Burnaby Mountain	29.3	-7.2	9.4
Tsawwassen	29.2	-5.7	10.8
Richmond-Airport	29.0	-4.4	11.4
Vancouver-Portside	28.9	-4.0	11.3

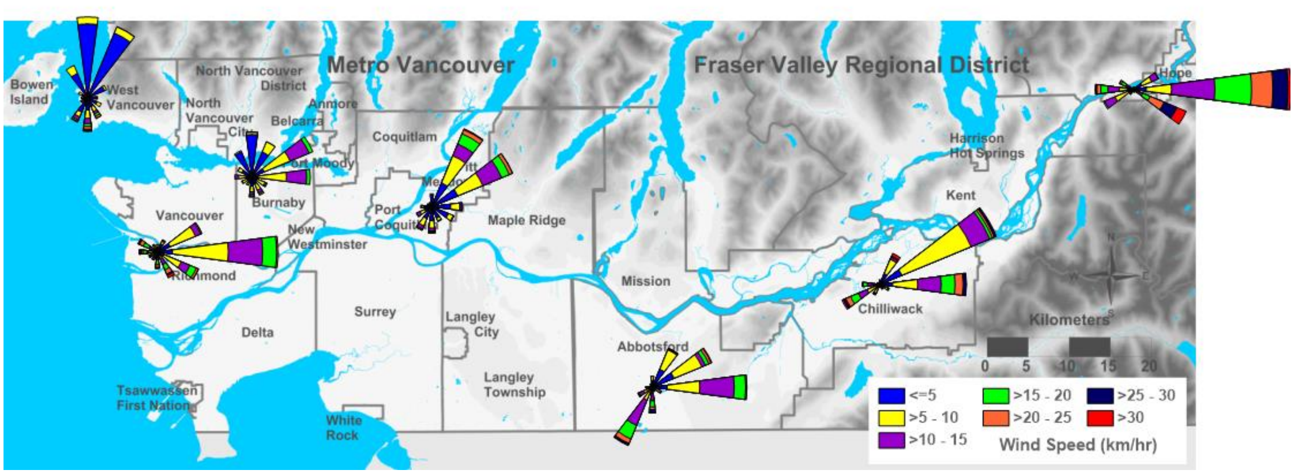


Figure 59: Winter (Jan, Feb, Dec) representative wind roses throughout the LFV, 2018.

Table 11: Frequency distribution of hourly air temperature, 2018.

Air Temp (deg C)	Burnaby-Kensington Park	N. Vancouver-2nd Narrows	Port Moody	Chilliwack	North Delta	Burnaby Mountain	Surrey East	Richmond South	Burnaby South	Pitt Meadows	Burnaby-Burmount	Burnaby-Capitol Hill	Burnaby North	N. Vancouver-Mahon Park	Langley	Hope	Maple Ridge	Richmond-Airport	Coquitlam	Abbotsford-Mill Lake	Horseshoe Bay	Annacis Island	Tsawwassen	Mission	Agassiz	Abbotsford Airport	Vancouver-Templeton	Vancouver-Portside	Vancouver-Clark Drive
-12 to -9										2						2													
-9 to -6			9	7	5	13		5		12				4	3	39	1		2	2				3	10				1
-6 to -3	39	34	71	65	79	102	57	51	5	75	41	73	35	34	80	119	95	16	57	63	14	21	43	70	64	70	59	10	44
-3 to 0	199	178	287	206	222	249	196	209	104	301	151	184	179	183	269	263	248	143	230	204	135	128	156	237	198	215	195	150	192
0 to 3	664	547	693	806	764	1217	609	487	385	651	470	851	519	514	676	1089	689	345	681	683	529	347	547	751	767	735	619	410	458
3 to 6	1531	1325	1100	1371	1531	1552	1342	1214	1313	1426	1249	1629	1051	1462	1375	1313	1349	1139	1388	1349	1432	1028	1100	1149	1193	1250	1330	1349	1266
6 to 9	1434	1615	1561	1237	1520	1330	1493	1679	1709	1405	1523	1424	1164	1488	1498	1120	1415	1780	1470	1369	1603	1263	1739	1411	1334	1413	1508	1695	1591
9 to 12	1249	1283	1238	1270	1249	1467	1310	1317	1427	1190	1424	1191	1161	1334	1295	1159	1227	1418	1253	1338	1400	1215	1469	1360	1267	1346	1306	1377	1347
12 to 15	1299	1317	1305	1109	1268	1069	1322	1366	1437	1318	1363	1271	1299	1248	1356	1077	1292	1367	1330	1293	1257	1321	1524	1262	1135	1332	1351	1181	1213
15 to 18	968	1108	1058	1025	878	700	991	1144	1012	943	965	877	1022	1066	901	960	951	1227	929	1013	1152	1254	1134	1020	1033	1005	1056	1214	1119
18 to 21	672	733	718	693	594	489	658	716	711	607	712	611	728	755	559	674	632	780	666	650	697	752	589	643	745	574	709	784	750
21 to 24	354	337	348	375	305	333	351	296	337	306	416	360	335	345	287	343	321	332	317	331	333	350	265	321	380	307	352	377	372
24 to 27	199	198	198	250	177	179	205	171	202	213	215	201	224	204	201	237	240	156	217	218	148	202	113	224	258	198	207	167	222
27 to 30	127	67	139	181	109	38	148	69	102	171	152	81	86	65	158	214	164	33	153	167	37	112	15	169	194	145	45	29	150
30 to 33	21	3	18	97	19		33	5	14	67	55	2	7	1	47	92	86		53	55	1	17		59	82	42			20
33 to 36				16						7					2	13	13			6				7	10	1			
>=36																													
Missing	4	15	17	52	40	22	45	31	2	66	24	5	950	57	53	46	37	24	14	19	22	750	66	74	90	127	23	17	15
Data Completeness	1	100%	100%	99%	100%	100%	100%	100%	100%	99%	100%	100%	89%	99%	99%	100%	100%	100%	100%	100%	100%	91%	99%	99%	99%	99%	100%	100%	100%

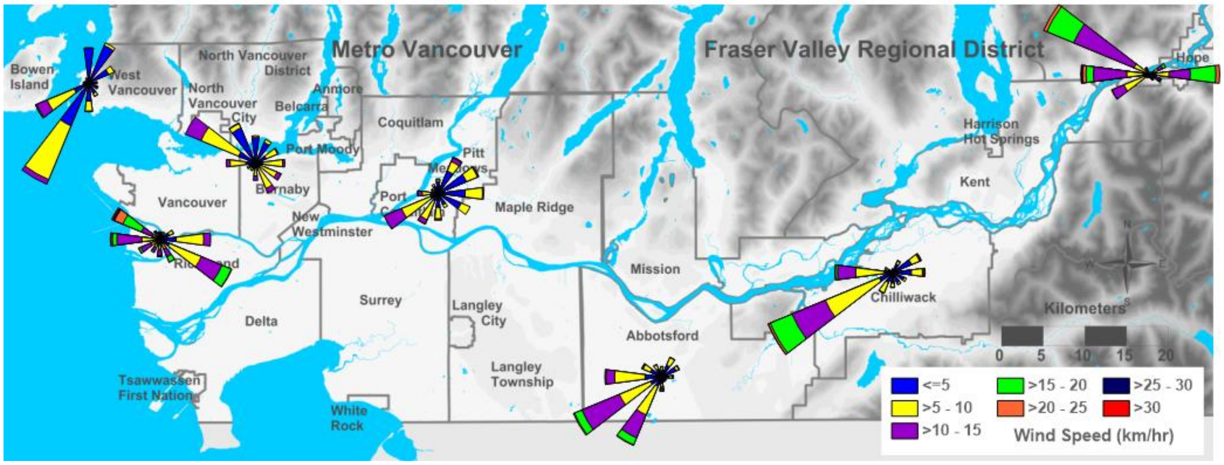


Figure 60: Summer (Jun, Jul, Aug) representative wind roses throughout the LFV, 2018.

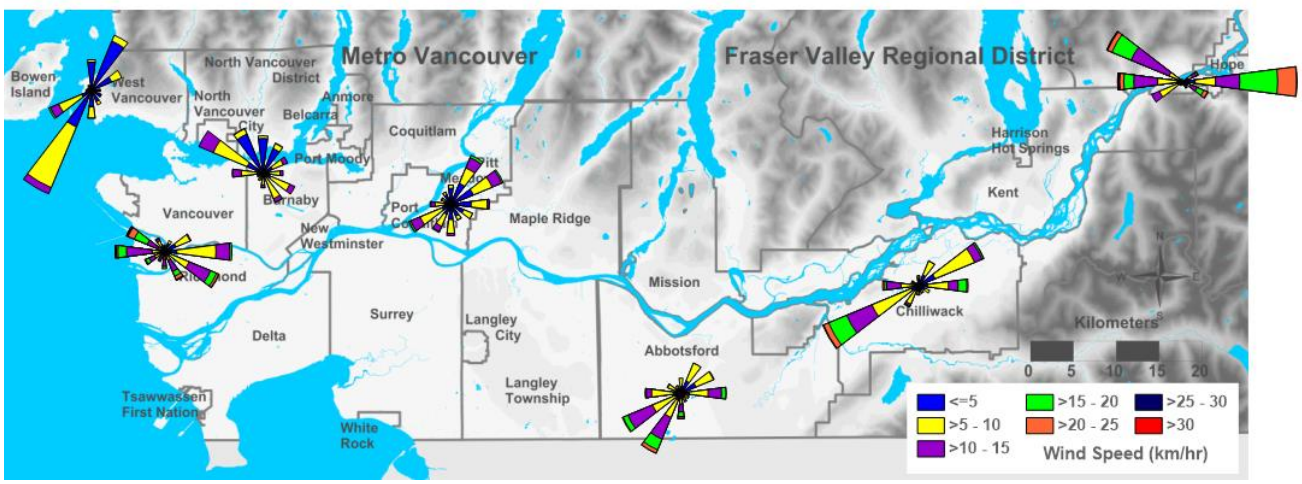


Figure 61: Spring (Mar, Apr, May) representative wind roses throughout the LFV, 2018.

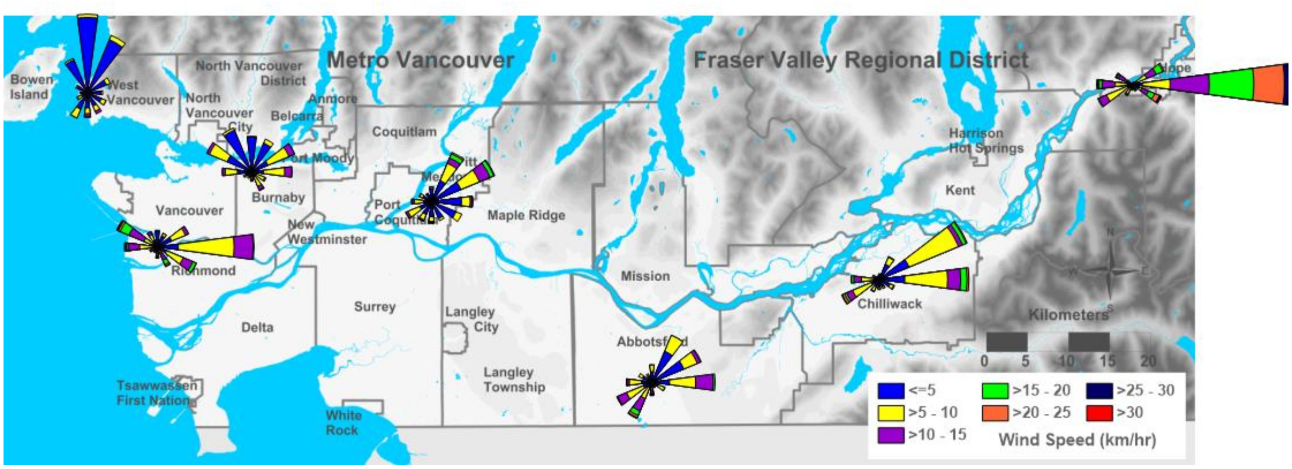


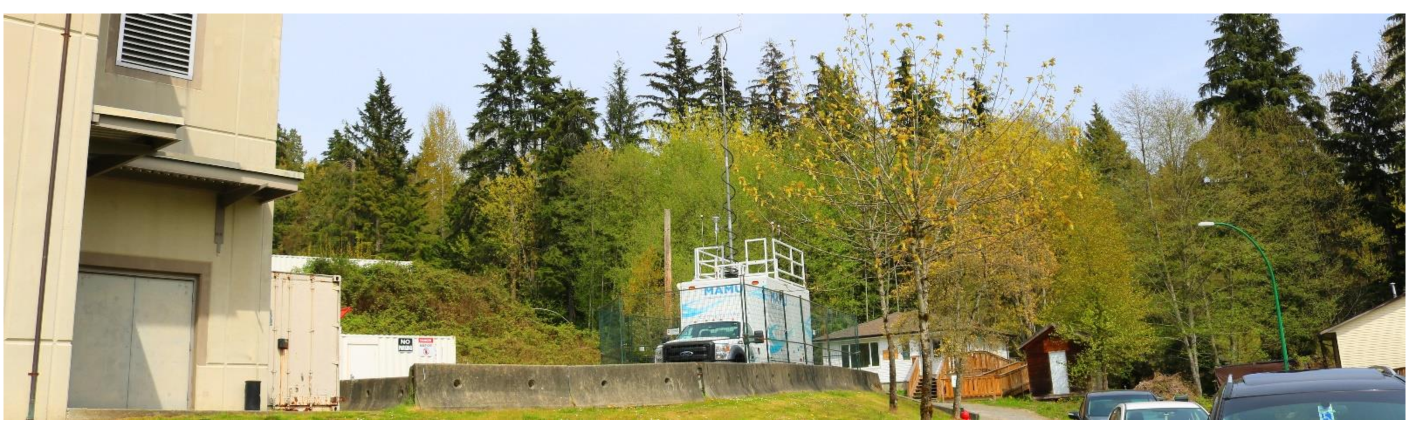
Figure 62: Fall (Sep, Oct, Nov) representative wind roses throughout the LFV, 2018.

Section H –Specialized Monitoring Initiatives

Specialized air quality monitoring studies complement the monitoring network. The studies typically allow for characterization of air quality at finer spatial scales, such as at the neighbourhood scale, and allow investigation of air quality problems on the local scale. The regional monitoring network may not be ideally suited to address local scale issues and therefore performing specialized local air quality studies is an important component to characterizing air quality in the LFV.

A Mobile Air Monitoring Unit (MAMU) that is capable of monitoring particulate and gaseous pollutants along with meteorology is utilized throughout the region to conduct specialized air quality studies. In addition to MAMU, Metro Vancouver utilizes small mobile units along with several portable air quality monitors.

Specialized studies in 2018 included an air quality monitoring study at Tsleil-Waututh Reserve Lands in North Vancouver. The purpose of the study was to gain a better understanding of sulphur dioxide (SO_2) levels in the area and contributing emission sources, such as the nearby oil refinery and marine vessels. The study compares air quality levels to Metro Vancouver's ambient air quality objectives and to other areas monitored by Metro Vancouver in the region and specifically the Burrard Inlet Area.



Section I – Monitoring Network Operations

Network History

Air monitoring in the region began in 1949, when the City of Vancouver established a dustfall monitoring network. Monitoring for total suspended particulate was added in later years. Following the Pollution Control Act (1967), provincial air quality programs initiated monitoring of dustfall and total suspended particulate in other areas of the region.

In 1972, provincial and municipal air quality responsibilities were transferred to Metro Vancouver, including operation of air quality monitoring programs. In 1998, a Memorandum of Understanding established cooperative management of the monitoring network by both Metro Vancouver and the Fraser Valley Regional District.

Continuous monitoring of gaseous pollutants began in 1972 under the auspices of the federal National Air Pollution Surveillance (NAPS) program. Several new stations were established to measure SO_2, O_3, CO, NO_X and VOC. Over the years, stations and equipment have been added or removed in response to changing air quality management priorities. Mobile Air Monitoring Units and portable instruments provide added flexibility to carry out measurements at many locations. Some monitoring is part of co-operative programs with industry and other governments.

Monitoring Network Partners

Several partners contribute to the on-going management and operation of the Lower Fraser Valley Air Quality Monitoring Network. The government partners include:

- Fraser Valley Regional District
- Environment and Climate Change Canada
- BC Ministry of Environment and Climate Change Strategy

Other monitoring network partnerships:

- The Vancouver International Airport Authority provides partial funding for the Vancouver International Airport station (T31).
- Parkland Refining (BC) Ltd. provides funding for the Burnaby North (T24) and Capitol Hill (T23) stations.
- Trans Mountain Pipeline LP provides funding for the Burnaby-Burmount (T22) station.
- Port of Vancouver provides funding for the Tsawwassen (T39) station in Delta.

Metro Vancouver continues to operate and maintain the monitoring stations and equipment, and to collect real-time data from the regional monitoring network on behalf of all partners.

Hastings Saw Mill, Vancouver and ships loading lumber, 1896 (Courtesy of City of Vancouver Archives).

Federal Government

Metro Vancouver co-operates with the federal government by providing field services for three major nation-wide sampling programs under the National Air Pollution Surveillance (NAPS) program of Environment Canada.

- Canister sampling of VOC has been conducted in the LFV since 1988. The federal government supplies equipment and Metro Vancouver staff provide field exchange of canisters, calibration and routine maintenance. Sample canisters are sent to the federal laboratory in Ottawa, for analysis of up to 175 VOC.
- A second program involves dichotomous particulate sampling at three sites. This long-term program samples PM at two size fractions: 10 to 2.5 μm (coarse), and under 2.5 μm (fine). Samples are collected every sixth day, and returned to Ottawa for detailed chemical analysis.
- In 2003 a $PM_{2.5}$ speciation sampling program was initiated. Particulate speciation samplers are operated at the Burnaby South and Abbotsford Airport stations. $PM_{2.5}$ samples are taken every sixth day in specially designed cartridges. The samples are sent to the federal laboratory in Ottawa where they are analyzed for various particulate species.

Quality Assurance and Control

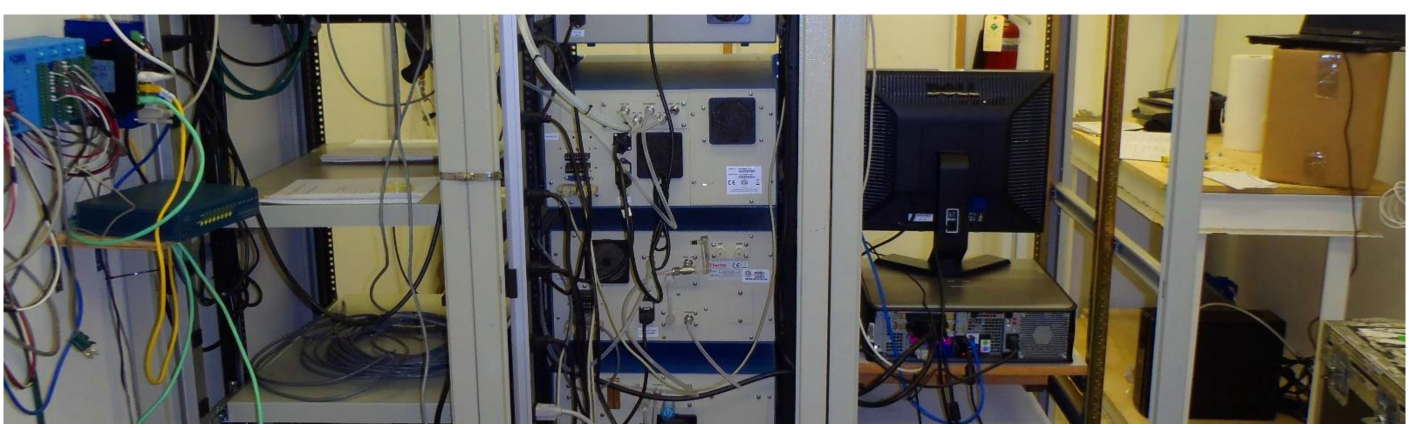
Air quality monitoring data is regularly reviewed and validated. Technicians perform regular inspections and routine maintenance of the monitoring equipment and stations.

In addition, technicians perform major repairs to any instrument in the network, as required. Through the data acquisition system, technicians can check on instruments remotely prior site visits. This system also allows for calibration of the instruments either automatically or upon demand. Portable calibration equipment is used to evaluate instrument performance.

Continuous air quality monitors are subject to performance audits and multi-point calibration every four to six months. In addition, all other instruments and samplers in the network are subjected to annual and/or biannual calibrations. All reference materials and quality control procedures meet or exceed Environment Canada and/or U.S. Environmental Protection Agency requirements. Metro Vancouver coordinates quality assurance procedures and activities with both the provincial and federal government.

Database

Data from continuous air quality analyzers are transmitted to Metro Vancouver's central database using internet, phone lines and cellular links. Hourly averages for each monitor are calculated from the one-minute data and stored in the database. For a measurement to be considered valid (and stored for further use), at least 75% of the relevant data must be available. Calibration data and instrument diagnostics are also retained by the data acquisition system



Section J –Wildfires, Air Quality Events and Climate Change

Significant events have occurred in the past that have impacted air quality within the Lower Fraser Valley. Historically, these events have occurred relatively infrequently and are not unique to the region. They include large structural fires, dusting events and wildfires. In the last 30 years, notable events have included 1998 long-range transport of dust from Asia, 2005 Burns Bog fire, 2012 Siberian wildfires, and 2015, 2017 and 2018 Pacific Northwest wildfires.

In recent years, wildfire activity has increased in severity, become more widespread and have been linked to a changing climate. Wildfires produce considerable amounts of smoke that can be transported great distances. Wildfire smoke is a complex mixture of many gases and small particles. The mixture can change quickly depending on the weather, what is burning, the temperature of the fire, and how far the smoke has travelled. Of all the pollutants in wildfire smoke, fine particulate matter ($PM_{2.5}$) poses the greatest risk to human health.

Locally, the presence of wildfire smoke can result in two differing outcomes for ground-level ozone production. Wildfire smoke can either enhance or inhibit ozone production depending on the amount of smoke present. The mixture of chemical contaminants in wildfire smoke includes ozone precursors which can enhance the ozone production to levels not typically experienced in the region. A past study by Teakles et al. (2017)[1] indicated that a wildfire smoke event in 2012 was responsible for an enhancement of 8-hour ozone concentrations at coastal B.C. sites by as much as 10 ppb. Conversely, if the wildfire smoke becomes dense enough, the smoke can block solar radiation, decrease air temperatures and inhibit the production of ozone. Effects of both inhibition and enhancement of ozone due to smoke have been experienced in the LFV.

Wildfires and Air Quality

Historically, episodes of degraded air quality due to smoke from wildfires outside the region have been infrequent. Since 2015, however, wildfire smoke impacts have increased significantly. In 2015 eight air quality advisory days occurred due to wildfire smoke, primarily associated with large fires north of Pemberton. There were no air quality advisories in 2016, while 2017 and 2018 experienced significant and lengthy smoke-related air quality impacts due to wildfires burning throughout the Pacific Northwest, including BC and the US. There were 19 advisory days in 2017 and 22 advisory days in 2018, the most in Metro Vancouver's history.

In 2018, the total number of fires in British Columbia were nearly twice as many as 2017. In 2018, the total area burned was over three times greater than the 10-year average with 13,543 km^2 burned while the 10-year average was 3,690 km^2 (Table 11).

Table 11. Total fires and area burned in British Columbia.

Year	Total Fires	Area Burned (km^2)
2015	1,858	2,806
2016	1,050	1,004
2017	1,353	12,161
2018	2,117	13,543
10-year average	*1,758*	*3,690*

The 2018 wildfire season was one of the worst in British Columbia's history, with the largest area burned. This led to the most air quality advisory days that the region has experienced in a single year. Figure 65 shows summertime exceedance days due to elevated $PM_{2.5}$ in three wildfire years: 2015, 2017 and 2018. The colour corresponds to the maximum $PM_{2.5}$ 24-hour rolling average with dark red signifying concentrations greater than 100 $\mu g/m^3$.

In 2015, Vancouver was the most severely impacted in the region by smoke coming from wildfires burning in Pemberton and Sechelt. The highest maximum 24-hour rolling average of $PM_{2.5}$ within the region was measured at Vancouver-Clark Drive with a concentration of 121.5 $\mu g/m^3$. In 2017, the most severe episode occurred during an 11-day period when outflow winds brought smoke from wildfires burning in the BC Interior resulting in the highest 24-hour rolling average of 101.8 $\mu g/m^3$ at Hope.

[1] Teakles, A.D., So, R., Ainslie, B. et al. (2017) Impacts of the July 2012 Siberian fire plume on air quality in the Pacific Northwest. Atmos. Chem. Phys. 17, pp. 2593-2611.

In 2018, the region was impacted by extensive wildfires burning throughout the Pacific Northwest as well as several in-region wildfires, a bog fire and a large barge fire. The region experienced unprecedented wildfire smoke impacts in 2018 with the highest maximum 24-hour average $PM_{2.5}$ concentration measured on record (257 μg/m^3 in Hope) during the longest advisory in Metro Vancouver's history (14 continuous days).

In 2018, the $PM_{2.5}$ objective was exceeded on July 27 and 28 at the Richmond-Airport station due to a bog fire in Richmond. The bog fire resulted in intermittently elevated $PM_{2.5}$ in surrounding municipalities but did not result in exceedances at any other monitoring station.

During this period there was also wildfire smoke present from distant fires in Siberia and Alaska, although the smoke was not thought to have contributed significantly to elevated PM levels. The smoke contributed to a noticeable haze throughout the region. On July 30, $PM_{2.5}$ concentrations remained high and a one-day $PM_{2.5}$ advisory was issued as a precautionary measure, however no exceedances of $PM_{2.5}$ were recorded on the day.

On August 9 a $PM_{2.5}$ advisory was issued for the Eastern Fraser Valley due to wildfires burning in Agassiz (High Creek), Chilliwack (Nixon Road) and east of Manning Park. At the time, there was also a small wildfire burning in West Vancouver (near Whyte Lake) producing some localized smoke in Howe Sound. In a satellite image taken on the day of the advisory (Figure 66) smoke can be seen in the Fraser Canyon extending into the eastern portion of the Fraser Valley Regional District.

The following day the $PM_{2.5}$ advisory was expanded to include Metro Vancouver when several municipalities were blanketed with smoke from a large barge fire in Surrey. The fire broke out at a metal recycling facility in Surrey in the early morning hours of August 10 and smoke extended into New Westminster, Burnaby and Coquitlam. The barge fire resulted in exceedances of the $PM_{2.5}$ objective at the New Westminster monitoring station while at the same time Agassiz and Hope were in exceedance due to wildfire smoke at the eastern end of LFV. The air quality advisory was cancelled on August 11th.

On August 13, widespread smoke was experienced due to wildfire smoke from fires burning throughout the Pacific Northwest (Figure 66). An unprecedented fourteen-day advisory was issued whereby all monitoring stations in the region experienced exceedances of the $PM_{2.5}$ objective. The advisory was the longest continuous advisory in Metro Vancouver history, lasting from August 13 to 27. For three continuous days (August 13, 14, and 15) the $PM_{2.5}$ objective was exceeded at every monitoring station in the LFV.

On August 17 with the onset of the afternoon sea-breeze, cleaner marine air displaced the smoke (Figure 66). However, the smoke returned the following afternoon and widespread smoke was again experienced throughout the region (Figure 66). Hope measured Metro Vancouver's highest 24-hour rolling average $PM_{2.5}$ concentration on record on August 19 with a concentration of 257 μg/m^3. As the smoke continued to persist, every monitoring station was in exceedance on August 20 and continued to be for five days straight. August 23 was perhaps the most severe day across the region when the 24-hour $PM_{2.5}$ average was greater than 100 μg/m^3 at all monitoring stations.

It was not until the morning of August 26 when the hourly $PM_{2.5}$ concentrations returned to below 25 μg/m^3. The 14-day advisory was lifted on August 27 making it the longest and most severe air quality advisory in Metro Vancouver history.

Smoke returned to the region in the afternoon of September 5 and a one-day advisory was issued on September 6 when several monitoring stations exceeded the 24-hour $PM_{2.5}$ objective. Satellite imagery showed the smoke likely originated from wildfires burning east of Manning Park.

In 2018, there were summer ozone exceedances on 12 days with more than half of the days thought to be influenced and enhanced by the presence of smoke. The enhancement of ozone due to wildfire smoke can result in exceedances of Metro Vancouver's ozone objectives in locations that do not typically experience exceedances such as the western portion of Metro Vancouver. A good example of a smoke influenced day in 2018 occurred on August 21 when smoke was prevalent throughout the region. On this day the 1-hour and 8-hour ozone objectives were exceeded throughout the region including the following western stations: Burnaby-Kensington Park, Richmond-South, and North Vancouver-Mahon Park.

Exceedances in the western portion of Metro Vancouver (i.e., North Vancouver) are not common and it is thought that ozone was enhanced on August 21 due to wildfire smoke that was prevalent throughout the region.

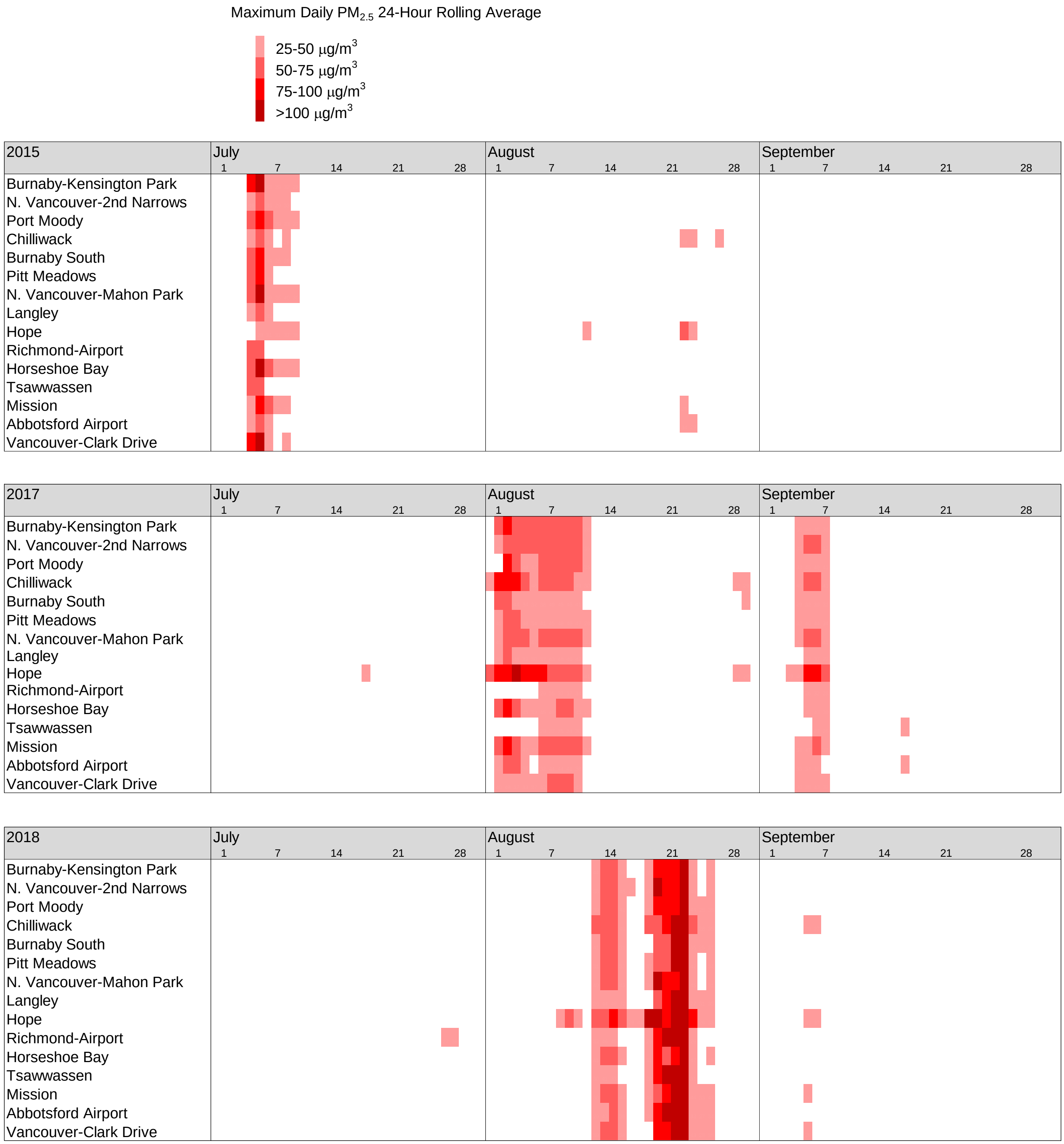


Figure 63: Comparison of exceedances days on three wildfire influenced years: 2015, 2017, and 2018.

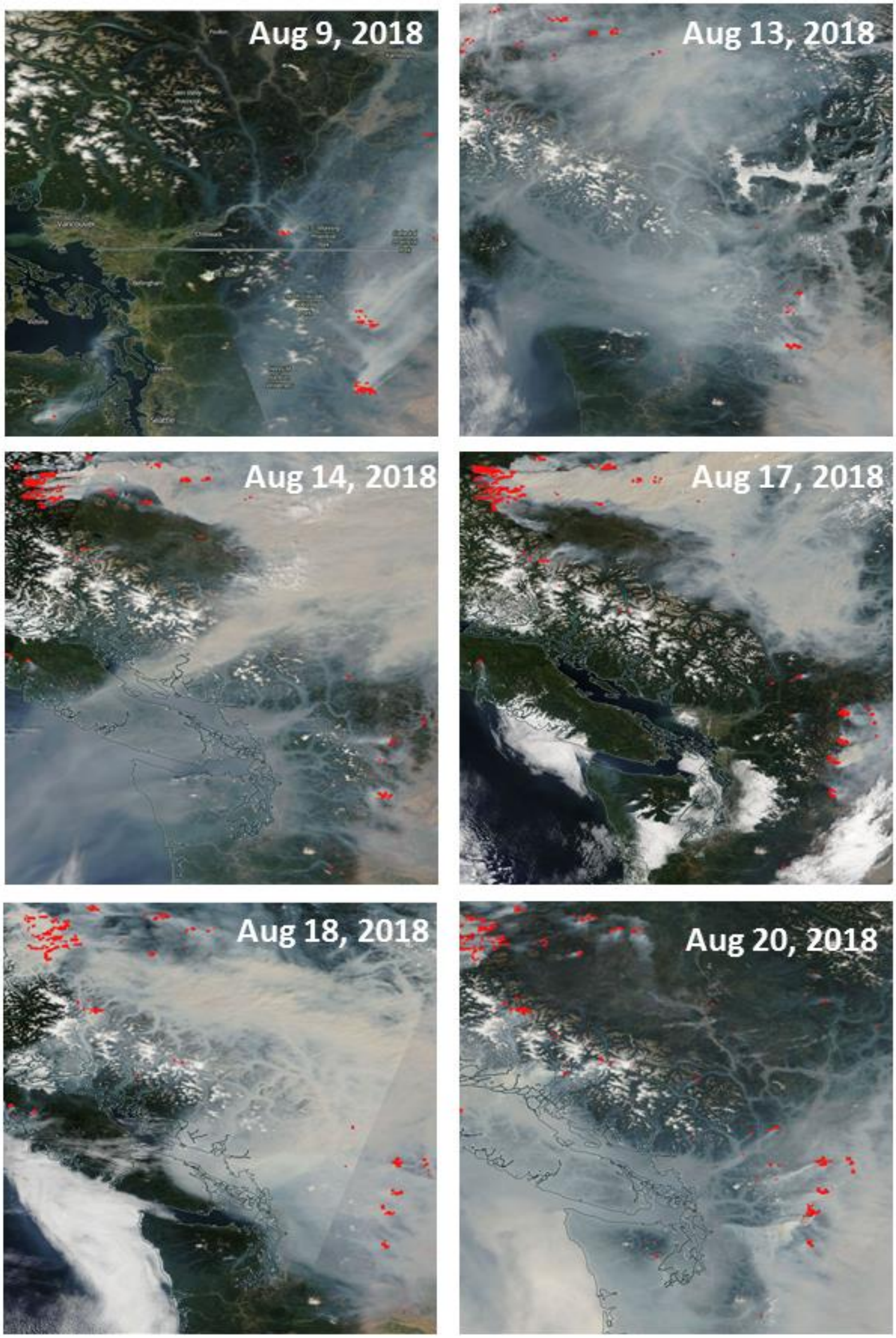


Figure 64: Satellite imagery taken from NASA Worldview during days impacted by wildfire smoke in 2018.

Climate Change

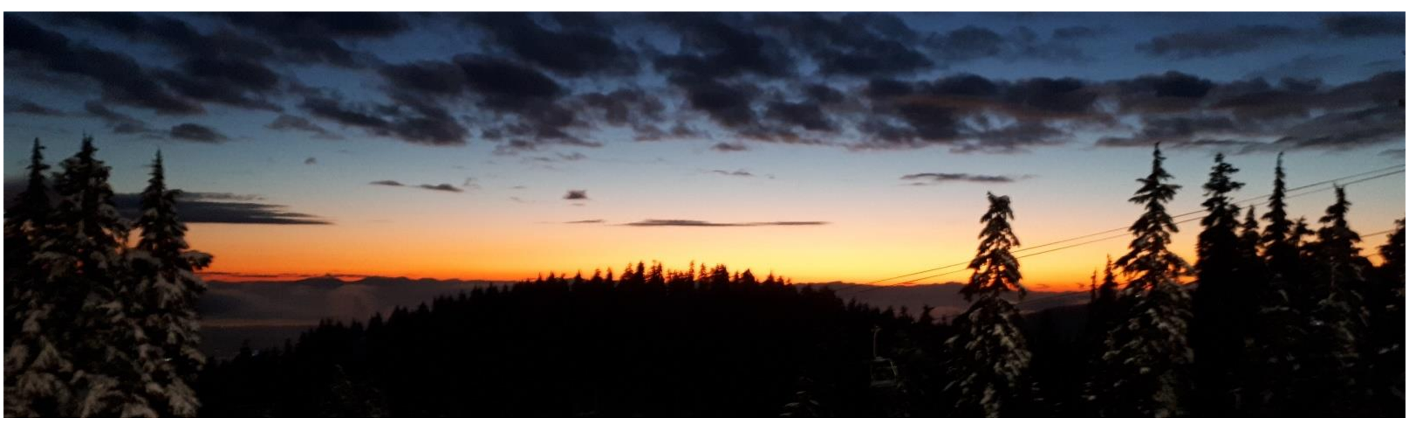
Climate projections indicate the region will experience hotter, drier summers and wetter, warmer winters. A warming climate is likely to increase frequency and duration of wildfires and associated smoke impacts, while also increasing in-region ground level O_3 formation through the intensity and duration of summer heatwaves.

A study focused on the extreme 2017 wildfire season in British Columbia, found that human-induced climate change contributed greatly to the extreme warm temperatures, high wildfire risk, and large burned areas (Kirchmeier-Young, Gillett, Zwiers, Cannon, & Anslow, 2019[2]). The authors concluded that as the climate continues to warm, it can be expected that extreme wildfire seasons like 2017 in BC will become more likely in the future.

Public awareness of air quality and health has also grown with the recent summer wildfire smoke impacts. The public has inquired about air quality, health effects, and steps that can be taken to reduce their own health risk during these events. Since late 2017, Metro Vancouver has been working with local health authorities, BC Centre for Disease Control, Health Canada, the BC MOECSS, the FVRD and experts from outside BC to develop communication materials for residents on wildfire smoke health impacts and interventions for reducing these impacts.

Metro Vancouver is also looking at further developing collaborations, such as working with member jurisdictions on provision of air quality shelters, to ensure that people will be better protected from the health impacts of wildfire smoke going forward.

Metro Vancouver's updated air quality management plan, now referred to as the Clean Air Plan, considers the increasing impacts of wildfire activity when developing strategies and actions to reduce health risk for Metro Vancouver residents. In parallel, Metro Vancouver's series of Climate 2050 Roadmaps identifies actions that will help the region adapt to climate-related impacts on regional air quality. For example, a warming climate is likely to increase frequency and duration of wildfires and associated smoke impacts, while also increasing in-region ground-level ozone formation through the intensity and duration of summer heatwaves.



[2] Kirchmeier-Young, M. C., Gillett, N. P., Zwiers, F. W., Cannon, A. J., & Anslow, F. S. (2019). Attribution of the Influence of Human-Induced Climate Change on an Extreme Fire Season. *Earth's Future, 7*(1), 2-10. doi:10.1029/2018EF001050

Appendix A – 2018 Non-Continuous Pollutant Measurements

This appendix summarizes non-continuous pollutant measurements collected from air quality stations in the Lower Fraser Valley (LFV) Air Quality Monitoring Network in 2018 and describes related monitoring activities and programs conducted during the year.

Air Quality Measurements

The LFV Air Quality Monitoring Network primarily employs continuous monitors which provide data in real-time every minute of the day. The network also contains specialized air quality monitors that sample the air on a non-continuous basis. Non-continuous 24-hour (daily) samples are collected on filters and/or in canisters every sixth or twelfth day depending on the site.

Non-continuous samples of volatile organic compounds (VOC) and particulate are collected throughout the LFV. VOC refers to a group of organic chemicals. A large number of chemicals are included in this group but each individual chemical is generally present at relatively low concentrations compared to other common air contaminants. These data can then be used to help determine the emission sources contributing to the contaminants in the air.

Non-continuous samples are collected in accordance with the National Air Pollution Surveillance (NAPS) program. After collection, samples are transported to and analyzed in a federal laboratory in Ottawa to determine pollutant concentrations. Obtaining results of non-continuous sampling from the federal laboratory may introduce a time lag compared to continuous monitoring, and thus this report has been produced as an appendix.

Particulate Sampling

Non-continuous 24-hour (daily) fine particulate ($PM_{2.5}$) and inhalable particulate (PM_{10}) samples are collected at monitoring stations in the LFV. A detailed analysis is conducted for four of these stations (Port Moody, Burnaby South, Abbotsford Airport and Vancouver-Clark Drive) which includes some trace metals, sulfate, nitrate, ions, and elements.

Using specialized instrumentation that is able to provide 'speciation' of particulate matter, detailed information about individual chemical constituents and composition of fine particulate is obtained from three stations (Burnaby South, Abbotsford Airport, Vancouver-Clark Drive). Various compounds that form $PM_{2.5}$ are identified, including additional trace metals such as iron, vanadium, and lead and other additional elements, as well as ammonia, elemental and organic carbon, volatile nitrate and acidic precursors.

Volatile Organic Compounds (VOC)

While there are many thousands of organic compounds in the atmosphere that meet the definition of a VOC, the NAPS measurement program focuses on VOC that are important precursors in ozone formation and/or are known to have toxic effects. In order to report and track the most important VOC in relation to these two main focus areas, a number of priority VOC, as defined below, have been selected and reported in this appendix.

VOC species have a range of photochemical reactivity, and thus potential to lead to ozone formation. In the report *Metro Vancouver VOC Policy Options Review* (2015), a ranking of VOC is presented based on work by Environment and Climate Change Canada that classified the reactivity of the VOC species and their relative abundance in the LFV. The top ranked VOC for ozone formation in LFV were ethylene, 1-butene/isobutene, isoprene, 2-methyl-2-butene, and m- and p-xylene.

Toxic VOC have been identified as a concern from a human health perspective due to known acute or chronic health effects. The *Toxic Air Pollutants Risk Assessment* (2015) for the LFV commissioned by Metro Vancouver identified high priority toxic VOC in the LFV based on cancer and/or non-cancer health risks associated with measured 2010 VOC levels. The study identified high priority VOC based on estimated health risks: formaldehyde, benzene, acrolein, acetaldehyde and 1,3-butadiene.

Acrolein was reported in previous years, however the NAPS program no longer includes acrolein, which they have indicated is due to inadequacies found in the sampling method. The NAPS program will determine validity of historical measurements and if measurements of acrolein will be provided in future years.

Non-Continuous $PM_{2.5}$ and PM_{10} Sampling

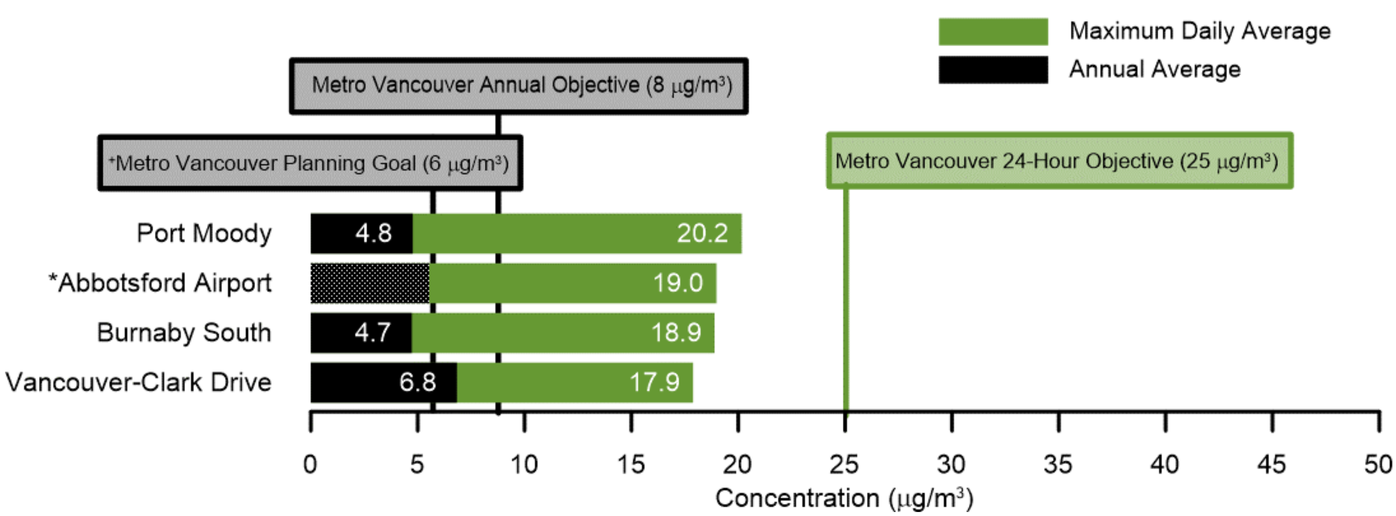
Non-continuous 24-hour (daily) $PM_{2.5}$ samples are collected on filters every sixth day in accordance with the NAPS program schedule. After sample collection, the filters are weighed in the laboratory to determine $PM_{2.5}$ concentrations.

Figure A1 presents maximum daily and average $PM_{2.5}$ values from the non-continuous monitors that operated in 2018. Data provided by non-continuous samplers remained below Metro Vancouver's 24-hour $PM_{2.5}$ objective while measurements collected by the continuous monitors exceeded the objective. An unprecedented twenty-two-day air quality advisory was issued due to smoke that blanketed the region transported from wildfires burning outside our region. Non-continuous measurements were considerably lower than the continuous record mainly due to the sampling schedule (i.e., non-continuous sampling is midnight to midnight every one in six days and while the continuous monitor measures every hour of every day). Continuous measurements are provided in Section D. Stations were below the Metro Vancouver annual objective of 8 $\mu g/m^3$.

Using specialized particulate matter speciation instrumentation, detailed information about the chemical composition of $PM_{2.5}$ is obtained from three stations in the network (Burnaby South, Abbotsford Airport, Vancouver-Clark Drive) as a result of analysis carried out by the federal NAPS program. From the 24-hour samples collected at these three sites, the various compounds that collectively contribute to overall $PM_{2.5}$ are identified in a federal laboratory. A detailed laboratory analysis by NAPS is also carried out on the filter samples collected in Port Moody. These detailed data are not shown in this report.

Non-continuous sampling provides the longest record of $PM_{2.5}$ measurements in the LFV. Figure A2 shows $PM_{2.5}$ measurements made in Port Moody over the last two decades. The short-term peak concentrations reflect the highest levels that occur, represented by the 99^{th} percentile of the 24-hour average for each year.

Historically, the average long-term trend shows a slight decline in concentrations while peak trends show considerable variability. The differences in peak trends from year to year are likely driven by meteorological variability and wildfire activities. Most evident in the long-term peak trend is that in both 2015 and 2017 historically high concentrations were measured, a result of the unprecedented wildfire smoke that inundated the region.



⁺ Metro Vancouver's Planning Goal of 6 $\mu g/m^3$ is a longer term aspirational target to support continuous improvement.
**Data completeness criteria was not met at this station.*

Figure A1: Non-continuous particulate ($PM_{2.5}$) monitoring, 2018.

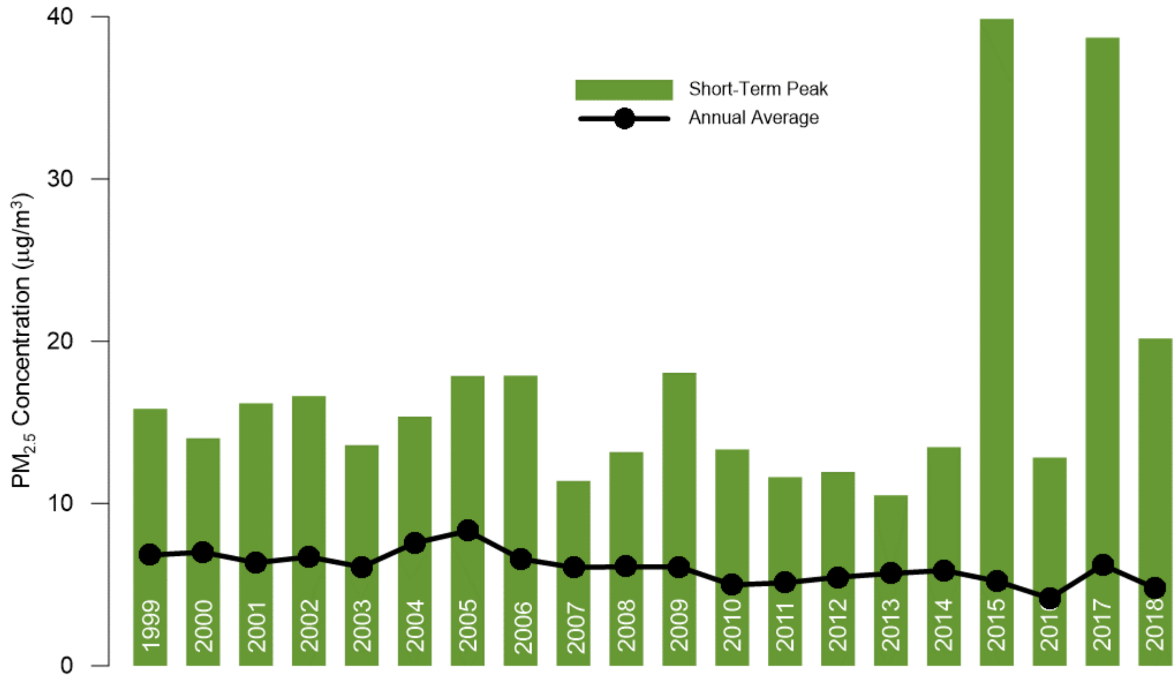
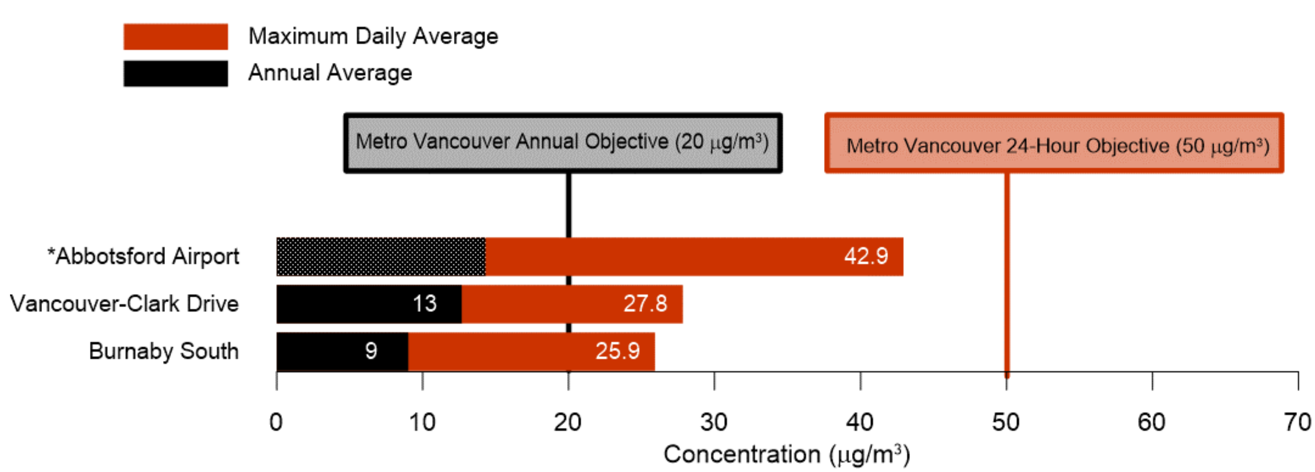


Figure A2: Fine particulate ($PM_{2.5}$) trends at Port Moody, 1999 to 2018.

Non-continuous 24-hour (daily) PM coarse fraction (PM_{10} - $PM_{2.5}$) samples are collected on filters every sixth day in accordance with the NAPS program schedule. After collection, samples are weighed in a laboratory to determine the PM coarse fraction concentrations during the sampling period. PM_{10} is the sum of $PM_{2.5}$ and the PM coarse fraction.

Figure A3 presents maximum daily average and annual average PM_{10} values from the non-continuous monitors that operated in 2018. Values calculated by the non-continuous monitors did not exceed Metro Vancouver's PM_{10} objectives. However, the maximum 24-hour rolling averages measured by the continuous monitors exceeded the objective at all monitoring stations as described in Section D. The timing of the non-continuous sampling schedule resulted in the avoidance of the maximum peaks measured by the continuous monitors.



**Data completeness criteria was not met at this station.*

Figure A3: Non-continuous inhalable particulate (PM_{10}) sampling, 2018.

Volatile Organic Compounds (VOC)

Volatile organic compounds are organic compounds containing one or more carbon atoms that have high vapour pressures and therefore evaporate readily to the atmosphere. In 2018, VOC samples were collected at eight sites in the LFV. In cooperation with the federal NAPS program, canister sampling of VOC has been conducted in the LFV since 1988. Canisters sent to the federal laboratory are analyzed for up to 175 species of VOC.

For analytical purposes, VOC can be considered either nonpolar (i.e., hydrocarbons and halogenated hydrocarbons) or polar (i.e., compounds containing oxygen, nitrogen, sulphur, etc.). Nonpolar VOC can be characterized by sampling with evacuated metal canisters and well-established analytical methods. In contrast, polar VOC require specialized sampling and analytical methods to measure trace levels because of their chemical reactivity, affinity for metal and solubility in water. Because of this, polar VOC were only measured at two locations (Port Moody and Abbotsford-Airport) in 2018.

Characteristics

VOC refers to a class of organic chemicals that can vaporize into the atmosphere at normal ambient temperatures and pressures. This group comprises many chemicals but individual compounds are generally present at low concentrations in air compared to other common air contaminants.

Locally, VOC can be found in urban smog and are precursors to the formation of other contaminants present in smog such as ozone and fine particulates. Some VOC (*e.g.* carbon tetrachloride) can contribute to depletion of the stratospheric ozone layer and may contribute to climate change. Other VOC (*e.g.* benzene) can pose a human health risk.

Under the Canadian Environmental Protection Act some VOC are included in the Toxic Substances List.

Emissions of some VOC are managed under permits and industry-specific regulations within Metro Vancouver.

Sources

VOC can originate from direct emissions, volatilization (*i.e.* changing into the gas phase) of substances in the liquid or solid phase, and formation from precursor pollutants via chemical reactions in the atmosphere. Sources of VOC in Metro Vancouver include, but are not limited to, emissions from the combustion of fossil fuels, evaporation from industrial and residential solvents and paints, vegetation, agricultural activities, petroleum refineries, fuel-refilling facilities, the burning of wood and other vegetative materials, and large industrial facilities.

Monitoring Results

Figure A4 shows the maximum daily total VOC and average total VOC from each VOC monitoring station in 2018. The data indicates that the highest average total VOC levels were measured at stations close to specific industrial sources near Burrard Inlet along with the near-road monitoring station at Vancouver-Clark Drive. The highest daily total VOC concentration was observed at Burnaby-North on June 13, 2018.

Figure A5 provides data from 1999 to 2018 from sampling undertaken at the Port Moody station as an example of the long-term trends in total VOC concentrations. Both annual average and short-term peak (95^{th} percentile) VOC concentrations have decreased since the 2000s. However, there as been a slight upward trend in average VOC concentrations since 2012.

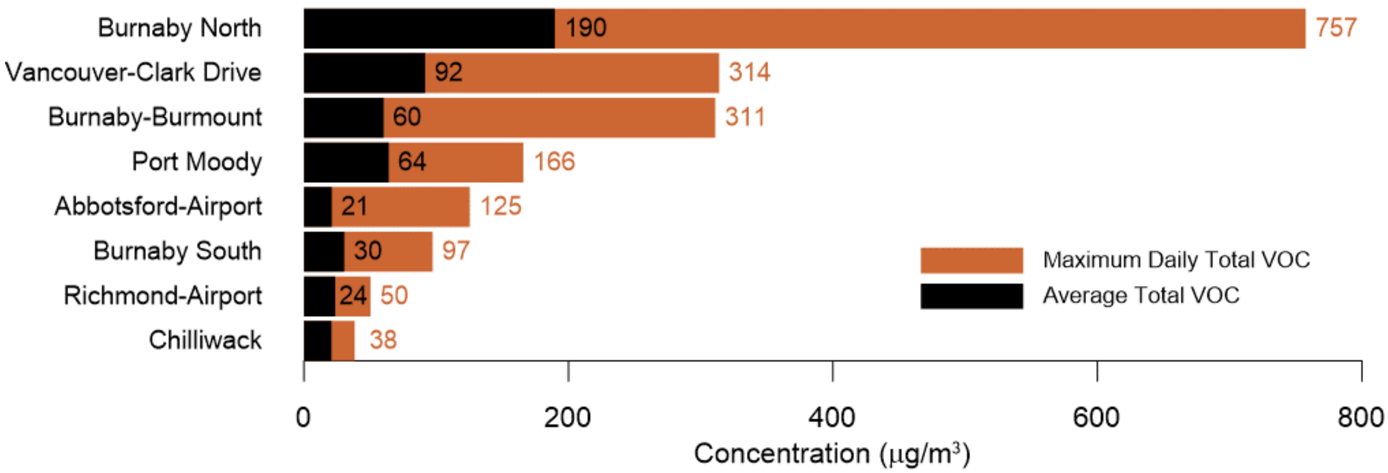


Figure A4: Total VOC monitoring, 2018.

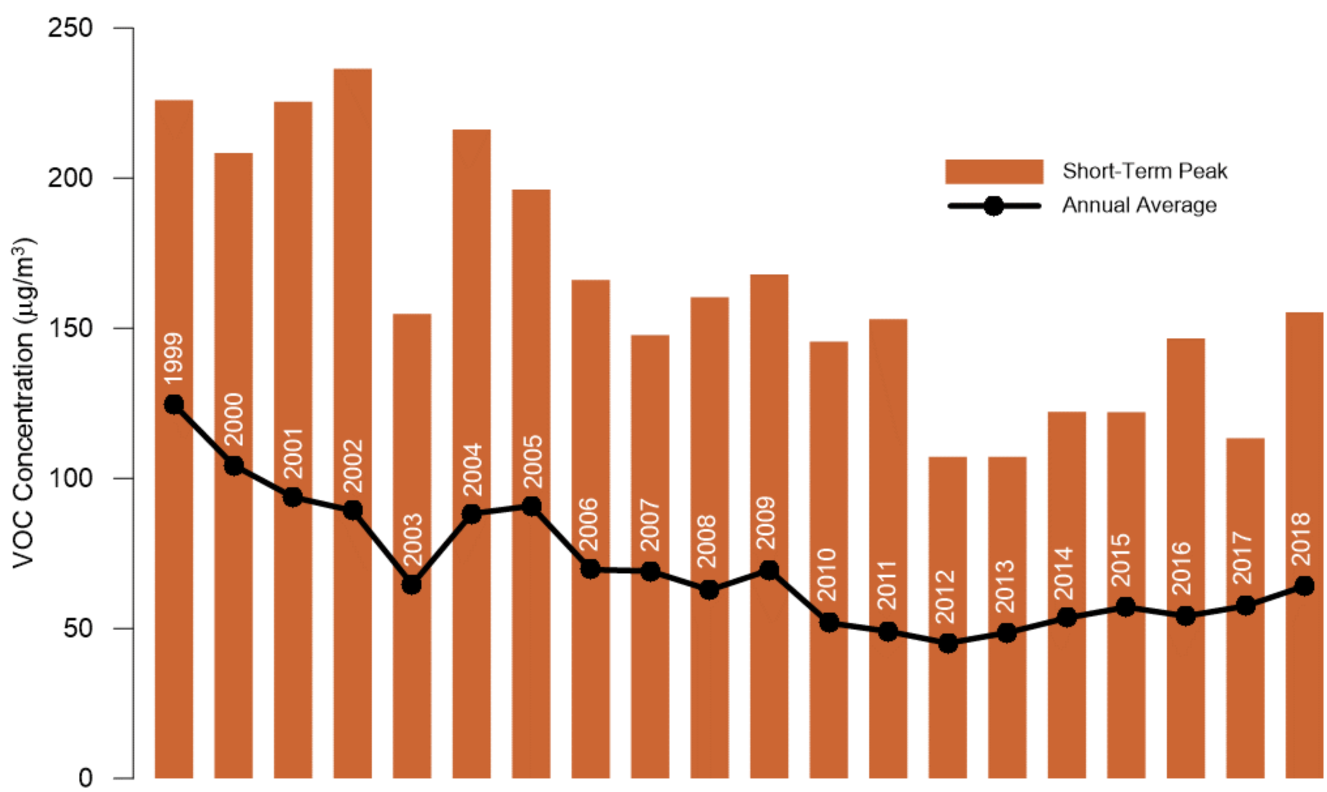


Figure A5: Total VOC trends at Port Moody, 1999 to 2018.

Ethylene

Characteristics

Ethylene has been prioritized for monitoring in the region because of its ozone producing potential. Ethylene, also known as ethene, has the chemical formula C_2H_4. It is a colorless gas with a sweet odour and taste. Ethylene is degraded in the atmosphere by reactions with hydroxyl radicals, ozone and nitrate radicals and is the number one ranked VOC in the LFV for its ozone producing potential.

Sources

Ethylene occurs naturally and is also manufactured for a number of uses. Ethylene is a natural product emitted by fruits, flowers, leaves, roots, and tubers. Ethylene is also emitted from the burning of vegetation, agricultural wastes, and refuse, and from the incomplete combustion of fossil fuels. Globally, biomass burning to clear land for agriculture or other uses is the largest source of anthropogenic ethylene emissions, followed by combustion of fossil fuels, which is estimated to be the largest anthropogenic ethylene emissions source in the LFV. Cigarette smoke contains ethylene, and it is also used as a chemical intermediate and precursor in industrial organic synthesis, in the welding and cutting of metals, as a plant growth regulator, and as a refrigerant.

Monitoring Results

Figure A6 illustrates the results of ethylene monitoring in 2018. Figure A6 displays the maximum daily concentration as well as the annual average for each ethylene monitoring location. The highest average and peak concentrations occurred at Vancouver-Clark Drive.

Ethylene is the number one ranked VOC for its ozone producing potential in the LFV. Concentrations have steadily declined over the last two decades.

Figures A7 and A8 illustrate the long-term average and peak ethylene trends in the LFV, respectively. Average levels have continually decreased at all sites in the last 20 years. Peak levels decreased considerably in the late 1990s and early 2000s at most sites but over the last five years peak concentrations have remained relatively constant. Vancouver-Clark Drive is not included in the long-term trends since the station has only recently been established.

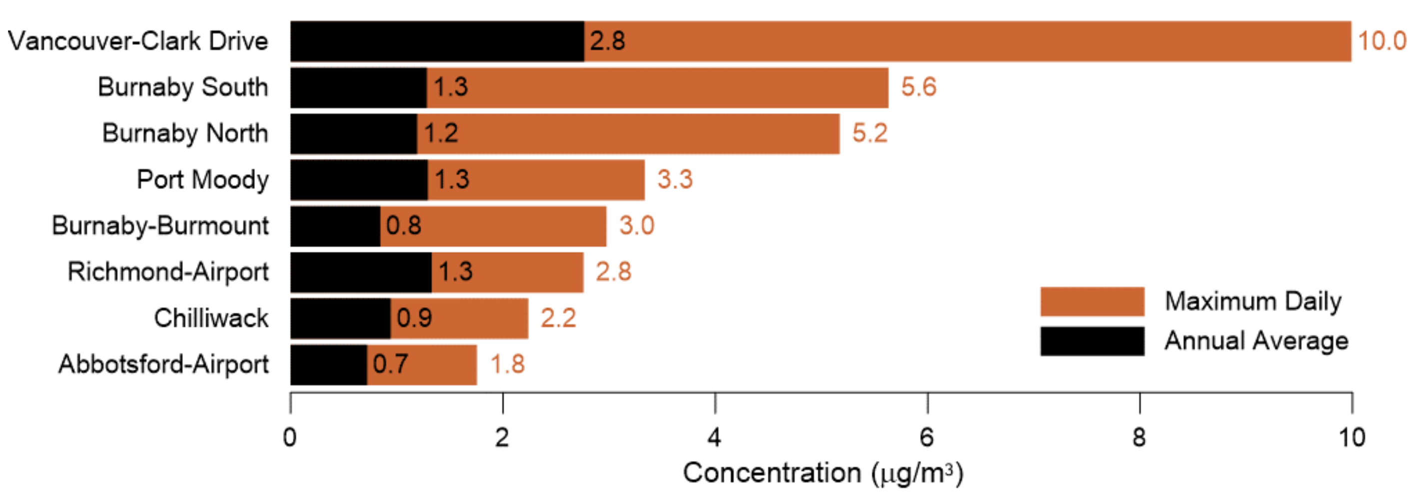


Figure A6: Ethylene monitoring, 2018.

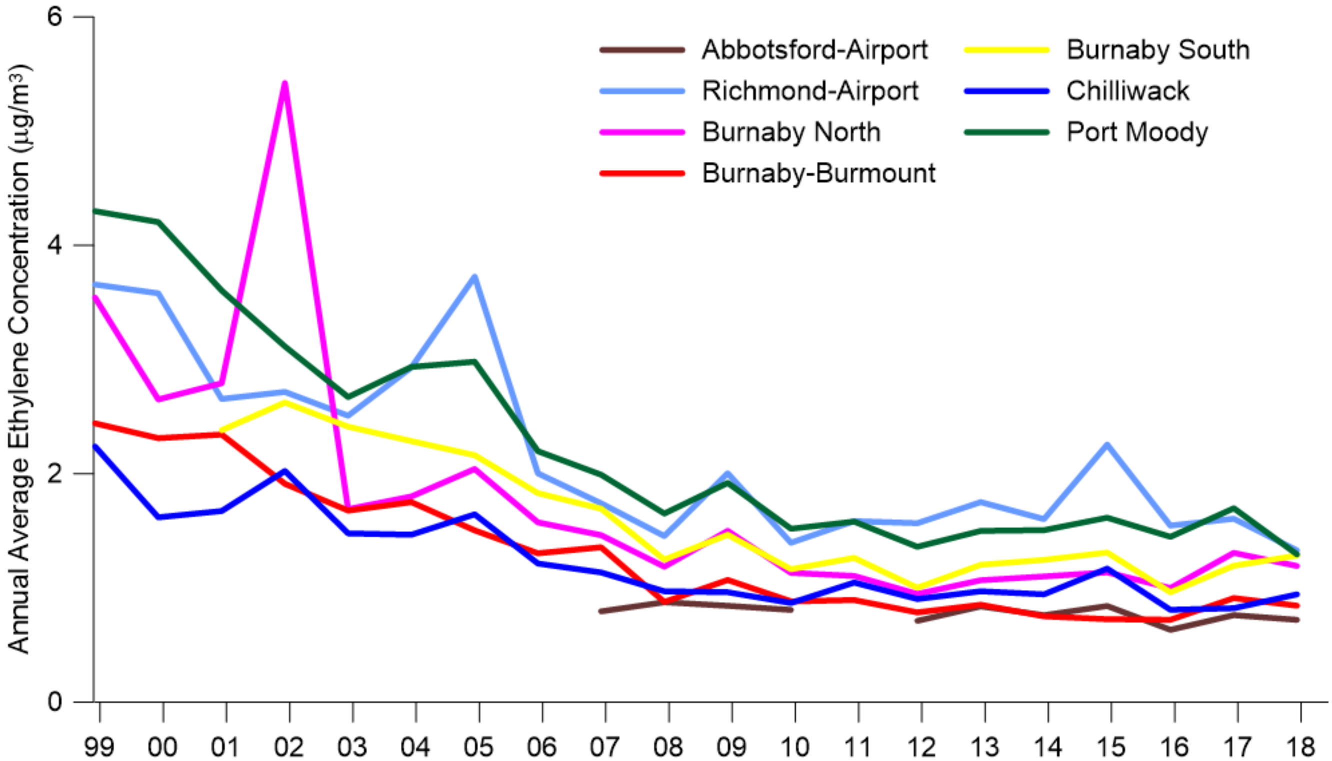


Figure A7: Annual ethylene trend, 1999 to 2018.

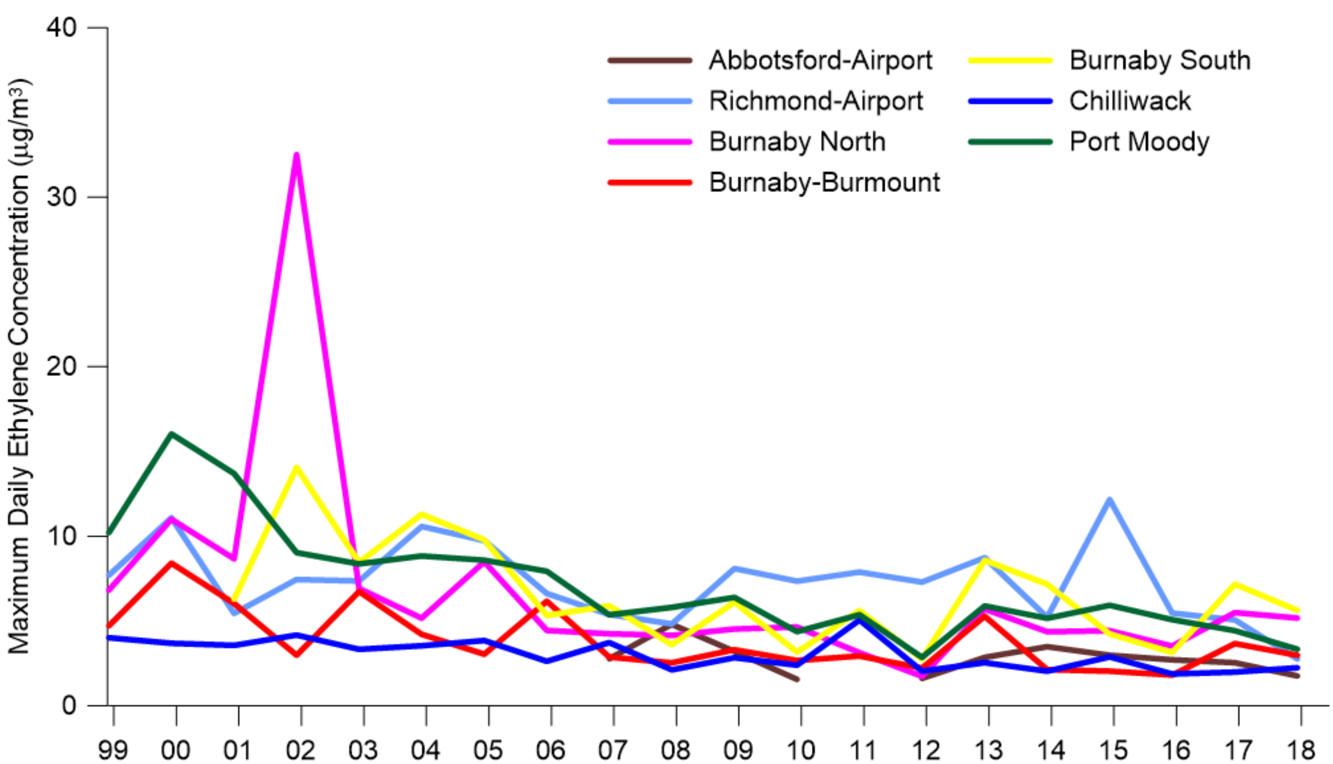


Figure A8: Short-term peak ethylene trend, 1999 to 2018.

1-Butene/isobutene

Characteristics

1-Butene/isobutene are isomers of butene with the chemical formula C_4H_8. Monitoring has been prioritized from an ozone production perspective as the second highest ranked VOC for ozone producing potential in the LFV. They are colourless gases with a slightly aromatic odour.

Sources

1-Butene/isobutene are emitted by both natural and anthropogenic sources. They are present in crude oil as minor constituents, and used by industry and consumers as components of adhesives and sealants, fuels and fuel additives, intermediates, and plasticizers. They may be released into the environment by petroleum refineries, through the burning of waste plastics, as a volatile emission from gasoline and from the burning of wood. 1-Butene/isobutene have been widely detected in the exhaust gas of vehicles using gasoline and diesel and from jet engines. They are also naturally occurring plant emissions from mixed deciduous forests, and have also been found in the volatile organic fraction emitted during the heating of soybean, rapeseed, peanut, and Canola oils. In the LFV, the primary sources of 1-butene/isobutene are gasoline solvent evaporation, chemical manufacturing, and refinery tank farm fugitive emissions.

Monitoring Results

Figure A9 illustrates the results of 1-butene/isobutene monitoring in 2018. Figure A9 displays the maximum daily concentration as well as the annual average for each 1-butene/isobutene monitoring location. The highest concentrations occurred at the Burnaby North station that is adjacent to the refinery tank farm where petroleum products are stored.

1-Butene/isobutene are emitted both by natural and anthropogenic sources and are the second most important VOC in terms of its ozone producing potential in the LFV.

Figures A10 and A11 illustrate the long-term average and peak 1-butene/isobutene trends in the LFV, respectively. Average levels have decreased considerably since the late 1990s. Historically, Burnaby North has experienced the highest average and peak levels of 1-butene/isobutene. The variability of the maximum daily concentrations is likely a result of variability in emissions and meteorology. Vancouver-Clark Drive is not included in the long-term trends since the station has only recently been established.

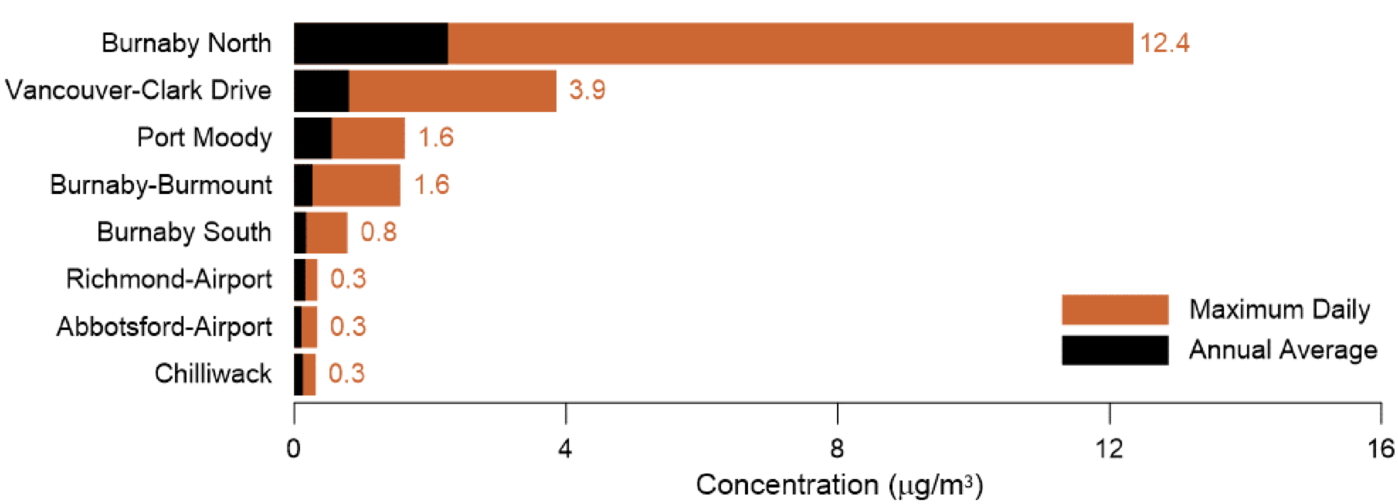


Figure A9: 1-Butene/isobutene monitoring, 2018.

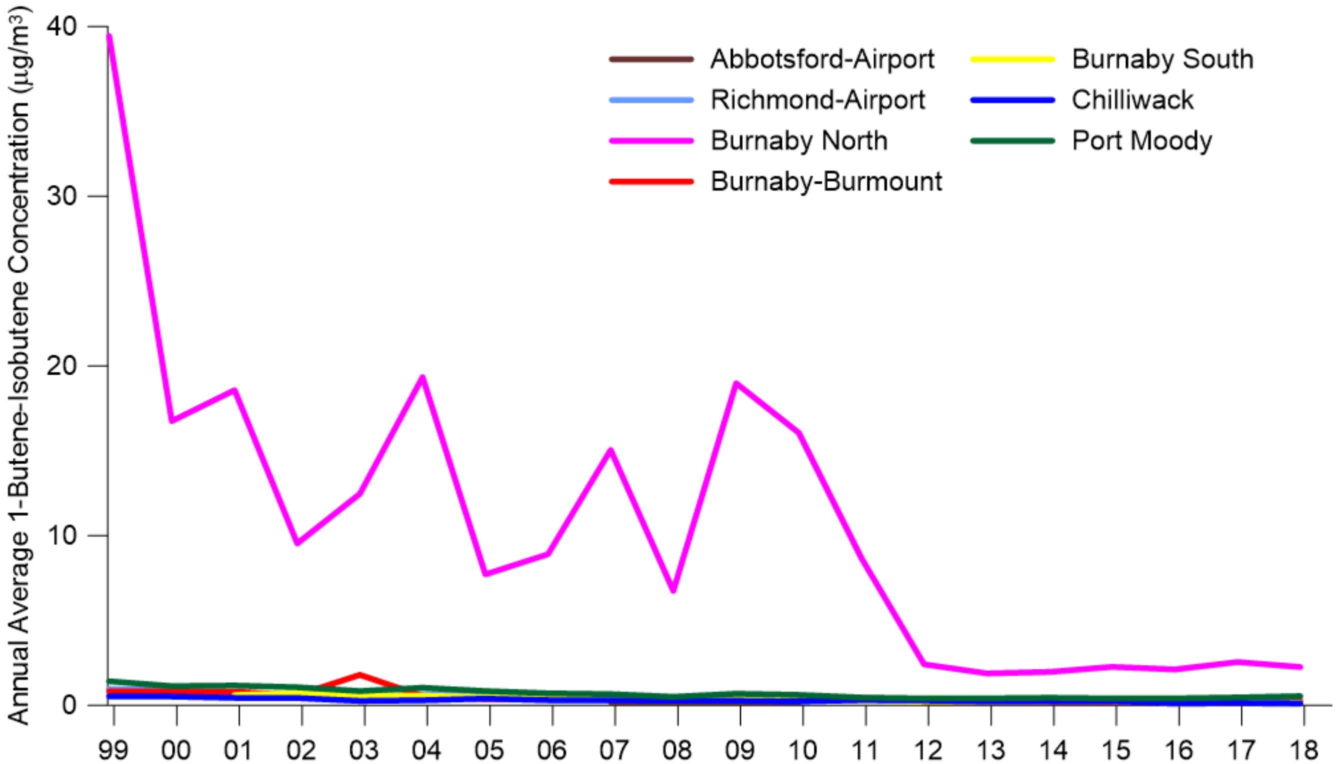


Figure A10: Annual 1-butene/isobutene trend, 1999 to 2018.

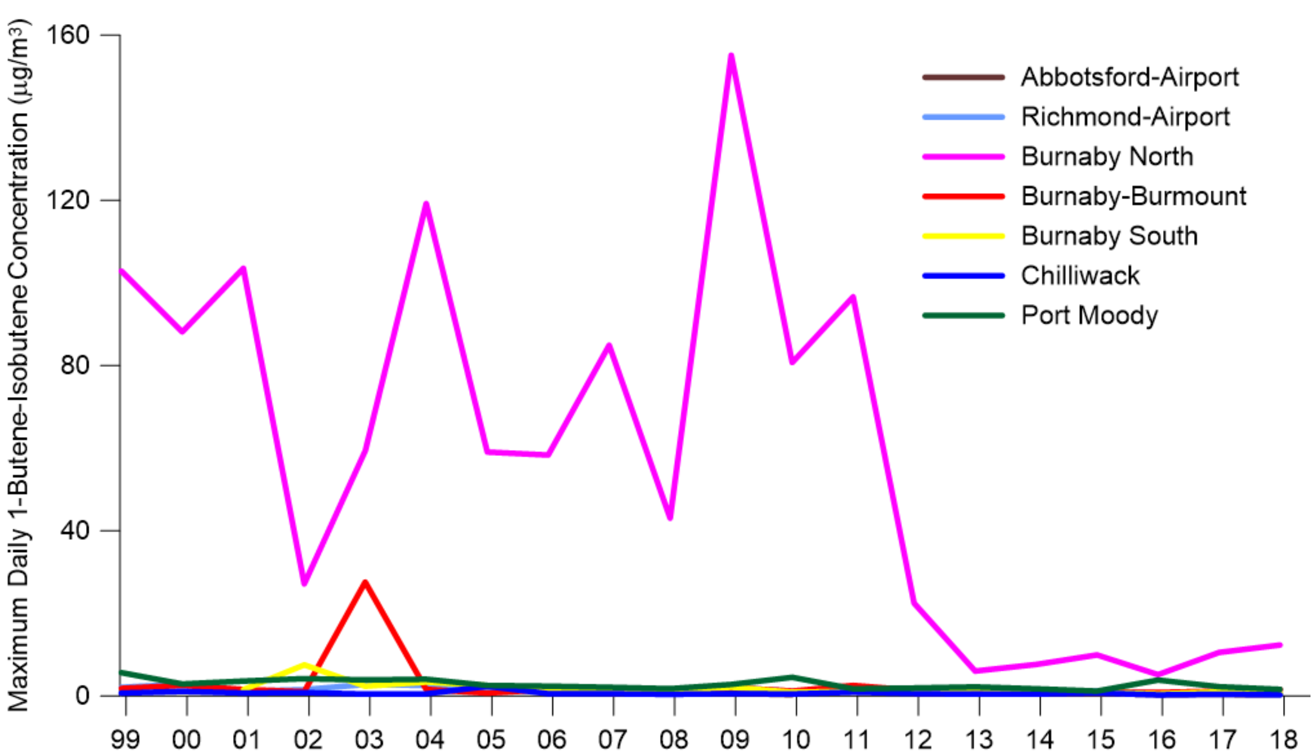


Figure A11: Short-term peak 1-butene/isobutene trend, 1999 to 2018.

Isoprene

Characteristics

Isoprene is the third highest ranked VOC for its ozone producing potential in the LFV. Isoprene is a colourless, volatile liquid hydrocarbon with the chemical formula C_5H_8 and has a mild aromatic petroleum-like odour. Vapor-phase isoprene is degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals and thus is of interest due to its ozone producing potential.

Isoprene is a priority from an ozone production perspective and is released to the atmosphere by natural sources and during the production of heavy petroleum oils.

Sources

Isoprene is emitted by both natural and anthropogenic sources. Biogenic isoprene is emitted to the atmosphere by many tree and plant species. Isoprene can be emitted by petroleum refineries, the manufacture of vehicle tires and a wide variety of other products including medical equipment, toys, shoe soles, elastic films and threads for textiles and golf balls, adhesives, paints and coatings. In the LFV, biogenic emissions from plants, vehicle exhaust emissions, and refinery and tank farm fugitive emissions are the primary sources of isoprene.

Monitoring Results

Figure A12 illustrates the results of isoprene monitoring in 2018. Figure A12 displays the maximum daily concentration as well as the annual average for each isoprene monitoring location. The highest concentrations occurred at the Burnaby-Burmount station that is adjacent to the Burnaby Mountain tank farm where petroleum products are stored.

Figures A13 and A14 illustrate the long-term average and peak isoprene trends in the LFV, respectively. Historically, the North Burnaby station adjacent to the refinery tank farm measured the highest annual average isoprene levels, but over the past 10 years, the Burnaby-Burmount station adjacent to the Burnaby Mountain tank farm has recorded the highest average levels. Maximum daily values show little discernible trend from the mid-90's to present, but in recent years the maximum daily concentration has mostly been measured at the Burnaby-Burmount station. Vancouver-Clark Drive is not included in the long-term trends since the station has only recently been established.

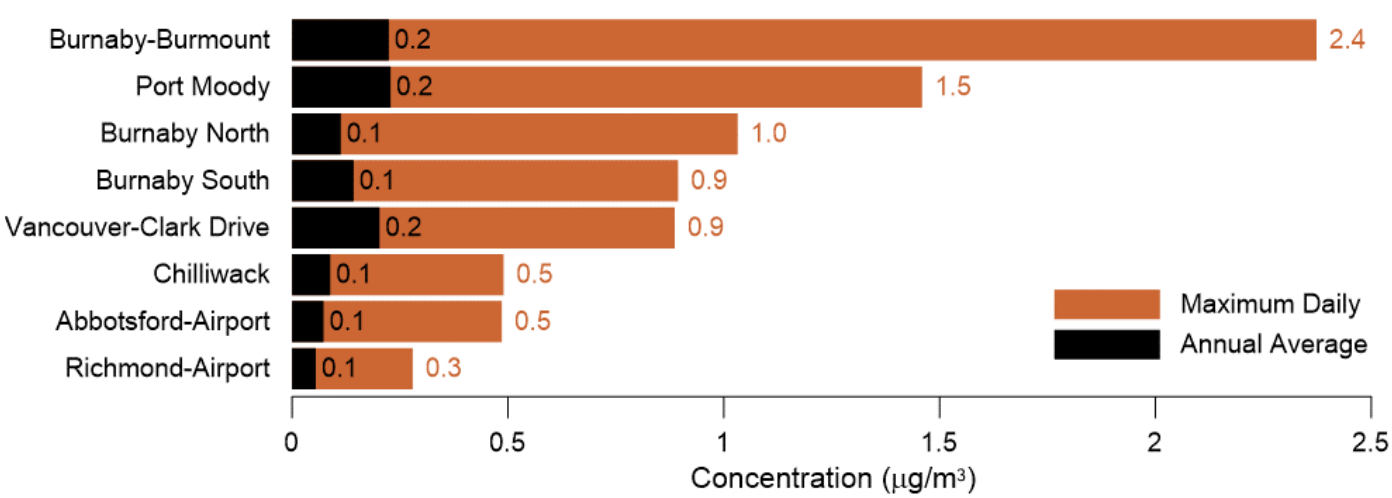


Figure A12: Isoprene monitoring, 2018.

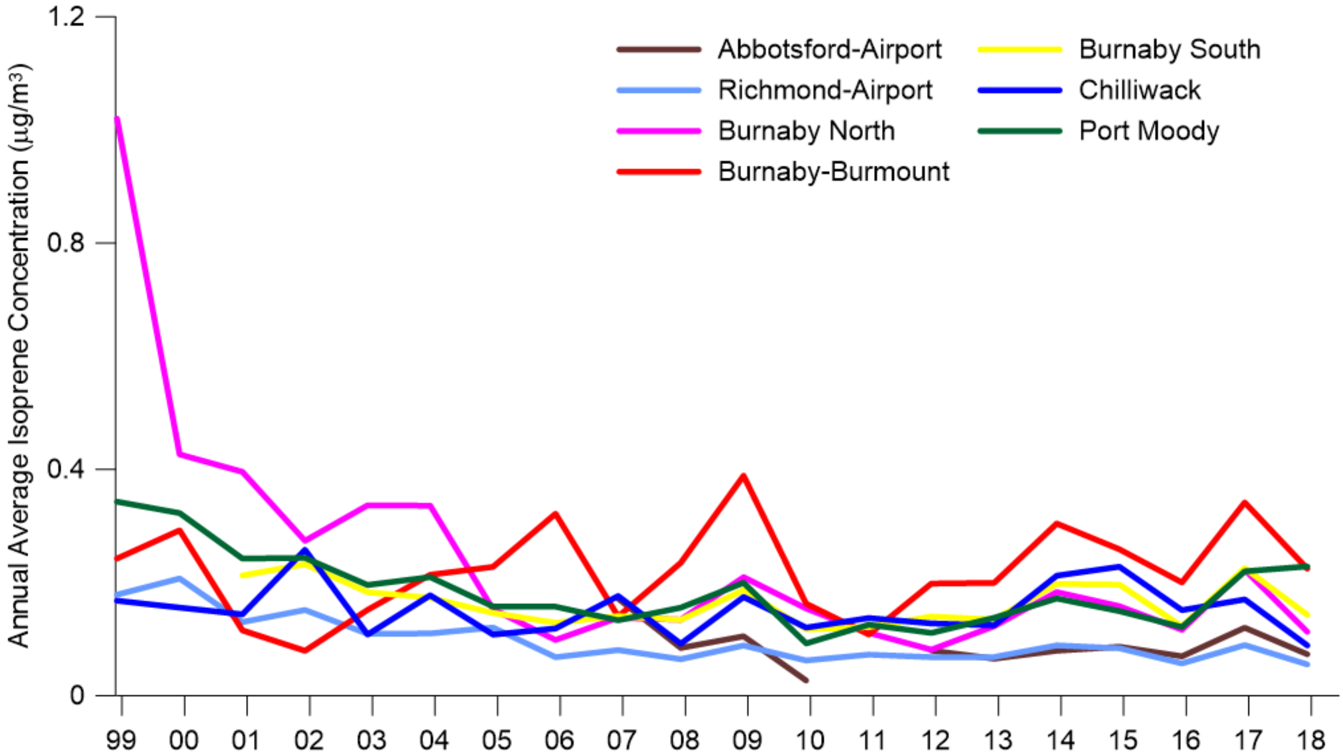


Figure A13: Annual isoprene trend, 1999 to 2018.

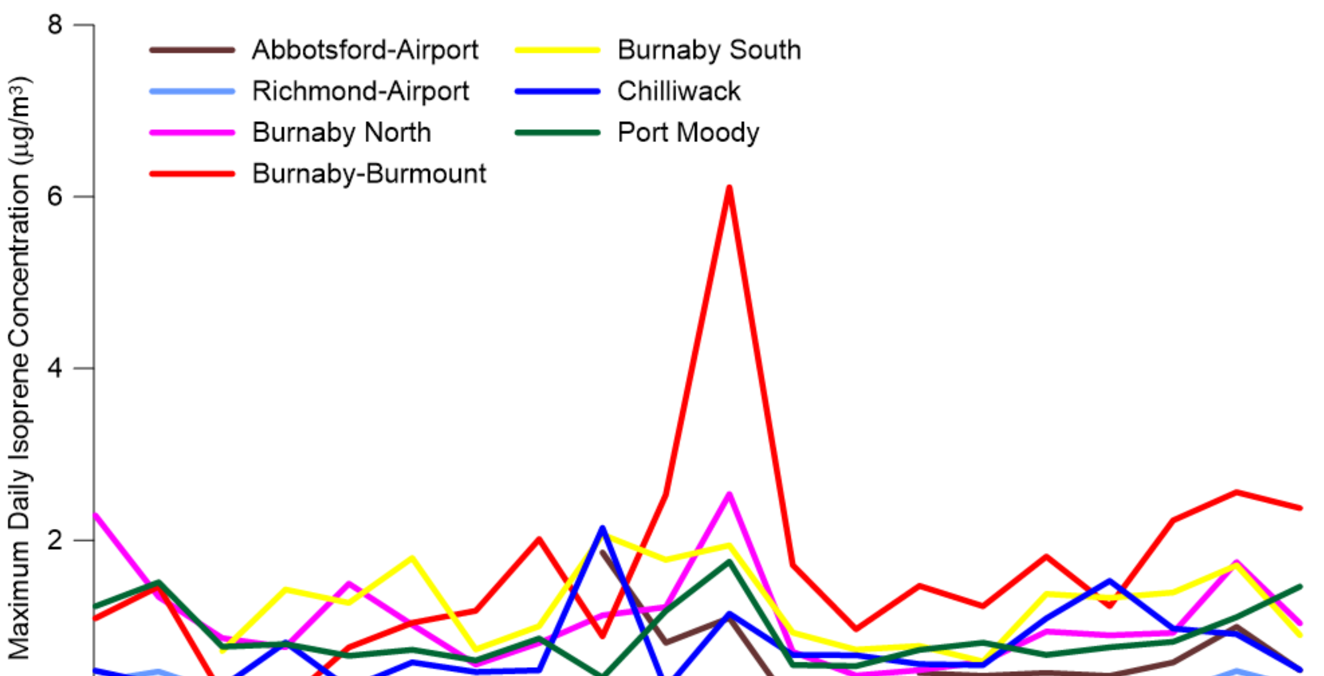


Figure A14: Short-term peak isoprene trend, 1999 to 2018.

2-Methyl-2-butene

Characteristics

2-Methyl-2-butene is a clear colourless liquid with the chemical formula C_5H_{10} and a petroleum-like odour. The compound is degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals, ozone, and nitrate radical. The compound is of interest because of its involvement in the reactions that form ozone and is the fourth highest ranked VOC for its ozone producing potential in the LFV.

2-Methyl-2-butene is a component of refinery gas and used as an agricultural chemical, fuel and fuel additives, and intermediate in chemical manufacturing. It reacts to form ground-level ozone.

Sources

2-Methyl-2-butene is used by industry and consumers as an agricultural chemical, fuel constituent and fuel additive, and intermediate in chemical manufacturing. It is also a component of gas emitted during petroleum refining. The primary sources of 2-methyl-2-butene in the LFV are refinery and tank farm fugitive emissions, and vehicle exhaust emissions.

Monitoring Results

Figure A15 illustrates the results of 2-methyl-2-butene monitoring in 2018. Figure A15 displays the maximum daily concentration as well as the annual average. The highest concentrations occurred at the Burnaby North station that is adjacent to the refinery tank farm. The second highest concentrations occurred at Vancouver-Clark Drive likely due to the proximity of the station to the adjacent gas station.

Figures A16 and A17 illustrate the long-term average and peak 2-methyl-2-butene trends in the LFV, respectively. The contaminant 2-methyl-2-butene follows a similar long-term trend as 1-butene/isobutene with average levels decreasing considerably since the late 1990s. Historically Burnaby North has experienced the highest average and peak levels of 2-methyl-2-butene. The variability of the peak levels is likely due to meteorological and emissions variability. Vancouver-Clark Drive is not included in the long-term trends since the station has only recently been established.

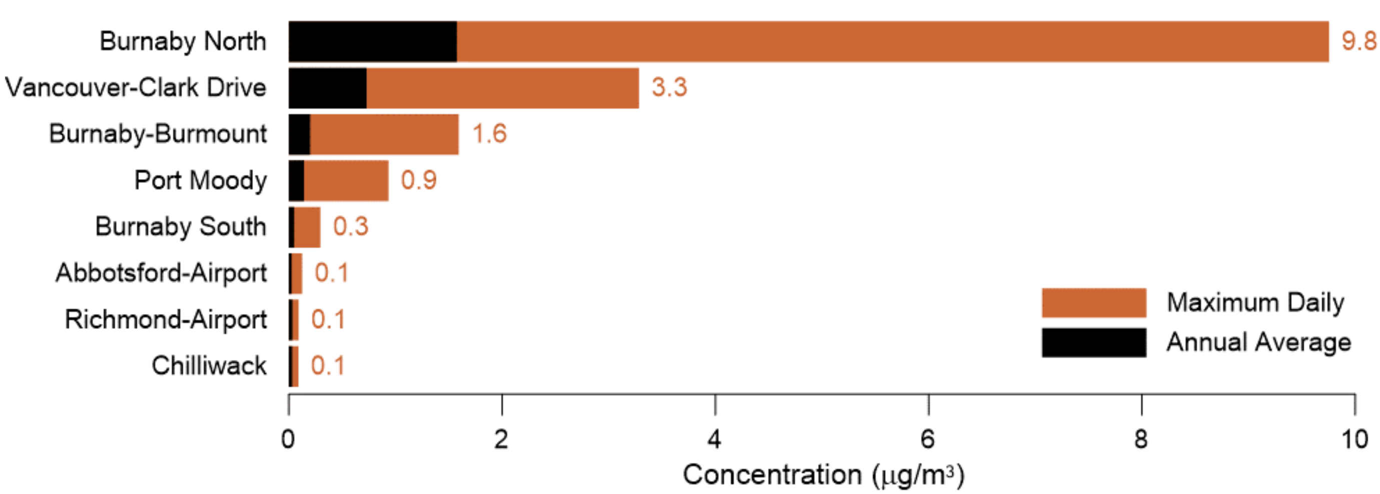


Figure A15: 2-Methyl-2-butene monitoring, 2018.

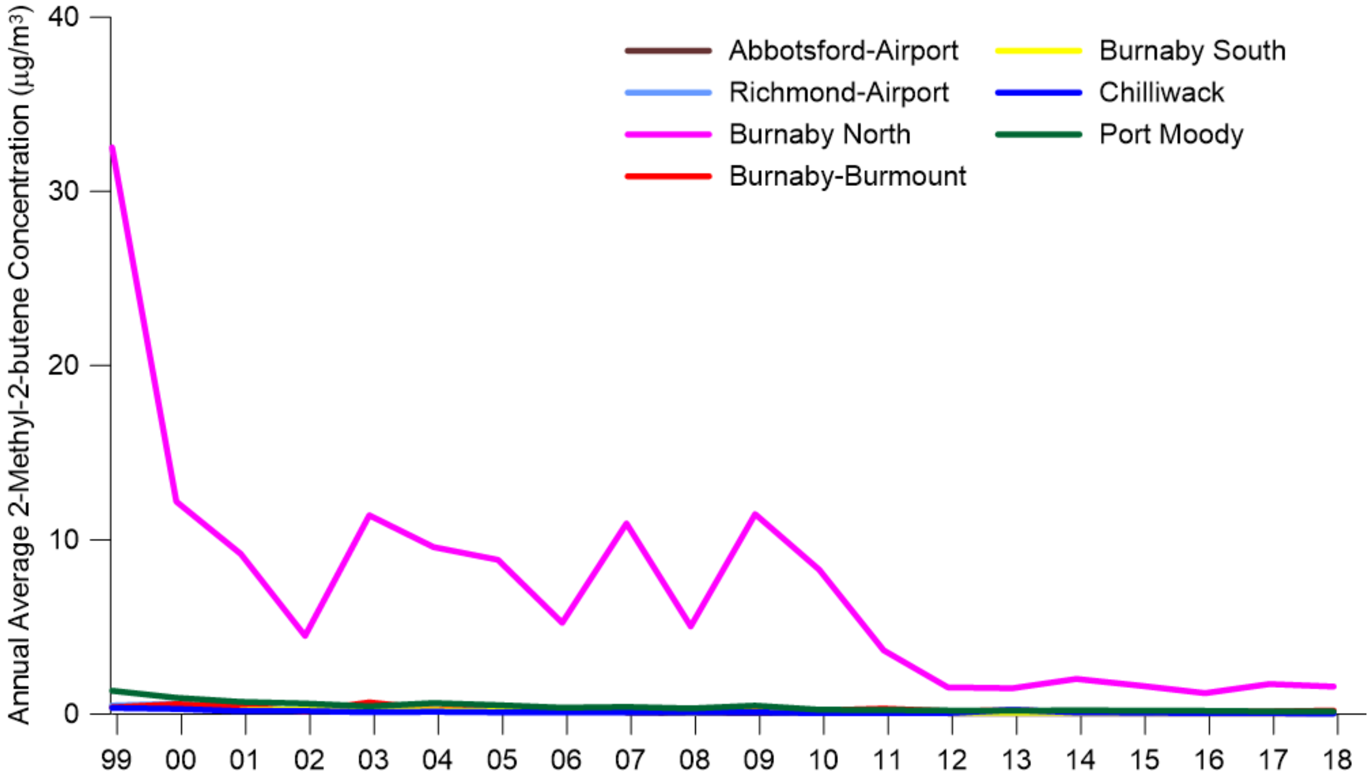


Figure A16: Annual 2-methyl-2-butene trend, 1999 to 2018.

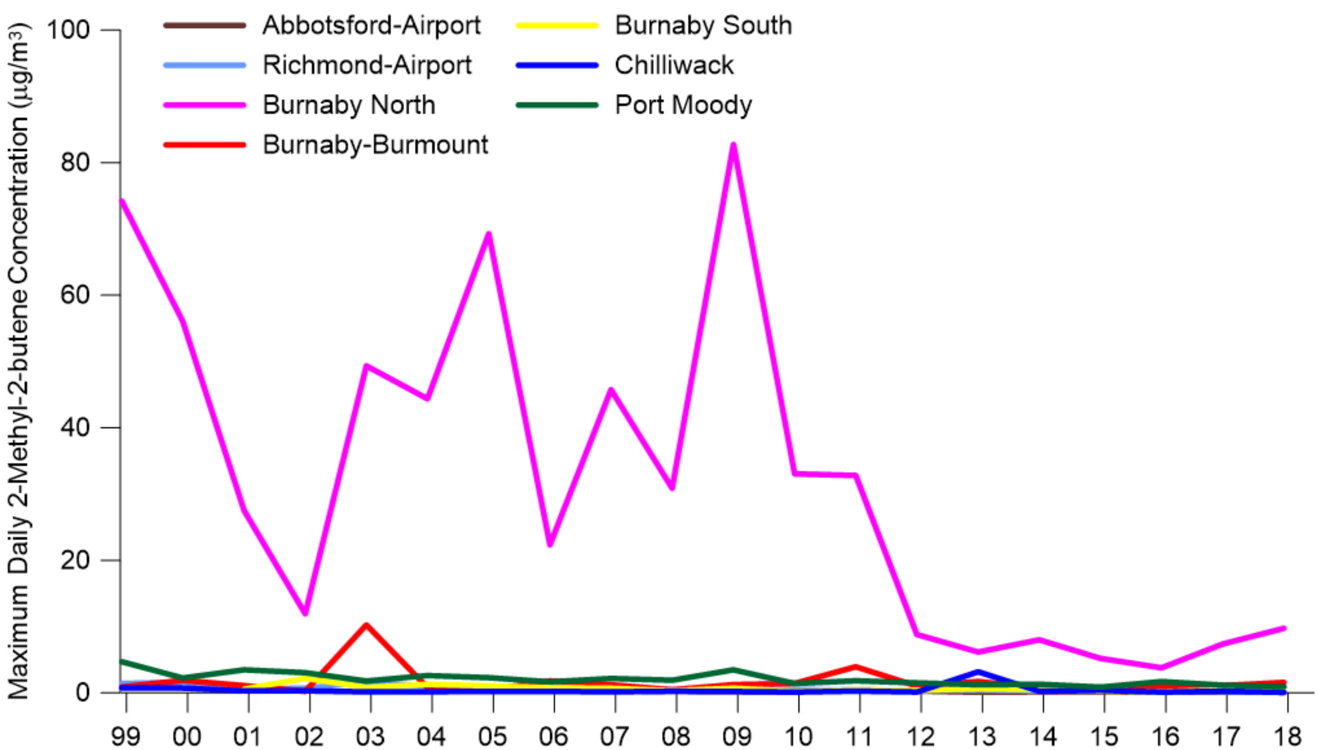


Figure A17: Short-term peak 2-methyl-2-butene trend, 1999 to 2018.

M- and p-xylene

Characteristics

Xylenes are a family of three aromatic hydrocarbon isomers (ortho-, meta- and para-xylene) with the chemical formula C_8H_{10}. They are colourless liquids that are nearly insoluble in water and have a sweet odour. From an ozone production perspective m- and p-xylene are the fifth highest ranked VOC for ozone producing potential in the LFV.

Sources

Xylenes are used in the production of industrial chemicals, as solvents in products such as paints and coatings, and are blended into gasoline. Xylenes are released into the atmosphere as fugitive emissions from industrial sources, from vehicle exhaust, and through volatilization due to their use as solvents. In the LFV, the primary sources of m- and p-xylene are vehicle emissions and solvent evaporation.

Monitoring Results

Figure A18 illustrates the results of m- and p-xylene monitoring in 2018. Figure A18 displays the maximum daily concentration as well as the annual average for each xylene monitoring location. The highest daily maximum and average concentrations occurred at Burnaby North followed by Vancouver-Clark Drive.

Xylenes, released into the atmosphere as fugitive emissions from industrial sources, vehicle exhaust, and solvents, react to help form ground-level ozone.

Figures A19 and A20 illustrate the long-term average and peak m- and p-xylene trends in the LFV, respectively. Burnaby North and Port Moody have historically experienced the highest annual average m- and p-xylene concentrations. Overall the annual average exhibits a downward trend at most locations. The most recent years exhibit lower maximum daily concentrations relative to previous years. Vancouver-Clark Drive is not included in the long-term trends since the station has only recently been established.

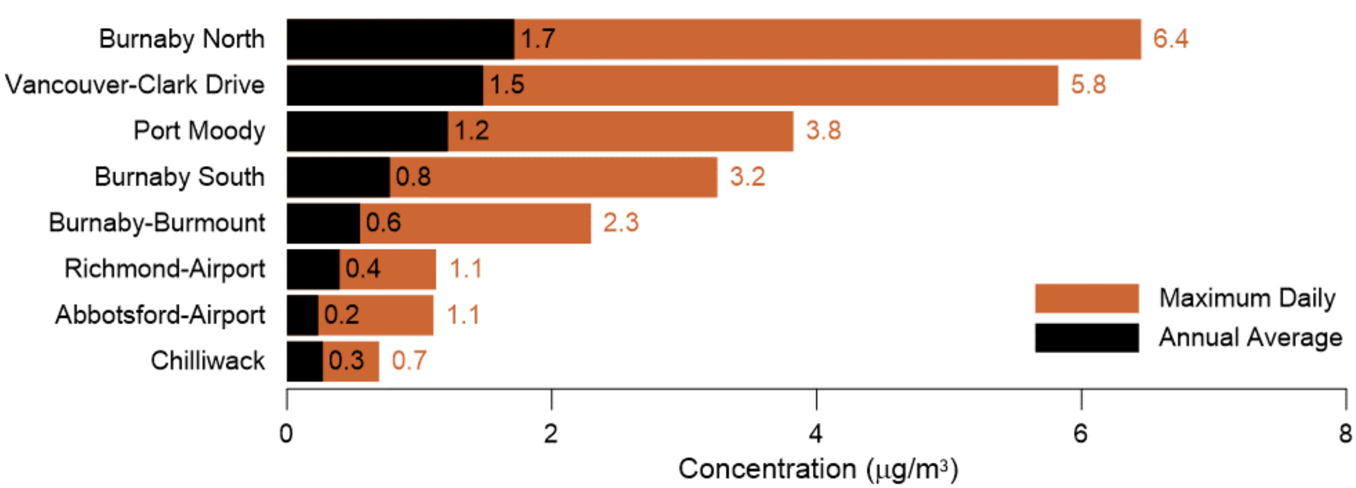


Figure A18: M- and p-xylene monitoring, 2018.

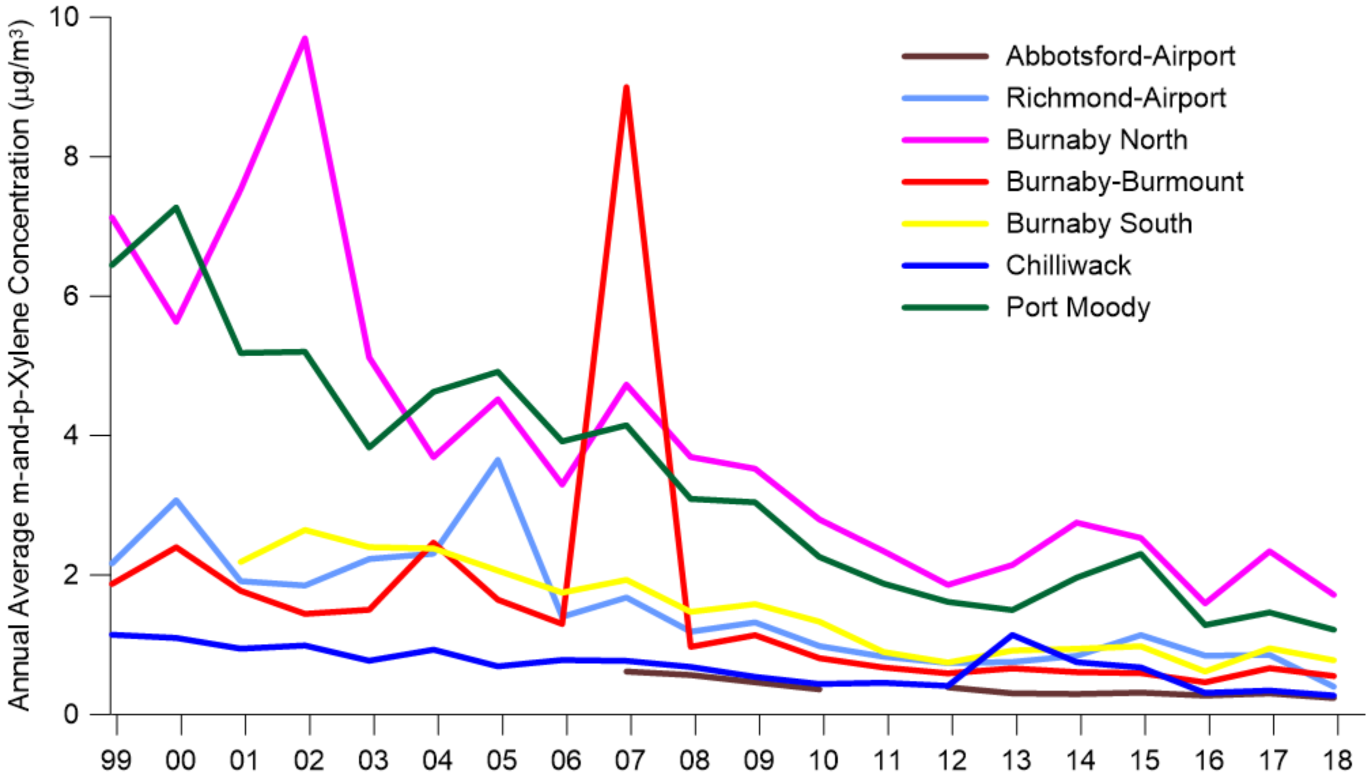


Figure A19: Annual m- and p-xylene trend, 1999 to 2018.

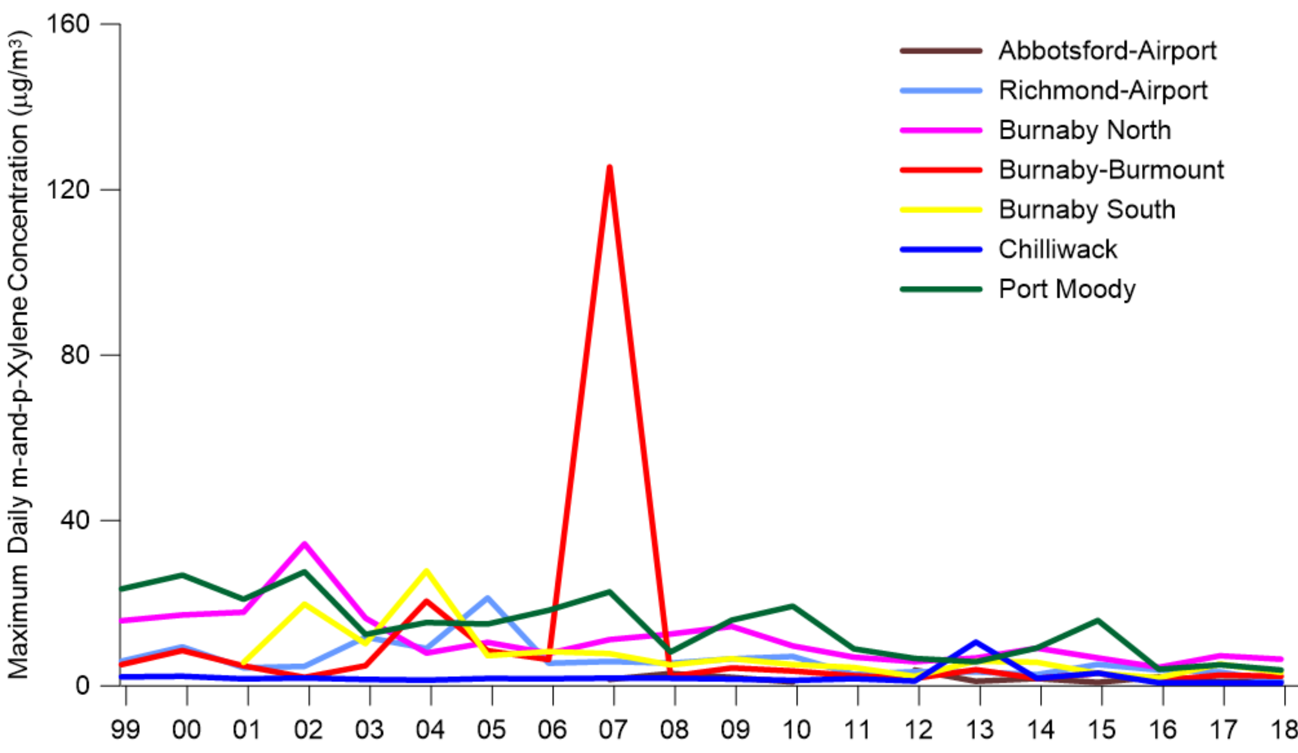


Figure A20: Short-term peak m- and p-xylene trend, 1999 to 2018.

Formaldehyde

Characteristics

The chemical formula for formaldehyde is CH_2O, and it is a colourless gas with a pungent, suffocating odour at room temperature. The US EPA considers formaldehyde a probable human carcinogen and acute (short-term) and chronic (long-term) inhalation exposure can result in adverse human health effects. At ambient concentrations measured in the LFV in 2010 it poses a lifetime cancer risk greater than Health Canada's 1 in 100,000 screening threshold[1].

Sources

Formaldehyde is used mainly to produce resins used in particleboard products and as an intermediate in the synthesis of other chemicals. One of the most common uses of formaldehyde is manufacturing urea-formaldehyde resins, used in particleboard products. It also has minor uses in agriculture, as an analytical reagent, in concrete and plaster additives, cosmetics, disinfectants, fumigants, photography, and wood preservation.

The primary sources of formaldehyde emissions in the LFV are exhaust from fossil fuel combustion, residential wood burning, and fugitive emissions from industrial facilities. It is important to note that formaldehyde may also be formed in the atmosphere through chemical reactions of other precursor species, so measured levels of ambient formaldehyde are likely due to both primary emissions and secondary formation.

Monitoring Results

Figure A21 illustrates the results of formaldehyde monitoring in 2018. Figure A21 displays the maximum daily concentration as well as the annual average for the two formaldehyde monitoring locations. The highest daily concentration occurred at the Port Moody station. Formaldehyde is a polar VOC and is sampled at two stations in the network.

Formaldehyde is a probable human carcinogen and acute and chronic inhalation exposure can result in human health effects.

Historically polar VOC have only been routinely measured at Port Moody. Figures A22 and A23 illustrate the long-term average and peak formaldehyde trends at Port Moody and Abbotsford-Airport, respectively. There does not appear to be a discernible trend in average and peak levels for formaldehyde at Port Moody. Due to resource limitations in the federal NAPS program, analysis of polar VOC was limited in Canada between 2011 and 2013 and therefore a gap is present during these years.

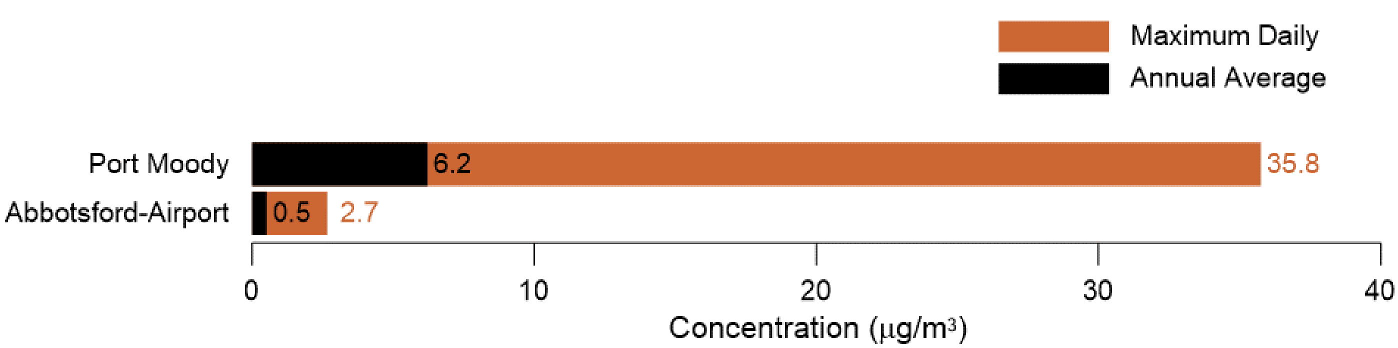


Figure A21: Formaldehyde monitoring, 2018.

[1] Toxic Air Pollutants Risk Assessment and Emissions Inventory for the Lower Fraser Valley, Metro Vancouver, 2015.

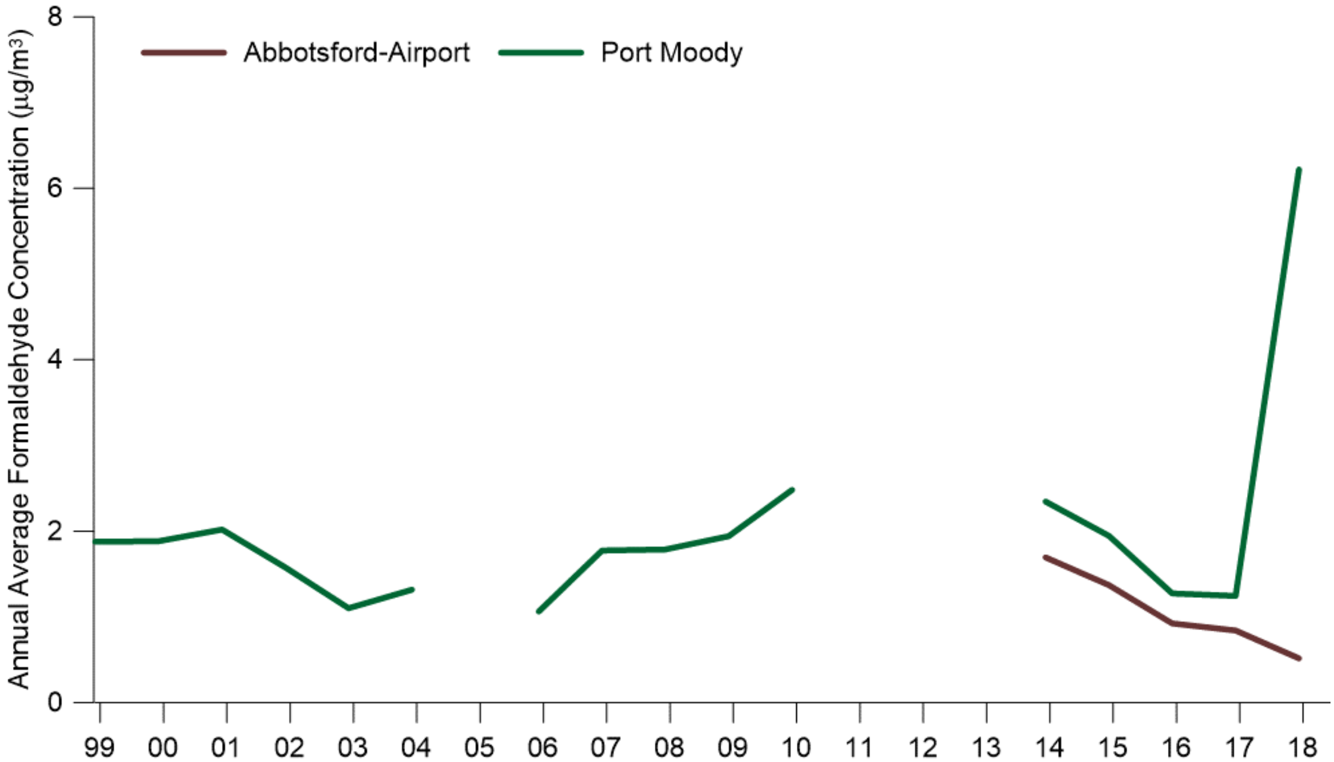


Figure A22: Annual formaldehyde trend, 1999 to 2018.

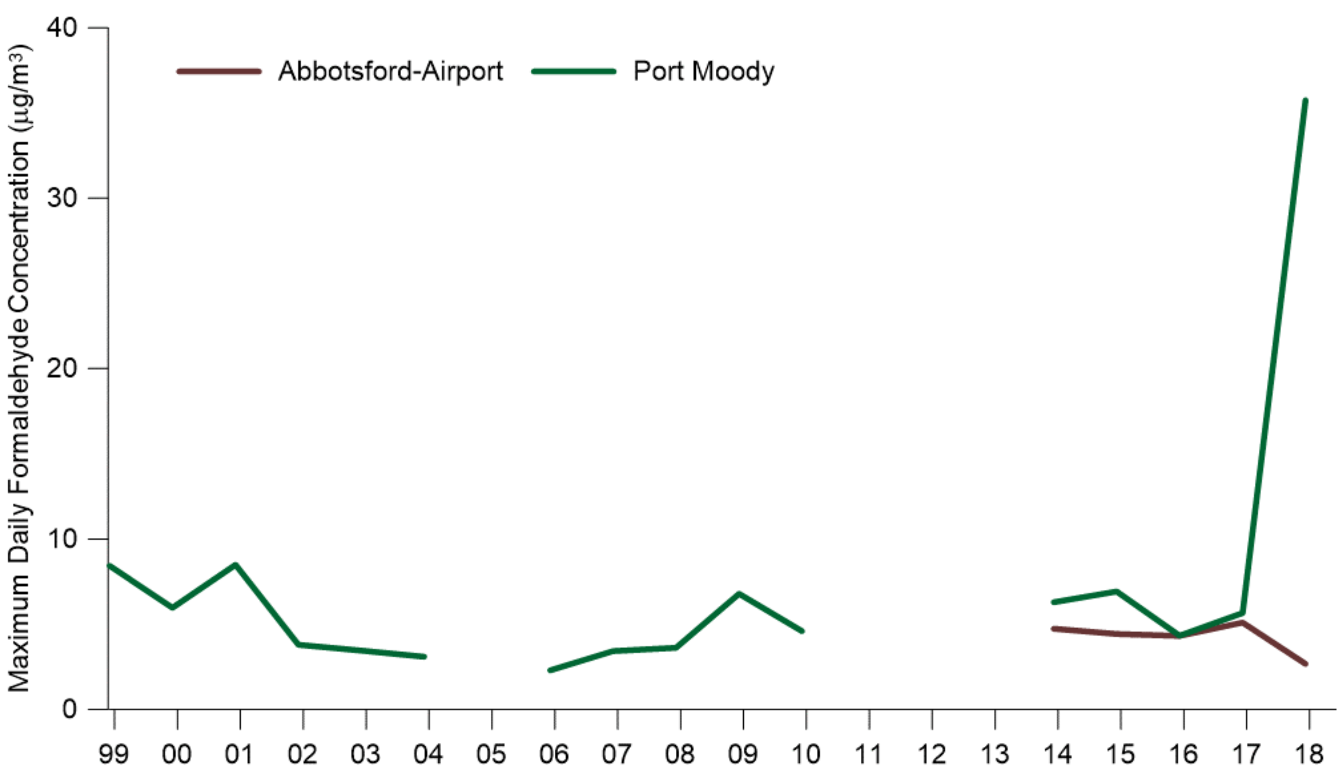


Figure A23: Short-term peak formaldehyde trend, 1999 to 2018

Benzene

Characteristics

Benzene is an aromatic hydrocarbon with a sweet odour at high concentrations and the chemical formula C_6H_6. At ambient temperature it occurs as a volatile, colourless, highly flammable liquid that is somewhat soluble in water. Benzene has been classified by the US EPA as a known human carcinogen and has both acute and chronic inhalation exposure effects. At ambient concentrations measured in the LFV in 2010, it poses a lifetime cancer risk greater than Health Canada's 1 in 100,000 screening threshold[2].

Benzene levels have decreased regionally over the last two decades mainly due to federal gasoline regulations.

Sources

Benzene is found in emissions from burning coal and oil, motor vehicle exhaust, and evaporation from gasoline service stations and in industrial solvents. In the LFV, the primary sources of benzene include gasoline engine exhaust, service station fugitive emissions, and residential wood burning, as well as refinery and tank farm fugitive emissions.

Monitoring Results

Figure A24 illustrates the results of benzene monitoring in 2018. Figure A24 displays the maximum daily concentration as well as the annual average for each benzene monitoring location. The highest concentrations occurred at the Burnaby North station that is adjacent to the refinery tank farm. The second highest concentrations occurred at Vancouver-Clark Drive likely due to the combination of fugitive emissions from the adjacent gas station and vehicle exhaust.

Figures A25 and A26 illustrate the long-term average and peak benzene trends in the LFV, respectively. Average levels of benzene decreased considerably in the mid-2000s at Burnaby North while other monitoring sites exhibited a more constant decrease since the mid-1990s. Reductions in benzene levels regionally can be attributed mainly to benzene emission reductions from transportation and refinery sources brought on by federal gasoline regulations. Due to its proximity to the refinery tank farm, the Burnaby North has consistently exhibited the highest average annual and peak levels of benzene in the region. Vancouver-Clark Drive is not included in the long-term trends since the station has only recently been established.

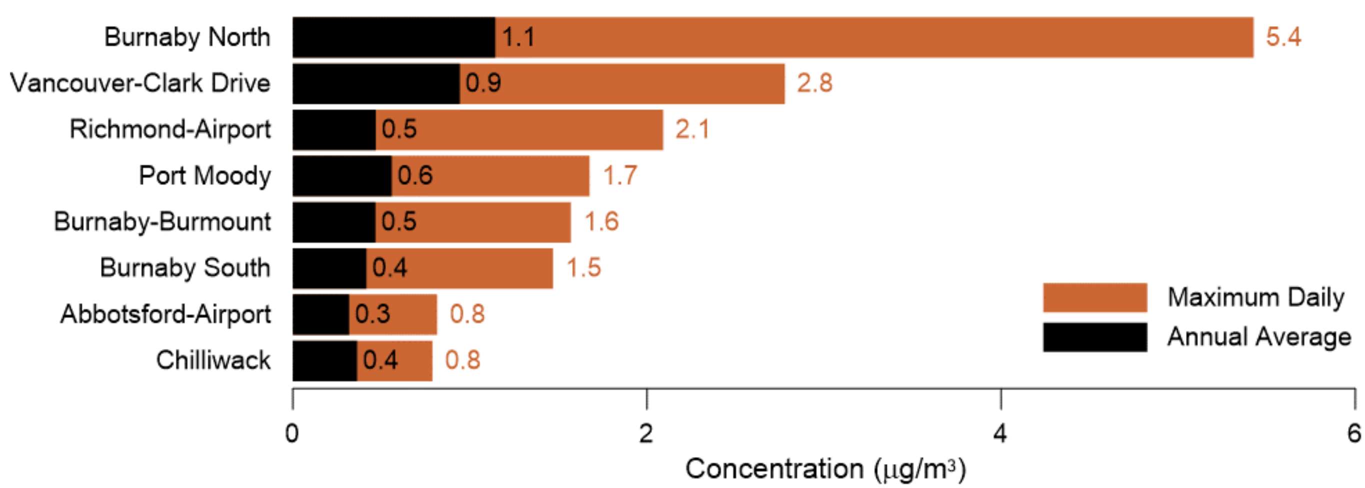


Figure A24: Benzene monitoring, 2018.

[2] Toxic Air Pollutants Risk Assessment and Emissions Inventory for the Lower Fraser Valley, Metro Vancouver, 2015.

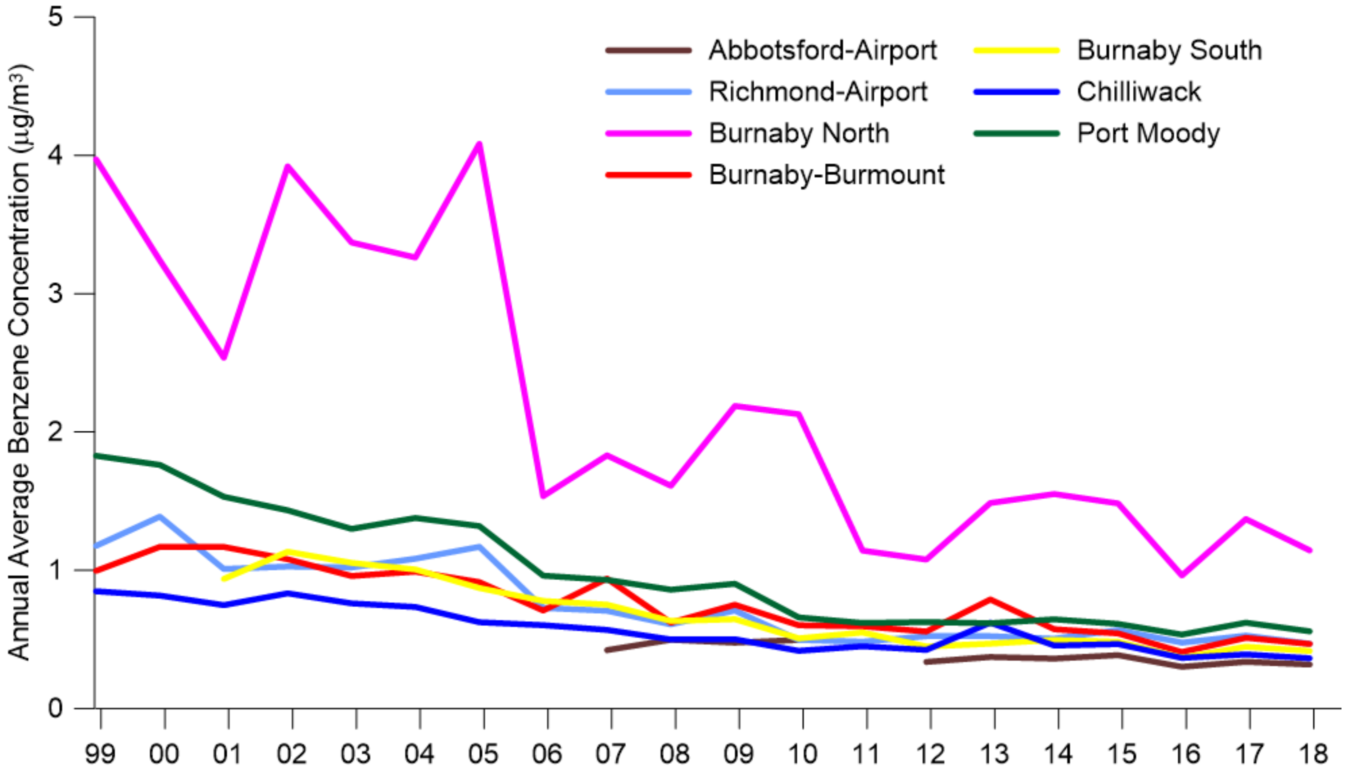


Figure A25: Annual benzene trend, 1999 to 2018.

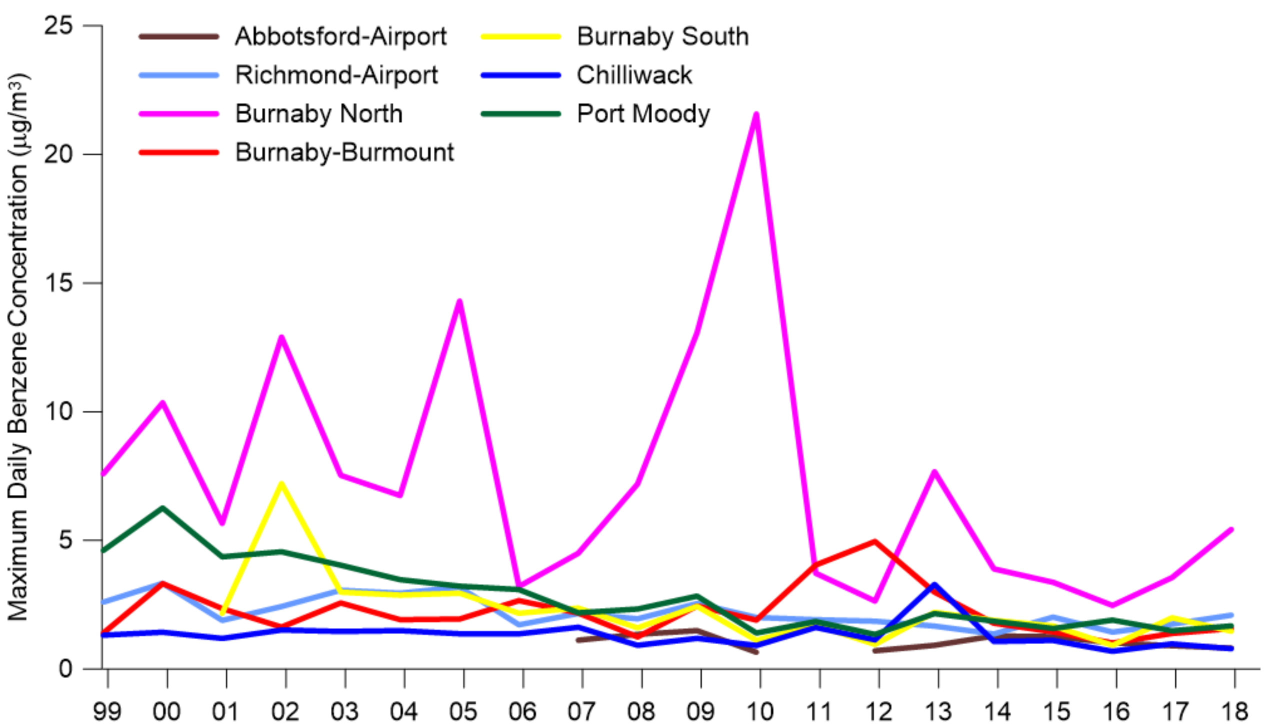


Figure A26: Short-term peak benzene trend, 1999 to 2018.

Acetaldehyde

Characteristics

Acetaldehyde is a colourless volatile liquid that is flammable and soluble in water. Its chemical formula is CH_3CHO, and at dilute concentrations it has a fruity and pleasant odour. Acetaldehyde is considered a probable human carcinogen and has both acute and chronic human health effects. In the LFV, at ambient concentrations measured in 2010, it poses a non-cancer health risk greater than Health Canada's 0.2 hazard quotient screening threshold[3].

Sources

Acetaldehyde is an intermediate product of plant respiration and formed as a product of incomplete wood combustion in fireplaces and woodstoves, coffee roasting, burning of tobacco, vehicle exhaust, and waste processing. Acetaldehyde is also used in the production of perfumes, polyester resins, and basic dyes. Acetaldehyde is also used as a fruit and fish preservative, as a flavoring agent, and as a denaturant for alcohol, in fuel compositions, for hardening gelatin, and as a solvent in the rubber, tanning, and paper industries.

In the LFV, the primary sources of acetaldehyde include natural sources, gasoline engine exhaust, and residential wood burning.

Monitoring Results

Figure A27 illustrates the results of acetaldehyde monitoring in 2018. Figure A27 displays the maximum daily concentration as well as the annual average for each acetaldehyde monitoring location. Acetaldehyde is a polar VOC and is sampled at two stations in the network.

Acetaldehyde is considered a probable human carcinogen with potential for both acute and chronic human health effects.

Historically polar VOC have only been routinely measured at Port Moody. Figures A28 and A29 illustrate the long-term average and peak acetaldehyde trends at Port Moody and Abbotsford-Airport, respectively. There does not appear to be a discernible trend in average and peak levels for acetaldehyde at Port Moody. Due to resource limitations in the federal NAPS program, analysis of polar VOC was limited in Canada between 2011 and 2013 and therefore a gap is present during these years.

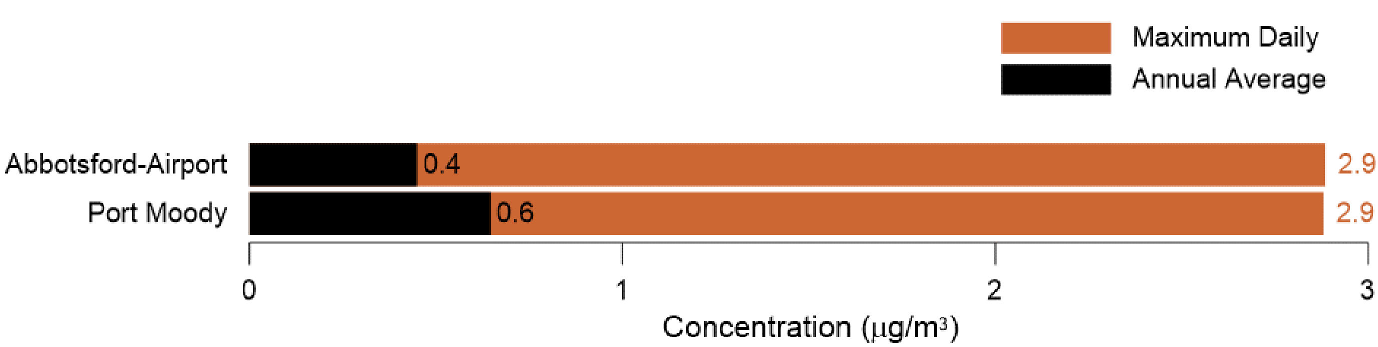


Figure A27: Acetaldehyde monitoring, 2018.

[3] Toxic Air Pollutants Risk Assessment and Emissions Inventory for the Lower Fraser Valley, Metro Vancouver, 2015.

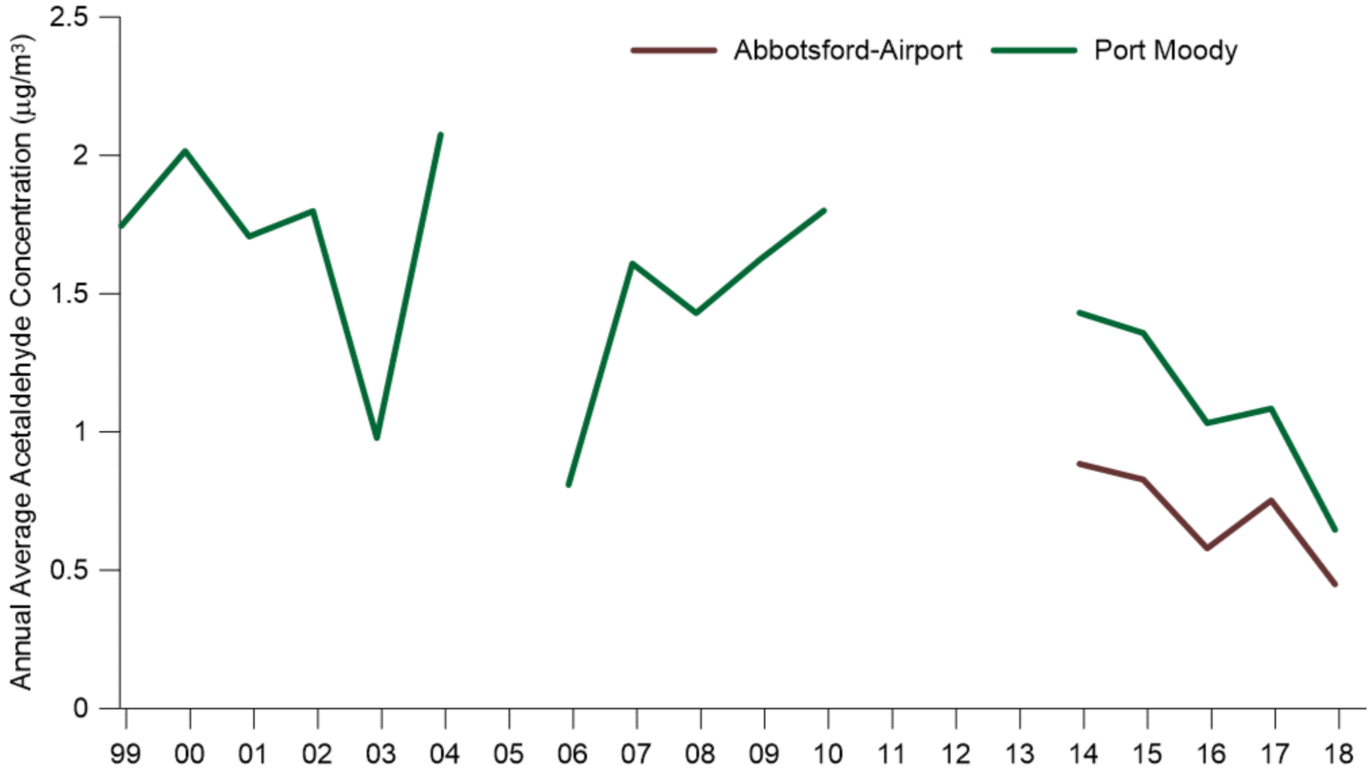


Figure A28: Annual acetaldehyde trend, 1999 to 2018.

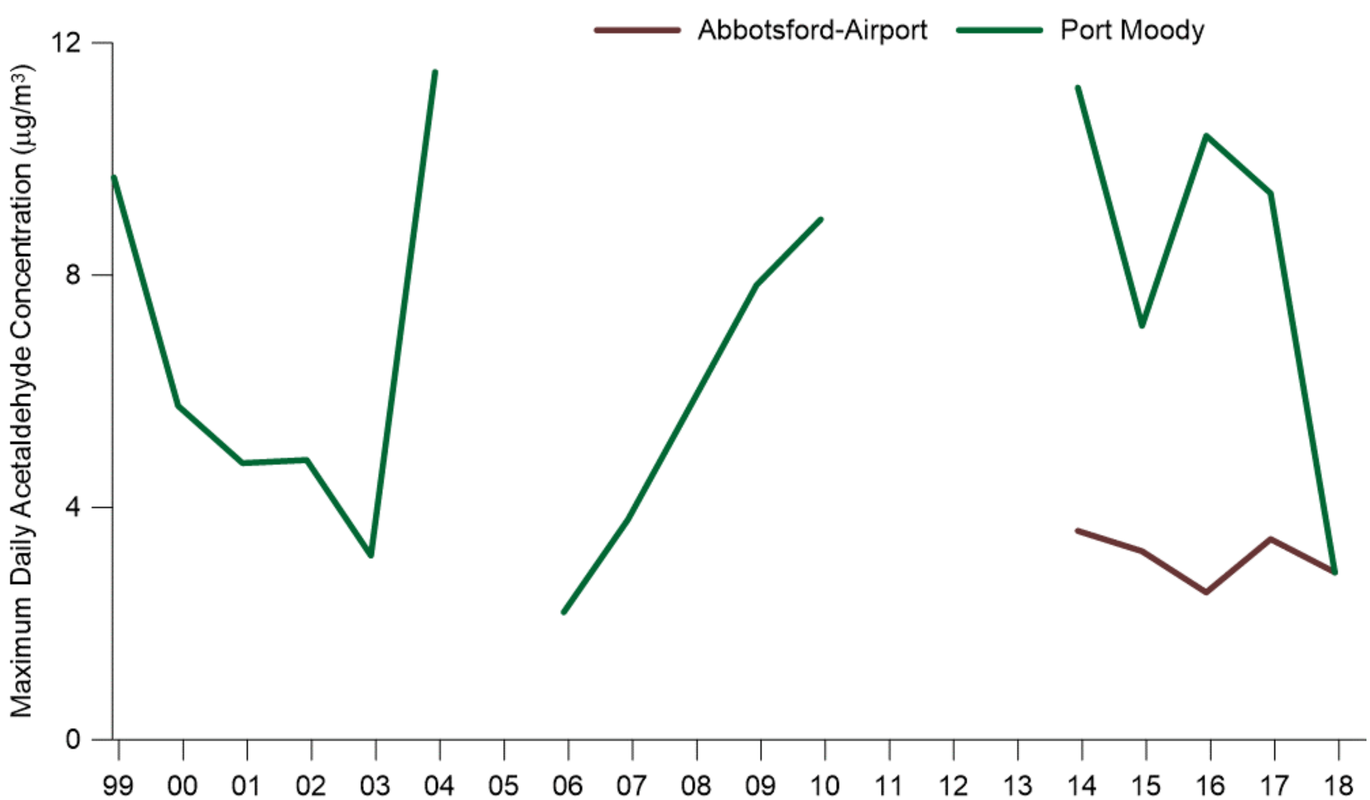


Figure A29: Short-term peak acetaldehyde trend, 1999 to 2018.

1,3-Butadiene

Characteristics

1,3-Butadiene is a colourless gas with mild gasoline-like odour with the chemical formula C_4H_6. 1,3-Butadiene has been classified by the US EPA as a known human carcinogen and has both acute and chronic inhalation exposure effects. At current ambient concentrations measured in the LFV it poses a lifetime cancer risk greater than Health Canada's 1 in 100,000 screening threshold[4].

1,3-Butadiene levels have decreased regionally over the last two decades mainly due to improvements in internal combustion engine efficiency.

Sources

1,3-Butadiene is found in emissions from gasoline internal combustion engines in on-road vehicles, off-road vehicles, and aircraft. In Metro Vancouver, residential wood burning is also a significant source, and oil refinery emissions have historically contributed to 1,3-butadiene emissions.

Monitoring Results

Figure A30 illustrates the results of 1,3-butadiene monitoring in 2018. Figure A30 displays the maximum daily concentration as well as the annual average for each 1,3-butadiene monitoring location. The highest concentrations occurred at the Vancouver-Clark Drive station.

Figures A31 and A32 illustrate the long-term average and peak 1,3-butadiene trends in the LFV, respectively. Average levels of 1,3-butadiene decreased considerably in the mid-2000s at Burnaby North while other monitoring sites exhibited a more constant decrease since the 1990s. Reductions in 1,3-butadiene levels regionally can be attributed to continuing improvement in the emissions performance of gasoline internal combustion engines driven by federal emissions regulations. Vancouver-Clark Drive is not included in the long-term trends since the station has only recently been established.

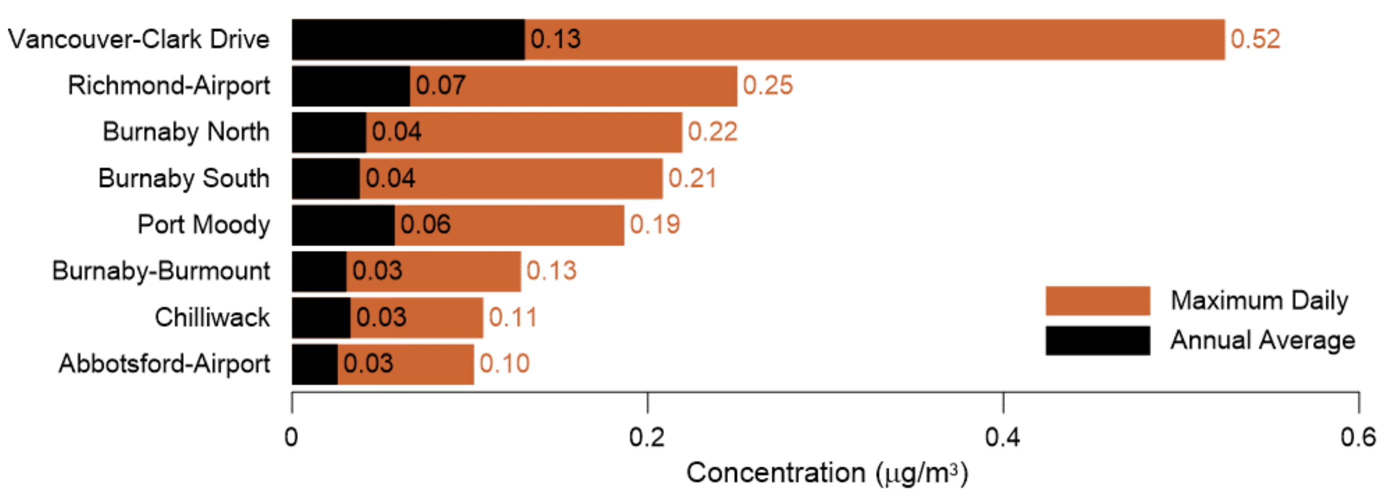


Figure A30: 1,3-Butadiene monitoring, 2018.

[4] Toxic Air Pollutants Risk Assessment and Emissions Inventory for the Lower Fraser Valley, Metro Vancouver, 2015.

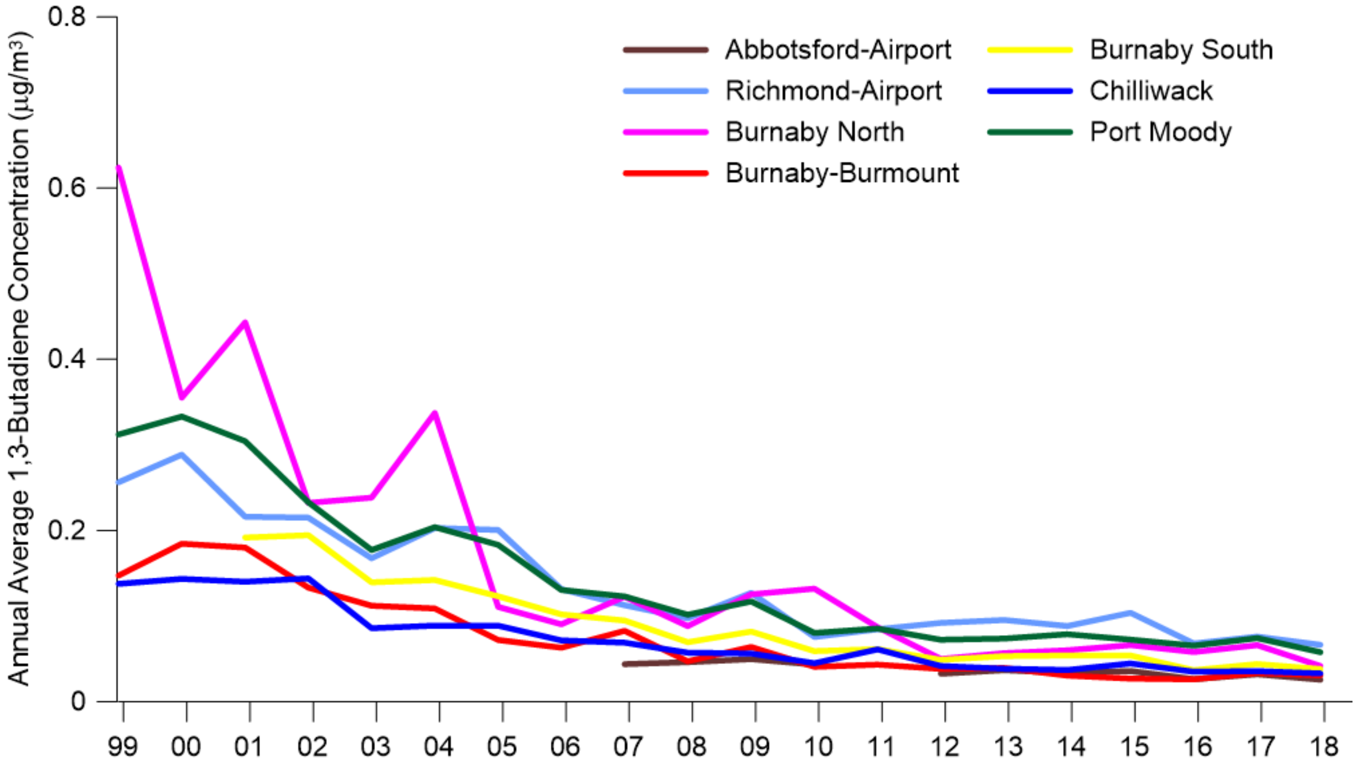


Figure A31: Annual 1,3-butadiene trend, 1999 to 2018.

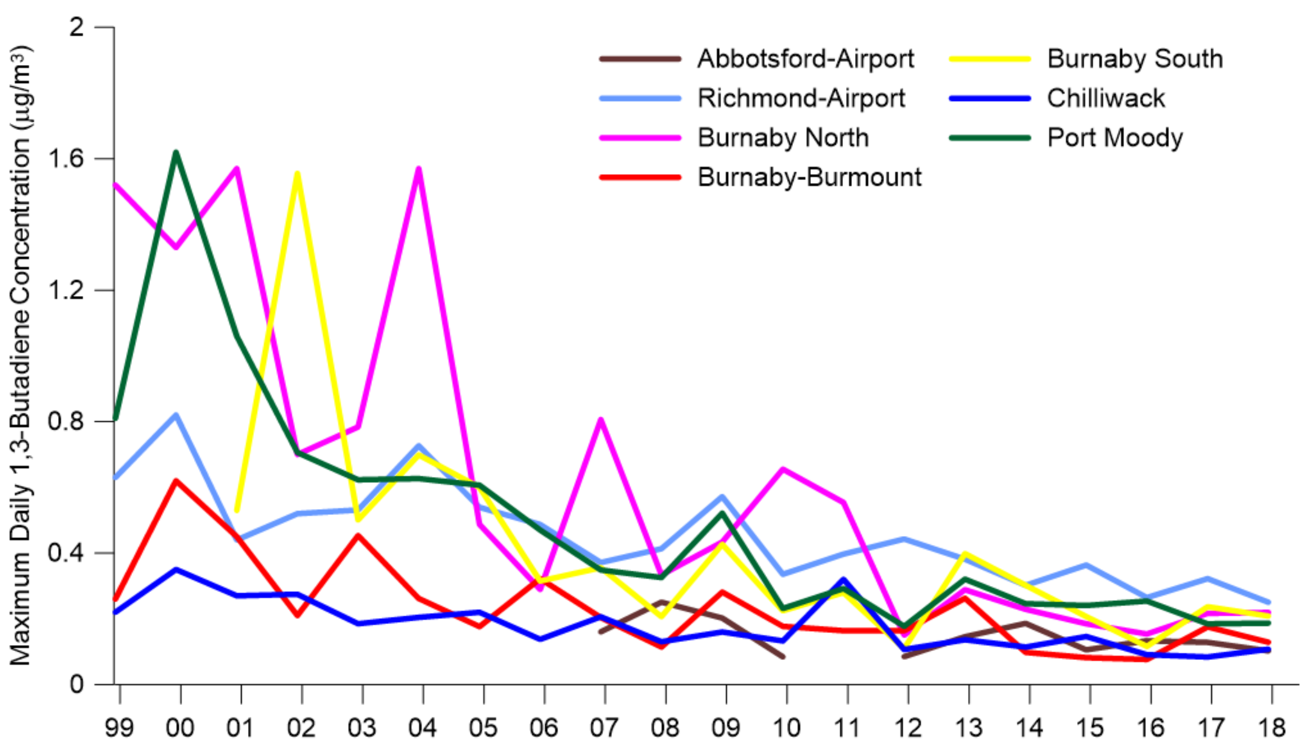


Figure A32: Short-term peak 1,3-butadiene trend, 1999 to 2018.