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Particulate Matter in Sechelt, 2012-2018

Summary of data collected at the Sechelt air quality monitoring sites from December 2012 to June 2018

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BRITISH COLUMBIA

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Particulate Matter in Sechelt, 2012–2018
Project Summary

Air Quality in Sechelt

Sechelt is located along the coast of southwestern British Columbia (B.C.) and is the most populated region of the Sunshine Coast. Over the past few decades there has been an increase in industrial development, and residential woodburning is common. Because of this, there have been concerns about local air quality and the levels of inhalable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) in the air within the community.

Monitoring air quality

With the help of the Sunshine Coast Clean Air Society and local residents, the B.C. Ministry of Environment and Climate Change Strategy installed instruments (monitors) in Sechelt to measure PM from 2012 to 2018. One monitor was installed at the Trail Bay Mall (in the downtown area), and others in East Porpoise Bay (a residential neighbourhood). Monitoring PM at more than one location can help show how air quality may be different even within the same community. Each monitor took a daily average (24-hour) sample every six days.

Findings

PM levels are generally low, which means that the air quality is good in Sechelt. Rarely, smoke from wildfires can affect air quality in Sechelt and cause high levels of PM, especially $PM_{2.5}$. During times when air quality was not impacted by wildfires, daily average PM in Sechelt was low, especially compared to the AQO levels and to PM levels in other B.C. communities. PM levels at both monitors were lowest in winter, which differs from other B.C. communities ($PM_{2.5}$ is usually high because of residential woodburning). PM levels at East Porpoise Bay were often similar to those at Trail Bay Mall, especially during warmer months. Collaboration and local-level engagement and activities can help continue to maintain and further improve air quality in Sechelt.

Particulate Matter (PM)

What is PM? PM is a mixture of tiny solid and liquid particles in the air. These particles come in many shapes and sizes and are made up of many different chemicals. Inhalable PM refers to particles with a diameter smaller than 10 micrometers, which is written as "PM_{10}." Similarly, "$PM_{2.5}$" refers to particles with a diameter smaller than 2.5 micrometers.

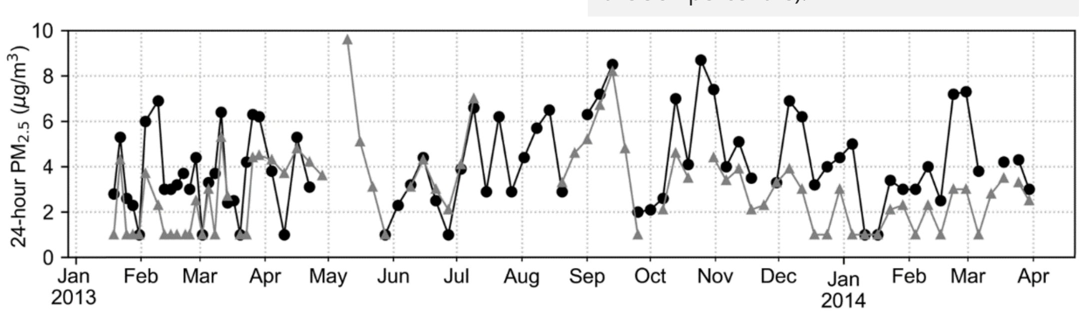
Where does PM come from? PM can be released (emitted) directly into the air or formed through chemical reactions of different air pollutants. PM_{10} includes dust, soot, mold and pollen. $PM_{2.5}$ can come from smoke from forest fires and residential woodburning, fossil fuel combustion, and industrial processes.

Why do we monitor PM? PM can be harmful to your health. When inhaled, $PM_{2.5}$ can make its way deep into your lungs and bloodstream, which may aggravate existing lung and heart disease, increase the risk of cancer, and reduce life expectancy. PM can also affect the environment; it is the main cause of "haze."

Air Quality Objectives (AQOs)

B.C. AQOs, along with federal-level standards, are used to help guide air quality management. AQOs are levels of air pollutants that should not be exceeded in a specific region over a given period. AQOs may be calculated in different ways ("statistical forms"). The 24-hour $PM_{2.5}$ B.C. AQO is achieved when the daily average values are lower than 25 µg/m^3 (based on the 98th percentile).

One PM monitor was placed at the Trail Bay Mall (pictured above), and another in East Porpoise Bay.



Daily average $PM_{2.5}$ measured at Trail Bay Mall (black circles) and East Porpoise Bay (grey triangles) during the monitoring period when both monitors were operating. The sample values are similar from both sites during warmer months (Jun-Sep). All samples during this period are generally low, especially compared to the AQO.

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Acronyms

AQO	Air Quality Objective
CAAQS	Canadian Ambient Air Quality Standards
CCME	Canadian Council of Ministers of the Environment
B.C.	British Columbia
EE	exceptional event
ENV	Ministry of Environment and Climate Change Strategy
EMS	Environmental Monitoring System
EPB	East Porpoise Bay (monitoring site)
LOD	Limit Of Detection
MODIS	Moderate Resolution Imaging Spectroradiometer
NAPS	National Air Pollution Surveillance (program)
PM	particulate matter
PM_{10}	particulate matter with an aerodynamic diameter less than or equal to 10 µm
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than or equal to 2.5 µm
PMco	particulate matter with an aerodynamic diameter larger than 2.5 µm but smaller than 10 µm
PG	Planning Goal
TBM	Trail Bay Mall (monitoring site)
TF	transboundary flow
QA	quality assurance

1. Introduction

The British Columbia (B.C.) Ministry of Environment and Climate Change Strategy (ENV), with assistance from the District of Sechelt, the Sunshine Coast Clean Air Society (SCCAS) and local volunteers, operated a temporary non-continuous air quality monitoring station at the Trail Bay Center (Mall) in Sechelt, B.C., from December 2012 through June 2018. During this period, a second temporary non-continuous monitor was established within the same community for comparison. The goals of this monitoring program were to: (1) assess the spatial and temporal variability of particulate matter (PM) in Sechelt, and (2) compare the measurements of PM in Sechelt to relevant air quality objectives. This report is the most recent in a series of reports relating to PM monitoring in Sechelt.

1.1 Location

The District of Sechelt (Sechelt) is located on the south coast of B.C., approximately 50 km northwest of the City of Vancouver (Figure 1). Sechelt is the most populated center on the Sunshine Coast, with 10,216 inhabitants in 2016, which represents an increase of 10.0% from 9,291 inhabitants in 2011, and 20.2% from 8,499 inhabitants in 2000 (Statistics Canada 2017). The municipal boundaries are adjacent to reserve land areas of the Shishálh (Sechelt) First Nation. Sechelt is a popular destination for outdoor recreational activities.

Sechelt is within the Georgia Strait Air Zone.[1] The climate is warm and temperate, and most precipitation occurs during the fall and winter months (Environment and Climate Change Canada 2020).

Sechelt has undergone significant development and expansion over the past few decades, especially along the ocean waterfront, leading to an increase in land clearing, construction, residential wood combustion, backyard burning and vehicle use. As a result, there have been local concerns regarding the impacts on air quality and human health associated with emissions from these sources (e.g., Gleeson 2017, District of Sechelt 2010). Specifically, most concerns have been related to airborne dust and PM that may originate from local gravel operations and open burning. There are numerous businesses that conduct sand and gravel mining, concrete batching and handling materials adjacent to the community. Several local bylaws and regulations have been enacted in Sechelt to prohibit open burning with the exception of controlled campfires (per the Open Air Burning Bylaw No. 486[2]). Some recreational parks in the area, such as the Porpoise Bay Provincial Park, have also adopted a “clean air policy,” where fires can only be lit at a limited number of communal firepits. Since 2015, the Sechelt Fire Department has also prohibited all backyard burning (the combustion of waste material and garden refuse outdoors) and any burning of material as a result of land clearing within the District.[3]

To assess the concerns related to PM, ENV conducted a monitoring program at the Trail Bay Mall (Figure **1**) to measure ambient PM in Sechelt from June 1999 through May 2009. A second monitoring program was initiated in December 2012, which ran until June 2018, and included a short-term secondary monitoring site at East Porpoise Bay (see Section 2 for further details). During this second program, both inhalable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) were monitored.

[1] B.C. is divided into seven air zones, which are areas that typically exhibit similar air quality characteristics, issues, and trends. To learn more about air zones, see: https://www2.gov.bc.ca/gov/content/environment/air-land-water/air/air-quality/current-air-quality-data.

[2] https://www.sechelt.ca/LinkClick.aspx?fileticket=oPZ6t4SpeTo%3d

[3] http://www.secheltfiredepartment.ca/burning-regulations/

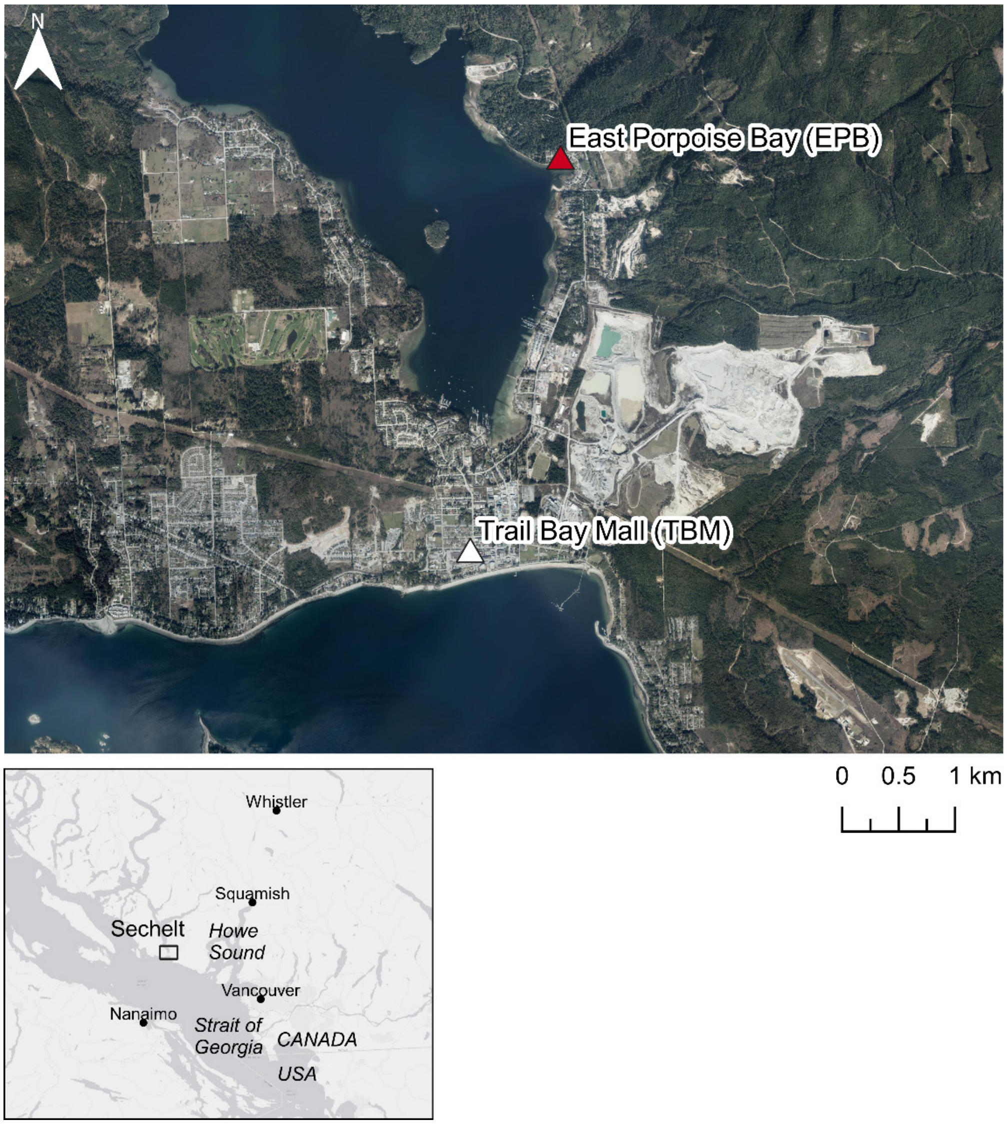


Figure 1. Location of Sechelt, B.C. (top) Location of Trail Bay Mall (TBM) and East Porpoise Bay (EPB) monitoring sites in Sechelt. The full extent of the District of Sechelt is not shown in this frame. (bottom) Location of Sechelt on the Sunshine Coast, relative to other cities and towns in B.C. The rectangular outline corresponds to the extents of the top panel.

1.2 Particulate matter

PM consists of small airborne solid particles and/or liquid droplets. PM is composed of many different chemical compounds and is emitted directly into the atmosphere from natural and anthropogenic sources and formed through secondary chemical and physical reactions. The size of PM varies greatly and is directly related to the severity of potential impacts on human and environmental health. Inhalable particulate matter (PM_{10}) is composed of PM with an aerodynamic diameter less than or equal to 10 micrometers (µm). PM_{10} includes dust, soot, mold and pollen. Fine particulate matter ($PM_{2.5}$) is composed of PM with an aerodynamic diameter less than or equal to 2.5 µm; $PM_{2.5}$ is therefore a subset of PM_{10}. $PM_{2.5}$ is primarily emitted through combustion and secondary chemical formation.

Both PM_{10} and $PM_{2.5}$ can be inhaled by humans. Negative health outcomes are associated with both short-term and long-term exposure to PM. Owing to its smaller size, $PM_{2.5}$ can penetrate deep into the lungs and bloodstream. Studies have found that exposure to $PM_{2.5}$ can adversely impact the respiratory system, cardiovascular system and cognitive functioning. There is also evidence that elevated levels of $PM_{2.5}$ are correlated with increased mortality (e.g., Pinault *et. al* 2017).

1.3 Air quality objectives and standards

Air quality objectives and standards are limits on the level of contaminants in the ambient environment established by government agencies to protect human health and the environment. ENV uses a set of levels defined by the Canada Ambient Air Quality Standards (CAAQS), developed under the auspices of the Canadian Council of Ministers of the Environment (CCME), and the Provincial Air Quality Objectives (AQOs). Generally, provincial AQOs are equivalent to or more stringent than the federal CAAQS; however, AQOs are non-statutory, meaning that they are not legally binding from the perspective of airshed management.[4] ENV has also developed Planning Goals (PGs), which are voluntary targets to guide airshed planning efforts and encourage communities to maintain good air quality in the face of economic growth and development.

Air quality objectives and standards consist of three components: (1) a numerical value, (2) an averaging period and (3) a statistical form (Table 1). Values calculated from measured concentrations using the same averaging period and in the same statistical form of the objective are referred to as "metric values." Achievement of an objective or standard is met when the metric value is less than or equal to the numerical value (maximum threshold). For example, the annual AQO for $PM_{2.5}$ is met when the metric value (annual average of all 24-hour average $PM_{2.5}$ measurements[5] from a single monitor) is below 8 $\mu g/m^3$.

Before metric values are calculated, the following procedures should also be applied to each air pollutant dataset:

- Quality Assurance (QA): QA should be performed and invalidated[6] data should be removed from the dataset (see Section 2.2 for QA procedures used in this analysis).

[4] AQOs in B.C. are binding requirements only if referred to in an authorization or regulation (B.C. Ministry of Environment and Climate Change Strategy 2020).

[5] 24-hour average $PM_{2.5}$ values must be based on continuous 1-hour measurements (Canadian Council of Ministers of the Environment 2012).

[6] Data may be considered invalid if there were known issues related to instrument performance, sample handling, sample analysis, or data reporting.

Table 1. Current B.C. AQOs and 2020 CAAQS for PM_{10} and $PM_{2.5}$.

Pollutant	Averaging Period	Criteria	Value ($\mu g/m^3$)	Statistical form
PM_{10}	24-hour	AQO	50	Annual maximum value.
$PM_{2.5}$	24-hour	CAAQS	27	Annual 98th percentile of daily average values, averaged over three consecutive years.
		AQO	25	Annual 98th percentile of daily average values.
	Annual	CAAQS	8.8	Annual average, averaged over three consecutive years.
		AQO	8	Annual average.
		PG	6	Annual average.

- Transboundary flow (TF) and exceptional event (EE) analysis: Samples subject to the influence of TF or EEs should be identified and excluded from metric value calculations so that long-term management strategies are not based on air quality conditions that are beyond local or provincial control (Canadian Council of Ministers of the Environment 2019). EEs include wildfires and prescribed forest fires. A set of objective criteria are used to determine if air quality was influenced by TF/EE (an example of this procedure for the Georgia Strait Air Zone is provided in B.C. Ministry of Environment and Climate Change Strategy (2019)).
- Completeness assessment: For annual-based $PM_{2.5}$ metrics, a dataset is deemed complete when a minimum of 75% of samples are available and deemed valid by year, and 60% by quarter (Canadian Council of Ministers of the Environment 2012). Metric values should only be calculated when data completeness criteria are met; this ensures that metric values are representative (so that seasonal bias is limited).

2. Monitoring Program

2.1 Monitoring sites

ENV conducted monitoring of ambient PM_{10} at the Trail Bay Mall (TBM) in Sechelt (Figure 1, Table 2) from June 1999 through May 2009. The results from this program are summarized in several reports: Shead (2002), Shead (2003), Shead (2004) and McCoy (2006). Overall, the results indicated that air quality conditions in Sechelt were generally good, and PM_{10} concentrations were usually low throughout the year.

Due to continued local concerns from residents regarding ambient dust (especially with respect to operations at a local gravel mine), ENV worked with the District of Sechelt and residents of East Porpoise Bay to conduct a second short-term monitoring program. PM monitoring at the TBM site was re-established so that new data collected could be compared to data from the first monitoring program (Figure 2). Monitoring at TBM was originally planned for a maximum of three years, but was then extended for an additional 3.5 years, totalling 6.5 years of observations (from December 2012 until June 2018). Both $PM_{2.5}$ and PM_{10} were measured at TBM during this program.

Table 2. Monitoring site description. The EMS ID indicates the station identification code used in ENV's database. Dates are not indicative of data completeness or number of valid samples.

EMS ID	Name	Abbr.	Location type	Address/ Description	Established date	Closed date
E237978	Sechelt Trail Bay Mall	TBM	Village	5755 Cowrie Street (on roof)	1999-06-16	2018-06-07
E291989	Sechelt East Porpoise Bay	EPB	Residential	6409 Marmot Road	2012-12-17	2014-03-30

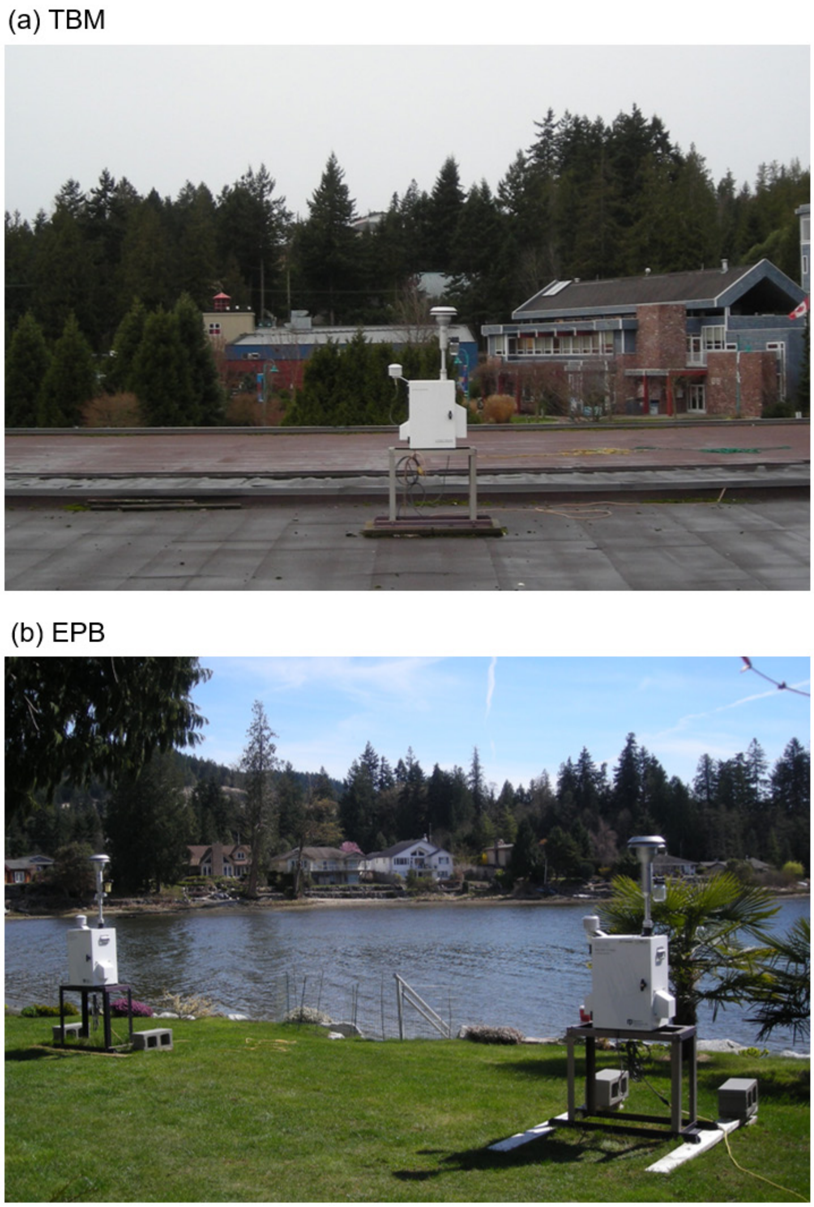


Figure 2. PM monitors in Sechelt. (a) Trail Bay Mall (TBM) monitoring site with dichot instrument, facing east; and (b) East Porpoise Bay (EPB) monitoring site with two Partisols, facing south.

Monitoring at more than one location can help illustrate spatiotemporal variations in air quality, even within a single community. A second monitoring site was installed at East Porpoise Bay (EPB), approximately 3.5 km north of TBM and closer to closer to areas of recent increased industrial activity (Figure 1, Figure 2). The EPB site is also in a residential neighbourhood, where local air quality may be influenced by smoke from residential woodburning. PM_{10} and $PM_{2.5}$ were monitored at EPB for 16 months (from December 2012 through March 2014).

2.2 Instrumentation

PM_{10} and $PM_{2.5}$ samples were collected at TBM and EPB using Rupprecht & Patashnick Partisol Plus air samplers (Model 2000H and Model 2000D). These instruments can be run using one of the following configurations:

a. as a "Partisol", where a single PM size is sampled on a filter by a single instrument; or
b. as a dichotomous sampler ("dichot"), where multiple PM sizes are sampled using a single instrument. In this configuration, air is drawn through an inlet and initial filter by a pump, and the flow is split so that $PM_{2.5}$ is collected on one filter, and coarse PM (PMco, PM with an aerodynamic diameter that is larger than 2.5 µm but smaller than 10 µm) is collected on another.

Both configurations provide a 24-hour average (time-integrated) sample for each sampling day. The filters are weighed in an analytical laboratory before and after sampling, and the difference in mass yields the amount of PM. Given the air flow of the instrument is one cubic meter of air per hour, dividing the resulting mass by 24 hours yields a 24-hour average mass of PM per cubic meter of air (with units $\mu g/m^3$). When the instrument is used as a dichot, the sum of the mass of $PM_{2.5}$ and PMco yields the total mass of PM_{10}. Because samples are collected and averaged over 24 hours, high PM levels that are short-lived may not be easily identifiable.

At TBM, PM samples were collected using a dichot for the entire monitoring period. At EBP, a single dichot was used at the beginning of the monitoring program. Due to instrument issues, two Partisols (one to sample PM_{10}, and another to sample $PM_{2.5}$; see Figure 2) were used from August 7, 2013, to the end of the monitoring period. Data from both sampling configurations are treated as a single continuous dataset in this report.

The Partisols at TBM and EPB were operated such that 24-hour samples were collected every third day (3-day sampling) from December 2012 through March 2013, and every sixth day (6-day sampling) from April 2013 through the end of the monitoring periods. Most samples were taken on days that corresponded to the monitoring schedule from the National Air Pollution Surveillance (NAPS) program. Although a non-continuous sampling schedule does not provide complete time coverage, a 3-day or 6-day sampling schedule will result in samples from each day of the week over long-term monitoring programs, which reduces day type (weekday versus weekend) bias.

2.3 Data capture and processing

All PM data were obtained from ENV's Environmental Monitoring System (EMS) online database.[7] The following processing steps were applied:

a. PM sample values less than the limit of detection (LOD) were set to half the LOD. The sample LOD was 2 $\mu g/m^3$; this means that all 24-hour values between zero and 2 $\mu g/m^3$ were assigned a value of 1 $\mu g/m^3$.

[7] The EMS online database can be accessed from: https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/environmental-monitoring-system

b. QA procedures were applied to identify invalid data, which were then excluded from the final dataset.[8] Samples were deemed invalid when a laboratory error was documented, when there was an error in the instrument flow rate, or when the PM_{10} concentration was less than the $PM_{2.5}$ concentration.
c. Only samples taken at the NAPS 6-day sampling frequency were retained. While this does exclude some samples from analysis, creating a dataset with a consistent sampling frequency reduces potential seasonal bias in the resulting statistics. Additionally, using a 6-day sampling frequency that aligns with the NAPS program schedule ("NAPS days") allows for comparison between the results from this monitoring program to those in previous reports and to other monitoring sites.
d. Samples taken when air quality was influenced by wildfires (EEs) were identified. Following the criteria outlined in B.C. Ministry of Environment and Climate Change Strategy (2019), days were deemed to be influenced by an EE when (a) there was evidence of wildfire smoke in the region (e.g., by examining photographs or Moderate Resolution Imaging Spectroradiometer [MODIS] visible satellite imagery), and (b) when the 24-hour $PM_{2.5}$ value exceeded the 2020 CAAQS for 24-hour $PM_{2.5}$ (27 µg/m^3). Both $PM_{2.5}$ and PM_{10} data sampled on the day were then omitted from further statistical analysis.

Only years with complete data should be used for analysis; annual datasets of PM were deemed complete following the criteria described in Section 1.3.[9] In the analysis that follows, various statistical measures and metric values[10] were calculated for all years, and completeness percentages are provided for reference.

3. Monitoring results and discussion

3.1 Overview

During this monitoring program, a total of 282 samples of PM_{10} and 282 samples of $PM_{2.5}$ were collected at TBM (Table 3). Similarly, 69 samples of PM_{10} and 60 samples of $PM_{2.5}$ were collected at EPB.

Table 3. Total number of valid samples ("total") and number of valid samples taken on NAPS days (n). The number and percent of data below the LOD (2 µg/m^3) collected are based on n.

	PM_{10}				$PM_{2.5}$			
Site	**total**	**n**	**n < LOD**	**% < LOD**	**total**	**n**	**n < LOD**	**% < LOD**
TBM	307	282	0	0	307	282	40	14.2
EPB	87	69	0	0	73	60	13	21.7

PM_{10} (Figure 3) and $PM_{2.5}$ (Figure 4) concentrations at TBM and EPB were generally low, and lower than other stations in B.C. over the same period (for example, see B.C. Ministry of Environment and Climate Change Strategy (2019)). Many $PM_{2.5}$ samples collected were below the LOD.

[8] Additional QA and data handling was performed to compile the data used in this report; notably, erroneous (invalid) data and samples taken on non-NAPS scheduled days were omitted. Resulting data and statistics may differ from previous reports.
[9] For a program with 6-day sampling frequency, 60 samples per year (15 samples per quarter) should be taken. To meet completeness criteria, there must be a minimum of 45 valid samples per year (75%) with 9 valid samples per quarter (60%).
[10] The metric values in this report are not akin to true metric values since they are based on non-continuous data (Canadian Council of Ministers of the Environment 2012); therefore, they cannot be used to determine Air Zone management levels as part of the Air Quality Management System.

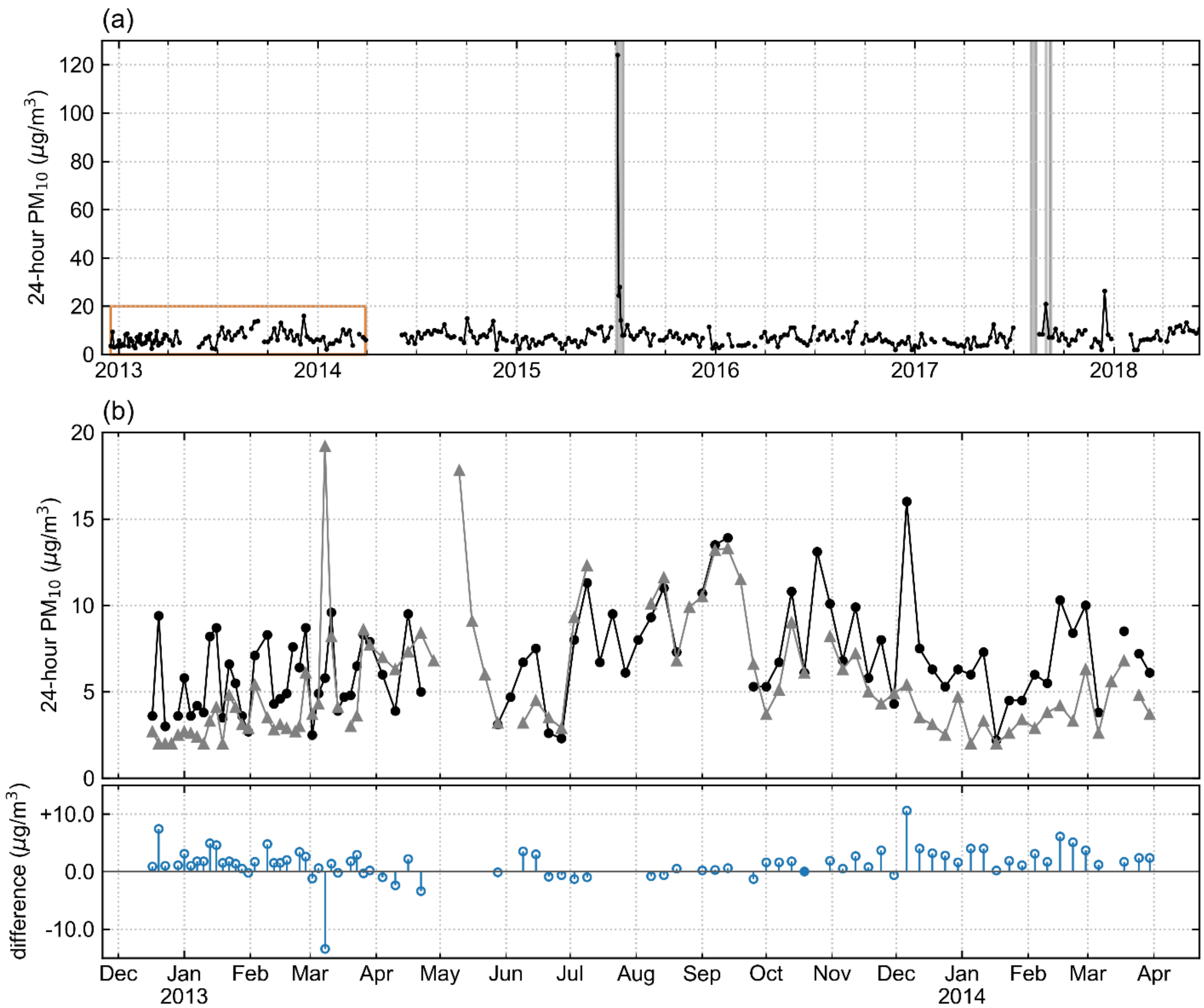


Figure 3. All valid PM_{10} concentrations measured in Sechelt during the monitoring program (includes non-NAPS days). PM_{10} measured at (a) TBM, (b)(top) TBM (black circles) and EPB (grey triangles), and (bottom) difference between synchronous PM_{10} measurements at TBM and EPB (positive values indicate higher concentrations at TBM; a filled circle indicates that PM_{10} values were the same at both sites). The period of monitoring in (b) is indicated by the red box in (a). Wildfire periods are indicated by shaded regions, but do not necessarily indicate that EE criteria are met.

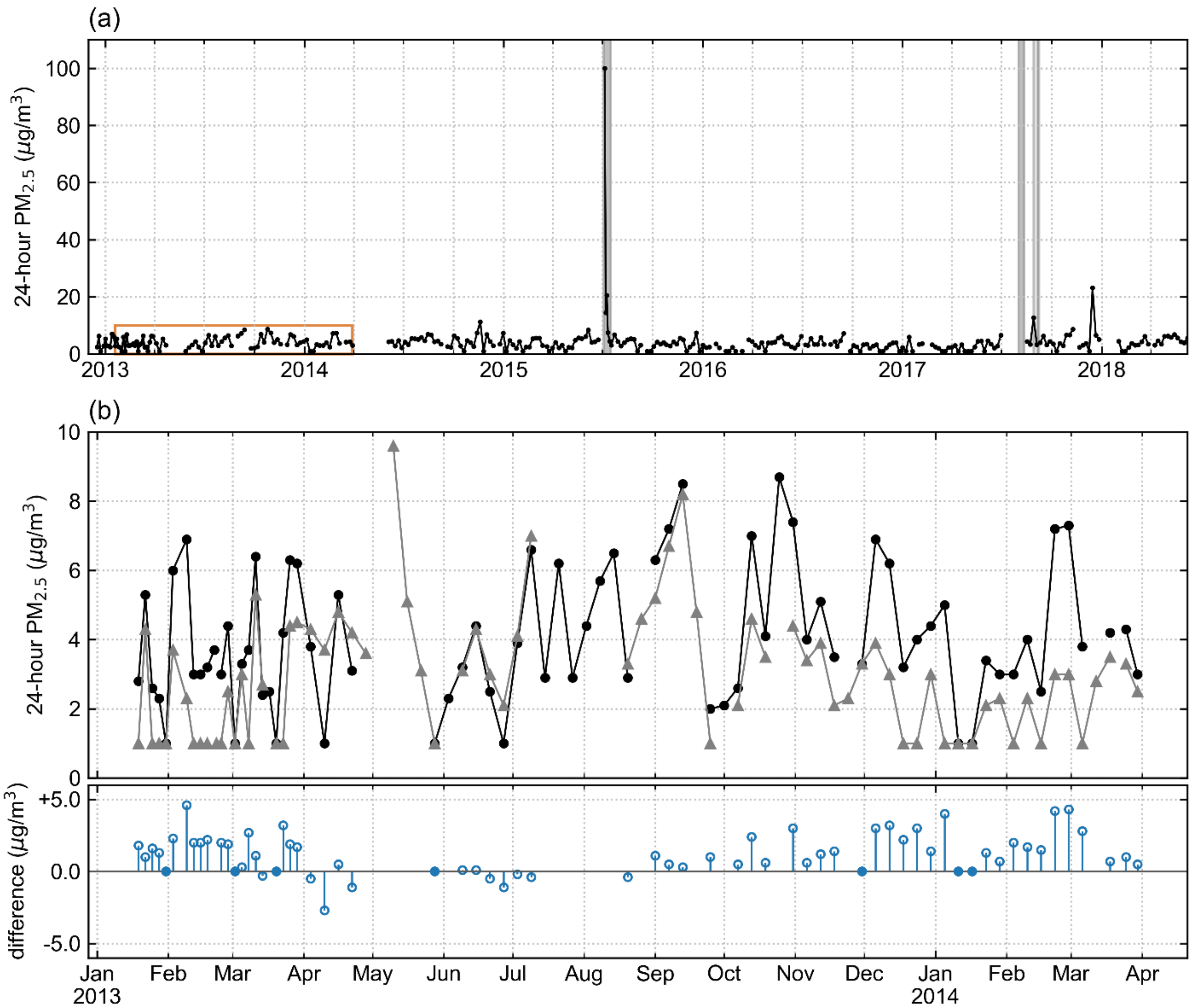


Figure 4. All valid $PM_{2.5}$ concentrations measured in Sechelt during the monitoring program (includes non-NAPS days). $PM_{2.5}$ measured at (a) TBM, (b)(top) TBM (black circles) and EPB (grey triangles), and (bottom) difference between synchronous $PM_{2.5}$ measurements at TBM and EPB (positive values indicate higher concentrations at TBM; a filled circle indicates that $PM_{2.5}$ values were the same at both sites). The period of monitoring in (b) is indicated by the red box in (a). Wildfire periods are indicated by shaded regions, but do not necessarily indicate that EE criteria are met.

Most of the highest PM values measured at TBM were caused by smoke from wildfires; however, only data from one day met all EE criteria (see Section 2.3). On July 3, 2015, a wildfire (the Old Sechelt Mine Fire) ignited 2 km west of Sechelt. The first sample at TBM during this event was taken on July 4 (per the sampling schedule); 24-hour PM concentrations were low, owing to the southerly winds which pushed the smoke northward into surrounding inlets and away from TBM (Figure B-1). In the days that followed, smoke emitted from other wildfires in southwestern B.C. was widespread throughout the region from approximately July 5 through July 11 (Figure B-2). Only one sample (July 5) at TBM during this period was attributed to an EE, as the 24-hour $PM_{2.5}$ CAAQS was exceeded: the 24-hour PM_{10} concentration was 124 µg/m^3 and the 24-hour $PM_{2.5}$ concentration was 100 µg/m^3. Though wildfire smoke may have influenced PM sampling at TBM on other days during this period, all other valid samples were included in the final dataset since they are unlikely to significantly influence the final metric values.

Other periods when 24-hour PM concentrations were elevated at TBM but did not exceed the 24-hour CAAQS (27 µg/m^3) or AQO (25 µg/m^3) included:

- Multiple wildfires in western USA caused widespread smoke across the eastern portion of the Lower Mainland, which triggered an air quality advisory in Metro Vancouver on August 29, 2017 (the 24-hour $PM_{2.5}$ at TBM was 12.7 µg/m^3; Figure B-3).
- A wintertime event on December 15, 2017, where the 24-hour $PM_{2.5}$ concentration was 23.2 µg/m^3. Based on data available, there is no clear indication of what caused comparatively elevated PM on this day. Hourly PM levels were similar on the eastern side of Vancouver Island (e.g., in Courtenay and Duncan), but this may be indicative of influence from local emissions sources rather than regional air quality conditions.

While there was another wildfire in August 2017 (B.C. Ministry of Environment and Climate Change Strategy 2019), the TBM monitor was not operational during this period.

Finally, despite the presence of some nearby industrial sources (e.g., gravel mine), no dust events were easily identifiable within the data from TBM or EPB during the monitoring period. Even if dust events had occurred in Sechelt, they may not have been detected by the instruments for several reasons, including: distance from source to monitor (larger particles may settle out closer to the source as they travel downwind, before they reach the monitor), meteorological conditions (such as wind speed and direction, causing the monitors to be located upwind rather than downwind of the emissions source), using a non-continuous sampling schedule, and using a 24-hour average sampling (which can make it difficult to determine if there was a substantial but short-lived increase in PM). A large fraction of PM from gravel sources may also be larger than PM_{10}, which means most of the dust from the source would not be measured by the instruments.

3.2 Statistics and metric values

The metric values reported here cannot be used to determine Air Zone management levels as part of the Air Quality Management System since they are not based on continuous (1-hour) measurements (per Canadian Council of Ministers of the Environment 2012).

While analyzing all valid data (including data influenced by EEs) helps communities understand their exposure to the air quality conditions that occurred, analyzing data without the influence of EEs helps guide air quality management. Once the influence of EEs (wildfires) were removed from the dataset (n = 1, which occurred in 2015), there were no exceedances of the 24-hour PM_{10} AQO or the 24-hour $PM_{2.5}$ AQO or CAAQS at TBM (Table 4) or EPB (Table 5). The 24-hour metric value at TBM for PM_{10} (26.3 µg/m^3) and $PM_{2.5}$ (12.9 µg/m^3) were the highest during this monitoring period and are likely attributed by days impacted by wildfire smoke that were not considered EEs.

Table 4. Summary statistics of PM_{10} and $PM_{2.5}$ measured at TBM. All concentrations are expressed in µg/m^3. "C" is a completeness flag, where "Y" indicates that the dataset is complete. The 98th percentile (p98) for $PM_{2.5}$ is equal to the 24-hour AQO metric value. Similarly, the annual mean for both PM_{10} and $PM_{2.5}$ represent the AQO annual metric values. The number of days above the 24-hour AQO ("n > [value in µg/m^3]") are also indicated. The CAAQS annual and 24-hour metrics are reported for $PM_{2.5}$ for all years, irrespective of completeness criteria being met.

Year	PM_{10}					$PM_{2.5}$						
	C	Annual Mean	Max 24 h	p98	n > 50	C	Annual Mean	Max 24 h	p98	n > 25	CAAQS annual	CAAQS 24-h
2012	–	3.4	3.6	3.6	0	–	2.1	2.8	2.8	0	–	–
2013	Y	7.3	16.0	13.9	0	Y	4.4	8.7	8.5	0	3.2	5.6
2014	–	7.6	15.0	14.0	0	–	4.3	11.3	7.7	0	3.6	6.3
2015	Y	7.0	14.2	12.2	0	Y	3.7	8.4	7.5	0	4.1	7.9
2016	Y	6.3	13.3	11.5	0	Y	3.1	7.2	6.2	0	3.7	7.1
2017*	–	6.8	26.3	21.0	0	–	3.9	23.2	12.9	0	3.6	8.9
2018	–	8.1	13.2	12.7	0	–	4.2	6.9	6.7	0	3.8	8.6

* PM_{10} sampling was not operational during the event January 25, 2017; it is unclear if the 24-hour PM_{10} AQO would have been exceeded or considered an EE.

Table 5. Summary statistics of PM_{10} and $PM_{2.5}$ measured at EPB. $PM_{2.5}$ monitoring at EPB did not start until 2013. See Table 4 for a description of each column.

Year	PM_{10}					$PM_{2.5}$						
	C	Annual Mean	Max 24 h	p98	n > 50	C	Annual Mean	Max 24 h	p98	n > 25	CAAQS annual	CAAQS 24-h
2012	–	2.4	2.7	2.7	0	–	–	–	–	–	–	–
2013	Y	6.5	17.8	13.3	0	Y	3.6	9.6	8.3	0	–	–
2014	–	3.8	6.8	6.7	0	–	2.0	3.5	3.4	0	2.8	5.9

There were no exceedances of annual $PM_{2.5}$ AQO or CAAQS at either monitoring site (Table 4, Table 5). In fact, the annual $PM_{2.5}$ metric values were all below the PG level of 6 µg/m^3.

There was little interannual variability of mean and median 24-hour PM_{10} and $PM_{2.5}$ concentrations at TBM (Figure 5, Figure 6). Maximum concentrations were variable, which likely indicates the occurrence of infrequent, local-scale "events" (e.g., high-wind dust events, traffic disruption, accidental fire), or the remaining influence of wildfire smoke impacts that were not considered as EEs. The $PM_{2.5}$ concentrations of a large number of samples from both sites were reported below the LOD (all lower whiskers in Figure 6 are equal to half the LOD, 1 µg/m^3; see Table 3).

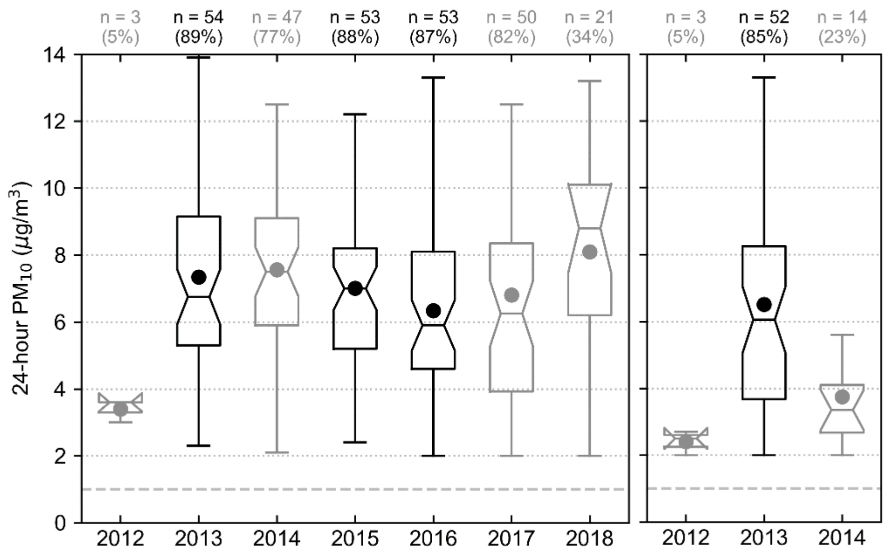


Figure 5. Distribution of 24-hour PM_{10} concentrations measured at (left) TBM and (right) EPB. Data on non-NAPS days and EEs are excluded. Box extents indicate the 25th and 75th percentile of the data. The horizontal line within each box represents the median (50th percentile). Box notches indicate the extent of the 95% confidence interval around the median. Whiskers extend to the last datum less the length of 1.5 times the interquartile range (75th to 25th percentile). The mean is represented by a filled circle. Outliers are omitted for clarity. Complete years of data (based on completeness thresholds described in Section 1.3) are plotted in black; incomplete years of data are plotted in grey. The number of samples (n) and estimated completeness are labelled above each data series. Half the LOD (grey dashed line) is also drawn, which represents the lowest possible value in each data series (i.e., all samples are ≥ 1 μg/m^3).

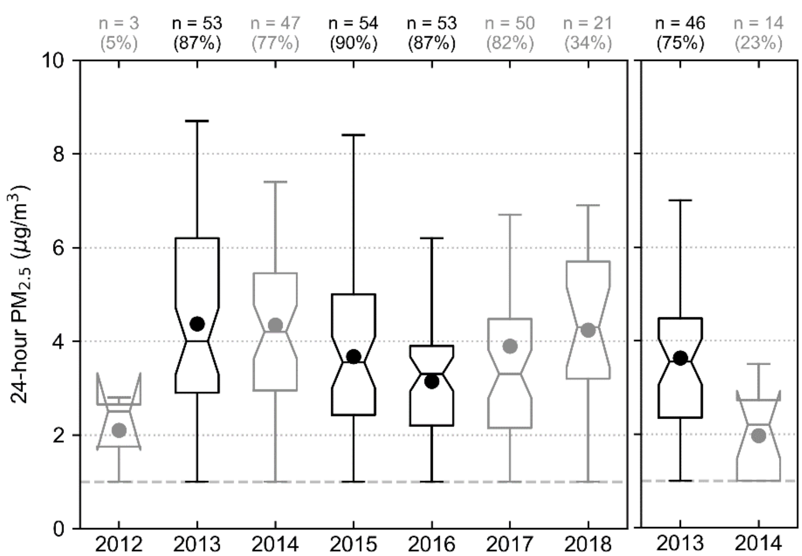


Figure 6. Distribution of 24-hour $PM_{2.5}$ concentrations measured at (left) TBM and (right) EBP. Data on non-NAPS days and EEs are excluded. Refer to Figure 5 for a description of styles and plot elements.

When compared to samples taken during the first monitoring program (e.g., McCoy 2006), the mean, median, and maximum 24-hour PM_{10} concentrations have decreased (see Appendix A for additional statistics). During the second monitoring program, there was no statistically significant change (decrease or increase) in any of the percentiles of either 24-hour PM_{10} or 24-hour $PM_{2.5}$ concentrations at TBM (Figure 7). Relatively constant values in the lowest concentrations may imply that there have not been significant changes to "background" PM in Sechelt. While there has not be a statistically significant change in the highest values (> 90th percentile), they are still relatively low, especially when compared to AQOs (see Table 4). For example, the highest 24-hour PM_{10} metric value was 26.3 µg/m^3, which is only 53% of the 24-hour PM_{10} AQO.

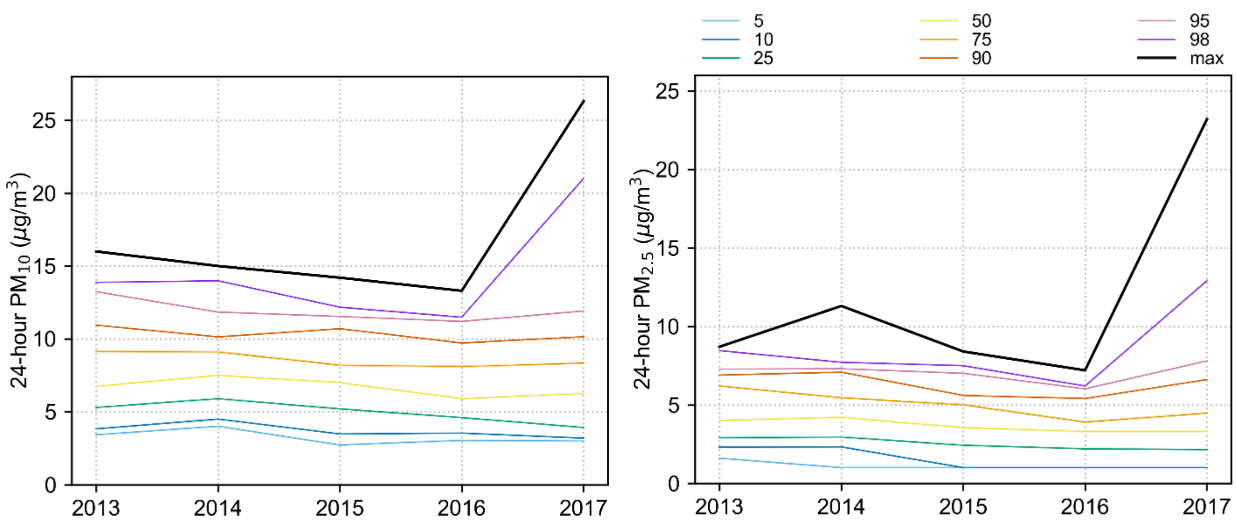


Figure 7. Maxima and percentiles at TBM for (left) 24-hour PM_{10} and (right) 24-hour $PM_{2.5}$. EE data are omitted. Refer to Table 4 for data completeness by year.

At both sites, there is a measurable difference between summer and winter[11] median values of PM_{10} and $PM_{2.5}$ (indicated by non-overlapping notches of the boxes[12] in Figure 8 and Figure 9). The highest 24-hour PM_{10} and $PM_{2.5}$ concentrations generally occurred during the summer, and the lowest in winter (based on mean and median values). This differs from some communities in B.C., where peak $PM_{2.5}$ concentrations are typically observed in the winter due to the prevalence of smoke from residential woodburning. The higher concentrations in the summer observed at TBM and EPB cannot be solely attributed to wildfire smoke events that were not considered EEs during this monitoring period. At TBM, there is some evidence that there is greater seasonal variation in 24-hour PM_{10} concentrations than $PM_{2.5}$ concentrations, especially between fall and winter. This pattern may be attributed to local dust generation (e.g., from resuspended dust on unpaved roads).

[11] Seasons are defined as: Winter = December, January, February; Spring = March, April, May; Summer = June, July, August; Fall = September, October, November.

[12] Notches on a boxplot indicate the range of the 95% confidence interval of the median (50th percentile). While not a formal statistical test, if notches from two boxes do not overlap, there is "strong evidence" (95% confidence) that the medians differ.

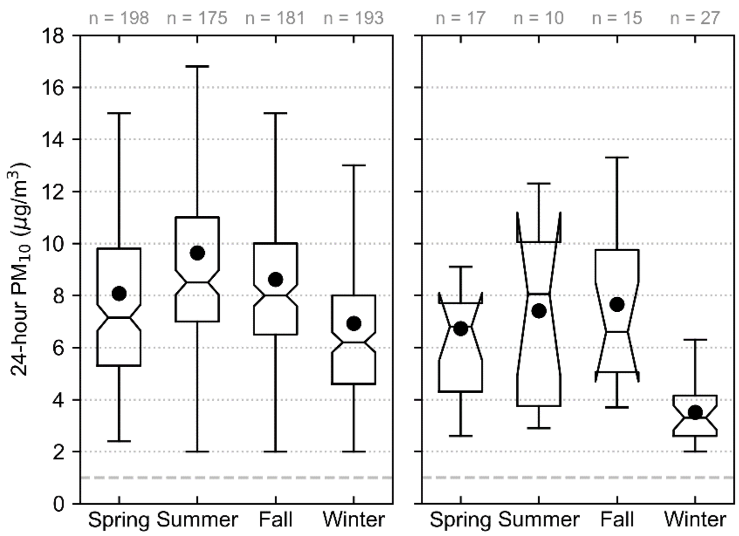


Figure 8. Distribution of 24-hour PM_{10} concentrations measured at (left) TBM and (right) EBP. Data on non-NAPS days and EEs are excluded. Refer to Figure 5 for a description of plot elements; styles for completeness criteria and colours from Figure 5 are not applicable.

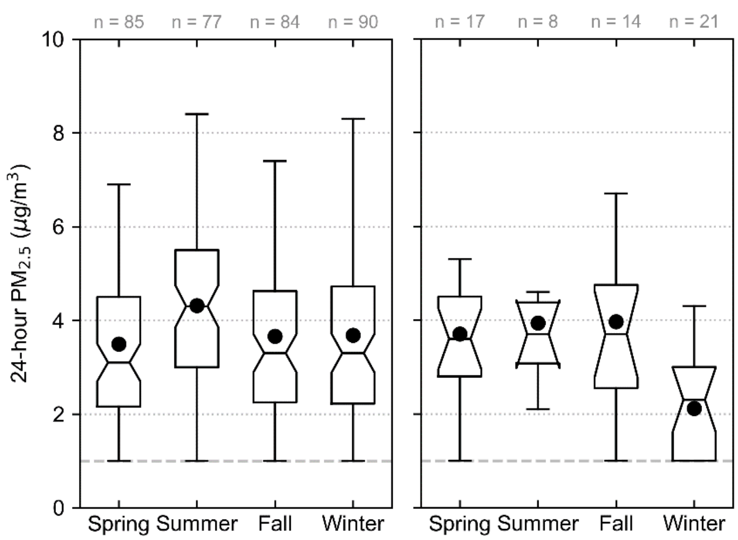


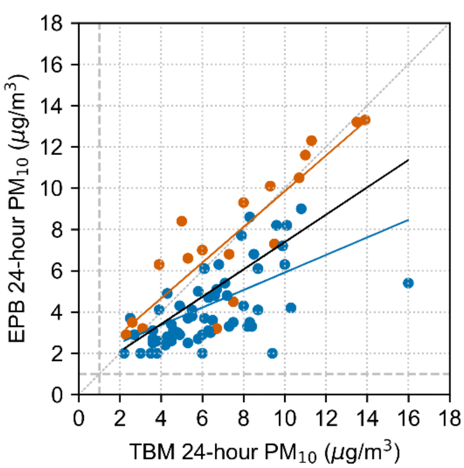
Figure 9. Distribution of 24-hour $PM_{2.5}$ concentrations measured at (left) TBM and (right) EBP. Data on non-NAPS days and EEs are excluded. Refer to Figure 5 for a description of plot elements; styles for completeness criteria and colours from Figure 5 are not applicable.

3.3 Comparison of air quality between monitoring sites

PM concentrations at EPB are similar to those at TBM. PM_{10} and $PM_{2.5}$ are generally lower at EPB during cold months[13] (see Figure 9 and Figure 10), and air quality is similar among the sites during warm months (difference between samples on a given day is smaller; see lower panel of Figure 3 and Figure **4**). A simple linear regression was applied to all data (including non-NAPS days, but excluding EEs), which further substantiates this finding: slopes are closer to 1.0 for samples taken during warm months, with higher positive correlation coefficients (r) (Table 6, Figure 10). Other findings include: (a) 24-hour PM_{10} concentrations at EPB do not greatly exceed those at TBM, despite the proximity to some industrial sites, and (b) 24-hour $PM_{2.5}$ concentrations at EPB during cold months are often low (below the LOD), and often lower than those at TBM, despite the proximity to potential influence from residential woodburning.

Table 6. Linear regression results for 24-hour PM_{10} and $PM_{2.5}$ values at TBM and EPB. The slope (m) and intercept (b) are in units of μg/m³.

	PM_{10}					$PM_{2.5}$				
Season group	**n**	**m**	**b**	**p-value**	r	**n**	**m**	**b**	**p-value**	r
Warm	18	0.86	1.20	< 0.05	0.88	15	0.76	1.21	< 0.05	0.91
Cold	59	0.42	1.67	< 0.05	0.41	42	0.58	-0.09	< 0.05	0.70
All	77	0.66	0.76	< 0.05	0.59	57	0.62	0.28	< 0.05	0.65



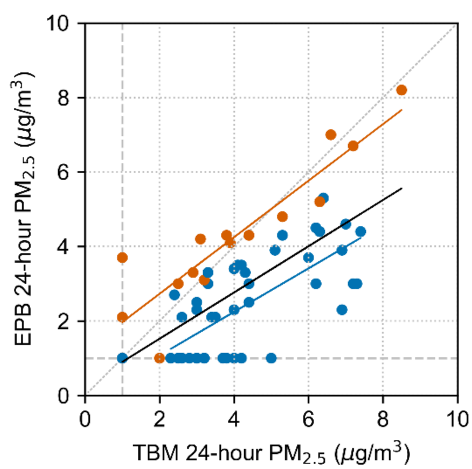


Figure 10. Valid samples of 24-hour PM_{10} (left) and $PM_{2.5}$ (right) at TBM and EPB. Samples during cold months (October through March) are plotted in blue; samples during warm months (April through September) are plotted in orange. A linear regression (solid black line) was applied to all samples; linear regression for cold (blue) and warm (orange) months are also provided. Half the LOD (grey dashed line) is indicated, which represents the lowest possible value in each data series.

[13] Cold months are September through March; warm months are April through August.

4. Discussion and future work

Based on the data collected during the second monitoring program at two locations in Sechelt, there is little evidence of local air quality issues related to PM_{10} or $PM_{2.5}$ in terms of meeting air quality objectives; air quality in Sechelt can be regarded as excellent.

To determine if localized dust events were occurring, monitoring at EPB was conducted. The monitoring results from EPB were not significantly different from those at TBM, and there were no exceedances of the AQOs.

Short-lived and sporadic increases in PM may be a concern in some neighbourhoods in Sechelt. These types of events can be caused by localized sources such as smoke from woodburning appliances (such as woodstoves), open burning of vegetative debris and resuspended dust from industrial sources and unpaved roads. These sources of PM tend to be quite localized and intermittent, which makes it difficult to capture in typical monitoring networks. Continuous monitoring or more refined monitoring targeting local emissions sources[14] may be useful, but local initiatives and programs can be more effective in addressing those sources and minimizing their impacts on air quality, namely:

- Working with local governments on updating and enhancing local air quality bylaws and outreach and education programs, and
- Supporting local airshed groups in their ongoing educational, stewardship and monitoring programs.

5. Summary

Sechelt is the most populated center on the Sunshine Coast of B.C. and has undergone significant development and expansion over the past few decades. Temporary air quality monitoring stations at TBM and EBP were established in 2012 to measure non-continuous time-integrated samples of PM_{10} and $PM_{2.5}$; this was the second monitoring program to be conducted at TBM (the first monitoring program was from 1999 to 2008). The goal of this monitoring program was to assess if there have been changes in air quality conditions and examine the variability of PM concentrations across the community.

While the statistics presented in this report do not represent true metric values (due to the non-continuous sampling method) and completeness criteria were not always met, they can provide useful insight to the air quality conditions in Sechelt:

- PM levels are generally low, indicating overall good air quality.
- There have been no statistically significant changes in 24-hour PM_{10} and $PM_{2.5}$ statistics at TBM from 2012-2018, though some of the metric values and other statistical measures have slightly decreased since the first monitoring program (1999–2008).
- During the monitoring period, PM levels at TBM and EPB were lower than at other stations in B.C.; many samples of $PM_{2.5}$ were below the laboratory LOD.
- The highest PM values measured at TBM were caused by smoke from wildfires. There was no clear indication of high dust events.

[14] For example, Lehigh Hanson Materials Limited (Lehigh Materials), who currently operates the gravel mine in Sechelt, has implemented a local network of low-cost PurpleAir sensors to monitor PM_{10} and $PM_{2.5}$ concentrations near the mine. PurpleAir sensors cannot be used for regulatory monitoring purposes and may yield measurements that differ from those measured with typical regulatory monitoring instruments.

- There were no exceedances of the annual or 24-hour AQOs for PM_{10} or $PM_{2.5}$ at either site (once the influence of wildfires was removed). The annual $PM_{2.5}$ metric values were below the PG level (6 µg/m^3) as well.
- The highest 24-hour PM_{10} and $PM_{2.5}$ concentrations generally occurred during the summer, the lowest in winter. This differs from other communities in B.C., where high $PM_{2.5}$ concentrations occur in the winter due to residential woodburning.
- PM concentrations at TBM and EPB were similar, despite proximity to different potential emissions sources.

Continued collaboration at the local level can help support activities to continue reducing PM emissions and continue improving air quality in Sechelt.

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Appendix A: Ambient particulate matter statistics

Table A-1. 24-hour PM_{10} statistics and metric values at TBM, excluding data from EEs. Data are from NAPS days only. The estimated annual percentage completeness ("comp.") is based on the number of samples (n). All concentration values are in μg/m³.

Year						Percentile							AQO
	n	comp.	mean	min	max	10	25	50	75	90	95	98	n > 50
1999	30	50	13.1	4.0	69.0	5.9	7.0	9.0	15.3	22.1	32.6	48.1	1
2000	57	93	9.8	4.0	25.0	5.0	7.0	9.0	12.0	14.4	17.0	21.4	0
2001	57	93	8.2	3.0	19.0	5.0	6.0	8.0	10.0	11.0	12.2	17.4	0
2002	46	75	8.1	4.0	23.0	4.0	5.0	7.0	10.5	13.0	14.8	15.8	0
2003	36	59	8.4	4.0	16.0	6.0	7.0	8.0	9.0	11.5	13.3	14.6	0
2004	30	49	8.1	4.0	14.0	5.0	5.3	8.0	10.0	12.1	13.0	13.4	0
***2005**	45	74	9.5	4.0	24.0	5.4	7.0	9.0	11.0	13.0	14.0	15.2	0
2006	49	80	8.5	5.0	15.0	5.8	7.0	8.0	9.0	13.0	13.6	15.0	0
2007	43	72	7.4	2.5	14.0	3.7	5.3	7.0	9.6	11.8	13.8	14.0	0
2008	52	85	9.2	2.0	26.8	3.8	6.0	8.1	11.4	16.2	18.6	21.9	0
2009	21	34	10.8	3.8	49.8	5.1	5.8	6.5	13.7	17.6	18.3	37.2	0
2012	3	5	3.4	3.0	3.6	3.1	3.3	3.6	3.6	3.6	3.6	3.6	0
2013	54	89	7.3	2.3	16.0	3.8	5.3	6.8	9.2	10.9	13.2	13.9	0
2014	47	77	7.6	2.1	15.0	4.5	5.9	7.5	9.1	10.1	11.8	14.0	0
2015	53	88	7.0	2.4	14.2	3.5	5.2	7.0	8.2	10.7	11.5	12.2	0
2016	53	87	6.3	2.0	13.3	3.5	4.6	5.9	8.1	9.7	11.2	11.5	0
2017	50	82	6.8	2.0	26.3	3.2	3.9	6.3	8.4	10.2	11.9	21.0	0
2018	21	34	8.1	2.0	13.2	5.4	6.2	8.8	10.1	11.5	12.0	12.7	0

*Statistics up to 2005 may differ from those presented in previous reports, due to updated data handling and quality assurance procedures.

Table A-2. As in Table A-1, but including data from EEs. Only years affected by including data during EEs are included.

Year						Percentile							AQO
	n	comp.	mean	min	max	10	25	50	75	90	95	98	n > 50
2015	54	90	9.2	2.4	124.0	3.5	5.3	7.0	8.5	11.2	11.8	14.1	1

Table A-3. 24-hour $PM_{2.5}$ statistics and metric values at TBM, excluding data from EEs. Data are from NAPS days only. The estimated annual percentage completeness (“comp.”) is based on the number of samples (n). All concentration values are in µg/m^3. A minimum value of 1.0 indicates that half the value of the LOD was used (LOD = 2 µg/m^3). Some CAAQS metric values may be reported using incomplete years of data.

Year						Percentile							AQO	CAAQS		
	n	comp.	mean	min	max	10	25	50	75	90	95	98	n > 25	n > 27	24 h	Annual
2008	34	56	2.8	1.0	7.8	1.0	1.0	2.2	4.1	5.7	6.3	7.3	0	0	–	–
2009	21	34	4.0	1.0	20.3	1.0	2.0	2.8	4.6	6.6	8.3	15.5	0	0	11.4	3.4
2012	3	5	2.1	1.0	2.8	1.3	1.8	2.5	2.7	2.7	2.8	2.8	0	0	–	–
2013	53	87	4.4	1.0	8.7	2.3	2.9	4.0	6.2	6.9	7.3	8.5	0	0	5.6	3.2
2014	47	77	4.3	1.0	11.3	2.3	3.0	4.2	5.5	7.1	7.3	7.7	0	0	6.3	3.6
2015	54	90	3.7	1.0	8.4	1.0	2.4	3.6	5.0	5.6	7.0	7.5	0	0	7.9	4.1
2016	53	87	3.1	1.0	7.2	1.0	2.2	3.3	3.9	5.4	6.0	6.2	0	0	7.1	3.7
2017	50	82	3.9	1.0	23.2	1.0	2.2	3.3	4.5	6.6	7.8	12.9	0	0	8.9	3.6
2018	21	34	4.2	1.0	6.9	2.3	3.2	4.3	5.7	6.2	6.3	6.7	0	0	8.6	3.8

Table A-4. As in Table A-3, but including data from EEs. Only years affected by including data during EEs are included.

Year						Percentile							AQO	CAAQS		
	n	comp.	mean	min	max	10	25	50	75	90	95	98	n > 25	n > 27	24 h	Annual
2015	55	92	5.4	1	100.0	1.0	2.5	3.6	5.0	5.7	7.4	8.3	1	1	8.2	4.7
2016	53	87	3.1	1	7.2	1.0	2.2	3.3	3.9	5.4	6.0	6.2	0	0	7.4	4.3
2017	50	82	3.9	1	23.2	1.0	2.2	3.3	4.5	6.6	7.8	12.9	0	0	9.1	4.2
2018	21	34	4.2	1	6.9	2.3	3.2	4.3	5.7	6.2	6.3	6.7	0	0	8.6	3.8

Table A-5. 24-hour PM_{10} statistics and metric values at EPB. There were no EEs during this period. Data are from NAPS days only. The estimated annual completeness ("comp.") is based on the number of samples (n). All concentration values are in µg/m³.

Year						Percentile							AQO
	n	comp.	mean	min	max	10	25	50	75	90	95	98	n > 50
2012	3	5	2.4	2.0	2.7	2.1	2.3	2.5	2.6	2.7	2.7	2.7	0
2013	52	85	6.5	2.0	17.8	3.1	3.7	6.1	8.3	11.4	12.7	13.3	0
2014	14	23	3.7	2.0	6.8	2.2	2.7	3.3	4.1	6.1	6.5	6.7	0

Table A-6. 24-hour $PM_{2.5}$ statistics and metric values at EPB. There were no EEs during this period. Data are from NAPS days only. The estimated annual completeness ("comp.") is based on the number of samples (n). All concentration values are in µg/m³. A minimum value of 1.0 indicates that half the value of the LOD was used (LOD = 2 µg/m³). Some CAAQS metric values may be reported using incomplete years of data.

Year						Percentile							AQO	CAAQS		
	n	comp.	mean	min	max	10	25	50	75	90	95	98	n > 25	n > 27	24 h	Annual
2013	46	75	3.6	1.0	9.6	1.0	2.3	3.6	4.5	5.3	6.9	8.3	0	0	–	–
2014	16	23	2.0	1.0	3.5	1.0	1.0	2.2	2.7	3.0	3.2	3.4	0	0	5.6	2.8

Appendix B: Additional figures

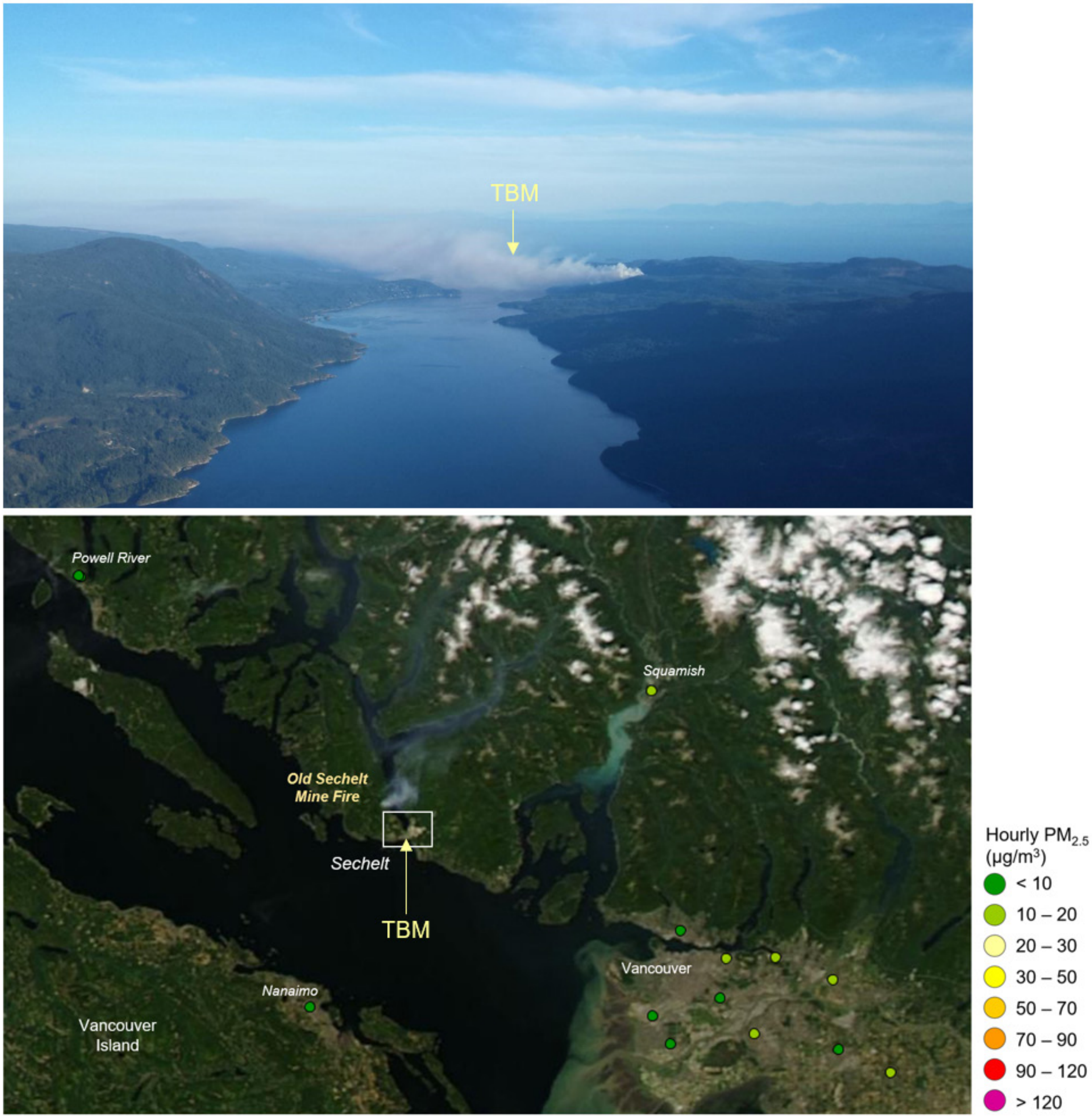

Figure B-1. Old Sechelt Mine Fire in Sechelt, July 2015. (top) Photograph of the smoke plume from the Old Sechelt Mine Fire, facing south. The village of Sechelt and TBM monitoring site are obscured by the plume. Taken by BC Wildfire Services on July 2, 2015. (bottom) Satellite imagery (via MODIS Aqua) is valid at ~13:30 LST; 1-hour $PM_{2.5}$ concentrations (coloured circles) on July 4, 2015, at 14:00 LST. Layers available from the U.S. Environmental Protection Agency's AirNow-Tech platform (www.airnowtech.org).

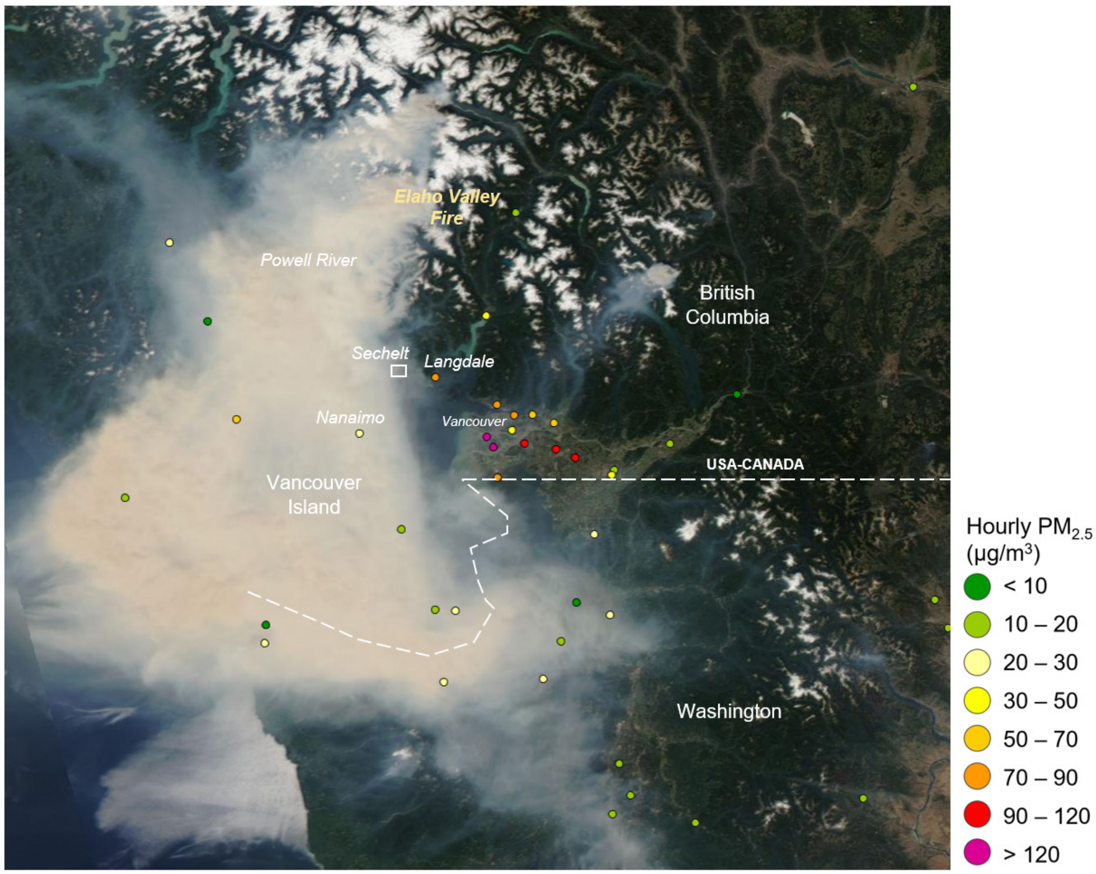

Figure B-2. Smoke from fires in southeastern B.C., July 5, 2015. Satellite imagery (via MODIS Aqua) is valid at ~13:30 LST; 1-hour $PM_{2.5}$ concentrations (coloured circles) are valid at 16:00 LST. Layers available from the U.S. Environmental Protection Agency's AirNow-Tech platform (www.airnowtech.org).

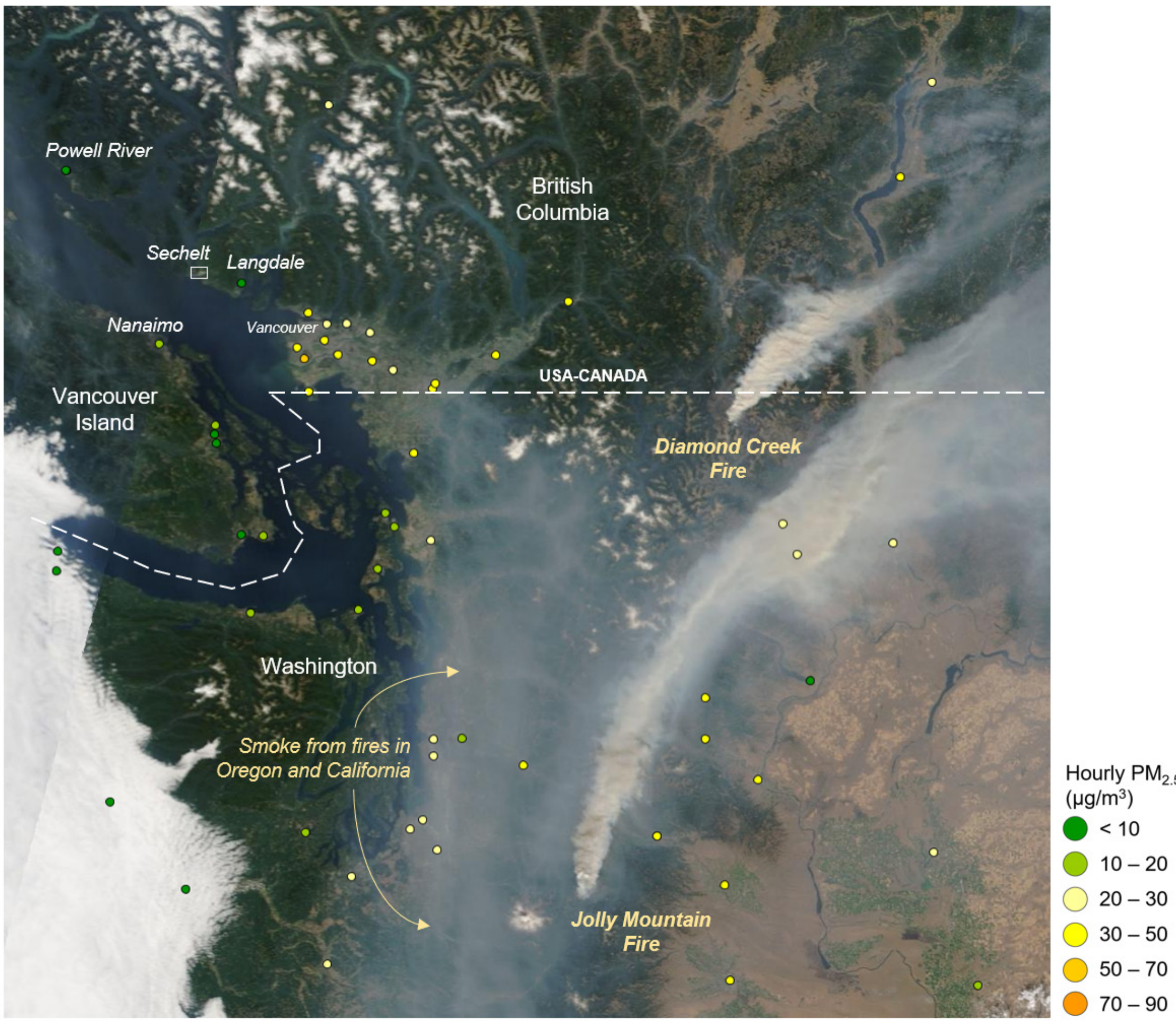

Figure B-3. Smoke from fires in southeastern B.C., August 29, 2017. Satellite imagery (via MODIS Terra) is valid at ~10:30 LST; 1-hour $PM_{2.5}$ concentrations (coloured circles) are valid at 10:00 LST. Layers available from the U.S. Environmental Protection Agency's AirNow-Tech platform (www.airnowtech.org).