Updated Micro-emissions Inventory for the Bulkley Valley Airshed of BC

PHASE 4

FINAL REPORT

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Executive Summary

The Bulkley Valley – Lakes District (BVLD) in Northwestern BC, is marked by jagged mountain peaks and serene river valleys, the same features that make it a hub of resource activity and a hot-spot for particulate matter pollution. A combination of local sources, and local geography combine to give what would be a pristine northern paradise, a clouded grey hue of an unrinsed dishcloth.

The District has numerous air quality advisories each year, and community concern regarding local air quality, particularly particulate matter (PM), has led to some promising initiatives. But the truth is in the data, and despite local efforts more needs to be done to reduce particulate pollution, particularly finer particles or less than 2.5 μm (microns) in diameter ($PM_{2.5}$), or sub-micron nano-sized particles formed largely via incomplete fuel combustion (PM_1). Not only are small particles more difficult to see, they are also harder to measure and are more adept at triggering human health responses.

This micro-emissions inventory is considered "micro" because 1) it only inventories airborne particulate matter (PM) which is an extraordinarily diverse class of pollutant in terms of both chemical and physical properties; and 2) it covers a relatively small region (≈ 41500 km^2) approximating the BVLD, and over-lapping mostly with the Bulkley-Nechako Regional District, but also with some of the Kitimat-Sitikine Regional District.

This report summarises the methods and premise used to estimate PM emissions from sources that may be making a substantial contribution to PM pollution in the area. Appendix B contains more detailed source information and is provided in digital form for further use. The goal was to provide an update of the year 2000 and 2001 MEI produced for the BVLD Airshed Management Society (Weinstein, 2005), and improve the spatial representation of emission sources and effects and provide some guidance to local decision makers.

1 Introduction

1.1 Background

Of all the necessities of life air is perhaps the most important. While we can go hours or days without water or food, respectively, we can only be minutes without air. However, the quality of the air we breathe depends on its composition, which is affected by the release of thousands of substances, originating from a variety of anthropogenic (industrial, commercial, residential) and natural (biological, chemical, physical) activities or processes.

Detailed information regarding the releases of these 'atmospheric emissions' is required for activities such as: airshed planning, human health protection, risk assessment, conservation efforts, project permitting and/approval approval, community education, local interest and atmospheric modelling (e.g. climate, pollution and even weather, forecasts). This information is typically prepared in the form of an emissions inventory (EI) that can vary significantly in terms of scale, detail, source and/or contaminant inclusion, accuracy, and format depending on the purpose for which the inventory is developed, and the information available at the time of EI preparation.

The air pollutants most commonly inventoried, emitted and regulated are known collectively as 'criteria air contaminants' (CAC, or sometimes 'common air contaminants') and include carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulphur (SO_x), volatile organic compounds (VOC), and particulate matter (PM). These are considered 'criteria' pollutants due to their direct impacts on human and environmental health; and for their contributions to acid deposition ('acid rain') and photochemical 'smog' formation. With the exception of CO, all CAC represent a class or grouping of pollutants rather than a single chemically distinct substance (see: Glossary, Appendix A.1). Ammonia (NH_3) is also a commonly inventoried pollutant, particularly in agricultural areas, and is a chemically distinct substance. Specific jurisdictions or organisations may inventory additional pollutants due to unique problems with pollutants not considered a CAC; [e.g. Canadian Association of Petroleum Producers (CAPP) Inventory of Greenhouse Gases and Criteria Air Contaminants (Clearstone Engineering 2005)].

Inventories of atmospheric emissions are often created for regulatory purposes. In these cases lower jurisdictional levels may report emissions within their geographic area to higher jurisdictional levels. An example would be the federal governments' reporting of greenhouse gas (GHG) emissions to the *United Nations' Framework Convention on Climate Change* (UNFCCC)—information that is supplied to the federal government by each province/territory, who collect information on/from individual sources/emitters. Similarly, some atmospheric pollutants are reported at the inter- or multinational-level due to their ability to be transported over long distances through mechanisms such as the United Nations Economic Commission for Europe (UNECE)'s 1979 *Convention on Long-Range Transboundry Air Pollution Agreement* (CLRTAP) or the 1991 *Canada-United States Air Quality Agreement*[1]. But many air pollutants can have more direct impacts, and at more local scales. As such these emissions may be of interest to local communities, their members and their representatives.

[1] See: http://www.unece.org/fileadmin//DAM/env/lrtap/welcome.html and https://www.canada.ca/en/environment-climate-change/services/air-pollution/issues/transboundary/canada-united-states-air-quality-agreement-overview.html, respectively

Local and regional concern regarding PM emissions and ambient PM levels (exposure) led to the formation of a micro-emissions inventory (MEI) of PM prepared for the region's Airshed Management Society (AMS) in 2005, based on year 2001 and 2002 data (Weinstein, 2005). The inventory was considered 'micro' for two main reasons: first, it represented emissions at the regional/community level—the BVLD (≈35,000 km^2); and second, it accounted for emissions of PM only.

Fifteen years later, this MEI is out-of-date. The use of 2001 and 2002 emissions means that two decades have passed since the data presented in the inventory were timely. This document represents an updated MEI for the BVLD using data for the years 2015 and 2016. Although these years are also in the past, they represent years for which data were most readily available (see Section 2.1).

The purpose of the MEI on which this report is based is four-fold:

- help understand how PM emissions vary with space and time in the BVLD,
- identify primary sources / source-types that contribute to reduced regional air quality,
- inform decision-makers of options for improved airshed management and planning, and
- provide an answer to: "what is the 'best' emissions inventory that can be developed for the BVLD based on the available information and resources".

This document represents the final inventory report, including background, methods used, results and related data. The report aims to achieve all four individual purposes in a combined and holistic manner.

1.2 Regional Geography and Meteorology

Geographic elements such as topography local and meteorology both strongly influence the way pollutants disperse and eventually settle in any given area. As such, spatial aspects also influence biological outcomes and/or impacts—i.e. whether or not a biological receptor will be affected by a specific source, combination of sources, etc. The MEI includes sources located within what is roughly the Bulkley Valley and Lakes District (BVLD) of BC as shown in Figure 1. The study area has a total area of 41,497 km^2. The area is mountainous, with elevations ranging from 600 – 1650 masl.

As illustrated by Figure 1, the BVLD represents an area of complex terrain, marked by the main Bulklely Valley and its tributaries, as well as numerous water features. Mountains and valleys have specific meteorology that affects pollutant 'behaviour', particularly how pollutants are distributed and transported, as well as how they may interact with one another and with biological receptors such as humans. Suspended particles (PM) have the habit of collecting in low-lying areas such as valleys particularly during the winter or night-time when a persistent stable boundary layer may inhibit atmospheric mixing near the land surface and down valley breezes transport back towards their source of origin.

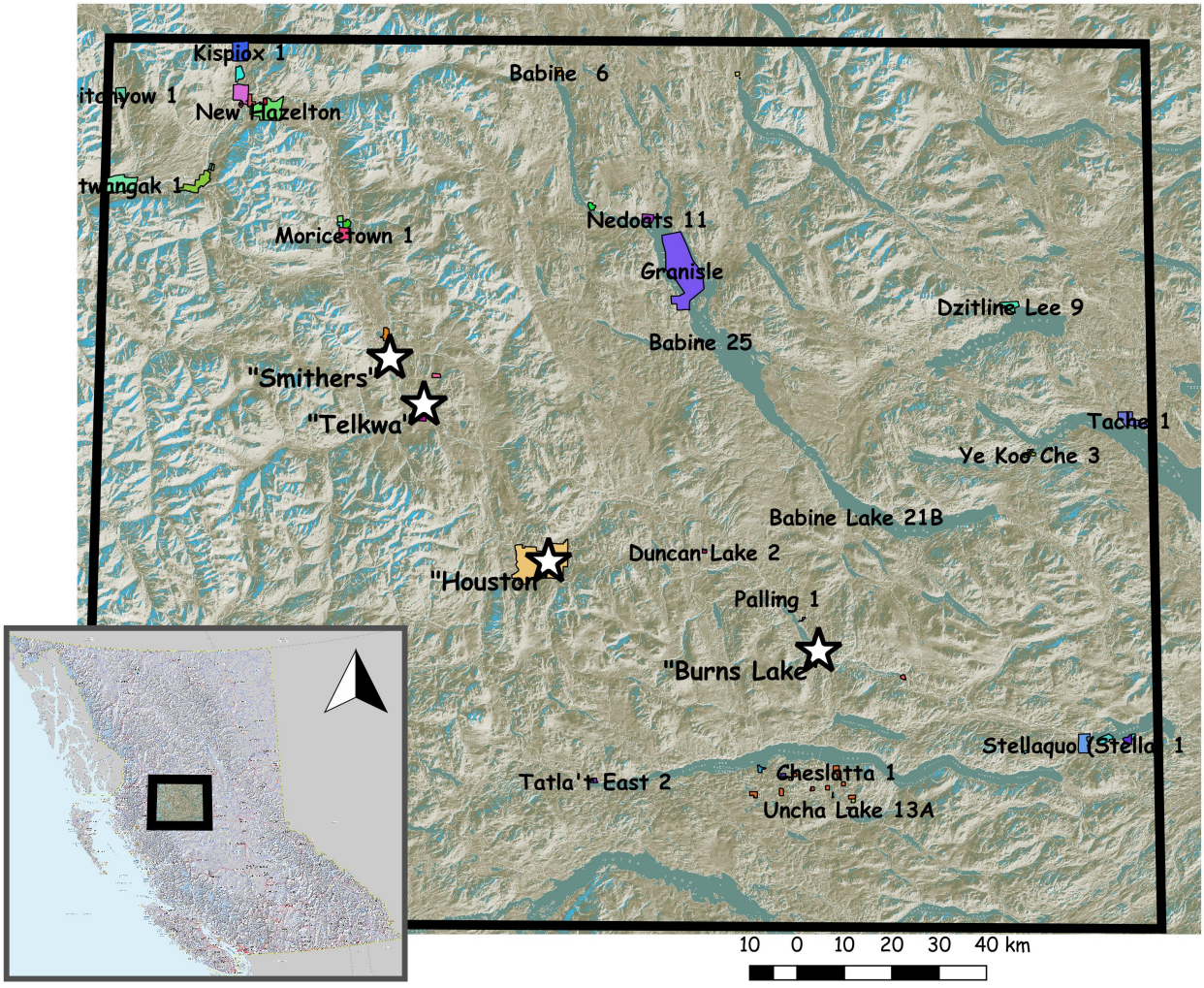


Figure 1. Map of study area in relation to province of BC showing the locations of MOECC's meteorological/PM monitoring stations (white stars) and some of the local communities (coloured polygons); all labelled. Other maps presented in this report use the same scale and

The mountain and valley breeze cycle, typical of temperate zones with complex terrain, is illustrated in Figure 2. In the early morning, sunlight hits and consequently warms the valley slopes, which warm the air that's in contact with them. This heated air expands, becoming less dense than the surrounding valley air, and rises gently up the valley slopes—an air current known as a 'valley breeze' (Figure 2a). This rising air intensifies and during the afternoon the strengthened valley breeze develops an airflow up towards the head of the valley (Figure 2b) developing a region of low pressure at the valley bottom. If the upward moving air masses carry sufficient moisture they build cumulus clouds along mountain ridges and can develop into late afternoon rain showers or thunderstorms. Valley breezes are strongest on slopes with southern exposure as they receive the most incoming solar radiation. East-facing slopes will begin to warm first just after dawn, but will also become shaded first in the afternoon. This shading, or lack of direct sunlight, cools the slopes and the air in contact with them. Consequently, the cooler air becomes more dense relative to surrounding air and sinks, creating a downslope flow (Figure 2c) and eventually a down valley wind, known as a 'mountain breeze', which dominates mountain valleys and slopes in all directions after dusk (Figure 2d).

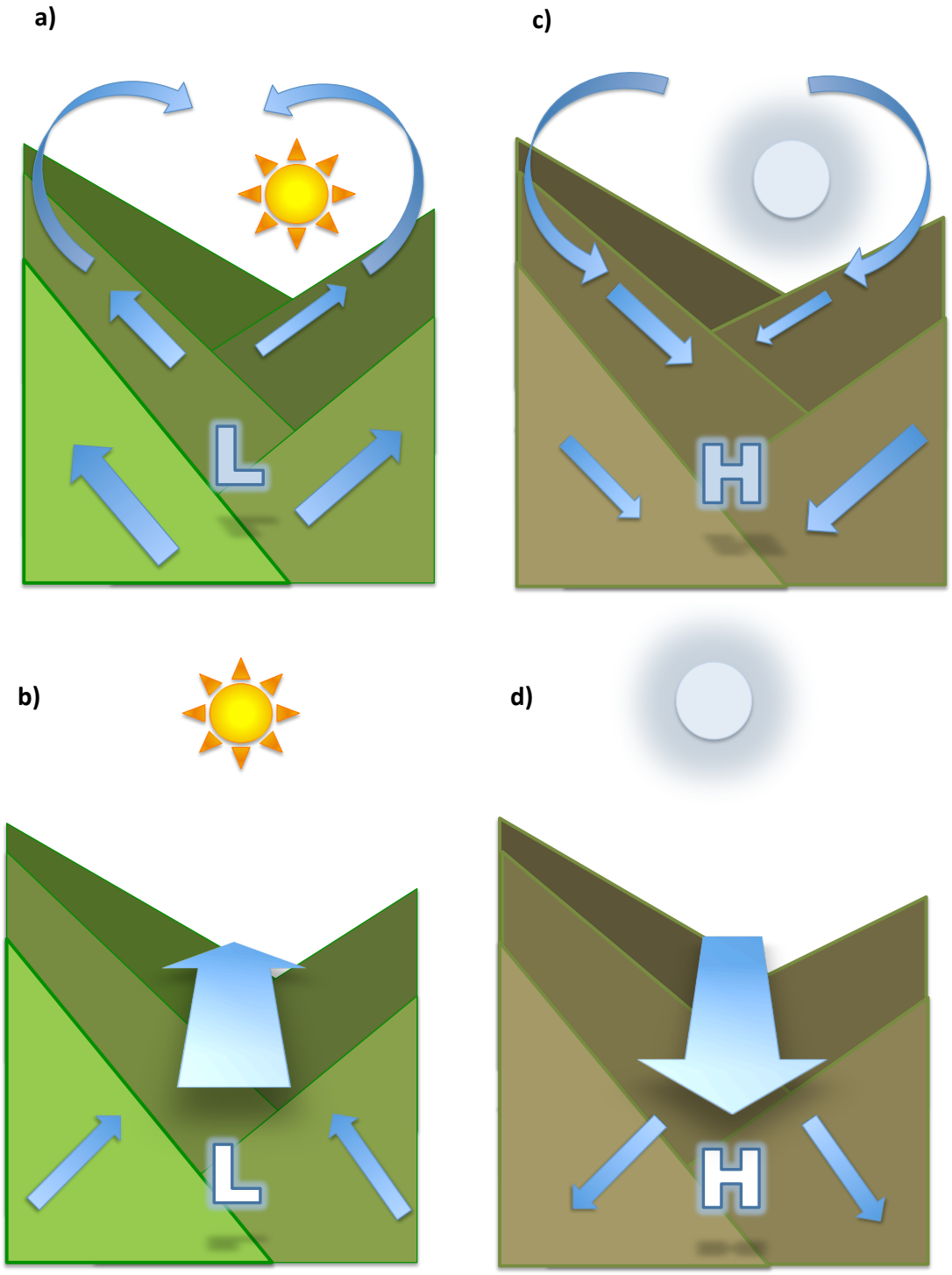


Figure 2. Graphical representation of local airflow in complex terrain and a temperate climate, from top-left down: a) valley breeze developing shortly after sunrise; b) developed midday valley breeze; c) mountain breeze developing just after dusk; and d) developed mid-night (early morning) mountain breeze.

The down valley mountain breeze also dominates winter months when there are more hours of cooling (dark) than warming (sunlight), meaning that pollutants such as PM may have little chance to escape their valley of origin. Instead, pollutants keep flowing back down into the valley

from which they originate. This wintertime pollutant build-up is worsened in times of general atmospheric stability— when cold air sits below (rather than above) warmer air thereby inhibiting vertical mixing and pollutant transport or dispersion. Pollutants may persist in valleys for days on end, or for as long as this 'temperature inversion' that inhibits vertical mixing persists.

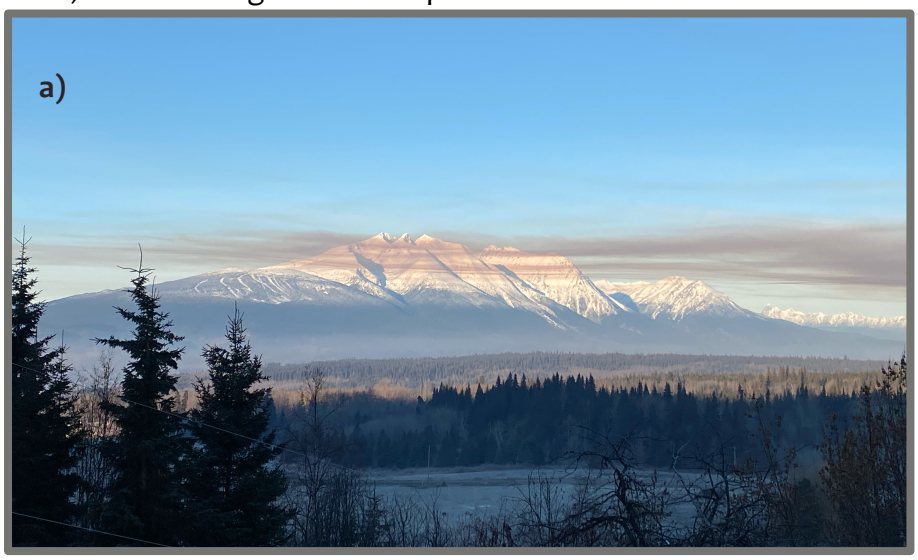
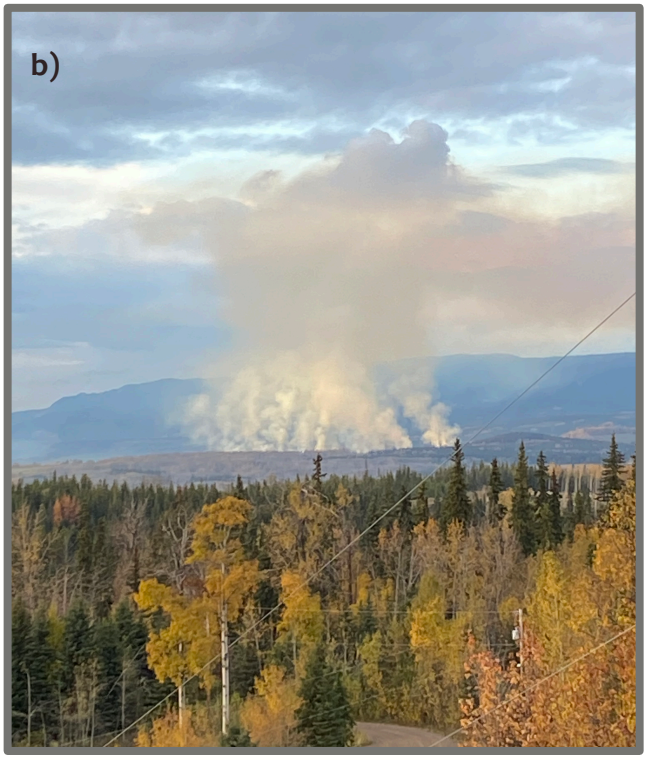


Figure 3. Photos taken in the study area from Hillcrest Road just off Babine Lake Road a) around 9:00 am in the winter showing the settled night-time PM beginning to slowly lift from the valley floor, but likely will not make it out of the valley; and b) autumn open burning for resources management showing an evening inversion capping plume-rise at about the same height as the photographer. Images courtesy of Servaas Mes, all rights reserved.



The BVLD, is therefore prone to the accumulation of pollutants, as are the smaller surrounding (tributary) valleys. Valleys are also where the majority of the region's population resides, where local agriculture is practiced (Government of BC 2018c), and where the majority of large pollutant sources are located (see following). It follows that pollutant accumulation may be of particular concern in the low-lying areas of the BVLD, where PM is most likely to influence human-, crop-, and/or animal health.

Winds are the largest driver of pollutant dispersion, mixing and eventual fate at the surface**.** The government of BC's MOECC has four meteorological monitoring stations in the BVLD (see Figure 1). In 2015 and 2016 wind speed and direction were measured in each Smithers, Houston, and Burns Lake, while precipitation measurements are taken in Telkwa. These sites also monitor ambient PM; however, the Telkwa site measured only $PM_{2.5}$ and stopped doing so in May 2015.

All monitoring sites are located within the (Bulkley River) valley where residents are most likely to be exposed to PM. Winds in the area tend to be very light (Figure 4a-f) and their prevalence varies greatly from site to site; thus illustrating how the local topography influences local air flow, climate and therfore, pollutant transport.

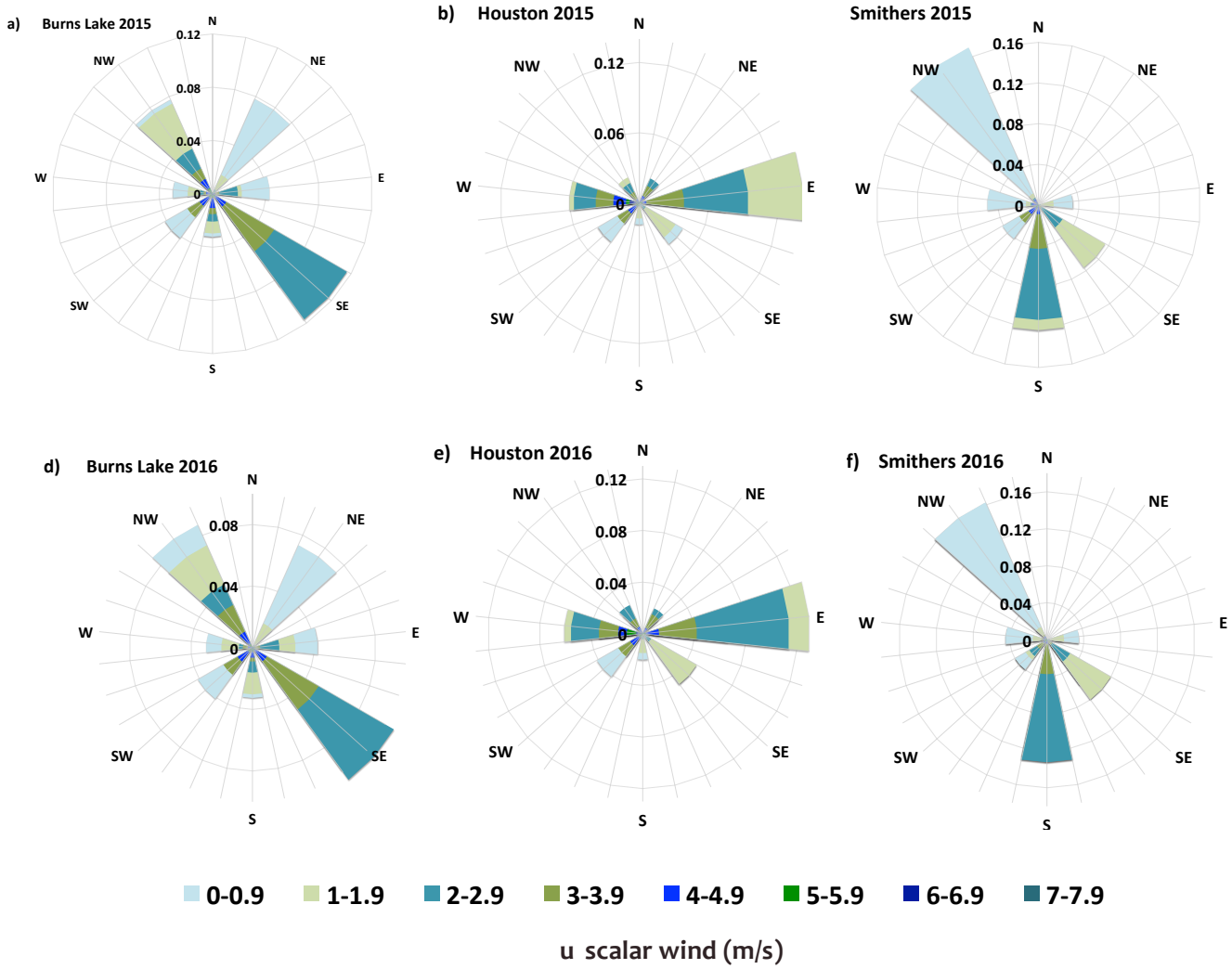


Figure 4. Wind roses for the year 2015 (a-c) and 2016 (d-f), developed using MOECC wind speed and direction data from sites in Burns Lake, Houston, and Smithers—that also monitor PM; Telkwa did not have scalar wind measurements for either year. Data were processed and displayed using Microsoft Excel for Mac™ as ratios of wind events rather than a count or percentage. Note that darker colours, representing stronger winds are less frequent and therefore confined to wind rose centers.

The BVLD is marked not only by complex terrain in peaks and valleys, but as indicated by the "L" in its name, the District is also home to hundreds of lakes. Like mountain slopes and valleys, bodies of water can inflict a strong influence on local pollutant movement and transport. Lakes have more moderate seasonal and diurnal temperature patterns than land surfaces, and so tend to be cooler than the surrounding air/land in the summer, while warmer than the surrounding air/land in the winter (the same can hold true for night and day). Lakes also have a relatively smooth surface with little friction or drag to slow winds down.

These sudden changes in temperature and roughness at the lakeshore alter the properties of an air mass in a number of ways. For example, a parcel of warm moist air coming from the west encounters a calm water body (lake) of a cooler temperature (Figure 5). The air mass begins to

cool and becomes denser so it sinks. Because of the smooth surface the parcel's flow (speed) quickens and diverges (spreads out). This divergence causes air from above to sink and, and inhibits any updraft that may promote cloud formation. But by the time the air mass reaches the other side of the lake it is near saturation. The parcel rises as it is heated by the warmer land surface to produce clouds, and potentially rain. Additionally, because the air mass is travelling faster on the lake due to less surface friction, it is more susceptible to the Coriolis force, which causes winds (in the Northern Hemisphere) to veer to the right. Once nearing the lake's leeside, winds converge as they begin to encounter surface friction (sticks, vegetation, boulders, undulations, etc.). The parcel therefore slows down, becomes less susceptible to the Coriolis force and eventually continues on its westerly way, save the rising aloft to make some clouds first. All of these local-scale influences on air mass trajectory and behaviour have an analogous effect on the movement of pollutants such as PM within those air masses.

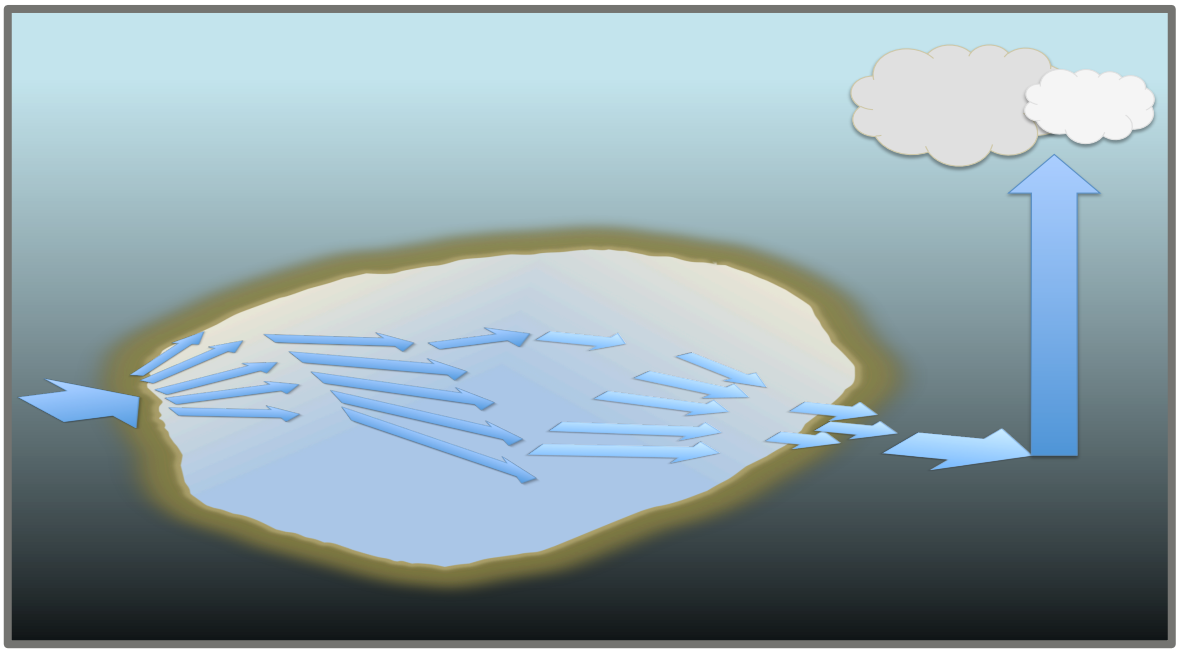


Figure 5. Effect of a lake on local airflow, travelling from west to east (left to right).

1.3 Pollutants of Concern (Particulate Matter)

Particulate matter (PM) is a non-gaseous class of atmospheric pollutants that exist in either solid or liquid (aerosolised droplets or condensed vapour) form. Unlike gaseous pollutants, such as the other CAC, particles are not measured by concentration (%) or volume ratio of air (e.g. parts per billion [ppb]). Rather, PM is measured in micrograms per cubic metre ($\mu g/m^3$). Gases can also be measured in $\mu g/m^3$, but because air that is warmer, or under lower pressure, has an increased volume, changes in temperature and pressure alter a measureof $\mu g/m^3$, but not ppb. This is important when tracking an air parcel as it moves up a hill or across a lake for instance, or when comparing pollutant levels at sites that may vary in elevation or climate, at different times of year, etc.

In addition, larger particles weigh more than smaller particles of the same composition, such that a measure of $PM_{2.5}$ in $\mu g/m^3$ could mean a thousand or more times the number PM_{10} particles with the same mass measurement ($\mu g/m^3$) of the same composition. As fine particles are more harmful from a health perspective, finding their way much deeper into the human respiratory tract (Kampa and Castanas 2008), the quantification of particles by mass, although standard, may deserve to be revisited. Some researchers use a count per volume measurement unit—for example the number of particles per centimetre squared (or similar) which may be more relevant to human health, and easier to measure.

When PM is emitted directly from a source, it is referred to as 'primary' PM. 'Secondary' forms of PM are produced by chemical reactions between primary pollutants and other substances— for example H_2SO_4 (sulphuric acid), exists as a liquid aerosol formed from reactions between SO_2, free radicals, and water vapour in the atmosphere). Such secondary particles are beyond the scope of this MEI due to the chemical and physical complexity of such reactions; and emissions inventories (by definition) only look at primary pollutants emitted directly from sources. The results however, may then be used in (photo)chemical models to predict and simulate secondary pollutant formation and transport, along with other chemical and physical aspects of PM, its journey and its fate.

That being said, even primary PM is chemically and physically complex. Airborne particles may be large or small, liquid or solid, chemically composed of virtually anything and take on an infinite number of shapes. Thousands of different compounds and elements can exist as airborne PM; and particulate composition, as well as additional physiochemical properties such as crystal or aggregate structure, can have a significant influence on the biological outcomes of PM exposure (Bølling et al. 2009).

Take the example of soot (pure carbon, or C) and road dust (silica, SiO_2). Not only do they have different sources—soot from (incomplete) combustion and silica from the mechanical wear of substrate—they also have very different health impacts. Soot, although composed mainly of elemental carbon, is often associated with additional hydrocarbons condensed on its surface—including polycyclic aromatic hydrocarbons (PAH), some of which are considered carcinogens (e.g. benzo(a)pyrene or fluoranthene). Soot also often forms an aggregate of many finer particles stuck together (AMS 2012). Conversely, silica-based dusts (from roads, mining, and other geological disturbances) may vary in crystalline structure depending on their mineral form (clay, quartz, tridymite, etc.), and are less likely to contain PAH or other hydrocarbons on the surface. Then again, silica from road dust may contain fuel or motor oil deposits, as well as salts and wetting or dust-control agents. Additionally, silica itself has been linked to cancer (IARC 1997), and compound-specific ailments such as silicosis and silico-tuberculosis—particularly in miners (Bhagia 2012).

Particles may also be composed of, or contain, heavy metals and other potentially harmful (or benign) elements. According to the Canada's National Pollutant Release Inventory (NPRI), there are some such sources of atmospheric heavy metals within the airshed. In the BVLD PM is the pollutant of main concern. This is not only due to the local geography and topography that promote pollutant build-up and persistence, but also due to the type of air pollutant sources in the region, including:

1) Forest sector sources
    a. Road and off-road dust
    b. Vehicular diesel exhaust
    c. Mill/plant effluent
    d. Smoke from open burning
2) Metal ore extraction/mining
    a. Facility, road and off-road dust
    b. Vehicular diesel exhaust
    c. Process Fuel
    d. Mineral and ore dust
    e. Condensable process vapours
3) Natural Resource Open Burning
    a. Smoke
    b. Ash
    c. Polycyclic aromatic hydrocarbons (PAH)
4) Transportation
    a. Vehicular fuels exhaust (gasoline, diesel)
    b. Electricity production/consumption (electric vehicles if any)
    c. Unpaved road dust
    d. Paved road dust (asphalt, salt/de-icing, wetting agents)
    e. Brake pads and tires
    f. Motor oil
    g. Water vessel fuel (diesel) exhaust
    h. Recreational vehicles and pleasure craft (off-road dust, exhaust)
    i. Aeroplanes and helicopters
5) Residential and commercial heating
    a. Oil (diesel) and gas (propane or methane)[2] (forced air) furnaces or boilers
    b. Wood and pellet furnaces and boiler
    c. Wood and pellet stoves/fireplaces
6) Residential burning[3]
    a. Combustion of (usually moist) yard and garden waste
    b. Combustion of household refuse
7) Agriculture
    a. Exhaust from combustion engines (diesel and gas)
    b. Soil dust from tilling and erosion
    c. Soil and liquid particles or aerosols from crop dusting or spraying of pesticides
    d. Dust or aerosols from broadcast fertilizer application
    e. Smoke from open burning of crop waste
8) Natural and un-regulated sources

[2] PM emissions from natural gases such methane and propane are extremely low; however, if the furnace isn't properly maintained, serviced or functioning, incomplete combustion can cause the formation of soot and ultrafine particles in the furnace. Further, volatized compounds such as complex organics that can be formed from incomplete combustion may adhere to the surface of soot and other PM from the furnace or elsewhere.

[3] Also includes smoke and other emissions from open burning of waste branches, bark, stumpage, etc in the forest sector, already listed as 1 f)

a. Wildfires
b. Sea salt
c. Volcanism
d. Long-range transport of foreign dust (e.g. from Asia)
e. Vegetation (pollen, condensable VOC)
f. Land-slides
g. Commercial and residential food preparation
h. Use of aerosol sprays
i. Smoke from the use of tobacco, smudge, incense, etc.
j. Outdoor camp-/cook-fires

Not all of these sources were included in the MEI; however, it should be noted that each of these PM sources has a unique chemical signature, temporal emissions' profile, and particle size ratio (Appendices A.3, A.4 and A.5). Because PM is not composed of a single chemical, or even chemical class, the make-up of PM from specific sources is an important aspect of airshed management, and the protection of human and environmental health. However, determining the chemical make-up of PM from different sources can be timely, costly, and sometimes impracticable, to obtain.

1.4 Health and Environmental Impacts of PM

In terms of ambient exposure, PM is the most likely of all inventoried CAC[4] to exist at levels known to directly impact human health. Additionally both primary (directly emitted) and secondary (formed in the atmosphere) PM are associated with negative human health outcomes. Once inhaled into the respiratory system, PM has been shown to cause not only respiratory injury such as asthma, chronic obstructive pulmonary disease (COPD), decreased lung function and other pulmonary disease (Pope and Kappos et al, 2004; Hrebenyk et al, 2005; Dockery, 2006); but also less obvious conditions that include arterial hypertension, established coronary artery disease, obesity, adverse pregnancy outcomes, cancers, and diabetes (e.g. Kappos et al, 2004; Lelieveld and Pöschl, 2017). Airborne fine particles can make their way to, and impact, every system in the human body. Fine particles ≤2.5 μm in diameter ($PM_{2.5}$) are considered particularly damaging because they can travel more deeply into lung tissue, from where they can then make their way through capillaries and blood vessels to reach other organs (Kampa and Castanas 2008). Particles of ≤1.0 μm (referred to as 'sub-micron', 'nano', or ''ultra-fine' particules) are even more biologically mobile/damaging—the smaller the particle, the larger its capacity to impact human health.

Using an odds ratio approach, Weichenthal et al. (2017) found a relationship between the rates of myocardial infraction (heart attack) and measured $PM_{2.5}$ in Kamloops, Courtenay and Prince George BC between 2008 and 2015—a relationship that increased during winter months when temperatures were <6.44°C, thought the be related to biomass burning (wood smoke).

[4] Inventoried CAC are primary pollutants emitted directly from a source and are included in emissions inventories, as opposed to measured CAC which also include secondary pollutants that are reaction products between CAC and/or additional atmospheric components (see CAC in Glossary)

Damage to these diverse aspects of the human system creates comorbidities that also influence our responses to other stressors. For example, exposure to air pollution, or more specifically fine particles, can increase the risk and severity of other ailments, particularly those with respiratory and/or cardiovascular components. For instance an increase in mortality rates from COVID-19 (severe acute respiratory syndrome coronavirus (SARS-CoV-2)) has been attributed to air pollution—or more specifically $PM_{2.5}$) (Pozzer et al. 2020) as was true of its predecessor SARS (SARS-CoV-1) (Cui et al. 2003).

Ambient Air Quality Standards (AAQS) and Air Quality Objectives (AQO) form the basis of air quality management in Canada and supersede all previous Canada-wide Standards. They set a maximum threshold for the concentration of a specific pollutant in the ambient atmosphere. In 2012, the Canadian Council of Ministers of the Environment (CCME) derived two 24-hour AAQS for $PM_{2.5}$ as: 28 µg/m³ (to obtain by 2015) and 27 µg/m³ (to obtain by 2020). Both values were developed for comparison with 3-year averages of the annual 98th percentile of daily (24-hour average) concentrations (CCME 2012).

In 2009 BC adopted a 24-hour Provincial Ambient Air Quality Criteria (AAQC) for $PM_{2.5}$ of 25 µg/m³ (in addition to the existing 24-hour PM_{10} AQO of 50 µg/m³) representing the annual 98thpercentile of 24-hour concentrations. In contrast to CCME's standard, BC's threshold percentile is based on a single year of data (BC MOECCS 2020), rather than three. BC's objective is more in-line with the World Health Organization's (WHO) 24-hour $PM_{2.5}$ standard of 25 µg/m³; however, the WHO standard is more stringent in that it uses the 99th percentile of measurements on which to base compliance, rather than the 98th (WHO 2005). While a 24-hour threshold is useful in protecting human health from episodes of poor air quality at the daily, rather than annual or multi-annual time-scales, in order to protect human health from the chronic effects of $PM_{2.5}$, annual limits have also been developed. In BC these are an annual objective of 8 µg/m³, and an annual 'planning goal' of 6 µg/m³ (BC MOECCS 2020) representing the annual average of hourly PM measurements. There are no hourly ambient standards for PM, because ill effects generally occur with repeated and/or chronic exposure (with the exception of acute respiratory failure from smoke inhalation, which usually happens in indoor/enclosed environments).

The 2015 and 2016 24-hour 98th percentile $PM_{2.5}$ and 24-hour average PM_{10} concentrations from the MOECC sites in the BVLD are shown in Table 1 for comparison withe BC's AQO for PM. Exceedances of the 24-hour AQO for $PM_{2.5}$ and PM_{10} were more frequent in 2015. Houston and Telkwa both had 98th percentiles of 24-hour $PM_{2.5}$ that exceeded the provincial AQO of 25 µg/m^3, and Smithers' was close enough to call it a tie (Table 1). While Burns Lake managed to escape any $PM_{2.5}$ exceedances in 2015 and 2016, it had the highest levels of PM_{10} and the most frequent exceedance of the 24-h AQO of 50 µg/m^3—more than half of all combined exceedances from the three sites. Burns Lake appears to have a relatively high proportion of coarse particles (PM_{10}) whereas Houston seems prone to finer textured particles (i.e. $PM_{2.5}$). This PM size ratio can tell us quite a bit about both the risk to human health, and the source of PM pollution affecting each municipality.

Table 1. Averaged 24-hour and annual PM2.5, and the average of the 24-hour average PM10 as well as the number of times in a year the 24-hour average exceeded BC's AQO for the 2015 and 2016 inventory years. The

24-hour averages are rolling averages so as to eliminate diurnal bias. Data are form the MOECCS monitoring sites shown in Figure 1 and were provided as hourly averages. Exceedances of AQO are underlined and all units are µg/m3 except for the last two columns of count data.

Site	$PM_{2.5}$				PM_{10}			
	24-hour 98th %		Annual		Avg 24-hr Avg.		# of 24 hr > 50	
	2015	2016	2015	2016	2015	2016	2015	2016
Burns Lake	18.69	18.33	7.09	6.83	15.68	14.81	367	212
Houston	28.33	26.37	9.66	8.76	14.61	13.76	90	41
Smithers	24.97	22.42	8.31	7.29	14.65	13.07	172	124
Telkwa	31.20	–	9.14	–	–	–	–	–
All Sites	27.44	23.07	8.52	7.638	15.00	13.89	629	377

1.5 Factors that influence Exposure and Related Risks (Spatial and Temporal, source size)

Particulate matter arrives in BC all the way from Asia (McKendry et al. 2001), and your wood-burning fireplace may bother your asthmatic neighbours. Air pollution knows no borders, and PM is no exception. In particular, fine particulate ($PM_{2.5}$) can travel 1000s of kilometers before finally depositing on the surface; and over this time, may undergo both physical and chemical changes.

Larger sources (such as Asia, or a major point source reporting to the NPRI) tend to produce emission plumes that travel further in space and time. There are a few reasons for this: 1) emission sources are generally warmer than their surroundings (most involve combustion) which makes them buoyant and rise to higher levels of the atmosphere; 2) larger emission sources typically have taller 'stacks' or points of exit, which further pushes plumes aloft from their sources at the surface; 3) the higher in the atmosphere a pollutant reaches, the less affected it is by surface forces such as drag or precipitation that tend to interrupt pollutant transport and help remove things like PM from the air; and 4) statistically speaking, the larger the plume the greater the chance of a portion being transported further—for instance 1% of a 10 t plume may make a significant contribution to surface level air quality some distance away, but 1% of a 1 g plume may not be measureable once dilution due to mixing is accounted for.

While larger sources have impact farther away, smaller sources can have more impact locally. A lack of (or minimal) plume rise, promoted by inverted temperature gradients and low release heights, means PM remains close to the surface where is it eventually deposited. The closer to the surface PM is emitted, the less of a distance it will travel. Figure 6 provides a graphical representation of how PM risk-level—ranked a unitless 1-10 with 10 being the highest—changes with both the size of the source and the distance from it.

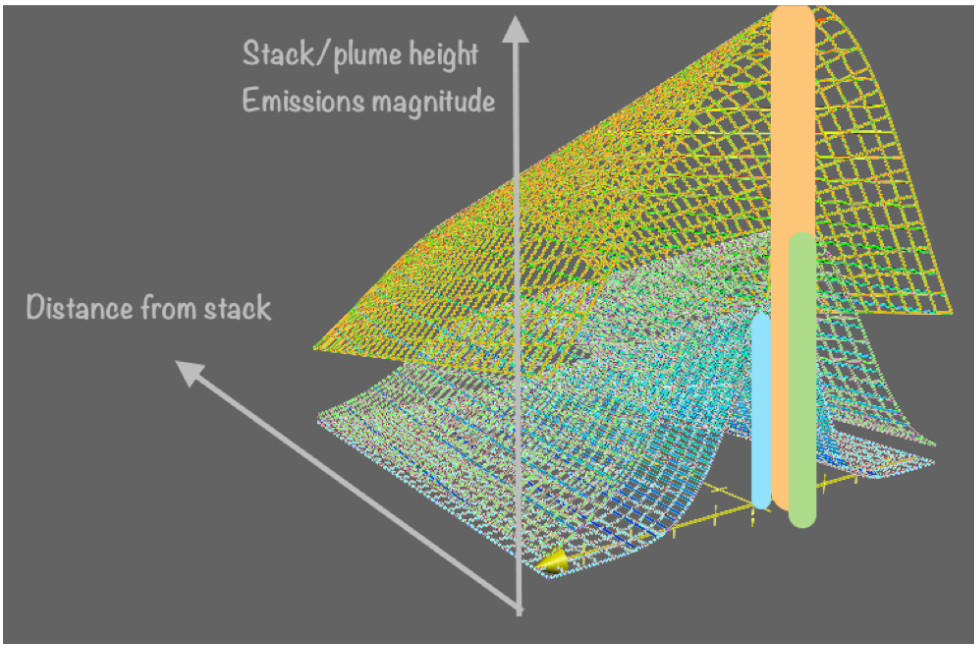


Figure 7. A three-dimensional graph, with dimensionless axes, illustrating how source size and distance affect PM exposure at any given receptor. The shape of the curve also represents pollutant concentration within the plume. The figure is purely illustrative and was not developed using real data

In Figure 6 the wide green, blue and orange vertical lines against the y-axis represent stacks, or points of release, and are paired with the 3D surfaces of similar colours, which represent the plumes. Not only does the highest point on the surface represent height of release or height of the plume as it moves away from the stack, but the magnitude of y also represents the concentration of pollutants in the plume; the curvature signifies the concentration gradient within the moving plume—highest in the centre and lower (in height and concentration) as you move away. The smallest stack (blue) has a narrow plume that reaches the surface and any receptor (such as your neighbour) relatively close to the stack, whereas the tallest (orange) stack's plume won't intersect the surface until it's off the page—longer distance transport. To some extent plumes of larger particles will behave more like those of smaller stacks, and smaller particles of taller stacks, with heavier particles not being transported as far or spreading out (mixing) as much as fine particles, even at the source.

Fine particles ($PM_{2.5}$) are generally lighter and can remain suspended in air for much longer than the coarse fraction of PM_{10} (i.e. PM >2.5µm); and although the shape of particles is not generally accounted for or discussed, this too can affect the distance a particle travels by influencing aerodynamic resistance. Similar to how a full sheet of paper will fall more slowly than a crumbled piece of paper despite having the same mass, surface area and gravitational forces acting upon them. But, most particles of very different shapes will also have a variable chemical composition, which can too affect transport due to reactions with sunlight, water, other air components and pollutants, etc. Similarly, liquid and solid particles of the same size may behave differently in the atmosphere. However, at the regional/airshed scale for which the MEI was developed, local terrain and the meteorology it influences are likely the most significant drivers of PM transport;

and particle speciation at the chemical- or structural-level is beyond the scope of available data, and the scope of the MEI.

2 Methods

2.1 Scale Determination and Source Inclusion

One of the many challenges in EI development at any scale is limiting what could be limitless. An inventory could endlessly grow and evolve over time; to include represent the entire globe, at finer and finer spatial resolution, with the introduction of evermore sources and pollutants, and the inclusion of new sources, or removal of shut-downs, as they arise. Although this may sound 'ideal' from an airshed management perspective, it isn't practical, and a balance must be found between the imaginable and the achievable.

For the BVLD's MEI, inventory scale and detail were determined by two main factors:

- the purpose/end-use of the information
- the resources available (time, funding, computing, data)

The updated MEI attempts to capture as many PM emission sources as possible, including area sources such as residential heating and road dust; and large stationary point source5 such as those that self-report to Canada's National Pollutant Release Inventory (NPRI). The largest caveats in the development of this inventory were:

- a lack of data, which limited the sources that could be included, and the data/accuracy of derived emissions' estimates
- insufficient computing capabilities[6]: most of which was Geographic Information System (GIS) related

During the scoping phase (Phase 1) of this MEI project, seven different scoping measures (or elements) were chosen: spatial, temporal, chemical, causal, utilizational, financial and practical. Spatially, the study area chosen is similar to that used by Weinstein (2005) and roughly represent the BVLD or the AMS' airshed management plan area (AMS 2012). The actual boundaries of study (black outline in Figure 1) were chosen somewhat arbitrarily and moved around a number of times. In addition, there was some consternation regarding significant PM sources at or beyond the boundary. Initially, important or large out-of-bounds sources, particularly those upwind of the BVLD, were going to be included. However, then yet another boundary would need to be determined—a buffer so to speak—that would contain additional sources. But that is yet another way of expanding the study area boundaries, and we set boundaries for a reason (so as to contain what could be limitless). So, a decision was made to only include sources in the study as round to the nearest 10th of a degree latitude or longitude; the limits of the bounding box being 53.7 –

[5] In this report the terms "point" and "stationary" are used to discern from "area" and "mobile" sources, respectively. See glossary for more information.

[6] There are many more files and datasets than one may imagine; the folder for the MEI and report in its entirety is over 27.5 GB (Gigabytes) in size, but only essentials and final versions of data and maps are provided as a digital Appendix B.

55.4°N and -124.7 – -128.1 °W. This placed some source right on the boundaries, or even appearing to be outside of the study area on maps (for instance if they had a latitude of 55.447°N).

Besides the size of the study area, which was set to be both practical and relevant (from a management perspective), the spatial element of the MEI comes into play in terms of source location and the respective contribution to atmospheric PM load at any given location.
For instance point sources, with distinct locations and spatial coordinates (latitude and longitude) allow for the direct measurement of distance between themselves and sensitive receptors—such as vulnerable members of the population. Whereas an area source, such as residential heating, may only be estimated as an average for the area in question, due to a lack of information regarding who burns what, when and where (information that would also lead to a much larger dataset). However, one can reasonably assume that emissions from emission from residential heating occur more in areas of human residence, during the colder months, and when people are home.

Bringing us to the temporal aspect of source inclusion, if it is a winter long weekend, are people more likely to be home with their families, using more heat and lighting the wood fire, and less likely to be driving around producing road dust, or do they all want to get away for a while leading to heavy exhaust emissions from the idling that also forces people to dirt roads as an alternative. In short, the more spatial and temporal information, or the higher the spatial and temporal resolution of the MEI, the more usability an inventory has. However, you may also introduce more and compounded error with more variables, and end up with an unmanageable dataset. The ideal and the practical must balance.

There were some changes made in source inclusion between this updated MEI and the previous MEI (Weinstein 2005). These were:

1) Residential Backyard burning was not included
2) Road dust emissions were calculated for unpaved, rather than paved, roads.
3) Residential heating with gas and oil were included
4) Commercial heating was also included as a potential source of PM

Backyard burning was omitted from this MEI for a few reasons:

1. No improved methods over those of Weinstein (2005) were identified, and the method results are easily updated by revising the population numbers. The emissions estimates from backyard burning can also be spatially refined by estimating emissions at the municipal, census, or community level. Alternatively, EFs can even be allocated spatially by household using more detailed population dataset (such as that provided digitally in Appendix C).

2. The validity of the US-EPA defaults and emission factors is questionable. First, the routine open-burning of 28% of waste seems extraordinarily high, particularly for household waste, and even in rural areas. Assuming that there is rural garbage collection it seems that the open burning of garbage would be more the exception than the rule. It's surprising that since the 2005 MEI was prepared, more municipalities haven't followed Smithers' suite in banning open burning entirely.

3. The EF used for backyard burning appear unfitting. For instance the EF (in kg/t) for household waste burning, are lower than the EF for leaves, brush or grass. It isn't clear what the assumed moisture content of the yard waste would be, and moisture inhibits the complete combustion of any fire fuel. However, assuming both waste streams are dry, on a per tonne basis I would expect household waste to have higher PM emissions. Although comparable in terms of carbon and hydrogen content, household waste contains higher amounts of nitrogen and sulphur, which easily oxidise more than once to produce nitrate and sulphate aerosols. A more heterogeneous waste mixture (such as household waste) would also promote more incomplete combustion (different substances require different combustion temperatures, etc.) and the production of a more diverse set of PM including halides (in particular fluorides and chlorides), metals, and ultrafine hydrocarbons and soot (elemental carbon). Shemweell and Levendis (2000) found laboratory-produced combustion-derived emission rates from polymers (aka plastics) to be higher than the EP AEF used—for PM_2 (particles < 2 μm in diameter) alone; and household waste is known to be high in such polymers.

4. The PM emissions contribution was relatively small.

Reasons for the other MEI inclusions/exclusions are discussed more in the following sections for specific source types. A detailed list of assumptions made in MEI development is also provided in Appendix A.2. The methods used to estimate and quantify PM emissions within the study area are described in the following sections for each PM source type with detailed data and methods provided for each source/section in Appendix B (digital).

2.2 Large Stationary ('Point') Source Emissions

Large stationary emission sources are associated with spatially discrete commercial/industrial facilities that are required to report to the Canada's NPRI. Estimated emissions from large stationary point sources were also verified and compared against emissions permits received from BC's Ministry of Environment and Climate Change (MECC). Only one PM source was found to overlap between the permits and the NPRI, Pinnacle Renewable Energy Inc.'s wood pellet manufacturing plant just east of Burns Lake. The permit entry was kept, rather than the NPRI entry because the emissions estimates in the permit are the "maximum" that a source is permitted to emit. Although this maximum is rarely if ever reached, and results in emissions over estimates, this is in line with the commonly used "worst case scenario" of EI, and within the general precautionary principle of environmental science—if you don't know for sure, it is best to proceed with caution.

The NPRI records for these sources are representative of an entire facility, so although represented as 'point sources' (i.e. with a single latitude and longitude) some of these sources may represent emissions from a variety of processes and over a larger, facility-sized, area. For example, PM may be emitted from a fuel-fired boiler stack, on-site vehicles, and on-site road or off-road dust. The author does not think that emissions for these sources could be better estimated than those of the source owners themselves (i.e the data provided would be used with the same emission factors and yield the same results). That being said, the NPRI has its faults.

These faults may be in terms of the way emissions are estimated; or 'who'/ 'what' is included in the inventory (aka required to report).

There are substantial NPRI reporting exemptions; be they based on employee hours, energy usage, pollutant thresholds, or another activity limit—as published annually in Canada's *Gazette* (e.g. 20,000 employee hours per year, or ten full-time workers). These threshold-based exemptions can (and do) ultimately mean that many smaller industrial and commercial sources go unreported. However, being 'smaller' doesn't mean these emission sources are insignificant, particularly when considered on a cumulative basis (Krzyzanowski 2009). The reader is encouraged to familiarise themselves with NPRI reporting requirements should they be interested in knowing more[7]. Data used for NPRI sources in the BVLD is available in Appendix B.1.

Sources of PM emissions permitted by MOECCS under requirements of the Environmental *Management Act* (*EMA*) and not included elsewhere[8], were added using maximum discharge amounts, maximum discharge rates and permitted operating schedule as defined in the respective permit (see: Appendix B.2). The 'all_ams_discharges_v10_-_nov3-_2020_1.xls' ("alldischarges file") (Government of BC, 2020a) was used to extract permitted sources operating within the BVLD. However, this file contained only "maximum discharge rates" in units of mg/m^3 or kg/day without any rates of operations, fuel usage, etc. Therefore each source's permit was accessed using an Authorization Number search to give maximum discharge rates and operating schedules (Government of BC, 2020b), thereby allowing emissions of TPM (E_{TPM}) for each individual source to be calculated in tonnes/year (t/y) as follows:

$$E_{TPM} = Q_{MAX} \times PM_{MAX} \times t \times \frac{1}{m}$$

where, Q_{MAX} is the maximum allowable rate of discharge for an individual source (m^3/min, m^3/y, kg/d, m^3/month, t/y, etc.);
PM_{MAX} is the maximum mass of PM allowed in a specified volume or mass of discharge[9] (mg/m^3, kg/t, etc.) [what the alldischarges file actually contained];
t is a function of annual operating time that depends on the units of Q_{MAX};
m is factor converting mass into tonnes (t);
x (below) is any positive real number

For example: if Q_{MAX} = *x* m^3/min, then *t* = 120,000 min/year (of operating time) assuming the source in question only operates 40 hours a week, 50 weeks a year. If Q_{MAX} = *x* kg/d then *m* = 1000 kg/t; and if Q_{MAX} = *x* m^3/y then *m* = *x* m^3/t — or the density of the material being disposed of. In the case of the open burning of wood, without any Burn Registration Number (BRN overlap), the same values used for wood density in emissions estimates from open burning with a short-term BRN were used (Table 2). For open burning by *EMA* permit (10 sources in total), the equation became:

[7] A synopsis of NPRI reporting requirements can be found at: https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/report/requirements-fact-sheet.html
[8] Or 'removed from elsewhere', such as the Pinnacle Renewable Energy Inc. plant discussed earlier in this section
[9] Also known as "Discharge Max" in the BC_alldischarges file [see Appendix B.2]; and as "Characteristics of the Discharge" in Permits issued under the *Environmental Management Act,* and in Wakelin [2005])

$$E_{TPM} = \rho_{wood} \times Q_{MAX} \times PM_{MAX} \times \frac{1}{1000}$$

where, ρ_{wood} is average estimate wood density for the area in t/m^3 (Table 2);
Q_{MAX} is in m^3/y (wood) 2.2-2
PM_{MAX} is in kg/t (weight of PM per tonne of wood); and
$\frac{1}{1000}$ converts kg to t

Table 2. Forest species composition (%) and wood densities (kg/m^3) used to estimate burning emissions from major and small license debris burning in the BVLD using the CONSUME model (Equation 2.6), after Gonzalez (1990), and used for estimating emissions from permitted source that also included open burning.

	District/TSA	Spruce (black)	Pine (lodgepole)	Balsam fir	ρ_{AvgOD} (kg/m^3)
Low Elevation	Morice	50	50	-	453.25
	Lakes	40	60	-	456.2
	Bulkley	50	30	20	437.35
Mid-High Elevation (>800 m)	Morice	40	30	30	428.65
	Lakes	40	40	20	436.6
	Bulkley	50	30	20	437.35

Because permits are active for multiple years, it was assumed that 2015 and 2016 emissions from permitted sources would be the same, with the exceptions of 2016 being a leap year and therefore representing 366 days, and the Huckleberry Mine closure on September 1, 2016.

The maximum allowed rates of discharge were used, as these (permits) were the only data available for these sources (with the one pellet plant exception). The maximum represents a 'worst-case-scenario' thereby providing a conservative estimate and evoking the 'precautionary principal'—an important concept from the perspective of public health protection—and was assumed to be a realistic interpretation of what 'could' be emitted. Basic source information garnered from the alldischarges file and individual source permits, as well as calculated annual emissions, are provided in Appendix B.2a and B2.b. The value of TPM in the permits was divided into $PM_{2.5}$ and PM_{10} size fractions using the PM size distribution ratios given in Table 4 below, and in Appendix A.4 2.2-1
for additional source types.

An exception to any large source reporting requirements is NEWPRO (Northern Engineered Wood Products), who due to changes from a pellet plant in 2015, to one that manufactures particle board in 2016, was not in operation for these years and there had no emissions produced or reported during the inventory period. NEWPRO's emissions are therefore not included in the MEI but are discussed briefly in section 4.0, and data are included in.

Table 4. Normalised size distribution ratios for TPM used to estimate the annual emissions of PM_{10} and $PM_{2.5}$ for large stationary sources holding an emissions permit under the *EMA*.

PM RATIOS	TPM	PM_{10}	PM_{25}	Source
Drying Kilns	1.0	0.5800	0.1900	Wakelin (2005)
Hog Fuel Fired Boilers	1.0	0.9000	0.7597	Wakelin (2005)
Cyclones (most)	1.0	0.4000	0.2000	Wakelin (2005)
Molybdenum dryers, crushers, etc.	1.0	0.5100	0.1500	Wakelin (2005)
Vent Fans	1.0	0.5800	0.1900	Wakelin (2005)
Gold Crushers	1.0	0.4035	0.1053	AMEC (2013)
Open Burning	1.0	0.7078	0.6164	CONSUME (US Forest service, 2015)

2.3 Mobile and Linear Source Emissions

Data for mobile emissions estimates from road transport were limited. For instance, the Europe-based COPERT Street-level model v. 5.1.1 (Emisia 2018) could not be used with information from the Government of BC's Traffic Data Program (Government of BC 2018a) due to insufficient data. With the exception of a permanent count site at Pipers Glen on route 16 west of the Nachako River bridge and west of Fort Fraser (P-45-1EW) traffic monitoring sites in the BVLD have 'short count' data (48 hours to one week) reported every three years—the most recent available being from July 2014 for all other sites when this project was initiated. Additionally, traffic volume counts exist only for paved primary roads, which although they likely get the most traffic, they only represent 3.2% of the study area's total road length. However, as of August 2017 some BVLD sites and data (such as speed) have been added the Ministry of Transportation's traffic data site providing a list of the traffic count sites throughout the province and the dates/roads for which these data are available[10].

Spatial road attribute data were retrieved from BC's Digital Road Atlas (GeoBC 2018) as shapefiles and loaded into a Quantum Geographic Information System (QGIS). BC's Digital road atlas classifies road surfaces as described in Table 5. Because gravel and dirt roads make up the majority of the area's routes, they are considered to be an important source of 23egional PM emissions. The three road surface types assumed to contribute to 'road dust' emissions (i.e. dust from the road itself) were loose, recreational, rough and unknown—collectively 'unpaved roads'. Unpaved roads are assumed to produce the most dust during the wamer fair weather (snowless) months, approximately July 1 – September 30 (Government of BC, 2018b).

In this respect 'road dust' is considered to be airborne particles that were once part of the road itself—as gravel, sand, or 'dirt'. This would be mostly silicate minerals or 'silicates', a group of minerals composed of mostly silica and oxygen, including clay, quartz, mica, garnet and tourmaline. This dust would become airborne from weathering and subsequent mechanical disturbance, such as a logging truck or passenger vehicle. Considering the large proportion of unpaved roads in the study area, unpaved roads were considered to be a potentially important source of PM.

[10] see: https://prdoas6.pub-apps.th.gov.bc.ca/tsg/

Conversely, Weinstein (2005) estimated PM emissions from paved roads in the region. These emissions were not composed of road material itself, but rather remnants of "winter traction promotion" (salt, gravel, de-icing agents) that get kicked up in the spring (mostly March) after snowmelt and drying, that leads to what is termed the 'road dust season'

Table 5. Road classifications used in BC's Digital Road Atlas including the corresponding cumulative length (2-dimensional) of each class represented within the study area shown in Figure 1 (GeoBC 2018).

Surface	Description	Length (km)
boat	Some form of boat or water travel required (i.e. ferries)	11.9
loose	A maintained gravel road	14 708.3
overgrown	A road that has become overgrown with vegetation	282.3
paved	A permanently hard surface such as asphalt or concrete	1341.9
rough	An unmaintained gravel or dirt road	21 698.6
seasonal	A seasonal road including winter ice roads and summer recreational roads	313.4
unknown	An unknown surface type	3755.9
	TOTAL:	**42 112.3**

Because traffic data were both temporally and spatially sparse, as were road- and behavioural-characteristics (of humans), mobile exhaust emissions from neither passenger nor transport vehicles were included in the MEI, but were certainly on the list of inclusions and would be a first choice addition to the MEI. There were no sufficient data at the beginning of this project; however, a methodology section for transportation (primarily exhaust) emissions was prepared, but was removed as the estimates were never completed. As there now appears to be new road and traffic data available for the region, this methodology has been included as an Appendix (A.6).

2.3.1 Road Dust Emissions

Environment Canada's Road Dust Calculator (Environment Canada 2008) was used to estimate road dust from unpaved roads throughout the study area. Although the calculator is designed for facility-based NPRI reporting, each census block was treated as a single facility for these purposes; and the following assumptions were made.

The majority of passenger vehicles are pick-up trucks (45%) and SUVs (34%) with 4-wheel drive and on average a 6 cylinder gasoline-based engine. The remainder are primarily 4 cylinder cars with front wheel drive (20%) with the remaining 1% of passenger vehicles being comprised of vans. These estimates are based on the ratios of new and used vehicles at local car lots (e.g. Coast

Mountain GM[11] and Hoskins Ford Sales[12] s both in Smithers) and are assumed to be representative of the region's passenger vehicle make-up.

It was also assumed that 80% of drivers make at least one road trip each day; and that the driving population is represented by those aged 16 – 79

The total (2D) length of all roads with a road surface classified by the Road Atlas (GeoBC 2018) as either 'loose' (a maintained gravel road) or 'rough' (an unmaintained gravel road) were classified as unpaved. Roads with a road surface of 'unknown' were also included in the calculated total length of unpaved road because after visual inspection, most if not all 'unknown' surfaces were connected to a loose or rough road. In terms of road class, these unpaved roads were either 'local', 'resource', or for the most part 'unclassified' and usually leading to resource roads. Road surfaces classified as 'seasonal' were not included due to their relatively small number and uncertainty whether they are winter or summer roads. Being 'seasonal' and having much lower usage, they could also not be grouped with the other roads for the purpose of emissions estimation. In addition 'overgrown' roads were not included as they are not considered to be used, and if they are, will not produce much dust, except perhaps under extremely dry conditions.

The total length of these unpaved road classes in the BVLD was calculated by making the following SQL selection query:

"RDSURFACE" IN ('loose', 'rough', 'unknown')

followed by calculating 'basic statistics for numeric fields' on the field "SEGINGTH2D", now representing the lengths of only unpaved annual-use roads. The total length of unpaved roads within the study area was calculated as 40,162.811 km. Road length was summed across each census division for use in the road dust calculator (used on each census division separately).

For comparison, 'seasonal' roads totalled 313.384 meters in length. Because 95% of the length of study area roads are not paved (total road length is 42,112.300 km), it was assumed that most residents outside of municipal limits will drive on an unpaved road twice daily (if they make one trip a day). It is also assumed that due to the rural nature of the region, that most people over 16 will drive, although some families that may share a vehicle. So, it was assumed that 80% of the area's population drives a vehicle each day to and from somewhere.

So, *average daily traffic* (*ADT*) for each vehicle class driving on the entire unpaved road network can be estimated as:

$$ADT\ (\#/day/vehicle\ type) = (population_{(16-79)})*0.8)*vehicle\ ratio \qquad 2.3\text{-}2$$

Where passenger vehicle classes include pick-up trucks, SUVs and cars with a vehicle ratio based on that of the local car lots (see previous section). The ADT of transport trucks was based on the number of people employed in agriculture and resources or trades (which includes transport) and also multiplied by 0.8 assuming that people in these occupations drive large trucks 80% of the

[11] See: http://www.coastmountaingm.com/
[12] See: http://www.hoskinsford.com

time. Although this may represent an overestimate (i.e. some drive smaller trucks, or equipment that doesn't move as much), the census data relied upon are from 2011 (the most recent available) and it was expected that the population had increased in all census divisions since then. Calculations of road dust, using the NPRI's Road Dust Calculator (Environment Canada 2008) were preformed separately for each census unit (N=26) in the BVLD using data for a population between the ages of 16 and 79. It was assumed that there is no anthropogenic dust control, but that natural factors (such as precipitation) mitigate some of the emissions of road dust, and these naturally moderated values from the road dust calculator were used.

Documentation for ECCC's road dust calculator can be found on the NPRI webpages[13] and more detailed input an output data can be found in Appendix B.3-1.

2.3.2 *Ferry and Barge Exhaust Emissions*

Roads classified as 'boat' represent ferry or barge routes. In the 2015 – 2016 inventory years there were four existing 'boat' or ferry/barge courses within the study area. Two of the routes, both on Babine Lake, have boats named 'Babine Charger' and 'Babine Itinerant', respectively; and transport primarily logging trucks and forestry workers. One of the other 'boat' routes on Tahtsa Reach was used to transport equipment, vehicles, and staff to and from the Huckleberry mine, but made her last voyage on August 31, 2016 when mining operations at Huckleberry were suspended indefinitely. The fourth route on Francois Lake is serviced by the 'Francois Forester', a passenger ferry used by workers and residents that runs every 25 min each way from 5:30 am to 11:00 pm.

Boat specifications such as boat type length, and no of trips per day, were found either on-line via search engines, or the route operator was contacted by telephone. Because all the water vessels' transport cargo and vehicles (including full lumber trucks) they were assumed to be of the Roll on Roll Off (RORO) type, with a flat deck that lies near flush with the dock surface for easy loading/unloading. A PM emission factor for 'Ferries and RORO ships' in kg/GTkm (kilograms per gross tonne kilometer) was used to calculate ferry and barge emissions as found in Denier van der Gon and Hulskotte (2010) based on a boat's GT class. Values of GT, for all but the unnamed boat on Tahtsa Reach that no longer runs to Huckleberry Mine, were found in The Nauticapedia, (2019). For the unnamed boat, GT was calculated using estimates of barge size from Catherwood Towing—the operator/owner of the tugboat (named "Sea Imp IV") that pulled the barge. It was assumed that the amount of fuel and PM emissions required for pulling the barge by tug, would be similar to the emissions from a free-running vessel of the same size (volume or GT).

Ferry and barge emissions were calculated as:

$$E_{ship} = EF_{GT} \times GT \times \left(d_y \times \frac{r}{d} \times l_{run}\right) \qquad 2.3\text{-}3$$

where, E_{ship} is the annual PM emissions in t/y,
EF_{GT} is the emission factor for vessels of the same volume class (GT) in kg/GTkm,

[13] https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/report/sector-specific-tools-calculate-emissions/road-dust-unpaved-surfaces-guide.html

GT is the gross tonnage, a measure of volume,
d_y is the number of days the ship operated in year y ,
$\frac{r}{d}$ is the number of runs/routes completed each day, and
l_{run} is the length of the ship run in km

If GT is not known (as for the Huckleberry barge) it can be calculated as:

$$GT = \mathrm{V}_{ship} \times \mathrm{K} \qquad 2.3\text{-}4$$

where, V_{ship} is the ship's internal volume

$$\mathrm{V}_{ship} = l_{ship} \times w_{ship} \times d_{ship} \qquad 2.3\text{-}4$$

and, K is a coefficient calculated using

$$K = 0.2 + (0.2 \times \log_{10} V_{ship}) \qquad 2.3\text{-}1 \quad 2.3\text{-}5$$

All parameters and calculations for mobile/linear emissions are given in Appendix B.3-1 and B.3-2 for road dust and barges, respecitvely. It was considered beyond the scope of this study, and an exercise in futility, to estimate PM emissions associated with leisure watercraft in the study area—they are neither registered nor do they have usual routes.

2.4 Residential and Commercial Heating

All estimates of PM emissions from both residential and commercial heating were calculated using reported consumption totals (in GJ) from the Community Energy and Emissions Inventory (CEEI) (Government of BC, 2020c); energy to mass or volume using conversions in BC Ministry of Environment (2014); and the AP 42 US-EPA emission factors for wood, fuel oil, natural gas and propane (US-EPA 2017). Because the CEEI is community based, it has a much better spatial resolution than other similar data, and despite being developed for greenhouse gas (GHG) inventorying, this and other GHG data sources may prove useful in future inventory development and updating. Although all "unincorporated areas" (small communities) were all classed together for the Bulkley-Nechako, separate energy usage counts were available for Burns Lake, Fraser Lake, Granisle, Houston, Smithers, Talkwa, Hazelton and New Hazelton—depending on the heat/energy source. Differences between calculations for different sources are discussed briefly in the following.

2.4.1 *Residential Wood Burning*

The use of wood as residential heat is fairly common in the BVLD. Wood is relatively inexpensive as a fuel source, readily available, safe and easy to use, and few things can go wrong with a conventional wood stove or fireplace. Then there is the warm glow and soft crackle, and the images that a hearth conjures; of romance, sugar plum fairies, roasting chestnuts and like. In addition to heat, some people use woodstoves or fireplaces to cook meals (Figure 8), while

others keep them for purely aesthetic reasons. Despite how smokey they can be, the nostalgia many of us have for the fireside can be deeply rooted and hard to give up.

Wood burning appliances come in many forms, all of which have different emissions profiles. Still the most complete survey/report for wood burning appliances in the BVLD (those for Smithers may lack some context of the rest of the BVLD, [e.g. Jesse Hiemstra &Co. 2016]) is Rensing (2005). Although it is assumed that total numbers have changed since 2005, including the Provincial Woodstove exchange programme having some successes from its implementation at the local level (Allen et al. 2012), it was assumed that with the exception of the wood exchange programme, that the ratio of different wood burning technologies hasn't changed. Therefore Table 3 of Rensing (2005) was used to divide the wood usage data from Government of BC (2020c) into GJ per appliance type, and the numbers were modified using local woodstove exchange information from Smithers, Telkwa and Hazelton (Sue Brookes and Matt Davey *Pers. Comm.* Oct. 2020) and energy intensity was calculated using factors in BC Ministry of Environment (2014). The US-EPA (2017) emission factors for woodstoves (Chapter 1, s. 10) and fireplaces (Chapter 1, s. 9) were then used to calculate emissions in tonnes per year—after some unit conversions and assumptions, including:

- Wood combusted for residential heat is completely dry and contains 0% moisture;
- Wood burning fireplace inserts have the same emissions factor as either catalytic or non-catalytic wood stoves (whose emissions differ ≈2%);
- Wood burning boilers and furnaces of all types have similar emissions to conventional fireplaces; and
- Exchanges through the woodstove exchange programme were from conventional woodstoves to certified noncatalytic.

Beginning in 2006, by 2015 the BVLD's Woodstove Exchange Program had exchanged 238 old and polluting woodstoves, for cleaner and more efficient sources of heat. By 2015 there had been 166 such woodstoves exchanged in Smithers and 72 in Telkwa, in 2016 another three and one, and so on (Sue Brookes and Matt Davey *Pers. Comm.* Oct. 2020). These numbers up to and including 2015 and 2016 were used to modify the residential wood heat emissions to reflect changes in technology not captured by the old (2005) survey.

Figure 8. An indoor wood-burning fireplace with an insert that increases efficiency and reduces PM emissions, being used to prepare a sizzling meal.

Results are presented in Chapter 3 of this report. See Appendix A.2 for a full list of assumptions made in MEI development, why they were made, and what their impact may have been on emission values. Appendix B contains all of the data used and the calculations made for each emission type—wood heating is Appendix B.4.1.

2.4.2 *Hydrocarbon-based Fuels*

Although residential fuel oil, gas and propane are not known for their PM emissions the way wood fireplaces are, under imperfect conditions (which are what happen to exist most of the time) there is incomplete combustion of any fuel, which can lead to un-combusted superfine carbon particles, and hydrocarbons (most of which are <1 μm in size).

Fuel usage data from Government of BC (2020c) in GJ per appliance type were used, and energy intensity was calculated using factors in BC Ministry of Environment (2014). The US-EPA (2017) emission factors for fuel oil (Chapter 1, s.3), Natural Gas (Chapter 1, s.4) and propane (Chapter 1, s.5) were used, along with some unit conversions, to estimate PM emissions from the respective heating source in tonnes/y.

Because commercial fuel usage data were also available, they were included using the same methodology (Appendix B.4.2 and B.4.3). It should be noted however, that rather than being divided into TPM, PM10, and PM2.5, liquid fuel PM emissions are classified as either 'filterable' or 'condensable' (see Glossary Appendix A.1).

Emissions of PM from the "unincorporated areas" of the Bulkley-Nechako were spatially distributed in QGIS using a map of census divisions and the following formula:

$$253.543864 * (\text{"POP\_TOTAL"} / \text{if} (\text{"HEATING\_ALL\_TONNES\_RES\_TOTAL\_16"} \text{ is null}, \text{sum} (\text{"POP\_TOTAL"}), 1)) \quad \text{2.4.2-1}$$

Which takes the total value of PM from residential heating in the unincorporated areas, and multiplies it by the proportion of the population living in that area that doesn't already have a value for PM emissions from residential heating, This propagated the column in the attribute table fully. The result was then mapped using:

$$\text{IF} (\text{"UNCORP2016"} < 1000, \text{"UNCORP2016"}, \text{"HEATING\_ALL\_TONNES\_RES\_TOTAL\_16"}) \quad \text{2.4.2-2}$$

Such that unincorporated areas—which are smaller and all had < 1000 tonnes of PM emitted per year—and the municipalities, all received the correct PM release values.

2.5 Resource Management Debris Burning

Burn data reported by major and minor forestry licenses in the study area were obtained from the BC MOECC (c/o Ben Weinstein). The emissions equation used in the previous MEI (Weinstein

2005) was used to estimate PM emissions (E_{PM}) in tonnes (t) from resource management and debris burning as follows:

$$E_{PM} = BQ\ x\ \frac{PpnMassConsumer}{100} \times \frac{EF_{PM}}{1000}\left(1 - \frac{\%soil}{100}\right) \quad 2.5\text{-}1$$

where *BQ* (t) is the base quantity of wood burned; *PpmMassConsumer* is the percentage of fuel (biomass) that fully combusts (assumed to be 90%); EF_{PM} is the emission factor for TPM, PM_{10} or $PM_{2.5}$; and $\left(1 - \frac{\%soil}{100}\right)$ is the adjustment for soil content in the pile (assumed to be 5%).

The *BQ* is further estimated using:

$$BQ = \#Piles \times M_{W/p} \times \frac{1}{1000} \quad 2.5\text{-}2$$

$$M_{W/p} = V_{W/p} \times \rho$$

$$V_{W/p} = V_{pile} \times PackingRatio$$

$$V_{pile} = D_{pile} \times CorrectionforPileShape$$

$$D_{pile} = L_{pile} \times W_{pile} \times H_{pile}$$

$$\rho = \rho_{AvgOD} + M_{H_2O/m^3}$$

$$M_{H_2O/m^3} = \frac{MCD}{100} \times \rho_{AvgOD} \quad 2.5\text{-}8$$

where,
$M_{W/P}$ (kg) is the mass of wood per pile,
$V_{W/P}$ (m^3) is the volume of wood per pile,
V_{pile} (m^3) is the volume of the pile,
D_{pile} (m^3) are the combined pile dimensions (volume),
L_{pile} (m) is the pile length,
W_{pile} (m) is the pile width,
H_{pile} (m) is the pile height,
ρ (kg/m^3) is the wet density of the wood pile,
ρ_{AvgOD} (kg/m^3) is the average oven dry density of the wood pile,
M_{H_2O/m^3} (kg/m^3) is the mass of water per m^3 of the wood pile,
MCD is the moisture content of the pile on a dry basis, and
$\frac{1}{1000}$ converts from kg to t.

Emission factors (EF_{PM}) from the CONSUME model, produced by the US Forest Service (2015) and now part of the Fuel and Fire Tools package, were used to estimate PM emissions from resource and debris burning within the BVLD (US Forest Service 2015). In particular, EF_{PM} for

Woody Fuel Accumulation (such as piles) were used, are very similar to those used by Weinstein (2005), and were clarified using the documentation from Consume 3.0 (Prichard et al. 2006). Parameters used for all burn areas are given in Table 6.

Tree species were determined using Appendix Table H from Weinstein (2005); and despite the changes in forest districts/timber supply areas (TSA) since 2005, it was assumed, in regards to major licenses, that: 1) Morice and Lakes merged into Nadina; 2) Canadian Forest Products (CANFOR) is in Morice; and 3) Babine Forest Products (BFP) is in Lakes (*Weinstein Personal Communication, July 2018*). Both Pacific Inland Resources (PIR) and Houston Forest Products Company (HFP) operated in both the Bulkley and Morice districts as defined in their respective burn plans. The tree species' mix and resulting wood densities, calculated as averages from western Canada retrieved from Gonzalez (1990) and using ratios of forest composition for each forest district/TSA, are given in Table 3.

Table 6. Parameters used in calculating PM emissions from resource and debris burning for major and small licenses in the 2015 and 2016 calendar years; most after Weinstein (2005).

Parameter	**Value**
Combustion Efficiency	90%
Soil Content	5%
Pile size	10 m x 10 m x 5 m
PackingRatio	0.2 (20%)
CorrectionforPileShape[14]	π/8 (≈0.393)
MCD	25%
EF_{TPM}	10.95 kg/t
EF_{PM10}	7.75 kg/t
$EF_{PM2.5}$	6.75 kg/t

Some burn records were missing dates or other information. For instance CANFOR's 2015 burn plan was missing the field 'Number Piles Actually Burned' and instead the field 'Number Piles Planned to Burn' was used in estimating the PM emissions associated with debris burning by this major license in 2015.

For all minor license burns, forest make-up and resulting wood density were estimated based on the district listed in the license. For those licenses without a listed district: Lake Babine First Nation's, Baker and Morris', and Wetzin'kwa Community Forest Corporation's, licenses were assumed to be in the Bulkley Forest District; while Driftwood Timber Ltd. was assumed to be located in Lakes.

[14] Assuming a paraboloid shaped pile (i.e. mound with a circular base).

3 Results

3.1 Emission Totals and Airshed Patterns

Total emissions of PM for sources within the study area and included in the MEI are given by source type in Table 6. From these results we see that open burning as part of resource extraction makes and unpaved road dust, as the largest contributors to PM emissions within the BVLD. However, open burning (an activity which is also included as a part of some of the NPRI and permit totals) is a much more important source of fine particulate matter ($PM_{2.5}$)—the PM that poses the greatest risk to human health.

Table 6. Summary of PM sources included in the MEI in tonnes/year Totals are given at the top of the table and the top of each source type (bold). Sources under "other heating" include fuel oil, gas and propane, and have emissions classified as the 'filterable' and 'condensable' fractions of TPM because they are all fine particles of <2.5 micron in size. Their totals (TPM) were therefore added to the total of TPM, PM_{10} and $PM_{2.5}$.

		2015			2016		
		TPM	**PM_{10}**	**$PM_{2.5}$**	**TPM**	**PM_{10}**	**$PM_{2.5}$**
All Sources	**TOTAL**	**9,803.98**	**4,888.03**	**3,003.16**	**10,129.63**	**5,023.45**	**2,991.99**
Point Sources							
NPRI	Total	**1712.00**	**812.80**	**328.14**	**2310.00**	**1146.80**	**489.66**
EMA Permits	Total	**410.36**	**208.20**	**111.83**	**387.52**	**189.72**	**97.80**
	Forestry	*338.71*	*151.22*	*68.97*	*339.63*	*151.62*	*69.16*
	Mining	*71.64*	*56.99*	*42.85*	*47.89*	*38.10*	*28.64*
Linear Sources							
Transportation	Total	**3878.06**	**1096.63**	**112.09**	**3888.56**	**1099.51**	**112.27**
	Unpaved Roads	*3875.36*	*1093.93*	*109.39*	*3885.98*	*1096.93*	*109.69*
	Barge and Ferry	*2.699*	*2.697*	*2.697*	*2.587*	*2.585*	*2.585*
Area Sources							
Open Burning	Total	**3473.37**	**2458.32**	**2141.12**	**3208.78**	**2271.05**	**1978.02**
	Major License	*3389.88*	*2399.23*	*2089.65*	*3187.19*	*2255.77*	*1964.70*
	Minor License	*83.49*	*59.09*	*51.47*	*21.60*	*15.28*	*13.31*
Residential Heating	*Wood*	**325.82**	**307.70**	**305.62**	**330.90**	**312.50**	**310.38**
Other Heating	Total	**4.3752**	**3.2780**	**1.3158**	**3.8604**	**3.2149**	**1.2974**
Other Residential	*Fuel Oil**	*0.8413*	*0.6424*	*0.4175*	*0.4238*	*0.6520*	*0.4238*
	Gas	*1.4579*	*1.0935*	*0.3645*	*1.4290*	*1.0717*	*0.3572*
	Propane	*0.2041*	*0.1458*	*0.0583*	*0.1841*	*0.1315*	*0.0526*
Commercial l Heating	*Gas*	*1.6621*	*1.2466*	*0.4155*	*1.6014*	*1.2011*	*0.4004*
	Propane	*0.2097*	*0.1498*	*0.0599*	*0.2221*	*0.1586*	*0.0635*
		TPM	**Filterable**	**Condensable**	**TPM**	**Filterable**	**Condensable**

*of the condensable fraction of PM from fuel oil, a ratio of 0.65 is inorganic and 0.35 is made up of condensable organics.

The MOECCS PM monitoring stations in the BLVD have already been presented in terms of location in section 1.2; and in terms of AQO exceedances and relevance to human health (section 1.4. This section provides a brief, look at some other aspects of the monitoring data alongside some of the regions largest emitters.

Figure 9 again shows the monitors' locations in the BLVD, but this time each site is given a marker whose size is dependent on the concentration of PM measured. This monitoring graphic is also combined with large stationary sources that meet all the requirements of reporting the Canada's National Pollutant Release Inventory (NPRI), also given (red) markers of a size that represents their magnitude; and sources requiring a provincial permit under the *EMA* are shown in browns. The graduated markers are divided like pie charts to show the relative contributions of PM_{10} and $PM_{2.5}$ to either the reception, or the release, of TPM with darker colours of the pie representing larger particles (TPM-that which remains after accounting for the relative contributions of PM10 and PM2.5), while the lightest colours represent fine particles or $PM_{2.5}$. The monitoring stations measure $PM_{2.5}$ and PM_{10} and so do not represent any information regarding very coarse particles (>10μm) in size that may still be airborne, albeit briefly. Such size classes are representative of sources such as unpaved roads or active surface mines.

The fine particle influence (the palest pie pieces) is apparent down the very centre of the valley, the sources appearing closest to monitors, with a coarser PM makeup emitted a little further north. The Endako mine is the region's largest single source of PM, and the coarse particles it emits may be responsible for some of PM_{10} measured at Burns Lake, particularly with the dominant southwest winds (Figure 5a). Note from Figure 9 that Smithers and Houston have a higher PM2.5 fraction, while Telkwa only measured $PM_{2.5}$

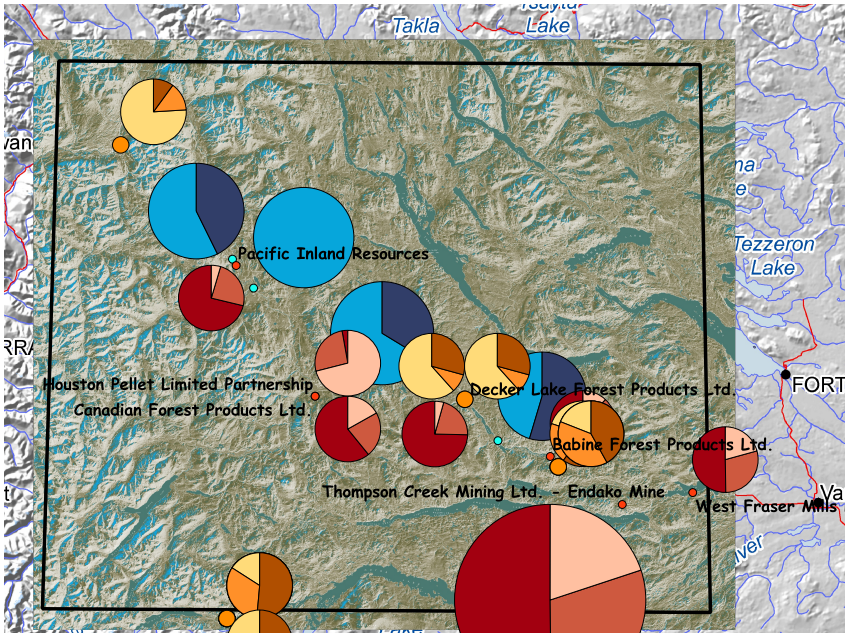


Figure 9. Map of PM monitoring locations run by the MOECCS (blue), and large stationary ('point') sources (reporting to the NPRI [red] or requiring provincial permits [brown]); all with markers showing

relative ambient concentrations, or emissions, and the typical (average) fine to coarse emission ratios, for 2015. The Telkwa site only monitored only $PM_{2.5}$ and only up until May 2015.

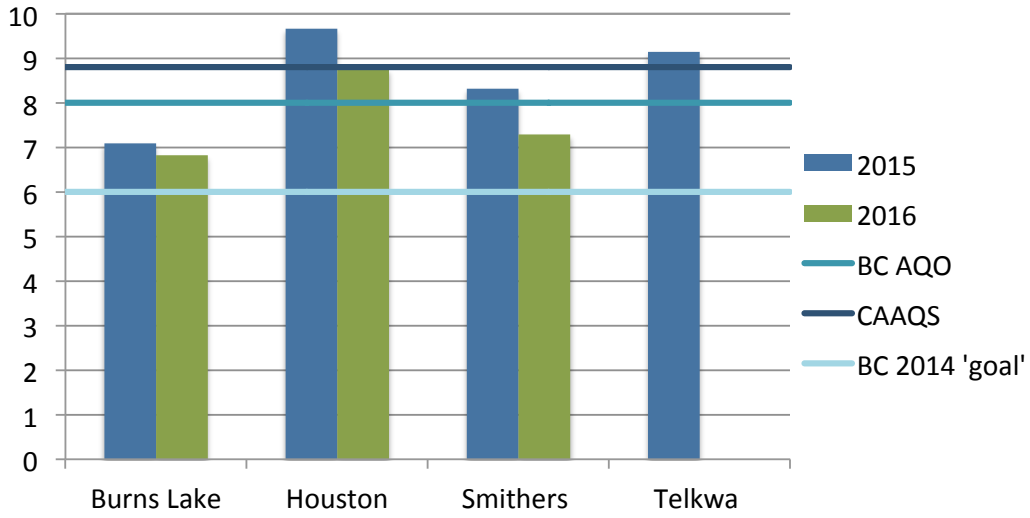


Figure 10. Chart of annual average concentrations (bars) of $PM_{2.5}$ (mg/m^3) compared with relevant ambient air quality criteria (lines).

Figure 10 shows a bar plot of annual average $PM_{2.5}$ emissions measured at the MOECCS sites over the 2015 and 2016 inventory years (figure 1 and 9), compared with the provincial annual AAQC for $PM_{2.5}$.

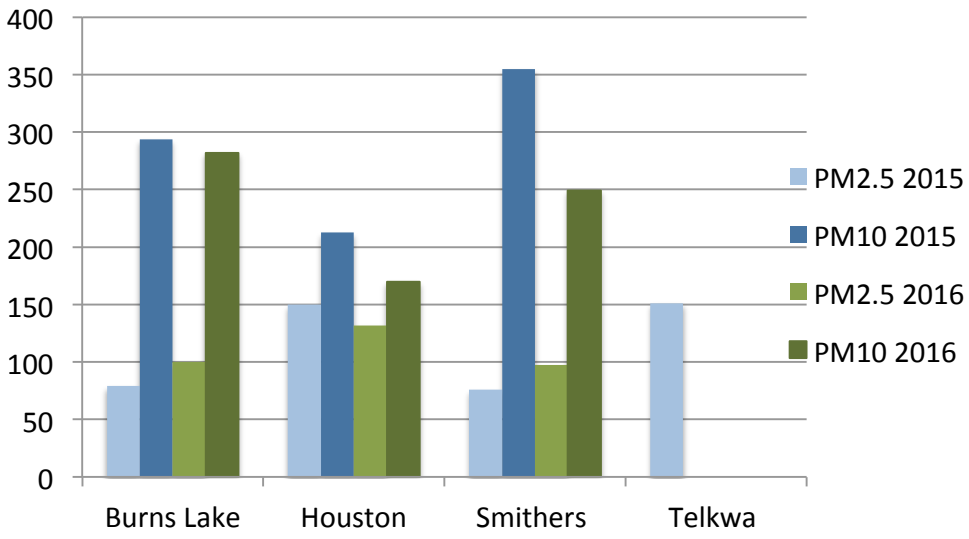


Figure 11. Bar chart showing measured maxima of $PM_{2.5}$ and PM_{10} concentrations at MOECC's Burns Lake, Houston, Smithers and Telkwa stations. Telkwa only measured $PM_{2.5}$ and for only part of the year (until May 2015).

The year 2015 appears to have had relatively poor air quality, particularly in terms of PM_{10} (in Smithers, average measured PM2.5 concentrations are actually higher in 2016). Looking at the summary Table (6) we see that there was more open burning in 2015 compared to 2016, and this

open burning carried out annually to clear the land for natural resources, emits high levels of PM. However, looking at the seasonal trends in PM concentration (Figure 12) it seems as though the fall (when open burning occurs) was not particularly different in 2015 compared to 2016 (Figure 12 c) and d)). What is apparent in Figure 12 is a seasonal pattern in regional PM that is more pronounced for PM_{10} than $PM2_{.5}$ (c and d, versus a and b, respectively), and that Burns Lake seems to receive more PM10 than the other, possibly form that very large mine just to the south. What we do see in 2015 is more gradual transition to summertime low PM In 2015, in particular the months of May and June have PM10 concentrations up in the teens ($\mu g/m^3$), while the following year they were near zero at this same time. This likely implies one of two things: there was an earlier start to the 2015 wildfire season, or a delayed start to the summer such that residents needed to use more heat than usual. Well it turns out to be a little of both, but in reverse, with 2015 being the norm rather than the exception. According to some of the local news outlets, 2016 had an early but wet start to the summer (which would dampen heating, and forest fire starts), and by mid-August had only seen one-third of the wildfires as 2015 by same time in the season[15].

Figure 12. Monthly averages of PM2.5 (a and b) and PM10 (c and d) for the 2015 (a and c) and 2016 (b and d) inventory years measured at the MOECCS sites in the BVLD.

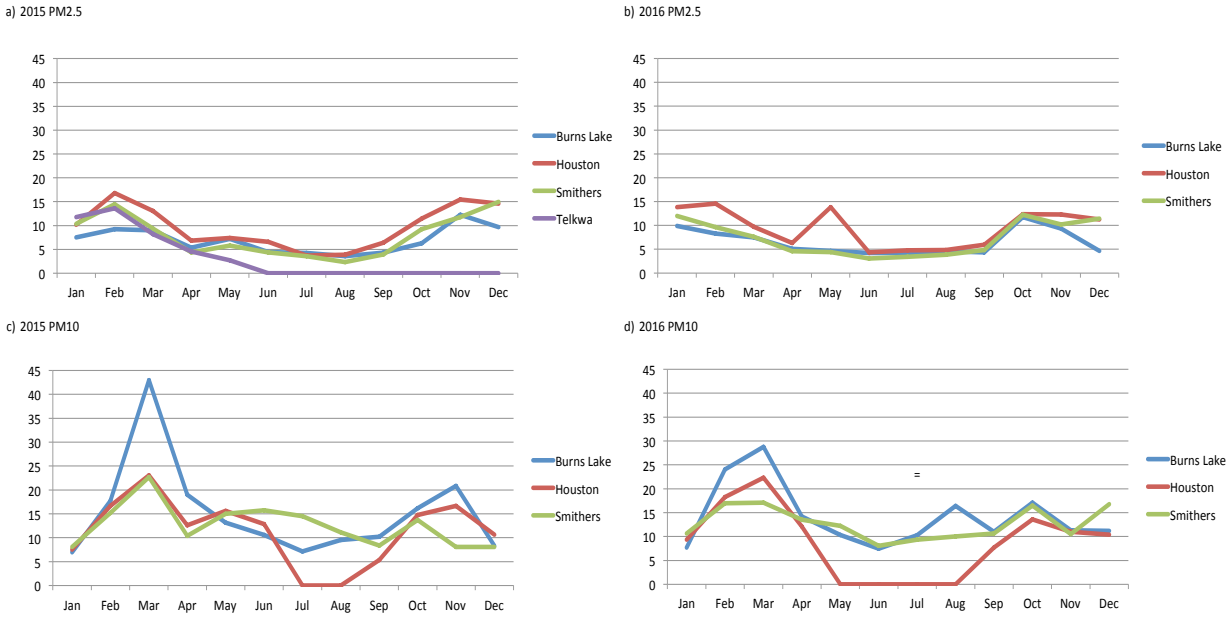


Figure 12. Line charts of monthly average measurements of PM taken at MOECC operated monitoring stations within the AMPA: a) and b) show $PM_{2.5}$ for 2015 and 2016, respectively; and similarly c) and d) show monthly PM_{10}.

3.2 Large Stationary Sources

All individual NPRI sources within the study area (Figure 1) are listed in Appendix B.1 along with accompanying source information, GPS coordinates, operating schedules and annual emission

[15] Smithers Interior News, August 16, 2016. "Slow B.C. forest fire season may heat up".

totals of TPM, PM_{10} and $PM_{2.5}$ (t/y). Basic source data and the results of annual emission concentration estimates (in t/y) for sources permitted provincially under the Environmental Management Act are found in Appendix B.2.

Sources with emission permits under the *EMA* are presented along side NPRI sources as they too can be classified as 'large' and 'stationary', and a comparison between these two types of sources/datasets is particularly useful in future MEI updating and planning

Figure 13 is the 2016 version of Figure 9 above, displaying both NPRI (red) and permitted (brown) sources in relation to one another, and the MOE monitoring stations (blue), each showing the relative contributions to PM10 and PM2.5.

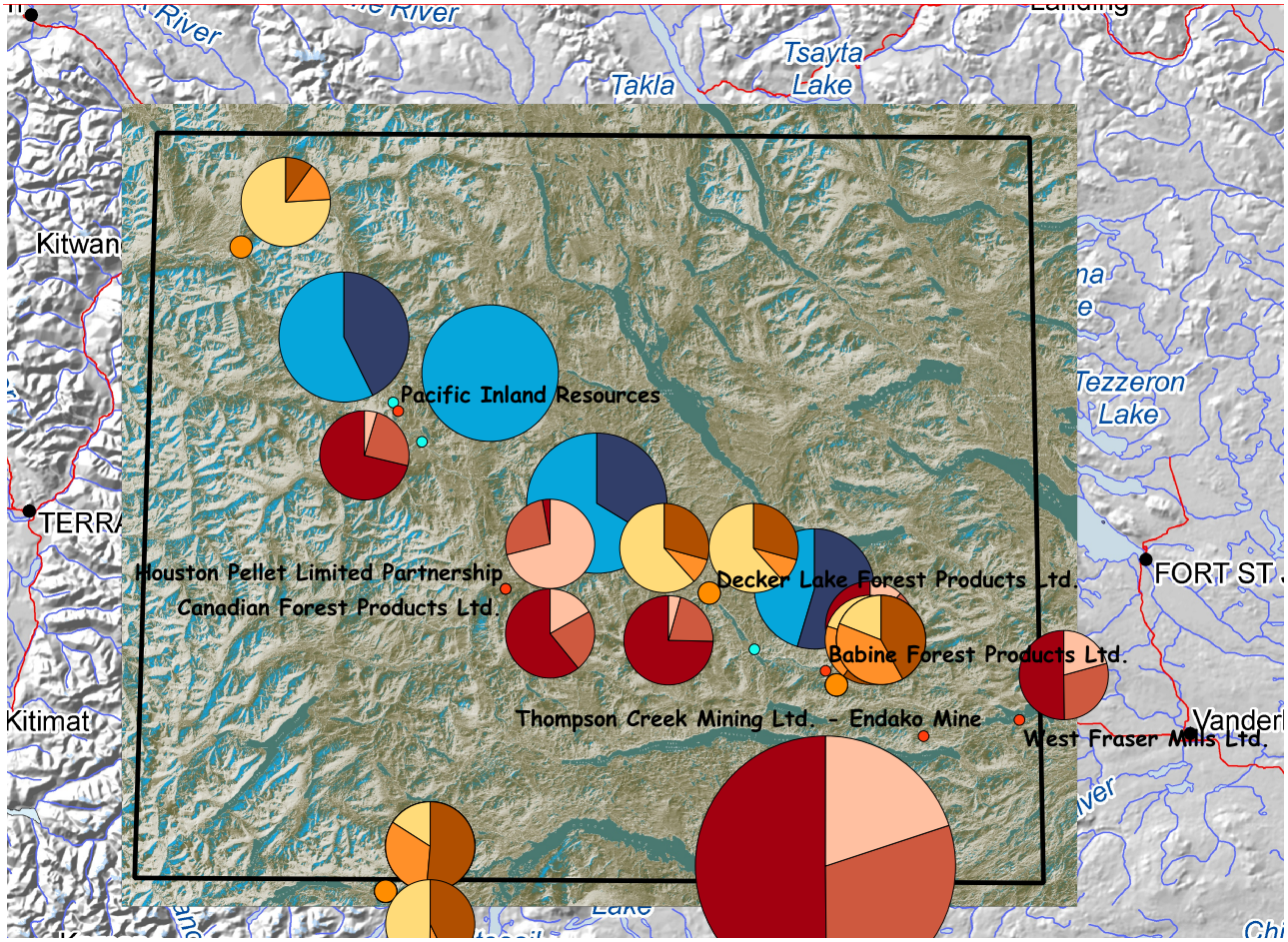


Figure 13. Map of PM monitoring locations run by the MOECCS for 2015 and 2016, and large stationary ('point') sources—those reporting to the NPRI and those with provincial permits—all with markers showing relative PM ambient concentrations, stack emissions, and coarse (dark colour) versus fine (light colour) PM for 2015.

3.3 Mobile Sources

In retrospect it would be good to have somewhat accurate estimates of dust production from both paved and unpaved roads, as they would have differing chemical, temporal and spatial profiles and complement one another in illustrating PM diversity. However, road dust emissions are notoriously over-estimated, one reason being the lack of differentiation between 'suspendable' and 'transportable' PM (Weinstein 2005), the former being able to

become aloft in air, the latter being able to travel distances from its source and remain aloft longer. Larger or coarser PM particles, such as PM10 and greater, settle from air very quickly, whereas finer particles (PM2.5) can remain suspended in air for weeks, providing adequate time to be transported long distances, particularly when emitted from an elevated release point (small stack). Without any elevated release or buoyancy provided by the heat of combustion, road dust—composed of primarily of coarse particles settles, very quickly and does not become transported over large distances. Unpaved road dust contains ten times more PM10 than PM2.5, and is more than 70% coarse particles > 10 µm in diameter, still part of the TPM size class because they are suspendable. Additionally, originating from the ground gives road dust a very short distance to travel before depositing on the surface (section 1.5).

Still neither the unpaved road estimates in this updated MEI, or the paved road estimates of Weinstein (2005) take into account what may be the largest source of vehicular PM—fine particles from brake and tire wear (Winkler et al. 2018). Furthermore, the actual paving of roads (with asphalt) produces considerable PM in the form of secondary condensable hydrocarbons (or secondary organic aerosols. Ir was found that when exposed to moderate sunlight it emitted 300% of these cretai

However, because the calculator assumes that 100% of the unpaved road network within a census district is travelled by 100% of drivers, and it is unlikely that 100% of people in the more urban areas drive on unpaved roads at all, further assumptions and correction factors were used to make the emissions more realistic (see Appendix B.3 for detailed methodology).

Although road dust represents a "mobile" or moving emissions source, the speed of travel and rates of dust plume dispersion, etc. are not included here, and this rate feature will need to be included should these emissions be used for modelling as a mobile source. Here they are presented as either area or linear source, calculated and allocated by census district, which is much more spatially resolved than an average for the entire study area, and considered acceptable to some models.

Temporally speaking unpaved roads are likely more travelled in the fair weather months and this is also the time of year when dust would be more likely to become suspended—from ice-free and dry unpaved surfaces.

Because the NPRI's Road Dust Calculator (Environment Canada 2008) relies on both census data (to determine the number of drivers) in addition to unpaved road length, urban centres have the highest level of PM emissions. Many of the remote census divisions have no population data, or no population between the ages of 16 and 79, meaning that no PM emissions could be estimated for these areas. This is likely incorrect due to the number of unpaved roads (mostly for resource/logging use) in these areas. However, there is not enough information available to estimate the level of traffic on these 1000s of roads in the BVLD. Therefore, it is assumed that these resource and agricultural emissions were captured in the MEI total through the addition of transport trucks to the estimates, based on the number of residents working in the trades (which includes trucking) or agriculture and resources. Due to this, road dust emissions in populated areas were likely over estimated and were modified such that only 1% of the urban population drove on a dirt road daily (but the

model still assumes they travelled 100% of the dirt road length). Such on- and off-site dust (PM) emissions from the physical transport of resources/people, and from the physical extraction/harvest of those resources, are not generally reported oe tracked, but are sometimes included (at least for on-facility dust) in facility-wide NPRI estimates and various approval applications.

Results from the Road Dust Calculator were mapped in QGIS and are shown by census division because that is how they were calculated (the number of roads and people within a division) using 5 classes of natural breaks (jenks) (Figure 14 a-c, respectively). The method used is not considered accurate or representative of road dust emissions in the region.

Fist, the calculator is designed to estimate unpaved road dust at an industrial facility, not a public road network. In this way it is set-up for every vehicle to travel each road a user specified number of times a day. A more accurate method may actually be to use less variables overall, but information we know more about. The new road count data may help with this. Other factors such as number of residents per household, whether an unpaved road leads to a paved road, whether an unpaved road had residences, and the ditancer between the unpaved road and a municipality, may be variables that allows for a more accurate/realistic estimation of road dust. Further, such as calculation tool should vary by road class and/or surface (e.g. different expressions for paved and unpaved roads, exclusion of ferries and driveways, etc). Even more ideal would be a calculator that also includes estimates of PM from exhaust emissions and from tire and brake wear; and of course accounts for seasonality, particulrlt with complex terrain like the BVLD. It should also differentiate between size classes of PM and at the very least eliminate the unnecessary inclusion of any particles > 10 μm which will not travel very far (unless you are interested in the effects of road salt roadside vegetation for instance).

Figure 14. Results from the road dust calculator for each census division.

3.4 Residential Sources

3.4.1 Heating

The burning of wood in a woodstove or fireplace as either a primary or supplemental heat source receives a lot of attention in terms of PM emissions. Maybe it's the signature odour of wood-smoke, a characteristic owed to it by polycyclic aromatic hydrocarbons (PAH); or maybe it's because the some of the smoke particles are fairly large, making the emissions and their source easier to see.

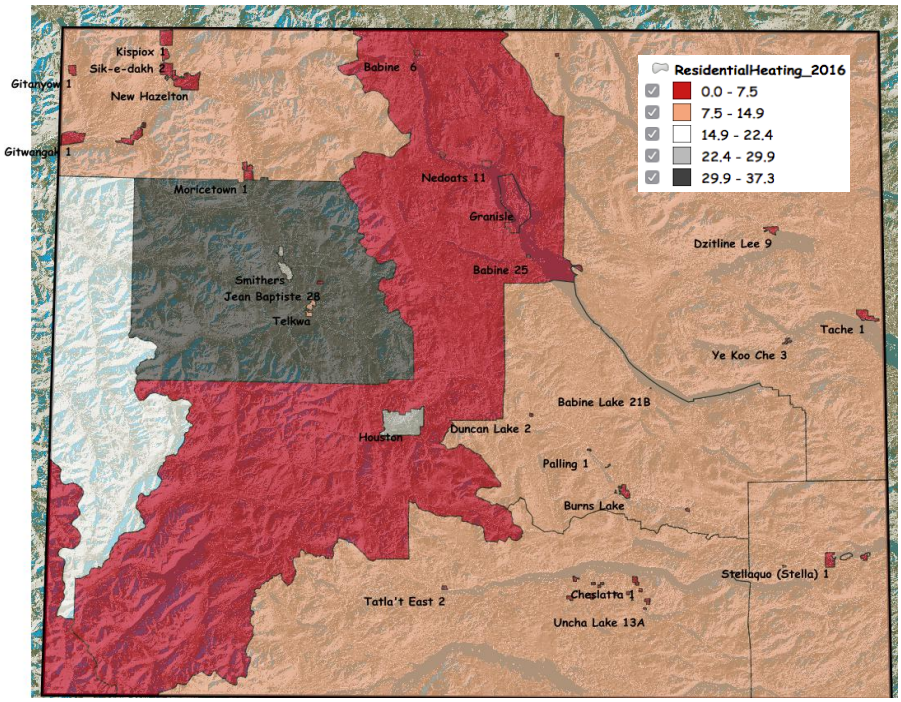
But despite having larger particles than other heat sources (e.g. natural gas; see Appendices A.5 and A.6,), the US-EPA (2017) report that Rau and Huntzicker (1984) found 95 percent of the particles emitted from a wood stove to be less than 0.4 micrometers in size, putting them in the category of "ultrafine" and also increasing the likelihood and diversity of potential health impacts linked to exposure.

One such particle type is a group of hazardous air pollutants (HAP) known as POM (polycyclic organic matter. This group includes potential carcinogens such as benzo(a)pyrene (BaP), the formation of which is due to the production of free radicals in the flame zone during conditions of incomplete combustion. Combustion efficiency improves as burn rate and flame intensity increase. Noncatalytic fireplace inserts reduce emissions by directing unburned hydrocarbons and CO into an insulated secondary chamber, where mixing with fresh, preheated makeup air occurs and combustion is enhanced.

Fireplace emissions are highly variable and are a function of many wood characteristics and operating practices. In general, conditions that promote a fast burn rate and high flame intensity enhance secondary combustion and thereby lower emissions. Conversely, higher emissions will result from a slower burn rate and lower flame intensity. Such generalisations apply more correctly to the earlier stages of the burning cycle, when significant quantities of combustible volatile matter are being forced from the wood (a combination of increased temperature, pressure and the chemistry beginning to occur). Later in the burning cycle, when all volatile matter has been driven out, the charcoal that remains burns with relatively few emissions (US-EPA, 1996b).

If we look at the residential heating emissions by census grouping (Figure 15) there appear to be some discrepancies between areas and the amount of energy used and/or emissions produced from residential heating, for instance the Municipality of Houston and the district of Bulkley-Nechako A that is home to Smithers and Talkwa are the most emissions intensive jurisdictions in the region. However, if we display the same information on a per capita basis (i.e. divide TPM emissions by the population residing in each area) the distribution is much more even, and all categories, based on the quantile of PM, have 6.9 t/person at one (or both) ends of the range. (Figure 16) This would be your per capita residential heating emissions factor for PM in kg/person. However, Smithers[16], Houston and Telkwa a have per

[16] The symbology given to Smithers in Figure 16 is incorrect based on the results—it should be displayed in grey.



capita heat EF of 25.3, 22.7, and 11.9 kg/person years.

Remember that for heating particles are fine and classified as "filterable" versus "condensable" rather than particles size.

Figure 15. Total residential heating emissions by census division (2015 and 2016).

Problems with PM emissions in the BVLD led to some local initiatives to both educate the public and reduce emissions in the airshed and have been quite successful. And although emission of PM from propane, NG and oil are lower than most wood burning appliances m it is important to remember that they arte not PM-free and need to be properly installed and maintained to achieve the highest combustion efficiencies. The emissions of PM from fossil-fuel based heating are of a similar magnitude to those of backyard burning as estimated by Weinstein (2005).

Figure 16. Per capita residential heating emissions by census division (2015 and 2016).

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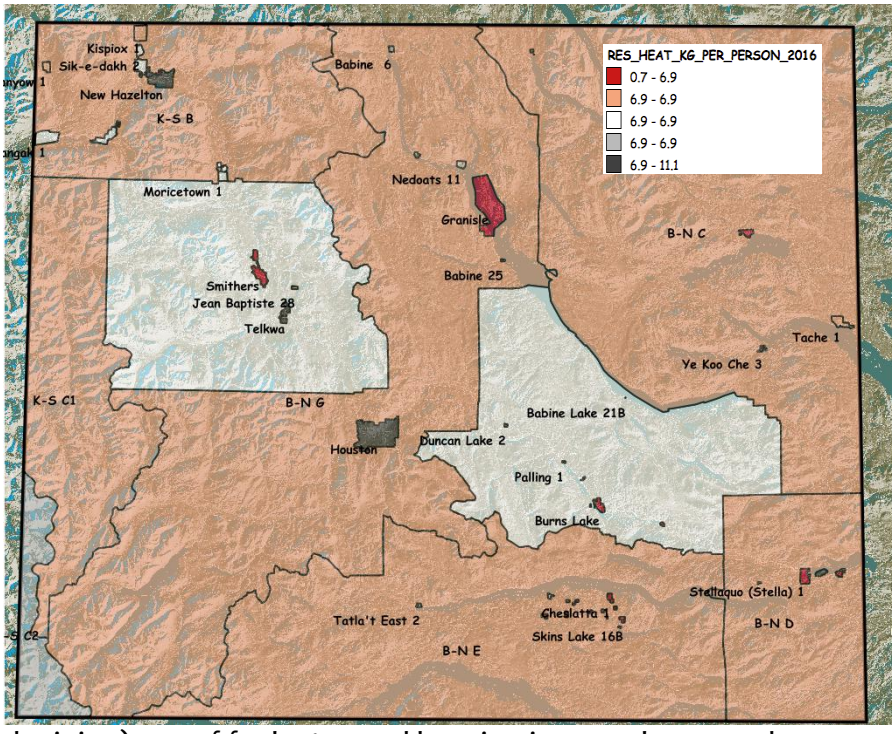
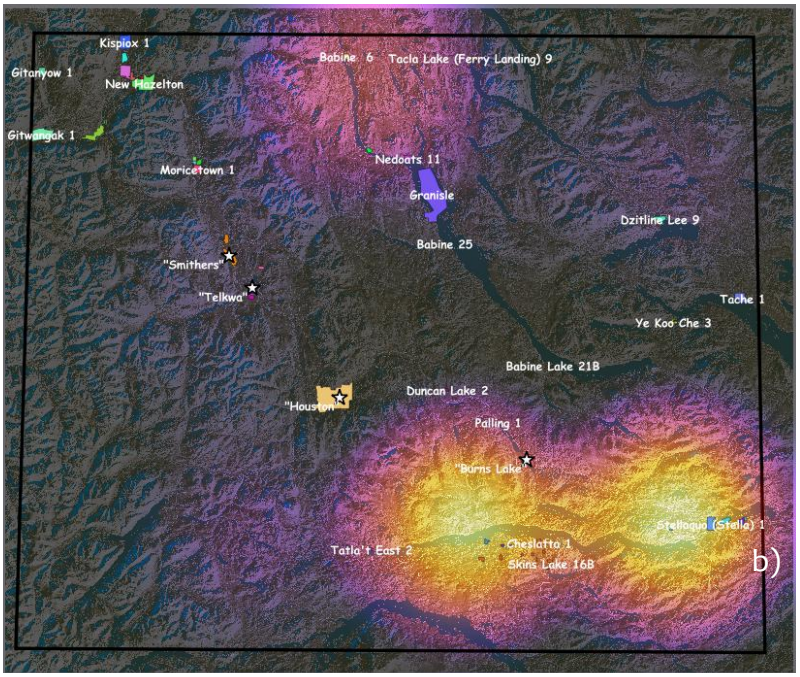
1.1. *Forestry, Natural Resource and Agricultural Burning*



Open burning was a common activity included in Permits given under the *Environmental Management Act*, representing 10 of the 25 individually permitted study area sources (See Appendix B.2-3). These open burning sources, unlike those presented here, make up part of a facility permit that also includes other resource extraction activities (forestry and mining) use of fuel, etc., and burning is a regular enough activity to warrant a permit. Therefore, in effort not to separate sources within a facility permit,

these open burning events are included in the previous section (3.2) on Permitted sources rather than under open burning. That being said, open burning represents the largest PM source in the study area, and if the burning from permits was iincluded it would be even higher. For air quality to improve in the region open burning may be the next source that needs some changes.

Figure 17. 'Heat maps" showing the intensity of TPM emissions from resource burning in 2015 a) and 2016 b) with a 50 km influence radius.



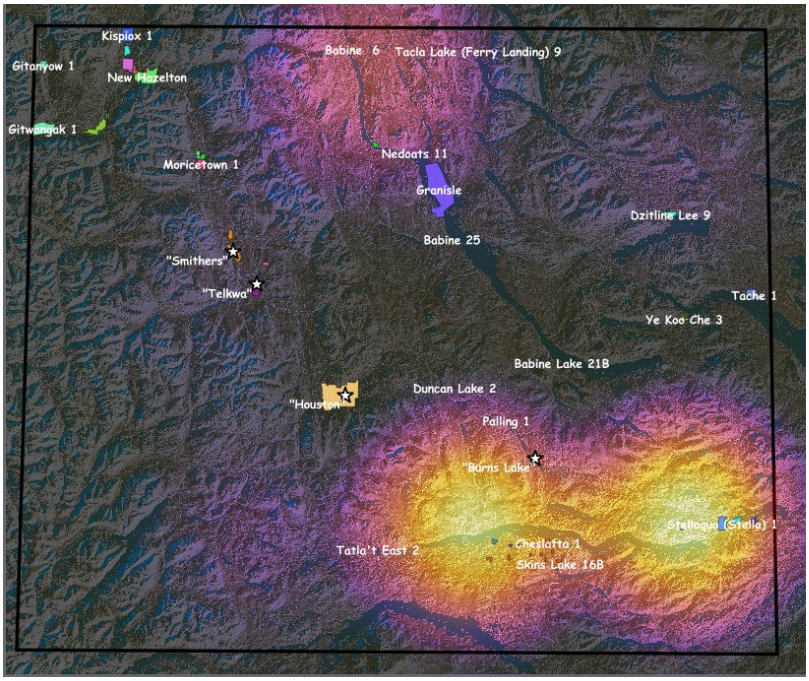


Figure 17 shows 'heat maps' of autumnal open burning within the study area in 2015 a) and 2016 b), with no obvious difference between years. Heat maps are used to display spatial densities, in this case resource burning in the fall (Sept. to Oct.) of 2015 and 2016. The heat surface is drawn based on an intensity field (in this case TPM) and a distance of influence. In the latter case a 50 km (100 mm at a 1:500,000 scale) radius was chosen to reflect how far the smoke from any given burn may travel., and both years were given identical parameters. However, the smoke plume(s) could likely travel much further and Figure 18 shows a heat map produced for 2015 with a 100 km radius of influence for comparison. There were also a number of burns just outside of the study area that would too be capable of influencing local air quality.

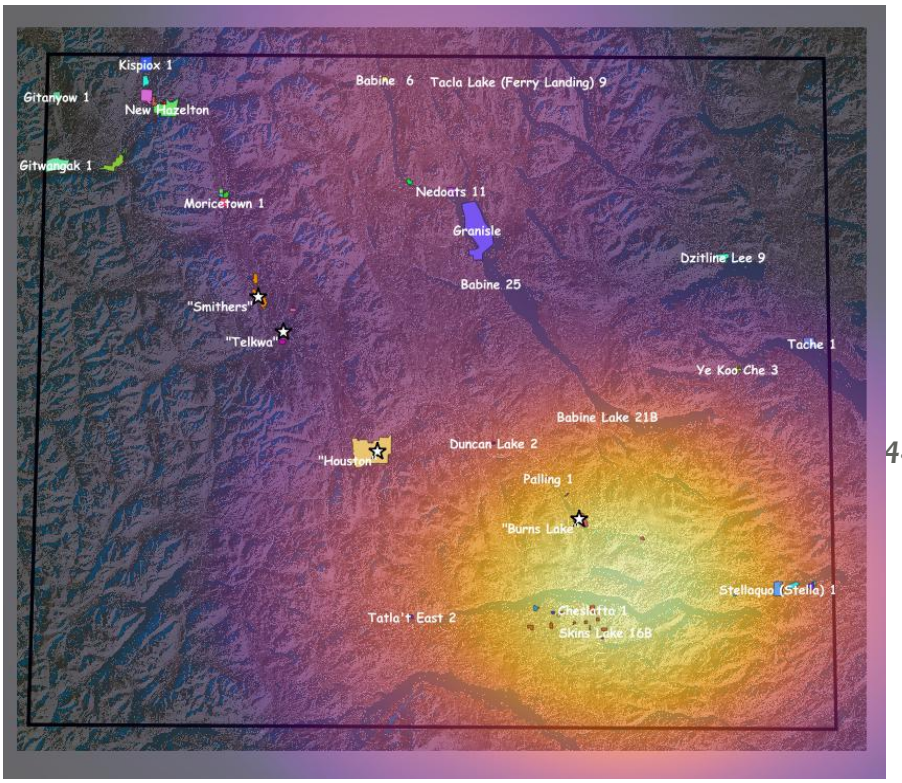


Figure 18. 'Heat map" showing the intensity of TPM emissions from resource burning in 2015 with a 100 km radius of influence.

4.2 *Miscellaneous/Additional Sources*

There are a number of source types that were not included in the MEI, largely because 1) there were insufficient data available to produce or justify any emissions estimate; 2) there simply was not enough time to complete an assessment of each source, and sacrifice needed to come from somewhere; or (3) a combination of both of the above. Most of these are listed in section 1.3, and include natural sources such as:

- Wildfires
- Sea salt
- Volcanism
- Long-range transport of foreign dust (e.g. from Asia)
- Vegetation (pollen, condensable VOC)
- Land-slides
- Commercial and residential food preparation
- Use of aerosol sprays
- Smoke from the use of tobacco, smudge, incense, etc.
- Outdoor camp-/cook-fires

Natural sources are generally not included in EI that are usually reserved for anthropogenic sources that we can regulate and control—should we chose to do so. However, make up some of the total PM dose and the different compounds in PM will react with one another and other atmospheric constituents, despite their source.

From a human-made PM stand-point:

- Automobile exhaust
- Automobile brake and tire wear
- Household and commercial cooking and cleaning (bakeries, meat smoking, etc.)
- Backyard burning
- Camp fires and generators in parks
- Airplane exhaust
- Recreational vehicles and pleasure-craft
- Fuel-based landscaping tools and equipment

3.5 Data Quality, Accuracy and Sources of Error)

It is crucial for the reader or user of the MEI to understand that any and all of the numbers presented in the MEI are estimates, not absolute values or measurements. An estimate is largely an educated guess about something we know about, but don't know the definitive answer. It is the difference between guessing how many jelly beans are in the jar, and opening the jar to count them.

But you can't open the jar, so in order to get the most accurate guess possible you may decide to count the jelly beans in a vertical row from top to bottom, and another in the horizontal. Depending on the shape of the jar you may wish to count a second traverse row in the horizontal (if rectangular) or employ the use of π (if circular). In both instances you are making assumptions to aid in your estimate, for instance that the arrangement of jelly beans is uniform throughout the jar, there are no large air spaces, nothing else is in the jar other than jelly beans, all the jelly beans are the same size, etc. Similarly, assumptions were made in the development of the MEI, some of which may be more valid than others (See Appendix A.2).

For instance it is unlikely that natural gas and propane furnaces didn't contribute much PM to the airshed—but would a correct assumption have been to ignore them and assume 100% complete combustion for all furnaces? DO 80% of people actually drive twice a day, and do people only burn perfectly dry seasoned wood?

Another source of error is the use of maximum value estimates, or worse case scenarios, particularly in terms of *EMA* permitted sources. The probability of them being precise measures of actual emissions is very low, meaning these source PM emissions are over-estimated and are actually lower (either that or they are consistently exceeding the permitted discharge amount and essentially performing an indictable offence under the *EMA*).

Sources types that were completely omitted from the MEI are another source of error and uncertainty. For instance the omission of seasonal and overgrown roads lead to study area road length being reduced by 0.67% and 0.74% causing error, but the emissions associated with these roads would have been so uncertain, that including them likely would have introduced an even higher level of error. Greater error is due to the lack of

vehicular emissions, paved road dust, and secondary particle from non-fuel vehicular sources. However, a new tool should be developed that can adequately classify and generate emissions datasets for roads in the region, as the methods used here, in Weinstein (2005), or elsewhere for that matter, seem very inaccurate.

Sometimes more detail adds more error, or 'compounds' the error. For instance you may have a one variable estimate for something that has 40% error. That may sound high, so you decide more detail is warranted. Getting rid of the one variable in favour of six others that seem more accurate because they have more detail. But, if each of them has 7% error, you are left with a total error of 42% or more if your estimates determine other estimatess—even worse off than at the beginning.

4 Discussion

4.1 Trends and changes over time

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A few major changes have occurred in the BVLD that affect local air quality since the 2000/2001 MEI was developed by Weinstein (2005). One major shift that has contributed to an improvement in the airshed's air quality is the wood stove exchange program that has seen nearly 300 inefficient wood stoves operating in the BVLD, exchanged for more efficient (and less polluting) woodstoves between 2006 and the present. Comparing this MEI with Weinstein (2005) residential wood burning TPM emissions have been reduced by over 30%. This doesn't all seems to be due to woodstove exchange program whose numbers were manually deducted. Since 2006 the Woodstove exchange program focused within the communities of Smithers, Telkwa and The Hazeltons has swapped out a total of 281 inefficient woodstoves for improved efficiency models —197, 79, and 5 for the respective communities. Assuming a switch from conventional to catalytic, and the annual burning of four and a half tonnes per stove (from Weinstein, 2005) this exchange programme has reduced PM_{10} emissions in the BVLD by 6.45 t/y. If the exchange were from conventional to masonary woodstoves, PM_{10} levels decreased by 15.81 t/y. Either way, or somewhere in between, it's a step towards clearer air in the BVLD.

So there has either been a general change or reduction in wood burning that isn't documented, or it has something to do with a difference in methodology.

Another step towards general air quality improvement in the BLVD and the province in general is the discontinuation of beehive burners in the forest sector—a source type that contributed nearly 10% of the area's emission in 2000 and 2002; 1654 t/y and 1769 t/y of TPM to the airshed, respectively. So important were beehive burners as emission sources that they were deservedly given their own emissions category in Weinstein (2005). They were also an icon of BC's sawmill culture, but saw their last days in December 2007 as per the *EMA*'s *Wood Residue Burner and Incinerator Regulation* (B.C. Reg. 22/2006).

Another large change for the region in terms of PM emission culprits was when West Fraser Mills Ltd, operating as Pacific Island Resources' (PIR)'s shut down their wood pellet plant in late 2014. Residents of the region had already had just about enough of PIR's emissions from five cyclones, eight drying kilns and wood refuse fired oil boiler for energy production (Northern Engineered Wood Products (NEWPRO) in 2017.
However, even as these developments act to reduce PM emissions, still other shifts in activities increase them. For instance, community members have remarked on the increased use of generators at BC Parks and Recreation Campgrounds. Apparently an increase in usage in the summer of 2020, combined with now common generator usage, combined with wood smoke to make campground PM emission obvious. Certainly just one of many additional sources to include in any improved and updated MEI for the region.

4.2 Inventory Usage and Updating

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As mentioned in the beginning, inventory development and improvement are limitless. The addition of new sources, finer spatial and temporal detail, and more accurate method of quantifying the tonnes released, could be infinite. Nonetheless, more detail doesn't necessarily mean more accuracy; and no emissions inventory will ever be 'perfect'.

The request to update this inventory was simple, 20 years has passed by and things may have changed. As discussed in the previous section things have changed, some for the better, others potentially for the worse. But, if the communities and the respective decision-makers remain informed and up-to-date on emissions in the region, policy and incentives can be developed to instigate the positive developments that improve air quality, and suppress those actions that lead to further air quality decline—all while balancing the economy and social requirements, with the health and environmental impacts of particle pollution—not an easy feat.

The appendices of this inventory have been provided in digital format, as have the mapping files. The hope is that they are easy enough to understand that the MEI can become somewhat of a living entity. If an industry [picks up and leaves town, they can be removed to see the impact. If a new development that contributes PM is being proposed or approved to set up shop in the region, they can be added. Adjustments and refinements can me made to temporal profiles and spatial allocation as new information arises; and if so inclined, the data should be fit for regional dispersion and/or forecast modeling—with some tweaks to the formats dependent on which model is used.

The most important determinator in MEI update focus is the end use. If used for modelling, spatial and temporal allocation are important; if policy-making, then a break-down of sources into further subtypes may help point out where efforts of the most needed. Decisions regarding where to place new air monitors, could maybe use some spatial refinement and even a model run to fully support placement decisions.

Should years be mixed, and does it matter if it means you are using the mot recent data for each class/variable?

4.3 Future Research, Emerging Technologies and Moving Towards a Well-Managed Airshed

It seems ridiculous to burn all your garden matter so that all your soil nutrients drift away on the wind, and then apply chemical fertilizer to your lawn and garden because system is now in deficit; however, to date Smithers (BVLD-AMS, 2006) is the only community to outright ban the open burning of yard waste or household refuse within municipal limits.

Local green bin pick-up and or composting facilities are promoted as an alternative to backyard burning, a compost bin incentive combined with education couldn't hurt. Much of it comes down to being afraid compost will be dirty, or smell, but if done properly this is not the case.

An outright ban on the burning of anything but dry seasoned wood or pellets within city limits, or the entire area, and requiring a 'burn permit' or BRN for any type of backyard burning (other than a small campfire for cooking, keeping bugs away and staying warm) seems warranted. It is surprising and seemingly out-dated for the burning of household refuse to be acceptable—but it occurs across the country. That being said, there is a BC Government webpage that claims the burning of garbage or construction debris "is illegal unless specifically authorised"[17]; perhaps this law just needs to be advertised?

Road dust can be somewhat controlled with wetting, but part much of the issue is salt dust remaining in the spring after snow melt. As shown by this inventory unpaved road are another source. Thankfully road dust is composed of coarser particles and doesn't travel too far; and despite being the larges contributor to PM in this and the year 2005 inventory (Weinstein 2005), it likely isn't the largest culprit in terms of human health effects. Not only are the particles to large to transport, they are also too large to travel very far into the airways. As mentioned above (section 3.3) it also seems to be overestimated by the various tools available to assist with PM estimation.

Incomplete combustion is what makes PM from wood-smoke (and other heating fuels such as NG and propane) the most harmful. Combustion efficiency improves as burn rate and flame intensity increase; and factors such as moisture content and oxygen levels can at least partially control combustion efficiency. However, inefficient wood burning appliances, industrial boilers, and open burning can all create a myriad of harmful particles including tiny sub-micron carbon spheres, and POM or other hazardous hydrocarbons that adhere to the surface of otherwise chemically benign smoke (carbonaceous) particles or become part of the particle physical matrix.

These types of harmful chemicals also form during pyrolytic reactions involving the incomplete combustion of fossil fuels, such as natural gas, propane or diesel fuel—also commonly used for heating in the BVLD. Not really known for their emissions of PM, a

[17] https://www2.gov.bc.ca/gov/content/environment/air-land-water/air/air-pollution/smoke-burning/burning-outdoors

modern gas furnace is generally quite efficient, factors such as servicing, cleaning, fuel quality and even placement, can influence burn efficiency, and as shown in section 3.4.1 these appliances contribute to the PM load in the BVLD airshed. Like furnace effluent, fireplace and woodstove emissions are highly variable and depend on a combination of wood characteristics, equipment design and operating practices.

One of the simplest and most effective ways to reduce harmful emissions from externally fired combustion engines may be education of the operator. This could come in a variety of forms, depending on the specific target audience. Inefficient combustion not only produces more toxic emissions, it also burns more fuel—meaning it costs more money. Everyone loves to save money, no matter how they feel about their neighbours, the environment. Making people aware of cost savings could lead to the added benefit of cleaner air. Fuel producers also play a role, for instance businesses who deliver firewood by the cord. There isn't really any positive reinforcement mechanism for them to have customers need less of their product; but there are potential incentives, or penalties, that may reduce practices such as the common "of course this wood is seasoned for over a year". Similarly, boilers using heavier (higher grade) fuel oils combust more efficiently at lower loads (such as 50% of their rating) (US-EPA, 2007); however, the load at which enhanced efficiency makes up for the load reduction is unclear.

Noncatalytic fireplace inserts reduce emissions by directing unburned hydrocarbons into an insulated secondary chamber, where mixing with fresh, preheated air enhances combustion (US-EPA 2007).
In general, conditions which promote a fast burn rate and a higher flame intensity enhance secondary combustion and thereby lower emissions. Conversely, higher emissions will result from a slow burn rate and a lower flame intensity. Such generalizations apply particularly to the earlier stages of the burning cycle, when significant quantities of combustible volatile matter are being driven out of the wood. Later in the burning cycle, when all volatile matter has been driven out of the
wood, the charcoal that remains burns with relatively few emissions.

The science of air pollution is constantly changing as well. Electrochemical sensors such as the Purple Air Monitors that are being used by AMS throughout the BVLD on collaboration with the University of Northern British Columbia (UNBC) are showing real promise as an affordable and reliable alternative to traditional air quality monitors that cost tens of thousands of dollars. In the past decade or so, electrochemical sensor technology has improved greatly, particularly in terms of measurement sensitivity. Such sensors used to only find purpose in occupational and emergency settings as they could only register concentrations (of gases) in ppm, despite AQO being in ppb, levels at which human and environmental health effects are known to occur. While increased sensitivity can also have its challenges, for instance electrochemical PM sensors have a habit of registering those tiny glittery ice crystals that form under the right conditions of temperature (cold) and relative humidity (when moist air meets the cold) and these sorts of measurement artefacts may need to accounted for / teased from data sets with a standard algorithm that accounts for the conditions under which such artefacts form en masse.

We are also always learning more about pollutants themselves—their chemical make-up, the size of particles, etc. For instance a decade ago no one really spoke much of PM1, or superfine sub-micron nanoparticles—our filters that were once the sole way of measuring PM were too coarse to catch them let alone all those condensables that come in more flavours and colours than even the fanciest of jelly beans in the jar you have to guess the number of. Now imagine you also had to guess the relative proportion of each colour and flavour, without even know what colours and flavours exist. That is quite a bit like the mixed science and art of developing a PM emissions inventory. To go back to the fourth goal of the updated MEI: to determine "the best" inventory that can be developed for the BVLD based on existing data and what we know. That wasn't realty accomplished here, it would have taken even more time, which of course requires even more money. The best MEI is likely one that keeps evolving as new information and data sources arise; one that can be modified or updated to be used for different purposes. But one must be weary of the infinite nature of something that could become so detailed you get stuck drowning in a pile of numbers. At the same time, there are so many variables from source characteristics, to size fractions, to weather condition, things that affect the completeness of combustion, the chemical species of the PM, whether it's organic or inorganic, is it chemically benign or coated/impregnated with a compound that can lead to cancer or inheritable genetic mutations? Ideally the "best" inventory could deal with all those variables, answer all those questions, and more. But, as we strive for perfection we sometimes must settle for what's possible at the moment. A perfect MEI doesn't exit for PM in the BVLD, or anywhere on Earth for that matter. But, thankfully the respective communities and residents realise, at least to some degree, that particulates matter.

5 Acknowledgements

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