Prince George Air Quality Emissions and Modelling: Appendix A

Updated Prince George Micro-Emission Inventory (2016)

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1. Executive Summary

This appendix provides supplementary material for the main *Prince George Air Quality Emissions and Modelling* report. The Prince George modelling system consists of four primary pieces: the micro-emission inventory (MEI), the meteorological model (CALMET), the dispersion model (CALPUFF), and the web-based analysis and simulation tool (AirQuest). Each section is explored in detail in individual appendices. This appendix will expand on the technical details of the first section, the Prince George MEI.

The Prince George MEI lists the emission rates of PM_{10}, $PM_{2.5}$, SO_2 and NO_x (= NO + NO_2) as well as various other parameters for each of the emission sources within the airshed. It was originally developed in an earlier phase of the project and has been subject to multiple iterations of testing and improvements. The MEI is grouped into ten main emission source categories, allowing for the apportionment of modelled air pollutant concentrations at specific times and locations to specific emission sources categories.

The MEI was updated from the previous (2005) inventory to represent emissions in 2016. Most of the emission source updates focused on the industrial emissions, as this source category was expected to have changed the most over the 11-year period. A new site list was produced based on the active air permits during the modelling period and updated emission data were collected or calculated from stack tests, site operator data, and various allocations produced from tests on similar equipment. Approximately 60% of the emission data were updated from the previous inventory. Additional, less-intensive updates were made to the fugitive dust source, and the open burning source was removed.

Many of the emission sources received additional updates during Phase 2, prior to this study, but subsequent to Phase 1 documented in Stantec (2010). Most significant of these was the implementation of vegetative capture and precipitation reduction for dust sources. Vegetative capture is the reduction of dust emissions due to physical impaction with vegetation near the source. Precipitation reduces dust emissions to 0 when it is occurring or when snow is on the ground – these reduction effects are reduced as the surfaces dry based on the precipitation amount, the time since precipitation, and the ambient temperature. These changes to the modelling method are most noticeable for the road dust source, which was significantly reduced since the previous MEI.

Particulate matter (PM) would exist in Prince George, even if there were no anthropogenic emissions within the city. This is due to the import of natural and anthropogenic PM from outside the airshed and is called *background* PM. These background levels make up a significant portion of the contributions to monthly and annual mean particulate concentrations in the airshed. Typical background concentrations of respirable particulate matter (PM_{10} and $PM_{2.5}$) were calculated based on monitoring data from low-pollution wind sectors following methods outlined in Veira et al, 2013. Particulate matter can be directly emitted into the atmosphere – this is called *primary* PM; it can also form in the atmosphere from the conversion of gases (mainly oxides of sulphur and nitrogen reacting with ammonia) – this is called *secondary* PM.

Concentrations of secondary PM were determined after the fact based on the output model results.

Hourly emission rates for each hour in 2014-2016 were assigned to each emission source based on the MEI data. CALPUFF, the dispersion model, used these hourly emissions along with the meteorological output from CALMET to calculate hourly ambient concentrations spatially across the Prince George airshed. The CALPUFF results can then be analyzed, and source reduction scenarios simulated using the AirQuest web-based tool.

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4. Introduction

The Micro-Emission Inventory (MEI) is a list of all sources of PM_{10}, $PM_{2.5}$, NO_x (assumed 90% NO, 10% NO_2) and SO_2 in the Prince George Airshed. PM is of primary concern from a health perspective, however, NO_x and SO_2 are modelled in order to estimate the production of secondary formation PM. The MEI includes details about each source such as emission rate, temporal variation in emission rate, emission height, emission temperature, location, source configuration (point, line or area), etc. The MEI is processed through the CALPUFF/CALMET modelling system to calculate the ambient levels of pollutants from each source for each hour over the 2014-2016 period at all receptor locations.

4.1. Individual Source Modelling

The micro-emission inventory (MEI) is split into multiple source categories to allow attribution of modelled ambient concentrations to specific emission sources. Each source in the MEI is modelled individually. Sources can be geographically allocated as areas, lines, or points. CALPUFF treats area and line sources as point sources emitting from the center of their defined region. As a result, care must be given when assigning emissions to these source types.

4.2. Inventory Regions

The area sources in the model have rectangular or polygonal regions that differ between area source types (Figure 1). The regions do not cover the entire airshed, just where relevant emissions occur. During Phase 1 the commercial neighbourhoods were developed (Figure 1A). A concern with these, such as overlapping regions and irregularity in shape and size, were noted in previous work and the residential neighbourhoods comprised of rectangular areas were produced as a result (Figure 1C). The commercial source regions used in the original MEI are still implemented in this phase due to data limitations. In future an update to the commercial sources to utilize the Phase 2 ‘Residential Neighbourhoods’ could be done for consistency, although this is not expected to affect the results very much. Currently, only residential heating and residential miscellaneous emissions utilize the ‘Residential Neighbourhoods’ regions. In addition, there are separate regions defined for the major road areas (road dust and on-road mobile emissions) as well as for the rail yards in the city (Figure 1B, Figure 1D). CALPUFF assumes emissions come from a single point located at the midpoint of regions.

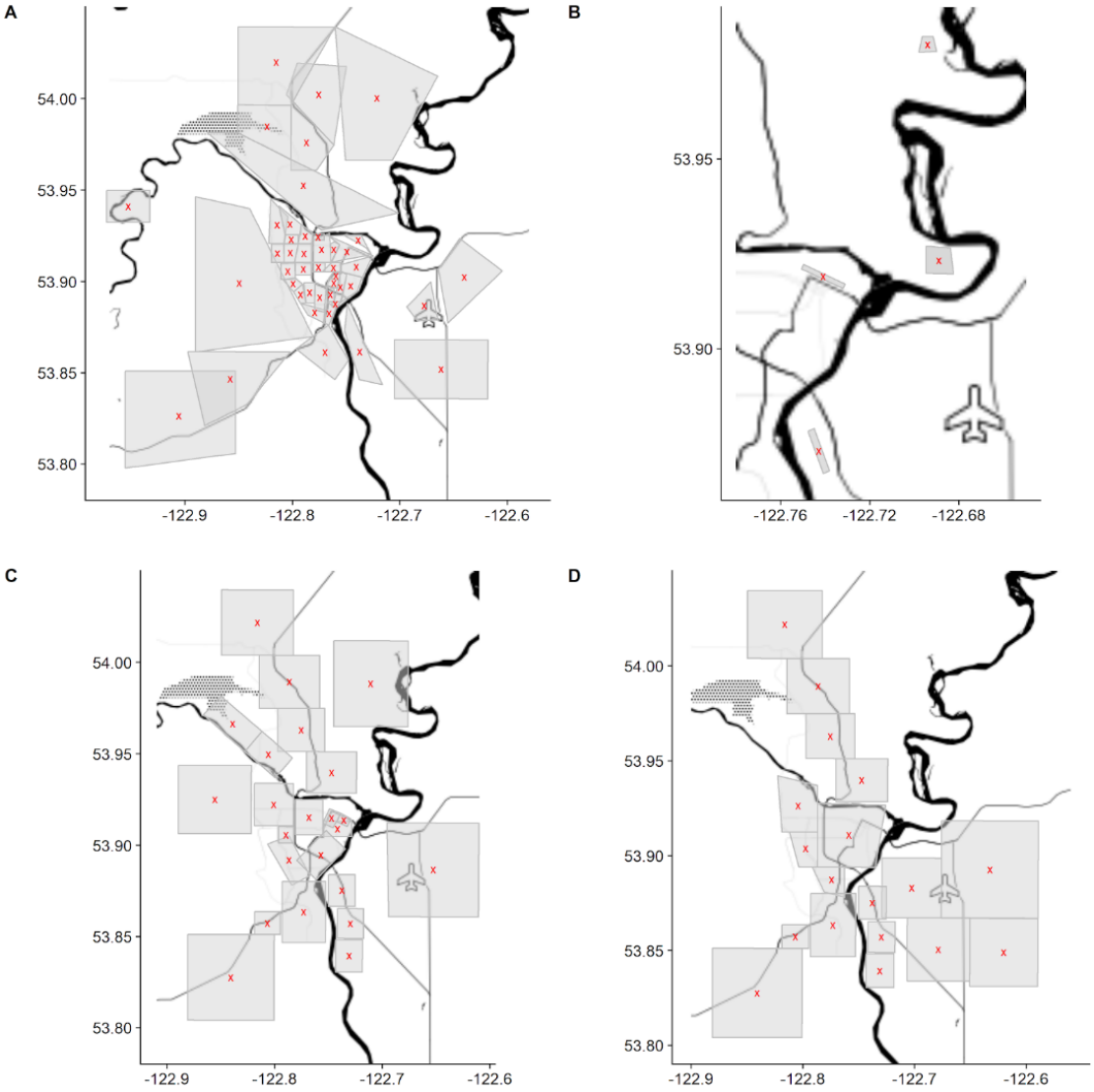


Figure 1. Regions and midpoints used in the Prince George micro-emission inventory. There are 44 commercial neighbourhoods (A), 4 rail yards (B), 23 residential Neighbourhoods (C), and 18 road areas (D). In the dispersion model, CALPUFF, emissions are assumed to originate from the midpoints of each region (marked with an 'x'). Emission sources which do not use these areas are modelled as either line sources (rail lines, arterial roads, etc.) or point sources (industry, fugitive dust, etc.).

5. Emission Source Categories

The Prince George MEI is separated into ten main source categories – the proportion of total average emission rates, along with the annual total emission rates, for each emission source category are displayed in Table 1. The total emission rates are the three-year means of the yearly totals for each source. Average emission rates do not take into consideration temporal variability in emissions. The sources with the highest annual emission rates are industry, residential heating, commercial dust, road dust, and on-road mobile; the remaining sources have much lower annual emissions.

Table 1. Total and average annual emission rates by modelled emission source category. Totals (tonnes per year) are averaged for the three model years; there was little to no interannual variation. Average emission rates (grams per second) do not take into consideration temporal variability in emissions. Dashed lines separate groups of common emission categories – from top to bottom: Industry, dust sources, on-road mobile, heating sources, rail yards/lines, and miscellaneous sources.

Emission Source	Total Emission Rates (t/y)				Average Emission Rates (g/s)			
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	PM_{10}	$PM_{2.5}$	SO_2	NO_x
Industry	1259.2	956.5	6940.1	1268.4	39.93	30.33	220.07	40.22
Road Dust	378.8	60.6	0.0	0.0	12.01	1.92	0.00	0.00
Commercial Dust	758.0	148.7	0.5	268.5	24.04	4.71	0.01	8.51
Fugitive Dust	33.6	4.0	0.0	0.0	1.06	0.13	0.00	0.00
On-Road Mobile	31.6	22.1	24.7	1654.6	1.00	0.70	0.78	52.47
Residential Heat	193.7	190.8	4.2	123.6	6.14	6.05	0.13	3.92
Commercial Heat	5.5	5.5	0.4	70.8	0.17	0.17	0.01	2.24
Rail Yards/Lines	13.2	12.6	14.2	708.3	0.42	0.40	0.45	22.46
Restaurants	25.6	23.9	0.0	0.0	0.81	0.76	0.00	0.00
Miscellaneous	31.3	30.6	17.5	152.7	0.99	0.97	0.55	4.84
Total	**2698.6**	**1423.0**	**881.3**	**4230.8**	**85.6**	**45.1**	**27.9**	**134.16**

Since the most recent report on the project by Stantec (2010) documenting the Phase 1 work, the Prince George MEI has gone through several updates, including those made in this phase of the project (Phase 3). Significant changes were made during Phase 2 to the road dust, rail yards/lines, and restaurants sources, and the fugitive dust source was added in the work done between Stantec (2010) and the start of the current phase (Table 2). Most other sources were changed as well, however, these changes were less significant. The total average emission rates across most source categories were reduced for every pollutant in the current MEI, especially for PM_{10} and $PM_{2.5}$ from Road Dust and for SO_2 from industry. The Road dust reductions were the result of an improvement in the dust emission estimation method (dust reductions due to vegetative capture were implemented) – not from an actual reduction in road dust emissions. The 25% reduction in SO_2 is a result of industrial reductions, mainly from the three pulp mills (see Section 6.1).

Table 2. Average annual emission rates by modelled emission source category for the Stantec (2010) micro-emission inventory (MEI). Average emission rates (grams per second) do not take into consideration temporal variability in emissions. Dashed lines separate groups of common emission categories – from top to bottom: Industry, dust sources, on-road mobile, heating sources, rail yards/lines, miscellaneous sources, and open burning. The fugitive dust source was not included in the Stantec (2010) MEI, and the open burning sources were removed in the current MEI. The total average emission rate from the current MEI (See Table 1) are included for comparison.

Emission Source	Total Emission Rates (t/y)				Average Emission Rates (g/s)			
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	PM_{10}	$PM_{2.5}$	SO_2	NO_x
Industry	2193.3	1597.9	9214.8	1353.5	69.55	50.67	292.2	42.92
Road Dust	4328.6	619.4	0.0	0.0	137.26	19.64	0.0	0.0
Commercial Dust	433.3	49.8	0.0	0.0	13.74	1.58	0.0	0.0
Fugitive Dust	--	--	--	--	--	--	--	--
On-Road Mobile	32.5	23.3	23.3	1552.2	1.03	0.74	0.74	49.22
Residential Heat	167.1	164.6	4.1	135.0	5.3	5.22	0.13	4.28
Commercial Heat	6.3	6.3	0.6	82.0	0.20	0.20	0.02	2.60
Rail Yards/Lines	171.6	164.3	44.5	2031.5	5.44	5.21	1.41	64.42
Restaurants	198.0	183.9	0.0	0.0	6.28	5.83	0.0	0.0
Miscellaneous	58.3	56.1	0.0	12.6	1.85	1.78	0.0	0.4
City Open Burns	31.2	30.9	1.3	9.5	0.99	0.98	0.04	0.30
MoF Open Burns	66.5	58.0	1.9	8.5	2.11	1.84	0.06	0.27
Total (Stantec 2010)	**7686.9**	**2958.7**	**9290.5**	**5175.1**	**243.75**	**93.82**	**294.6**	**164.1**
Total (Current)	**2698.6**	**1423.0**	**881.3**	**4230.8**	**85.6**	**45.1**	**27.9**	**134.16**

The total annual emission rates for both the Current MEI and the Stantec MEI presented in Table 1 and Table 2 are displayed together in Figure 2. The PM_{10} emission rates for the road dust, commercial dust, and industry sources changed most significantly since the Stantec (2010) MEI. Reductions in the Road Dust source are the result of an improvement of the dust estimation method (dust reductions from vegetative capture and precipitation were added), and not from actual reductions in this source's emissions. Previously, the PM_{10} in the MEI was dominated by emissions from road dust and industry. The current MEI, however, has a larger proportion of emissions from industry and commercial dust. Industrial emissions are lower in total in the current MEI as a result of reductions to several of the larger industrial emitters. Commercial dust average emission rate estimates nearly doubled, based on revisions done prior to the current updates. Many of the smaller contributing sources (Rail Yards/Lines, Restaurants, and Miscellaneous) were also reduced during this time. In addition, the two 'Open Burns' sources were removed in the current MEI and the Fugitive Dust source was added. The $PM_{2.5}$ emission rates for industry, road dust, and commercial dust have changed notably since the Stantec (2010) MEI. Industrial $PM_{2.5}$ and PM_{10} emissions were reduced by nearly half in the current updates. Commercial Dust emission rates for $PM_{2.5}$ also increased (in previous revisions) to over double in the Current MEI. A smaller change was noted for the residential heating source, increasing

slightly in total source emissions of PM_{10} and $PM_{2.5}$. The Restaurant and Rail Yards/Lines sources received reductions in revisions done prior to the current updates. Changes were also seen in the emissions of SO_2 and NO_x. However, these are only included for modelling secondary formation particulate matter (which is a small contributor relative to the other emission sources) therefore variations in SO_2 and NO_x emissions will have a low impact on the model simulations.

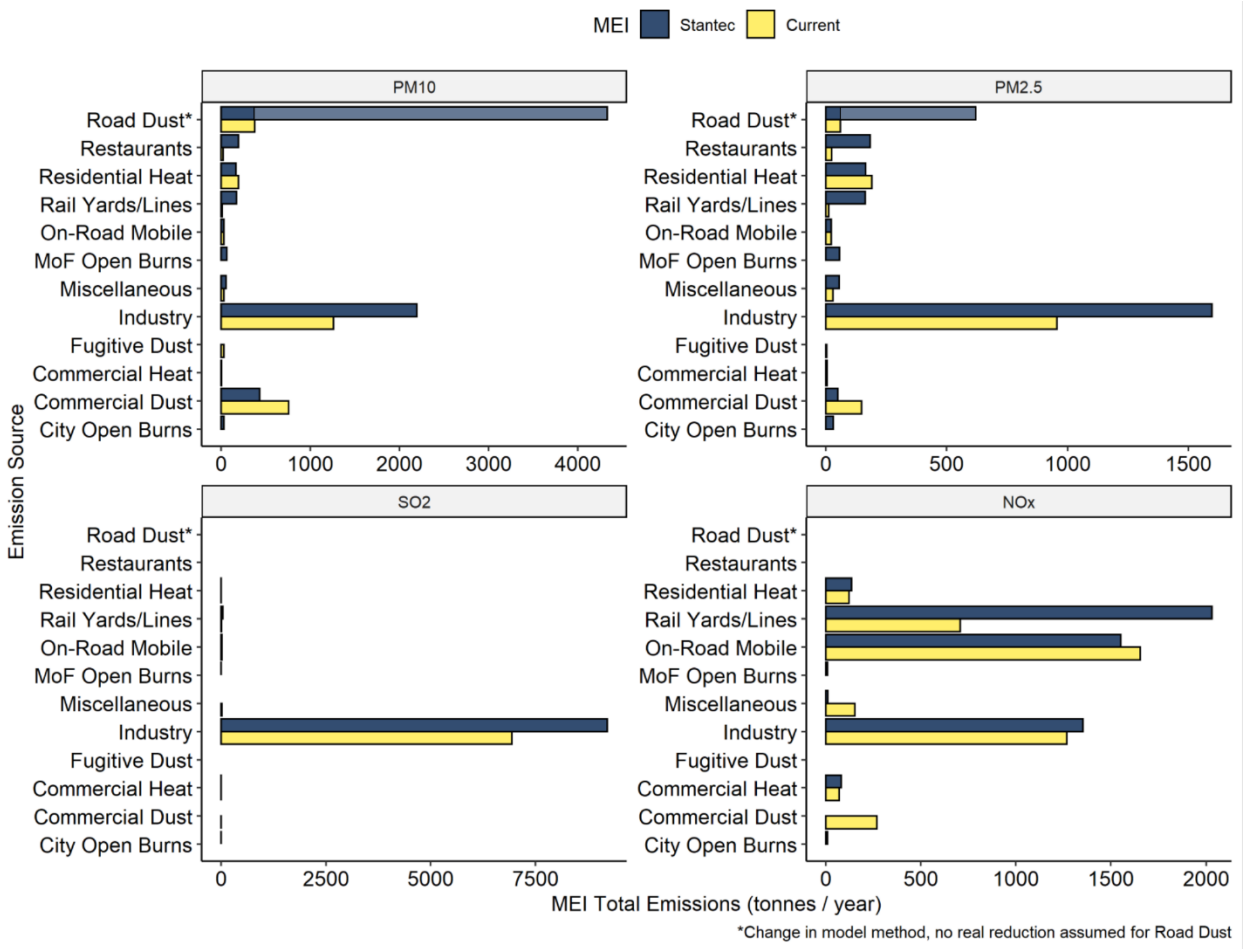


Figure 2. Average total annual emission rates by modelled emission source category for the Stantec (2010) micro-emission inventory (MEI) in blue as well as the Current MEI in yellow. The fugitive dust source was not included in the Stantec (2010) MEI, and the open burning sources were removed in the current MEI. The grey portion of the bar for much of the Stantec MEI PM_{10} and $PM_{2.5}$ emissions from Road Dust indicates an overall reduction in emission rates due to the implementation of precipitation scavenging and vegetative capture estimations in the emission from this source. As these changes are a result of improvements to modelling methods, they do not constitute any actual reductions in emissions from this source.

5.1. Industry

Industrial emissions were modelled as point sources from 22 sites permitted under the *Environmental Management Act* to release air pollutants of interest. Each site had 1 - 19 units permitted to emit these pollutants, each of which is considered as a separate point source in the emission inventory. Stack parameters, operational data, and average emission rates vary by equipment based on the best available data (See Section 6.1). Each unit emits their average emission rate during the hours, weekdays, and months prescribed in their operational data. Several unique cases had their hourly emissions altered if additional site operator data were provided, typically for long equipment shutdowns.

5.2. Dust Sources

Modelling of dust emissions was separated into three sources: road dust, commercial dust and fugitive dust. A major change from the Stantec (2010) work involved the implementation of vegetative capture for all dust sources (this was completed during Phase 2, prior to this current update). Depending on the density of vegetation near the emission source, a certain percentage of dust emissions will impact the vegetation and be removed from the atmosphere. To try and capture this effect, transportable fractions are assumed for each source based on the local vegetation density, using the method outlined in Pace (2005). The need for this was based on an analysis of $PM_{2.5}$ speciation data collected at Plaza 400 in 2005 (Rubin et al, 2008), compared with Calpuff model results from an earlier phase of this project. This analysis suggested that in the Stantec (2010) results, the modelled dust contribution was much too high. As a result of these improvements to the modelling method, there was a significant reduction in the estimated emissions from the dust sources – especially for road dust. In addition, estimated dust emissions are further reduced based on the time since the last precipitation event. After a precipitation event, depending on the magnitude of precipitation accumulated and the current air temperature, the emission rates scale back up as the wet surfaces dry. If it is currently precipitating, or if there is snow on the ground, dust emission rates are set to zero.

Road dust was modelled as both a line source (arterial roads) and as an area source (paved and unpaved residential roads). Area source emissions were assigned to the ‘Road Areas’ regions (See Section 4.2) and line source emissions were assigned to arterial roads in 3 - 12 segments, averaging 1.5 km in length each. Hourly peak emission weighting factors were determined using a traffic model and are divided into weekend factors and weekday factors (Figure 3). Weekend factors peak at 14:00 and reach a minimum at 03:00, while weekday factors are bimodal with the afternoon peak shifted to 16:00 and an additional lower peak appearing in the morning at 08:00. Road dust emissions are marginally lower in the winter and on weekends (even more so on Sundays). Peak PM_{10} and $PM_{2.5}$ emissions are calculated based on silt loading, traffic per hour, mean vehicle speed, and road length for each road segment. These peak emissions are then reduced by the transportable fraction and time since precipitation methods described above, then allocated to each hour reduced further based on the temporal weighting factors applicable for that hour/day/month.

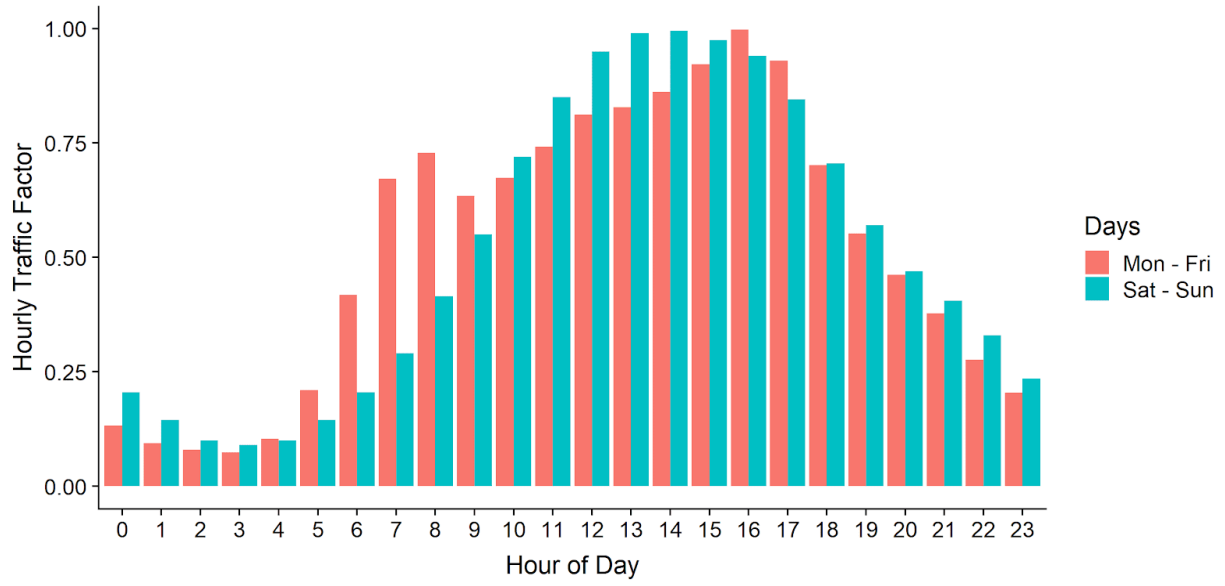


Figure 3. Hourly traffic weighting factors for weekdays and weekends utilized in the Prince George micro-emission inventory to allocate traffic-based emissions (i.e. road dust and on-road mobile). A higher weighting factor indicates more emissions assigned to that hour.

Commercial dust emissions were allocated to the 'Commercial Neighbourhoods' and included dust emissions from construction, gravel pits, farm vehicles, and parking lots. Emissions were allocated based on knowledge of typical activities occurring in each region. All sources had 80% emissions on Saturdays, 50% on Sundays and 100% on weekdays; monthly and hourly emissions varied by emission type (Table 3). Peak emission rates were calculated for each source type from activity data and were subject to reduction by vegetative capture, precipitation events and the prescribed temporal weighting factors.

Table 3. Temporal factors for the commercial dust and fugitive dust emission sources. A dashed line separates the commercial and fugitive sources. The notes column indicates any periods where emissions are reduced but not eliminated. 'Variable' active hours indicate that the emissions are not either 'on' or 'off' and emit a varying amount based on the determined amount of activity for that hour.

Emission Type	Active Months	Active Days	Active Hours	Notes
Construction	Apr - Nov*	All	08:00 - 19:00	*25% in Apr and Nov
Gravel Pits	Apr - Nov*	All	06:00 - 18:00	*25% in Apr and Nov
Farm Vehicles	Apr - Jun*, Sep - Oct*	All	08:00 - 20:00	*50% in Apr, Sep, and Oct
Parking Lots	Mar - Nov*	All	All Hours, Variable	*50% in Mar and Nov
Industrial Vehicles	All	Mon - Sat	07:00 - 20:00	
Material Handling	All	Mon - Sat*	07:00 - 20:00	*50% on Sat

Fugitive dust emissions were modelled as point sources at 22, mostly industrial, sites. This source considered vehicle traffic, material handling, and stockpile dust emissions at each site where the activity occurred. Temporal factors for vehicle traffic and material handling emissions are summarised in Table 3. Vehicle traffic and material handling emissions occurred between 07:00 and 20:00, with no emissions on Sunday from either, and half emissions from vehicle traffic on Saturday. There was no monthly variation in emissions for vehicle traffic or material handling. Wind-blown stockpile emissions were assigned to the hour of the maximum wind speed for each day using the 'wind speed fastest-mile' method detailed in AP-42 (2006). Essentially, the wind speed fastest-mile is determined for each day, and if that exceeds the friction velocity of the pile (dependent on particle size), wind-blown pile emissions will occur. Yearly vehicle traffic emissions were calculated and allocated to sites in Phase 2. Material handling and stockpile emissions were calculated using emission factors and handling rates/pile sizes. All emissions were subject to reduction from vegetative capture, precipitation and the predefined temporal factors.

5.3. On-Road Mobile

The modelling of emissions from vehicle tailpipes (also known as On-Road Mobile emissions) was split into area sources (residential roads) and line sources (arterial roads) in the same way that road dust was modelled (See Section 5.2). The same temporal profiles, arterial road segments, and 'Road Areas' regions were used for allocating the On-Road Mobile emissions. Emission factors for all four pollutants were calculated using the Mobile62C model based on data from 2003. These were used in combination with the road dust traffic data to compute peak emission rates for each area/segment, which were then scaled by the temporal profile to produce hourly emission rates.

5.4. Heating Sources

Residential heating and commercial heating were modelled separately. Both were area sources; however, residential emissions were allocated to the 'Residential Neighbourhoods' while commercial emissions were allocated to the 'Commercial Neighbourhoods'. Residential heating considers emissions from both natural gas burning and wood burning for use as heat. Natural gas burning emissions are assigned based on each area's population, as most residences had natural gas installed as well as utilizing wood heat. Not all residences burn wood for heating however, so the population weightings were adjusted for the percentage of wood stoves in each neighbourhood. Particulate emissions from heating are dominated by those from wood heating, as emissions from natural gas make up only 4% of the annual residential heating $PM_{2.5}$ emissions. Residential emissions are highest on the weekends and Friday, and peak during the Winter months with almost no emissions in July. Hourly emissions peak at 21:00 - 22:00 and ramp down until 06:00; at 07:00 there is another smaller peak when residents first wake up. Emission rates then begin decreasing until 10:00 before climbing once again to the evening peak. Emission rates for each hour were calculated using emission factors and the amount of wood or natural gas burned by region and were subject to reduction from the temporal factors.

Natural Gas usage by the commercial sector was provided in a previous phase of the project, and total natural gas burned was assigned to neighbourhoods using this and knowledge of commercial activity present in each neighbourhood. Commercial heating emissions occur at all hours and days; however, emissions are reduced by 20% for the hours 20:00 - 05:00 and by 30% on weekends. Monthly emissions factors were the same for commercial heating as they were for residential heating, highest in January and lowest in July. Hourly commercial heating emission rates were produced for each region using the total natural gas burned and emission factors in combination with the prescribed temporal factors.

5.5. Rail Yards and Lines

Rail emissions were split into road and yard sources. Railroads were modelled as segmented line sources with four lines leaving Prince George plus one along the Fraser River. Each line is divided into 4 - 9 segments, and the emissions from each segment are modelled as a point source from the segment center. Railroad emissions did not vary with time, emitting a constant value equal to the average daily emission rate calculated for that segment. Railyard emissions are allocated to the 'Rail Yards', consisting of 4 yards each with emissions from switchers, line locomotives, and/or mobile sources within the yard. Most yards operate all hours/days/months, except for Northwood Mobile and Bridgeyard Mobile which are only active for the hours 23:00 - 07:00 and 07:00 - 23:00, respectively. Hourly emission rates of each pollutant were calculated using updated information provided in a previous phase of the project regarding what 'notch' level, and the average emission rates for each notch level, the locomotives typically operate at.

5.6. Miscellaneous Sources

Miscellaneous sources are those with lesser or more localized contributions. These can be broadly grouped into three main categories: restaurants, residential miscellaneous and commercial miscellaneous. Emissions resulting from cooking at commercial restaurants was modelled as a point source with 140 individual restaurants, based on work done in Phase 2, subsequent to the Phase 1 inventory presented in Stantec (2010). Every site emits for 12 months a year and 7 days a week, with activity hours assigned based on what combination of meals (breakfast, lunch, dinner) the restaurant serves (

Table 4). Breakfast emissions occur between 06:00 and 08:00, lunch between 11:00 and 13:00, and dinner between 16:00 and 20:00; each restaurant served at least two meals. Individual restaurants were each assumed to emit 16 mg s^{-1} and 14.9 mg s^{-1} of PM_{10} and $PM_{2.5}$ respectively, allowing for hourly emissions to be determined from the prescribed cooking hours.

Table 4. Months, days, and hours which restaurant emissions occur in the Prince George micro-emission inventory (MEI) for each meal cooked by individual restaurants. Emissions are equal to 16 mg s^{-1} and 14.9 mg s^{-1} for PM_{10} and $PM_{2.5}$ respectively and occur for every month and day, however, are zero outside of a restaurant's 'Active Hours'. Each restaurant in the MEI cooked at least two meals.

Meal Cooked	Active Months	Active Days	Active Hours
Breakfast	All	All	06:00 – 08:00
Lunch	All	All	11:00 – 13:00
Dinner	All	All	16:00 – 20:00

Many smaller emissions sources were grouped into residential and commercial miscellaneous and modelled as area sources. The residential miscellaneous emissions are allocated to the 'Residential Neighbourhoods' (See Section 4.2), and includes cigarette smoking, lawn equipment use, and barbequing. The commercial miscellaneous source captures emissions from the airport, Pacific Western Brewing, welding and autobody shops, non-road mobile emissions (mostly construction equipment), and farm mobile emissions. All sources emit 7 days a week, with commercial sources having reduced emissions on weekends, and have variable hourly and monthly profiles (Table 5). Emissions for each source are based on emission factors and region populations.

Table 5. Temporal profiles for the residential and commercial miscellaneous sources in the Prince George micro-emission inventory. A dashed line separates residential and commercial sources. Emissions are assumed to be constant for the months/days/hours prescribed, except for certain periods of reduced emissions for certain sources.

Misc. Source	Active Months	Active Days	Active Hours	Notes
Cigarettes	All	All	08:00 - 22:00	
Lawn Equipment	June - Sept	All	12:00 - 20:00	
Barbeque	June - Aug	All	16:00 - 19:00	
Airport	All	All*	06:00 - 20:00 21:00 - 23:00**	*80% on Sat, 50% on Sun **50% emissions
PWB	All	All*	08:00 - 19:00	*80% on Sat, 50% on Sun
Welding & Autobody	All**	All*	08:00 - 16:00	*80% on Sat, 50% on Sun **50% in Jan/Dec
Non-road Mobile	May - Oct	All*	08:00 - 19:00	*80% on Sat, 50% on Sun
Farm Mobile	May, June, Sept, & Oct	All*	08:00 - 20:00	*80% on Sat, 50% on Sun **50% in April

5.7. Open Burning

During earlier phases of the project, open burning within the city limits was still permitted and was modelled as an area source, however, residents are now no longer allowed to do so. As a result, this source has been removed from the current modelling system. In addition, open burning outside the city limits, which is still permitted, was modelled as a point source in Stantec (2010). However, due to technical and time constraints this source could not be updated to be valid for the current modelling period. As a result, open burning is not considered in the current

modelling system. These sources made up only 3% of the total annual emissions of $PM_{2.5}$ concentration in the Stantec (2010) MEI.

5.8. Secondary Particulate Matter

Secondary particulate matter is formed from constituents (gases) present in the atmosphere, instead of directly emitted from a source. The modelling of secondary particulate matter is completed after CALPUFF is run using the POSTUTIL processor. Hourly concentrations of SO_2 and NO_x are modelled with CALPUFF then a proportion is converted to SO_4 and NO_3 within CALPUFF's ARM/Rivad chemical transformation module (Scire et. al. 2011), depending on assumed monthly background ozone and ammonia values for the airshed. The secondary particulate matter concentrations were then calculated for each grid cell by applying the following formula:

$$\mathbf{SO_4 * 1.375 + NO_3 * 1.291}$$

These gridded concentrations can then be added to the model PM_{10} and $PM_{2.5}$ outputs and are treated as an additional source.

5.9. Background Concentrations

The background concentration source is to estimate what the concentrations of PM_{10} and $PM_{2.5}$ would be if anthropogenic source emissions within the airshed did not exist. This includes emissions from nearby airsheds (for example the Bulkley Valley) and long-range transport (for example trans-Pacific) as well as natural sources (such as pollen and dust). Average background concentrations for wet, dry, and all conditions were calculated for each season based on the low-pollution wind sector method used in Veira et al, 2013 (See Section 6.3). This method selects observations of PM concentrations at the Prince George Plaza 400 station from 2009 – 2016 when winds are coming from a range of directions and within a range of wind speeds that are shown to have the lowest pollution (taking into consideration locations of large emission sources). Background levels are highest during dry conditions and lowest when it has rained in the past 48 hours. Background PM_{10} peaks in the Spring and is lowest in the Winter, while $PM_{2.5}$ is highest in the Fall and lowest in the Spring. These concentrations only vary based on season and precipitation conditions (with 12 possible values) – consequently they may not fully capture the true variability in the background concentrations of the Prince George airshed.

6. Inventory Updates

6.1. Industry

The industrial emissions were the primary source category to be updated to represent 2014 - 2016 conditions. A new site list was developed based on an analysis of the active air permits within the airshed during the modelling period. Twenty-two sites were identified to be operational within our modelling domain with a total of 119 emitting units - compared to the 32 sites and 149 emitting units previously. A total of 5 new sites were added and 15 sites were removed, broken down by industry type in Table 6.

Table 6. Changes to the Prince George micro-emission inventory industry type distribution between Phase 2 (valid for 2003 - 2005) and Phase 3 (valid for 2014 - 2016) of the modelling project. 'Change' represents the absolute change from 'Phase 2' to 'Phase 3' directly. A total of 5 new sites were added and 15 sites were removed.

	Number of Industrial Sites		
Industry Type	**Change**	**Phase 2**	**Phase 3**
Asphalt Paving Mixture and Block Manufacturing	0	3	3
Electric Motor Repair	-1	2	1
Industrial Inorganic Chemicals Industries	-1	4	3
Other Wood Products Manufacturing	0	2	2
Prefabricated Wooden Buildings Industry	-1	1	0
Pulp Industry	0	3	3
Ready-Mix Concrete Industry	-1	2	1
Refined Petroleum Products Industry	0	1	1
Sawmill & Planing Mill Products Industry	-4	10	6
Services to Livestock	-1	1	0
Softwood Veneer and Plywood Industry	-1	1	0
Storage Facilities Bulk Solids	-1	2	1
Wood Preservation Industry	0	1	1

Emission rates were gathered from several sources for each of the emitting units (

Table 7). Mean values from annual/semi-annual stack tests were given first priority, followed by additional data from the site operator, if provided. These make up 19% and 11% of the emission rate inputs respectively. Next, inputs from the previous MEI were used as long as the emitting unit was still operational during the modelling period, approximately 39% of the current emission rates were determined from the previous MEI. Allocations were created from tests performed on similar equipment for roughly 27% of the emission rates, and the remaining 5% were filled through assumptions or rescaling of emissions from similar equipment on site.

Table 7. Data sources utilized for determining average emission rates of all 119 industrial emitting units in the emission inventory. Values indicate the number of emitting units with data from that source; the total column is calculated as a percentage of the total. The order follows the priority assigned to each data source. 'Other' consists of calculations or assumptions made to fill in the remaining data.

Data Source	**Emission Rate Input Data**				
	PM_{10}	**$PM_{2.5}$**	**SO_2**	**NO_x**	**Total**
Stack Test Mean	37	37	8	8	**18.9%**
Provided by Site Operator	6	6	20	19	**10.7%**
Phase 2 Inputs	42	42	49	52	**38.9%**
Baghouse Allocation	14	14	14	14	**11.8%**
Large Cyclone Allocation	5	5	5	5	**4.2%**
Small Cyclone Allocation	8	8	8	8	**6.7%**
NG Boiler - Other Allocation	3	3	2	2	**2.1%**
NG Boiler - Pulp Allocation	0	0	2	2	**0.8%**
2016 or Earlier Permit	0	0	2	1	**0.6%**
Other	4	4	9	8	**5.3%**

Several of the larger emitting units had annual or quarterly stack tests performed for total particulate matter, SO_2, and/or NO_x (

Table 7). These tests included information regarding the gas exit velocity and temperature as well as the pollutant emission rates; where available these values were averaged for all stack tests performed within the 2014 - 2016 period. These averages were then used directly in the MEI for that emitting unit. The mean coefficient of variation across all sites with multiple stack tests performed is ~40% (Figure 4). This variability is not captured in the mean stack test value utilized by the current MEI.

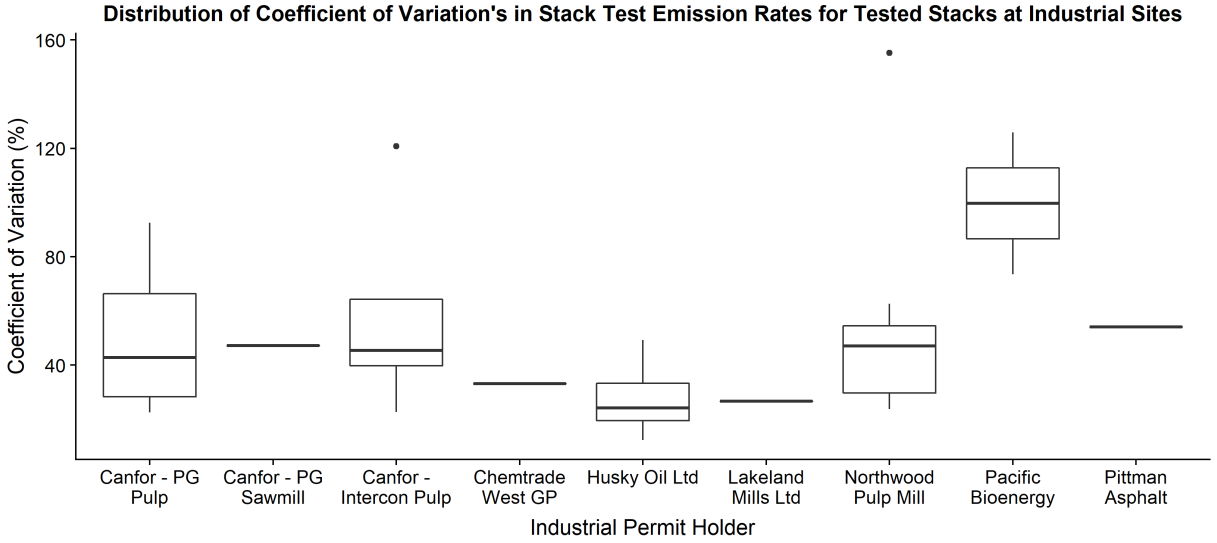


Figure 4. Boxplots of coefficient of variation found for stack tests performed on individual emitting units at industrial sites where more than one stack test was performed for Total PM, NO_x, or SO_2 within the 2014 to 2016 period. Plots with a single line indicates only one emitting unit and pollutant was tested at that site.

Individual reports were submitted for feedback to each of the site operators, several of whom provided additional information on their emitting units. Several units, such as the 'Power Boiler #2' at the Northwood Pulp Mill, were reported to be shut down for periods of time and had their emissions set to 0 for the appropriate times. The other units affected were the Greymont Western 'Lime Storage Silo (Un)Loading' and the Chemtrade 'Sulphuric Acid Plant Alum Storage and Reactor', which often emit less than their permits imply.

Any remaining values were transferred from the previous MEI where available. The previous work involved more in-depth site surveys than performed in the current work, and emission rates are unlikely to have changed significantly at most locations. Remaining data were infilled with allocations developed in the current phase of the project (a similar method was implemented for some sources in the previous MEI). These allocations were based on tests performed on similar equipment. Allocations were produced to infill data for the following four equipment types (Table 8): baghouses, cyclones, pulp mill natural gas boilers, and non-pulp mill natural gas boilers (NG Boiler - Other). Baghouse emissions from an anonymous saw mill (named "Mill 339"), located in central British Columbia, were extracted from a test performed for the Forest Products Association of Canada. These values were used as the baghouse allocation directly. The cyclone allocation was based on the average of tests performed for the Forest Products

Association of Canada on eight lumber industry cyclones in Canada. Cyclone emissions were measured on eight different cyclones and were differentiated by size: estimates for 'large cyclones' were based on six tests, and estimates for 'small cyclones' on two tests. The NG Boiler - Other allocation is based on the average inputs from stack test data for the natural gas boilers located at an oil refinery, a wood preservation site, and a sulphuric acid plant within the model domain. The NG Boiler - Pulp allocation is calculated in a similar manner for the boilers at the three pulp mills.

Table 8. Industrial source emission allocations utilized for several emitting units in the Prince George micro-emission inventory. If emission data were not available for an emitting unit the appropriate allocation was used. Allocations are based on stack test preformed on similar emitting units.

Allocation Type	Stack Parameters (m)		Gas Parameters		Emission Rates (g/s)			
	Height	Diameter	Velocity (m/s)	Temp. (ºC)	PM_{10}	$PM_{2.5}$	SO_2	NO_x
Baghouse	10	1.4	12.8	26.0	0	0	0	0
Large Cyclone	10	1.4	12.8	27.3	0.18	0.04	0	0
Small Cyclone	10	1.4	12.8	16.6	0.04	0.01	0	0
NG Boiler- Other	11	0.7	7.6	119.0	0.03	0.03	0.02	0.25
NG Boiler- Pulp	54.6	3.1	17.0	196.4	2.15	1.56	0.41	2.33

6.2. Fugitive Dust

Fugitive dust emissions were estimated in Phase 2 subsequent to the Stantec (2010) MEI. Updates to the fugitive dust source in the present study were not as intensive as they were for industry. Seven sites were removed from the previous MEI as there were not operational during the current modelling period. No new sites were added however due to time limitations. The timings of fugitive dust emissions from material handling and vehicle traffic were shifted from 08:00 - 18:00 to 07:00 - 20:00 to better suit observations following analysis of the hour average PM_{10} observations and model outputs at surface stations. In addition, a conversion error was found in the emission calculations for material handling, remedying this led to more reasonable modelled PM_{10} concentrations at surface stations.

6.3. Background Concentrations

Following work done by Viera et al (2013), background concentrations of PM_{10} and $PM_{2.5}$ were calculated for the 2014 - 2016 period. Hourly observations from the Prince George Plaza 400 station from 2009 - 2016 were trimmed to those records with a wind speed of 3-5 m s^{-1} and a wind direction within any of the following ranges: 350º - 10º, 150º - 170º, and 230º - 250º; matching the low-pollution sectors found for this station by Veira et al, 2013. Observations were further trimmed to ignore observations of PM_{10} above 30 µg m^{-3} or of $PM_{2.5}$ above 10 µg m^{-3}.

Due to a $PM_{2.5}$ monitor change in 2013 from a TEOM to a SHARP that resulted in a change of the monitored levels, hourly TEOM data from 2009 - 2013 were fit to the hourly SHARP data

with a linear model. An overlap period from 2013 - 2015 allowed for the development of the following correction formula, produced prior to trimming the data:

$$\mathbf{PM_{2.5\ SHARP} = 1.1 * PM_{2.5\ TEOM} + 2.8\ \mu g\ m^{-3}}$$

In addition, daily precipitation data at the Prince George Airport Auto station from 2009 - 2014 data was distributed evenly to each hour of the day and used both to estimate background concentrations as well as in CALMET. This precipitation record was used to bin the observations, trimmed to the wind sectors, based on three precipitation conditions: regular, dry, and wet (Table 9).

Table 9. Precipitation conditions used in the Prince George micro-emission inventory for developing average background concentrations of respirable particulate matter (PM_{10} and $PM_{2.5}$). Average concentrations were determined for each season and precipitation condition then assigned accordingly to the modelling period.

Regular Conditions	All available data (even if no precipitation data available)
Dry Conditions	Those hourly data with 48h precipitation < 2mm
Wet Conditions	Those hourly data with 48h precipitation >= 2mm

The trimmed and binned observations were then grouped by season (annual, winter, spring, summer, fall) and averaged to produce a typical background concentration for each season, pollutant, and precipitation condition combination (Figure 5). Background levels are highest during dry conditions and lowest when it has rained in the past 48 hours. Background PM_{10} peaks in the Spring and is lowest in the Winter, while $PM_{2.5}$ is highest in the Fall and lowest in the Spring.

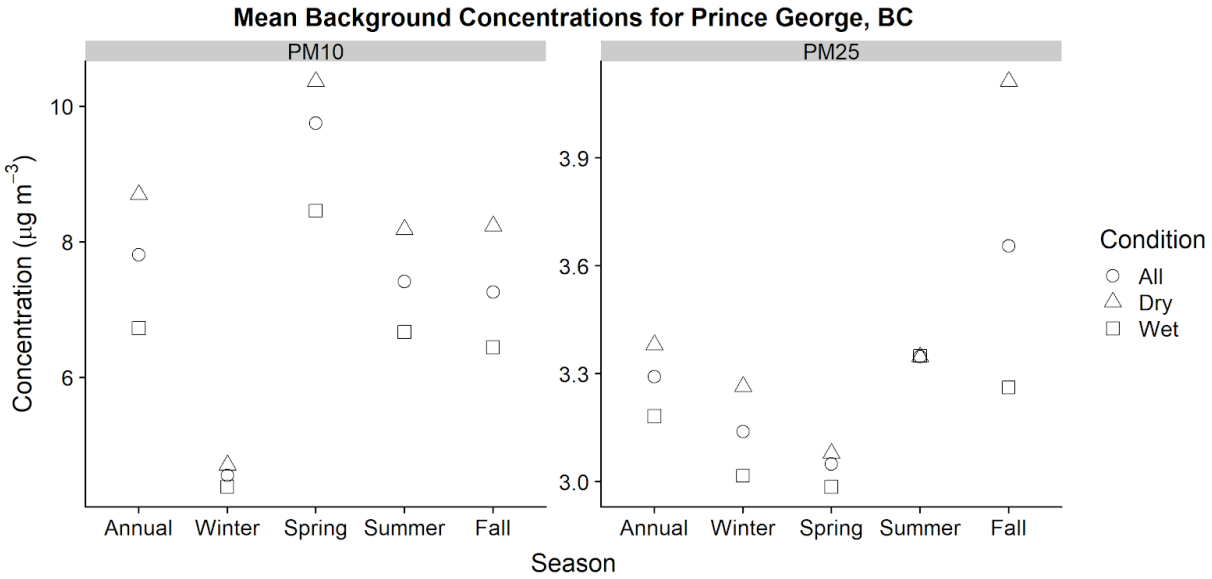


Figure 5. Mean background concentrations (µg m^{-3}) of respirable particulate matter (PM_{10} and $PM_{2.5}$) developed for the Prince George Airshed. Average background concentrations were determined for each season and precipitation condition (All data, 48h precipitation < 2 mm, and 48h precipitation >= 2 mm), based on ambient data from the Plaza 400 observation station and precipitation observations from the Prince George Airport station.

7. Conclusions: Limitations, Future Work and Recommendations

The updated MEI included important updates to the major sources, including industrial emissions that had changed since the 2005 inventory. Due to technical and time limitations not every imagined improvement to the minor sources could be made. Further analysis of dispersion model results (based on the updated MEI) point to possible issues in some sources. While a perfect modelling system does not exist, it is important to acknowledge possible limitations when using the MEI and outline future improvements to be made.

Unlike previous renditions of the project, emissions from open burning were not included. In 2005, this source only made up 3% of the modelled annual average $PM_{2.5}$ concentration at the Plaza 400 site (Stantec 2010). Since 2005, open burning has been eliminated within the city, which would further reduce the actual open burning emissions in 2014-2016. Based on data from the Open Fire Tracking System, there were approximately forty open burns per year within the model domain from 2014 - 2016. Additional details on the date, size and duration of each fire were not available. Consequently, due to time constraints open burning emissions were not included, which would slightly reduce the total modelled PM_{10} and $PM_{2.5}$.

Emissions from rail activity have likely increased since 2005 due to the implementation of an inland port terminal in Prince George in 2007. Emission and rail activity data were requested, but not provided. Estimated 2005 rail emissions are less than 1% of PM_{25} emissions and modelled concentrations from rail using these emissions are relatively low in most neighbourhoods, however these values are almost certainly underestimated in 2014-2016, given the increase in rail activity that has occurred.

Several other sources were also not updated with 2014 - 2016 data. These sources that were not listed in section 6, were considered lower priority due to their small relative impact and/or lower risk of significant changes in the 11-year period.

CALFUFF results suggest that emissions from Residential Heating, 96% of which is from wood burning, contribute to a higher than expected proportion of the ambient $PM_{2.5}$ levels in many neighbourhoods in the Winter. When winds are from the south to west at Plaza 400, placing the monitoring site downwind from several of the residential areas, the model overpredicts $PM_{2.5}$ by approximately 17%. Weekend $PM_{2.5}$ and PM_{10} concentrations tend to be overpredicted by the model as well. These overpredictions by the model could be due to overestimation of residential wood emissions and should be investigated further.

When winds are from the east to northeast (winds coming from the heavy industrial area) PM_{10} and $PM_{2.5}$ are underpredicted by the model at Plaza 400. PM_{10} is underpredicted at Plaza from this wind sector by ~42%, similarly for $PM_{2.5}$ (~41%). These underpredictions are much less when winds are from other directions for respirable particulate matter (5% for PM_{10} and 8% for $PM_{2.5}$). Industrial emissions are modelled using an average value which is either on or off, depending on whether the site is operating at that time. Average values are determined from stack test results for the major sources - these stack tests are performed under normal operating

conditions at facilities and may not represent emissions under sub-optimal conditions, so may under-represent true average emission rates. Also, in reality these emissions can vary by time of year and time of day – the mean coefficient of variability for the stack test results was ~40%. As many of these average values are based on a few single-point-in-time measurements, this variability is not captured. SO_2 concentrations however are overpredicted by ~291% at Plaza 400 with winds from the east to north. The overprediction of SO2 is much less with winds from other directions: ~ 109% with winds from the south to west. The overprediction is likely due to significant overestimation of SO_2 from pulp mill incinerators, which account for about 90% of the SO_2 emissions in the airshed. The incinerator emissions are not measured with stack tests, but are conservatively estimated using emission factors and pulp production levels.

CALPUFF modelled NOx levels are much higher than observed at Plaza 400. This is partly due to over-conversion of NO_x to NO_2 by the model, but also likely results from overestimation of NO_x emissions from vehicles in the MEI (On-road Mobile category). While this would not have a major effect on modelled PM since secondary PM levels are not very large, it should be investigated in future work.

8. MEI File Structure

The Prince George MEI primarily consists of a set of spreadsheets detailing the emission parameters for each source category. In addition, there are several programs and datasets utilized to calculate various effects, such as dust reduction by precipitation and hourly traffic flows. There are separate directories for each source category, each containing that source's MEI spreadsheet and a Python script. The Python scripts are used to allocate emission rates to each hour within the modelling period - it is here that the effects of precipitation, vegetative capture, and temporal weighting factors are applied. The hourly emission rates for each source, output by the Python scripts, are stored in nested directories with the following naming structure:

data/ems_files/source_category/sub_source/sub_sub_source/year

Where the 'sub_source' and 'sub_sub_source' detail the emitting site and the emitting units. The root directory (data/ems_files) is located in the same directory as the MEI source category directories (each source category directory also has a 'symbolic link' to this 'data' directory as well). Source categories are labelled with computer-friendly code names, detailed in Table 10. For example, the industrial emissions ('2per') from a specific stack (nb1) at an industrial permit holder's (p1069) location for a single year (2014) would be found in:

data/ems_files/2per/p1069/nb1/14

Table 10. Model code names used to refer to the 14 emission source categories in the Prince Georgge micro-emission inventory. These code names are used throughout the modelling system, while the source category names are purely for display-purposes.

Source Category	Model Code Name
Industry	2per
Paved Road Dust	3rd_pvd

Unpaved Road Dust	3rd_unpvd
Rail roads	4rai_rd
Rail yards	4rai_yd
On-road Mobile	5rmo
Residential Heating	6hea
Open Burning (Outside of Urban Centre)	7bur_mof
Commercial Heating	8chea
Residential Miscellaneous	9res
Commercial Dust	10com_dust
Commercial Miscellaneous	10com_misc
Commercial Restaurants	10com_res
Fugitive Dust	11fug

In addition to these hourly emission files for each source category, there are several other inventories located in the 'data' directory. Hourly observations of precipitation for the airshed (See Appendix B) are located in the 'precipitation_data' directory. The 'silt_data' directory contains files which detail the amount of dust present on arterial and residential roads. In addition, this directory contains several Python scripts used to determine the hourly reduction to be applied to dust sources as a result of recent precipitation (rain and snow) levels (See Section 5.2). Hourly records of ambient air temperature from the Prince George Plaza 400 observation station for each year are stored in the 'temperature_data' directory, used for calculating the emission temperature for many sources, allowing for a variable gas emission temperature (a source's gas emission temperature can be described as 'A+5' or 'Ambient temperature + 5 degrees). The final directory located in the 'data' directory is 'traffic_data'. This directory contains a Python script used to calculate hourly, monthly, and day-of-week traffic weighting factors. These weighting factors are used when allocating the hourly emissions from traffic-based sources (road dust and on-road mobile).

9. References

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