PRINCE GEORGE AIR QUALITY

Dispersion Modelling Study – A Revision

FINAL REPORT

Prepared for:

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and

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DISCLAIMER

This report is based on and limited to information obtained by and provided to Stantec at the time of preparing the report. The dispersion modelling upon which the report is based was governed by recommendations from the Regional Working Group (RWG) of the Prince George Air Improvement Roundtable (PGAIR), the March 2008 Guidelines for Air Quality Dispersion Modelling in British Columbia, the CALPUFF users manual, and Stantec's professional judgment.

Dispersion modelling is an iterative process and is considered a tool for providing the best estimate of source pollution impacts, with refinements introduced in each new cycle based on what was learned previously. An inherent part of any modelling process is to identify areas for refinement that may be implemented in future modelling that may be performed. Accordingly, Section 8.2 of this report presents a list of additional investigations that may be conducted in the future. These include investigations into i) emissions from, and the behaviour of, area sources generally (and commercial restaurants in particular); ii) the size distribution of on-road dust; iii) the role of secondary particulate matter formation; and iv) the inclusion of fugitive emissions from industrial and commercial parking lots.

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EXECUTIVE SUMMARY

This Revision Study attempts to apportion a wide variety of source contributions to inhalable and respirable particulate matter levels in Prince George (PM_{10} and $PM_{2.5}$). It builds on the Prince George Air Quality Research Modelling Study conducted by the Research Working Group and the University of Northern British Columbia. The RWG had developed an emission inventory and conducted a dispersion modelling study to identify key fine particulate matter emissions sources in the Prince George Airshed. The purpose of that study was to guide the development of the Phase III Air Quality Management Plan. After completion of the interim PGAQ study a third party review was commissioned by PG AIR. The RWG accepted a number of recommendations in the Review Report, and selected Stantec to implement these recommendations.

Stantec conducted dispersion modelling using the improved micro-emissions inventory and the CALPUFF dispersion model system. The CALPUFF chemical transformation module was used to predict concentrations of both the primary and secondary PM_{10} and $PM_{2.5}$. A revised receptor grid was developed, with special attention placed on the receptors whose locations coincide with the airsheds monitoring stations: Plaza, Lakewood, Gladstone, Glenview, BC Rail, and Van Bien. Other RWG-approved recommendations were also addressed.

Concentrations of PM_{10} and $PM_{2.5}$ were predicted at numerous receptors, as well as at monitoring station locations. At the monitoring station locations, each source and each source categories' contribution to the predicted concentrations were developed. The top contributors to air contaminant concentrations were identified. Isopleths overlain on an airshed base map identified areas likely exposed to high concentrations and potentially exceeding the objectives. Finally, the PG AIR PM Emission Reduction Targets were tested by modelling the recommended reduction scenarios.

Monitoring Site Receptor Results are presented in detail in subsection 6.4.1. This analysis focused on the Plaza site, however some detail on all sites is provided. At the Plaza site the top contributors to PM_{10} are on-road dust, permitted users, commercial restaurants, and residential heating. On-road dust is by far the strongest contributor to PM_{10}. At the Plaza site the top contributors to $PM_{2.5}$ are permitted users, on-road dust, locomotives, and commercial restaurants. Secondary particulate matter is 5% of PM_{10} and 10% of $PM_{2.5}$.

The assumed background contribution is approximately one quarter of the PM_{10} (27%) and one seventh (15%) of $PM_{2.5}$. Background accounts for particulate matter transported into the airshed, and unknown sources in the airshed that were not accounted for in the micro-emissions inventory.

Airshed Results are presented in detail in subsection 6.4.2. Isopleth maps are presented in Appendix A. The isopleth maps indicate that a substantial part of the bowl area and industrial regions have elevated predicted concentrations. There is some variation from year to year, but the pattern is largely consistent. There is not a great amount of seasonal variation. The Plaza monitoring site results indicate that a combination of on-road dust, permitted users, locomotive and restaurant emissions are primary contributors in the bowl area. In the BC Rail area locomotives and permitted users are primary contributors. The Gladstone monitoring site predictions suggest that the maxima over College Heights are attributable largely to on-road dust and permitted user sources. The maxima over the Hart Highlands are similarly attributable to dust, permitted user and residential heating sources.

The Test of PG AIR PM Emission Reduction Targets are discussed in section 7. Isopleth maps showing airshed patterns needed for meeting the PG AIR emission targets (Goal 1 and Goal 2), considering background, were produced (Appendix A). Using the year 2005 data, the annual airshed emissions for all the major source categories were reduced by 40%. When compared to unreduced results the areas in exceedance have decreased somewhat, but not eliminated completely. This means that the 40% reduction on all significant sources, envisioned to be achieved by 2016, will not achieve the 2013 goals. Performing the same analysis for the top 25 permitted users emissions indicated some reductions in areas near the sources, but insubstantial reductions in the airshed overall. With the modelled predictions as a reference level, it is apparent that about a 75% reduction in all major source categories will be needed to lower all airshed $PM_{2.5}$ annual concentrations to the annual 5 $\mu g/m^3$ target set out by PG AIR.

Recommendations regarding airshed management and further investigations are presented in section 8. Measures to inhibit or suppress road dust are ranked high. Continued improvement in permitted users particulate matter emissions are important. As improvements become feasible or necessary, reductions should be pursued. Restaurant, locomotive, and other minor source contribution reductions are also important. Other recommendations regarding background air quality, micro-emissions inventory management, and air quality forecasting. It is also recommended that PG AIR revisit their $PM_{2.5}$ Emission Reduction targets.

Further investigations have also been listed and prioritized. Given the uncertainty regarding the split in size fraction between PM_{10} and $PM_{2.5}$ in road dust it is recommended existing samples be re-analyzed, and modelling re-done should the new data warrant it. Emissions from the Commercial Restaurant sub source category should be revisited, and re-modelled if the new data warrants it. Additional study is needed as well on the subjects of fugitive emissions form parking lots, and secondary particulate. It is also suggested that the program would benefit from a suitably qualified full-time researcher to coordinating future work and to conduct any future investigations.

This Revision Study has produced a great deal if information that will guide the PG AIR Phase III planning process. By implementing the recommended actions stemming from the planning process Prince George will meet the combined goals of minimizing deleterious effects on particulate air quality and encouraging residential, commercial, and industrial development.

ABBREVIATIONS AND ACRONYMS

AAQO .... Ambient Air Quality Objective

agl .... above ground level

asl .... above sea level

BC .... British Columbia

CANFOR .... Canfor Corporation

CARB .... California Air Resources Board

CEC .... California Energy Commission

CNR .... Canadian National Railway

CWS .... Canada Wide Standard

DOT .... Federal Department of Transport

EC .... Environment Canada

EIG .... Emission Inventory Groupings

EPA .... Environmental Protection Agency

FPAC .... Forest Products Association of Canada

FW .... Fuelwood

GIS .... Geographic Information System

GJ .... Gigajoules

GVRD .... Greater Vancouver Regional District

HI .... Heating Index

IC .... Prince George Air Quality Implementation Committee

ICBC .... Insurance Corporation of British Columbia

LTO .... Landing and take-off

m .... metre

masl .... metres above sea level

MEI .... Micro Emissions Inventory

MOE .... British Columbia Ministry of Environment

MOF .... British Columbia Ministry of Forests

MOT .... Ministry of Transport

MOU	Memorandum of Understanding
NCASI	National Council for Air and Stream Improvement Inc.
NG	Natural Gas
NH_3	Ammonia
NO_x	Oxides of nitrogen
NO_2	Nitrogen Dioxide
NPRI	National Pollutant Release Inventory
PG	Prince George
PG AIR	Prince George Air Improvements Roundtable
PGAQ	Prince George Air Quality
PGAQRM	Prince George Air Quality Research Modelling
PGAQMP	Prince George Air Quality Management Plan
PM	Particulate matter
PM_{10}	Particulate matter less than 10 µm in diameter
$PM_{2.5}$	Particulate matter less than 2.5 µm in diameter
ppm	parts per million
PSEU	Permitted Source Emission Units
PWB	Pacific Western Brewery
RAC	Railway Association of Canada
RWG	Research Working Group
SEU	Source Emission Unit
SO_x	Oxides of sulphur
SO_2	Sulphur dioxide
STI	Sonoma Technologies Inc.
$\mu g/m^3$	micrograms per metre cubed
UNBC	University of Northern British Columbia
US EPA	US Environmental Protection Act
VOC	volatile organic compounds
VTK	vehicle travelled kilometre

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1 INTRODUCTION

This Revision Study builds on the Prince George Air Quality Research Modelling Study (or PGAQ) conducted by the Prince George Air Improvements Roundtable (PG AIR) Research Working Group (RWG, a working group of PG AIR) and the University of Northern British Columbia (UNBC) between 2006 and 2009. The PGAQ study consisted of both an emission inventory development and a dispersion modeling phase. The objective was to identify key particulate matter (PM) emissions sources in the Prince George airshed. The results of the PGAQ study were to guide the development of the Phase III Air Quality Management Plan. After completion of the interim PGAQ study a third party review was commissioned by PG AIR (the Review Report). The RWG accepted a number of recommendations in the Review Report, and selected Stantec Consulting to implement these recommendations.

This Revision Study was conducted with an improved micro-emissions inventory, the result of internal and third party reviews. The CALPUFF dispersion model system, with an active chemical transformation module, was used to predict concentrations of both primary and secondary PM_{10} and $PM_{2.5}$ throughout the airshed. A revised receptor grid was developed to better resolve predicted locations of high concentrations. Special attention was placed on the receptors whose locations coincided with the airsheds air quality monitoring stations: Plaza, Lakewood, Gladstone, Glenview, BC Rail, and Van Bien. Other RWG-approved recommendations were also addressed.

Concentrations of PM_{10} and $PM_{2.5}$ .were predicted at a 1.5 metre high receptor array centered on the Prince George urban area. The 1.5 metre height was chosen to approximate the breathing elevation of an outdoor human receptor. For all source emission units (SEU), the study required two sets of simulations, approximately 1,500 CALPUFF runs for each set. A full receptor dispersion simulation (with 1,873 receptors) predicted each source's contribution to the airshed concentrations. Airshed isopleth maps revealed areas likely exposed to relatively high concentrations predicted to exceed the BC air quality objectives. Another set of simulations predicted each SEU's PM_{10} and $PM_{2.5}$ contributions at the ten air quality monitoring locations. More simulations tested the PG AIR $PM_{2.5}$ reduction scenarios. In total, more than 3,000 CALPUFF dispersion and secondary formation simulations were performed at 1,883 receptors for 26,304 hours in study years 2003 to 2005.

The emissions reduction results have produced the information that should guide the PG AIR Phase III planning process. To help meet the specified PG AIR's ambient targets, high contributor SEUs and source categories were identified as reduction targets. Study isopleth maps detailing the concentration patterns could be used as input into City and Regional District land use planning process. These information sources should support the combined goals of enhancing air quality while encouraging residential, commercial, and industrial development.

Background information is presented in Section 2. Specific study objectives are discussed in Section 3. Methodologies, including quality assurance procedures, are presented in Section 4. The Prince George airshed micro-emissions inventory is summarized in Section 5. Section 6 introduces a modeling strategy for each category of sources. A comparison of predicted and measured concentrations confirms model performance. Discussions of monitoring site receptor and airshed results complete the section. Section 7 describes the results from the PG AIR PM emission reduction simulations. Section 8 summarizes study findings and conclusions. Section 9 recommendations provide PG AIR with a forward looking course of action. Detailed information such as CALPUFF options and full descriptions of the emission inventories and modelling results are found in the Appendices.

2 BACKGROUND

2.1 Overview

Prince George is a city of nearly 80,000 residents located in northern British Columbia (BC). Like any other northern location with varied topography, the PG area has its own unique set of influences affecting air quality. Substantial emission sources, low wind episodes, concentration-enhancing topography and meteorology frequently result in the trapping of pollutants in the densest urban and residential portion of the city (the "bowl"). Arguably, the area includes the most important industrial and service centre in northern BC. Industrial, commercial and residential activities result in many sources of air contamination. The area is home to a large number of local commuters frequenting the road network. The location is at the junction of two major highways ensuring high volume and transient vehicle traffic. Canadian National Railway (CNR) operates major rail lines and yard facilities within and near the city.

Prince George has among the highest measured levels of $PM_{2.5}$ in the province. It is frequently in exceedance of the recently adopted provincial $PM_{2.5}$ 24-hour standard of 25 µg/m^3 (as a 98th percentile) and annual standard of 8 µg/m^3. In years 2003-2005, Plaza exceeded the $PM_{2.5}$ Canada Wide Standard (CWS) of 30 µg/m^3 (as a 3-year rolling average of the 98th percentile 24-hour value). Prince George also has high levels of other air pollutants. This PG air-quality situation has generated political and health issues and has prompted concerted action by local stakeholders. In 1998, the PG Air Quality Technical Management Committee published the first Air Quality Management Plan (PGAQMP, phase I) becoming effective in 1999. PG AIR, RWG, and a Monitoring Committee were established to enact the plan. Source reduction activities carried out under this plan achieved decreases in the largest PM emission sources, including pulp mills, road-dust, domestic woodburning and open burning. Despite these actions, ambient $PM_{2.5}$ levels remained substantial in the bowl area, indicating the need for more precise source identification.

To promote the continuous improvement in air quality, PG AIR developed the next phase of the PGAQMP (the Phase II plan). Phase II activities started with the identification of the major source areas. Area source identification was performed by conducting a wind sector analysis of the continuous $PM_{2.5}$ data, using annually averaged levels at the Plaza site (BC MOE, 2006). The distribution of $PM_{2.5}$ concentrations by wind direction from 1998 through 2002 showed the highest concentrations consistently located in the northeast to southeast sector. The causes seemed to be the prevalence of low-speed channeled winds, combined with substantial sources in that sector. A co-varying relationship between the sulphur gases, which originate almost exclusively from sources in that sector and $PM_{2.5}$ corroborates the results of this analysis. Similar studies of the other pollutants such as the sulphur oxides (SO_x) and nitrogen oxides (NO_x) revealed the same patterns (Jackson & Spagnol, 2006).

The wind sector analysis provided basic information about the potentially most substantial $PM_{2.5}$ source types. However, individual sources were not identified. The Phase III PGAQMP needs to recognize specific targets for emission reduction. These high impact sources need to be identified in a robust and defensible way, ideally using several lines of evidence to strengthen confidence in their identification.

There are various methods to identify emission sources. One method is to identify ambient levels with some other indicator such as wind direction (e.g., the MOE 2006 wind sector analysis). Another method is to use receptor based approaches with speciated $PM_{2.5}$ and PM_{10} data (Graham & Sutherland, 2004 and STI, 2008). The third is to use dispersion modelling, the predictive approach. To ensure the defensibility of a study, consistency in the results obtained by these three approaches represents the ideal.

A receptor model has severe limitations. Many emitters have similar profiles and are indistinguishable by a receptor model approach. Also, profiles change between source and receptor because of chemical reactions. A dispersion modelling study offers the superior method for determining the emissions from specific sources, as long as those sources are known and can be characterized. A major advantage of the dispersion modelling approach is that it offers the best method for simulating the various scenarios required for source reduction planning.

The current study began in early 2006 and was supported by various related activities. Field studies were undertaken for the industrial facilities holding emissions permits. A road surface dust characterization study for the Prince George road network was performed. After the micro-emissions inventory (MEI) was compiled, the dispersion simulations started. The source apportionment approach required a separate simulation for each source for each of the six years of that study period (about 3000 simulations with many repeats).

Internal and third party reviews identified several deficiencies in the MEI and methodologies. Jackson *et al* (2009) improved the fuelwood burning component of the emissions inventory. The CN Rail (CNR) locomotive emissions inventory was improved after more duty cycle information was available. Many other revision activities continued to improve the MEI. At the same time, through continued research, sensitivity testing and other means, the modelling system was improved and the dispersion simulations redone.

2.2 Airshed Geography

The airshed shown in Figure 2.1 covers the computational domain. The red dots show the location of the receptor points where the PM_{10} and $PM_{2.5}$ concentrations at the 1.5 m agl flagpole heights were computed. The blue dots show the position of the Table 2.1 monitoring sites where the concentrations are computed at the instrument inlet heights. The PG urban area (with the bulk of the human receptors) is located approximately in the centre of the airshed. The geographic extent of the depicted area is approximately 20 km in each direction from the urban centre. The boundary is 40 km (UTM) in both the easting and northing direction. The river systems are the high profile domain landmarks. The airshed defines the areal extent of emission sources that are included in the

MEI. PM_{10} and $PM_{2.5}$ emission sources outside of the airshed, though sometimes very important, cannot readily be modelled except as background concentrations. Background PM_{10} and $PM_{2.5}$ concentrations imply a certain amount of cross boundary transport suggesting connectivity with other airsheds.

2.3 Topography

Ideally, airshed domains should have higher topography close to its borders. Under certain meteorological conditions, this desirable feature can serve to inhibit PM_{10} and $PM_{2.5}$ trans-boundary transport. The PG airshed topography can be looked upon as a plateau with a few hills surrounding the major rivers. The Figure 2.1 topographic representation shows the Tabor Mountain to the east, Cranbrook Hill to the west, and the Hart Highland area to the north. Under certain meteorological conditions, valleys also serve to inhibit exchange of air between the valley bottom and the hill tops. Figure 2.1 shows that the topography lowers appreciably at the intersection of the rivers resulting in a topographic “bowl” effect that defines the City of Prince George urban topography. Local topography can have a profound effect on the air exchange between different parts of the airshed and is an important consideration for air quality and dispersion modelling studies. For example, the Airport Hill where the CBC site is located often steers the southbound low level winds and air pollutants towards the Prince George urban area.

2.4 Monitoring Stations

The PG airshed monitoring stations are the responsibility of MOE and the PG AIR Monitoring Working Group. The stations are listed in Table 2.1. Site locations are shown in Figure 2.1. The CBC and Jail stations do not measure PM. The BC Rail and Glenview stations did not measure $PM_{2.5}$ prior to 2005.

Table 2.1: The MOE Monitoring Stations and Species Measured

Name	Species Measured
BC Rail Warehouse	PM_{10}
CBC Transmitter	SO_2
Gladstone School	PM_{10}, $PM_{2.5}$, SO_2, dis$PM_{2.5}$ *
Glenview School	PM_{10}
Jail	SO_2, TRS
Plaza 400	NO_x, PM_{10}, $PM_{2.5}$, SO_2 ,TRS, CO
Western Acres	dis (PM_{10}, $PM_{2.5}$)
Van Bien	dis PM_{10}, $PM_{2.5}$
Lakewood	TRS, dis(PM_{10}, $PM_{2.5}$)
North Nechako	New station

NOTES:

* The discontinuous PM monitors are prefixed with a “dis”. PM_{10} = particulate matter sized 10 microns or less; $PM_{2.5}$ = particulate matter 2.5 microns or less; SO_2 = Sulphur Dioxide; NO_x = Nitrogen Oxides; TRS = Total Reduced Sulphur; CO = Carbon Monoxide.

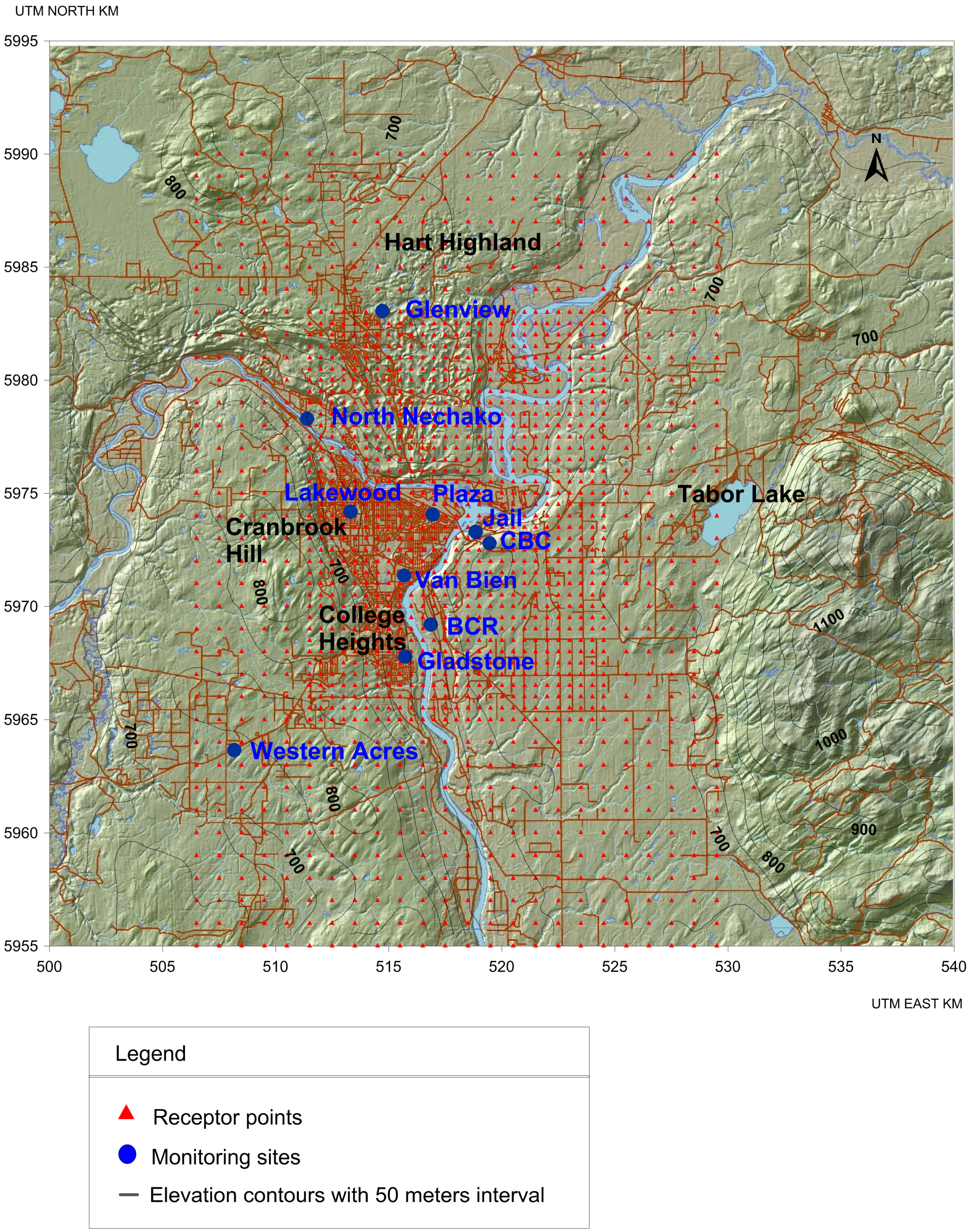

Figure 2.1: The Prince George Airshed with Receptor Points, Monitoring Sites, and Elevation Contours.

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2.5 Meteorology

The meteorology of the airshed has a profound effect on both the PM_{10} and $PM_{2.5}$ emissions and their subsequent dispersion. Road-dust PM_{10} and $PM_{2.5}$ emissions are suppressed by rain and snow fall. A residual snowpack remaining on Prince George roads can suppress road-dust emissions for days, even months. Cold temperatures result in higher heating requirements resulting in greater PM_{10} and $PM_{2.5}$ emission rates. Strong winds can eject dust and other surface-lying materials (e.g., biogenic sources, surface deposited PM_{10} and $PM_{2.5}$) but can also act to disperse the launched PM_{10} and $PM_{2.5}$ effectively. Once PM_{10} and $PM_{2.5}$ is emitted into the airshed, the ambient meteorological conditions largely determine how well they disperse. Turbulence and the wind disperse PM_{10} and $PM_{2.5}$ into the surrounding air. Wind speeds determine the transport rates and wind direction determines the final destinations of all air-contaminants. Stagnant conditions and temperature inversions, coupled with the bowl topography can restrict the vertical mixing and the dilution of air contaminants resulting in higher ambient concentrations.

One upper air station and seven surface observing stations routinely report the PG airshed meteorology. The meteorological station sites are listed in Table 2.2 along with station information. The upper-air station is administered by Environment Canada (EC). The airport reporting station is administered by Transport Canada (DOT). The UNBC station is administered by the Environmental Science & Engineering Programs at UNBC. The remainders of the stations (Plaza 400, Lakewood, Gladstone, Glenview BC Rail and Van Bien) are the responsibility of the BC Ministry of Environment (BC MOE or MOE).

Table 2.2: PG Airshed Meteorological Stations and their Attributes

Site Name	Administrator	Elev.ASL (m)	Meteorological sensors
Upper Air Meteorological Station			
Upper Air Met	EC	601.0	Temp, wind, RH, pressure
Surface Meteorological Stations			
Plaza 400	MOE	595.0	Temp, wind, RH, SR
Northwood	MOE	577.0	Temp, wind
PG Pulp	MOE	600.0	Temp, wind
Airport	DOT	691.0	Temp, wind, RH, pressure, cloud cover/height, precip.
Glenview school	MOE	750.0	Temp, wind
UNBC	UNBC	761.4	Temp, wind, RH, pressure, SR
Gladstone school	MOE	610.6	Temp, wind, RH

NOTES:
RH = relative humidity, temp = temperature, precip = precipitation, N/A means non-applicable, SR = solar radiation.
The elevations (m) are for the base of the station as determined by the digital elevation model data used.
ASL data were provided by MOE and includes platform elevation

2.6 Land Use

The surface condition will sometimes have a substantial effect on the local environment and air contaminant dispersion. Open fields encourage windier conditions. Wind flow through forests and urban areas produces increased wind turbulence. The urban heat island effect decreases the low level atmospheric stability. Air flow over water bodies can moderate temperature changes increasing the low level atmospheric stability in summer and decreasing the stability during cold air outbreaks.

More important is the seasonal changes in the surface condition. Winter snow cover will result in less wind flow friction velocity decreasing the turbulence. An increase in the surface albedo (reflectivity of solar radiation) will alter the surface energy balance. As spring approaches, a snow covered area requires a greater amount of heat due the latent heat requirements of snow melt, increasing the probability of low level inversions. A realistic representation of the surface condition is an important part of model development.

A snow covered scenario was assumed between the months of November 15 through to March 15; the remainder of the year was assumed to be a non-snow covered landscape.

3 PROJECT OBJECTIVES

The findings of PGAQ Revision Study will provide information to support the Phase III Prince George Air Quality Management Plan (PGAQMP)**.** These information requirements include:

- Identification of the relative contributions of each major PM source category (defined in Subsection 5.1) to ambient air quality
- Identification of the relative contribution of each Source Emission Unit (SEU) and Sub-source Categories (defined in Subsection 5.1) to the PM source category contribution
- Identification and ranking of the top contributors
- Examination of the scenarios necessary to support the PG AIR reduction targets.

4 PROJECT METHODOLOGIES

The PGAQ study consisted of the following overlapping phases:

- Development of the Micro Emissions Inventory (MEI)
- Dispersion modelling of the emission rate estimates
- Results extraction
- Preparation of an Interim Report
- Internal and third party reviews
- Revision Study needed to implement review recommendations.

These phases are discussed below.

4.1 Phase 1: MEI Development

The MEI improvement activity was a major task. Inventory development included the categorization of the SEU parameters required for dispersion modelling previously non-existent and needing definition. Through various levels of reviews, the MEI information was developed, validated, revised, enhanced and revalidated (See Appendix C). The MEI data valid dates are centered on year-2005 (the last year of the study period) now considered the MEI valid date. Year 2005 is the logical verification year for the study results. Going forward, it must be recognized that the MEI contains perishable data, and the continuous management will be required.

4.2 Phase 2: Dispersion Modelling

The primary airshed dispersion modelling tool used was the CALPUFF modelling system. It is comprised of a suite of modules including: CALMET for the geophysical and meteorological environment modelling; CALPOST, a statistical processing program used to summarize and tabulate the concentration results; CALSUM, providing summations and POSTUTIL for merging results.

Most modelling studies are initial and boundary value exercises and dispersion modelling is no exception. Besides the emission rate estimates and parameters characterizing the SEUs, the input requirements include the modelling of the geophysical, topographic, and meteorological environments. The input data needed to produce the modelling environment are stored in Excel spreadsheets and are written out in model compatible formats as required.

As recommended by the RWG, the Revision Study shortened the study period to three years (2003 to 2005). Meteorological data including precipitation from both the upper air and surface stations defined the meteorological environment. The Canadian Digital Elevation Data (CDED) defined the topographic environment. Two land-use regimes defined the annual surface condition; the winter regime valid from November 15 to March 15 had much more snow cover.

4.3 Phase 3: Results Extraction

After the dispersion simulations ended, the results were extracted from the output files. For each of the monitoring site receptors, concentration predictions from each of the emission sources were extracted for each of the study period years. Results from the airshed receptor set were used to depict concentration patterns on isopleths maps.

4.4 Phase 4: Interim Report

An internal Interim Report was produced to fully document the Interim Study.

4.5 Phase 5: Reviews

Members of the RWG performed internal reviews of the interim study inputs and findings. After several revisions, a third party review was commissioned. Revisions were made based on the recommendations for improvements produced by both the RWG and the third party reviewer.

4.6 Phase 6: Rework

Stantec Consulting performed the rework for the Revision Study, addressed most of the recommendations, and included the PG AIR reduction scenario tasks. The results of the Revisions Study rework are documented with this report.

5 MICRO-EMISSIONS INVENTORY

5.1 Overview

Emission Inventories

Emission inventories often cover jurisdictional areas. The National Pollutant Release Inventory (NPRI) is managed by Environment Canada. BC MOE maintains an emission inventory valid for British Columbia (MOE-Victoria) assumed valid in year 2000. The Greater Vancouver Regional District (GVRD) maintains a regional emissions inventory covering the lower Fraser Valley. Smaller domain coverage is typically balanced by increasing detail resulting in micro-emissions inventories (MEI). For the airshed that they characterize, MEIs are usually the most accurate. At the same time, the data are usually not transferable to other airsheds.

The Prince George MEI (Appendix C) is very detailed. It includes all known sources within the Prince George airshed. Ideally, all MEI data should be valid at approximately the same time. Unfortunately, this is not always possible. Some emission data contained in the 1995 MOE-Omineca inventory were not improved upon. The same is true of data taken from the 2000 MOE-Victoria inventory. Emissions data that were improved upon were assumed valid for year 2005, but may actually be valid for years before or after. The current MEI is referred to as the PGAQ-2005 to distinguish it from the others valid for the Prince George airshed. The current MEI includes only the PM_{10}, $PM_{2.5}$, NO_x, and SO_2 emissions and related information. Both peak and average rates are included.

Source Categories

Emission inventory management requires a logical division of sources. Traditional MEI categories include the following major source groups; point, area, and mobile. However, the MEI development trend is to provide increasing detail requiring greater categorization. The PG MEI categorization has the following structure;

- **Major Source Category or 'category'**

  This is the highest-level grouping of sources in this study. It includes: Industrial, Commercial, Residential, Mobile, and Other source categories.

- **Sub-source Category**

  This is the second highest-level grouping of sources in this study. The sub-source categories include: permitted users, commercial heating, commercial dust, commercial restaurants, commercial miscellaneous, residential heating, residential others, on-road dust, on-road mobile, locomotive, open and MOF burning.

- **Emission Inventory Groupings (EIG) or 'facilities'**

  The permitted users sub-source category consists of 33 facilities listed by name (e.g. Husky, Northwood, PG Pulp, Intercon, etc.). These facilities operate with a MOE permit. Other facilities not requiring MOE permits are the CNR and CANFOR train yards.

- **Permitted Source Emitting Unit (PSEU)**

  The PSEUs are the non-divisible industrial installations generating emissions. 150 PSEUs are located within the 33 permitted facilities. These units have outlets generating emissions authorized by BC MOE permits.
- **Source Emitting Unit (SEU)**

  This is a sub-grouping of any other sub-source category. There are approximately 350 SEUs (not counting PSEUs) and they include: Highway 16, downtown restaurants, Southyard line locomotives, Millar Addition heating etc. SEUs are discrete emission sources adding to the airshed air-contaminant concentrations.

The relationships of the major source and sub-source categories are as follows:

- **Industrial Sources** include:
  - permitted emissions from facilities operating under MOE permits
  - non-permitted point and fugitive emissions from the same facilities (e.g. emissions caused by industrial yard activities).
- **Commercial Sources** include:
  - emissions produced by the heating of commercial buildings
  - emissions from other commercial activities such as construction, restaurant cooking, farming, airports, etc.
- **Residential sources** include:
  - emissions from residential heating activity
  - emissions from residential activities other than heating (e.g. lawnmowers, BBQs, etc.).
- **Mobile sources** include:
  - vehicle exhaust and wear emissions while traveling the road system
  - emissions that result from vehicular activity suspending dust (silt) while traveling the road system
  - emissions originating from the active locomotive diesel engines.
- **Other sources** include:
  - emissions resulting from the BC Ministry of Forest (MOF) and City of Prince George permitted burns
  - background sources, including wind-erosion, pollen suspension, and transboundary transport
  - aerosol formations resulting from the presence of precursor discharges followed by chemical transformations and VOC condensations.

Details pertaining to the above categories are provided in Section 5.2.

Emissions modelling methodology

Emissions data for some PSEUs were provided through engineering studies such as stack tests. Other PSEU emissions data were provided by the facility operators or extracted from the available literature.

Most SEU emissions data were obtained by emissions modeling through use of local activity data and emission factors published by government and industry agencies. Emission factors are representative values relating PM_{10} and $PM_{2.5}$ emissions to activities responsible for the releases. Emission factors for some processes have higher confidence levels than others. Another component necessary for emissions modeling is knowledge of natural emissions suppression mechanisms, or regulatory emission control programs.

5.2 Discussion

5.2.1 Industrial Sources

5.2.1.1 Permitted-User Emissions

Data Acquisition

On a best-efforts basis, PSEU emission rates were developed by the following hierarchy of procedures, in declining order of priority:

- use of facility stack test reports submitted to MOE-Omineca
- use of emissions data submitted by the site operator
- use of stack test reports of analogous operations in different but similar localities (e.g. Quesnel, Williams Lake)
- use of stack test information for similar equipment found in the literature (e.g. FPAC[1] study for cyclones and baghouses)
- the result of calculations using process rates and emission factors (e.g. U.S. EPA, NCASI[2] kiln emission factors)
- use of information provided by previous PG studies
- use of information provided by MOE contracted studies for similar airsheds such as Levelton[3] (2004) for Williams Lake, Plain (2001, 2004) for Quesnel and Williams Lake
- use of information from personnel and studies originating from MOE-Victoria
- use of emissions data contained in the MOE-Victoria (2000) emissions inventory and/or Environment Canada NPRI[4]

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[1] Forest Products Association of Canada, found online at http://www.fpac.ca/en/.
[2] National Council for Air & Stream Improvement Inc., found online at www.ncasi.org
[3] MOE-Cariboo provided the emission inventory for the Quesnel and Williams Lake studies.

- use of the manufacturer specifications
- use of the maximum emission levels set by permits negotiated between the company and MOE
- use of a judicious combination of the above procedures

After the preliminary review and estimations were completed, a letter was sent to each permit holder. Each letter explained the project objectives, listed the emissions and facility information, asked for a user review and requested revisions if the permit holder determined the necessity. Attachments to the letters contained the PSEU emissions and facilities information.

Throughout the study period, the emissions environment started and remained dynamic. New facilities were permitted and others stopped operating. Aging equipment probably resulted in greater emissions; better operating procedures probably had the opposite effect. Hours of operations were constantly changing. Some of the data provided by the facility operators probably reflected the near-term environment (2007) differing somewhat from the target year (2005).

To better determine the PSEU operating hours, MOE conducted a telephone survey (early 2008). The results were incorporated into the MEI.

Emission Summaries

Peak and annual average emissions rates are summarized in Table 5.1. Annual rates account for down time, whereas peak rates do not. Details are included in Appendix C. If operating information was unavailable, constant rates were assumed, increasing the average annual summary rates.

Table 5.1: Summary of Emission Rates (g/s) Based on Industry Group

Industry Group	Emission Rates (g/s)							
	Peak				Annual Average			
	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NO_x	SO_2	PM_{10}	$PM_{2.5}$
Sawmill & planning mill products industry	4.98	0.86	8.15	4.44	4.53	0.78	5.58	3.48
Pulp Industry	30.14	259.42	56.88	44.37	30.14	259.42	56.88	44.37
Other wood products manufacturing	1.35	0.07	5.30	1.72	1.35	0.07	5.29	1.70
Softwood veneer and plywood industry	2.64	0.02	0.94	0.57	1.98	0.01	0.71	0.42
Industrial inorganic chemical industries	1.95	7.24	1.40	1.27	1.79	7.14	0.34	0.29
Refined petroleum products industry	2.89	24.53	0.59	0.34	2.89	24.53	0.59	0.34
Others	1.95	2.07	1.28	1.07	0.23	0.25	0.22	0.19
Total	45.9	294.2	74.5	53.8	42.9	292.2	69.6	50.8

[4] National Pollutant Release Inventory, found online at http://www.ec.gc.ca/pdb/npri/npri_home_e.cfm .

Data Gaps

The best characterized PSEU PM_{10} and $PM_{2.5}$ emissions are the filterable particulates. Highly uncertain are the aerosol formation rates from the condensable emissions. Stack sampling methods for industrial sources can measure the condensable portion of emissions either in the back-half of the sampling train, or through specialized sampling equipment that allows the exhaust gas to cool prior to aerosol deposition. However, stack sampling is only regularly carried out by the larger permitted users, and condensable emissions measurements are only made when requested. MOE does not require condensable organic matter testing on combustion sources such as power boilers or energy units. Lumber kiln condensable emissions are not considered owing to the lack of reliable local emission estimates. Condensable organics are monitored on dryer type emission sources such as veneer dryers, pellet dryers or wood fiber dryers. On these units, it was found that condensable PM rates are about 3-7 times that of the filterable PM. Other emission unit condensable aerosols will probably have a much lower ratio, but given their numbers (e.g. kilns), could add appreciably to the total.

5.2.1.2 Industrial Fugitive Emissions

Industrial yard and stockpile fugitive emissions are not included due to the absence of an inventory. Some of the permits for the industrial facilities do include fugitive dust control clauses for the yard dust. The maximum allowable accumulation is typically 1.75 mg/square-decimetre/day. Unfortunately, inventories of industrial facility yards do not exist. To carry out emissions modelling, activity estimates of each of the industrial facilities are needed, but this information does not exist at present. Therefore, fugitive emissions estimates from industrial yards were not attempted. Rectifying this omission could be the subject of future work.

5.2.2 Commercial Sources

5.2.2.1 Commercial Heating

Commercial building heaters are powered by electricity or natural gas (NG) burning or both, but only natural gas burning produces emissions. The Terasen Gas year-2005 Prince George area NG consumption data includes aggregate numbers of user accounts and consumption data within residential, commercial and industrial categories. The commercial and industrial user data were subdivided into 20 or more subcategories. Approximately 10.6 million gigajoules (GJ) of NG were consumed in total. 2.5 million GJ were consumed by residential consumers and 6.3 million GJ were consumed by heavy industry such as pulp & paper, chemical and wood product manufacturing. The 1.8 million GJ remaining were assumed to have been consumed by commercial users.

To prevent double counting, consumption that appeared to be covered in the permitted users inventory was factored out. However, the process is uncertain. If some of the facilities are NG space heated (supplemental to the NG consumed in the industrial processes), the NG consumption may not be covered. Large facilities office-heating NG consumptions, distinct from the manufacturing plant usages, were included as commercial usage.

According to the Terasen report, the following categories are included as commercial usage: agriculture, apartment & condo, commercial/office, construction, education, food/beverage manufacturing, government building, greenhouse, health, hotel, laundry, metal manufacturing, mining, miscellaneous, non-metal manufacturing, printing, pulp & paper (office), recreation, restaurant, retail/wholesale, textile manufacturing, transportation, unknown, utility and wood products manufacturing.

Emission Factors and Airshed Emissions

When compared to other burning and heating sources, NG is a clean burning fuel with very low PM_{10} and $PM_{2.5}$ emissions. The high temperature NG flame causes nitrogen to combine with oxygen to form nitrogen oxide gases, mostly NO. Sulfur containing odorants are added for leak detection, causing small amounts of SO_2 emissions to occur during combustion. $PM_{2.5}$ emissions are both filterable and condensable, the sum of which is very low. $PM_{2.5}$ emissions are mostly composed of larger molecular-weight hydrocarbons that are not fully combusted. Increased PM_{10} and $PM_{2.5}$ emissions can occur from NG furnaces/boilers with maintenance issues. Emissions rate estimates are found in Appendix C.

Temporal Usage

NG consumption has a seasonal variation. Along with the 2005 consumption data, Terasen Gas provided the monthly load distributions for each of the residential, commercial and industrial users. The residential user category showed the most variation, followed by the commercial. The industrial user category showed the least variation since many of the heavy industries operated 24hours, 7 days a week throughout the year with only minimal maintenance down-time. For all commercial heating users, an abnormally cold winter day would have markedly increased both the instantaneous consumption and the emissions.

5.2.2.2 Other Commercial Emissions

The commercial category is composed of a mixed collection of sources, all with unique considerations. The emission rates can be highly variable in space and time. Both average annual and peak emission rates were routinely calculated. Even peak rates required some amount of averaging.

Airplane Emissions

Aircraft movement data are published by Statistics Canada[5] as a number of landing and take-offs (LTOs). An LTO represents a plane landing, moving along the airport and taking off. The itinerant LTOs represent the flights that take-off from one airport and land at another or exit the control zone of the airport before returning to its departure point. The local LTOs represent flights that stay within a certain boundary of the airport normally landing back where the flight began (e.g. flight training,

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[5] Statistics Canada data are available on-line at http://www.tc.gc.ca/pol/en/Report/TP577/tp577.htm and http://www.tc.gc.ca/pol/en/Report/tp141e/tp141.htm.

sight-seeing, etc.). Emission factors for a representative aircraft LTO were arrived at by assuming a mix of aircraft (U.S. EPA, 1998[6]).

Pacific Western Brewery

Previously, the brewery did not require an MOE air emissions permit. However, PM_{10} and $PM_{2.5}$ were emitted from the handling and drying of grain. In 2007, Pacific Western Brewery (PWB) handled about 1075 tonnes of grain (25 trucks carrying about 43 tonnes of grain). Brewery PM emission factors for grain handling and drying are 4 kg/tonne. Boiler emissions were included with the commercial natural gas heating emissions estimates.

Restaurants

PM_{10} and $PM_{2.5}$ emissions from restaurant activities result from both the cooking process and fuel burning. Most of the fuel consumption is natural gas although other fuels may also be used. Earls and Moxies use wood stoves to cook pizzas. The fuelwood consumption is very low and was ignored. The greatest source of emissions from restaurant activities is from meat and deep fried potatoes cooking (Roe, 2003). Charbroiling is probably the greatest PM_{10} and $PM_{2.5}$ emissions contributor, resulting from the incomplete combustion of grease and meat additives. Though providing lower emissions, other cooking processes contribute to PM_{10} and $PM_{2.5}$ levels. For example, Tim Horton's restaurants use deep fryers to produce donuts. All restaurants were included in the emission estimates.

Following through from the Interim Study analysis for year 2007, Canada AllPages[7] listed 258 "Food and Dining" places in Prince George including 24 "Fast Food" restaurants. Roe (2003) provides the basic information for a new calculation based on California surveys. The average emissions per restaurant were applied to produce average emission rates for all 258 restaurants. The Interim Study and Third Party reviews confirmed this procedure.

The above calculations assumed that the U.S. commercial cooking patterns applied to the Prince George area. Also, the exercise treated all restaurants with the same emission rates even though fast food restaurants are the greater emitters. It is recognized that not all outlets are full facility restaurants, so the methodology probably resulted in an overestimate. However, a concentration of fast food restaurants can result in much greater local emissions. For example, in the College Heights area there are six restaurants in a city block, mostly charboilers.

The Prince George area also has a number of outdoor fairs and picnics. The frequencies of these activities are low, the durations short, but the peak emissions can be high. The information necessary to include these activities was unavailable.

[6] http://www.epa.gov/ttnchie1/trends/procedures/trends_procedures_old.pdf
[7] Canada AllPages is found at http://bc.allpages.com/prince-george/.

Welding Shops

Electric arc welding produces PM_{10} and $PM_{2.5}$ emissions. Canada AllPages lists 42 welding shops in the Prince George area. U.S. EPA AP-42 (1995) provides emission factors for welding electrode consumption, but recent consumption amounts were not available. The 1995 MOE-Omineca estimates (Fudge, 1996) based on 45 welding shops were assumed valid.

Auto-body shops

PM_{10} and $PM_{2.5}$ emissions (lead, chromium and cadmium) occur from the sanding of vehicles and the welding of vehicle parts. Canada AllPages lists 37 auto-body repair shops in the Prince George area. The 1995 MOE-Omineca inventory placed the number of auto-body shops at 27 (Fudge, 1996). All 37 auto body shops were re-modelled. Emission rates per auto body shop are unchanged.

Construction of buildings

Dust emissions from construction activities are caused by: demolition of any existing structures; site preparation; soil loading and unloading operations; and the finish site grading/excavation. For residential construction, direct estimates of disturbed land area are generally not readily available. Housing start data were used instead.

Construction information was provided by the City of Prince George. Detailed information is available at the Prince George city web site[8]. Year 2005 estimates were used for the inventory (Appendix C). $PM_{2.5}$ was assumed to be 10% of PM_{10}. The silt content of resuspended dust was assumed to average 30%, an estimate offered by UNBC soil scientists. The precipitation-evaporation index was assumed to be 53. These emission rate estimates are likely conservative.

Gravel pits

PM_{10} and $PM_{2.5}$ emissions at gravel pit operations are the result of drilling, crushing and loading of stones. The emissions occur near the surface so the nearby areas notice the greatest impact. InfoPages[9] listed 22 suppliers of sand and gravel operating in the Prince George area. EPA-AP42 (1995) provides emission factors[10] for stone material processing. There are currently five gravel pit areas; College Heights, Cranbrook Hill, North Nechako, Austin West and Airport areas. The emissions estimates for these gravel pits are included in Appendix C.

Off-road mobile construction vehicle exhaust

Most off-road mobile construction vehicles are powered by diesel engines and produce the same exhaust emissions as on-road vehicles powered by diesel engines. The year-2005 ICBC vehicle inventory showed 539 construction-type vehicles. The California Energy Commission (CEC) web

[8] Building permit statistics for the City of Prince George: http://www.city.pg.bc.ca/city_services/cpd/building_permit/statistics/
[9] Infopages is found at: www.infopages.ca .
[10] http://www.epa.gov/ttn/chief/ap42/ch11/final/c11s1902.pdf .

site[11] contains construction project descriptions, including construction vehicle emission estimates[12]. It was assumed that most of the PM_{10} emissions were in the $PM_{2.5}$ size range.

Off-road dust emissions from farm vehicle traffic

The year-2005 ICBC vehicle inventory lists only three farm vehicles, assumed to be farm tractors, with a gross weight ranging from 1.5 to 5 tonnes. An inquiry was made at Huber Farm Equipment Ltd, the only supplier of farm tractors in Prince George. The Huber salesperson suggested that there were about 200 commercial size tractors and 300 hobby size farm tractors operating within a 20 km radius of Prince George. It seems that most of the farm tractors are not registered for road travel, so either they remain deployed on the farms or are transported by a carrier vehicle.

Farm vehicles working the fields induce dust emissions just like on-road vehicles. The U.S. EPA dust emissions model from unpaved roads could be used to estimate these emissions. It was assumed that the silt content of resuspended dust is 10%, required for arable land. The tractor speed while operating was assumed to be 5 m/s, the average weight 2.5 tonnes.

Off-road mobile farm vehicle exhaust

Most off-road mobile farm vehicles are powered by diesel engines and produce the same exhaust emissions as on-road vehicles. The emission factors are stated in g/hp-hr and the activity rates are calculated in terms of capacity, load and hours of usage.

It was assumed that the commercial size tractors have about 200 hp capacity and the hobby size tractors have about 50 hp. The load usage was about 50% for 12 hour days during the two month tilling season and the same during the two month harvesting season. Farm vehicle emission factors vary substantially. Medium U.S. EPA[13] emission factor values for NO_x and PM are 5.0 and 0.5 g/hp-hr, respectively. The SO_x emission factors were assumed equal to the off-road construction vehicles. Since the PM_{10} emissions were from an internal combustion source, all PM_{10} emissions were assumed to be in the $PM_{2.5}$ range.

Non-road vehicle dust

Another major source of fine dust emissions is from vehicle activity on private roads, parking lots and industrial yards. Forklifts, trucks, and loading/unloading equipment move over industrial and commercial yard areas, often unpaved. Personal owned vehicles travel over dust laden parking lots when arriving/leaving the facilities. Unpaved surfaces have their own reservoir of silt often transported to nearby paved areas. Road traction material laid down on MOT highways and city streets is often tracked to nearby paved city parking lots. Wind-blown dust is deposited on paved parking lots. At industrial sites, surface loading is replenished by spillage of material and trackout from unpaved roads and industrial staging areas.

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[11] The web site is found at: http://www.energy.ca.gov
[12] The document is available at http://www.energy.ca.gov/sitingcases/eastshore/documents/applicant/afc/volume02/Appendix%208.1E.pdf
[13] AP-42 document found at http://www.epa.gov/otaq/models/nonrdmdl/nr-009a.pdf .

The location and size of the major industrial and commercial parking lots could be determined from aerial photographs[14]. The same is true of private roads. Many of the industrial yards are paved, but a limited survey showed some to be unpaved. Many of the private roads are unpaved. Vehicle speeds on private, usually unpaved roads, can produce substantial dust emissions. Unfortunately, the surface characterizations and vehicle type and numbers frequenting these sites are currently not available preventing any reasonable estimates. Successor studies are required to provide this basic information.

Bulk estimates of the dust emissions from on-road vehicles entering/leaving parking lots were estimated. It was assumed that all commercial parking lots and most industrial parking lots are paved. Vehicle speeds on parking lots are usually low, but the silt loading could be much higher, potentially producing appreciable dust emissions. For example, the silt loading on city arterial roads has been found to average 1-4 g/m^2. A sample swept from a UNBC parking lot produced a silt loading of about 8 g/m^2.

The number of vehicles on the road at any one time was estimated. It can be assumed that, at the end/start of the trip, the same number of vehicles have to find/leave a parking lot. It was assumed that vehicles traveling at 10 km/hr on the parking lots take 10 minutes to find a parking spot or leave the parking lot. Silt loading was assumed to be 8.0 g/m^2 (the UNBC parking lot sample value). A 40% precipitation reduction factor during the winter months was assumed.

5.2.3 Residential Sources

5.2.3.1 Residential Heating

NG is used by the majority of the Prince George residences but not always as the only source of heat. Fuel-wood (FW) is used both as a primary source of residential heat and to supplement the other more conventional heating systems (NG and electric). FW remains popular as a secondary heating fuel because of the esthetic value of the burns and the availability of an inexpensive supply. The accessibility of plentiful and cheap FW in the Prince George area will continue to encourage its use for residential heating. Wood pellet residential heating fuel use is rising. These resulting PM emissions are important since they occur close to the surface, are numerous, and located within the core of residential areas.

Wood and Wood Pellet Fuel

Although concerned mostly with fuel-wood emissions, a 2005 Prince George city survey polled residents for information about their heating fuel usage and habits. A study conducted by UNBC carefully processed the survey results (Jackson et al, 2009). Each response was studied and the estimated fuelwood emissions were allocated to the area of origin. Extrapolations were made to cover all the area households. Survey responses with undetermined locations had emission estimates allocated to the entire airshed.

[14] A summary of the major industrial parking lots and open areas has been developed.

The same division and subdivision structure used by the UNBC study was assumed as well as the same PM emissions allocations. The outlying communities of Miworth, Beaverly and Pineview, situated within the Prince George airshed, were provided with emission estimates comparable with a Prince George neighborhood.

Natural Gas Fuel

The emissions from the consumption of NG were allocated according to the number of residences in the neighborhoods. U.S. EPA emission factors were used to determine the emissions. It was assumed that all PM_{10} exists in the $PM_{2.5}$ size range.

Annual and Diurnal Variations

Heating fuel emission rates have strong annual and diurnal variations. Residential heat loss due to lower outside air temperatures is the major reason for the heating requirements. Wind, exposure and construction quality also play a role in the heat-loss rate. Accounting for all the influences affecting residential heating requirements is difficult as people respond differently to temperature exposures, so simplifications must be made.

Heating–degree-day is a quantitative heating index (HI) that reflects the demand for heat. The North American standard “balance point” temperature is 18°C. When the ambient temperature is 18°C or above, the residence is assumed not to need any heating. Although useful, the index has several problems. Strictly speaking, heat requirement is not a linear function of temperature. Intuition and knowledge of outdoor daily temperature variation suggests there is a greater aggregate heat requirement in the early morning than in the later afternoon. The diurnal residential heating cycle, though heavily influenced by outside temperatures, can be heavily skewed by the inhabitant’s management practices. The highest heat requirements are probably during the morning period, and probably during the weekends and especially during periods of extreme cold temperatures.

For the Prince George areas, peak emissions often occur when the atmospheric dispersion capacity is low providing the conditions for air contaminant exceedances.

5.2.3.2 Other Residential Emissions (except open burning)

Residential source emissions occur close to the surface, potentially resulting in maximum effects on nearby residents. Most residential PM emissions are a result of space heating activities. However, there are other residential activities that produce substantial emissions. Examples are residential small engine operations; generators, chainsaws, leafblowers, lawnmowers, pressure washers, snowblowers, and outdoor and indoor cooking activities.

All residential emissions can be highly variable in space and in time. Average emission rates are provided to facilitate annual rate estimates. However, peak rates are more representative for the periods that the sources are emitting. Unfortunately for some sources, emission rates cannot be estimated due to the lack of information. Sources of information included other emission inventories such as: the 1995 MOE-Omineca, the 2000 MOE-Victoria and the NPRI. U.S. EPA[15] and California Air Resources Board (CARB) [16] procedures and emission factors were used where applicable.

Cigarette smoking

As a result of enforced indoor smoking restrictions, smoking activities have moved outdoors. To produce emission estimates, CARB methodology was followed. Cigarettes producing PM_{10} and $PM_{2.5}$ emissions are smoked by about 25% of the northern B.C. population[17]. For the Prince George area, this amounts to approximately 20,000 people (BC Stats, 2007; Environment Canada, 2002). A consumption rate of one pack per day (20 cigarettes) was assumed.

Outside residential equipment

There are no emission control devices on household lawn, garden, yard and recreational marine equipment. Example non-road devices are lawnmowers, weed-eaters, chainsaws, marine motors, etc. The ubiquitous operation of these devices can be major contributors to summer season PM_{10} and $PM_{2.5}$ emissions. Most of the U.S. EPA emission factors have not changed[18] since 1995. For these sources, the 1995 MOE-Omineca inventory estimates (Fudge, 1996) were assumed valid.

Barbecues

PM_{10} and $PM_{2.5}$ emissions from summer barbecues can affect local areas substantially. Since most modern barbeques are fueled by clean-burning propane, most barbeque PM_{10} and $PM_{2.5}$ emissions are a result of grease flares. Most residential barbecue cooking takes place in summer and during the evenings. It was assumed that half the residences have barbecues using one kilogram of meat once a week for 4 months of the year. The barbequing took place between 16:00-20:00 hours (one/sixth of the day). In units of g/kg, Roe (2003) suggests the following PM_{10} emission factors in g/kg: 33.0 for hamburger; 17.0 for steak and 10.0 for chicken. An average is about 20 g/kg. Almost all of the emissions are in the $PM_{2.5}$ size range. The total annual emissions are close to the MOE-Omineca estimates (Fudge, 1996).

Indoor Cooking

PM_{10} and $PM_{2.5}$ emissions resulting from indoor cooking are usually vented to the outside. Fuel emissions are covered in the heating section. Currently, emission factors or rates for this activity were not found. Overall, it was expected that the emission rates are small, but could be locally substantial.

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[15] EPA documents are found at http://www.epa.gov/ttn/chief/.
[16] http://www.arb.ca.gov/ei/areasrc/districtmeth/BayArea/C766.pdf
[17] http://www.bcstats.gov.bc.ca/data/ssa/reports/tobacco/smokingstats_20062007.pdf .
[18] An example is the: "Nonroad Engine and Vehicle Emission Study Report "
(EPA-21A-2001 or EPA460/3-91-02, November 1991), posted at http://www.epa.gov/nonroad/.

5.2.4 Mobile Sources

5.2.4.1 On-road Mobile Emissions

This section deals with the exhaust emissions from on-road vehicle and a small quantity of PM_{10} and $PM_{2.5}$ discharged from other working parts of the vehicles such as brakes and tires, together termed "mobile emissions".

The exhaust from the motor vehicles traveling the Prince George road network is an obvious emissions source. Due to incomplete combustion of carbonaceous fuel, motor vehicle exhausts include PM_{10} and $PM_{2.5}$, carbon monoxide, oxides of nitrogen and sulphur and hydrocarbons. On-road exhaust emissions are a function of many factors including: vehicle speed and type, types of roads, gasoline vapor pressure, fuel type and sulphur content, and ambient air temperatures as well as vehicle maintenance.

The EC Mobile6.2c[19] model estimates emission factors for various mixtures of on-road mobile vehicles operating under a range of conditions. The primary application is to support the development of on-road mobile emission inventories (similar to this exercise). The vehicle types treated by Mobile6.2c include gasoline-fueled and diesel motor vehicles, as well as specialized vehicles such as natural-gas-fueled or electric vehicles. Only gasoline and diesel fueled vehicles were considered in this emissions study. Mobile6.2c provided the emission factors for mobile, tire and brake-wear PM, and oxides of nitrogen and sulphur.

In year 2000, gasoline supplied to western Canada had sulphur content of up to 500 ppm (parts per million). Husky reported sulphur content of 233 ppm in their locally supplied year 2000 gasoline decreasing by year 2005 to the federal government legislated 30 ppm. Local market manufacturers met the requirement at different times, but it was assumed that all on-road vehicle gasoline contained this amount in year 2005.

Diesel fuels are blended according to specifications using light, intermediate and heavy diesel varieties. Light diesel has a sulphur content of almost zero and is a desirable fuel during the winter. Intermediate and heavy diesel varieties are blended and used more often in the warmer seasons[20]. For year 2005, Husky reported a gasoline sulphur mass content of 27.5 ppm and a diesel sulphur mass content of 50 ppm and 340 ppm for winter and summer respectively.

Using these specifications, Mobile 6.2c was run for each of the year-2005 winter/summer scenarios. Because of the greater number of gasoline fuel vehicles in the vehicle inventory, the difference between summer and winter emission factors produced by Mobile 6.2c is very small. Emission Factors of 0.42 g/VTK (vehicle travelled kilometres) and 0.30 g/VTK for PM_{10} and $PM_{2.5}$, respectively were used. The emission rates were the product of the vehicle activity and the emission factors (Appendix C).

[19] The Mobile6.2 web site is found at www.epa.gov/otaq/m6.htm.
[20] All information from Husky Oil was provided by Katja Otting, Environmental Coordinator..

5.2.4.2 On-road Dust Emissions

The major source of airborne PM in the Prince George airshed results from the resuspension of dust, originating as granular material deposited on the road surfaces. Most on-road dust resuspension is initiated by the influence of road vehicles. The upward momentum of the dust particles caused by the vehicle's turbulent aerodynamic wake provides the vertical forcing. The particles are then carried further from the source by wind advection or atmospheric instability. PM_{10} and $PM_{2.5}$ originates from the silt component of the road surface dust. The larger particles redeposit quickly; smaller particles (PM_{10} or less) stay airborne for longer periods of time. Road-dust PM emissions are very difficult to quantify. Variability in emissions is great and can vary by orders of magnitude over short distances. The standard procedure is to use the U.S. EPA bulk estimate modelling. These bulk estimates smooth over the great variability and are adequate for baseline analyses but should be expected to provide poorer estimates for shorter-term events.

The same emissions modeling procedure as used in the Interim Study was used. The U.S. EPA emissions model determines the emission rates as a function of the emission factors, road-vehicle activity rates, silt content, and vehicle weight. For both the paved and unpaved road dust emissions modelling, the characterization of the silt content in the surface layer was conducted as per the procedure developed for Prince George by Peter Jackson, Dennis Fudge, and the City of Prince George. The small correction representing a contribution from the 1980s fleet exhaust was ignored, since its inclusion had minimal impact.

Paved on-road emissions modeling require an apportionment of $PM_{2.5}$ within the PM_{10} size range. The EPA emissions models assume $PM_{2.5}$ at 14.3% of PM_{10} (EPA AP-42, 2006). Since the City claimed low silt traction material, the Interim Study assumed that a percentage ratio of 10.0% would be more appropriate. However, the Third Party Review recommended that the EPA standard be maintained. After confirmation from the RWG, this recommendation was implemented by Stantec. The predictable result was a large increase in $PM_{2.5}$ emissions from on-road vehicles.

A dust silt measurement program was carried out by UNBC and the City of Prince George in 2007/08. The sampling frequency was intermittent and the (assumed) March/April peak period was missed. A precipitation suppression algorithm applicable to local conditions and hourly emission rates was developed and implemented. Details are found in Appendix C.

5.2.4.3 Railway Locomotive Emissions

CNR is the only railway company presently operating in the Prince George airshed. The description of railway operations is essentially a description of the Prince George CNR operations except that CANFOR operates two switcher locomotives dedicated to their Northwood yard. Locomotives produce moderately high levels of pollution, due to the incomplete combustion of the diesel fuel. Most of the locomotive PM emissions are in the $PM_{2.5}$ size range. During burning, the sulphur in the diesel fuel becomes oxidized to form SO_x leading to sulphate production. The high temperature of combustion produces NO_x, which leads to nitrate production. These aerosols add to the $PM_{2.5}$ concentrations.

No legislation exists in Canada limiting locomotive emissions. However, Canadian railways have agreed to monitor and report their emissions. In 1995, The Railway Association of Canada (RAC) and EC signed a Memorandum of Understanding (MOU) to that effect (Environment Canada, 1995). Responsibility for the monitoring of locomotive emissions has since been transferred to TC (Transport Canada, 2005). RAC has agreed to voluntarily limit NO_x emissions at the 1989 levels. During this period, U.S. EPA required American locomotive builders to manufacture engines with progressively reduced emissions. U.S. EPA set down a three-phase “Tier” approach (Tier 0, 1, and 2) with respectively reduced emission requirements, implemented in stages from years 2000 to 2005. Canadian railways have indicated that they will purchase replacement locomotives with the higher Tier 2 standards (Dunn, 2001) as the older ones are decommissioned. So incrementally, modern higher horsepower fuel-efficient locomotives are replacing the older model locomotives. In the meantime, emissions from older still operating locomotives represent a large portion of the exhaust emissions from the locomotive fleet. The older models are usually deployed in the railway yards carrying out switching assignments; the newer models are assigned to the rail lines. Unfortunately, the Prince George CNR railway yards and tracks are found in very close proximity to the urban areas[21]. The bowl topography and meteorology lends itself to lowered atmospheric dispersion exacerbating the air-contamination problem by allowing higher local concentrations near the downtown and urban areas.

In Western Canada, most diesel fuel is derived from the Canadian oilsands. Sulphur levels are set by railway specifications at 0.5% percent maximum. However in today’s operating environment, railways fuels are delivered well below the specified maximum level. In Western Canada, the railway fuel has sulphur content at 500 ppm or less.

Facility Information

There are four train yards in the Prince George area. CANFOR operates Northwood; CNR operates three yards: Bridgeyard, Northyard and Southyard and services Northwood. The yards are connected together by local rail lines.

Northwood’s main purpose is to service the Northwood pulp mill. Two CANFOR locomotives are dedicated to the Northwood yard. Two CNR SD40 locomotives are time-shared daily between Northwood and Bridgeyard, spending the night shift at the Northwood yard. The SD40 locomotives run from Bridgeyard along the Bridgeyard track to Northwood just before midnight and return in the morning. Bridgeyard’s main purpose is to service the Prince George Pulp and Intercon pulp mills. Two switcher locomotives operate full time in Bridgeyard. Before year 2005, three switchers operated full time in Northyard, moving approximately 1000 cars daily. Redeployment brought about by the CNR purchase of BCR, lowered the Northyard switching requirement to a single switcher and slug[22] in 2007. The largest CNR operation takes place in Southyard. Three pairs of switchers operate full time in Southyard, moving approximately 1600 cars daily.

[21] An alternate view suggests that Prince George, a transportation centre, grew up around the railway operations.
[22] A slug is an accessory to a diesel locomotive, used to increase adhesive weight.

Four main rail lines service the remainder of the airshed:

- The Stuart sub runs (north) to Fort St James and Chetwynd and leaves from Odell, about 30 miles north of Prince George
- The Fraser sub runs (east) from Northyard to McBride
- The Nechako sub runs (west) from Northyard to Prince Rupert
- The Prince George sub runs (south) from Southyard to Quesnel.

The number of locomotives found on these rail lines within the airshed is variable and is estimated to be about 66 daily, distributed over the rail system. Some units are hauling empties to be reloaded, and some cars are at full tonnage. Typical locomotive speeds are about 15 km per hour including switching rising to about 20 km per hour when switching is not required. The Prince George airshed is defined to be about 20 km in each direction from the Prince George urban centre. These assumptions suggest that the road locomotives remain in the airshed for 5 to 8 hours.

CNR does not routinely shut down the yard switchers in colder weather, since radiator cooling water does not contain antifreeze. At higher temperatures, yard engines equipped with a smart system shut down automatically when not in service. It was assumed that the locomotives are idling or working and a typical load rate applies to all. For a switcher locomotive, the Railway Association of Canada suggests a duty cycle with 81% idling time[23]. The locomotive inventory is found in Appendix C.

5.2.5 Other Sources

5.2.5.1 Open Burning

Open burning events include burning for resource management, wildfire and backyard burning. Open burning can include wood, grass and agricultural waste burning. The City of Prince George is responsible for regulating open burning within the city boundaries. The City permitted backyard burning is the only residential open burning included in this study. BC Ministry of Forests (MOF) Omineca and MOE are responsible for regulating open burning outside of the city proper but within the Omineca region. MOF is responsible for wildfire management including monitoring. Open burning produces high concentration PM_{10} and $PM_{2.5}$ because of incomplete combustion and poor venting. The cumulative effect of a large number of airshed open burn emissions can be quite large. Studies in other airsheds (Weinstein, 2005) have determined that open burning emissions are a major source of their PM_{10} and $PM_{2.5}$ concentrations.

Open burning produces mostly PM_{10} and $PM_{2.5}$ emissions and an insubstantial amount of NO_x and SO_2. Wood burning PM_{10} and $PM_{2.5}$ emissions are a function of many parameters including wood species type, moisture content, burn temperature, and burn efficiency. The Prince George forest

[23] http://www.ec.gc.ca/cleanair-airpur/CAOL/transport/publications/mou/eng/c3_e.htm#3.5

species are assumed to be pine, spruce and fir in relatively equal amounts. Grass and waste burn emissions are assumed to be of secondary importance to the wood burning emissions.

Where possible, the U.S. Forest Service Consume3.0[24] model was used to estimate PM_{10} and $PM_{2.5}$ burning emissions. Consume3.0 predicts pollutant emissions based on a number of factors including fuel loadings, fuel moisture, and other environmental factors.

Ministry of Forests Permitted Burning

Permits issued in spring, summer and fall are valid for a maximum of two weeks. Permits issued from December to March are valid until March 31. Further details are not available. The greatest numbers of permits are valid during the April to November period. Although the data base is small, it seems that two annual peaks occur, one in May and the other in October, reflecting MOF forest-fire danger policy. The emission rates were averaged over an eight month period from April to November. The averaged rates smooth over the intense but very intermittent peak emissions.

City of Prince George Permitted Burning

The City of Prince George Clean Air Bylaw regulates burning in the City of Prince George[25]. There are two types of permits allowed by the City of Prince George, written and verbal. Written permits are for land clearing debris (slash piles) and would require permission from MOE as well. Verbal permits are for small backyard burning, typically yard and garden waste or a campfire. These would be fairly small, short term burns. The City reported 459 verbal permits in 2005 and 32 and 27 written permits in 2004 and 2005 respectively. Most of the permits are granted during the April to November period. The amount and type of burn material covered by the permit is not known, so emissions based on U.S. EPA emission factors would be highly suspect. The year-2000 MOE-Victoria emission rates scaled to the Prince George airshed were used.

Wildfire Burning

The wildfire season also occurs from April to November, peaking in August. The Prince George MOF office is responsible for the suppression or containment of wildfires in the Omineca region[26]. The yearly number of wildfires recorded by MOF-Omineca within the Prince George airshed is highly variable. Small wildfires can have a large effect on nearby PM_{10} and $PM_{2.5}$ concentrations and large wildfires can affect the entire airshed. However, it would be difficult to quantify the individual contributions to the PM_{10} and $PM_{2.5}$ airshed concentrations of each wildfire. Also wildfires are not a-priori manageable, so were not considered a target for airshed management planning.

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[24] http://www.fs.fed.us/pnw/fera/products/consume.html
[25] http://www.pgairquality.com/air_quality.html#copgcab
[26] A map of the B.C. Forest districts is found at: http://www.for.gov.bc.ca/dpg/AboutPG/Distmap.gif

5.2.5.2 Background Sources

Unknown sources and sources that cannot be quantified may add substantially to the airshed PM_{10} and $PM_{2.5}$ concentrations. The latter group includes natural biogenic emissions (e.g. pollen), wildfires, transport from other airsheds (e.g. Bulkey valley) and other countries (e.g. Asian dust). Wind erosion mechanisms can resuspend surface lying dust resulting in wind-blown emissions. The contributions from these sources are often treated as background concentrations. Fudge and Sutherland (2004) estimated that PM_{10} and $PM_{2.5}$ background concentrations could be responsible for 40% and 20% of the total Plaza site PM_{10} and $PM_{2.5}$ concentrations. If so, comparable levels of unaccounted emissions are influencing the airshed, demonstrating an information gap. Continued research has reduced those percentages somewhat. To narrow the gap, more research is needed.

5.2.5.3 Secondary Formations

Most PM_{10} and $PM_{2.5}$ found in the Prince George airshed are due to the direct emissions that are later dispersed. Further sources of PM_{10} and $PM_{2.5}$ are from the production of atmospheric aerosols created sometime after emission of the precursors. Aerosol formations can be roughly categorized into two groups: inorganic (nitrates and sulphates) and organic. Organic formations are difficult to estimate and are usually treated as background sources. Nitrate and sulphate inorganic aerosols are formed by the chemical transformations of NO_X and SO_2 gases. The chemical transformation rates are highly variable and depend greatly on the presence of ozone, ammonia and favorable atmospheric conditions. Formations can take place anywhere and at any height in the airshed after the emissions and transport.

The NO_x and SO_x reactions can occur in the gaseous phase or the aqueous phase with fog/cloud (H_2O) droplets acting as the host medium. On a sunny day, sunlight initiates the photochemistry that dominates the daytime transformations. On a foggy day or a day with high relative humidity, the presence of water droplets allows the aqueous phase transformation. Afterwards, sunlight may cause the fog to evaporate leaving a sulphate particulate. Both temperature and relative humidity influence both the nighttime transformation rates. NH_3 is preferentially scavenged by sulphate, and the formation of nitrate is limited by the availability of the ammonium ion that is limited by the airshed ammonia concentrations. Since the mixing heights are lower in winter, NH_3 concentrations are likely higher near the surface, leading to higher sulphate and nitrate concentrations.

It seems likely that the nitrate and sulphate formations are higher near sites where NH_3, SO_2 ad NO_x emissions take place simultaneously or in close proximity. Since the pulp mills emit all these air contaminants, it is probable that nitrate and sulphate formations are higher near these sites. Where known, the emission rates for the SO_2 and NO_x precursors were included in the MEI. Estimated ammonia airshed concentrations are based on a speciation study carried out by Sonoma Technologies Inc. (STI, 2007) of California.

5.3 Summary

The revised and improved PM_{10} and $PM_{2.5}$ micro-emissions inventory (MEI) is summarized in Table 5.2 and detailed in Appendix C. It will henceforth be referred to as the PGAQ-2005 inventory. Both the peak and average emission rates are included. The emission inventory is obviously dominated by dust sources. The sub-source categories that include a large dust component are the on-road and commercial dust sources.

Some emissions sources are relatively well characterized (permitted users) and others have much higher levels of uncertainty (commercial dust). Levels of uncertainty are subjective evaluations and if offered, the information value could be vague. However uncertainties in the MEI do exist and should be acknowledged, as the MEI provides input data that are carried forward to the dispersion modeling and the final results.

Table 5.2: Summary of the PGAQ-2005 Micro-Emissions Inventory

Category	Sub Category	Peak Emissions				Average Emissions			
		NO_x	SO_2	PM_{10}	$PM_{2.5}$	NO_x	SO_2	PM_{10}	$PM_{2.5}$
		g/s				g/s			
Industrial Sources	**Permitted users[1]**	45.91	294.20	123.17	74.54	42.92	292.20	69.55	50.67
Commercial Sources	**Commercial heating[2]**	2.60	0.02	0.20	0.20	2.60	0.02	0.20	0.20
	Commercial miscellaneous[3]	0.00	0.00	5.98	5.64	0.00	0.00	1.33	1.26
	Commercial dust[3]	0.00	0.00	78.54	8.43	0.00	0.00	13.74	1.58
	Commercial restaurants[3]	0.00	0.00	12.83	11.90	0.00	0.00	6.28	5.83
Residential Sources	**Residential heating[2]**	4.28	0.13	5.30	5.22	4.28	0.13	5.30	5.22
	Residential others[3]	0.34	0.03	7.57	7.57	0.04	0.00	0.52	0.52
Mobile Sources	**On-road dust[4]**	0.00	0.00	392.17	56.10	0.00	0.00	137.26	19.64
	On-road mobile[3]	140.64	2.11	2.93	2.11	49.22	0.74	1.03	0.74
	Locomotive[5]	66.94	1.46	5.72	5.59	64.42	1.41	5.44	5.21
Other Sources	**City open burns[6]**	0.61	0.08	1.99	1.97	0.30	0.04	0.99	0.98
	MOF open burns[2]	0.27	0.06	2.11	1.84	0.27	0.06	2.11	1.84
Airshed Emission Sources	**Sum of the above**	261.6	298.1	638.5	181.1	164.1	294.6	243.75	93.82
Percentage Contribution (%)									
Industrial Sources	**Permitted users**	17.55	98.70	19.29	41.16	26.16	99.19	28.53	54.15
Commercial Sources	**Commercial heating**	0.99	0.01	0.03	0.11	1.59	0.01	0.08	0.21
	Commercial miscellaneous[3]	0.00	0.00	0.94	3.11	0.00	0.00	0.55	1.34
	Commercial dust	0.00	0.00	12.30	4.65	0.00	0.00	5.64	1.68
	Commercial restaurants	0.00	0.00	2.01	6.57	0.00	0.00	2.58	6.21

Table 5.2: Summary of the PGAQ-2005 Micro-Emissions Inventory (cont'd)

Category	Sub Category	Peak Emissions				Average Emissions			
		NO_x	SO_2	PM_{10}	$PM_{2.5}$	NO_x	SO_2	PM_{10}	$PM_{2.5}$
		g/s				g/s			
		Percentage Contribution (%)							
Residential Sources	Residential heating	1.63	0.04	0.83	2.88	2.61	0.04	2.17	5.56
	Residential others	0.13	0.01	1.19	4.18	0.03	0.00	0.21	0.55
Mobile Sources	On-road dust	0.00	0.00	61.42	30.98	0.00	0.00	56.31	20.93
	On-road mobile	53.77	0.71	0.46	1.16	30.00	0.25	0.42	0.79
	Locomotive	25.59	0.49	0.90	3.09	39.27	0.48	2.23	5.55
Other Sources[7]	City open burning	0.23	0.03	0.31	1.09	0.19	0.01	0.36	0.87
	MOF open burning	0.10	0.02	0.33	1.01	0.17	0.02	0.76	1.63
Totals expressed as tonnes per year		8,249	9,400	2,0136	5,711	5,174	9,290	8,772	3,549

NOTES:
[1] operational hour information is used to convert peak to average emission rates; high emitters have near constant emissions
[2] peak emission rates are highly variable and difficult to quantify. Stantec defaulted to use the same rate for both.
[3] peak to average emissions calculations include activity factors
[4] peak to average emissions calculations include precipitation suppression and activity factors
[5] northyard switchers operate in the afternoon, adding them augments the average emissions
[6] burning emissions occur during daylight hours and only during the non-winter years
[7] Background and Secondary sub-categories are not included as these cannot be expressed in emission rate form

The arithmetic sum of the peak rates forms a theoretical, not a practical, upper bound to the Prince George airshed emissions estimates. For the various source categories, peak rates occur during different months of the year and at different hours during the day. Permitted facilities, railway sources, and on-road mobile sources produce peak emissions during the summer, dust sources during the late spring and summer, and heating sources during the winter. Both on-road-dust and on-road mobile sources produce peak emissions during the early morning and late afternoon rush-hour traffic periods. Heating emissions peak during the early morning and late evening hours.

The peak rates can be substantially higher than the average rates and these peak emissions do occasionally overlap (e.g. peak road dust emissions overlap with peak emissions from a permitted emission source). Episodic events probably occur when the phasing phenomenon coincides with favorable meteorological situations. For each sub-category, the calculation methodologies for the average and peak emissions are outlined below.

Permitted Users: Annual average emission rates were calculated by multiplying the peak emission rates by an operating-hours factor (stated as a decimal fraction of the total number of hours). Since most of the substantial emitting units are operating 24/7, there is little difference between the peak and average rates.

Residential & Commercial Heating: The average emission rate is the annual total averaged over the year. January heating requirements can be four times as high as the annual average, producing the same emission rate multiple. Heating requirements are even higher during the January (winter) arctic outbreaks, thus resulting in an even greater multiple to the average emissions. These cold-spell peak emissions can be very high are non-representative and therefore are not offered.

Residential & Commercial Sources: These sub-source categories represent a collection of sources, all with different temporal variations. Most of the residential emissions (yard and recreational equipment) occur during the summer periods and during the weekend afternoons. The commercial source emission group is composed of three sub-source categories. The commercial miscellaneous subgroup covered the non-road exhaust activity that is concentrated in the non-winter months. The same is true of the commercial dust group. Restaurant activity is year-round with small variations compared to the diurnal variations.

On-road dust & mobile sources: Average emissions were estimated by multiplying the peak emissions with an annual average load factor. The load factor is the average number of vehicles on the road at any time. The daily, day of the week and monthly variability are shown in Appendix C, Figures B2.1-B2.3. The large decrease from peak to average emission estimates reflect the large diurnal variability. On-road dust emissions were suppressed further by precipitation.

Locomotive sources: The average duty cycle assumed for the yard switchers included a 45% idling time. Two short-run switchers were time-shared between Northyard and Bridgeyard, producing emissions incrementally added to the average. The rail locomotive activities were averaged over the rail line network. However, the schedules could easily have brought a greater number of locomotives closer to the Prince George centre resulting in higher peak emissions.

MOF and City of Prince George open burning: The open burning emission estimates included the emissions from the MOF and City of Prince George permitted burns. The greatest numbers of permits were valid from April to November.

Background Emissions: PM_{10} and $PM_{2.5}$ from airshed emissions, transboundary flow, and emission processes not quantified or included in the modelling represents a study limitation. **Secondary Formations**: All sub-source categories included SO_2 and NO_X emissions except for the dust sources. For some sub-sources, SO_2 and NO_X estimates were not possible. Where included, the SO_2 and NO_x emissions follow the same variations as the PM_{10} and $PM_{2.5}$ in the same category.

The improve micro-emissions inventory is summarized in Table 5.2. The major sources of NO_x in the airshed, especially important for the bowl area, are the railway locomotives. Also, the on-road mobile sources provide a substantial amount of NO_x emissions. The identified major sources of SO_2, especially important for the bowl area are the Husky refinery and the three CANFOR pulp mills.

6 DISPERSION MODELLING

6.1 Overview

The MEI data outlined in Section 5 were used as input to the modeling component of the study. The CALPUFF modelling system was used to predict the concentrations from both the dispersion of the primary PM emissions and formation of the secondary PM.

Airshed Grid Mode

The Prince George airshed modelling domain with receptor points, monitoring sites, and elevation contours is illustrated in Figure 2.1. The domain consisting of 1873 discrete receptors defines the nested receptor grid. The inner receptor grid is centered over the urban area and has a resolution of 500 m. The outer receptor grid resolution lowers to 1000 m. Contaminant concentrations were calculated at a flagpole height of 1.5 m above ground level. These results valid at the discrete receptors were used to calculate PM_{10} and $PM_{2.5}$ airshed patterns. Although emissions occurred over the entire PG airshed, the predicted concentration results are available over the receptor grid only. The same receptor grid was used when assessing the PG AIR reduction targets.

Monitoring Grid Mode

Ten discrete receptors were identified (Table 6.1) and coincide with the location of the MOE monitoring stations at the equipment inlet height (Table 2.1). Only six of the ten monitoring locations measured PM_{10} or $PM_{2.5}$; BC Rail, Gladstone, Glenview, Plaza, Van Bien, and Lakewood. To evaluate model performance, predicted modelling results were compared to available MOE monitoring site data (Section 6.4).

Table 6.1: Monitoring Station Information

Name	Above Sea Level Elevation (m)	UTM (east)	UTM (north)	Platform Height (m)	Sensor Height above Platform (m)	Total Sensor Height AGL (m)
BC Rail*	595.0	516858	5969212	8.5	3	11.5
CBC	733.3	519455	5972807	2.5	1	3.5
Gladstone*	618.0	515730	5967786	4.9	4.5	9.4
Glenview*	736.6	514714	5983051	7.8	3	10.8
Jail	620.5	518845	5973302	2.5	1	3.5
Plaza*	570.2	516950	5974065	20	3	23
Western Acres	747.8	508164	5963660	0	4	4
Van Bien*	593.0	515682	5971371	0	5	5
Lakewood*	607.0	513310	5974198	8	2	10
North Nechako	591.2	511383	5978305	0	3	3

NOTE:
* Stations for which monitoring data were available and compared to predicted $PM_{2.5}$ and PM_{10} concentrations

Modelling Runs

For each emission source, one full-receptor dispersion simulation predicted the source contribution to the hourly airshed concentrations; the second dispersion simulation determined the predictions at the monitoring sites (approximately 3,000 CALPUFF runs in total). More dispersion simulations were performed to predict the results for the PG AIR $PM_{2.5}$ reduction scenarios.

Source Emitting Unit Temporal and Spatial Allocations

Each source emissions unit (SEUs) was modelled as either a point, line, or area object. The spatial allocations of the emissions to the SEUs were followed by temporal adjustments of the emission rates. The permitted user emissions, yard locomotives and MOF burns were modeled as point sources. Emissions from roads and rail activities were modeled as line sources. All others were modeled as area sources. The sub-source categories and the respective modelling types are listed in Table 6.2.

Table 6.2: Emission Sources Categories and Modelling Object Types

Source Groups	Sources	Modelling Type
Permitted users	Emission stacks	Point
On Road dust	Highways & arterial roads - paved	Line
	Collector, residential, lanes – both paved and unpaved	Area
Locomotive	Road locomotives	Line
	Yard locomotives	Point
On-road mobile	Highways & arterial roads	Line
	Collector, residential, lanes	Area
Residential heating	Wood, natural gas, furnace oil	Area
Open burning	MOF permitted burns	Point
	Open burning	Area
	Wildfires	Area
Commercial heating	Natural gas	Area
Residential sources	Smoking, barbeque, residential equipment	Area
Commercial sources	Non-road mobile Non-road dust Restaurants, etc.	Area

The permitted user point sources were placed in the industrial facility yards, the yard locomotive point sources in the railyards, and the MOF burn point sources in the outlying areas. The line sources were placed on the highways, arterial roads and rail lines. The area sources covered the Prince George neighborhoods and outlying communities (Table 6.3). The neighbourhood locations are shown in Appendix F, Figures F.2 and F.3.

Table 6.3: Prince George Neighbourhoods and the Number of Residences per Neighbourhoods

Subdivision	# of Residences	Subdivision	# of Residences
Total Number of Prince George Residences			**20598**
Airport	85	Lakewood	511
Assman	156	Lansdowne	21
Austin East	1064	Millar Addition	1130
Austin West	393	Nechako	291
BCR Industrial	2	North Nechako	796
Blackburn	480	Old Summit Lake	170
Carter Industrial	10	Peden Hill	312
Central Fort George	2196	Perry	113
Chief Lake	540	Pinecone	407
College Heights	2482	Pinewood	340
Cranbrook Hill	607	Quinson	758
Crescents	345	Recreation Place	13
DL 777	6	Seymour	266
Downtown	375	South Fort George	486
Foothills	578	Southwest	1085
Fraserview	62	Spruceland	418
Hart Highlands	1292	Van Bow	90
Heritage	977	VLA	452
Highglen	205	Westwood	473
Highland Park	611		
Outlying Communities			
Beaverley	1100	Miworth	1100
Pineview	1615		

NOTE:
* Provide by email communication from Ms. Jocelyn White, Environmental Coordinator, City of Prince George

It was assumed that the area emissions were located at 2.0 m, just above the human receptor height of 1.5 m. Emissions from an area heat source start with a rise temperature of 2.0 degrees above ambient temperature and has a small initial upward velocity. Emissions from a dust source are initiated with a temperature equal to ambient temperature, and a small initial upward velocity.

6.2 Discussion

6.2.1 Industrial Sources

6.2.1.1 Permitted Users Emissions

Table 6.4 shows a list of the type of individual permitted source emitting units (PSEUs) that are included in the emission inventory. Emissions from the PSEUs are modelled as point sources. For dispersion modelling applications, air contaminants and rate information have to be supplemented with a number of operational parameters. This information now forms part of any advanced emissions inventory (Appendix C).

PM_{10} and $PM_{2.5}$ emissions from each of these PSEUs have different size distributions resulting in varying deposition, but with deposition distances decreasing with increasing PM size. Three categories of PM_{10} size distributions were arbitrarily defined: Fine, Medium and Coarse, with mean diameters of 1.0, 2.0 and 3.0 microns, respectively. The $PM_{2.5}$ mean diameter was set equal to 1.0 micron.

Table 6.4: Permitted Source Emitting Units and PM_{10} Size Characteristics

Emitting unit	Size	Emitting Unit	Size
NB –NG boiler	Fine	WB – Wood baghouse	Fine
CT – Cooling tower	Fine	NK – NG kiln	Fine
CB – Chemical baghouse	Fine	SK – Steam kiln	Fine
CK – Lime Kiln Stack	Fine	CD – Chemical dryer	Fine
CS – Chemical Silo	Fine	FB – Fine dust baghouse	Fine
BD – Bioenergy dryer	Fine	OS – Oven stack	Fine
BB – Bioenergy baghouse	Fine	OK- Heated Oil Kiln	Fine
PS – Chemical Plant Stack	Fine	FB – Plywood baghouse	Fine
CH- Crude Heater	Fine	SE – Sawmill energy	Medium
SC – Small sawmill cyclone	Medium	RG – Regenerator	Medium
SS – Smelt stack	Medium	LC – Large cyclone	Medium
PB – Power stack	Medium	BS- Boiler stack	Medium
TS – Tank stack	Medium	VD – Veneer dryer	Medium
IS – Incinerator stack	Medium	TS – Asphalt Processor	Coarse
		BC – Bioenergy cyclone	Coarse

Figure 6.1 shows the predicted PM_{10} airshed concentration pattern from the year-2005 permitted users emissions. As expected, the maximum concentrations are close to the industrial areas north of the Nechako River and the BCR site. Note that Figures 6.1 thorough 6.31 are presented in Appendix A.

6.2.1.2 Fugitive Emissions

Modelling of fugitive emissions from industrial facility yards was not possible since an emissions inventory for fugitive emissions does not exist. This is unfortunate, since it is anticipated that activity induced and wind erosion emissions from industrial yards and stockpiles could be substantial and locally important. During optimum wind conditions the PM_{10} and $PM_{2.5}$ concentrations could add substantially to the airshed totals. A successor project to study the influences of these emission sources is recommended.

6.2.2 Commercial Sources

6.2.2.1 Commercial Heating

The best method for estimating heat requirements is with a link to outside temperatures. A heating index (HI) is a function of the difference between the ambient outside temperatures and 18ºC (the North American standard). The NG heating emissions for each hour were directly proportional to the HI for each hour. These emissions were selectively allocated to neighborhood areas and treated as area sources. Where possible, the commercial users NG consumptions were matched to the neighborhoods according to the predominant urban zoning. Where a probable location was not apparent, the emissions allocations were spread evenly across all neighborhoods. Naturally, the emissions have a seasonal variation, non-existent during the summer period but large in the winter months.

Emissions from NG burning are mostly $PM_{2.5}$ sized larger molecular-weight hydrocarbons resulting from incomplete combustion. The mean diameter for both was set to 1.0 microns. At the heating vent outlet, the plumes are usually upwardly mobile, so a small initial velocity was assumed. Figure 6.2 (in Appendix A) shows the predicted PM_{10} airshed concentration pattern from the year-2005 emissions. Expectedly, the maximum concentrations are found over the bowl area where most of the commercial activities take place.

6.2.2.2 Other Commercial Emissions

Section 5.2.2 introduced a number of PM_{10} and $PM_{2.5}$ emission sources collectively known as other commercial sources. The sources have unique temporal variations. These PM_{10} and $PM_{2.5}$ emissions were spatially allocated according to the Prince George neighborhoods or outlying communities where these activities were most likely to take place. The spatial allocations were guided by the PG-map web site[27].

Airport/airplane emissions: The airport control tower operates 19 hours per day (05-00-24:00) and the hours close to midnight are slow. It was assumed that the emissions are spread over the operational hours. There were no day of the week variations.

Pacific Western Brewery dust: The brewery office suggested that a 12 hour operation (hours 08:00-20:00) covered most of the production activity. There were no day of the week variations.

Restaurant cooking: Restaurant hours are typically from 6:00-24:00 hours and not all are open simultaneously. During the hourly openings, there are secondary peaks during the early morning, noon and supper periods (7:00 a.m., 12 p.m. and 6:00 p.m.) with the subsequent slow periods. At the vent outlet, the plumes are usually upwardly mobile, so a small initial velocity was assumed.

Welding shops electrode consumption: It was assumed that the welding shops operate during the normal working hours (08:00-1700). There were no day of the week or annual variations.

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[27] PG map site: available online at http://pgmap.princegeorge.ca

Autobody shop sanding: It is assumed that the autobody shops operated during the normal working hours (08:00-17:00). There were no day-of-the-week or annual variations.

Building construction dust and vehicle exhaust: It was assumed that the construction work causing both dust and vehicle exhaust emissions occurred from April to November. Construction work is a day-time (06:00-18:00 hours) activity. There were no day-of-the-week variations.

Gravel pit dust: The gravel pit operating season occurred from April to November with 12-hour operational days. There were no day-of-the-week variations. This gravel pit areas are College Heights, Cranbrook Hill, North Nechako, Austin West and Airport.

Non-road commuter vehicle dust: It is assumed that parking lot dust emissions caused by vehicle activity approximated the same temporal patterns as the on road commuter traffic (Appendix C). There were no day of the week variations.

Farm vehicle dust and exhaust: It was assumed that most farm vehicle emissions occurred during the tilling season (April & May) and then again during the harvesting season (September & October). Working hours during these periods were from 06:00-18:00. There were no day-of-the-week variations. For the April-May tilling season, half the farm tractors were operating during the 12 hour working days. The same was true during the September-October harvesting season. It was assumed that $PM_{2.5}$ is 10% of the PM_{10} size amount.

To minimize the number of dispersion simulations, the emissions were blended together into three sub-source categories. Figures 6.3, 6.4 and 6.5 (in Appendix A) show the predicted PM_{10} airshed concentration patterns from the year-2005 commercial sub-source categories:

- Figure 6.3 shows the predicted contributions from the commercial miscellaneous sources: airport/airplane, Pacific Western Brewery, welding shops and autobody shop sanding emissions. The maximum concentrations are found over the bowl, BCR and airport areas.
- Figure 6.4 shows the contributions from the commercial dust sources: building construction, gravel pit, farm vehicle dust, off road commuter vehicle dust. The concentration pattern shows various maxima over the city areas and the effects of one of more of the construction, gravel pit, farming and parking lot sources.
- Figure 6.5 shows the contributions from commercial restaurants. The maximum concentrations are found over the bowl and some of the suburban areas.

6.2.3 Residential Sources

6.2.3.1 Residential Heating Emissions

Section 5.2.3 discussed emissions from fuelwood (FW), and natural gas (NG) heating. Most of the heating requirements are NG fueled, but as a clean burning fuel, the emission rates are relatively small. The basic spatial emissions allocations were based on the results of a UNBC study (Jackson et al, 2009). The basic temporal emissions allocations were made using the HI methodology. Secondary temporal adjustments made for resident management practices included lower heating overnight and during the normal working hours. The dispersion modelling assumed area sources with a rise temperature of two degrees above the ambient. At the heating vent outlet, the plumes are usually upwardly mobile, so a small initial velocity was assumed. Both the PM_{10} and $PM_{2.5}$ sizes were set to 1.0 microns.

Figure 6.6 (in Appendix A) shows the predicted PM_{10} airshed concentration pattern from the year-2005 residential heating emissions. The maximum concentrations are found over the bowl and the College Heights areas.

6.2.3.2 Other Residential Emissions

Other than heating emissions, Section 5.2.3 identified the following residential activities producing PM_{10} and $PM_{2.5}$ emissions: cigarette smoking, barbeque cooking and household equipment operations. To minimize the number of dispersion simulations, the emissions were blended together.

Cigarette Smoking: Cigarette smoking is a year-round activity but has a diurnal variation. Most smoking takes place during the day and evening hours. It was assumed that cigarette smoking hours start at 8:00 and continue to 24:00 hours (BC Stats, 2007; Environment Canada, 2002). There were no day of the week or annual variations.

Outside residential equipment: The operation of lawn, garden, yard and recreational equipment is mostly a summer afternoon and evening activity. The activity starts in May and continues to the end of October. Most of the activity occurred during the hours of 16:00 - 20:00.

Barbeques: Residential barbeque cooking starts in May and continues to the end of September. Most of the activity is assumed to occur during the hours of 16:00 - 20:00. Barbeque plumes are usually initially upwardly ascending, so a small initial rise velocity was assumed.

These PM_{10} and $PM_{2.5}$ emissions were allocated according to the number of residences located in the neighborhood and modelled as area sources. The rise area was given a small rise velocity and the area temperature equaled 2˚C above ambient. All PM_{10} was in the $PM_{2.5}$ range. Figure 6.7 (in Appendix A) shows the predicted PM_{10} airshed concentration pattern from the year-2005 other residential emissions. Similar to the residential heating pattern, the maxima are found over the residential areas. The predicted concentrations are small compared to the other sources.

6.2.4 Mobile sources

6.2.4.1 On-road Mobile Emissions

Most of the heavier and faster traffic is found on the highways and the arterial roads. Ideally the road dust emissions should be modelled with every street represented as a separate line object, however the enormity of the task would make this approach difficult. Therefore simplifications were necessary. The highways and arterial roads were modelled as line objects and the collector, residential and lane road roads were treated as area objects. For each hour, reductions from the peak rates were determined by the diurnal, day of the week and yearly traffic patterns (Figures B2.1 to B2.3).

For the line emissions, the buoyancy setting was determined through sensitivity testing. For the area emissions, the rise area was given a low rise velocity and a temperature equal to 2˚C above the ambient. Since most of the PM_{10} is in the $PM_{2.5}$ size range, a mean diameter of 1.0 micron was assumed.

A number of segments specified the line objects. Four areas were assumed to cover most of the Prince George road network. They are described as follows:

- Bowl – the area covering the Prince George urban area;
- Hart – the area that encompasses most of the road network to the north of the bowl;
- SW – the area that encompasses most of the road network to the southwest of the bowl; and
- SE – the area that encompasses most of the road network to the southeast of the bowl area.

Figure 6.8 (in Appendix A) shows the predicted PM_{10} airshed concentration pattern from the year-2005 on-road mobile emissions. The maxima in the concentration patterns tend to line up with the heavier traffic routes.

6.2.4.2 On-road Vehicle Dust Emissions

The on-road dust modeling is similar to the on-road mobile, with some differences. The two types of emissions occur simultaneously; however, the on-road dust emissions can be much larger. The highways and arterial roads were modelled as line objects. Paved collector, residential and lane dust emissions were modelled as area emissions. Unpaved collector, residential and lane dust emissions were modelled separately as area emissions. The areas are identical to the ones described above.

Similar to the on-road mobile emissions, traffic pattern modelling was used to reduce the emissions from the peak rates. Unlike the on-road mobile emissions, precipitation suppression was implemented (Appendix C). Most of the PM is in the PM_{10} range so a diameter was assumed equal to 6.0 microns.

As pointed out in Section 5.2.4.2, the RWG requested implementation of the Third Party Review recommendation that the EPA paved road standard of $PM_{2.5}$ to PM_{10}.of 14.3% be maintained. This change resulted in larger road dust contributions to the $PM_{2.5}$ concentrations.

The lack of dust emission buoyancy resulted in greater deposition and lessened dispersion. Figure 6.9 (in Appendix A) shows the predicted PM_{10} airshed concentration pattern from the year-2005 on-road vehicle dust emissions. The concentration maxima tend to line up with the heavier traffic routes.

6.2.4.3 Railway Locomotive Emissions

A reorganization of the Prince George railway operations occurred after the CNR takeover of BCR in 2005. The major change in CNR operations was the relocation of most of their switching operations from Northyard to Southyard. The major effect of the CNR reorganization on the modelling project was the presence of one emissions regime before year 2005 and another for year 2005 (the validation year).

During yard operations, the yard locomotive locations are variable, but it is recognized that the yard locomotives spend more time near the yard depots, located approximately near the centre of the yards. The locations of the road locomotives are highly variable and could be anywhere on the rail line. The yard locomotives were modelled as point sources and the rail lines as uniform buoyant line sources. All emissions rates were held constant except for emissions of two switchers that travelled from Northyard to Northwood. A number of segments defined the rail line and the road locomotive emissions were spread evenly over the segments. The buoyancy parameter was determined by sensitivity testing with the emissions height at 4.25 m. The yard locomotives were modelled as point sources approximately near the centre of the yard with an exit temperature of 455K.

Figure 6.10 (in Appendix A) shows the predicted PM_{10} airshed concentration pattern from the year-2005 locomotive emissions. The maxima occur close to the CNR yards. However, the maxima in the concentration pattern are not pronounced, suggesting that appreciable dispersion occurred.

6.2.5 Other Sources

6.2.5.1 Open Burning

The MOF and the City of Prince George open burning emissions were modeled separately. Since the burn area is very small compared to the airshed domain, the MOF burning emissions were modeled as point sources. The City of Prince George burning emissions were modeled as neighborhood area sources.

Each MOF permitted burn was treated as a separate event, later summing all concentration predictions to form an annual composite. Durations were assumed to be a function of number of woodpiles, the larger the number the longer the burn. Some MOF permitted burns occurred over the winter season, but the most active burning months were from May to November. A burn temperature of 400 K was assumed.

The Prince George City permitted burns were modelled as neighborhood area emissions. As with the MOF burning season, it was assumed that the most active months were from May to November. The rise areas assumed a small initial rise velocity and temperature 2˚C above ambient. Most emissions were in the $PM_{2.5}$ size range and assumed to have a 1.0 micron diameter.

Figure 6.11 (in Appendix A) shows the predicted PM_{10} airshed concentration pattern from the year-2005 Open Burning emissions. The “hot spots” are likely where MOF permitted burning may have occurred.

6.2.5.2 Background Sources

Predicted annual average values for PM_{10} and $PM_{2.5}$ are lower than those measured values at most of the monitoring sites. To account for the many sources that have not been identified and modelled, and particulate transported from outside the airshed, background concentration values were added to the predicted concentrations.

The Hightower, Alberta, monitoring site was identified by the MOE as the closest and most representative source of background particulate data. This site is 300 km to the east of Prince George in the Rocky Mountain foothills and 50 km to the northwest of Hinton, Alberta. The Hightower background PM concentrations are likely due to pollen, wind erosion, long-range transport, and wildfires. There are very few industrial emissions sources nearby (some forestry and oil and gas). The monthly minimum hourly values for years 2000-2004 were averaged to yield assumed background concentrations of 5.1 and 1.3 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively[28]. Subsequently, Fudge and Sutherland (2010) suggested use of average monthly concentrations for the Hightower site, however this recommendation has not been implemented pending further discussion.

6.2.5.3 Secondary Formations

The formation of ammonium sulphate and ammonium nitrate aerosols were modelled with the CALPUFF RIVAD module. Airshed emission estimates of the nitrogen oxides (NO_x) and the sulphur oxides (SO_2) are required as inputs. Sulphate and nitrate concentrations are higher in winter. Since ammonia is preferentially scavenged by sulphate, the formation of nitrate is limited by the availability of the ammonium ion that is limited by the airshed ammonia concentrations. Unfortunately MOE does not measure ammonia concentrations in the Prince George area. Ammonium ion concentration estimates are taken from a separate report prepared by STI (2008). Like all other PM, the aerosols are subject to gravitational settling after formation. A mean diameter of 0.48 microns was assumed.

The predicted annual averaged secondary formation patterns are shown in Figures 6.12 and 6.13 (in Appendix A) for year-2005 ammonium nitrate and ammonium sulphate formations respectively. Figure 6.12 does show maximum concentrations east of the bowl area, probably influenced by NO_x emissions from the locomotive and vehicle exhaust. Both ammonium nitrate and ammonium sulphate distributions are relatively even near the city core. This pattern is expected since secondary formations likely occur away from the emission sources.

6.3 Comparison of Predicted and Measured Values

Table 6.5 compares the predicted and measured annual average concentrations of PM_{10} and $PM_{2.5}$ at the five Prince George monitoring locations where these measurements are available (Plaza, Lakewood, Gladstone, BC Rail, and Van Bien[29]). These predicted values include the secondary particulate contributions and the Hightower values (5.1 µg/m^3 and 1.3 µg/m^3 for PM_{10} and $PM_{2.5}$) as a constant background source.

[28] This information was provided by Mr. Dennis Fudge, BC MOE.
[29] Glenview is not included since measured data were not available when this document was prepared.

Table 6.5: Comparison of Predicted and Measured Annual Averaged Concentrations of PM_{10} and $PM_{2.5}$ at Prince George Monitoring Locations: Years 2003-2005

	2003		2004		2005	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
	Concentrations ($\mu g/m^3$)					
Plaza Predicted[1]	17.99	8.31	18.51	8.34	18.75	8.86
Adjusted Measured levels[2]	19.52	10.77	20.31	12.10	20.63	10.40
Difference	1.53	2.46	1.80	3.76	1.88	1.54
Unadjusted Measured levels[3]	19.50	9.80	20.30	9.50	20.60	7.80
Difference	1.51	1.49	1.79	1.16	1.85	-1.06
Lakewood Predicted[2]	15.96	7.15	18.19	7.28	17.56	7.59
Measured Levels[3]	14.37	- -	14.98	- -	17.07	10.30
Difference[4]	-1.59	- -	-3.21	- -	-0.49	2.71
Gladstone Predicted[2]	13.37	5.76	12.76	5.57	12.84	5.63
Measured Levels[4]	14.80	- -	14.60	- -	15.10	10.00
Difference[5]	1.43	- -	1.84	- -	2.26	4.37
BC Rail Predicted[2]	19.14	10.18	18.65	9.93	18.60	9.76
Measured Levels[4]	24.40	- -	25.88	- -	27.41	- -
Difference[5]	5.26	- -	7.23	- -	8.81	- -
Van Bien Predicted[2]	21.17	8.58	19.36	8.11	21.07	8.56
Measured Levels[4]	18.53	- -	19.16	- -	22.88	11.20
Difference[5]	-2.64	- -	-0.20	- -	1.81	2.33

NOTES:

- Indicates "no measurement", therefore differences are not available.

[1] Modelled values include secondary formation predictions and background estimates.

[2] Measured results for the Plaza location, including 2004 and 2005 adjusted values, provided by BC MOE.

[3] Measured results for the Plaza location, including 2004 and 2005 unadjusted values, were provided by BC MOE (available at: http://www.env.gov.bc.ca/epd/regions/omineca/air/annual_info.htm)

[4] Data provided by Mr. Dennis Fudge at BC MOE.

[5] Difference calculations are "measured minus predicted".

In Table 6.5 a positive difference indicates measured values exceed the annual average predicted values (model under predicts), and a negative difference indicates that the annual averaged predicted values exceed those measured (model over predicts). These results show that the model is performing very well, at times over-predicting, but usually under-predicting. There is a high degree of confidence in the results of this dispersion modelling exercise.

Note that for the Plaza site there are adjusted and unadjusted values for PM_{10} and $PM_{2.5}$ (provided by the Prince George MOE office). The difference between adjusted and unadjusted PM_{10} are nil, however the unadjusted figures were provided to one decimal place. There are large differences in $PM_{2.5}$ owing to adjustments made by Mr. Dennis Fudge as per methods he developed to account for underestimate wintertime values (Fudge, 2010). The adjusted values are greater than the unadjusted values. Generally, the difference between the measured values and the predicted values (plus background) is least for the unadjusted values.

Some uncertainty results from use of background values derived from measurements taken at a site 300 km to the east of Prince George and in different years. The values used were the Hightower minimums, suggesting that higher values would be defensible. If the Fudge and Sutherland (2010) recommendations were implemented, the background values would be higher (7.0 µg/m^3 and 1.9 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively).

Ideally background values should be measured regionally, away from as many local sources as possible.

6.4 Results Summary

6.4.1 Monitoring Site Receptor Results

This section presents the detailed predicted results at the Plaza airshed monitoring site. Results pertaining to Lakewood, Gladstone, Glenview, B.C. Rail and Van Bien monitoring stations are provided in Appendix D. Where possible, predicted values are compared to measured values.

6.4.1.1 Predicted Contributions by Source Category at the Plaza Site

The contributions to predicted annual averaged PM_{10} and $PM_{2.5}$ concentrations by source category are presented for the Plaza site in Table 6.6. These same data (2003-2005 average) are presented in two pie charts in Figure 6.4.1.

For Plaza site, predicted annual averaged PM_{10} and $PM_{2.5}$ concentrations for 2003–2005 (Table 6.6) are presented for all major and sub-source categories. Secondary formation and background concentrations are included as line items. After summing the modeled results, an arithmetic difference “measured minus modeled” provides a comparison with measured values. The modeled sums are generally lower than the observed levels, but given the uncertainty range in both sets of data, the values are comparable.

Table 6.6: Contributions by Source Category to Predicted Annual Averaged PM_{10} and $PM_{2.5}$ Concentrations at the Plaza Site: 2003 - 2005

Source Category	Sub Source Category	2003		2004		2005	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
		Concentrations (µg/m^3)					
Industrial Sources	**Permitted users**	2.57	1.58	2.47	1.51	2.54	1.63
Commercial Sources	**Commercial heating**	0.14	0.14	0.06	0.06	0.08	0.08
	Commercial miscellaneous	0.15	0.14	0.15	0.15	0.15	0.15
	Commercial dust	0.53	0.11	0.56	0.12	0.54	0.12
	Commercial restaurants	0.99	0.92	1.00	0.93	1.13	1.04

Table 6.6: Contributions by Source Category to Predicted Annual Averaged PM_{10} and $PM_{2.5}$ Concentrations at the Plaza Site: 2003 – 2005 (cont'd)

Source Category	Sub Source Category	2003		2004		2005	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
		Concentrations (µg/m^3)					
Residential Sources	Residential heating	0.59	0.59	0.56	0.55	0.81	0.81
	Residential others	0.02	0.02	0.02	0.02	0.08	0.08
Mobile Sources	On-road dust	5.40	1.19	5.98	1.29	5.70	1.24
	On-road mobile	0.43	0.31	0.44	0.32	0.47	0.34
	Locomotive	1.07	1.01	1.12	1.06	1.00	0.95
Other Sources	Open/MOF burning	0.18	0.18	0.18	0.18	0.30	0.28
Secondary Formations		0.82	0.82	0.85	0.85	0.85	0.85
Background	Hightower minimum	5.10	1.30	5.10	1.30	5.10	1.30
Sum modelled[1]		17.99	8.31	18.51	8.34	18.75	8.86
Adjusted Measured levels[2]		19.52	10.77	20.31	12.10	20.63	10.40
Difference[4]		1.53	2.46	1.80	3.76	1.88	1.54
Unadjusted Measured levels[3]		19.50	9.80	20.30	9.50	20.60	7.80
Difference[4]		1.51	1.49	1.79	1.16	1.85	-1.06

NOTES:

[1] The "sum modelled" values include secondary formation predictions and background estimates.

[2] Measured results for the Plaza location, including 2004 and 2005 adjusted values, were provided by BC MOE.

[3] Measured results for the Plaza location, including 2004 and 2005 unadjusted values, were provided by BC MOE (available at: http://www.env.gov.bc.ca/epd/regions/omineca/air/annual_info.htm)

[4] Difference calculations are "measured minus predicted".

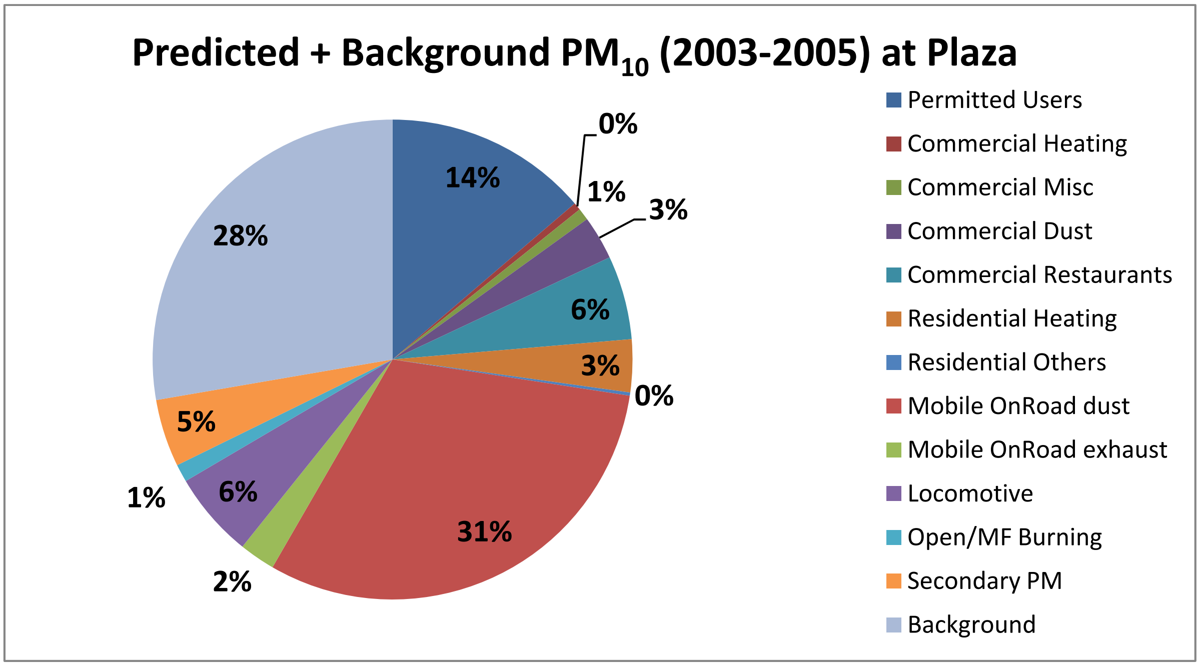
Table 6.6 illustrates the relative contributions by both major source and sub-source categories. The top contributors to PM_{10} are on-road dust, permitted users, commercial restaurants, and residential heating. On-road dust is by far the strongest contributor to PM_{10}. The top contributors to $PM_{2.5}$ are permitted users, on-road dust, locomotives, and commercial restaurants. Secondary particulate matter is 5% of PM_{10} and 10% of $PM_{2.5}$.

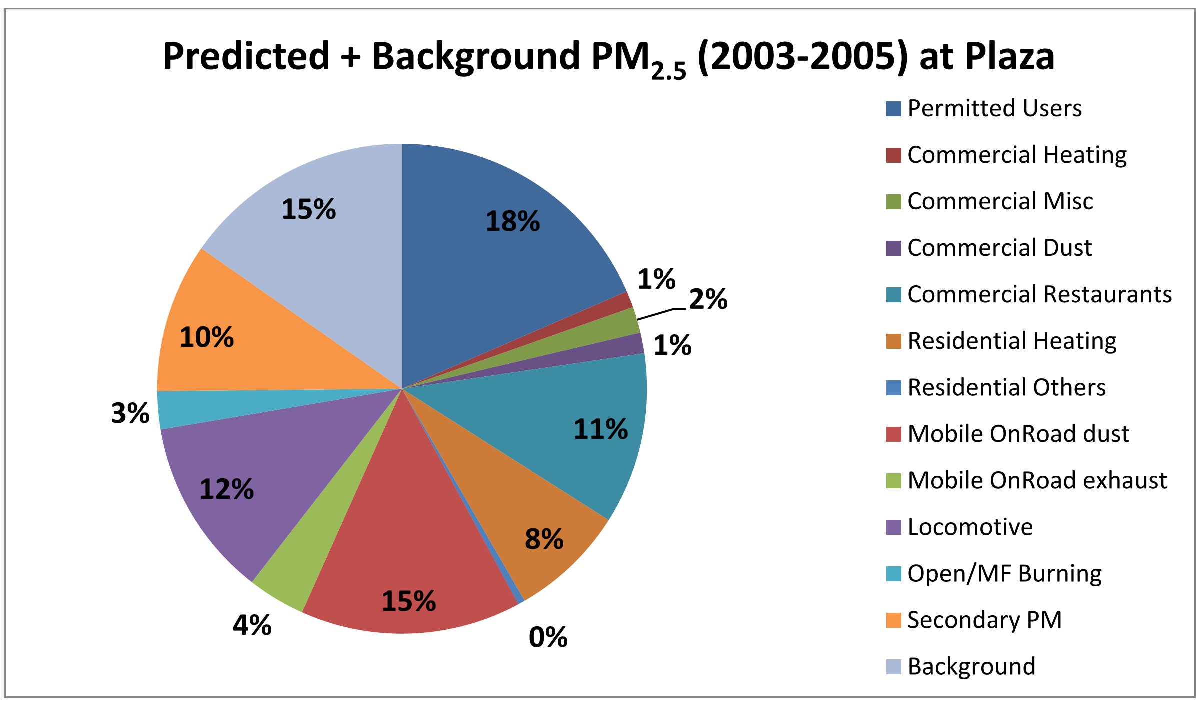
Background accounts for particulate matter transported into the airshed, and unknown sources in the airshed that were not accounted for in the micro-emissions inventory. The assumed background contribution is approximately one quarter of the PM_{10} (27%) and one seventh (15%) of $PM_{2.5}$.

For all sub-source categories, the ratios of $PM_{2.5}$ to PM_{10} concentrations are equal to or higher than the equivalent emission rate ratios. This reflects the fact that the PM_{10} aggregate has higher weights than $PM_{2.5}$ aggregate resulting in greater deposition increasing as the increasing distance from source to receptor. This effect is especially marked for the on-road dust predictions.

Similar results for the Lakewood, Gladstone, Glenview, B.C. Rail and Van Bien are provided in Appendix D.

Figure 6.4.1: Contributions by Source Category to Predicted Annual Averaged PM10 and PM2.5 Concentrations at the Plaza Site: 2003 - 2005





6.4.1.2 Ranked Listing of Source Category Contributions.

The sub-source contributions to predicted $PM_{2.5}$ and PM_{10} concentrations at the Plaza site are ranked by actual and percentage terms and presented in Table 6.7 (year 2005 only). There are three modes to illustrate the effect of considering secondary PM:

- Results #1 show the sub-source contributions for the primary PM_{10} and PM $_{2.5}$ only.
- Results #2 show the sub-source contributions for the primary and secondary PM_{10} and $PM_{2.5}$
- Results #3 show the sub-source contributions for primary and second PM_{10} and $PM_{2.5}$ with the background source added in the table as a line item.

Table 6.7: Ranked Contributions to Predicted Annual Average $PM_{2.5}$ and PM_{10} Concentrations at the Plaza Site by Sub-Source Category: Year-2005

Plaza	Sub Source Category	2005 PM_{10} (µg/m^3)	2005 $PM_{2.5}$ (µg/m^3)	2005 PM_{10} (%)	2005 $PM_{2.5}$ (%)
#1 Primary PM Predictions	Permitted users	2.54	1.63	13.54%	18.42%
	On-road dust	5.70	1.24	30.40%	13.96%
	Commercial restaurants	1.13	1.04	6.01%	11.78%
	Locomotive	1.00	0.95	5.35%	10.71%
	Residential heating	0.81	0.81	4.35%	9.15%
	On-road mobile	0.47	0.34	2.48%	3.79%
	Open/MF burning	0.30	0.28	1.58%	3.17%
	Commercial miscellaneous	0.15	0.15	0.83%	1.66%
	Commercial dust	0.54	0.12	2.88%	1.30%
	Residential others	0.08	0.08	0.43%	0.91%
	Commercial heating	0.08	0.08	0.42%	0.89%
#2 Primary and Secondary PM Predictions	Permitted users	2.74	1.83	14.61%	20.67%
	Locomotive	1.40	1.34	7.45%	15.15%
	On-road dust	5.70	1.24	30.40%	13.96%
	Commercial restaurants	1.13	1.04	6.01%	11.78%
	Residential heating	0.82	0.82	4.37%	9.20%
	On-road mobile	0.66	0.53	3.52%	5.99%
	Open/MF Burning	0.30	0.28	1.58%	3.18%
	Commercial miscellaneous	0.20	0.19	1.07%	2.19%
	Commercial dust	0.55	0.12	2.91%	1.35%
	Commercial heating	0.08	0.08	0.45%	0.96%
	Residential others	0.08	0.08	0.43%	0.91%

Table 6.7: Ranked Contributions to Predicted Annual Average $PM_{2.5}$ and PM_{10} Concentrations at the Plaza Site by Sub-Source Category: Year-2005 (cont'd)

Plaza	Sub Source Category	2005 PM_{10} (µg/m³)	2005 $PM_{2.5}$ (µg/m³)	2005 PM_{10} (%)	2005 $PM_{2.5}$ (%)
#3 Primary and Secondary PM Predictions Background is added as a line Item in this table	Permitted users	2.74	1.83	14.61%	20.67%
	Locomotive	1.40	1.34	7.45%	15.15%
	Background	5.1	1.3	27.20%	14.67%
	On-road dust	5.70	1.24	30.40%	13.96%
	Commercial restaurants	1.13	1.04	6.01%	11.78%
	Residential heating	0.82	0.82	4.37%	9.20%
	On-road mobile	0.66	0.53	3.52%	5.99%
	Open/MF Burning	0.30	0.28	1.58%	3.18%
	Commercial miscellaneous	0.20	0.19	1.07%	2.19%
	Commercial dust	0.55	0.12	2.91%	1.35%
	Commercial heating	0.08	0.08	0.45%	0.96%
	Residential others	0.08	0.08	0.43%	0.91%

The $PM_{2.5}$, results #1 group show that permitted users contributions predominate closely followed by on-road dust, locomotives and commercial restaurants. Lesser contributors include residential others, commercial heating, and commercial dust. Including the secondary $PM_{2.5}$ (group #2) raises the predicted contribution of combustion-related sources. Results #3 shows that the background concentration contributions are substantial (27% and 15% for PM_{10} and $PM_{2.5}$, respectively) and should be studied further.

The commercial dust (gravel pits) sub-source category does include a minute amount of NO_X/SO_2 emissions (heavy equipment operation). This results in some very small secondary particulate production where it may not be expected. The commercial restaurants, open burning, and residential others sub-source category sources do not include NO_X/SO_2 emissions, hence no secondary particulate production.

Similar results for the Lakewood, Gladstone, Glenview, B.C. Rail and Van Bien are provided in Appendix D.

6.4.1.3 Source Emitting Unit Ranked Contributions

Year-2005 SEU ranked contributions to predicted (primary) $PM_{2.5}$ & PM_{10} concentrations at the Plaza site are presented in Table 6.8. There are approximately 500 SEUs included in the MEI. The highest contributing SEU is Highway 16 (from the on-road dust sub-source category). However, downtown restaurants, residential heating (Millar Addition), and three locomotive SEUs also contribute to predicted $PM_{2.5}$ concentrations.

This may appear to conflict with the findings (by Sub Source Category) presented in Table 6.7, however it is important to remember that while one SSC may be dominant in the aggregate (e.g. Permitted Users in Table 6.7), it is not necessary for SEUs within that same sub-source category to rank amongst the top contributing SEUs (in Table 6.8).

Table 6.8: 10 Highest Ranked PM Contributors to the Predicted Plaza Site Concentrations

Source Emitting Unit	Sub-Source Category	2005 PM_{10} (µg/m^3)	2005 $PM_{2.5}$ (µg/m^3)
Highway 16	On-road Dust	1.410	0.355
Downtown	Restaurants	0.240	0.222
15th Avenue - Victoria - 1st ave	On-road Dust	1.150	0.210
Southyard Line Locomotives	Locomotives	0.207	0.196
Millar Addition	Residential Heating	0.194	0.194
Highway 97	On-road Dust	0.739	0.164
Railway to Quesnel	Locomotives	0.155	0.147
Railway to Jasper	Locomotives	0.145	0.137
DL 777	Restaurants	0.146	0.136
Railway to Fort St. James	Locomotives	0.131	0.124

Similar results for the Lakewood, Gladstone, Glenview, B.C. Rail and Van Bien are provided in Appendix D. A complete listing of the SEU ranked contributions are given in an Excel worksheet accompanying the final report.

6.4.1.4 Contributions from Permitted Source Emitting Units

Table 6.9 shows the contribution of refinery and pulp mill emissions to the predicted annual average $PM_{2.5}$ concentrations at all monitoring sites (2003–2005). Their contributions are presented both as concentrations and as percentages of the permitted users' emission inventory grouping (and not from the total of all major source categories). It is evident that the pulp mills have a greater influence on the Glenview and Van Bien sites compared to the BC Rail and Gladstone sites.

Table 6.9: Contribution of Refinery and Pulp Mill Emissions to the Predicted Annual Averaged $PM_{2.5}$ Concentrations at all Monitoring Sites: 2003 - 2005

Monitoring Site	$PM_{2.5}$ Concentrations (µg/m^3)			Percentage of Permitted Users Grouping (%)		
	2003	2004	2005	2003	2004	2005
Husky Refinery						
BC Rail	0.008	0.008	0.008	0.42%	0.45%	0.41%
Gladstone	0.006	0.007	0.006	0.56%	0.60%	0.57%
Glenview	0.007	0.006	0.009	0.92%	0.88%	0.99%
Plaza 400	0.013	0.013	0.015	0.82%	0.86%	0.91%
Van Bien	0.009	0.010	0.010	0.75%	0.84%	0.82%
Lakewood	0.009	0.008	0.009	0.89%	0.79%	0.85%

Table 6.9: Contribution of Refinery and Pulp Mill Emissions to the Predicted Annual Averaged $PM_{2.5}$ Concentrations at all Monitoring Sites: 2003 – 2005 (cont'd)

Monitoring Site	$PM_{2.5}$ Concentrations ($\mu g/m^3$)			Percentage of Permitted Users Grouping (%)		
	2003	2004	2005	2003	2004	2005
Northwood Pulp						
BC Rail	0.189	0.185	0.186	10.43%	10.40%	9.84%
Gladstone	0.166	0.163	0.162	14.76%	14.99%	14.66%
Glenview	0.197	0.203	0.225	27.42%	29.61%	24.99%
Plaza 400	0.310	0.299	0.315	19.72%	19.83%	19.38%
Van Bien	0.226	0.225	0.231	18.31%	19.31%	18.97%
Lakewood	0.233	0.210	0.217	22.23%	22.27%	19.94%
PG Pulp						
BC Rail	0.251	0.262	0.257	13.84%	14.76%	13.59%
Gladstone	0.197	0.205	0.200	17.52%	18.85%	18.12%
Glenview	0.180	0.171	0.241	25.08%	25.02%	26.75%
Plaza 400	0.251	0.232	0.295	15.96%	15.41%	18.13%
Van Bien	0.258	0.243	0.251	20.87%	20.84%	20.58%
Lakewood	0.204	0.169	0.215	19.53%	17.94%	19.74%
Intercon Pulp						
BC Rail	0.154	0.159	0.149	8.49%	8.95%	7.88%
Gladstone	0.122	0.125	0.116	10.85%	11.49%	10.52%
Glenview	0.112	0.104	0.147	15.61%	15.16%	16.36%
Plaza 400	0.189	0.174	0.215	12.03%	11.54%	13.21%
Van Bien	0.171	0.170	0.178	13.89%	14.60%	14.58%
Lakewood	0.149	0.121	0.150	14.21%	12.82%	13.74%

Table 6.10 shows the contribution of refinery and pulp mill emissions to the predicted annual average PM_{10} and $PM_{2.5}$ concentrations at all monitoring sites (2005 only). Their contributions are presented both as concentrations and as percentages of the total of all major source categories (the airshed).

A number of trends can be discerned from these results. Overall, the predictions show that the contributions from these permitted users to PM_{10} and $PM_{2.5}$ at the monitoring site is low. For example, the greatest pulp mill contribution to $PM_{2.5}$ at any monitoring site is 4.98% (PG Pulp at the Glenview site). Pulp mills consistently average approximately 3% of the total $PM_{2.5}$. Refinery emissions have much less influence on $PM_{2.5}$ at the monitoring sites. The greatest refinery contribution to $PM_{2.5}$ at any monitoring site is 0.17% (Glenview). Refineries consistently average approximately 0.1% of the total $PM_{2.5}$.

Table 6.10: Contribution of Refinery and Pulp Mill Emissions to the Predicted Annual Averaged PM10 & PM2.5 Concentrations at all Monitoring Sites: Year 2005

Monitoring Site	Permitted Users	2005 Concentrations		Percentage of All Major Source Categories	
		PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} (%)	$PM_{2.5}$ (%)
Plaza	Husky	0.023	0.014	0.12%	0.16%
	Northwood	0.393	0.315	2.10%	3.55%
	PG Pulp	0.322	0.295	1.72%	3.33%
	Intercon	0.227	0.215	1.21%	2.43%
Lakewood	Husky	0.014	0.008	0.08%	0.11%
	Northwood	0.272	0.217	1.55%	2.86%
	PG Pulp	0.233	0.215	1.33%	2.83%
	Intercon	0.158	0.150	0.90%	1.98%
Gladstone	Husky	0.010	0.006	0.08%	0.11%
	Northwood	0.200	0.162	1.56%	2.88%
	PG Pulp	0.220	0.200	1.71%	3.55%
	Intercon	0.124	0.116	0.97%	2.06%
Glenview	Husky	0.014	0.008	0.12%	0.17%
	Northwood	0.284	0.225	2.46%	4.65%
	PG Pulp	0.265	0.241	2.29%	4.98%
	Intercon	0.157	0.147	1.36%	3.04%
BC Rail	Husky	0.012	0.007	0.06%	0.07%
	Northwood	0.229	0.186	1.23%	1.90%
	PG Pulp	0.283	0.257	1.52%	2.63%
	Intercon	0.158	0.149	0.85%	1.53%
Van Bien	Husky	0.016	0.009	0.08%	0.11%
	Northwood	0.288	0.231	1.37%	2.70%
	PG Pulp	0.274	0.251	1.30%	2.93%
	Intercon	0.188	0.178	0.89%	2.08%

6.4.1.5 Highest 20-Day Monitoring Site Results

The 20 highest daily averaged PM_{10} and PM $_{2.5}$ concentrations predicted at the Plaza site in year-2005 are presented in Table 6.11 in chronological order. Fifteen of the 20 days fall between mid-January and mid March. These results likely demonstrate the limited winter time dispersion capability of the atmosphere enhanced by exceptional meteorological conditions.

The predicted daily values are depicted as both including and excluding the secondary particulates. The average increase by including secondary particulate formation is approximately 13% for PM_{10} and 26% for $PM_{2.5.}$ This indicates that secondary particulate formation is an important consideration, especially in winter.

Table 6.11: Twenty Highest predicted Daily Averaged PM10 & PM2.5 Concentrations at Plaza Site: Year 2005

Date	PM_{10} ($\mu g/m^3$)			$PM_{2.5}$ ($\mu g/m^3$)		
	No Secondary	With Secondary	% gain	No Secondary	With Secondary	% gain
13-Jan-05	37.9	43.9	16.1	23.5	29.6	25.8
26-Jan-05	31.1	36	15.9	16.9	21.9	29.2
4-Feb-05	24.8	27.3	10.2	8.8	11.3	28.7
7-Feb-05	29	32.6	12.3	14.9	18.4	23.8
8-Feb-05	26.3	28.4	8.1	10.6	12.7	20.2
15-Feb-05	28.3	30.9	8.9	14.1	16.7	17.9
16-Feb-05	35.9	39.3	9.4	15.4	18.7	21.9
17-Feb-05	27.1	29.7	9.7	12.6	15.2	20.9
18-Feb-05	35.1	41.1	17.1	16.7	22.7	35.7
21-Feb-05	37.7	42.3	12.3	18.3	22.9	25.3
24-Feb-05	27	30.4	12.6	12.4	15.8	27.5
25-Feb-05	52.7	59.7	13.3	23.1	30.1	30.2
28-Feb-05	33.8	38.1	12.6	16.3	20.6	26
3-Mar-05	22	24.9	12.9	10.1	12.9	28.3
14-Mar-05	31.4	35.1	11.9	13.2	16.9	28.4
22-Oct-05	12.3	15.6	26.9	7.5	10.8	30.2
5-Dec-05	31.2	35.8	14.6	18.6	23.2	24.4
6-Dec-05	20.6	22.9	10.8	10.9	13.1	20.3
15-Dec-05	30.8	34.3	11.4	17.4	20.9	20.1
16-Dec-05	23.6	25.8	9.3	11	13.2	19.9

6.4.1.6 Source Category Apportionment

Table 6.12 shows the contribution by sub-source category to the predicted average PM_{10} and $PM_{2.5}$ concentrations at all monitoring stations averaged for the 20 highest days in 2005. Note that in this table both the background and the secondary formation contributions are excluded.

A number of general trends are apparent. For PM_{10}, On-road dust is the greatest contributor at all sites, particularly at the Van Bien and Lakewood sites. Permitted users and locomotives are also important sources on these days. MOF and City burns are the least contributors, indicating they are not active during the 20 highest days. Of the active sources, residential other and commercial misc. are the smallest contributors.

For $PM_{2.5}$, on-road dust is a large contributor at all sites, particularly at the Van Bien and Lakewood sites. Locomotives are the next most important sources, particularly at the BC Rail and Gladstone sites. Permitted users are important contributors at all monitoring sites during the 20 highest days. MOF and City burns are the least contributors, indicating they are not active on these days. Of the active sources, residential other and commercial heating are among the smallest contributors.

Table 6.12: Contribution by Sub-Source Category to the Predicted Daily PM_{10} & $PM_{2.5}$ Concentrations at all Monitoring Stations for the Twenty Highest Days in 2005 (Secondary PM and Background Contributions Not Included)

Inhalable Particulate Matter (PM_{10})						
Sub-Source Category	**BC Rail %**	**Gladstone %**	**Glenview %**	**Plaza %**	**Van Bien %**	**Lakewood %**
Permitted users	19.2	18.0	15.5	14.2	6.3	10.4
On-road dust	43.0	50.4	53.2	53.7	72.5	64.7
Locomotive	22.1	12.8	11.0	9.3	5.5	7.2
On-road mobile	2.8	3.0	4.8	4.8	3.2	3.1
Residential heating	3.9	5.9	6.9	5.9	3.6	5.3
MOF & City burns	0.0	0.0	0.0	0.0	0.0	0.0
Commercial heating	0.3	0.4	0.3	1.0	0.3	0.5
Residential others	0.1	0.1	0.1	0.1	0.1	0.1
Commercial misc	1.4	1.7	1.7	1.0	0.6	0.6
Commercial dust	1.6	1.9	3.2	0.7	0.6	1.0
Restaurants	5.5	5.8	3.4	9.3	7.4	7.0
Respirable Particulate Matter (PM2.5)						
$PM_{2.5}$	**BC Rail %**	**Gladstone %**	**Glenview %**	**Plaza %**	**Van Bien %**	**Lakewood %**
Permitted users	20.2	22.6	22.6	17.4	11.2	15.3
On-road dust	22.9	28.5	34.5	29.4	42.7	37.1
Locomotive	34.4	18.5	12.6	13.2	10.4	11.0
On-road mobile	2.2	2.5	3.6	4.5	3.8	3.2
Residential heating	7.5	12.5	15.0	12.9	10.1	13.7
MOF & City burns	0.0	0.0	0.1	0.0	0.0	0.1
Commercial heating	0.4	0.5	0.4	1.6	0.6	0.8
Residential others	0.1	0.2	0.2	0.2	0.2	0.3
Commercial misc	1.5	1.9	2.1	1.4	1.0	0.8
Commercial dust	0.7	1.0	2.0	0.3	0.4	0.5
Restaurants	10.0	11.7	7.1	18.9	19.6	17.0

6.4.1.7 Seasonal Variations

Table 6.13 shows the contribution of refinery and pulp mill emissions to the predicted seasonal average PM_{10} and $PM_{2.5}$ concentrations at all monitoring sites (2005 only). Seasonal variations are approximated by three-month averages: January to March (winter); April to June (spring); July to September (summer); and October to December (autumn). There is not a great deal of seasonal variation. The predicted seasonal average concentrations are generally higher in the winter and lower in the summer months. This is likely a function of limited dispersion in winter, and more solar heating, and hence vertical mixing in summer. Note that in this table both the background and the secondary formation contributions are excluded.

Table 6.13: Contribution of Refinery and Pulp Mill Emissions to the Predicted Annual Seasonal PM_{10} and $PM_{2.5}$ Concentrations at all Monitoring Sites: Year 2005

Parameter	PM_{10}				$PM_{2.5}$			
Season	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Husky	Concentrations (µg/m^3)							
BCRail	0.015	0.015	0.014	0.011	0.009	0.009	0.008	0.006
Gladstone	0.012	0.012	0.011	0.009	0.008	0.007	0.006	0.005
Glenview	0.015	0.009	0.016	0.017	0.009	0.005	0.009	0.010
Plaza	0.029	0.022	0.025	0.023	0.018	0.013	0.015	0.014
Van Bien	0.021	0.016	0.017	0.015	0.013	0.009	0.010	0.009
Lakewood	0.022	0.010	0.017	0.018	0.014	0.006	0.010	0.011
NorthWood	Concentrations (µg/m^3)							
BCRail	0.277	0.245	0.231	0.206	0.230	0.189	0.183	0.172
Gladstone	0.243	0.223	0.198	0.179	0.200	0.172	0.158	0.149
Glenview	0.287	0.251	0.286	0.282	0.233	0.191	0.228	0.231
Plaza	0.467	0.432	0.395	0.352	0.376	0.328	0.310	0.288
Van Bien	0.349	0.304	0.285	0.257	0.282	0.231	0.225	0.212
Lakewood	0.346	0.275	0.290	0.283	0.277	0.207	0.233	0.233
PGpulp	Concentrations (µg/m^3)							
BCRail	0.327	0.336	0.319	0.235	0.297	0.299	0.287	0.216
Gladstone	0.257	0.258	0.241	0.186	0.234	0.230	0.218	0.172
Glenview	0.276	0.173	0.253	0.270	0.252	0.155	0.232	0.247
Plaza	0.323	0.274	0.309	0.304	0.301	0.245	0.281	0.280
Van Bien	0.297	0.291	0.312	0.282	0.273	0.259	0.283	0.262
Lakewood	0.273	0.158	0.264	0.274	0.255	0.142	0.246	0.255
InterCon	Concentrations (µg/m^3)							
BCRail	0.185	0.196	0.179	0.130	0.175	0.182	0.167	0.124
Gladstone	0.147	0.150	0.136	0.103	0.138	0.139	0.127	0.098
Glenview	0.159	0.101	0.157	0.165	0.150	0.094	0.148	0.156
Plaza	0.238	0.202	0.226	0.211	0.227	0.188	0.212	0.200
Van Bien	0.217	0.189	0.200	0.182	0.205	0.174	0.189	0.173
Lakewood	0.208	0.105	0.178	0.184	0.199	0.097	0.170	0.175

NOTE:
Secondary PM and Background Contributions Not Included.

6.4.1.8 Overall Conclusions

The predicted PM_{10} and $PM_{2.5}$ concentrations are dominated by the dust emission sources, especially those attributable to on-road vehicles. For the downtown area, the predicted concentrations attributed to restaurant emissions ranked high. While producing high concentrations locally, the permitted users' emissions do not appear to contribute substantially to predicted PM_{10} and $PM_{2.5}$ concentrations over the remainder of the airshed.

These conclusions may differ had fugitive dust emissions from industrial yards and storage piles been included in the dispersion modelling. As well, condensable PM emissions were not always available, perhaps leading to an under prediction in permitted users' contributions and secondary particulate matter formation. The restaurant contributions are probably high, since the same emission factors were applied to all Prince George "Food and Dining" outlets. The same may be true for the on-road $PM_{2.5}$ predictions, since the U.S. EPA emission factors may be non-applicable for vehicle activity on the City of Prince George low silt traction material.

6.4.2 Airshed Results

Airshed PM_{10} and $PM_{2.5}$ patterns are presented by mapping the predicted values at all domain receptors (Figure 2.1) as isopleths of equal concentrations. This is done for the annual averaged, the 20 highest days, and four seasonal intervals. The maps depict the predicted concentrations including those from background sources and secondary particulate formations.

The predicted values for the receptors close to the airshed maximums have to be treated with caution. Receptors on top or very close to emission objects can result in unrealistically high results. Dispersion modelling methodologies normally call for a buffer between the receptors and the SEUs. In this study the SEUs cover most of the airshed, so a buffering approach is not practical. As an alternative, the predicted values for all receptors were screened. In total, four receptors identified by their quantities as obvious outliers were removed from an array of 1,873 receptors (0.2%).

In this section isopleth maps depicting predicted PM_{10} and $PM_{2.5}$ concentrations for each of three years are presented, highlighting areas in excess of the BC Ambient Air Quality Objectives (AAQO). This is done for the annual averaged results (Appendix A: Figures 6:14 to 6.19), the 20 highest days (Appendix A: Figures 6:20 and 6.21), and seasonally for PM_{10} (Appendix A: Figures 6:22 to 6.25), and $PM_{2.5}$ (Appendix A: Figures 6:26 to 6.29).

6.4.2.1 Annual Averaged Results

Isopleth maps depicting PM_{10} and $PM_{2.5}$ concentration isopleths for each of years 2003, 2004 and 2005 are shown as Figures 6.14 to 6.19. Figures 6.15, 6.17 and 6.19 show the predicted $PM_{!0}$ concentrations from years 2003, 2004 and 2005 respectively. There is no BC PM_{10} AAQO for the annual averaging interval, and hence no exceedances possible. Figures 6.14, 6.16 and 6.18 show the predicted $PM_{2.5}$ concentrations from years 2003, 2004 and 2005 respectively.

Areas in which exceedences of the BC $PM_{2.5}$ AAQO for the annual averaging interval (8 $\mu g/m^3$) lie within the yellow contours (Table 6.14). These figures indicate that a substantial part of the bowl area and industrial regions have predicted concentrations in excess of the objective. There is some variation from year to year, but the pattern is largely consistent.

The Plaza monitoring site results indicate that a combination of on-road dust, permitted users, locomotive and restaurant emissions are primary contributors in the bowl area. In the BC Rail area locomotives and permitted users are primary contributors. The Gladstone monitoring site results suggest that the maxima over College Heights are attributable largely to on-road dust and permitted user sources. The maxima over the Hart Highlands are similarly attributable to dust, permitted user and residential heating sources.

Table 6.14: British Columbia 24-hour and Annual Ambient Air Quality Objectives

BC Ambient Air Quality Objective	Contaminant	
	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
24 hour	50	25[1]
annual	- -	8
annual (planned)	- -	6

NOTE:
[1] The 24-hour $PM_{2.5}$ AAQO is referenced to the 98^{th} percentile value (8^{th} highest daily value)

6.4.2.2 Twenty Highest Days

For the year 2005, the days with the 20 highest predicted PM_{10} concentrations at the Plaza site were averaged and plotted. Similarly, the predicted $PM_{2.5}$ concentrations for those same days were also averaged and plotted.

Figure 6.20 depicts isopleths of PM_{10}. The pink contour depicts the areas where concentrations are in excess of the BC 24-hour Level-B AAQO for PM_{10}. (50 $\mu g/m^3$). Since the AAQO is applicable to a single day, and this figure depicts the average of 20 days, the comparison is not wholly appropriate. However it does indicate areas where there is a high probability of predicted concentrations exceeding the AAQO on the worst days (e.g. the bowl area).

Figure 6.21 depicts isopleths of $PM_{2.5}$. The blue contour depicts the areas where concentrations are in excess of the BC 24-hour $PM_{2.5}$ AAQO (8 $\mu g/m^3$). The AAQO is applicable to a single day, and is referenced to the 98^{th} percentile value. This figure depicts the average of 20 days. Therefore the comparison is not wholly appropriate. However, Figure 6.21 does indicate areas (e.g. the bowl area) where there is a high probability of predicted concentrations exceeding the AAQO on the worst days.

6.4.2.3 Seasonal Variations

For the three-year study period, averaged seasonal PM_{10} airshed predictions are shown in Figures 6.22 to 6.25; averaged seasonal PM_{10} airshed predictions are shown in Figures 6.26 to 6.29. Seasons are approximated by three-month averages: January to March (winter); April to June (spring); July to September (summer); and October to December (autumn). There is not a great amount of seasonal variation. The predicted seasonal average concentrations are generally higher in the winter and lower in the summer months. This is likely a function of limited dispersion in winter.

Temporal variations of the source categories, combined with the meteorological effects, also play a role in determining these patterns. Permitted user emissions are constant but probably cause higher concentrations in winter due to the limited dispersion. Dust emissions are highest in the summer due to greater activity and less suppression by precipitation. Residential and commercial heating are highest in the winter.

7 TEST OF PG AIR $PM_{2.5}$ EMISSION REDUCTION TARGETS

Isopleth maps showing airshed patterns needed for meeting the PG AIR emission targets (Goal 1 and Goal 2), considering background, were produced. This was done by mapping predicted values that have been reduced following the target reductions at all receptors in the domain (Figure 2.1) as isopleths of equal concentrations. This is done for the annual averaging interval. The maps depict the predicted concentrations including the background and secondary particulate contributions.

Source apportionment by dispersion modelling assumes that there are linear relationships between the emissions from a source and the concentrations at a receptor point. The secondary transformation model is an exception. However the secondary particulates form a small part of the total predictions and that source's variance to the linear relationship can be ignored. If a goal is a certain percent reduction in concentrations at a receptor point, the reduction exercise would require the same percent reduction in the source emissions that affect that receptor point.

The following $PM_{2.5}$ reduction targets have been adopted by PG AIR:

- Goal 1: by December 31, 2013 the proposed BC $PM_{2.5}$ objectives are to be adhered to:
  - a) 24-hr concentration averages not to exceed 25 µg/m^3
  - b) annual averaged concentrations not to exceed 8 µg/m^3
  - c) continuous improvement target to 6 µg/m^3 annual average concentrations.
- Goal 2: by December 31, 2016:
  - d) 40% reduction on all significant emission sources
  - e) annual averaged $PM_{2.5}$ concentrations of 5 µg/m^3.

The PG AIR $PM_{2.5}$ emission reduction targets to be tested are

- Goal 1a: the contribution to the airshed concentrations for each major source category to be reduced by 40%
- Goal1b: the contribution to the airshed concentrations for the top 25 permitted users sources to be reduced by 40%.
- Goal 2a: the percentage reduction required to achieve the 2016 target.

7.1 Goal 1: PG AIR Emission 2013 Scenario

7.1.1 Part a)

Using the year 2005 predicted concentrations, the annual airshed emissions for all the major source categories were reduced by 40% by discounting all predicted values by 40%. The predicted $PM_{2.5}$

results are shown in Figure 6.30 (in Appendix A) with the yellow contour depicting the area in concentrations are in excess of the BC AAQO (8 $\mu g/m^3$). When compared to Figure 6.18 the areas in exceedance have decreased somewhat, but not eliminated completely. This means that the 40% reduction on all significant sources, envisioned to be achieved by 2016 will not achieve the 2013 goals.

Note that the predicted $PM_{2.5}$ concentrations at the monitoring sites can be determined by reducing all concentrations listed in the monitoring site results tables (Section 6.4.1) by approximately 40%.

7.1.2 Part b)

The top 25 permitted users' emissions for year-2005 were determined by their annual averaged $PM_{2.5}$ emission rate rankings (Table 6.15). These highest emitters usually have a combination of high peak rates and full facility operations. For year-2005, the emissions from these top 25 emitters were reduced by 40%. The results are shown in Figure 6.31. The yellow contours identifying areas where concentrations are in exceedance of the BC $PM_{2.5}$ AAQO. When compared to Figure 6.18, the exceedance areas have decreased somewhat. However, except for the immediate areas surrounding the Husky and pulp mill locations, the decrease is not considered to be substantial.

Table 6.15: Top 25 Highest $PM_{2.5}$ Emission Units after Adjusting for Operating Hours

Rank	Permit No.	Facility	Equipment Unit	$PM_{2.5}$ (g/s)
1	2761	PG Pulp	Power Boiler Stack #1	5.718
2	2559	NorthWood Pulp	Recovery Boiler Stack #1	5.471
3	2762	Intercon Pulp	Incinerator Stack	4.680
4	2559	NorthWood Pulp	Power Boiler #4	3.928
5	2761	PG Pulp	Incinerator Stack	3.830
6	2761	PG Pulp	Recovery Boiler Stack #1	2.565
7	2559	NorthWood Pulp	Smelt Stack #5	2.482
8	2761	PG Pulp	CoGeneration Power Stack #1	1.931
9	2559	NorthWood Pulp	Power Boiler #2	1.905
10	2559	NorthWood Pulp	Smelt Stack #1	1.658
11	2761	PG Pulp	Lime kiln Stack	1.578
12	2559	NorthWood Pulp	Recovery Boiler Stack #5	1.537
13	2761	PG Pulp	Dissolving Smelt Tank Stack #1	1.528
14	2762	Intercon Pulp	Combined Power and Recovery Boiler stack	1.331
15	2559	NorthWood Pulp	Incinerator Stack	1.070
16	2559	NorthWood Pulp	Incinerator Stack	1.070
17	2762	Intercon Pulp	Dissolving Smelt Tank Stack	1.066
18	2762	Intercon Pulp	Rotary Lime kiln CaCO3 stack	0.906
19	13405	Pacific Bioenergy	Cyclone	0.800
20	1778	Dollar Saver (Site 2)	Konus Kessel Energy System	0.635
21	1796	Winton Global	VOLCANO Heat Recovery	0.454
22	1787	Rustad Bros Canfor	Konus Kessel Heat System #2	0.388

Table 6.15: Top 25 Highest $PM_{2.5}$ Emission Units after Adjusting for Operating Hours (cont'd)

Rank	Permit No.	Facility	Equipment Unit	$PM_{2.5}$ (g/s)
23	13405	Pacific Bioenergy	Gas-fired Drum Dryer	0.350
24	2065	Husky Refinery	FCC Regenerator	0.336
25	6505	Woodland Windows	Wood Waste Boiler Stack	0.320

7.2 PG Air Emission 2016 Target

7.2.1 Part a)

The predicted annual averaged $PM_{2.5}$ concentrations are shown in Figures 6.14, 6.16 and 6.18 (Appendix A) for years 2003, 2004, and 2005 respectively. The isopleths show a high variability throughout the airshed. A $PM_{2.5}$ maxima of approximately 20 $\mu g/m^3$ persistently appears over the bowl area (between the Plaza, Lakewood and Van Bien monitoring sites). These sites report $PM_{2.5}$ annual averaged values close to 11 $\mu g/m^3$ (Lakewood & Van Bien, 2005). This modelling result suggests that $PM_{2.5}$ concentrations to the northeast could be higher than at Lakewood and Van Bien monitoring stations.

With the modelled predictions as a reference level, it is apparent that about a 75% reduction in all major source categories will be needed to lower all airshed $PM_{2.5}$ annual concentrations to the annual 5 $\mu g/m^3$ target set out by PG AIR. If the Lakewood and Van Bien measured values are used as a reference level, then a 55% reduction would be required.

Perhaps a 65% reduction is a more realistic target. The concentrations that can be expected by imposing a 65% reduction of all sources can be determined by reducing all concentrations found in the monitoring site results tables (Section 6.4.1) by 65%.

Alternatives to an 'across the board 'reduction target may achieve more cost effective reductions. For example, the on-road dust sources are proven to be a strong contributor to PM_{10} and $PM_{2.5}$ concentrations. These sources may be candidates for larger reductions, and potentially at a lower cost compared to reduction other source categories.

8 RECOMMENDATIONS

In this section preliminary recommendations are made on which category and individual sources should be prioritized for emission reduction (based on predictions, not considering background). These recommendations set out which categories or sources could (rather than should) be prioritized for emission reductions. The recommendations are based on the model results. Other factors such as technology, health impacts and cost-benefits, may be considered by PG AIR when finally prioritizing sources for reduction in their Phase III Air Quality Management Plan.

8.1 Airshed Management

The following recommendations for airshed management are listed below and are followed by further discussion. These recommendations are based on model results only.

- For all Prince George areas, methods should be developed to inhibit or suppress on-road dust emissions with greater efficiency.
- Permitted users are encouraged to continue to improve their particulate matter emission reduction efforts.
- Some of the bowl area restaurants should be identified as candidates for emissions reductions through greater emissions controls.
- The locomotives operating to/from and within the CNR Southyard should be identified as candidates for reductions by replacement with more efficient units.
- Background values of particulate matter and particulate matter precursors along with their temporal and meteorologically influenced variations should be established.
- PG AIR should continue to update and enhance the micro-emissions inventory.
- An air-quality forecasting program should be developed.

On-road dust: On-road dust emissions could be reduced by implementing a more aggressive road cleaning program. Other options include re-routing major highways and truck routes around the Prince George urban areas and lowering speed limits during the winter dry periods when surface lying road-traction materials are at their densest.

Permitted users: While reductions in this sub-source category are apparent only in close proximity to the sources continued improvement in permitted particulate matter emissions are important. As improvements become feasible or necessary, reductions should be pursued.

Restaurants: Although the predicted concentrations from the restaurant sources are probably conservative, these emissions sources should be investigated and mitigation measures for the heavier emitters developed.

Locomotives: Locomotive emissions from the Southyard would decrease if the locomotives working at and travelling to/from Southyard work at lower throttle settings. Since the locomotive emissions from Southyard affect the downtown area more than the emissions from the other yards, CNR should deploy their more efficient switchers there. CNR should be encouraged to purchase the more emissions efficient locomotives (Tier-2, Green Goat, etc.) for train yard activities.

Background: The requirement for a monitoring station dedicated to airshed background concentration determinations should be identified. If a dedicated monitoring station is not possible, then a mobile unit should be obtained and a background study conducted.

MEI Management: The micro-emissions inventory is valid for year 2005, and could already be out of date. Continuous management through enhancement and updating is required if the MEI will remain effective as an airshed management tool. VOC emissions information should be included in the MEI as the methodology to determine aerosol condensations from VOCs is constantly improving.

Air Quality Forecasts: Currently, air quality studies are made with recent, but sometimes dated, emissions data and historical meteorological data and not in real time. However a forward looking predictive system is possible. Since the daily and annual averages are skewed by episodic events, an air quality predictive system could identify the probability of episodic favorable conditions one to two days in advance. With these scenarios, calls for voluntary emission reductions from both industry and residents may help mitigate the episode levels.

PG AIR $PM_{2.5}$ Emission Reduction Targets: This study should be used to revisit the Goals set by PG AIR. Further investigations and monitoring could be driven by checking for achievement of the new goals.

8.2 Further Investigations

This study has identified gaps between measured and predicted PM_{10} and $PM_{2.5}$ levels at all the monitoring site locations. These gaps are small and within the expected uncertainty of the emissions estimation and dispersion methodologies. They could however be reduced by further investigations. The following activities are recommended, in order of importance:

- The Commercial Restaurant sub source category should be revisited, and re-modelled.
- Sub groups modelled as area sources may be revisited and remodelled.
- The size distribution of on-road silt (dust) between PM_{10} and $PM_{2.5}$ should be measured precisely and re-modelling completed, if the new data warrants it.
- The data necessary to model fugitive emissions from the industrial and commercial parking lots should be formulated.
- Commercial, Residential and Open Burning sources now spatially merged should be modelled independently.
- The role of secondary PM formation within the airshed should be studied through a refined aerosol emissions study.

- Road dust area sources may be separated into smaller areas.
- A suitably qualified full-time researcher should be hired and dedicated to coordinating future work, and to conduct any future investigations, such as an episode analyses study of the dispersion modelling results.

9 CONCLUSIONS

9.1 Monitoring Site Findings

The predicted PM_{10} and $PM_{2.5}$ concentrations are dominated by the dust source emissions, especially the dust emissions induced by on-road vehicle activities. While producing higher concentrations nearby, the emissions from the industrial-permitted operations do not appear to contribute to the PM_{10} and $PM_{2.5}$ levels substantially over the remainder of the airshed. If fugitive emissions originating from the industrial yards and storage piles could be modelled, or the condensable PM emissions could be estimated, these findings may require revision. For the downtown area, the predicted PM_{10} and $PM_{2.5}$ concentrations from restaurant emissions rank high, however the predictions are likely overestimates (conservative). For all areas the $PM_{2.5}$ predictions from on-road dust are expected to be conservative.

9.2 Airshed Findings

The airshed concentration patterns show that PM_{10} and $PM_{2.5}$ maxima are found over the bowl area and the heavy industrial areas north of the Nechako and BCR areas. These areas do not appear to suitable candidate regions for more commercial and industrial activity-related emissions. Areas further from the city are less affected.

9.3 Reduction Requirements

If the year-2013 and year-2016 levels targets are to be met over the entire airshed, deep cuts in all emissions may be necessary. The reductions needed to reach the year 2016 target may be as much as 65% or more.

10 REFERENCES

B.C. MOE, 2006: Wind Sector Analysis – Update to June 2004 Progress Report Prepared by the Prince George Air Quality Implementation Committee, 8 pp. [Available online at http://cirrus.unbc.ca/pgarwg/docs/BCMOE-Wind-Sector-Progress-Report-Update-2006-01-12.doc.]

B.C. Stats, 2007: Summary of Smoking Rates for BC, April 2006 through March 2007. [Available online at http://www.bcstats.gov.bc.ca/data/ssa/reports/tobacco/smokingstats_20062007.pdf]

Dunn, R., 2001: Diesel Fuel Quality and Locomotive Emissions in Canada. Pub. No. 13783E, Transport Canada, Transportation Development Centre, Montreal, QC, 18 pp. [Available online at http://www.tc.gc.ca/tdc/publication/pdf/13700/13783e.pdf]

Environment Canada, 2002: Environment Canada's Criteria Air Contaminant Emissions Inventory 2002 Guidebook

Environment Canada, 1995: Memorandum of Understanding between Environment Canada and the Railway Association of Canada. [Available online at http://www.ec.gc.ca/cleanair-airpur/CAOL/transport/publications/railwaymou/railwaymou.htm.]

EPA, 2006: Paved Roads/ [Available online at http://www.epa.gov/ttn/chief/ap42 /ch13/final/c13s0201_2006.pdf]

EPA, 1998: National Air Pollutant Emission Trends, Procedures Document, 1900-1996: Top 25 Emitting Point, Area, and On-road Sources of PM-10 and VOC Emissions in 1996 by MSAs. EPA-454/R-98-008, U.S. Environmental Protection Agency, Research Triangle Park, NC, 712 pp. [Available online at http://www.epa.gov/ttn/chief/trends/procedures/trends_procedures_old.pdf.]

Fudge, 2010: Adjusting TEOM $PM_{2.5}$ Values to Account for the Under-Estimated Values During Winter Season. Extended Abstract 2010-A-708-AWMA, submitted for presentation at 2010 AWMA Annual Convention and Exhibition, Calgary, Alberta.

Fudge, D., and D. Sutherland, 2010: Comments Respecting the Use of Hightower Background (2.4) in PG AIR Memorandum "PG AIR and MOE Revisions for Final Dispersion Model Report". March 19, 2010.

Fudge, D., and D. Sutherland, 2004: Estimating Pollution Contribution in Prince George through Wind Sector Analysis. [Available from B.C. Ministry of Environment, Omenica Region, Prince George, B.C.]

Fudge, D., 2005: B.C. Ministry of Environment (Prince George) 1995 Micro-emission inventory comprised of an Excel spreadsheet and supporting document**.**

Graham, M., and D. Sutherland, 2004: Description of Study for Identifying the most Significant Contributions to Ambient Fine Particulate (PM2.5) in Prince George, B.C. British Columbia Ministry of Water, Land and Air Protection, Environmental Protection Program, 14 pp.

[Available online at http://cirrus.unbc.ca/pgarwg/docs/MWLAP-PG-PM-speciation-study-outline-2004-11-30.doc

Jackson, P., and J. Spagnol, 2006: Air Quality Issues in Prince George: PowerPoint presentation. [Available online at http://cirrus.unbc.ca/pgarwg/docs/Jackson-Spagnol-PACHA-AQ-issues-in-PG-2006-06-12.pdf.]

Jackson, P., Grafton, W., deHogg, N., Fisher, D., 2009: Wood Burning Appliance Use & Emissions Inventory for Prince George, BC.

Levelton Consultants, 2004: Calmet Modeling for the Williams Lake Airshed. Prepared for B.C. Ministry of Environment. [Available from Earle Plain, MOE Cariboo Region, Williams Lake, B.C].

PG AIR, 2010: PG AIR and MOE Revisions for Final Dispersion Model Report, Memorandum provided to Stantec Consultants by Daniela Fisher, Prince George Air Improvement Roundtable, March 19, 2010. 44 pp.

Plain, E., 2001: Inventory of Common Air Contaminants Emitted in the Quesnel Airshed (2000). [Available from Earle Plain, MOE Cariboo Region, Williams Lake, B.C.]

Plain, E., 2004: Airshed Dispersion Modeling Project for Quesnel B.C. [Available from Earle Plain, MOE Cariboo Region, Williams Lake, B.C.]

Plain, E., 2004: Fine Particulate Source Apportionment for the Quesnel Airshed Using Results from a CALPUFF Modeling Exercise. [Available from Earle Plain, MOE Cariboo Region, Williams Lake, B.C.]

Roe, S., 2003: Methods for Developing a National Emission Inventory for Commercial Cooking Processes. Tech. Memo. for Emission Factor and Inventory Group, U.S. EPA, Research Triangle Park, NC. E.H. Pechan & Associates, El Dorado, CA, 32 pp. [Available online at http://www.epa.gov/ttn/chief/eiip/techreport/volume03/charbroilingtechmemo_122303.pdf.]

Sonoma Technology Inc., 2008: Source Apportionment of $PM_{2.5}$ in Prince George, British Columbia.[Available from Mark Graham, BC MOE]

Spagnol, J., Jackson, P., Fudge, D., 2009: Prince George Air Quality Research Modeling Study. [Available from Peter Jackson, UNBC]

Transport Canada, 2005: Transportation and the Environment. [Available online at http://www.tc.gc.ca/pol/en/Report/anre2005/5_e.htm.]

Weinsten, N., 2005: 2001 and 2002 Inventory of Particulate Matter Emissions for the Bulkley Valley – Lakes District Airshed. [Available from MOE-Skeena Region, Smithers, B.C.]