CALPUFF MODELLING
FOR THE
WILLIAMS LAKE AIRSHED

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND TERMS

$\mu g/m^3$	micrograms (of contaminant) per cubic metre of air
agl	above ground level
asl	above mean sea level
CAC	Criteria Air Contaminants
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CWS	Canadian Wide Standards
d	day
DEM	Digital Elevation Model
E	east direction
EC	Environment Canada
EPA	Environmental Protection Agency
g	gram
g/s	grams per second
h	hour
H_2S	hydrogen sulphide
ISC	Industrial Source Complex
K	temperature in Kelvin
km	kilometre
kPa(g)	pressure in units of thousands of Pascals above 101.3 kPa
L	litre
m	metre
m/sec	metres/second
m^3/sec	cubic metres per second
mg	milligram
mm	millimetre
MM5	Mesoscale Model 5
MSC	Meteorological Service of Canada
N	north direction

NO_3	nitrate
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen reported as NO_2
NTS	National Topographic Series
^{o}C	degrees Celsius
^{o}F	degrees Fahrenheit
Pa	pascal
PDF	Adobe Acrobat Format of document
PM	Particulate Matter
PM_{10}	Particulate Matter with an aerodynamic diameter less than or equal to 10microns
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter less than or equal to 2.5microns
RH	relative humidity
s	second
S	south direction
SO_2	sulphur dioxide
SO_4	sulphate
SO_x	sulphur oxides
t	metric tonne
t/y	tonnes/year
TPM	Total Particulate Matter
TSP	total suspended particulate
U	horizontal wind speed (m/s)
US EPA	United States Environmental Protection Agency
US	United States
UTM	Universal Transverse Mercator co-ordinates
VOC	volatile organic compounds, excluding methane and ethane
W	west direction
MOE	Ministry of Environment
yr	year

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1. INTRODUCTION

The Ministry of Environment (MOE) Cariboo Region identified air quality dispersion modelling as one of their tools to assist in management of pollutants in the Williams Lake airshed. Levelton Consultants Ltd. (Levelton) was retained by the MOE to assist the ministry in producing the modelling platform capable of modelling various pollutants from all emission sources in the airshed (permitted, commercial, mobile, and residential).

There are many benefits to using an air quality model for planning. For example, the model could help manage sources in the region to help determine the effects of reducing/increasing emissions on ambient air quality. Forecasts and backcasts can be made to determine trends in air quality over time, and sources can be apportioned to determine the most cost beneficial method to improve air quality in the airshed. The platform can be used for future modelling work as new industrial projects are proposed for the airshed, or as the community emissions change in size, spatially, or temporally.

The CALPUFF model was identified as the primary modelling tool to be used to establish the modelling platform. It contains the most advanced algorithms to address the terrain and meteorology of the area and was used to estimate the concentrations of pollutants in the Williams Lake airshed resulting from current emissions in the region. The dispersion of emissions from point, area, and mobile sources was simulated for a year (Jun 2003-2004) to establish the baseline. CALMET has been previously generated and is described in the report “CALMET Modelling for the Williams Lake Airshed” (Levelton 2004). The baseline modelling was then compared with ambient monitoring data in the airshed to determine sources of error and the model accuracy. The relative contributions of sources to air quality episodes establish a basis to identify which sources may be a priority to manage in the airshed.

The following sections provide a description of the methodologies used, the meteorological data, the emissions data, and a detailed analysis of predicted pollutant concentrations modelled by CALPUFF. The report also provides conclusions and some recommendations for future work.

2. METHODOLOGY

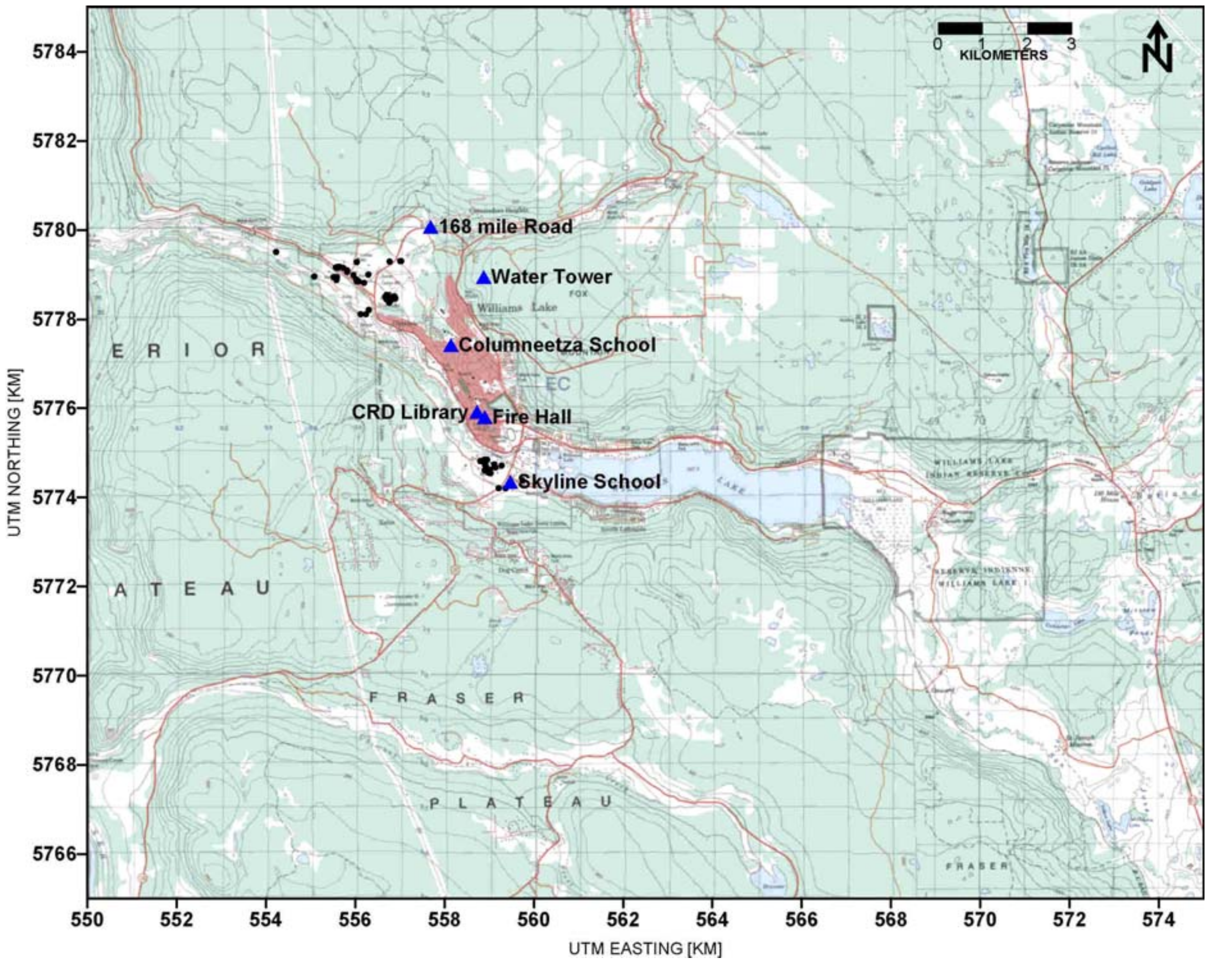
2.1 INTRODUCTION

The City of Williams Lake is located in the central Cariboo region of British Columbia, 240 km south of Prince George. The elevation at Williams Lake airport is 940 m above sea level, and the topography is dominated by the Fraser River Valley running north to south.

The airshed boundaries in this study are defined by UTM grid coordinates 550000 to 575000 metres Easting and 5761000 to 5789000 metres Northing, encompassing a 25 x 28 km rectangle area. An airshed can be defined as the volume of air that is affected by the emissions from a particular source, or group of sources. The modelling domain boundaries are defined by the map of the Williams Lake region in Figure 2-1. The map also shows the locations of industrial sources (represented by black dots) and air quality monitors (identified by red rectangles) used in the comparison with the model.

The primary tool used in the airshed modelling was the numerical dispersion model CALPUFF. CALPUFF is in fact a suite of numerical models (CALMET, CALPUFF, and CALPOST) that are used in series to determine the predicted pollution concentrations in an airshed. CALMET is a diagnostic computer model that can produce detailed three-dimensional fields of meteorological parameters based on surface and upper air measurements, digital land use data, and terrain data. The three-dimensional fields produced by CALMET are used by CALPUFF to calculate the dispersion of emissions over distances of a few metres to hundreds of kilometres. CALPOST, the third and final program, is a statistical processing program used to summarize and tabulate the concentrations calculated by CALPUFF.

The ambient concentrations that were predicted by the dispersion model were compared with the ambient air quality objectives and guidelines. A review of the guidelines is provided below, followed by the methodologies used in the CALPUFF model.



Note: Skyline, CRD Library, and Columneetza are continuous monitors (marked with red dots in the results plots .(Appendix B))

Figure 2-1 Map of the Williams Lake Airshed

3. AMBIENT AIR QUALITY GUIDELINES

This section is a review of air quality criteria regulated provincially and federally that are applicable to the Williams Lake Airshed. In Canada, the federal and provincial governments have issued ambient air quality objectives to ensure long-term protection of public health and the environment. Federal and provincial committees have established national ambient air quality objectives for the modelled contaminants in the Williams Lake Airshed. These include carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and particulate matter, including total suspended particulate matter (TSP), particulate matter less than 10 microns (PM_{10}) and particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). For Canada, up to three objective values have been recommended using the categories "desirable", "acceptable", and "tolerable". In B.C., Ambient Air Quality Objectives have been established and are the same or more stringent than the federal desirable objective. The general intent of the federal objectives is described in Table 3-1.

The current provincial and federal air quality objectives for NO_2, CO, SO_2, TSP and PM_{10} are shown in Table 3-2. B.C. has established ambient air quality guidelines that are designed to protect human health and the environment. These guidelines were compared against the predicted concentrations for the Williams Lake Airshed. Canada-wide Standards were also used to compare $PM_{2.5}$ and PM_{10} concentrations.

Table 3-1 Descriptions of the Federal Ambient Air Quality Objectives

Jurisdiction	Objective Description*	
Federal	Maximum Desirable (most stringent)	Long-term goal for air quality. Provides a basis for anti-degradation policy for unpolluted parts of the country and for continuing development of control technology.
	Maximum Acceptable	Provides adequate protection against adverse effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well being.
	Maximum Tolerable (least stringent)	Indicates appropriate abatement strategies required without delay to avoid further deterioration to air quality to protect the health of the general population.
B.C.	Level A (most stringent)	Provides long-term environmental protection. Required for new and proposed discharges and, within the limits of the best practicable technology, to existing discharges by planned staged improvements for these operations.
	Level B	Provides adequate protection against adverse effects on human health, vegetation and animals. Usually set as an intermediate objective for all existing discharges to reach within a specified time period, and as an immediate objective for existing discharges which may be increased in quantity or altered in quality as a result of process expansion or modification.
	Level C (least stringent)	Appropriate action is necessary to protect the health of the general population.

* ECO-LOG Canadian Pollution Legislation.

The definition of the Canada-wide Standards (CWS) corresponds to “the Canada-Wide Environmental Standards Sub-Agreement” and are a framework for federal, provincial, and territorial Environment Ministers to work together to address key environmental protection and health risk reduction issues that require common environmental standards across the country. Once the Ministers priorities for designated environmental contaminants or issue are established, jurisdictions work together to develop the appropriate type of standard.

Canada-wide Standards are guidelines for provincial jurisdictions, and hence do not represent official British Columbia standards. The process to establish a level has involved the participation of a variety of groups including industry, municipalities, environmental and aboriginal groups. Compliance with the CWS is based on monitoring data from Canadian communities with a population of more than 100,000 as a practical implementation target. As part of the agreement, jurisdictions are required to develop implementation plans to achieve the standards by 2010 by establishing and maintaining monitoring networks, producing air quality management plans and tracking progress (CCME, 2000).

The $PM_{2.5}$ standard is 30 µg/m^3 on a 24-hour average period, annual 98th percentile and averaged over three consecutive years. The *Science Assessment Document* (CEPA 1998) that supported the CWS $PM_{2.5}$ standard development identified Levels for both $PM_{2.5}$ and PM_{10}, which are intended to represent “estimates of the lowest ambient PM level at which statistically significant increases in health responses can be detected based on available data and current technology” (CEPA 1998). Recognizing that there is no apparent lower effects threshold for $PM_{2.5}$ and that the long-term goal should be to minimize the risks of these pollutants to human health and the environment, the CWS also contains provisions for continuous improvement (CI) and keeping clean areas clean (KCAC).

The lowest observable effects level for PM_{10} is 25 µg/m^3 averaged over 24 hours, and for $PM_{2.5}$ it is 15 µg/m^3 averaged over 24 hours.

Table 3-2 Ambient Air Quality Guidelines and Objectives for Main Air Contaminants

Parameter	British Columbia Objective		National Ambient Air Quality Objective	
	Level A *	Level B*	Maximum** Desirable	Maximum** Acceptable
	µg/m^3 (ppm)	µg/m^3 (ppm)	µg/m^3 (ppm)	µg/m^3 (ppm)
Nitrogen Dioxide				
1-hour Maximum	–	–	–	400 (0.21)
24-hour Maximum	–	–	–	200 (0.11)
Annual Mean	–	–	60 (0.03)	100 (0.05)
Carbon Monoxide				
1-hour Maximum	14,300 (12.4)	28,000 (24.28)	15,000 (13.0)	35,000 (30.0)
8-hour Maximum	5,500 (4.77)	11,000 (9.54)	6,000 (5.0)	15,000 (13.0)
Sulphur Dioxide				
1-hour Maximum	450 (0.17)	900 (0.34)	450 (0.17)	900 (0.34)
24-hour Maximum	160 (0.06)	260 (0.10)	150 (0.06)	300 (0.11)
Annual Mean	25 (0.01)	50 (0.02)	30 (0.01)	60 (0.02)
TSP				
24-hour Maximum	150	200	–	120
Annual Mean	60	70	60	70
PM_{10}				
24-hour Maximum		50	–	–
Annual Mean			–	–

* Concentrations given in micrograms per cubic metre at 20^{o}C, 760 mm Hg, dry basis, and, in parentheses, ppm by volume.

** Concentrations given in micrograms per cubic metre at 25^{o}C, 101 kPa, dry basis, and, in parentheses, ppm by volume.

Source: B.C. Ministry of Water, Land, and Air Protection

CALPUFF Model Input Data

CALPUFF is a three-dimensional, multi-species non-steady-state puff type Gaussian dispersion model that can simulate the effects of time- and space-varying meteorological conditions on emission transport, transformation, and removal. CALPUFF is designed to simulate the dispersion of emissions based on the three-dimensional diagnostic meteorological fields produced by CALMET. The statistical processing program CALPOST processes the binary output file produced by CALPUFF.

The CALPUFF model involves far more complicated and comprehensive simulation processes compared to the conventional steady-state, single-layer and single-species models, such as the US EPA Industrial Source Complex (ISC3) model. Expanded capabilities include non-steady-state effects (spatial in-homogeneity, causality, fumigation, etc.), complex terrain algorithms, calm and low wind speed conditions, flexible source variability options, chemical transformation, and differential advection and dispersion.

3.1.1 Modelling Domain and Grid Selection

The CALPUFF modelling domain encompasses a 25 by 28 kilometer area. Within the selected CALPUFF modelling domain, a nested grid of receptors was created with the following spatial distribution (Figure 3-1):

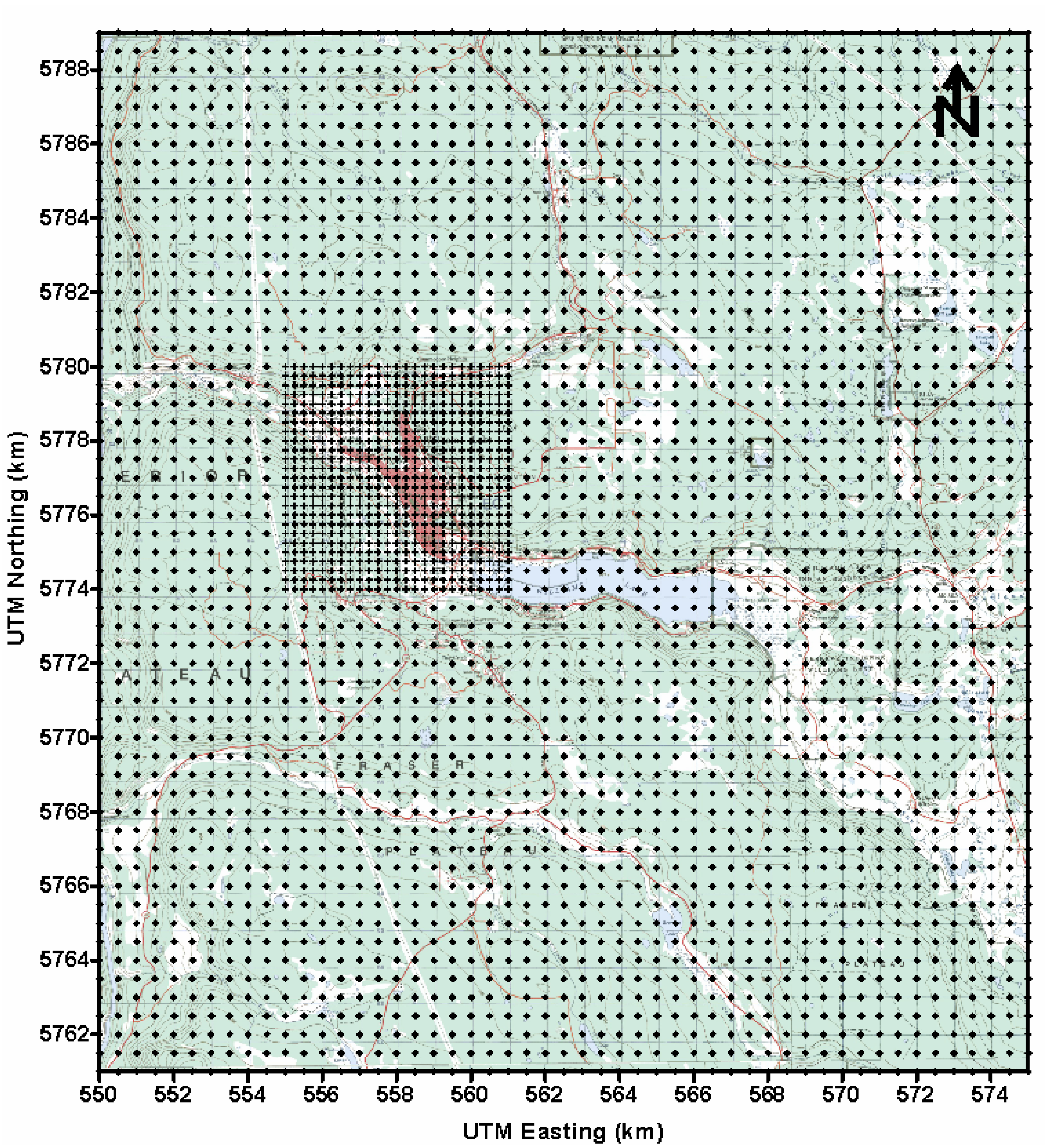
- 250-metre spacing in a 6 x 6 km area encompassing downtown Williams Lake;
- and an outer 500-metre spacing grid up to the edge of the modeling domain

Discrete receptors were also located at the ambient monitoring locations (Table 3-3) within the Williams Lake airshed, so that ambient air quality measured at these stations could be compared with modelled results:

Table 3-3 Ambient air quality monitoring stations

Air Quality Monitoring Station	UTM Easting (meters)	UTM Northing (meters)
168 Mile Road	557694.7	5780076.4
Water Tower	557881.6	5778949.1
Columneetza School	558138.6	5777424.0
CRD Library	558725.9	5775915
Fire Hall	558902.5	5775804.3
Skyline School	559470.8	5774354.9

Each receptor represents a point for which ambient concentrations are calculated. There are a total of 3361 discrete receptors within the CALPUFF domain. The same digital terrain files that were used to extract the CALMET grid cell elevations were used to generate the receptors for the CALPUFF grid (elevations in meters above sea level).



Note: Five discrete receptors for ambient monitoring stations not shown on map can be found in FIGURE 2-1

Figure 3-1 Map of Discrete Receptors used in the CALPUFF Model

3.1.2 CALPUFF Model Options

Table 3-4 gives a summary of the technical options used in the CALPUFF model for the Williams Lake Airshed modelling. Unless stated otherwise in the Table, the model options that were used follow the default regulatory options that are currently recommended by the U.S. EPA.

Table 3-4 Model Options Used in CALPUFF

Parameter	Option Selected	U.S. EPA Default
Terrain Adjustment Method	Partial Plume Path Adjustment	√
Transitional Plume Rise	Modelled	√
Stack Tip Downwash	Modelled	√
Vertical Wind Shear above Stack Top	Not modelled	√
Chemical Mechanism	MESOPUFF II	√
Wet Removal	Not Modelled	
Dry Deposition	Not Modelled	
Method Used to Compute Dispersion Coefficients	Pasquill-Gifford Coefficients for Rural Areas/McElroy-Pooler Coefficients for Urban Areas	√
Partial Plume Penetration of Elevated Inversion	Modelled	√
Minimum Wind Speed Allowed for Non-Calm Conditions	0.5 m/s	0.5 m/s

As was mentioned previously, the CALPUFF model has the capability to simulate calm periods. Calm periods are defined as those in which the puff transport speed is less than a user-supplied threshold speed (Scire et al., 2000b). In this application, the calm threshold was set to 0.5 m/s because it is the lowest non-zero wind speed that occurs at most of the observational meteorological stations.

3.1.3 Building Downwash Effects

Winds blowing across and around buildings create turbulence, which has a significant effect on the dispersion of airborne pollutants. If emissions are released through short stacks, a plume could potentially be trapped in the turbulent wake of a building by an effect referred to as building downwash. Two effects can result from the dispersion of pollutants within a turbulent wake:

- the increased turbulence disperses the plume more readily than with no building present, and;
- the increased dispersion causes portions of the plume to be forced down to the ground resulting in increased ground-level concentrations with the presence of the building.

The U.S. EPA Building Profile Input Program (BPIP) (U.S. EPA, 1993) was used to develop the wind-direction specific building heights and apparent building widths and to determine the Good Engineering Practice (GEP) stack height associated with each building for the Williams Lake Airshed. (Any stack taller than the GEP height would be unaffected by building wake effects.) The output provided by BPIP for point sources with significant buildings nearby was used as input to CALPUFF.

Building dimensions for buildings located near the point sources (used as input into BPIP) were derived from GPS measurements, and were simplified to right angled-buildings where necessary for modelling purposes.

4. AIRSHED EMISSIONS

Pollutant emission data was compiled for all point, mobile and area sources in the Williams Lake Airshed, and provided by MOE on a tonnes per year basis. Point sources include all of the sources that can be traced to a single, fixed emission point such as a smokestack. Mobile sources include sources that emit from multiple points that are not fixed in space such as vehicles, trains, and planes. Area sources include large sources or groups of point sources such as agricultural fields, forests, or gravel pits.

4.1 POINT SOURCES

Table A1 lists the point source locations and stack parameters for the 14 permitted industrial facilities within the Williams Lake airshed that were modelled. There were 71 point sources modelled in total. The UTM locations for the point sources were supplied by MOE. These locations were supplied to MOE by the facilities or obtained by MOE from GPS measurements taken on-site.

The elevations for each of the point sources were extracted from the nearest UTM coordinates (NAD 83) in the B.C. TRIM digital elevation data. In general, stack heights, stack diameters, exit velocities and stack temperatures were all provided by MOE via their permit database or supplied by the facilities. Emission rates in grams/second were calculated from the airshed emission inventory and/or if available, the air-permit for the source.

Emission rates were derived based on known operating conditions. A brief description of assumptions for operating times is provided in Table 4-1.

Dry kilns are hard to classify because emissions are based on humidity levels in each kiln. As a humidity level is reached, a series of roof vents open and close to maintain the desired level. The temperature and flow rates of the dryer were known, but this was not sufficient to classify the source. On average, dry kilns are approximately 8m high to the roof peak. These vents are approximately 24" x 24" and are spaced roughly 10 feet apart. Buildings vary slightly in size but are generally 36m x 9m. Therefore, all kilns utilized these assumptions in combination with the respective flow rates to parameterize a point source for the facility. For dry kilns where no exit velocity was known, a velocity of 10m/s was assumed.

Table 4-1 Williams Lake Airshed point sources

Permit Number	Site Name	Equipment	Operating Time
1548	West Fraser Mills	Planer Chip Cyclone	Monday – Friday 700 – 2400
		9" Sawmill Dust Cyclone	
		Planer Shavings & Mill Dust Cyclone	
		Chipper Cyclone	
		14" Sawmill Dust Cyclone	
		2 Sawdust & Shavings Cyclones - 1	
		2 Sawdust & Shavings Cyclones - 2	
		Three Lumber Dry Kilns - 1	24/7
		Three Lumber Dry Kilns - 2	
		Three Lumber Dry Kilns - 3	
1764	Weldwood of Canada	#1 Hog Boiler	24/7
		#2 Hog Boiler	Monday – Saturday (700-2400)
		Wet ESP on Dryer stacks	
		Hog Cyclone	
		Fuel Bin Baghouse	
		99" Saw Cyclone	24/7
		#3 Compressor Stacker Cyclone	Monday – Friday 700 - 1700
		#1 & #2 Composer Chipper Cyclone	
		#3 Composer Chipper Cyclone	
		Plywood Sander Baghouse	
		T & G Cyclone	24/7
2484	Riverside (Soda Creek)	Three Cyclones - 1 6	Monday - Friday 700 – 2400
		Three Cyclones - 2 7	
		Three Cyclones - 3 8	
		Nat Gas Lumber Dry Kiln	Monday - Saturday 700 – 2400
		Four Lumber Dry Kilns - 1	
		Four Lumber Dry Kilns - 2	
		Four Lumber Dry Kilns - 3	
		Four Lumber Dry Kilns - 4	

Table 2-4. (Cont.) Williams Lake Airshed point sources

Permit Number	Site Name	Equipment	Operating Time
3283	Riverside (West)	Nine Cyclones - 1	24/7
		Nine Cyclones - 2	
		Nine Cyclones - 3	
		Nine Cyclones - 4	
		Nine Cyclones - 5	
		Nine Cyclones - 6	
		Nine Cyclones - 7	
		Nine Cyclones - 8	
		Nine Cyclones - 9	
		Salton Hot Oil Energy Recovery	
		Two Hot Oil Lumber Dry Kilns - 1	
		Two Hot Oil Lumber Dry Kilns - 2	
		Natural Gas Lumber Dry Kiln	
		Hot Oil/ Nat Gas Lumber Dry Kiln	
		Planer Baghouse	Monday – Friday 24hr / day
		Chip Plant Baghouse	Monday – Friday 24hr / day
3679	Riverside (East)	Four Nat Gas Lumber Dry Kilns - 1	24/7
		Four Nat Gas Lumber Dry Kilns - 2	
		Four Nat Gas Lumber Dry Kilns - 3	
		Four Nat Gas Lumber Dry Kilns - 4	
		Kiln #5	
		Three Cyclones - 1 5	Monday – Friday 24hr /day
		Three Cyclones - 2 6	
		Three Cyclones - 3 7	

Table 2-4. (Cont.)   Williams Lake Airshed point sources

Permit Number	Site Name	Equipment	Operating Time
3849	Gene's Paving	Asphalt Batch Plant Stack	Monday-Friday (June-Sept.) (730 – 930)
7842	Ever-Redi Concrete	Concrete Batch Plant Silo	Monday-Friday (May-June) (800 – 1000)
8796	Parallel Wood Products	Sawdust Collection Cyclone	Sunday – Friday (1530-1530)
		Chip Collection Cyclone	
8808	NW Energy	Wood Waste Fuelled Boiler	24/7
10984	Jackpine Forest Products	Cyclone	Monday – Friday (700-1300)
		Nat Gas Lumber Dry Kiln	24/7
12259	Pal Lumber	Two Cyclones - 1	Monday – Friday (700 – 1530)
		Two Cyclones - 2	
12992	Williams Lake Cedar	Chip Bin Cyclone	Monday and Thursday 20hr per day Friday (0600-1630)
		Planer Cyclone	
		Two Nat Gas Dry Kilns - 1	24/7
		Two Nat Gas Dry Kilns - 2	
16134	Jackpine Engineered Wood	Chipper Cyclone 1	Monday – Friday (700 – 1530)
		Sawdust Cyclone 4	
		Planer Cyclone 2	
		Moulder Cyclone 3	
17557	Pinnacle Pellet WL	Baghouse	24/7

Table A2 lists the point sources with the calculated emission rates (in g/s) for CO, NOx, SOx, VOC, TSP, PM_{10}, and $PM_{2.5}$. These emission rates were calculated from the annual emission rate, and adjusted for those sources that did not run continuously throughout the year as outlined above. For example, a point source with an annual emission rate of 35t/yr would have an emission rate of 1.11 g/s if the source runs 24 hours a day, 7 days a week. For a different point source with an annual emission rate of 35 t/yr that only runs 5 days per week (260 days/yr), the emission rate would be 1.56 g/s.

4.2 AREA AND MOBILE SOURCES

Area and mobile sources include all other identified sources of emissions in that they do not require an industrial permit. In order to model these sources, emission sources were grouped together based on the location and manner in which they emit. Area and Mobile sources are modelled by classifying an area over which the emissions occur.

Table A3 lists the modelled area sources with their initial parameters. The sources from the inventory that are included in each area are also listed in the Table. Initial sigma-z is a parameter that identifies the initial vertical dispersion that the source has. For example, biogenic emissions are emitted from plants and trees and would not have an initial dispersion, while vehicle emissions would have dispersion from the wake of the vehicle and exhaust. The base elevations were extracted from the centre of the "area source" using the B.C. Trim digital elevation data. Each of the areas modelled in the Table are presented in Figure 4-1 and Figure 4-2.

For marine sources (Figure 4-2), base elevations were taken from the lake water levels (assumed to be equal to lakeshore elevations). Emissions from Marine were modelled for six months of the year, from May to October. Land clearing burning emissions were modelled from January – May and from September – December. Emissions from gravel pits and Land mowers were modelled for spring/summer/fall – 11 hr per day basis. Woodstove emissions were modelled for January – May and from September – December – on a 24hr/7days a week basis, these emissions were also varied diurnally using scaling factors (Table A4).

Road dust was modelled for two separate categories, paved and unpaved roads. Paved and unpaved roads within the Williams Lake Airshed were identified by MOE and are identified in Figure 4-3. The emissions were varied diurnally using scaling factors derived based on traffic data provided by MOE (Table A5). No dust emissions were assumed for January for paved roads and for the months of December and January for unpaved roads.

During the spring time, road dust emissions will be higher from paved roads as material that is placed on the roads during the winter is exposed. Although road dust may occur from unpaved roads during the rest of the year, the amount would be significantly less than the spring time.

The area sources were allocated based on land use data maps, telephone and address directories (to determine extent of commercial sources), and consultation with MOE. The CALPUFF model used a trapezoidal figure to parameterize each area.

Table A6 lists the area sources and their constant emission rates in $g/m^2/s$. The amount of emissions per metre squared of area was determined based on the emission inventory. Inventory emissions in tonnes/year were divided over the area for the emitting period to calculate a rate in $g/m^2/s$.

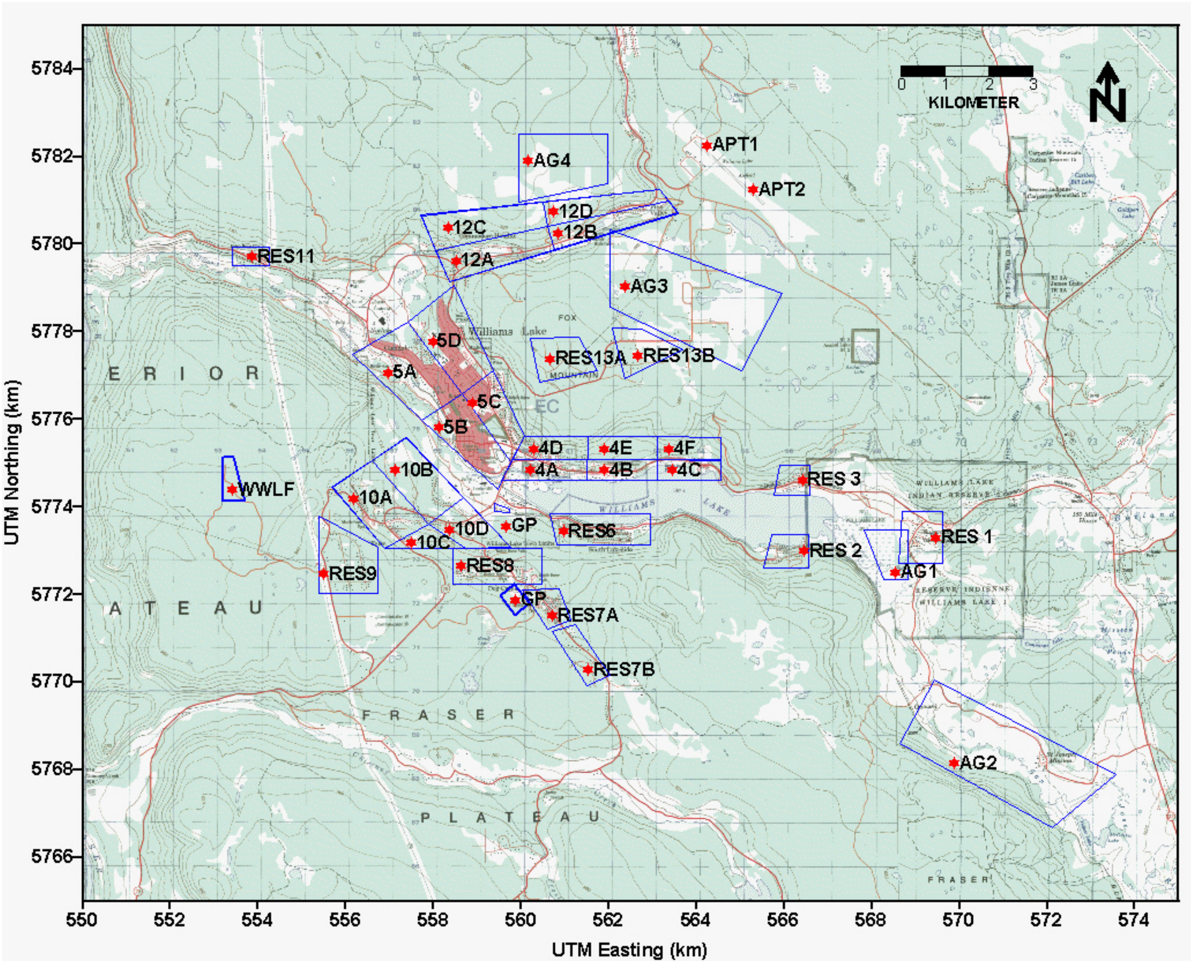


Figure 4-1 Williams Lake airshed modelled area sources (Residential, Landfill, Gravel pit, Agricultural and Airport).

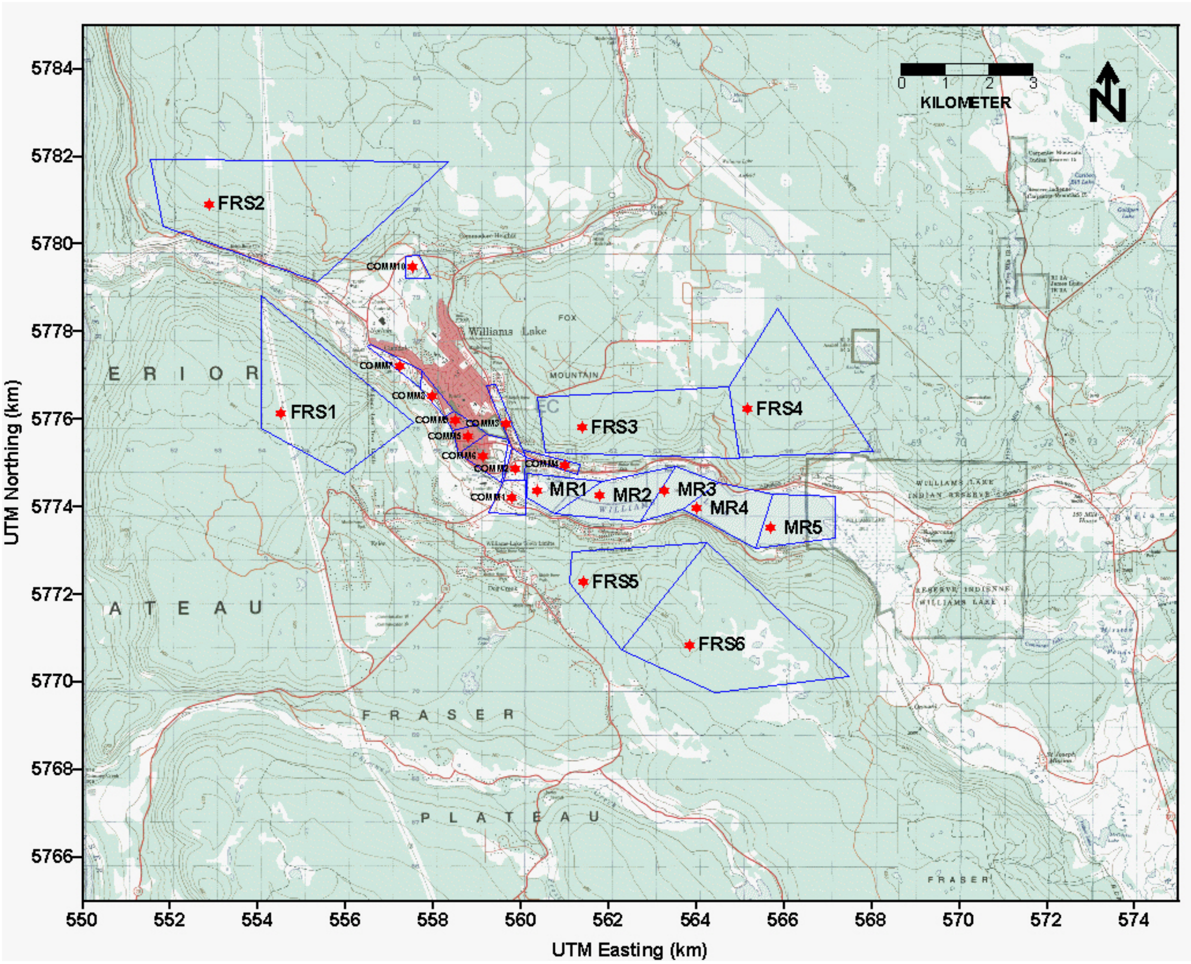


Figure 4-2 Williams Lake airshed modelled area sources (Forest, Commercial and Marine).

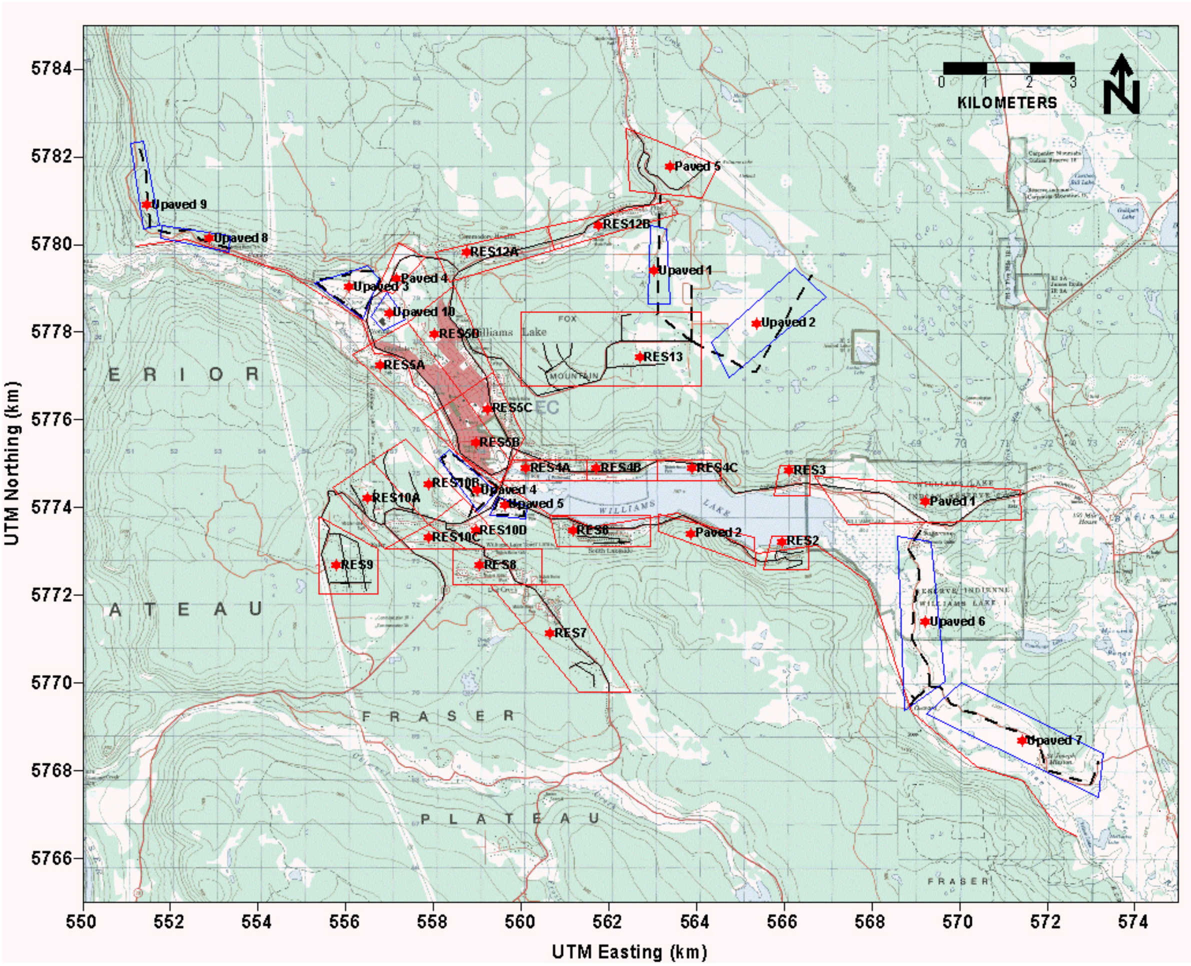


Figure 4-3 Williams Lake airshed modelled Area sources - (Mobile sources, Road Dust – paved (red) and unpaved (blue)

5. MODELLING RESULTS

5.1 MAXIMUM PREDICTED CONCENTRATIONS

The maximum predicted concentrations for each of the modelled pollutants are displayed in the following sub-sections. The figures that show the spatial distribution of concentrations and frequencies above applicable guidelines are presented in Appendix B. Each section contains a brief discussion of meteorological conditions that led to the maximum concentrations. It should be noted that the set of receptors that was used to predict concentrations did not take into account whether a particular receptor was located within private property or within a facility boundary. Therefore, the maximums should not be construed as absolute or be associated with any possible regulatory implications. The maximums represent a potential spatial distribution in the airshed, and the potential predicted maximum even if it is within a facility boundary or particular area source.

5.1.1 Carbon Monoxide (CO)

The maximum predicted concentrations of CO are presented in Table 5-1. The maximum predicted 1-hour concentration was 10863 $\mu g/m^3$ at 559.75 E, 5779.75 N. The maximum predicted concentration was 76% of the Level A Objective. The maximum occurred when the wind speed was 1 m/s winds from the south-east. Figure B-1 shows the maximum predicted 1-hour concentrations of CO for the Williams Lake Airshed. The highest concentrations occurred to the northwest of the city center.

The maximum predicted 8-hour concentration of CO was 4325 $\mu g/m^3$. The maximum predicted concentration was 79% of the Level A Objective. Figure B-2 shows the maximum predicted 8-hour concentrations of CO.

Table 5-1 Maximum Predicted CO Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Maximum Predicted Concentration [$\mu g/m^3$]	Ambient Guideline [$\mu g/m^3$]	Location UTM (E,N)
1-hour	10863	14300	559.75, 5779.75
8-hour	4325	5500	559.75, 5779.75

5.1.2 Sulphur Dioxide (SO_2)

The maximum predicted concentrations of SO_2 are presented in Table 5-2. The maximum predicted 1-hour concentration was 1481.2 $\mu g/m^3$ at 554.50E, 5779.50N. The maximum occurred north-west of Williams Lake near the Asphalt batch plant. Figure B-3 shows the maximum predicted 1-hour concentrations of SO_2 for the Williams Lake Airshed.

The maximum predicted 24-hour and annual average concentration of SO_2 was 63.83 $\mu g/m^3$ and 3.0 $\mu g/m^3$. The maximum predicted 1-hour ground-level concentrations exceed the air quality standard in a small area at the NW of Williams Lake. Figure B-4 shows the predicted frequency of exceeding the Level A Objective. Figure B-5 and Figure B-6 show the maximum predicted 24-hour and annual concentrations of SO_2.

Table 5-2 Maximum Predicted SO_2 Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Maximum Predicted Concentration [$\mu g/m^3$]	Ambient Guideline [$\mu g/m^3$]	Location UTM (E,N)
1-hour	1481.2	450.0	544.50, 5779.50
24-hour	63.8	160.0	554.50, 5779.50
Annual	3.0	25.0	559.75, 5774.00

5.1.3 Nitrogen Dioxide (NO_2)

As there are no existing objectives for ambient NO_x concentrations, a method is needed in order to convert NO_X concentrations predicted by the models to equivalent NO_2 concentrations. The Ozone Limiting Method (OLM), which has been adopted by MOE in the past was utilised. The method is outlined below:

If the ambient ozone concentration is greater than 90% of the maximum NO_X concentration, total conversion of NO_X to NO_2 is assumed.

If the ambient ozone concentration is less than 90% of the maximum NO_X concentration, the formation of NO_2 is limited by the ozone concentration, in which case the NO_2 concentration is set equal to the ozone concentration plus a correction factor accounting for in-stack or near-stack thermal conversion using the following equation:

$$[NO_2]_{max} = [O_3]_{ambient} + 0.1[NO_X]_{max}$$

The results are presented in this section for both the ozone limiting method predictions and assuming 100% conversion of NO_X to NO_2.

The maximum predicted concentrations of NO_2 are presented in Table 5-3. The predictions are based on 100% conversion of NO_x to NO_2 and also based on the Ozone Limiting Method (assuming 100 $\mu g/m^3$ ozone concentration as a conservative estimate). The maximum predicted 1-hour concentration was 2905 $\mu g/m^3$ assuming 100% conversion and 390.5 $\mu g/m^3$ using ozone limiting. The maximums occurred under stable conditions when the wind speed was less than 1 m/s from the south-east. Figure B-7 shows the maximum predicted 1-hour concentrations of NO_2 for the Williams Lake Airshed. The Level A objective was not exceeded.

The maximum predicted 24-hour average concentration of NO_2 was 377.1 $\mu g/m^3$ assuming 100% conversion (137.7 when ozone limited). Figure B-8 shows the maximum predicted 24-

hour concentrations of NO_x. The maximum predicted annual average concentration of NO_2 was 58.0 $\mu g/m^3$. Figure B-9 shows the annual average concentrations of NO_2.

Table 5-3 Maximum Predicted NO_2 Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Max. Predicted Concentration (100% Conversion) [$\mu g/m^3$]	Max. Predicted Concentration (Ozone Limiting) [$\mu g/m^3$]	Ambient Guideline [$\mu g/m^3$]	Location UTM (E,N)
1-hour	2905	390.5	400.0	559.00, 5774.75
24-hour	377.1	137.7	200.0	555.50, 5779.00
Annual	58.0	58.0	100.0	559.50, 5779.50

5.1.4 Volatile Organic Compounds (VOC)

The maximum predicted concentrations of VOCs are presented in Table 5-4. The maximum predicted 1-hour concentration was 1783 $\mu g/m^3$ at 559.00E, 5774.75N. The maximum occurred under calm to light (0.7 m/s) winds. Figure B-10 shows the maximum predicted 1-hour concentrations of VOCs for the Williams Lake Airshed. The highest concentrations occurred where biogenic and mobile emissions are more prevalent. As there are many sources of VOCs, concentrations are spread throughout the entire airshed. The maximum predicted 24-hour concentration of VOC was 432.4 $\mu g/m^3$. The maximum occurred under a light wind day when winds were from the south-east.

Table 5-4 Maximum Predicted VOC Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Maximum Predicted Concentration [$\mu g/m^3$]	Location UTM (E,N)
1-hour	1783.2	559.00, 5774.75
24-hour	432.4	558.00, 5777.50

5.1.5 Particulate Matter 10 Microns or less (PM_{10})

The maximum predicted concentrations of PM_{10} are presented in Table 5-5. Figure B-11 shows the 24-hour maximum predicted concentrations (including road dust) and Figure B-12 shows the annual average concentrations of PM_{10} (including road dust). Figure B-13 shows the 24-hour maximum predicted concentrations (excluding road dust) and Figure B-14 shows the annual average concentrations of PM_{10} (excluding road dust). The maximum predicted 24-hour concentration (not including road dust) was 561.4 $\mu g/m^3$. The maximums occurred under a sustained period of winds less than 1 m/s from variable directions. The maximum predicted annual average PM_{10} concentration (not including road dust) was 132.2 $\mu g/m^3$. The maximum annual concentrations were predicted in a very small area near the point sources at the south end and north end of town.

Table 5-5 Maximum Predicted PM_{10} Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Max. Predicted Concentration (No Road Dust) [$\mu g/m^3$]	Location UTM (E,N)	Max. Predicted Concentration (With Road Dust) [$\mu g/m^3$]	Ambient Guideline [$\mu g/m^3$]
24-hour	561.4	559.0, 5774.75	566.4	50
Annual	132.2	559.0, 5774.75	137.5	-

Frequency plots for PM_{10} excluding road dust are given in Figure B-15 and Figure B-16. Figure B-15 represents the frequency above the Level A Objective and Figure B-16 represents the frequency of PM_{10} concentrations over 25 $\mu g/m^3$.Frequency plots for PM_{10} excluding road dust are given in Figure B-17 and Figure B-18. Figure B-17 represents the frequency above the Level A Objective and Figure B-18 represents the frequency of PM_{10} concentrations over 25 $\mu g/m^3$. Predictions were above the Level A objective near the south and north end of town where point sources are prevalent for a significant amount of the time. The rest of the airshed predicted significantly lower frequencies.

5.1.6 Particulate Matter 2.5 Microns or less ($PM_{2.5}$)

The maximum predicted concentrations of $PM_{2.5}$ are presented in Table 5-6. The maximum predicted 24-hour concentration (not including road dust) was 285.3 $\mu g/m^3$. The maximum predicted annual average concentration of $PM_{2.5}$ (not including road dust) was 67.7 $\mu g/m^3$. The maximums occurred when winds averaged 1 m/s from the southeast. Figure B-19 shows the maximum predicted 24-hour concentrations of $PM_{2.5}$ (including road dust) for the Williams Lake Airshed. Figure B-20 shows the annual average concentrations of $PM_{2.5}$ (including road dust). The annual concentration was predicted above the guideline in a very small area of town. Figure B-21 and Figure B-22 show the 24-hour and the average $PM_{2.5}$ concentrations, respectively, with road dust not included.

Figure B-23 Figure B-24 Figure B-25 and Figure B-26 display the frequency of predicted concentrations. Figure B-23 and Figure B-25 present predictions above 30 $\mu g/m^3$ (for road dust included and excluded respectively). (Note that this does not necessarily constitute an exceedance of the CWS). Figure B-24 and Figure B-26 show predictions over 15 $\mu g/m^3$ (for road dust included and excluded respectively).

Table 5-6 Maximum Predicted $PM_{2.5}$ Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Max. Predicted Concentration (No Road Dust) [μg/m^3]	Location UTM (E,N)	Max. Predicted Concentration (With Road Dust) [μg/m^3]	Ambient Guideline [μg/m^3]
24-hour	285.3	559.00, 5774.75	287.4	30
Annual	67.7	556.75, 5778.5	71.3	-

5.1.7 Secondary Particulate Matter (SPM)

The maximum predicted concentrations of SPM are presented in Table 5-7. The maximum predicted 24-hour concentration was 51.2 μg/m^3. Figure B-27 shows the maximum predicted 24-hour concentrations of SPM for the Williams Lake Airshed. The maximum predicted annual average concentration of SPM was 6.0 μg/m^3. Figure B-28 shows the annual average concentrations of SPM.

Table 5-7 Maximum Predicted SPM Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Max. Predicted Concentration (No Road Dust) [μg/m^3]	Location UTM (E,N)
NO_3 24-hour	51.2	556.00,5779.00
NO_3 Annual	6.0	555.75, 5779.25
SO_4 24-hour	0.9	554.50, 5779.50
SO_4 Annual	0.02	559.75, 5774.00

5.1.8 $PM_{2.5}$ and Secondary Particulate

The maximum predicted concentrations of total $PM_{2.5}$ are presented in Table 5-8. The maximum predicted 24-hour concentration was 286.0 μg/m^3. The maximum predicted annual average concentration of total $PM_{2.5}$ was 68.8 μg/m^3, slightly higher than from $PM_{2.5}$ only.

Table 5-8 Maximum Predicted Total $PM_{2.5}$ Ground-Level Concentrations for the Baseline Scenario (including Road dust and SPM)

Averaging Period	Max. Predicted Concentration (No Road Dust) [μg/m^3]	Location UTM (E,N)	Ambient Guideline [μg/m^3]
24-hour	286.0	559.00, 5774.75	286.6
Annual	68.8	559.00, 5774.75	69.0

5.1.9 Total Suspended Particulate (TSP)

The inventory of the Williams Lake airshed includes emissions of TSP. Therefore, for completeness, the maximum predicted concentrations of TSP are supplied in this section. The maximum predicted concentrations of TSP are presented in Table 5-9. The maximum predicted 24-hour concentration was 1425.4 $\mu g/m^3$ (with no road dust) at 559 E, 5774.75 N. Figure B-29 shows the maximum predicted 24-hour concentrations of TSP (including road dust) for the Williams Lake Airshed. Figure B-30 shows the annual average concentrations (including road dust). Figure B-31 and Figure B-32 show the 24-hour and the annual predicted concentrations of TSP not including road dust, respectively.

Table 5-9 Maximum Predicted TSP Ground-Level Concentrations for the Baseline Scenario

Averaging Period	Maximum Predicted Concentration (No road dust) [$\mu g/m^3$]	Maximum Predicted Concentration (With road dust) [$\mu g/m^3$]	Location UTM (E,N)
24-hour	1425.4	1458.3	559, 5774.75
Annual	334.5	359.0	559, 5774.75

Figure B-33 shows the frequency of TSP above the Objective (excluding road dust).

5.1.10 Road Dust

The contribution of road dust emissions to ambient loadings is strongly influenced by meteorological conditions and physical deposition processes. Particulate matter such as road dust disperses similarly to a gaseous pollutant up to a point. Very fine particles behave much like gases, while heavy larger particles will deposit rapidly.

Meteorological conditions play the largest role in road dust dispersion. Precipitation suppresses emissions of road dust by causing it to adhere to road surfaces and by washing it off the surfaces. Precipitation also removes suspended road dust by the process of washout and rainout. Washout is the removal of suspended droplets after they are formed, and rainout is the process of incorporating particles into forming rain droplets as the nuclei on which droplets form.

Figure B-34 and Figure B-35 show the maximum predicted 24-hour and annual average concentrations of PM_{10} from Road Dust. The areas of unpaved roads to the east and west of Williams Lake had the highest impact from road dust. Figure B-36 and Figure B-37 show the maximum predicted 24-hour and annual average concentrations of $PM_{2.5}$ from Road Dust. Similar to the PM_{10}, the areas of unpaved roads had the highest impact from road dust.

6. MODEL PERFORMANCE

As outlined in the Background Air Quality Monitoring Report for Williams Lake (MOE 2002), air quality monitors that are pertinent to the modelled pollutants include 5 air quality monitors. This section provides a comparison of the modelled data with the observed continuous ambient monitoring data of particulate matter within the airshed.

6.1 DATA ANALYSIS

In order to determine how the model predicted for the various averaging periods, the predicted concentrations were compared to the ambient monitoring concentrations using three different approaches. First, results were tabulated, and predicted versus observed data were directly compared.

Secondly, many mathematical operations could be performed on the results, but the dimensionless Mean Square Error (M) performance measure was selected as a primary indicator of performance. This was done because a single number provides an easy comparison of the predicted and observed values. If C_o is the observed concentration, and C_p is the predicted concentration, then M is calculated as

$$M = (\bar{C}_p - \bar{C}_o)^2 / \overline{C_o C_p}$$

where the bars are averages.

This method places a higher weight on extreme values, because the difference in the observed and predicted concentrations (Cpi-Co) is normally highest at highest concentrations. The lower the value of M, the better the model has performed. M was calculated over the top ten observed and predicted values.

The final comparison involved the calculation of the fractional bias at each of the monitoring locations. The fractional bias (FB) is a performance measure used to determine if a model meets the minimum standards for operational performance (US EPA 1992). It is calculated according to:

$$FB = 2\,\frac{(OB-PR)}{(OB+PR)}$$

The fractional bias is calculated twice for each monitoring station. The first time using average values, where OB and PR are equal to the averages of the top twenty-five observed and predicted values, and the second time using standard deviation, where OB is the standard deviation of the highest twenty five observed values, and PR is the standard deviation of the highest twenty five predicted values. The resulting two values are then plotted with bias of average on the x-axis and bias of standard deviation on the y-axis. When used as a screening tool, the range of bias should be between –2.0 (extreme over prediction) and +2.0 (extreme under prediction) as a minimum in model performance. The closer the fractional bias is to the centre of the plot (zero), the fewer tendencies it has towards bias. The US EPA recommends using +/- 0.67 where the fractional bias over/under predicts by a factor of two. Ideally, many meteorological stations and monitoring stations would be used for the calculation, however, in this circumstance only 1-year of meteorological data and 5 monitors are available.

6.2 DIRECT COMPARISON

In general, as an averaging period increases, dispersion models improve in performance. Long-term model results are a good initial indicator of how a model may be performing. Statistics are generally not conducted on the longer term averages unless multiple years can be evaluated. Table 6-1 shows the annual average concentration predicted at each monitor for each pollutant monitored (road dust excluded), as well as the annual average monitored value. The values show whether the model is conservative or not, and how the long-term predictions differ from the monitors. Based on Table 6-1, $PM_{2.5}$ and PM_{10} have similar predicted concentrations to the monitored values. The $PM_{2.5}$ average predicted at the library is lower than the monitor value. For PM_{10} all predicted values are lower than the monitor values. Since the predicted values do not include road dust, this is not unexpected. Figure 6-2 presents the predicted and annual concentrations with road dust included.

Table 6-1 Monitored and Predicted Annual Average Concentrations – Without Road Dust

Pollutant	Value	Concentration [$\mu g/m^3$]		
		Columneetza School [$\mu g/m^3$]	Skyline School [$\mu g/m^3$]	CRD Library [$\mu g/m^3$]
$PM_{2.5}$	Monitor	6.9	6.7	6.1
	Predicted	9.2	9.2	5.1
PM_{10}	Monitor	18.6	28.5	20.2
	Predicted	10.4	16.9	5.8

Table 6-2 Monitored and Predicted Annual Average Concentrations – With Road Dust

Pollutant	Value	Concentration [$\mu g/m^3$]		
		Columneetza School [$\mu g/m^3$]	Skyline School [$\mu g/m^3$]	CRD Library [$\mu g/m^3$]
$PM_{2.5}$	Monitor	6.9	6.7	6.1
	Predicted	14.1	10.5	6.5
PM_{10}	Monitor	18.6	28.5	20.2
	Predicted	26.9	20.4	10.1

6.3 MEAN SQUARE ERROR

Table 6-3 shows the dimensionless Mean Square Error at each monitor location for each parameter for the top ten concentrations for the 1-hour and 24-hour averaging period.

Table 6-3 Mean Square Error of Top Ten Concentrations – Without Road Dust

Pollutant	Averaging Period	Columneetza School [$\mu g/m^3$]	Skyline School [$\mu g/m^3$]	CRD Library [$\mu g/m^3$]
PM_{10}	1-hour	0.22	0.01	0.77
	24-hour	0.19	0.05	1.20
$PM_{2.5}$	1-hour	0.41	1.24	1.65
	24-hour	0.04	0.65	0.01

Table 6-3 shows that the predicted extreme concentrations compare favourably to the measured data for the PM_{10} and $PM_{2.5}$ concentrations. Table 6-4 presents the mean square error when road dust is included.

Table 6-4 Mean Square Error of Top Ten Concentrations – With Road Dust

Pollutant	Averaging Period	Columneetza School [$\mu g/m^3$]	Skyline School [$\mu g/m^3$]	CRD Library [$\mu g/m^3$]
PM_{10}	1-hour	0.07	0.00	0.41
	24-hour	0.23	0.02	0.21
$PM_{2.5}$	1-hour	0.58	1.34	1.77
	24-hour	0.31	0.75	0.86

6.4 FRACTIONAL BIAS

The fractional bias was determined for each monitoring station for the top 25 values. The results were plotted together on a graph for the 1-hour and 24-hour averaging periods. Figure 6-1 and Figure 6-2 show the fractional bias for each period (road dust excluded and included respectively) to give an overall comparison of the model's performance at all monitor locations. The area of the graph with a fractional bias less than +/- 0.67 has been outlined for convenience.

The fractional bias figure shows that the PM_{10} and $PM_{2.5}$ maximum predictions are within US EPA performance protocol. $PM_{2.5}$ values on the 1-hour basis overpredicted. As PM_{10} did not consistently overpredict, the $PM_{2.5}$ speciation of emissions (most $PM_{2.5}$ emission estimates are a percentage of PM_{10}) may be too high.

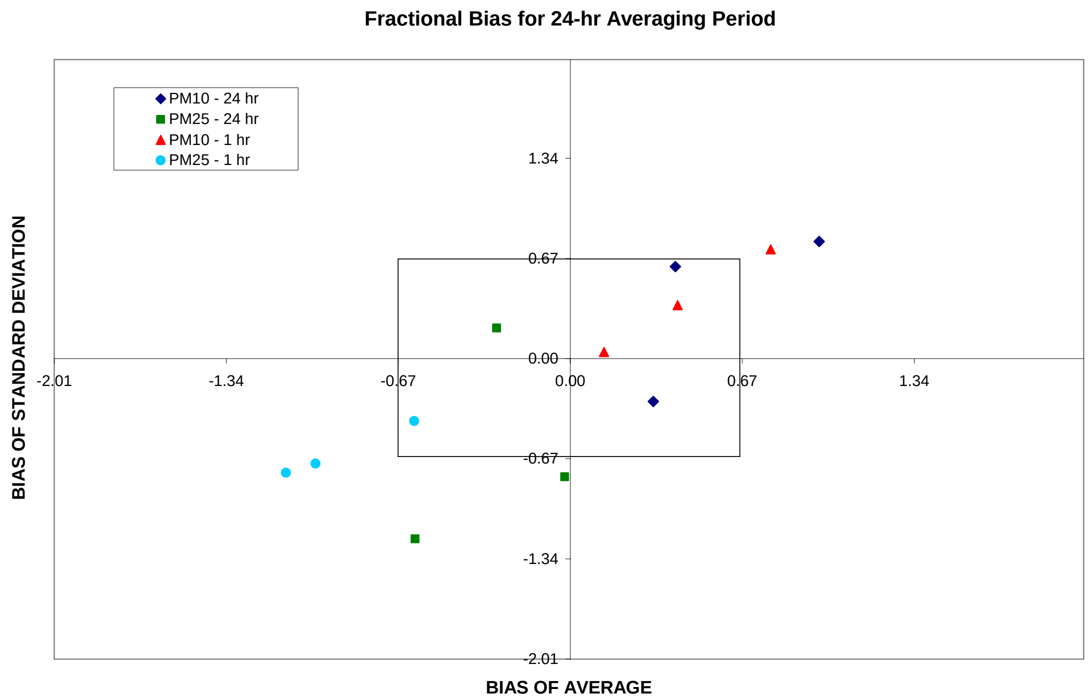


Figure 6-1 Fractional Bias Plot for the 1-hour and 24 hour Averaging Periods – Without Road Dust

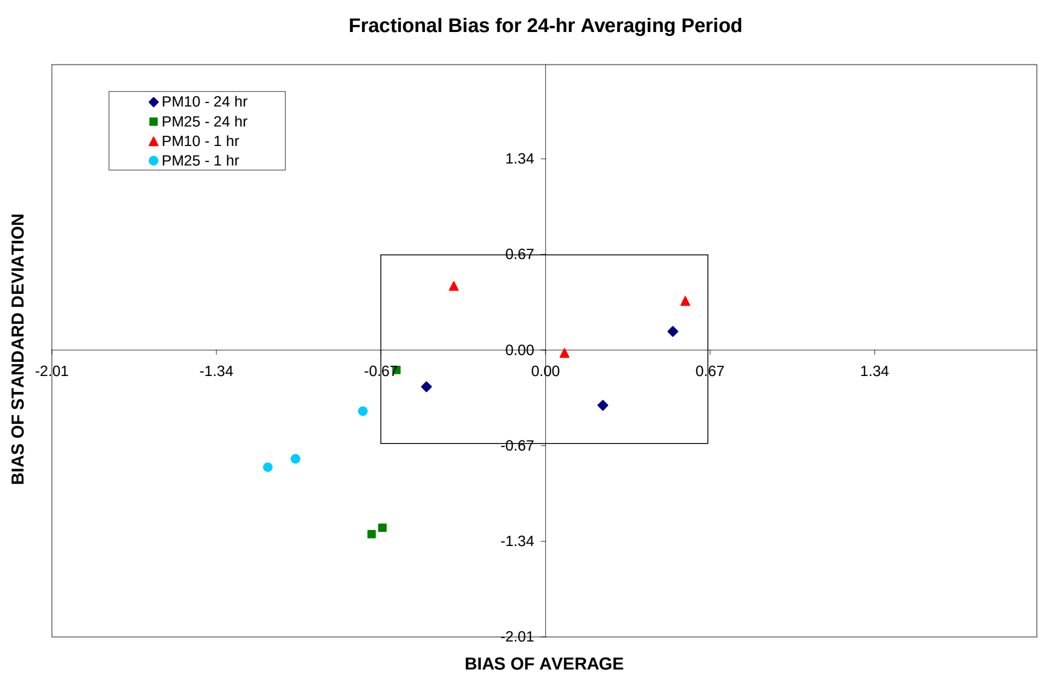


Figure 6-2 Fractional Bias Plot for the 1-hour and 24 hour Averaging Periods – With Road Dust

6.5 EPISODE ANALYSIS

An episode analysis of the modelling results for 2000 was conducted because of the number of exceedences that were predicted for PM_{10} and $PM_{2.5}$. An episode is defined as a period of at least 48-hours where the rolling average PM_{10} concentration is above 50 (A MOE Type 2 Episode) or when $PM_{2.5}$ exceeds 15 for at least 48 hours. In 2003, there were no occurrences of an episode during the modelled year.

7. CONCLUSIONS AND RECOMMENDATIONS

Overall, the CALPUFF model has provided results that are within a reasonable amount of error and can be considered conservative (especially for $PM_{2.5}$). The baseline modelling that has been conducted for this report provides a basis for future airshed management.

Selected sources can be remodelled for various emission parameters and added to the other model results to determine how it may affect the airshed as a whole. Also, sources can be reconfigured or refined to improve absolute model performance. For the modelling of point sources, stack tests and knowledge of the technology used at facilities provides an increased confidence in the model results for those sources.

It is important to note that some of the receptors where the maximum predictions occurred, could be within the plant boundary of an industrial source or near the edge of an area source (i.e. <5m), effecting the validity of the worst-case predictions. It is recommended that a check of receptors to source locations be conducted, specifically for particulate SO_2, and NO_X.

The following conclusions and recommendations are provided for each of the modelled pollutants:

SO_2

Recommendation: it is suggested that the assumed emission rates and source parameters of the Asphalt Batch plant be evaluated for whether it reflects the operating conditions of that plant, and checked against the model run.

June 17th Follow-up: A new emission rate was modelled based on lower tonnes emitted at the plant in 2000, and subsequently, SO_2 concentrations were reduced, but are still highest in the vicinity of the asphalt batch plant. The adapted emission rate is reflected in this report

CO

The modelled CO results are less than of the B.C. Level A Objectives. Therefore, monitoring for CO may not be a priority for the airshed at this time. However, there may be some merit to monitoring CO as it could assist in identifying potential relationships with ambient concentrations of road dust.

NO_X and NO_2

Recommendation: Examining the relationship between NO and NO_2 in the airshed is recommended. Source parameters should be checked. The railway emissions may have been a large contributor of NO_x, and could be re-evaluated for the amount of emissions allocated to the rail yard. In reality the length of railway in the airshed is 25km, and only a fraction of this is by the railyard, meaning the predicted results north of the railyard are likely too conservative.

June 17th Follow-up: Rail emissions were allocated over a larger area to account for the rail lines travelling through Williams Lake, resulting in lower emissions in the vicinity of the railyard. The model results for the baseline show NO_2 concentrations below the Level A objectives when using the ozone limiting method.

VOC – It is difficult to interpret VOC concentrations. If speciation of VOC emissions occurs, then the total model concentrations could be used to apportion the specific VOC of interest.

PM_{10} and $PM_{2.5}$ – source apportionment to the various area sources can be time consuming, but the higher the resolution of areas, the more accurate the model results will likely become. As improved information on speciation of particulate matter becomes available via source testing or EPA, it could be incorporated into the model to improve results. The particulate matter modelling provides a good basis for indicating how the model is performing. It appears that the model does overpredict in the short term (1hour) for extreme concentrations, but provides reasonable results over the annual period.

Recommendation: Further source apportionment of PM results would help identify management options for these pollutants.

June 17th Follow-up: A source apportionment was carried out and is available in the report: "Fine Particulate Source Apportionment or the Williams Lake Airshed Based on Calpuff Modelling" (Levelton, 2005).

Secondary Particulate – The model results do not show high levels of secondary particulate. Sulphate levels were low, while nitrate levels make up the bulk of the SPM. The recommendations outlined for NO_2 would also help to determine how the model performed with SPM.

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