George Massey Tunnel Replacement Project

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BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

Section 16.5

AIR QUALITY STUDY

Technical Volume

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Abbreviations and Acronyms

Term	Description
$\mu g/m^3$	micrograms (of contaminant) per cubic metre
µm	micron or micrometre
AAQO	Ambient Air Quality Objectives
CAC	criteria air contaminants
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
g/km	grams per kilometre
g/VkmT	grams per vehicle kilometre travelled
LFV	Lower Fraser Valley
N_2O	nitrous oxide
NH_3	ammonia
NO	nitric oxide
NOx	nitrogen oxides
O_3	Ozone
PM_{10}	particulate matter having a diameter equal to or smaller than 10 µm
$PM_{2.5}$	particulate matter having a diameter equal to or smaller than 2.5 µm
ppb	parts per billion
SFPR	South Fraser Perimeter Road
SO_2	sulphur dioxide
TAC	toxic air contaminants (also called air toxics)
U.S. EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VkmT	vehicle kilometres travelled
VOC	volatile organic compounds (excluding methane and ethane)

Glossary

Term	Definition
air pollutant	Any pollution agent or combination of such agents, including any physical, chemical, biological, radioactive (including source material, special nuclear material, and by-product material) substance or matter that is emitted into or otherwise enters the ambient air.
ambient air	Outdoor or open air.
annual average daily traffic	Total traffic measured over a one-year period divided by 365.
CALINE	California Line Source dispersion model; a steady-state Gaussian dispersion model designed to determine air pollution concentrations at receptor locations downwind of highways located in relatively uncomplicated terrain.
CALMET	A diagnostic three-dimensional meteorological model, the development of which was originally sponsored by the California Air Resources Board.
criteria air contaminant	A group of seven pollutants that are emitted predominantly into the air, and cause air issues such as smog and acid rain through their presence or interaction between one another. These seven contaminants are total PM, inhalable PM (PM_{10}), fine PM ($PM_{2.5}$), CO, NO_2, SO_2, and VOCs. A brief description of each CAC is provided in this glossary.
emission	The act of releasing or discharging air contaminants into the ambient air from any source.
emission factor	An emission factor is defined as the average emission rate of a given pollutant for a given source, relative to units of activity (e.g., kg of SO_2 emitted per kilometre travelled).
emission inventory	An emission inventory is a comprehensive account of air contaminant emissions and associated data from sources within the inventory area over a specified timeframe, which can be used to determine the effect of emissions on ambient air quality.
heavy-duty vehicle	A motor vehicle that is designed primarily for transportation of heavy goods (includes heavy-duty haul and refuse trucks).
light-duty vehicle	A motor vehicle that is designed primarily for transportation of persons and has a designated seating capacity of not more than 12 persons (includes light-duty gasoline vehicles and light-duty diesel vehicles).

Term	Definition
mesoscale	The scale of meteorological phenomena that range in size from a few kilometres to about 100 km. It includes local winds, thunderstorms, and tornadoes.
nitrogen oxides	Consist of nitric oxide (NO) and nitrogen dioxide (NO_2); reported as the equivalent NO_2.
particulate matter	Any aerosol that is released to the atmosphere in either solid or liquid form.
point source	Major stationary emission sources discharging from a stack.
receptor	A geographic location for which a computer model calculates a value (eg. ambient concentration of a pollutant).
secondary particulate	A contaminant formed by chemical reactions of gaseous contaminants in the air.
sulphur oxides	Gaseous sulphur dioxide (SO_2), for which national and provincial air quality objectives and regulations are in effect. Particulate or aerosol sulphate is excluded from emissions totals and is included under particulate matter. SO_X is reported as SO_2-equivalent.
volatile organic compound	Photochemically reactive hydrocarbons, excluding methane, ethane, acetone, methylene chloride, methyl chloroform, and several chlorinated organics, because of their low reactivity in the atmosphere (definition used by the U.S. EPA).

1.0 Scope of Study

This appendix provides supplemental technical information on the air quality study undertaken to support the assessment of effects of the George Massey Tunnel Replacement Project (the Project) on human health and inform the selection of strategies for mitigating such effects. This appendix describes the contaminants assessed, the applicable objectives and standards, study methods, and study results.

As is typical for most air quality assessments, the study comprised two components: emissions estimates and air quality dispersion modelling. Generally, emissions estimates encompass the identification of potential emission sources associated with a project, determination of the types and magnitudes of air contaminants emanating from project sources, and evaluation of the relative contribution of these emissions on contaminant loading in the project region. Dispersion modelling uses the emissions estimates to provide a prediction of the potential effects a project may have on local air quality in the future.

The B.C. Modelling Guideline, which outlines recommended steps (e.g. development of a conceptual as well as a detailed model plan) for completing modelling projects, was used to guide Project-related air-quality modelling. Metro Vancouver was involved in the model planning discussions from the early stages of model planning, and this consultation helped identify and address some of the issues noted in this assessment. A copy of the detailed modelling plan is provided as **Attachment A**.

2.0 Emission Parameters

2.1 Air Contaminant Characteristics

Vehicles emit CACs and TACs as a result of fossil fuel combustion. While vehicle tailpipe emissions and road dust from vehicle traffic yield air contaminants that affect air quality, the combustion of fuels from construction equipment and process combustion units, such as those in asphalt plants, produce a range of similar gaseous and particulate matter contaminants. Collectively, these contaminants may directly or indirectly act as precursors to the formation of other gases and particles in the atmosphere, which may have potential effects on human health and the environment. The key characteristics associated with these air contaminants resulting from fuel combustion are provided below.

2.1.1 Sulphur Dioxide

Sulphur is present in fossil fuels and is transformed into SO_2, a colourless gas that has a strong odour at elevated concentrations during the process of combustion.

2.1.2 Nitrogen Oxides

Oxides of nitrogen (NO_X) are a mixture of nitrogen dioxide (NO_2) and nitric oxide (NO). High temperature combustion processes typically emit 94 to 97 per cent of the NO_X as NO, with the remaining balance as NO_2. Once emitted, NO reacts with the oxygen in air to form NO_2.

Nitrogen dioxide is an important precursor to ground-level ozone formation that occurs through photochemical reactions involving VOCs. Elevated concentrations of NO_2 produce a brownish gas that is visible in the atmosphere. As the NO_2 reacts in the atmosphere with ammonia, fine particulate salts are formed, which increase $PM_{2.5}$ concentrations and reduce visibility.

2.1.3 Ammonia

Ammonia is a colourless gas that is a product of internal engine combustion, and is also widely used in industry to produce nitrogen-based products such as fertilizers, plastics, and explosives. It is one of the common air contaminants included in regional emissions inventories because of its role in the formation of secondary particulates. Agricultural operations are the major source of ammonia released to the atmosphere.

2.1.4 Carbon Monoxide

Carbon monoxide is a clear, odourless gas that reduces the blood's capacity to carry oxygen to tissues in the body. Carbon monoxide also participates to a minor extent in photochemical smog reactions that lead to increased ground-level ozone formation. Proper design and operation of combustion equipment helps keep CO emission levels and ambient concentrations at low levels.

2.1.5 Particulate Matter

Particulate matter (PM, PM_{10}, $PM_{2.5}$) includes mineral, carbonaceous, and other types of particles, as well as a mix of chemical compounds that may be adsorbed or adhered to particles, depending on the particles' origins. Particulate matter may be a primary contaminant, such as smoke emitted directly into the atmosphere, or a secondary contaminant formed by chemical reactions of gaseous contaminants in the air.

Particles larger than 10 microns are deposited in the human upper respiratory tract and are of less concern than particles equal to or less than 10 microns (PM_{10}) or particles equal to or less than 2.5 microns ($PM_{2.5}$). $PM_{2.5}$ is considered the particulate size range of primary concern for human health impacts, and poses the greatest risk to human health because it can pass through the respiratory system deep within the lungs, leading to increased morbidity and mortality (FPWGAQ 1997).

For vehicles and equipment that burn diesel fuel, the diesel particulate emitted is a complex mixture of particles composed of porous elemental carbon, sulphate, nitrate, and a range of organic compounds that are adsorbed on the surface or within the solid particles. The major organic constituents are hydrocarbons, polycyclic aromatic hydrocarbons, and nitro-polyaromatic hydrocarbons. Typically, 90 per cent of these particles are less than 2.5 microns in diameter. A review by the California Air Resources Board of the literature on the health effects of diesel exhaust concluded that it is carcinogenic (ARB 1998).

Black carbon, present in diesel particulate, is the most strongly light-absorbing component of PM, absorbing solar radiation at all wavelengths. Formed as a product of incomplete fuel combustion, black carbon has a shorter residence time than greenhouse gases in the atmosphere. Since its potential radiative warming effects tend to be localized, any appropriate mitigation measures targeting black carbon can help reduce the rate of climate warming in the short term. Diesel PM also contains other components, such as sulphates, nitrates, and organic carbon, which generally reflect light and may therefore partially offset the climate warming effect of black carbon.

Road dust is made up of airborne particles that are generated by the friction of moving tires on roads. As with other particulate matter, road dust poses potential hazards to human health and the environment.

2.1.6 Volatile Organic Compounds

As defined by Environment Canada, VOCs are gaseous organic compounds, excluding those with negligible photochemical reactivity such as methane and other compounds. Volatile organic compounds are reactive in the atmosphere and can lead to increased formation of ground-level ozone through complex reactions with NO_X in the presence of sunlight. Volatile organic compounds arise from the incomplete combustion of a fuel.

2.1.7 Toxic Air Contaminants

In addition to CACs emitted from fossil-fuel burning vehicles, small amounts of TACs are released, including acetaldehyde, acrolein, benzene, benzo(a)pyrene, 1,3 butadiene, naphthalene, and formaldehyde. These substances are sometimes referred to as hazardous air pollutants, which are known or suspected to have harmful effects on human health and the environment.

2.2 Federal and Provincial Ambient Air Quality Objectives

In Canada, the federal and provincial governments have established ambient air quality objectives (AAQO) to ensure long-term protection of public health and the environment. In addition to these objectives, Metro Vancouver has created regionally focused ambient air quality objectives. Metro Vancouver has authorization to create and enforce air quality objectives within Metro Vancouver under the Environmental Management Act. Federally, up to three objective values have been recommended using the categories of maximum desirable, maximum acceptable, and maximum tolerable. The maximum desirable objective is the most stringent standard. British Columbia has established similar objective values, designated as levels A, B, and C for Carbon Monoxide (CO) while other pollutants have a single objective for a specified averaging period. Level A is the most stringent, and is typically applied to new and proposed discharges to the environment; it is usually the same as the federal maximum desirable objective. The federal and provincial objectives are summarized in **Table 1**.

Table 1 Federal and Provincial Ambient Air Quality Objectives

Jurisdiction	Levels	Objective Description*
Federal	Maximum desirable (most stringent)	Long-term goal for air quality that provides a basis for an 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)	Denotes time-based concentrations of air contaminants beyond which, due to a diminishing margin of safety, appropriate action is required without delay to protect the health of the general population.
Provincial	Level A (most stringent)	Refers to desirable goals for all discharges and/or to be applied to all new discharges and to existing installations whose discharges are significantly changed in quantity or quality.
	Level B	Refers to the acceptable intermediate objectives for all other discharges, to be reviewed periodically by the Director of Pollution Control.
	Level C (least stringent)	The immediate objective for all applicable existing industries to meet within a minimum technically feasible period of time.

* **Source:** (B.C. MOE 2014, ECOLOG 2014).

3.0 Methods

The following general steps were followed to predict concentrations of the pollutants of concern:

1. Examine and analyze available ambient air quality, meteorological, and climate data.
2. Estimate the air contaminant emissions from vehicles for the three scenarios (existing 2011 conditions, and future (2031) conditions without, and with the Project).
3. Predict the effects of estimated emissions on ambient concentrations within the LSA using dispersion models.
4. Compare the predicted concentrations with applicable air quality objectives (e.g., federal, provincial and municipal)
5. Compare the estimated vehicle emissions for the existing and projected scenarios to emissions within the regional study area.

3.1 Air Quality, and Meteorological and Climate Data

Data from 2008 to 2012 were obtained from Metro Vancouver, which operates air quality monitoring stations for the region surrounding the Project area. Representative concentrations for the pollutants of concern were developed from the analyzed data. Data on toxic air contaminants (TACs) were obtained from the National Air Pollution Surveillance Network. Where available, meteorological data were also obtained from the Metro Vancouver sites, and from the Environment Canada station at Vancouver International Airport. **Table 2** lists the six ambient air quality monitoring stations from which data were used to characterize existing air quality in the vicinity of the Project area, and their coordinates.

Table 2 Ambient Air Quality Monitoring Stations and Parameters Measured

Station ID	Station Name	Location Coordinates	Air Quality Parameters Measured					
			NO_2	CO	O_3	SO_2	$PM_{2.5}$	PM_{10}
T13	North Delta	507167, 5445058	✓		✓		✓	
T15	Surrey East	522307, 5442275	✓	✓	✓		✓	
T17	Richmond South	492108, 5443180	✓	✓	✓	✓	✓	
T18	Burnaby South	501041, 5451379	✓	✓	✓	✓	✓	✓
T31	Richmond-Airport	488895, 5448177	✓	✓	✓	✓	✓	✓
T39	Tsawwassen	494004, 5428560	✓	✓	✓	✓	✓	

3.2 Emissions Estimates

3.2.1 Parameters that Influence Emissions and Air Quality

The following parameters that are known to influence emissions from vehicle traffic were accounted for in estimating emissions related to the Project:

- Vehicle volume and distance travelled – The number of vehicles using the road and the distance they travel directly influence the quantity of contaminants emitted to the air. More vehicles mean more contaminant emissions, and the greater the distance travelled, the greater the volume of contaminants emitted.
- Vehicle speed – Depending on its speed, a vehicle will emit each of the contaminants of concern at varying rates. There is an optimum speed at which a vehicle will emit the least contaminants, but this speed is different for each vehicle and vehicle type. There is generally a range within which most vehicles are operating at their optimum performance and thus minimizing combustion emissions.
- Fleet profile – Vehicle types differ in the emissions they produce; therefore, the proportion of vehicles of each type in the fleet can change the emissions inventory. A road with a greater proportion of heavy trucks and/or bus traffic will have greater emissions of certain contaminants and less of others when compared to a road with a lower proportion of heavy vehicles.
- Vehicle fuel efficiency – Newer vehicles tend to have better fuel efficiency and lower emissions than older vehicles. Turnover of older vehicles for new ones in the fleet can change the emission inventory since less fuel is burned in new vehicles and therefore less combustion-related emissions are produced for the same distance travelled.
- Regulation and legislation – Government regulations such as vehicle fuel efficiency requirements, for example, catalytic converters, and fuel cleanliness (lower sulphur content) can change the vehicle emissions.

3.2.2 Vehicle Emissions

Vehicle emission factors were determined using the U.S. EPA MOVES modelling simulator (U.S. EPA 2012). At the core of the methodology is the emission equation:

Emission (g) = activity data (VkmT) x emission factor (g/VkmT)

VkmT is the number of vehicle kilometres travelled. Emission calculations for vehicles are complex because of the many methods needed to determine reliable emission factors and activity data. Emission factors can vary significantly depending on:

- Vehicle type (e.g., light duty vs. heavy duty, gasoline vs. diesel)
- Mileage accumulation (age of vehicle)
- Speed (e.g., 20 km/h vs. 100 km/h)
- Control technology (e.g., catalytic converters)
- Other emission-reduction measures

The MOVES model generates emissions factors for highway motor vehicles and motorcycles fuelled by gasoline, diesel, and compressed natural gas (CNG). It also accounts for the effects on emissions caused by changes in vehicle emission standards; changes in vehicle populations and activity; and variation in local conditions such as temperature, humidity, pressure, and fuel quality.

The MOVES emission factors were generated by Sierra Research with support from Metro Vancouver. Although MOVES is a U.S.-based model, model input data from Metro Vancouver were used to ensure a good alignment between the Project and Metro Vancouver's regional mobile emission estimates and forecasts. These data included climate data, fleet age distribution, information on inspection and maintenance programs, and regulatory framework (e.g., renewable fuel requirement in B.C. of five per cent for gasoline and four per cent for diesel). Vancouver-specific data on fuel sales and fuel characteristics, such as Reid vapour pressure, ethanol blend market share, and biodiesel content were also used in the model to closely reflect conditions in the Project airshed.

Vehicle emission factors generated by MOVES take into account improvements in vehicle emission systems and technologies as newer technologies slowly penetrate the vehicle fleets and when newer vehicles with improved performance replace older ones. These vehicle technologies are mainly designed to improve fuel efficiency, reduce emissions, and improve the general safety of the driver.

The MOVES model generates emission factors for 13 types of vehicles, and for three distinct fuels (gasoline, diesel, and CNG), which are summarized, along with the existing 2011 and 2031 fleet profiles, in **Table 3**. The proportions of vehicle types (fleet profile) were also provided by Metro Vancouver, and as used in the *2010 Lower Fraser Valley Air Emissions Inventory and Forecast and Backcast* (Metro Vancouver 2013). Although Metro Vancouver's fleet profiles were developed for 2010 and 2030, they were deemed representative of the Project years of 2011 and 2031, and therefore adopted for use in this study.

As shown in **Table 3**, the fleet profile presents a very similar vehicle class breakdown in both 2011 and 2031. In 2011, light duty vehicles dominate the profile, accounting for 94.7 per cent of all vehicles, with 91.4 per cent being gasoline fuelled. Heavy duty trucks (motorhomes, refuse trucks, single and combination short- and long-haul trucks) account for 2.5 per cent, and buses account for 0.3 per cent of the fleet. Motorcycles account for the remaining 2.4 per cent. Electric vehicles account for 0.03 per cent (passenger cars and transit buses), whereas CNG buses only account for 0.003 per cent of the fleet.

Table 3 Fleet Profile for 2011 and 2031

Description		Percentage of Total Vehicles	
		2011	2031
Gasoline	Motorcycle	2.43	2.38
	Passenger Car	49.52	48.44
	Passenger Truck	31.35	30.68
	Light Commercial Truck	10.57	12.19
	Transit Bus	0.0001	0.0002
	School Bus	0.006	0.0045
	Refuse Truck	0.0003	0.0002
	Single Unit Short-Haul Truck	0.02	0.02
	Single Unit Long-Haul Truck	0.002	0.002
	Motor Home	0.60	0.59
Diesel	Passenger Car	0.72	0.72
	Passenger Truck	1.26	1.23
	Light Commercial Truck	1.31	1.51
	Intercity Bus	0.13	0.13
	Transit Bus	0.10	0.08
	School Bus	0.08	0.06
	Refuse Truck	0.05	0.04
	Single Unit Short-Haul Truck	0.65	0.62
	Single Unit Long-Haul Truck	0.06	0.07
	Motor Home	0.22	0.22
	Combination Short-Haul Truck	0.30	0.34
	Combination Long-Haul Truck	0.57	0.63
CNG	Transit Bus	0.003	0.005
Elect	Passenger Car	0.01	0.01
	Transit Bus	0.02	0.02

Emission factors for each vehicle type were provided by MOVES for a variety of vehicle speeds for the pollutants listed in **Table 4**. The MOVES-generated emission factors were subsequently multiplied by the traffic volumes to obtain the hourly, daily, and annual emissions for each Project road segment (described in **Section 6.6.5-1** and as follows):

- Segment 1: Bridgeport Road to Westminster Highway
- Segment 2: Westminster Highway to Steveston Highway
- Segment 3: Tunnel / new bridge and approach
- Segment 4: Highway 17A to Highway 17
- Segment 5: Highway 17 to Ladner Trunk Road
- Segment 6: Ladner Trunk Road to Highway 91

Table 4 Motor Vehicle Emissions Simulator Contaminant List

Contaminants	
Volatile organic compounds	Primary $PM_{2.5}$ - brake wear
Carbon monoxide	Primary $PM_{2.5}$ - tire wear
Oxides of nitrogen	Methane
Sulfur dioxide	Nitrous oxide
Ammonia	Carbon dioxide
Primary PM_{10} - organic carbon	Benzene
Primary PM_{10} - elemental carbon	Naphthalene
Primary PM_{10} - sulfate particulate	1,3-butadiene
Primary PM_{10} - brake wear	Formaldehyde
Primary PM_{10} - tire wear	Acetaldehyde
Primary $PM_{2.5}$ - organic carbon	Acrolein
Primary $PM_{2.5}$ - elemental carbon	Benzo(a)pyrene
Primary $PM_{2.5}$ - sulfate particulate	

Vehicle speed can also affect exhaust emissions. The emission rate in grams per kilometre (g/km) for many exhaust contaminants decreases with vehicle speed. The rate depends on the type of vehicle and engine technology.

Development of emission factors based on a variety of speeds allows for the simulation of free-flow and congested road conditions, which is a crucial factor when analyzing air quality conditions in the airshed. For this Project, different speeds were considered for each scenario and each road segment being assessed. While the speeds considered in each scenario are described in **Section 4.1**, **Table 5** and **Table 6** show a sample of CAC emission factors for different vehicle types travelling at a speed of 40 km/h, for the 2011 and 2031 scenarios respectively. Gasoline-fuelled vehicles — heavy duty vehicles in particular — have higher factors for CO, VOCs, NH_3, and SO_2 than other vehicle types. However, NOx and particulate matter emission factors are highest for diesel heavy duty vehicles. Motorcycles have the highest emission factor for VOCs than any other vehicle type. In general, most emission factors are expected to decline between 2011 and 2031. In Table 5 and Table 6, the VOCs emission factors include exhaust and running evaporative emissions and the PM_{10} and $_{2.5}$ emission factors include exhaust and brake and tire wear emissions.

Table 5 Example of Emission Factors of CACs by Vehicle Type for 2011 (g/VkmT) for 40 km/h Speed

2011 Emission Factors (g/VkmT)								
Fuel Type	**Vehicle Type**	**CO**	**NOx**	**VOCs**	**NH_3**	**SO_2**	**PM_{10}**	**$PM_{2.5}$**
Gasoline	Motorcycle	11.679	0.343	1.855	0.019	0.004	0.026	0.021
	Passenger Car	6.132	0.478	0.507	0.021	0.005	0.031	0.015
	Passenger Truck	8.542	0.752	0.556	0.020	0.007	0.043	0.019
	Light Commercial Truck	8.286	0.670	0.469	0.018	0.007	0.041	0.018
	Transit Bus	28.443	2.526	0.966	0.020	0.016	0.059	0.019
	School Bus	67.555	3.271	2.666	0.019	0.012	0.078	0.037
	Refuse Truck	30.805	3.543	1.067	0.024	0.024	0.067	0.021
	Single Unit Short-Haul Truck	31.800	2.407	1.143	0.023	0.014	0.073	0.025
	Single Unit Long-Haul Truck	23.054	2.057	0.837	0.023	0.013	0.069	0.022
	Motor Home	47.327	3.867	2.813	0.023	0.014	0.094	0.048

2011 Emission Factors (g/VkmT)								
Fuel Type	**Vehicle Type**	**CO**	**NOx**	**VOCs**	**NH_3**	**SO_2**	**PM_{10}**	**$PM_{2.5}$**
Diesel	Passenger Car	0.529	0.992	0.141	0.004	0.002	0.132	0.114
	Passenger Truck	1.527	2.456	0.337	0.012	0.004	0.160	0.134
	Light Commercial Truck	1.551	2.516	0.343	0.013	0.004	0.158	0.130
	Intercity Bus	2.916	10.230	0.434	0.015	0.010	0.775	0.663
	Transit Bus	2.073	5.118	0.307	0.012	0.006	0.283	0.235
	School Bus	2.875	5.707	0.545	0.012	0.005	0.419	0.344
	Refuse Truck	1.465	4.866	0.288	0.015	0.009	0.416	0.319
	Single Unit Short-Haul Truck	1.802	4.262	0.446	0.014	0.006	0.282	0.218
	Single Unit Long-Haul Truck	1.493	3.661	0.370	0.014	0.006	0.237	0.175
	Motor Home	2.412	7.597	0.757	0.014	0.006	0.448	0.392
	Combination Short-Haul Truck	2.829	8.510	0.453	0.015	0.011	0.645	0.547
	Combination Long-Haul Truck	3.200	9.923	0.822	0.015	0.013	0.536	0.434
CNG	Transit Bus	24.373	2.307	0.000	0.000	0.000	0.057	0.017

Table 6 Example of Emission Factors of CACs by Vehicle Type for 2031 (g/VkmT) for 40 km/h Speed

2031 Emission Factors (g/VkmT)								
Fuel Type	**Vehicle Type**	**CO**	**NOx**	**VOC**	**NH_3**	**SO_2**	**PM_{10}**	**$PM_{2.5}$**
Gasoline	Motorcycle	9.091	0.317	1.727	0.023	0.004	0.026	0.021
	Passenger Car	4.591	0.129	0.239	0.012	0.004	0.027	0.012
	Passenger Truck	5.328	0.207	0.198	0.013	0.005	0.039	0.016
	Light Commercial Truck	6.054	0.261	0.190	0.013	0.005	0.038	0.015
	Transit Bus	22.844	2.195	0.818	0.020	0.016	0.059	0.018
	School Bus	52.843	1.671	1.012	0.019	0.012	0.061	0.021
	Refuse Truck	27.642	3.334	0.975	0.024	0.024	0.066	0.021
	Single Unit Short-Haul Truck	27.568	1.936	0.694	0.023	0.014	0.069	0.021
	Single Unit Long-Haul Truck	20.897	1.784	0.573	0.023	0.013	0.067	0.020
	Motor Home	32.707	2.150	1.298	0.023	0.014	0.065	0.021

2031 Emission Factors (g/VkmT)								
Fuel Type	**Vehicle Type**	**CO**	**NOx**	**VOC**	**NH_3**	**SO_2**	**PM_{10}**	**$PM_{2.5}$**
Diesel	Passenger Car	2.201	0.298	0.091	0.004	0.001	0.025	0.010
	Passenger Truck	0.852	0.805	0.062	0.012	0.003	0.037	0.015
	Light Commercial Truck	0.755	0.799	0.062	0.013	0.003	0.040	0.016
	Intercity Bus	0.552	1.506	0.059	0.015	0.009	0.181	0.087
	Transit Bus	0.469	0.744	0.032	0.012	0.006	0.070	0.028
	School Bus	1.306	0.841	0.060	0.012	0.004	0.104	0.038
	Refuse Truck	0.396	0.955	0.035	0.015	0.008	0.142	0.053
	Single Unit Short-Haul Truck	0.648	0.777	0.049	0.014	0.006	0.091	0.033
	Single Unit Long-Haul Truck	0.536	0.695	0.042	0.014	0.005	0.089	0.031
	Motor Home	1.053	1.724	0.207	0.014	0.006	0.124	0.078
	Combination Short-Haul Truck	0.659	1.233	0.046	0.015	0.010	0.138	0.056
	Combination Long-Haul Truck	1.855	4.475	0.365	0.024	0.012	0.156	0.065
CNG	Transit Bus	10.625	1.992	0.000	0.000	0.000	0.056	0.016

3.2.2.1 Traffic Data

A range of future traffic scenarios in terms of tolling, traffic volumes, and congestion levels were considered, and the most conservative scenario was used in predicting future emissions. As discussed in **Section 5.1.2.4** of the Application, average annual daily traffic volumes (AADT) for 2030 were assessed using TransLink's RTM for two scenarios– with the new bridge in place and no tolls being applied (TL-RTM Untolled), and with a new tolled bridge in place (TL-RTM Tolled). Given the variability in the forecasting, and to ensure a conservative assessment for EA purposes, the upper range of forecast values (TL-RTM untolled, 2030 With the Project) was used as it represents the highest potential volume of traffic

Forecasts of total traffic within the Project area for the years 2011 and 2031 with and without the Project were generated. The traffic numbers were subsequently broken down to the various MOVES vehicle types, based on Metro Vancouver's fleet profiles. The traffic data and the emission factors from the MOVES model were used to determine the emission rates of the various contaminants for specific segments along the roadway. For each segment of road, the number of vehicles of each type and the associated emission factor were multiplied together to determine an emission rate per kilometre of road per vehicle. The dispersion model uses the emission rates, the road length, road width, and orientation, along with meteorological data, to predict ambient air quality resulting from traffic flowing on each road segment.

3.2.3 Road Dust

Road dust emissions are not generated as part of the MOVES model but were considered as part of the assessment. Therefore, road dust quantification followed the U.S. EPA methods described in *Compilation of Air Pollutant Emission Factors* (U.S. EPA 2011) AP-42, which deals with paved roads. According to AP-42 methods, road dust emissions are estimated using the following equation:

$$E = k \times (sL^{0.91}) \times (W^{1.02}) \times (1-P/4N)$$

where

k = particle size multiplier

sL = road surface silt loading

W = average weight of vehicles, the input of 1.9 tons was reused from 2005 Inventory

P = number of “wet” days with at least 0.254 mm precipitation

N = number of days in the period (1 year = 365 days)

The values for highway silt content and vehicle fleet average weight, as provided by Metro Vancouver, are 0.075 g/m^2 and 1.9 tonnes respectively. The data for number of wet days was collected from the meteorological station T17 for 2011 and totaled 147 days. The same values for silt loading, fleet weight, and wet days are considered for 2031. The resulting emission factors for road dust are as follows:

- PM = 0.53 g/VkmT
- PM_{10} = 0.10 g/VkmT
- $PM_{2.5}$ = 0.02 g/VkmT

The emission factors were applied to the total VkmT for the Project to estimate emissions from road dust. Road dust emissions were estimated to increase in direct proportion to the projected traffic volumes.

3.3 Air Quality Dispersion Modelling

Several models are available for air quality dispersion modelling, with each model offering different strengths and weaknesses. The selection of a model depends on several factors, the main ones being the types of sources, topography, accuracy required, and predictions of the parameters necessary to be assessed. The modelling approach used in this evaluation has been applied in other transportation-related projects in the Lower Mainland, and involves the use of a proven dispersion model for roadways, together with a reliable meteorological model for determining the winds near the Project area.

The *British Columbia Air Quality Modelling Guideline (B.C. Modelling Guideline)*, which outlines recommended steps (e.g. development of a conceptual as well as a detailed model plan) for completing modelling projects, was used to guide Project-related air-quality modelling. Metro Vancouver was involved in the model planning discussions from the early stages, and this consultation helped identify and address some of the issues noted in this assessment.

Predictions of ambient concentrations resulting from vehicle exhaust on highways in this and previous transportation-related assessments in B.C. employed the use of the CALINE3 (CALINE) model. Prior to the latest update of December 2015, the B.C. Modelling Guideline had included CALINE as a recommended model. As per Section 2.3.1 of the current version of the Modelling Guideline, CALINE would be considered an Alternate Model, as none of the Guideline-recommended models are specifically designed for traffic modelling.

CALINE is specifically designed for vehicle emissions from exhaust along roads. Other models such as CALPUFF, a Gaussian-Lagrangian puff dispersion model, or the Industrial Source Complex model (ISC3), a Gaussian plume model, can handle a variety of emission source types, but do not currently have explicit algorithms to address road sources. The BC Ministry does not recommend any particular models for dispersion modelling of road sources (B.C. MOE 2015). The CAL3QHCR model is an alternative dispersion model for road sources which is focused on modelling of CO and queuing of vehicles at traffic lights. As CAL3QHCR utilizes the CALINE3 algorithms for traffic in motion, the CALINE3 model was deemed the most appropriate model selection for this assessment.

CALINE is the model currently recommended by the U.S. EPA for prediction of air quality impacts of roadway (line) emission sources. Because the CALINE model is U.S. EPA-approved, it has gone through rigorous evaluation to ensure that the model is providing conservative, yet accurate results. Due to CALINE's conservatism, its predicted concentrations tend to be higher than observed ambient air quality, but the model will provide a worst-case estimate of a project's effects on local air quality.

Traffic volumes are put into CALINE and are based on the results from the EMME/2 traffic model for the three traffic (2011 – Existing Roads, 2031 – Without Project, 2031 – With Project) scenarios considered. Emission factors were obtained from MOVES (described in **Section 3.2.2**). CALINE uses road segments to define the roadways in the model and includes emission factors (adjusted for various speed categories), traffic volumes, and the road alignment. The emission rates, in grams per mile per vehicle, were developed for each pollutant and each road segment.

Peak morning rush-hour traffic data were used to determine the maximum one-hour emission rates and in turn the one-hour predicted concentrations. For averaging periods longer than one hour, the annual average daily traffic was used to develop appropriate emission rates. The daily and annual average scenarios take into consideration changes in congestion throughout the course of a day and week that will contribute to changes in the amount of emitted pollutants.

CALINE predicts hourly ambient concentrations at designated receptor locations. Receptors are grid points in Universal Transverse Mercator (UTM) coordinates, where the computer model calculates predicted ambient concentrations. Receptors in this study were spaced at 100 m intervals along the roadway and extended perpendicular to and on either side of the road at intervals of 5, 10, 15, 20, 25, 50, 100, 250, 500 and 1,000 metres from the road (**Figure 1**). In addition to the gridded receptors (yellow dots on **Figure 1**), sensitive receptors such as schools, daycares, hospitals, and other sensitive areas were identified and included in the CALINE receptor grid (purple and pink shapes on **Figure 2**).

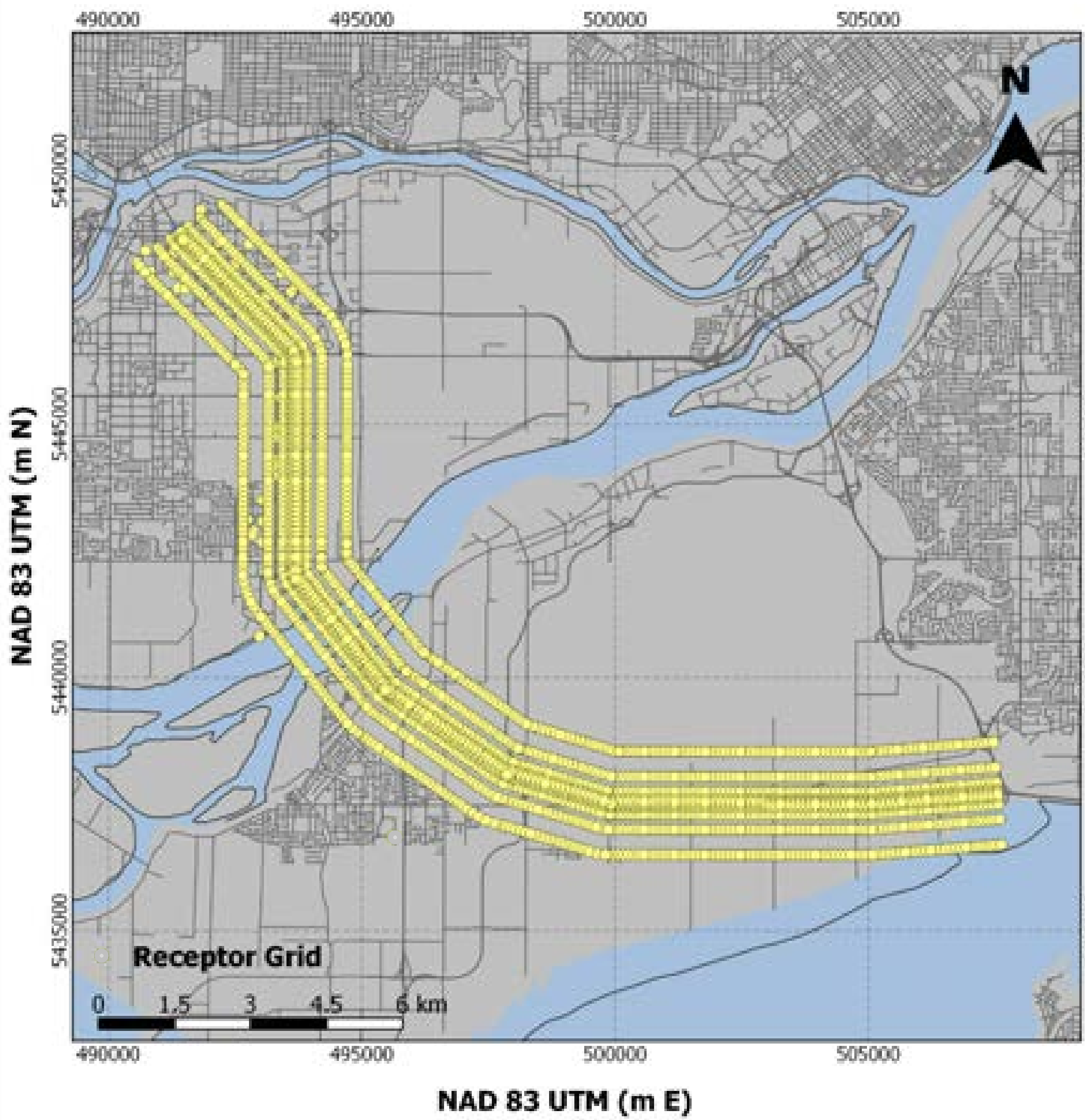


Figure 1 CALINE Receptor Grid

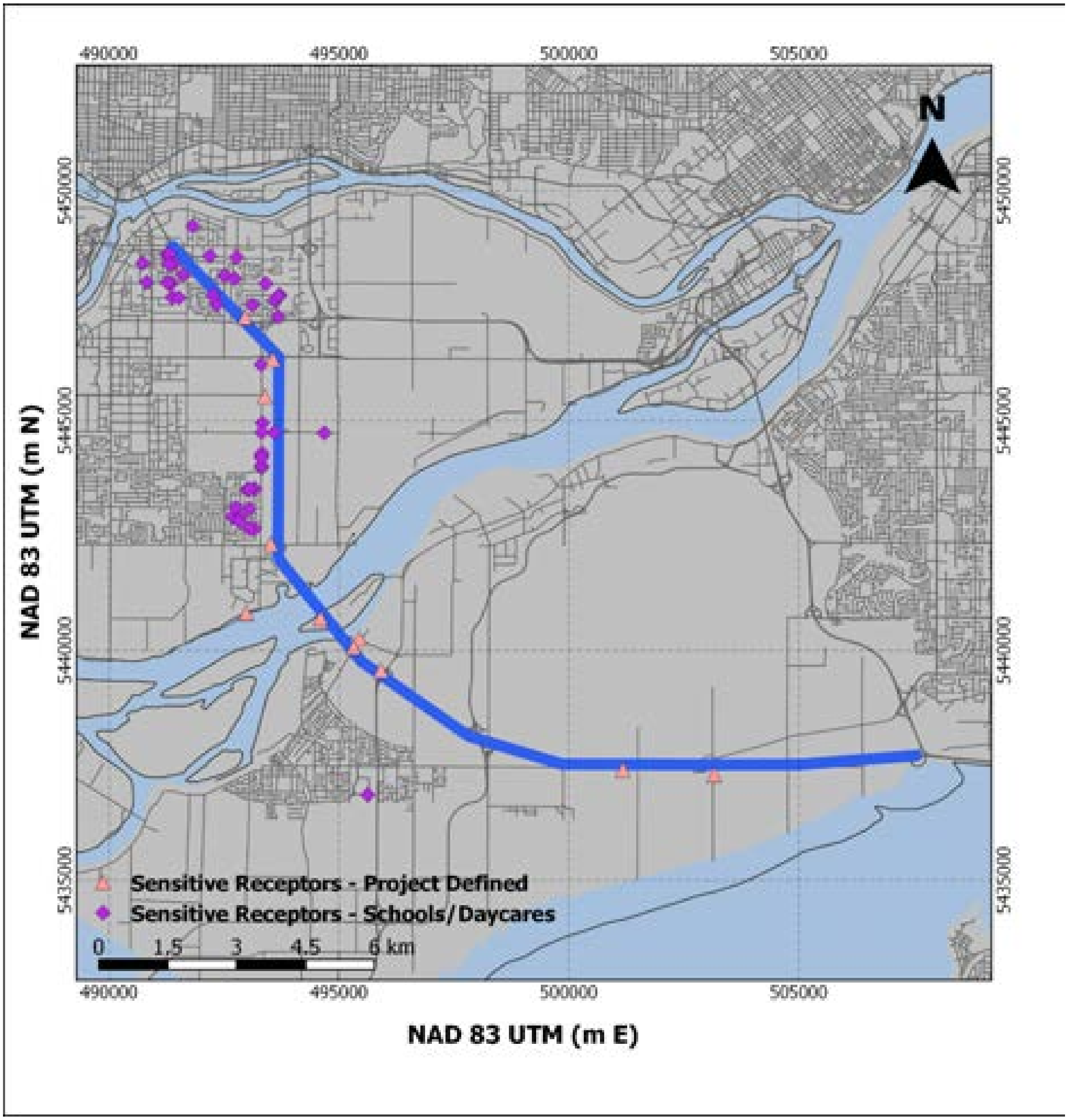


Figure 2 CALINE Sensitive Receptors Only

The CALMET model was used to provide an estimate of the wind fields (see **Section 3.3.1**, below). Meteorological data were extracted from CALMET for a location near the highway. The maximum predicted one-hour, 24-hour, and annual ambient concentrations of all modelled contaminants for traffic emissions were calculated at each receptor and are summarized, tabulated, and discussed in the sections below.

In addition to the maximum values, the maximum 98th percentile of the one-hour and 24-hour predicted ambient concentrations are also tabulated and discussed. The 98th percentile is the value for which ambient concentrations are equal to or less than, 98 per cent of the time. Therefore, if the one-hour 98th percentile for SO_2 concentrations is 8 μg/m^3, ambient concentrations will be equal to or less than 8 μg/m^3, 98 per cent of the time. The 98th percentile values are important to consider in addition to the maximum because the extreme maximum can often be an anomaly whereas the 98th percentile provides a better representation of maximum effects of the Project on local air quality. The air quality predictions were compared to the strictest applicable federal, provincial or regional (Metro Vancouver) air quality objectives.

3.3.1 Meteorological Data

The CALINE model requires input parameters of wind speed, wind direction, stability class, and mixing height to predict hourly contaminant concentrations. One year of data were extracted from the CALMET model output and used in the CALINE model. CALMET is a U.S. EPA-approved diagnostic meteorological computer model that generates three-dimensional fields of meteorological parameters based on surface and upper air meteorological data, digital land use data, and terrain data.

CALMET was used to characterize the meteorology near each modelled segment of the road for the period from January 1, 2012 to December 31, 2012. The model was run for the entire airshed at a 500 by 500 m grid resolution using a hybrid approach that integrates surface observations with prognostic model data. The surface observations were developed from the stations described in **Table 2**, while the prognostic data were generated from the Weather Research and Forecasting Non-hydrostatic Mesoscale Model, a state-of-the-science forecast model that was used to predict wind fields for the CALMET model. The CALMET model output was extracted at the spatial midpoint of the Project. For each modelled section, an hourly dataset representing one year of data was generated and formatted for input into the CALINE model.

Roughness length, a measurement of length that is used to indicate turbulence characteristics of a particular type of surface, is another parameter required by the model. For example, smooth plains where wind can blow without interference would have a very low roughness length (10 cm), while forested and urban areas with obstacles that can cause higher turbulence and have a longer roughness length. The roughness length for this study was presumed to be typical of an urban area (100 cm). Model results are presented in **Section 5.0**.

3.3.2 CALINE Model Geometry

The local study area extended from Bridgeport Road in Richmond to Highway 91 in Delta, and the EMME/2 traffic model divided the study area into the four road segments used by the CALINE model. For each segment that is modelled, CALINE requires:

- the beginning and end points of the segment (X and Y)
- traffic (number of vehicles per hour)
- emission rate (g/mile)
- whether the area is at grade (AG) or a bridge (BR) segment
- height (height of the bridge for bridge segments, and 0 m for at-grade segments; for the Project, the maximum allowed value of 10 m was used for the bridge segment)
- width of the road based on the existing road for the current and future-without-Project scenarios; for the future-with-Project scenario, incorporated increased lane widths

CALINE uses the UTM coordinates to determine the length and orientation of each segment. To account for dispersion of tailpipe emissions that occur in the turbulent wake behind a moving vehicle, three metres were added to either side of the road width, as recommended in the CALINE user guide (Benson 1979).

The use of the modelled bridge height option of 10 m, though in some cases less than the actual design height for the new bridge, allows the model to calculate the dispersion impact caused by air flowing under the bridge deck. Use of the lower height means the roadside concentrations are slightly higher than would be expected if a higher elevation was used. For modelling the existing Tunnel, the emissions that occurred within the Tunnel were distributed on an immediate segment at the entrance/exit on either side of the Tunnel.

For the two 2031 scenarios considered in this study (i.e., without and with the Project), an additional road segment was added to represent the two kilometres of the South Fraser Perimeter Road (SFPR)/Highway 17 that pass through the Project. Because SFPR was not operational until December, 2013, it was not considered in the 2011 scenario. The results presented in **Section 5** for the 2031 scenarios therefore account for the additional traffic resulting from SFPR.

3.3.3 Conversion for Oxides of Nitrogen

Vehicle emissions of NOx are primarily in the form of NO (94 per cent) with very little NO_2 (six per cent) present. Since there are no existing objectives for ambient NOx concentrations (the guidelines refer to NO_2), NOx concentrations predicted by the model were converted to equivalent NO_2 concentrations using the Ambient Ratio Method (ARM). In accordance with the AQMG, if 100% NO_x conversion leads to exceedances of the AAQO, the Ambient Ratio (AR) method should be implemented to convert predicted NOx concentrations into NO_2 concentrations. The AR method utilizes representative hourly NO_x and NO_2 monitoring data to characterize the NO_2/NO_x ratio given the ambient NO_x concentration. The method then applies this ratio to the model predicted NO_x emissions from the Project.

Ambient air quality data from Metro Vancouver station T18 (Burnaby South) was used to calculate the ratio of NO_2/NO_x. The resulting ratio was validated against NO_2/NO_x ratios and ambient air quality from Metro Vancouver stations T13 (North Delta) and T17 (Richmond South). For the 1-hour averaging period, an exponential equation of the form y = axb was fit to the upper envelope of observed NO2/NOx versus NOx, where a and b are empirically determined constants. The resulting equation was used to determine the ratio of NO2/NOx subject to the constraints that the equation is only valid for NOx values where the corresponding NO_2/NO_x ratio is less than 1. **Figure 3** illustrates the dependence of NO_2/NO_x ratio on ambient NOx air quality.

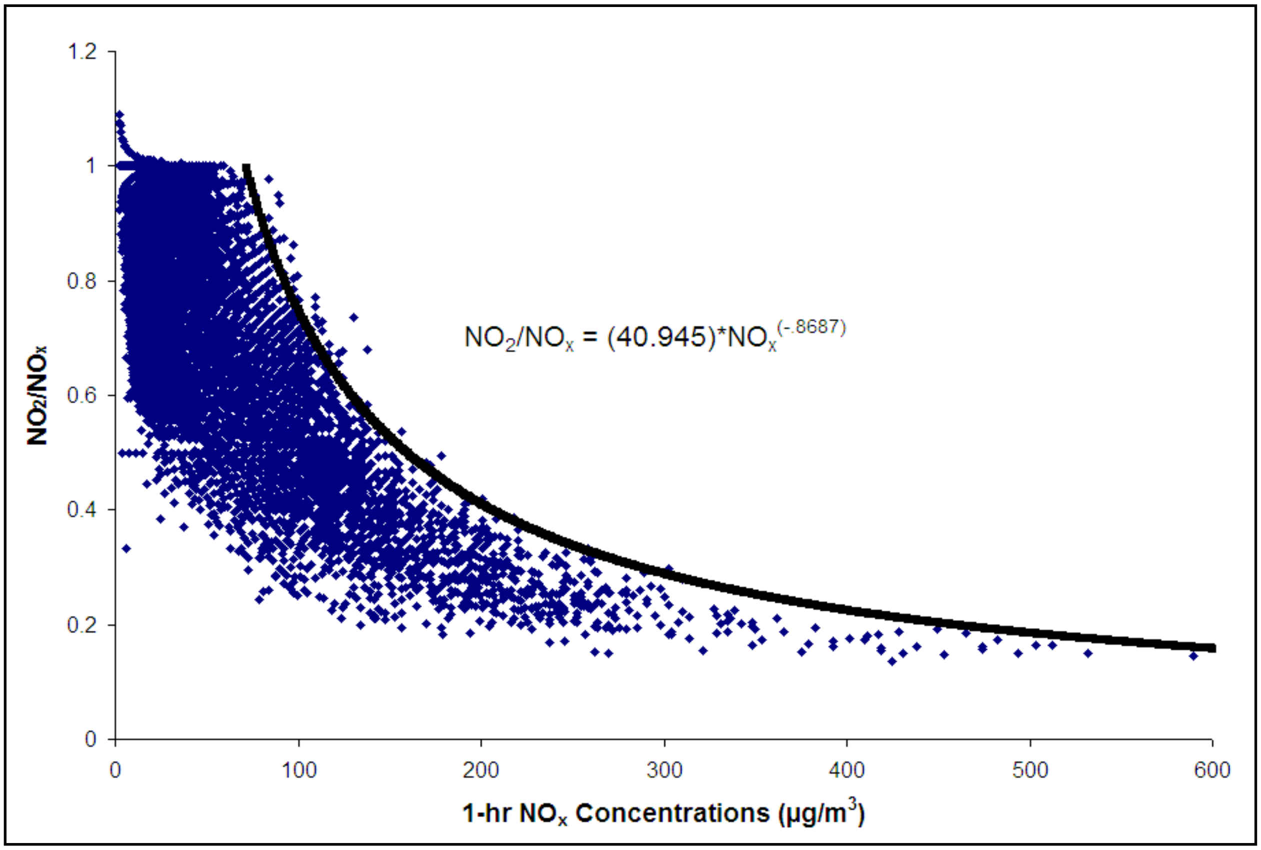


Figure 3 **NO_2/NO_x Ratio versus 1-hour Average NO_x Observations from Metro Vancouver Station T18 (Burnaby South)**

3.3.4 Ozone

Ground level O_3 is formed through a complex set of atmospheric chemical reactions with NOx, and VOCs acting as key precursor species. Recent research on ground-level O_3 formation in the Lower Fraser Valley (LFV) (Steyn et al. 2011) revealed that, in the eastern portions of the valley from approximately Abbotsford to Hope, O_3 production is limited by the availability of NOx; whereas, in western areas of the valley, from approximately Langley to the Georgia Strait, O_3 production is limited by the availability of VOCs. Both the relative amounts of available emissions and their locations affect the potential ground-level O_3 formation.

An estimate was made of potential changes in concentrations of ground-level O_3 based on changes in emissions of NOx and VOCs. The methodology was based on a simplified model developed for the LFV by Steyn et al. (2011). The projected change in net O_3 concentrations was estimated using the slope of the potential change in O_3 concentration listed in **Table 7**. Modelling of peak ozone is a complex process involving many chemical reactions of various pollutants and emissions. The US has developed the Community Mesoscale Air Quality Model (CMAQ), which could be used to model peak concentrations of ozone, however, there is no regulatory guidance on how the model should be used, and the possible error in prediction would be more significant than the potential changes in ozone that could be measured in the future.

Table 7 Ozone Concentrations in the Lower Fraser Valley and NOx/VOC Emission Changes

Parameter	Units	1985	2006	Change	Slope	
					VOC Limited Western LFV	NOx Limited Eastern LFV
VOC emissions	t/d	439	296	-143	($\mu g/m^3$ O_3 / tonne per day VOC emission)	($\mu g/m^3$ O_3 / tonne per day NOx emission)
NOx emissions	t/d	277	167	-110		
Mean O_3	$\mu g/m^3$	55.4	42.2	-13	0.09	0.12
Peak O_3	$\mu g/m^3$	138	89	-49	0.34	0.44

Notes:
1 Average daily emission rates (metric tonnes per day) within the LFV based on the Metro Vancouver emissions inventories (GVRD 2003, GVRD 2007 as cited in Steyn et al. 2011)
2. Domain-wide overall ozone performance statistics for all WRF/CMAQ simulations and for the National Research Council (Smyth et al. 2006 as cited in Steyn et al. 2011) MM5/CMAQ 2001 simulation
3. Table 53 Ozone performance statistics for daily peak ozone concentrations (Steyn et al. 2011)

3.3.5 Secondary Particulate Matter

Based on the overall reduction in emissions attributed to improvements in fleet performance (**Section 4.2.1**), it is anticipated that secondary particulate matter formation will decrease in the future with or without the Project. It should be noted that in locations with net NOx/VOC decreases, airborne radicals that formerly reacted with these compounds become free to react with SO_2, which can cause a small offsetting increase in sulphate aerosols (PM). However, sulphur emissions are also projected to decrease in the scenario of 2031 with the Project. Therefore, the result is expected to be a net reduction in secondary PM formation and is not considered further in this air quality evaluation.

3.3.6 Deposition

While vehicle emissions contribute to ambient air quality, they will eventually settle out of the atmosphere and deposit in areas surrounding the Project through sedimentation and precipitation processes. The CALINE model does not have the ability to model deposition, so the CALPUFF model, using the previously mentioned CALMET modelled data, was used for this purpose. CALPUFF is able to generate predicted wet and dry fluxes of pollutants.

Due to the computationally intensive nature of running CALPUFF, a sub-set of the road network was parameterized and run in the model that contained sensitive receptors, therefore representing a worst-case scenario. A 3.3 kilometer segment of Link 4 was chosen for parameterization in the CALPUFF model. Along this segment, 24 area sources were configured with a width of 14.4 meters and used the same emission factors, receptors and meteorology used in the CALINE model were used to model deposition and arrive at a predicted amount of deposition with distance from the side of the roadway. All other CALPUFF model parameters were set to default in accordance with the BC Air Quality Modelling Guideline.

For each of the three scenarios considered in the study, predicted maximum dry, wet, and total deposition were modelled for PM2.5, PM10, and total PM. The deposition modelling for the 2031 scenario with the Project predicts a maximum deposition of 4.56 g/m2/yr. **Table 8** presents dustfall deposition modelling results for the three scenarios in g/m2/yr.

Table 8 Maximum Predicted Deposition ($g/m^2/yr$)

Species	2011 – Existing Roads			2031 – Without Project			2031 – With Project		
	Dry Deposition	Wet Deposition	Total Deposition	Dry Deposition	Wet Deposition	Total Deposition	Dry Deposition	Wet Deposition	Total Deposition
$PM_{2.5}$	9.17E-04	4.07E-04	1.23E-03	9.47E-04	4.20E-04	1.27E-03	8.54E-04	4.15E-04	1.19E-03
PM_{10}	2.20E-01	6.29E-03	2.25E-01	2.68E-01	7.67E-03	2.74E-01	2.29E-01	7.50E-03	2.35E-01
PM	3.92E+00	4.56E-02	3.95E+00	5.09E+00	5.92E-02	5.13E+00	4.52E+00	5.46E-02	4.56E+00

3.4 Greenhouse Gases Evaluation

Greenhouse gases are contributors to the radiative warming effect of the environment that results in global climate change. The major GHGs include CO_2, CH_4 and N_2O, which are emitted from fuel combustion as well as other anthropogenic and natural sources. In addition, the warming effects of black carbon may be significant on a local geographic basis, especially on a shorter time scale[1].

In the context of GHG emissions generated in the Project alignment today, current congestion results in substantially more GHG emissions (CO_2-e) than would occur without such congestion. As illustrated in Table 8, the elimination of the one million vehicle delay hours, that occur annually due to existing congestion, would result in a reduction in CO_2-e emissions by existing traffic of more than 13,000 tonnes.

Table 9 Existing 2011 CO2-e Emissions, with and without Congestion

	2011 Existing Roads		
	Existing Emissions with Congestion (tonnes/yr)	**Emissions without Congestion (tonnes/yr)**	**Change from Existing with Congestion**
CO_2-e (20-year) [2]	163,157	149,774	-13,383 (-8.2%)

Considering future GHG emissions in the Project area, **Table 9** summarizes the comparison of emissions for the 2031 scenarios, with and without the Project. For the scenario without the Project, emission estimates have taken into account the effects of traffic congestion during rush hours on a weekday, as described in **Section 4.1**. Emissions for the 2011 existing scenario are also presented, to show the temporal reductions in GHG and black carbon emissions over time.

1 As described in **Section 2.1.5**, black carbon is present in PM generated by fuel combustion processes, and absorbs solar radiation at all wavelengths. Given its shorter residence time in the atmosphere than GHGs, the use of the 100-year GWP factors to determine CO_2 equivalency may not be appropriate. Hence, published 20-year GWPs for GHGs and black carbon (Solomon et al. 2007, Minjares et al. 2014) were used to estimate the magnitude of the climate change effects of Project-related black carbon emission and its potential contribution to local climate change. Other components such as sulphates, nitrates, and organic carbon (OC) present in particulate matter generally reflect light and have a cooling effect that may partially offset the warming effect of black carbon.

2 CO2e (equivalent) emissions are based on the following respective weighting factors for 20-year and 100-year global warming potential per tonne of emission: CO_2 (1 and 1), CH_4 (72 and 25), N_20 (289 and 298), and black carbon (3,200 and 900).

Table 10 **Forecast 2031 CO2e Emissions, with and without Project (untolled)**

Pollutant	2011 Existing Roads Emissions (tonnes/yr)	2031 Emissions (tonnes/yr)		Change from Without Project Scenario in 2031
		Without Project	With Project	
CO_2	146,939	129,338	121,493	-7,845
CH_4	12.2	15.0	15.1	0.1
N_2O	8.0	3.5	3.5	0
Black carbon	4.1	1.1	1.2	0.1
CO_2-e (20-year)	163,157	135,002	127,336	-7,666 (-5.7%)
CO_2-e (100-year)	153,287	131,753	123,973	-7,780 (-5.9%)
Note: Because the new bridge will be tolled, CO2-e reductions with the Project are projected to be greater than those noted above.				

As illustrated in **Table 10**, a substantial decrease in GHG emissions (CO2e) on the Highway 99 corridor is forecast between 2011 and 2031, both with and without the Project,[3] as newer engine technologies provide significant reductions in overall CO2e emission levels.

Even if the Project did not include tolling, CO_2-e emissions in 2031 are forecast to decrease by 7,700 to 7,800 tonnes (5.7% to 5.9%) relative to without the Project. This net GHG reduction reflects savings due to congestion relief associated with Project improvements, which more than outweigh emissions associated with higher traffic volumes in an untolled scenario.

The 7,700 to 7,800 tonne annual reduction can be characterized as a "worst case" scenario, since it is based on the Highway 99 corridor being untolled. As the Project will be tolled, GHG reductions are projected to be greater due to the dampening effect on traffic volumes.

3 The only forecast increase in emissions, for CH_4, is due to the combination of increasing traffic and increasing frequency of diesel-engine vehicles, which are projected to outweigh the decrease in CH_4 emission rates for similar-engine vehicles. This CH_4 emissions trend is also observed in Metro Vancouver's 2010 emissions inventory and forecast (Metro Vancouver 2013).

4.0 Emission Estimate Results

4.1 Emission Quantification

To assess the effects of the Project on air quality, the three scenarios (existing 2011 conditions, and future (2031) conditions without, and with the Project) were modelled. In addition to the differences in traffic volumes and road layout among scenarios, speed also changes within each scenario depending on whether peak rush-hour traffic is considered or daily time scales. Vehicle emissions are directly related to vehicle speed and therefore must be considered. The traffic volumes considered in the different scenarios are summarized in **Table 11**.

The emission factors associated with peak traffic periods are a a composite which consider 25% of the travel time at low speed to idling conditions and 75% of the time at 10 to 30 km/h. This emission factors were designed to simulate traffic under heavy congestion conditions and was used to estimate emissions for the following scenarios:

- Existing (2011) – peak period consisting of six hours of peak traffic per week day
- Future (2031) without the Project – peak period consisting of 10 hours of peak traffic per week day

Posted speeds were considered when modelling non-peak time periods for weekday and weekend days. Congestion conditions were applied to the Tunnel and adjacent roadway (Segment 3, in **Table 11**). Posted speeds were applied to the rest of the roadway upstream and downstream of the Tunnel as traffic is assumed to move through those sections without major congestion.

Table 11 Estimated Daily[a] Traffic Volumes for Each Modelled Scenario

Link #	Direction	Link Description	Existing Roads (2011)	Future (2031) Without Project	Future (2031) With Project
1	North Bound	Bridgeport to Westminster	39,000	45,000	48,000
1	South Bound	Bridgeport to Westminster	36,500	39,500	42,000
2	North Bound	Westminster to Steveston	38,500	45,500	52,000
2	South Bound	Westminster to Steveston	37,000	46,500	55,000
3[b]	North Bound	Tunnel/new Bridge	41,000	47,500	53,500
3[a]	South Bound	Tunnel/new Bridge	41,000	51,500	61,000
4	North Bound	Highway 17A to Highway 17	25,000	28,000	33,000
4	South Bound	Highway 17A to Highway 17	26,000	38,500	43,000
5	North Bound	Highway 17 to Ladner Trunk Rd	25,000	31,000	31,500
5	South Bound	Highway 17 to Ladner Trunk Rd	26,000	36,500	40,500
6	North Bound	Ladner Trunk to Highway 91	22,500	26,000	26,000
6	South Bound	Ladner Trunk to Highway 91	24,500	34,000	37,500

Notes

[a] Annual emissions are calculated by multiplying the emissions of a weekday by 261 plus by multiplying the emissions of a weekend by 104.

[b] Average daily traffic volumes were not broken down by weekdays and weekend days. While volumes can be expected to be greater on weekdays than on weekend days, for the purposes of calculating vehicle emissions, daily volumes were assumed to be the same throughout the week. Thus althogh the traffic volumes are similar, the speeds considered during weekdays and weekend days were different.

As presented in **Table 11** congestion is expected to increase in 2031 if no alterations are considered to the existing network. When drivers are faced with long travelling delays, there is a tendency to find alternative routes. This results in a decrease in the expected number of vehicles travelling on that route and an increase of traffic volumes on alternative routes. However, in the case of the projected 2031 scenario with the new bridge, no congestion has been assumed. The configuration with the Project will not only maintain the regular route users, but will also divert additional traffic from other routes.

4.2 Vehicle Emissions

Vehicle-generated emissions of CACs and TACs for the 2031 scenarios with and without the Project are summarized in **Table 12**, which also shows the per cent emission changes that may occur in the future scenarios when compared with the 2011 estimates.

Table 12 Annual Emissions: Existing and Future with and without the Project

Species	Emissions (tonnes/yr)			Change from 2011 (%)		Difference between Future With and Without the Project (%)
	Existing Roads	Without Project	With Project			
	2011	2031	2031	Without Project	With Project	
VOCs	234.4	139.9	123.5	-40%	-47%	-12%
CO	3594.5	3216.5	3444.7	-11%	-4%	7%
NOx	388.4	166.1	169.6	-57%	-56%	2%
SO_2	2.7	2.8	2.6	4%	-2%	-6%
NH_3	11.8	9.8	9.6	-17%	-19%	-2%
PM (Vehicles)	14.9	12.8	9.4	-14%	-37%	-27%
PM_{10} (Vehicles)	14.9	12.8	9.4	-14%	-37%	-27%
$PM_{2.5}$ (Vehicles)	11.0	7.2	6.3	-35%	-42%	-11%
Diesel PM	4.1	0.4	0.4	-89%	-91%	-18%
PM (Road Dust)	279.5	345.4	383.2	24%	37%	11%
PM_{10} (Road Dust)	53.6	66.3	73.5	24%	37%	11%
$PM_{2.5}$ (Road Dust)	13.0	16.0	17.8	24%	37%	11%
Benzene	7.8	4.1	4.2	-47%	-47%	1%
Naphthalene	0.5	0.3	0.3	-44%	-46%	-3%
1,3-Butadiene	0.8	0.4	0.4	-49%	-46%	5%
Formaldehyde	2.8	1.7	1.7	-37%	-40%	-5%
Acetaldehyde	2.4	1.3	1.3	-44%	-43%	1%
Acrolein	0.2	0.1	0.1	-47%	-50%	-5%
Benzo(a)pyrene	8.4E-04	5.7E-04	5.9E-04	-33%	-31%	3%

Table 12 shows that, in general, the predicted emissions of most pollutants are lower in 2031 than in 2011. Although traffic in 2031 is projected to have increased by 23 per cent without the Project and 37 per cent with the Project (as described in Section 4.1 and shown in Table 9), reductions in emissions per vehicle by 2031 are large enough to offset increases in traffic volume. The reductions in per-vehicle emission by 2031 are due to the introduction of newer engine technologies in the vehicle fleet that provide better fuel efficiency.

Road dust and SO_2 are the two pollutants that are not projected to decrease by 2031. Road dust emissions are dependent only on VkmT, silt loading, vehicle fleet average weight, and precipitation days per year. Since all parameters are considered constant from 2011 to 2031, except for the VkmT, road dust emissions increase in direct proportion to VkmT growth as a result of increased traffic volume.

SO_2 emissions are highly dependent on fuel quality and consumption. Since there is no new fuel regulation being planned or implemented, the increase that occurs in SO_2 emissions in 2031 without the project is likely due to number of vehicles entering the fleet resulting in higher overall fuel consumption. Although the SO_2 emission factors show a slight decrease from 2011 to 2031, this decrease is not enough to offset the anticipated increase in traffic volumes and congestion in 2031 without the Project. The emissions of SO_2 are lower in 2031 with the Project than without the Project due to the lower levels of congestion expected with the new bridge.

Most pollutants, including TACs, show a declining emissions trend when comparing the 2031 scenario with Project to 2031 without the Project. The decrease in emissions is due to less congestion expected to occur in the road network with the Project. Overall, the reduction in emissions per vehicle is greater than the increase in emissions that would be anticipated to occur as a result of increases in traffic volumes. The only exceptions to this are the emissions of CO, NOx, benzene, 1,3-butadiene, acetaldehyde and benzo(a)pyrene. The reduction of emissions per vehicle for these pollutants is not large enough to offset increases in traffic volume. Lastly, as mentioned previously, road dust emissions are only dependent on VkmT; therefore, the emissions are projected to increase linearly, in the 2031 with Project scenario, to the traffic growth in the absence of any other mitigating factors.

The declining emissions trend observed for road segment 3 (Tunnel) alone is much more significant when comparing the 2031 scenario with Project to 2031 without the Project. This trend is shown in **Table 13**. For the 2031 with Project scenario, all CAC pollutants associated with segment 3, with the exception of road dust, show a marked decline ranging from 56 per cent for VOC, 6 per cent for CO, 25 per cent for NOx, 45 per cent for SO_2, 73 per cent for vehicle PM_{10}, 55 per cent for vehicle $PM_{2.5}$ and 64 per cent for diesel PM. Similar trend is also observed for TAC emissions. This pollutant declining trend is attributable to less congestion on this segment after the Tunnel is replaced with a new bridge. The increase in road dust shown in **Table 13** is primarily due to the increase in VkmT as discussed previously.

Table 13 Annual Emissions: Existing and Future with and without the Project for Road Segment 3 (Tunnel / new bridge and approach)

Species	Emissions (tonnes/yr)			Change from 2011 (%)[1]		Difference between Future With and Without the Project (%)
	Existing Segment 3	Without Project	With Project			
	2011	2031	2031	Without Project	With Project	
VOCs	62.5	46.3	20.5	-26%	-67%	-56%
CO	683.7	604.6	570.8	-12%	-17%	-6%
NOx	78.1	37.5	28.1	-52%	-64%	-25%
SO_2	0.7	0.8	0.4	21%	-34%	-45%
NH_3	2.7	2.5	1.6	-5%	-40%	-37%
PM (Vehicles)	4.8	5.7	1.6	18%	-68%	-73%
PM_{10} (Vehicles)	4.8	5.7	1.6	18%	-68%	-73%
$PM_{2.5}$ (Vehicles)	2.9	2.3	1.1	-20%	-64%	-55%
Diesel PM	1.2	0.2	0.1	-87%	-95%	-64%
PM (Road Dust)	45.5	54.9	63.5	21%	40%	16%
PM_{10} (Road Dust)	8.7	10.5	12.2	21%	40%	16%
$PM_{2.5}$ (Road Dust)	2.1	2.5	2.9	21%	40%	16%
Benzene	1.7	1.0	0.7	-42%	-58%	-28%
Naphthalene	0.1	0.1	4.3E-02	-37%	-62%	-40%
1,3-Butadiene	0.2	0.1	0.1	-48%	-56%	-14%
Formaldehyde	0.7	0.5	0.3	-26%	-58%	-44%
Acetaldehyde	0.5	0.3	0.2	-39%	-56%	-28%
Acrolein	4.0E-02	2.3E-02	1.3E-02	-41%	-66%	-43%
Benzo(a)pyrene	2.2E-04	1.2E-04	9.7E-05	-44%	-55%	-21%

[1]**Note:** The emission numbers in columns 2, 3, and 4 have been rounded off to the tenth decimal place, an may not accurately reflect the percent change from 2011 as presented in this column.

5.0 Dispersion Modelling Results

5.1 Existing Air Quality

Ambient air quality evaluations provide an indication of the overall air quality within a localized area, rather than an analysis of specific emission sources. This type of an evaluation offers an insight into air quality within an area prior to the addition or modification of sources of air contaminants, such as the proposed modifications identified for the Project. The air quality evaluation can then be used to determine the capacity of the airshed to accept additional emission inputs while maintaining a desirable level of air quality.

5.1.1 Summary of Background Ambient Air Quality

The following are key results based on the data recorded at the monitoring stations:

- The measured CO concentrations are similar at T15, T18 and T31, while T39 records relatively low concentrations. Station T17 recorded the highest maximum one-hour concentration but was still well below the most stringent AAQO.
- The measured NO_2 concentrations were consistent across all monitoring stations.
- The measured ground level O_3 concentrations are similar at all locations. Each station recorded exceedances of the one-hour, 24-hour, and annual AAQO, while only T13, T15 and T17 exceeded the 8-hour average AAQO.
- The measured PM_{10} concentrations were similar at the two locations that monitor for PM_{10} (T18, T31).
- The measured one-hour $PM_{2.5}$ concentrations vary across stations while the 24-hour and annual concentrations are consistent across stations. T13, T18, T31, and T39 all recorded exceedances of the most stringent 24-hour AAQO.
- The measured SO_2 concentrations at the four stations where SO_2 is recorded (T17, T18, T31 and T39) are similar.

Except where noted, the Metro Vancouver monitoring stations can be considered as representative of the air quality in the Project area, and they can be used to set a baseline air quality against which effects of the proposed Project can be measured.

Baseline values for CO, NO_2, PM_{10}, $PM_{2.5}$, and SO_2 were established from the ambient air quality data analysis using data from the Metro Vancouver network of monitoring stations. **Table 14** presents the background values that are used as a basis for assessing the potential impact of the Project's emissions on the local air quality. For the non-annual averaging periods, the maximum 98th percentile from the six stations and five years of data analyzed are used as the background. The annual baseline value is the average of the maximum annual average ambient concentrations across all six ambient air quality stations.

Table 14 Background Values for CO, NO_2, PM_{10}, $PM_{2.5}$ and SO_2

	CO			NO_2			$PM_{2.5}$		PM_{10}		SO_2		
	1-h	8-h	Yr	1-h	24-h	Yr	24-h	Yr	24-h	Yr	1-h	24-h	Yr
Baseline Value ($\mu g/m^3$)	1,271	1,116	287.6	75.2	62.3	24.6	14.6	4.4	28.9	12.8	9.9	7.0	2.0

Table 15 provides a summary of the background values for the available TACs, benzene, and 1,3-butadiene. The 24-hour value in both cases is the maximum recorded concentration during the period while the annual concentration is based on the maximum annual average from the Burnaby South National Air Pollution Surveillance monitoring station.

Table 15 Background Values for Toxic Air Contaminants

	Benzene		1,3-butadiene	
	24-h	Yr	24-h	Yr
Baseline Value (µg/m3)	2.44	0.635	0.43	0.08

5.2 Results by Pollutant

Presented below are the predicted concentrations of CACs and TACs associated with Highway 99 traffic in the Project area. Each sub-section presents the results from the three traffic scenarios considered in this evaluation. For each pollutant, the most stringent ambient air quality objective is listed; bolded values indicate an exceedance of the applicable AAQO. For all pollutants except VOCs, predicted concentrations are presented for those averaging periods (i.e., 1-hour, 8-hour, 24-hour, or Annual) that have AAQO associated with them. There are no AAQOs for VOCs and formaldehyde; predicted concentrations of these compounds averaged over one hour, 24 hours, and one year are presented to facilitate a comparison of future conditions against current conditions.

5.2.1 Volatile Organic Compounds

Table 16 presents the predicted maximum and maximum 98^{th} percentile concentrations from the dispersion model for VOCs.

Table 16 Predicted Concentrations of Volatile Organic Compounds

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	2,796.7	1,167.9	1,832.2	764.2	393.5	134.4	n/a
24-hour	256.3	162.2	193.7	123.1	49.4	32.9	n/a
Annual	73.4	n/a	55.8	n/a	13.8	n/a	n/a

Note: n/a = not applicable

There are no AAQOs for VOCs, but the 2011 existing scenario has the highest predicted concentrations of the three scenarios, while the 2031 scenario with the Project has the lowest predicted concentrations.

5.2.2 Carbon Monoxide

Table 17 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for CO.

Table 17 Predicted Concentrations of Carbon Monoxide

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	**20,325.1**	8,616.0	**17,500.5**	7,422.3	10,977.6	3,758.8	14,300
8-hour	4,980.6	2,491.8	4,470.6	2,348.2	2,439.8	1,222.7	5,500

Note: Bolded values indicate exceedances of the relevant AAQO

For the existing scenario in 2011 and the 2031 without Project scenario, the maximum one-hour predicted concentration for CO exceeds the most stringent AAQO. None of the maximum 98th percentile 1-hour predications exceed the AAQO. The 2031 with Project 1-hour CO is 77 per cent of the most stringent objective of 14300 μg/m^3. There are no exceedances of the most stringent eight-hour AAQO.

5.2.3 Nitrogen Dioxide

Table 18 and **Table 19** presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for NO_2. Modelled concentrations of NOx were converted to NO_2 using 100% conversion (very conservative) and the Ambient Ratio Method method described in **Section 3.3.3**.

Table 18 Predicted Concentrations of Nitrogen Dioxide, 100% NO_x Conversion

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	**2,574.1**	**1,086.0**	**1,252.4**	**526.0**	**539.7**	184.0	188
Annual	**92.8**	n/a	**45.4**	n/a	18.6	n/a	40

Notes:
Bolded values indicate exceedances of the relevant AAQO;
n/a = not applicable

Table 19 Predicted Concentrations of Nitrogen Dioxide, ARM Conversion

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	115.6	104.1	105.9	96.0	96.3	87.3	188

Notes:
Bolded values indicate exceedances of the relevant AAQO;
n/a = not applicable

When NOx is converted to NO_2 with the 100% conversion method, all three scenarios exceed the one-hour objective with the exception of the 1-hour 98th percentile for the 2031 with Project scenario. This is a very conservative approach as all emitted NO_x does not convert to NO_2. Applying the more refined ARM method of NOx conversion, there are no exceedances of the 1-hour ambient air quality objectives. The ARM method is restricted to only 1-hour concentrations as there is not sufficient annual data to develop an ARM curve for annual concentrations.

Under ARM, the 2011 scenario is 61 per cent of the most stringent objective while the 2031 without project is 56 per cent of the objective. The 2031 with project is 51 per cent of the most stringent 1-hour objective.

5.2.4 Sulphur Dioxide

Table 20 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for SO_2.

Table 20 Predicted Concentrations of Sulphur Dioxide

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	27.6	11.6	29.9	12.5	8.3	2.8	196
24-hour	2.7	1.7	3.3	2.2	1.0	0.7	125
Annual	0.8	n/a	1.0	n/a	0.3	n/a	25

Note: n/a = not applicable

No exceedances were predicted for SO_2 in any of the three scenarios modelled. For the existing scenario, the maximum predicted one-hour concentration is 14 per cent of the objective, while the maximum predicted 24-hour and annual concentrations are two and three per cent of their respective objectives. The 2031 scenario without the Project has a maximum predicted one-hour concentration that is 15 per cent of the most stringent AAQO. The maximum 24-hour and annual concentrations are three and four per cent of their respective objectives. The 2031 scenario with the Project has a maximum predicted one-hour concentration of four per cent of the one-hour objective, while the maximum predicted 24-hour concentration and annual concentration are one percent of the objective.

5.2.5 Ammonia

Table 21 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for NH_3.

Table 21 Predicted Concentrations of Ammonia

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	11.0	6.9	10.5	6.9	3.8	2.5	100

For each of the three scenarios modelled, there are no exceedances of the 24-hour objective for NH_3. The 2011 scenario has a maximum predicted 24-hour concentration, which is 11 per cent of the objective. For the 2031 without the Project, the maximum 24-hour predicted concentration is 10 per cent of the objective, while the 2031 with the Project is four per cent of the objective.

5.2.6 Fine Particulate Matter

Table 22 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for $PM_{2.5}$.

Table 22 Predicted Concentrations of Fine Particulate Matter

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	12.1	7.6	9.6	6.4	2.5	1.7	25
Annual	3.5	n/a	2.8	n/a	0.7	n/a	8

Note: n/a = not applicable

No exceedances were predicted for $PM_{2.5}$ in any of the three scenarios modelled. For the existing scenario, the maximum predicted 24-hour concentration is 48 per cent of the objective. The maximum predicted annual average is 39 per cent for the 2031 without the Project and 10 per cent of the objective in the 2031 with Project scenario.

5.2.7 Inhalable Particulate Matter

Table 23 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for PM_{10}.

Table 23 Predicted Concentrations of Inhalable Particulate Matter

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	19.5	12.4	23.1	15.3	3.8	2.5	50
Annual	5.6	n/a	6.8	n/a	1.1	n/a	20

Note: n/a = not applicable

The predicted maximum 24-hour and annual concentrations for the 2011 existing scenario are under the most stringent AAQOs, and are 39 per cent and 28 per cent of the objectives, respectively. For the 2031 scenario without the Project, there are no predicted exceedances of the 24-hour or annual objective. The predicted maximum 24-hour concentration is 46 per cent of the most stringent objective, while the maximum predicted annual concentration is 34 per cent of the most stringent AAQO. With the Project operational in 2031, the maximum predicted 24-hour and maximum predicted annual concentrations are eight per cent and six per cent of the most stringent objectives, respectively.

5.2.8 Road Dust

Table 24 and **Table 25** present the predicted maximum and maximum 98th percentile concentrations from the dispersion model for the PM_{10} and $PM_{2.5}$ component of road dust.

Table 24 Predicted Concentrations of Inhalable Particulate Matter from Road Dust

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	37.1	23.1	45.1	29.2	29.5	19.6	50
Annual	11.7	n/a	14.2	n/a	8.1	n/a	20

Note: n/a = not applicable

None of the scenarios are predicted to exceed the AAQOs.

The maximum predicted 24-hour average concentration for the 2011 existing scenario is 74 per cent of the most stringent AAQO, while the maximum predicted annual average concentration is 59 per cent of the objective. In the 2031 scenario without the Project, the maximum predicted 24-hour average concentration is 90 per cent of the objective. The maximum predicted annual average concentration is 71 per cent of the most stringent AAQO. For the operational phase of the Project in 2031, the maximum predicted 24-hour average concentration is 59 per cent of the objective, while the maximum predicted annual average concentration is 40 per cent of the objective.

Table 25 Predicted Concentrations of Inhalable Fine Particulate Matter from Road Dust

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	9.0	5.6	10.9	7.1	7.1	4.7	25
Annual	2.8	n/a	3.4	n/a	2.0	n/a	8

Note: n/a = not applicable

There are no predicted exceedances of the $PM_{2.5}$ objectives for any of the three modelled scenarios. The maximum predicted 24-hour average concentration for the 2011 existing scenario is 36 per cent of the most stringent AAQO, while the maximum predicted annual average concentration is 35 per cent of the objective. In the 2031 scenario without the Project, the maximum predicted 24-hour average concentration is 44 per cent of the objective. The maximum predicted annual average concentration is 43 per cent of the most stringent AAQO. For the operational phase of the Project in 2031, the maximum predicted 24-hour average concentration is 28 per cent of the objective, while the maximum predicted annual average concentration is 24 per cent of the objective.

5.2.9 Benzene

Table 26 presents the predicted maximum and maximum 98^{th} percentile concentrations from the dispersion model for benzene.

Table 26 Predicted Concentrations of Benzene

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98^{th} Percentile	Maximum Predicted	98^{th} Percentile	Maximum Predicted	98^{th} Percentile	
1-hour	**58.0**	24.4	**32.4**	13.6	13.3	4.5	30
24-hour	**6.9**	**4.3**	**4.0**	**2.6**	1.7	1.1	2.3
Annual	**2.0**	n/a	**1.2**	n/a	**0.5**	n/a	0.45

Notes:
Bolded values indicate exceedances of the relevant AAQO
n/a = not applicable

For the existing scenario in 2011, the predicted maximum one-hour average concentration exceeds the AAQO, but the 98^{th} percentile does not exceed the objective. The 24-hour and annual concentrations also exceed the AAQO. The 2031 scenario without the Project has exceedances for the maximum predicted 24-hour and annual averaging periods. The maximum predicted 98^{th} percentile does not exceed the AAQO. In the 2031 with the Project operational, there are predicted exceedances for the annual objective only. The maximum predicted one-hour concentration is 44 per cent of the objective.

5.2.10 Naphthalene

Table 27 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for naphthalene.

Table 27 Predicted Concentrations of Naphthalene

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	0.5	0.3	0.3	0.2	0.1	0.1	22.5

For each of the three scenarios modelled, there are no exceedances of the 24-hour objective for naphthalene. The 2011 existing scenario has a maximum predicted 24-hour concentration that is two per cent of the objective. For the 2031 scenario without the Project, the maximum 24-hour predicted concentration one per cent of the objective, while the 2031 with the Project is less than one per cent of the objective.

5.2.11 1,3-butadiene

Table 28 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for 1,3-butadiene.

Table 28 Predicted Concentrations of 1,3-Butadiene

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	0.7	0.4	0.4	0.2	0.2	0.1	10
Annual	0.2	n/a	0.1	n/a	0.0	4.9E-02	2

Note: n/a = not applicable

The 24-hour average concentration is seven per cent of the most stringent AAQO, while the maximum predicted annual average concentration is 10 per cent of the objective. In the 2031 scenario without the Project, the maximum predicted 24-hour average concentration is four per cent of the objective. The maximum predicted annual average concentration is five per cent of the most stringent AAQO. For the 2031 scenario with the Project, both the maximum predicted 24-hour average concentration are two per cent of the objective.

5.2.12 Formaldehyde

Table 29 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for formaldehyde. There are no ambient air quality objectives available for formaldehyde.

Table 29 Predicted Concentrations of Formaldehyde

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	26.3	11.0	18.1	7.6	0.8	0.3	60

Note: n/a = not applicable

There are no exceedances of the BC Action air quality objective for formaldehyde on the 1-hour averaging period. The 2011 scenario maximum concentration is 44 per cent of the objective The 2031 without Project scenario and the 2031 with Project scenario are 30 per cent and 1 per cent of the objective, respectively.

5.2.13 Acetaldehyde

Table 30 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for acetaldehyde.

Table 30 Predicted Concentrations of Acetaldehyde

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	18.1	7.6	10.5	4.4	4.3	1.5	90
24-hour	2.1	1.3	1.3	0.9	0.5	0.4	500

No exceedances were predicted for acetaldehyde in any of the three scenarios modelled. For the existing scenario, the maximum predicted one-hour concentration is 20 per cent of the objective, while the maximum predicted 24-hour is less than one per cent of the objective. The 2031 scenario without the Project has a maximum predicted one-hour concentration that is 12 per cent of the most stringent AAQO. The maximum 24-hour is less than one per cent of the objective. The 2031 scenario with the Project has a maximum predicted one-hour concentration that is five per cent of the one-hour objective, while the maximum predicted 24-hour concentration is less than one per cent of the objective.

5.2.14 Acrolein

Table 31 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for acrolein.

Table 31 Predicted Concentrations of Acrolein

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
1-hour	1.7	0.7	0.9	0.4	0.3	0.1	4.5
24-hour	0.2	0.1	0.1	0.1	3.2E-02	2.1E-02	0.4

No exceedances were predicted for acrolein in any of the three scenarios modelled. For the existing scenario, the maximum predicted one-hour concentration is 37 per cent of the objective, while the maximum predicted 24-hour concentration is 41 per cent of the objective. The 2031 scenario without the Project has a maximum predicted one-hour concentration that is 19 per cent of the most stringent AAQO. The maximum 24-hour concentration is 24 per cent of the objective. The 2031 scenario with the Project has a maximum predicted one-hour concentration of six per cent of the one-hour objective, while the maximum predicted 24-hour is 8 per cent of the objective.

5.2.15 Benzo(a)pyrene

Table 32 presents the predicted maximum and maximum 98th percentile concentrations from the dispersion model for benzo(a)pyrene. For all three scenarios, the predicted maximum 24-hour and annual concentrations exceed the AAQO.

Table 32 Predicted Concentrations of Benzo(a)pyrene

Averaging Period	2011 - Existing Roads		2031 – Without Project		2031 – With Project		Ambient Air Quality Objective
	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	Maximum Predicted	98th Percentile	
24-hour	**8.9E-04**	**5.7E-04**	**5.1E-04**	**3.3E-04**	**2.3E-04**	**1.6E-04**	5.00E-05
Annual	**2.6E-04**	**n/a**	**1.5E-04**	**n/a**	**6.4E-05**	**n/a**	1.00E-05

Notes:
Bolded values indicate exceedances of the relevant AAQO
n/a = not applicable

5.2.16 Ozone

Estimations of the change in O_3 concentrations are summarized for 2031 with and without the Project are summarized in **Table 33** (Steyn et al. 2011). The analysis suggests that in the western portion of the LFV, which is VOC-limited, a reduction in NOx and VOC emissions without the Project would result in a very slight increase (less than 0.1 µg/m^3) in O_3 concentrations in 2031 compared with 2011 existing concentrations. A reduction in NOx and VOC emissions with the Project would result in a very slight increase (less than 0.1 µg/m^3) in O_3 concentrations in 2031 compared with 2011 existing concentrations. When comparing 2031 with and without the Project, the change in NOx and VOC emissions is so small that there is a negligible difference in expected O_3 concentrations.

Overall, the change in O_3 concentrations is negligible, with a worst-case estimate of a peak change of less than 0.1 µg/m^3 in 24-hour average concentrations. These changes in ground-level O_3 are considered to be negligible because they fall within the range of accuracy of O_3 sampling equipment (i.e., ±1 ppb or ±2 µg/m^3). Therefore, the change in O_3 levels, with or without the Project, would fall within the noise levels of O_3 monitoring equipment, resulting in no measurable change in O_3 levels in the LFV.

Table 33 Predicted Maximum Concentrations (µg/m³) for Ozone

Criteria	100 µg/m3	121.6 µg/m3	30 µg/m3	30 µg/m3
	O_3 Concentration, µg/m^3			
Emissions Scenario	**1 h**	**8 h**	**24 h**	**Annual**
2011 O_3 concentration	88.7	84.7	81.6	47.2
2031 without the Project	88.7	84.7	81.6	47.2
2031 with the Project	88.7	84.7	81.6	47.2

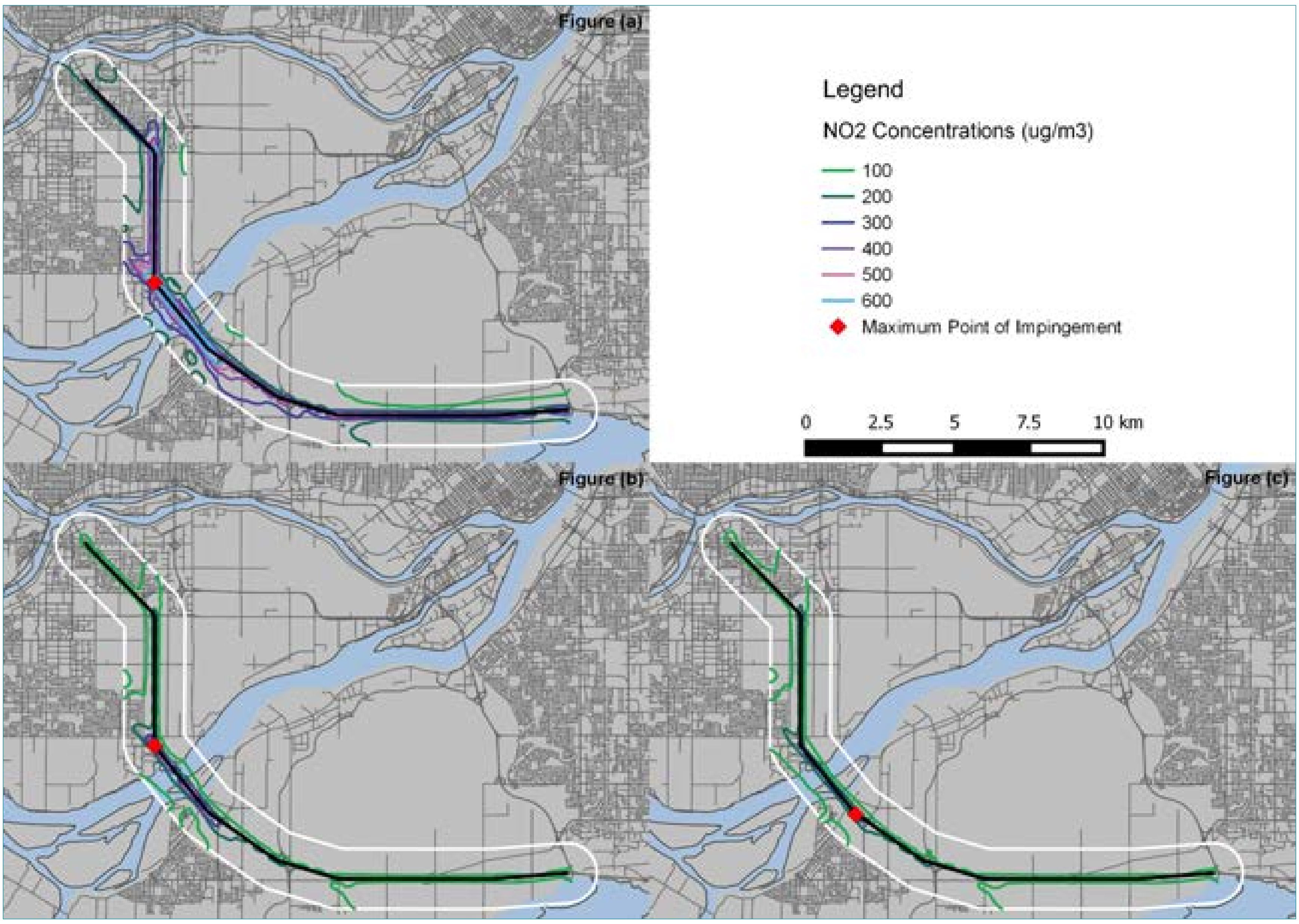
5.3 Spatial Variability of Predicted Concentrations

In the previous sections, tabular results were presented for the maximum predicted concentration for each pollutant under each of the three scenarios (**Table 16** to **Table 32**). The tabular results demonstrate the worst-case predictions at specific locations; however, to illustrate the spatial variability associated with dispersion, contour plots for NO_2 are presented in this section (**Figure 4** to **Figure 6**). These contour plots illustrate the decrease in concentration as a function of distance from the roadway. The contour plots clearly show that the highest concentrations are located in areas where there are a high number of vehicles, and that predicted concentrations are related to the distance from the road, with the highest values being recorded by the receptors that are five to 15 m from the road edge.

For the current scenario and the 2031 scenario without the Project, there are areas of higher concentrations located at the either entrance to the Tunnel. The 2031 scenario with the Project shows higher concentrations near at the southern end of the bridge, near Highway 17A.

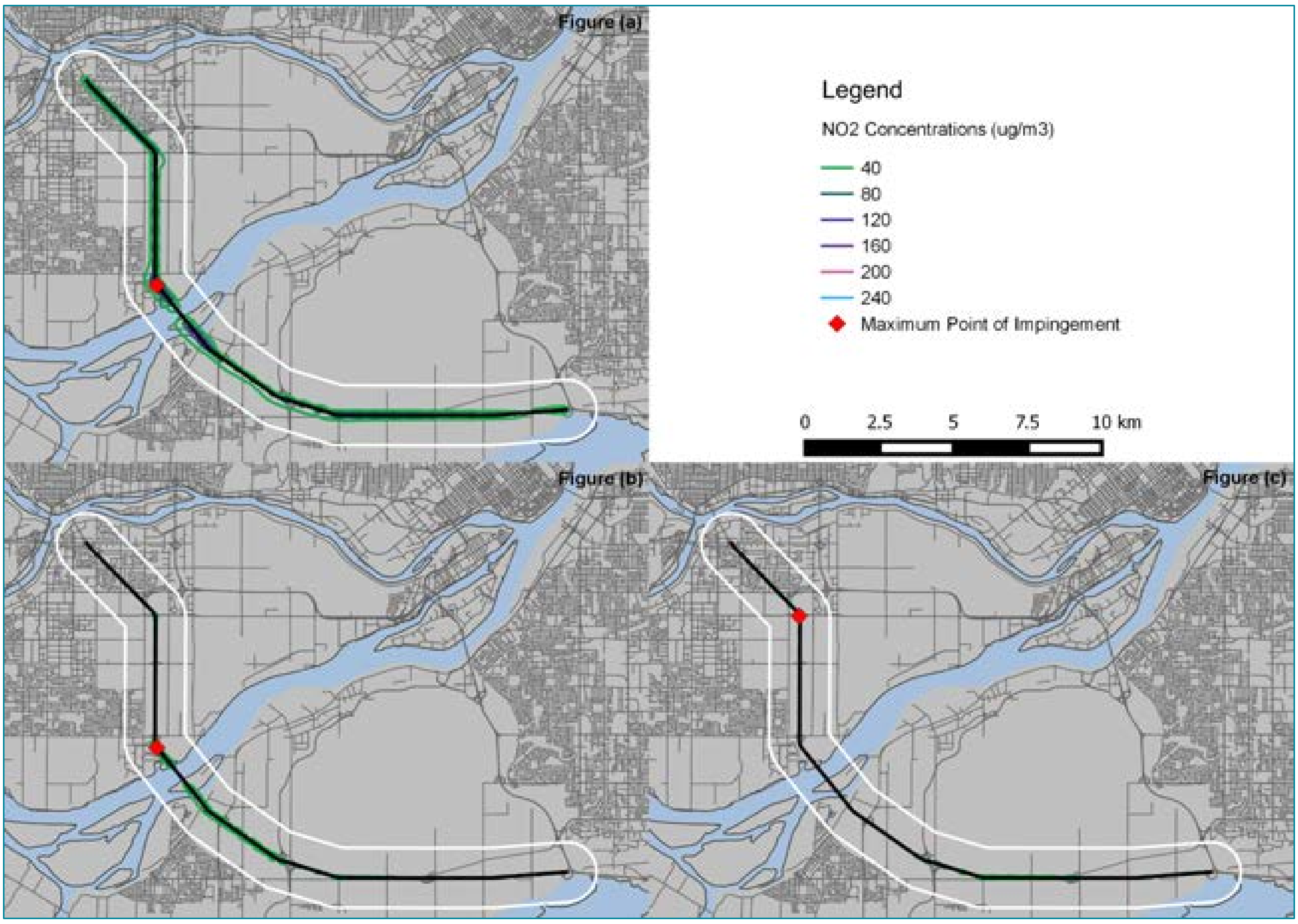
The locations of the maximum predicted values for one-hour, 24-hour, and annual averaging periods are also shown on **Figure 4** to **Figure 6**. While the figures present the maximum values for NOx, other pollutants exhibit similar patterns. Generally, in 2011 and 2031 without the project, concentrations are near the entrance to the Tunnel for all three averaging periods. Concentrations tend to decrease away from the road.

For the 2031 scenario with the Project, the maximum one-hour emission is located near the south side of the new bridge. Peak one-hour traffic is significantly higher on the new bridge than through the Tunnel, which likely contributes to the maximum one-hour emission occurring near the new bridge approaches. The 24-hour and annual averaging periods predict the maximum emission occur near Westminster Highway due to the increased traffic along that link. Because, for the purposes of this study, the new bridge has been modelled at a constant height of 10 m, this increases the dispersion that occurs before the plume reaches a receptor. This, along with the increase vehicle traffic, leads to the maximum 24-hour and annual concentration predictions to occur on near Westminster Highway and not on the new bridge.



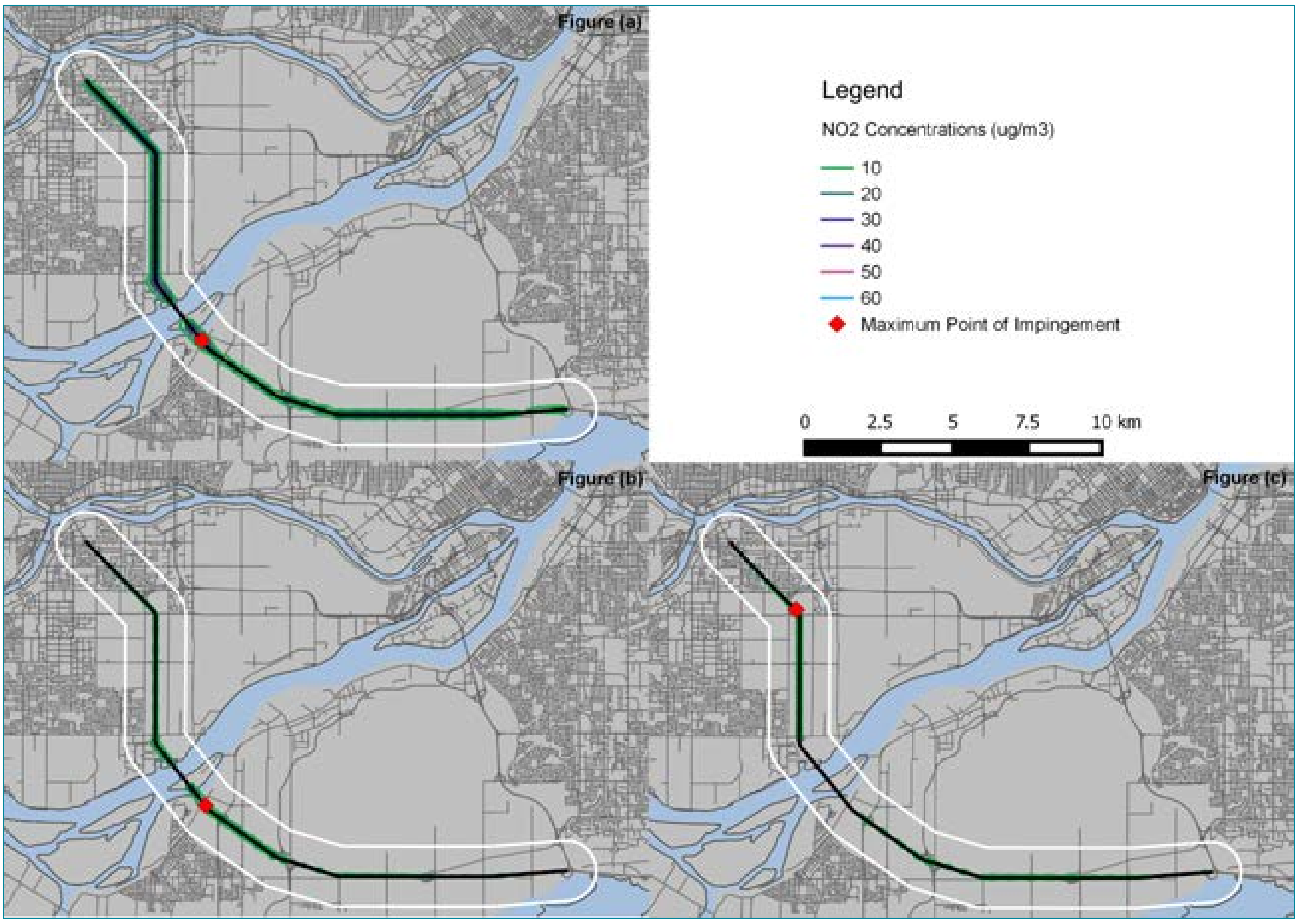
Notes: Figure (a): predicted NO_2 concentrations for current conditions, Figure (b): predicted NO_2 concentrations for future conditions without the Project, Figure (c): predicted NO_2 concentrations for future conditions with the Project

Figure 4 Spatial Variability of the Maximum Predicted 1-hour Nitrogen Dioxide Concentrations



Notes: Figure (a): predicted NO_2 concentrations for current conditions
Figure (b): predicted NO_2 concentrations for future conditions without the Project
Figure (c): predicted NO_2 concentrations for future conditions with the Project

Figure 5 Spatial Variability of the Maximum Predicted 24-Hour Nitrogen Dioxide Concentrations



Notes: Figure (a): predicted NO_2 concentrations for current conditions
Figure (b): predicted NO_2 concentrations for future conditions without the Project
Figure (c): predicted NO_2 concentrations for future conditions with the Project

Figure 6 Spatial Variability of the Maximum Predicted Annual Nitrogen Dioxide Concentrations

5.4 Summary

Table 34 shows predicted maximum concentrations of Highway 99-related emissions of key pollutants, based on dispersion modelling results. Of the three scenarios, the 2031 scenario with the Project has the lowest predicted maximum concentrations for all pollutants and averaging periods. While more vehicle traffic is predicted to use the road due to increased capacity, improvements in fleet technology, combined with a higher average travel speed and improved dispersion of pollutants, is expected to lead to reduced ambient concentrations, especially for 1-hour concentrations, in the study area.

Table 34 Summary of Maximum Predicted Highway 99-related Emission Concentrations

Pollutant	Averaging Period	2011 Existing (μg/m^3)	2031 Without Project (μg/m^3)	2031 With Project (μg/m^3)
CO	1-hour	20,325.1	17,500.5	10,977.6
	8-hour	4,980.60	4,470.60	2,439.78
NO_2 (100% conversion)	1-hour	2,574.1	1,252.4	539.7
	24-hour	327.2	157.1	67.8
	Annual	92.8	45.4	18.6
SO_2	1-hour	27.6	29.9	8.3
	24-hour	2.7	3.3	1.0
	Annual	0.8	1.0	0.3
PM_{10} (vehicles)	24-hour	19.5	23.1	3.8
	Annual	5.6	6.8	1.1
PM_{10} (road dust)	24-hour	37.1	45.1	29.5
	Annual	11.7	14.2	8.1
Total PM_{10}	24-hour	56.7	68.2	33.2
	Annual	17.4	21.1	9.2
$PM_{2.5}$ (vehicles)	24-hour	12.1	9.6	2.5
	Annual	3.5	2.8	0.7
$PM_{2.5}$ (road dust)	24-hour	9.0	10.9	7.1
	Annual	2.8	3.4	2.0
Total $PM_{2.5}$	24-hour	21.1	20.6	9.6
	Annual	6.3	6.3	2.7
Benzene	24-hour	6.9	4.0	1.7
	Annual	2.0	1.2	0.5
1,3-butadiene	24-hour	0.7	0.4	0.2
	Annual	0.2	0.1	0.0

6.0 Regional Air Quality Evaluation

6.1 Regional Emissions

This section discusses the potential effects of the proposed Project on regional air quality in 2031. Consideration is given to Project-related air emissions, as well future changes in regional emissions that may occur as a result of other transportation projects or changes in regulatory policies and programs, including those outlined in Section **6.2**. Forecast 2031 LFV emissions include projected emissions from these other transportation projects (Hou, personal communication, 2014) (**Table 35**). On a regional level, the Project pollutant emission contributions compared to the total forecast vehicle emissions in the LFV airshed are very small.

Table 35 Contribution of Project Emissions to the Lower Fraser Valley Vehicle Emissions

Pollutant	2031 Emissions (tonnes/yr)		Proportion of 2031 with Project to Overall LFV Vehicle Emissions (%)
	With Project	LFV Vehicle Emissions	
VOCs	123.5	6,514.0	2%
CO	3444.7	131,461.1	3%
NOx	169.6	9,167.1	2%
SO_2	2.6	56.7	5%
NH_3	9.6	436.9	2%
PM (vehicles)	9.4	332.2	3%
PM_{10} (vehicles)	9.4	332.2	1%
$PM_{2.5}$ (vehicles)	6.3	307.7	3%
PM (road dust)	383.2	38,559.6	1%
PM_{10} (road dust)	73.5	7,400.5	2%
$PM_{2.5}$ (road dust)	17.8	1,794.6	1%
Benzene	4.2	-	-
Naphthalene	0.3	-	-
1,3-butadiene	0.4	-	-
Formaldehyde	1.7	-	-
Acetaldehyde	1.3	-	-
Acrolein	0.1	-	-
Benzo(a)pyrene	5.9E-04	-	-

Notes: "-" = Information not available

Total estimated emissions of CACs from traffic in the 2031 scenario with the Project are between one and five per cent of the LFV total vehicle emissions. It is projected that, traffic being diverted from other routes (e.g., the Alex Fraser Bridge) will result in an additional reduction to emissions in the region due to the ease of traffic congestion. This anticipated decline in emissions represents a beneficial effect of the Project in the context of regional air quality, with forecast LFV emissions projected to be slightly lower than forecasted without the Project in full operation.

As discussed in **Section 4.1.1**, most pollutants show a declining emissions trend when comparing the 2031 with Project to the without Project scenario. This decrease in emissions, resulting from less congestion in the road network following the implementation of the Project, helps to further reduce the originally estimated 2031 LFV emission forecast prepared by Metro Vancouver.

6.2 Regional Air Quality

While it is not feasible to contemplate all projects and changes that may occur in the future, Metro Vancouver's emissions inventory does incorporate reasonable assumptions as to what future emissions will be, based on foreseeable changes within the LFV. Forecasted policy measures and new emission sources quantified in the inventory include Metro Vancouver Permit changes, a new waste-to-energy facility, and the Metro Vancouver Boiler and Heater Regulation (Metro Vancouver 2013).

Other reasonably foreseeable industrial projects that would result in emissions were also reviewed; none were considered to result in volumes of air emissions that might substantially influence local air quality. Those projects that could influence vehicle emissions are addressed within the context of the traffic modelling that incorporates certain land-use and marine activities. It was therefore assumed that modelling predicted concentrations, based on emissions in 2031 with the Project, when added to the existing background concentrations to account for contributions from all other sources, would appropriately describe potential effects of the Project on future regional air quality.

While some emissions are anticipated to remain steady, or to increase slightly in the future, conservative background concentration values were assumed to account as a reasonable surrogate for the contribution of those emissions, should there be additional emissions contributing to the ambient air quality in the vicinity of the Project in the future.

Table 36 provides an overview of regional air quality in 2031 with and without the Project in terms of maximum overall pollutant concentrations—i.e. predicted maximum Project-related emission concentrations plus background concentrations. Bolded values indicate an exceedance of the most stringent AAQO. Overall ambient concentrations of all pollutants in the region are predicted to be lower for the 2031 scenario with the Project when compared to the scenario without the Project in 2031.

Table 36 Predicted Regional Air Quality With and Without the Project in 2031

Pollutant	Averaging Period	Background Concentration (µg/m^3)	Overall Concentration in 2031 without Project (µg/m^3	Overall Concentration in 2031 with Project (µg/m^3)	Most Stringent AAQO (µg/m^3)
CO	1-hour	1271	**18,771.5**	12,248.6	14,300
	8-hour	1,116	**5,586.6**	3,555.8	5,500
NO_2 (ARM)	1-hour	-	105.9	96.3	188
	Annual	25	**70.4**	**43.6**	40
SO_2	1-hour	10	39.9	18.3	450
	24-hour	7	10.3	8.0	125
	Annual	2	3.0	2.3	25
Total PM_{10}	24-hour	29	**97.2**	**62.2**	50
	Annual	13	**34.1**	**22.2**	20
Total $PM_{2.5}$	24-hour	15	**35.6**	24.6	25
	Annual	4	**10.3**	6.7	8
Benzene	24-hour	2	**6.0**	**3.7**	2.3
	Annual	1	**2.2**	**1.5**	0.45
1,3-butadiene	24-hour	0.4	0.8	0.6	10
	Annual	0.1	0.2	0.1	2

Note: Bolded values indicate an exceedance of the most stringent AAQO

6.2.1 Summary of Key Findings

The air quality evaluation shows that local and regional air quality are predicted to be lower with the Project as compared to without it. Of the three scenarios considered, the 2031 scenario with the Project has the lowest predicted maximum concentrations for all pollutants and averaging periods. The 2031 with Project will increase vehicle capacity, and have a higher average travel speed and increased dispersion of pollutants near the bridge.

When comparing the existing (2011) road configuration scenario to 2031 without the Project (i.e., with the Tunnel still operational), there is a predicted improvement in some of the concentrations due to reduction in vehicle emissions through more stringent regulations, better technology, and turnover of the vehicle fleet.

When compared to the 2031 scenario without the Project, the 2031 scenario with the Project is predicted to result in further improvements in local air quality. While the 2031 scenarios with and without the Project both benefit from the same fleet emission improvements, the 2031 scenario with the Project also benefits from less congestion and higher vehicle speeds associated with the proposed Highway 99 improvements and Tunnel replacement. Some of the improvements related to the reduction in congestion have not been accounted for in this modelling, meaning the 2031 with Project scenario is a conservative estimate of the impact on air quality.

In the 2011 and 2031 scenarios without the Project, maximum predicted pollutant concentrations generally occur nearest the entrances to the Tunnel. Because the Tunnel is an enclosed structure, vehicle emissions can only exit through the Tunnel openings and exhaust fan towers. All of the emissions occurring inside the Tunnel are therefore concentrated and released over a small area. The new bridge, being elevated, will enable increased airflow along the entire crossing, resulting in improved dispersion of emissions and consequent improvement in local air quality near the bridge. The model shows that the locations of the maximum 1-hour concentration in the 2031 with Project occurs in the area south of the Bridge, near Highway 17A. The 24-hour and annual maximum concentrations with the Project are located in the area of Westminster Highway, which is a result of increased vehicle capacity resulting in more vehicles using Highway 99.

Overall ambient concentrations of certain pollutants exceed the most stringent AAQO under all three scenarios considered in this study; however, the number of pollutants that show an exceedance, as well as the degree of exceedance are similar in both of the 2031 scenarios, while the 2031 with Project scenario has significantly higher vehicle capacity and reduced congestion for the region.

7.0 References

Air Resources Board of California (ARB). 1998. Report to the Air Resources Board on the proposed identification of diesel exhaust as a toxic air contaminant (Part A). Exposure Assessment. As approved by the Scientific Review Panel on April 22, 1998. Available at http://www.arb.ca.gov/toxics/dieseltac/part_a.pdf. Accessed July 2014.

ATTACHMENT A

Dispersion Modelling Plan

Dispersion Modelling Plan

An electronic version of this plan is available from:
www.bcairquality.ca/reports/model-plans-instructions.html

GENERAL

Date: **February 15, 2016**

Facility Name, Company, Location (Lat, Long): **George Massey Tunnel Replacement Project**

Air Quality Consultant and Contact Name: **WSP**

Ministry Contact Name:

Li Huang

Air Quality Meteorologist

Clean Air Environmental Standards Branch

Ministry of Environment

3rd Floor, 2975 Jutland Road

Victoria, BC V8T 5J9

Tel: (250) 953-3433 Fax: (250) 356-5496

Level of Assessment (1, 2 or 3) and also provide rational for the proposed level of assessment:

Level 3 - This project is going through the BC environmental assessment process and covers a large spatial area.

Does this plan follow a modelling approach similar to that taken in a previous air quality assessment already reviewed and accepted by the Ministry? If so, provide the project name and Ministry contact:

Yes, this project follows methodologies developed for other large transportation infrastructure projects including the Sea to Sky Highway, Low Level Road Replacement, Port Mann Highway 1 and South Fraser Perimeter Road.

PROJECT DESCRIPTION AND GEOGRAPHIC SETTING

Provide an overview of the project description, including process description and the purpose of the dispersion modelling study.

To assess the impacts from vehicle traffic on air quality as it relates to the replacement of the George Massey Tunnel. This assessment will model three scenarios

1. **Current configuration of Highway 99 between Bridgeport and Highway 91**
2. **Current configuration with 2031 traffic of Highway 99 between Bridgeport and Highway 91**

3. **Highway 99 between Bridgeport and Highway 91 with a 10-lane bridge replacing the tunnel with 2031 traffic**

Future vehicle traffic volumes were obtained via traffic modelling while the fleet profiles were developed based on data from Metro Vancouver.

Provide a description of the following:

- Terrain characteristics within domain: flat terrain or complex terrain (i.e., will complex flow need to be considered?)
- Dominant land cover: urban, rural, industrial, agricultural, forested, rock, water, grassland

Within the 1-kilometer Local Assessment Area (LAA), which extends 1-kilometer from the modeled road link, the dominant land cover is agricultural and urban. Much of the urban land cover occurs in the northern portion of the LAA. The area is characterized as flat terrain at or near sea-level. Complex air flow will not be considered.

DISPERSION MODEL

Selected Dispersion Model:

- List model(s) and version to be used (see Section 2).

CALMET v6.334

CALINE3

- Specify any non-guideline models or versions (i.e., beta-test versions) planned for use (Section 2.3.1). Provide rationale.

CALINE3 was included in the previous version of the dispersion modelling guideline. It is currently EPA approved for transportation related dispersion modelling. The CAL3QHC model is built on the CALINE3 algorithms and was not used in this modelling assessment as it is for specialized modelling.

- If modifications to any of the models are planned, provide a description and the rationale (Section 2.3.2).

The CALINE3 model has been modified to allow for more receptors. No other changes to the source code have been made.

Default Switch Settings

- For AERMOD identify any switch settings that will be different than the recommended defaults (Section 7.7). Provide rationale.

N/A

- For CALMET/CALPUFF identify any key switch settings in CALMET and CALPUFF that will be different from the "black (do not touch)" defaults as per Tables 6.2 and 7.1. Provide rationale.

No CALMET switches have been changed.

- If the CALMET model is used, provide:
  - a CALMET domain map that also shows the locations of surface meteorological stations and upper air stations **Provided below.**
  - anticipated grid resolution: 500 (m)
  - number of grids in X and Y direction (NX = 340 , NY = 220)
  - vertical levels (m): 0 , 20 , 40 , 80 , 160 , 320 , 600 , 1500 , 3000

CALMET is used only to generate a single point of meteorology near the project site. Metro Vancouver operates ambient air quality monitoring stations which also record surface meteorology. Six Metro Vancouver stations were used along with a WRF prognostic data set. In addition to the six Metro Vancouver stations, the Environment Canada surface meteorology station located at the Vancouver International Airport was used in order to provide all of the parameters required by CALMET. The stations used were:

- **T13 – North Delta**
- **T15 – Surrey East**
- **T17 – Richmond South**
- **T18 – Burnaby South**
- **T38 – Annacis Island**
- **T39 – Tsawwassen**
- **Vancouver Airport – Environment Canada station**

AERMOD and Receptors

If the AERMET/AERMOD model is used, provide the following:

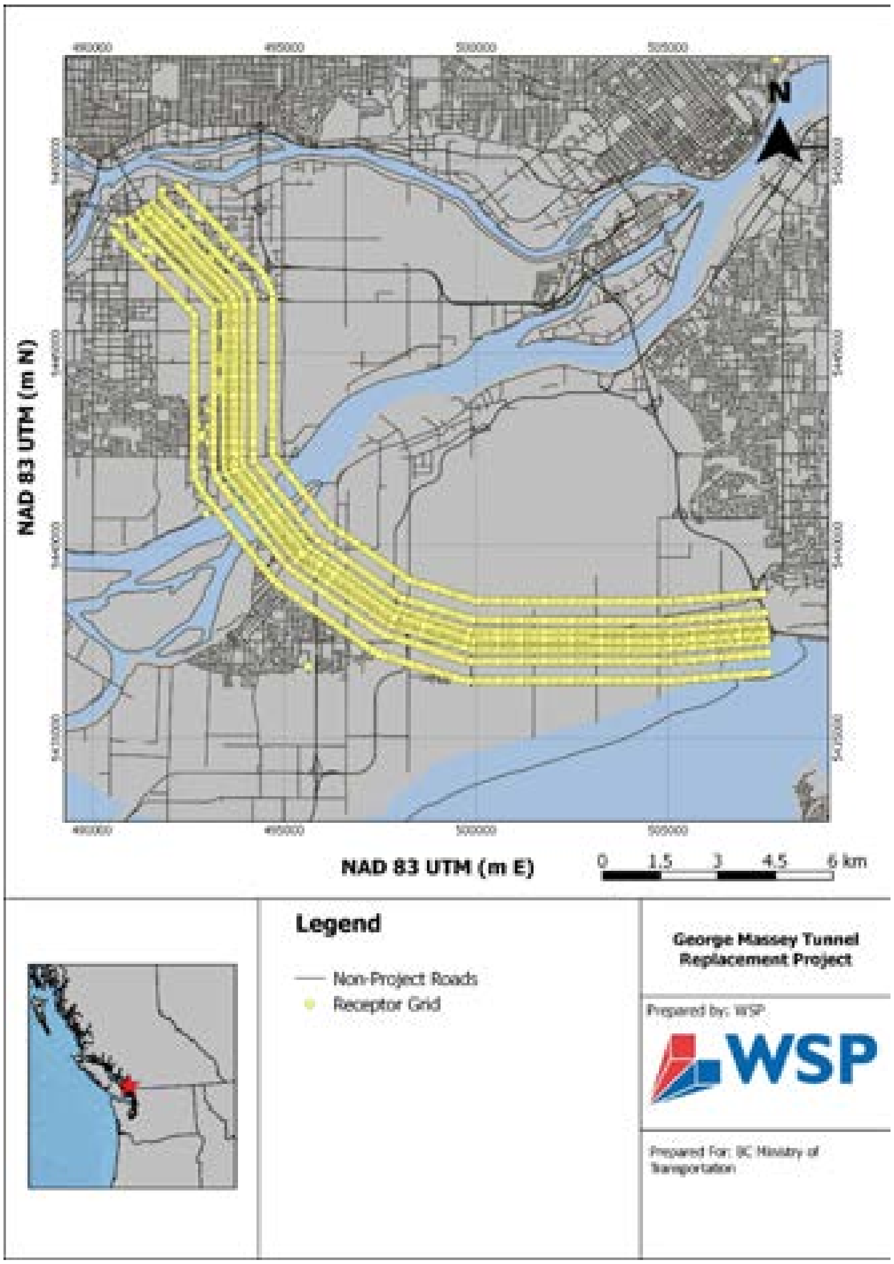
- proposed receptor grid spacing (see Section 7.2):
- an AERMET/AERMOD domain map that shows the locations of surface meteorological stations, upper air stations and receptor grid
- anticipated sensitive receptors (see Section 7.4) and also indicate them on the domain map (if applicable)
- receptor (flagpole) height (m) (see Section 7.5):

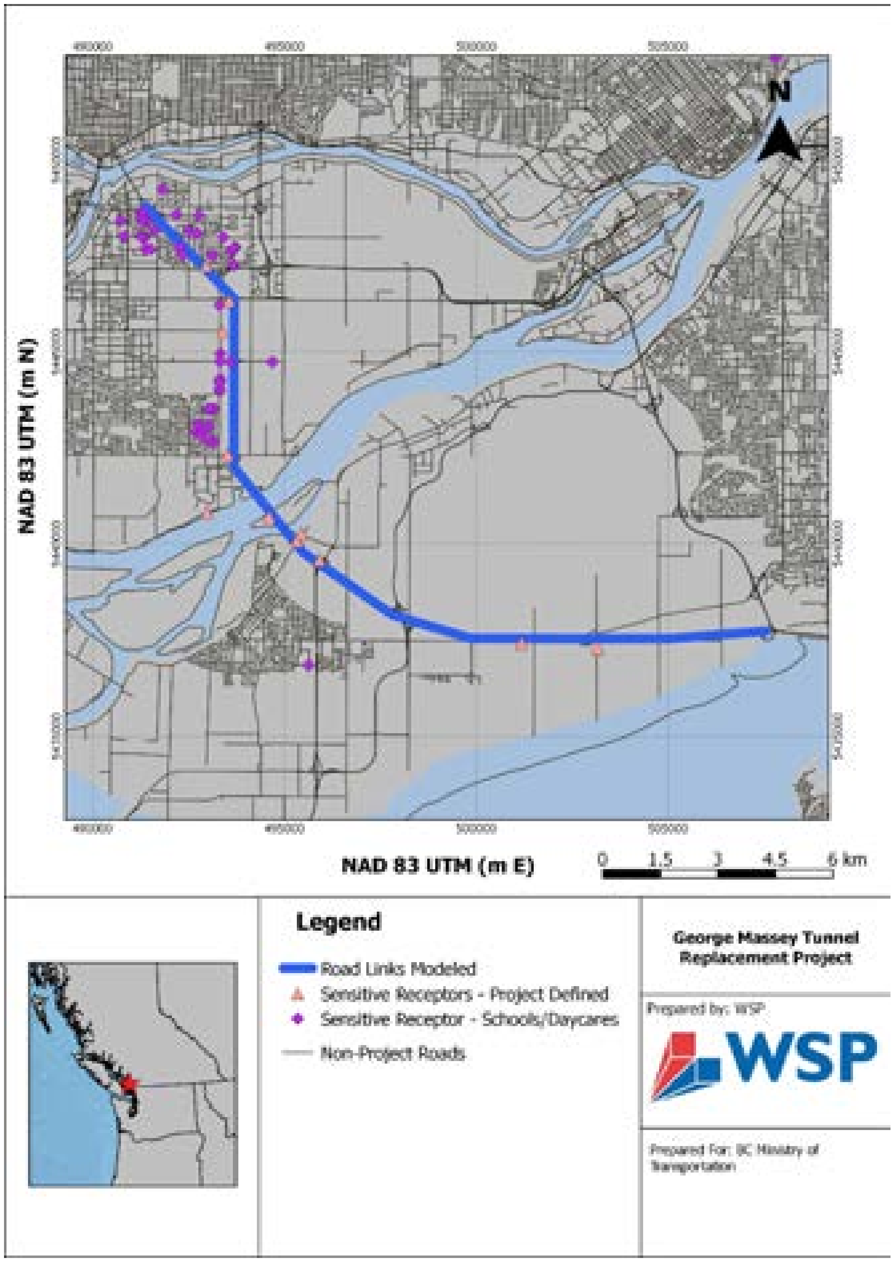
CALPUFF and Receptors

If the CALPUFF model is used, provide the following:

- proposed receptor grid spacing (see Section 7.2):
- a map of the CALPUFF domain and receptor grid
- anticipated sensitive receptors (see Section 7.4)) and also indicate them on the CALPUFF domain map (if applicable)
- receptor (flagpole) height (m) (see Section 7.5):

CALPUFF is not used but the receptor grid used in CALINE is shown below. Receptors are placed at intervals of 5, 10, 15, 20, 25, 50, 100, 250, 500 and 1000 meters perpendicular to the road. These lines of receptors are spaced in 100 meter intervals along the roadway. Sensitive receptors are shown in the second figure below. The sensitive receptors are all of the schools, daycares, care homes and hospitals occurring within the LAA as well as sensitive receptors identified by the project team. All receptors are placed at 0m.





PLANNED MODEL OUTPUT: AIR QUALITY ASSESSMENT NEEDS

<u>Output Requirements for</u>

What model output is required for decision makers and stakeholders? (i.e. what is the purpose of the assessment?). Circle as appropriate.

- Air Quality: concentrations, depositions, visibility, fogging, icing, other (specify)

Tables and Figures for Level 1 Assessment:

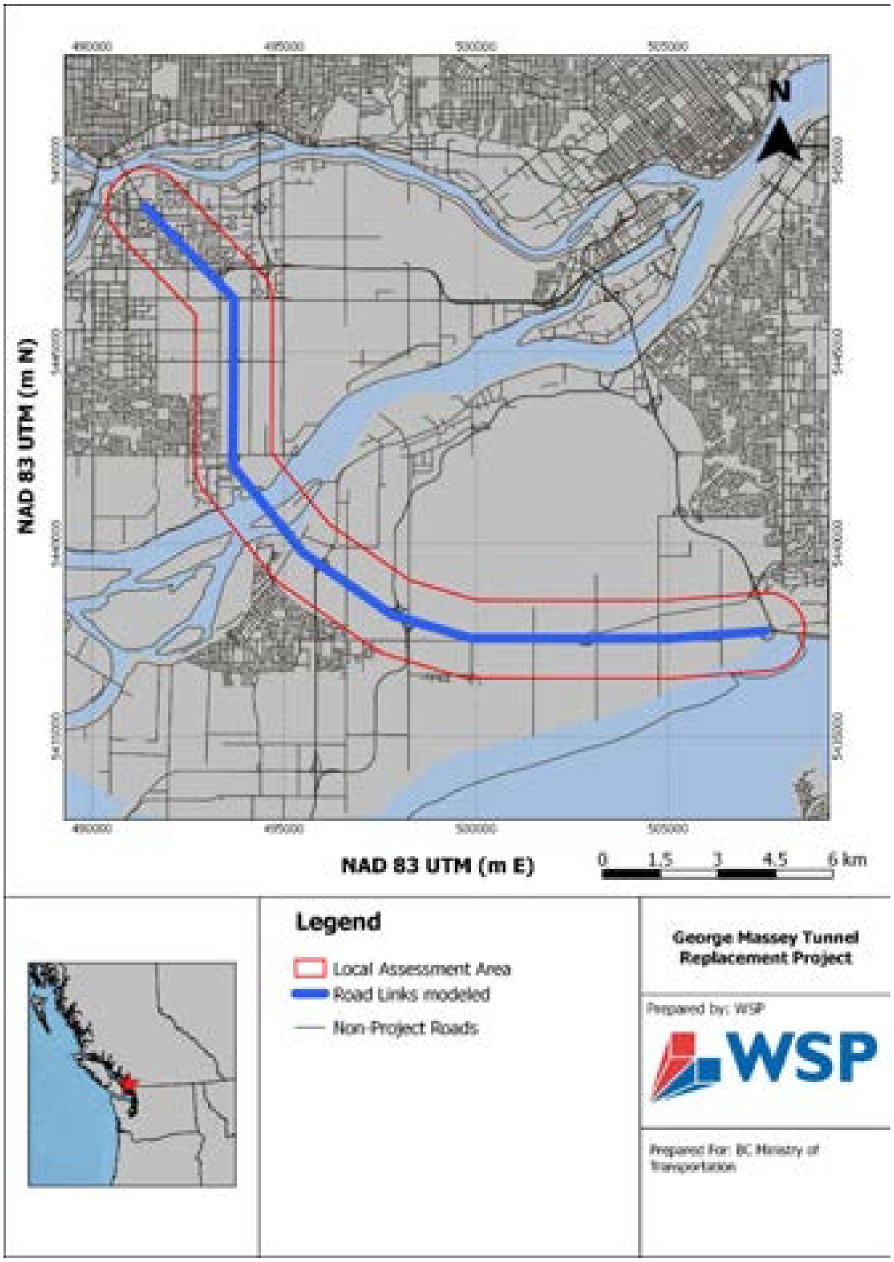
- **maximum concentration of contaminants predicted including location and corresponding meteorological conditions**
- printout of AERSCREEN model output

Tables and Figures for Level 2 and 3 Assessments (see detailed list in Section 8.3.2):

- **spatial distribution maps of air quality parameters (maximums, exceedance frequencies, annual averages)**
- **tables of maximum short and long time average air quality parameters (locations and associated meteorological conditions)**
- **tables of air quality parameters at select receptors of interest (maximums, frequency distributions)**
- tables of air quality parameters under certain emission situations (upsets, start-up)
- output spatial scale: **near-field (<10 km)**, local (<50 km), regional (>50 km)
- special output required for vegetation, health risk or visibility assessments
- other (specify):

EMISSION SOURCES AND CHARACTERISTICS

Provide a map showing the source locations, buildings, and facility fence line.
The LAA and road links are shown in the figure below.



Model Emission Scenarios

If applicable, describe the different model emission scenarios required for the assessment if multiple options are under consideration. For example, different source characteristics (stack dimensions, emission rates) or source arrangements (locations, types, buildings) may need separate modelling runs to examine the air quality implications of different scenarios.

To assess the impacts from vehicle traffic on air quality as it relates to the replacement of the George Massey Tunnel. This assessment will model three scenarios

1. **Current configuration of Highway 99 between Bridgeport and Highway 91**

2. **Current configuration with 2031 traffic of Highway 99 between Bridgeport and Highway 91**
3. **Highway 99 between Bridgeport and Highway 91 with a 10-lane bridge replacing the tunnel with 2031 traffic**

Future vehicle traffic volumes were obtained via traffic modelling while the fleet profiles were developed based on data from Metro Vancouver. Congestion is considered in the 2011 and 2031 without project scenarios along Link 2 (the tunnel) while traffic is free flowing in the 2031 with project scenario for all links.

CALINE has the ability to model a few types of roads including roads that are at grade and bridge links. Based on an investigation of the source code, these two road types result in identical executions of the code. Additionally, CALINE restricts the road height to 10 meters above ground level. In reality, the bridge will be at a height higher than 10 meters. It is expected that as the height of the bridge increases, dispersion improves and concentrations would be lower at ground level receptors. Therefore 10 meters is a conservative estimate of the predicted concentrations near the bridge.

<u>Contaminants Emitted for Each Emission Scenario</u>

Provide the following details of the sources to be modelled:

Specify Source, Type, Contaminants (extend Table as necessary)

Emission Number	Description	Type: Point (P), Area (A), Line (L), Volume (V)	Contaminants (SO_2, NO_x, $PM_{2.5}$. . .)	Basis of Emissions *(Section 5.3)*
Link 1	Bridgeport to Westminster Highway	L	VOC, CO, NO_2, SO_2, NH_3, PM_{10}, $PM_{2.5}$, Benzene, Naphthalene, 1,3-butadiene, Formaldehyde, Acetaldehyde, Acrolein, Benzo(a)pyrene	___current emission limits ___proposed emission limits _X_other (specify & justify) **Emissions are based on fleet profiles from the EMME/2 traffic model and Metro Vancouver fleet profiles. Emission factors are from the MOVES2012b vehicle emission simulator.**
Link 2	Westminster Highway to George Massey Tunnel/Replacement	L	VOC, CO, NO_2, SO_2, NH_3, PM_{10}, $PM_{2.5}$, Benzene, Naphthalene, 1,3-butadiene,	___current emission limits ___proposed emission limits _X_other (specify & justify)

			Formaldehyde, Acetaldehyde, Acrolein, Benzo(a)pyrene	**Emissions are based on fleet profiles from the EMME/2 traffic model and Metro Vancouver fleet profiles. Emission factors are from the MOVES2012b vehicle emission simulator.**
Link 3	George Massey Tunnel/Replacement to Highway 17A	L	VOC, CO, NO_2, SO_2, NH_3, PM_{10}, $PM_{2.5}$, Benzene, Naphthalene, 1,3-butadiene, Formaldehyde, Acetaldehyde, Acrolein, Benzo(a)pyrene	___current emission limits ___proposed emission limits _X_other (specify & justify) **Emissions are based on fleet profiles from the EMME/2 traffic model and Metro Vancouver fleet profiles. Emission factors are from the MOVES2012b vehicle emission simulator.**
Link 4	Highway 17A to Highway 17	L	VOC, CO, NO_2, SO_2, NH_3, PM_{10}, $PM_{2.5}$, Benzene, Naphthalene, 1,3-butadiene, Formaldehyde, Acetaldehyde, Acrolein, Benzo(a)pyrene	___current emission limits ___proposed emission limits _X_other (specify & justify) **Emissions are based on fleet profiles from the EMME/2 traffic model and Metro Vancouver fleet profiles. Emission factors are from the MOVES2012b vehicle emission simulator.**
Link 5	Highway 17 to Ladner Trunk Road	L	VOC, CO, NO_2, SO_2, NH_3, PM_{10}, $PM_{2.5}$, Benzene, Naphthalene, 1,3-butadiene, Formaldehyde, Acetaldehyde, Acrolein, Benzo(a)pyrene	___current emission limits ___proposed emission limits _X_other (specify & justify) **Emissions are based on fleet profiles from the EMME/2 traffic model and Metro Vancouver fleet**

				profiles. Emission factors are from the MOVES2012b vehicle emission simulator.
Link 6	Ladner Trunk Road to Highway 91	L	VOC, CO, NO_2, SO_2, NH_3, PM_{10}, $PM_{2.5}$, Benzene, Naphthalene, 1,3-butadiene, Formaldehyde, Acetaldehyde, Acrolein, Benzo(a)pyrene	___current emission limits ___proposed emission limits _X_other (specify & justify) **Emissions are based on fleet profiles from the EMME/2 traffic model and Metro Vancouver fleet profiles. Emission factors are from the MOVES2012b vehicle emission simulator.**

***** for PM emissions indicate whether it is filterable, or filterable + condensable, or if unknown (see Section 3.6)

Source Emission Rate Variability

Do emissions have sub-hourly variation (e.g., blow-down flares with high emission peaks during the hour)? If so, describe the approach to assess air quality implications of those sub-hourly high emission peaks.

Not considered.

Describe the approach to assess air quality implications under the 25, 50, 75% emission scenario. See Section 3.4.2.

N/A

If there are batch processes, provide a temporal emission profile (emission rate vs time) for each batch process.

N/A

Describe anticipated abnormal emission scenarios (e.g., start-up and shut-down) and their anticipated frequency of occurrence. See Section 3.4.3.

N/A

BASELINE CONCENTRATION

- Indicate method used to determine baseline concentrations for each pollutant (Section 8.1):

  __**X**__monitoring data (Section 8.1.1 and 8.1.2) _____establish monitoring program (Section 8.1.3)

_____modelled sources (Section 8.1.5)

_____other method (describe)

- If existing monitoring data to be used, complete the following Table:

Representative Air Quality Measurements

Station Name (Lat./Long./ or indicate on map)	Period of Record (start/end date)	Contaminants Measured
T13 – North Delta	**2008 - 2012**	**NO2, O3, PM2.5**
T15 – Surrey East	**2008 - 2012**	**NO2, CO, O3, PM2.5**
T17 – Richmond South	**2008 - 2012**	**NO2, CO, O3, SO2, PM2.5**
T18 – Burnaby South	**2008 - 2012**	**NO2, CO, O3, SO2, PM2.5, PM10**
T31 – Richmond Airport	**2008 - 2012**	**NO2, CO, O3, SO2, PM2.5, PM10**
T39 - Tsawwassen	**2008 - 2012**	**NO2, CO, O3, SO2, PM2.5**

- If baseline concentrations are anticipated to change in the future due to planned significant reductions or increases in emissions, provide a description of how these will be accounted for (e.g., construction of a nearby new facility or the planned decommissioning of a currently operating facility) and the uncertainties involved in estimating future emissions.

BUILDING DOWNWASH

- Potential for building downwash. Please provide rational if building downwash is not modelled.

N/A

- If building downwash included, provide a site map to indicate buildings to be processed by BPIP-PRIME, and also complete the following Table:

Source Height (m)	Distance from the Source to the Nearest Building (m)	Building Length (m)	Building Height (m)	Building Width (m)

GEOPHYSICAL DATA INPUT

Topography and Land Use Data

- Terrain data (specify source of data) and an elevation map for the model domain:

GeoGratis – Canadian Digital Elevation Data (CDED) at 1:50,000

- Land use data (specify source of data) and a land use map for the model domain:

Baseline Thematic Mapping digitical land use data at 1:250,000 scale from the BC Land and Resource Data Warehouse

Surface Characteristics

For AERSCREEN, provide seasonal values of surface characteristics (surface roughness, albedo and Bowen ratio) for input to MAKEMET.

N/A

For Level 2 and 3 Assessments, Indicate if recommended seasonally varied surface characteristics (surface roughness, albedo, Bowen ratio, etc.) (see Section 4.3 and 4.4) are used for the dispersion modelling study. If not, provide the proposed surface characteristics and the rationales.

No as there is not a substantial change in the land use between seasons along the project.

METEOROLOGICAL DATA INPUT (FOR LEVEL 2 AND 3 ASSESSMENTS ONLY)

Surface Meteorological Data

If surface observation data are used, provide a map with the location of each surface meteorological station identified and also provide the following:

Surface data was not used. A single point of meteorology was required for use in CALINE and CALMET was run in NOOBS mode in order to provide a grid point near the project.

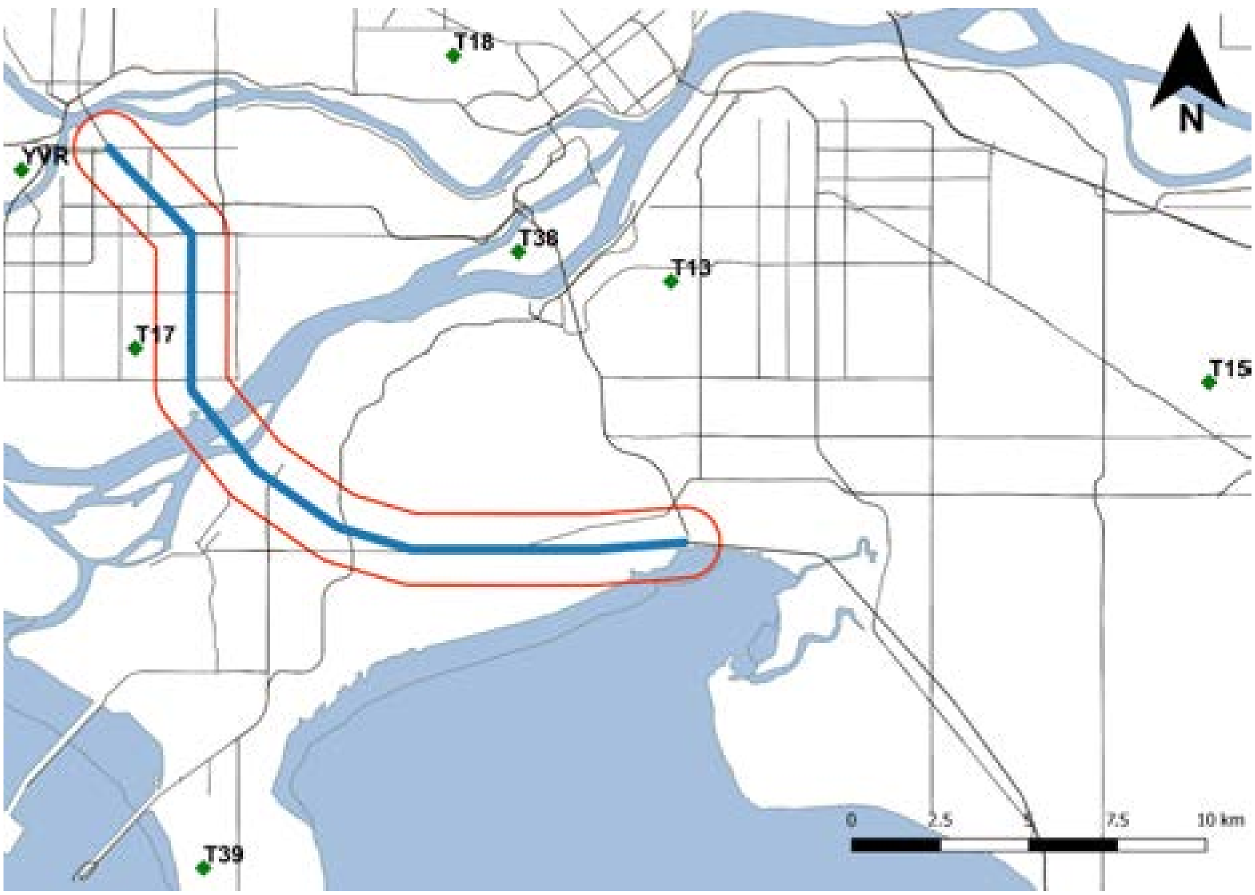
Surface Met Data and Location (lat/long or indicate on map)	Data Source MOE, MV, MSC, Site Specific, other (specify) [1]	Period of Record (start/end data) [2]	% of Wind Speeds = 0.0 [3]	Anemometer Height (m)	Parameters
T13 (see map below)	**MV**	**Jan 1, 2012 – Dec 31, 2012**	**0.93%**	**14.3**	**Wind Speed, Wind Direction, Temperature, Relative Humidity**
T15 (see map below)	**MV**	**Jan 1, 2012 – Dec 31, 2012**	**0.51%**	**16.9**	**Wind Speed, Wind Direction, Temperature**
T17 (see map below)	**MV**	**Jan 1, 2012 – Dec 31, 2012**	**2.6%**	**12.5**	**Wind Speed, Wind Direction, Temperature**
T18 (see map below)	**MV**	**Jan 1, 2012 – Dec 31, 2012**	**0.07%**	**19.9**	**Wind Speed, Wind Direction, Temperature, Relative Humidity**
T38 (see map below)	**MV**	**Jan 1, 2012 – Dec 31, 2012**	**0.85%**	**10.0**	**Wind Speed, Wind Direction, Temperature, Relative Humidity**
T39 (see map below)	**MV**	**Jan 1, 2012 – Dec 31, 2012**	**9.01%**	**10.8**	**Wind Speed, Wind Direction, Temperature,**

					Relative Humidity
YVR (see map below)	**MSC**	**Jan 1, 2012 – Dec 31, 2012**	**0.2%**	**10.0**	**Wind Speed, Wind Direction, Temperature, Relative Humidity, Pressure, Ceiling Height, Cloud Cover**

1. If data from a non - Ministry, MV or MSC station are planned to be used, follow guidance in Section 5.2.3

2. For data completeness and data filling, follow guidance in Section 5.5

3. For light and no wind conditions, follow guidance in Section 5.6



<u>Upper-Air Meteorological Data</u>

If upper air meteorological data are used provide the following:

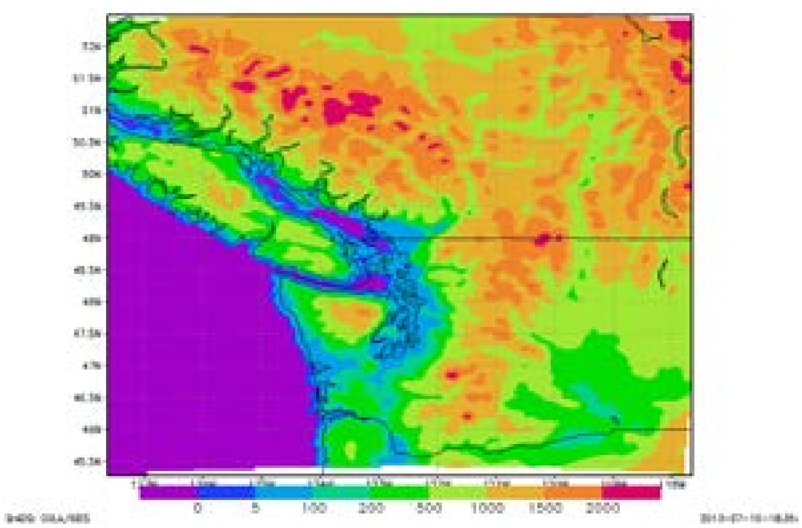
Station Name	Period of Record (start/end date) [1]	Distance between the Upper Air Station and Project (km)

[1.] For data completeness and data filling, follow guidance in Section 5.5.

NWP Model Output

If NWP output (different than the province-wide WRF output) used provide the following:

- Mesoscale Meteorological Model (Name\Version\Model Configuration): **WRF-NMM**
- Model Output Provider: **SENES Consultants Ltd**
- Domain (attach a map showing the horizontal extent):



- Horizontal and Vertical Grid Resolution and Height of Each Vertical Level: **~3km horizontal resolution with 18 sigma levels**
- Data Period (start/end date): **January 1, 2011 – December 31, 2011**
- Four Dimensional Data Assimilation is applied (Yes or No): **Yes**

NWP model output use (circle one below for the selected dispersion model):

- AERMET/AERMOD:
  - Extract pseudo surface station and pseudo upper air sounding (as input to AERMET), or
  - Create .SFC and .PFL files (AERMOD-ready files, skip AERMET)

- CALMET:
  - NWP only, or
  - Surface station and NWP, or
  - Surface station, upper air sounding, and NWP, or
  - Other (specify):

TREATMENTS

<u>NO to NO_2 Conversion:</u>

Identify the method to be used (Section 8.2).

__**X**__Ambient Ratio Method

- indicate monitoring station(s)

Data from T18 – Burnaby South were used to develop the curve. Other data from T13 – North Delta and T17 – Richmond South were used to validate the curve

_____OLM:

- specify O_3 concentration and how it was selected,
- if non default in-stack ratios are used, specify and provide rationale.

_____PVMRM (for AERSCREEN and AERMOD only):

- specify O_3 concentration and how it was selected,
- if non default equilibrium ratios and/or in- stack ratios are used, specify and provide rationale.

<u>Chemical Transformation:</u>

- Specify transformation method and provide details on inputs if Secondary $PM_{2.5}$, Acid Deposition or Visibility effects are to be estimated. Depending on the transformation method, this could include ammonia, ozone, hydrogen peroxide concentrations, nighttime loss and formation rates for nitrates and sulphates.

N/A

<u>Particle Deposition:</u>

- If non-recommended particle size distributions (see Section 3.6) are used, provide Table of particle emission (including heavy meals if modelled) size/density distribution and indicate the basis for the Table.

N/A

<u>Stagnation:</u>

- Provide an estimate of the frequency of stagnation based local meteorological data if available. If AERMOD is proposed, provide methodology on how stagnation periods will be treated (see Section 10.2).

N/A

<u>Shore/Coastal Effects:</u>

- If included, indicate whether sub-grid-scale Thermal Internal Boundary Layer option is selected along with the required input coastline coordinate data (see Section 10.3).

N/A

<u>Plume Condensation (Fogging) and Icing:</u>

- Indicate if this will be included (Section 10.6).

N/A

QUALITY MANAGEMENT PROGRAM

<u>Model Input Data</u>

Indicate the tests that will be undertaken to assure the quality of the inputs.

For the geophysical input data:

- **contour plot of topography**
- **plots of land use and land cover**

For the meteorological data:

- **wind rose (annual and/or seasonal)**
- **frequency distribution of surface wind speeds**
- **average hourly temperature plot (annual and/or seasonal)**

If NWP output is used, describe the tests undertaken to assure the quality of the output (Section 6.1)

- **wind rose at selected locations and heights (annual and/or seasonal)**
- **average hourly temperature plot at selected locations and heights (annual and/or seasonal)**
- **wind field plots for selected periods that indicate topographic influences such as channeling and thermally generated flows**

Model Output Data

For CALMET/CALPUFF applications, provide a list of the tests conducted to confirm the quality of the model output (intermediate pre-processing files and concentration/deposition predictions).

With respect to the pre-processed files that are prepared for CALPUFF input, there are several tests listed in Section 9.1.1 and 9.1.2 to check the output from the pre-processing utility programs to confirm that they have been properly processed. These are related to checking:

- terrain, land use
- sources (locations and elevation) and emission characteristics
- meteorological data (locations) and tests in confirm proper processing of the raw meteorological data (units, parameters)
- receptor locations and elevations

For CALMET output there are several tests listed in Section 9.1.3 to test the quality of the generated meteorological fields. These are related to reviewing the following:

- wind field maps (surface and different elevations) for select periods where topographic influences (channeling, thermally driven flows) would be evident
- wind roses and selected locations and elevations (annual, seasonal)
- frequency distributions of various meteorological parameters (annual, seasonal) such as PG-stability class, mixing heights
- plots of hourly average parameters such as temperature, mixing height, precipitation at key locations (seasonal and annual)

Note: The Ministry may require all computer files associated with the modelling to be submitted upon request.

MINISTRY REVIEW OF PLAN AND REVISIONS

A modelling plan can change over the course of developing the air quality assessment so acceptance of the initial submission of the plan is on the basis of the best information provided to date. Changes to the plan (additions, modifications) should be noted and agreed to with the Ministry as necessary. An updated Dispersion Modelling Plan may be necessary.