Heavy-Duty Diesel Vehicle Emissions in Greater Vancouver

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ABSTRACT

The Greater Vancouver Regional District (GVRD) recognized the importance of heavy-duty vehicle emissions in the Lower Fraser Valley airshed, and the need to investigate the issue and manage these emissions. In this study, the regional heavy duty diesel vehicle (HDDV) fleet operating in the Lower Fraser Valley area of the Province of British Columbia were characterized, and emissions and long-term trends of criteria air contaminants, toxics and greenhouse gases from HDDVs were estimated. Also the spatial distribution of diesel emissions and concentrations near major roads and nearby communities were estimated. According to vehicle registration statistics for 2003, there were 32,521 on-road and 1,982 nonroad commercial heavy duty diesel vehicles operating primarily in the region. Forty per cent of the onroad HDDVs were in the Class 7 and Class 8 weight classes (Heavy-Heavy). The GVRD's year-2000 emission inventory estimated that on-road HDDVs were responsible for 4.1% of the $PM_{2.5}$ emitted in the Canadian portion of the Lower Fraser Valley International Airshed in 2000. The implementation of more stringent HDDV emission standards and ultra low sulphur diesel fuel is projected to reduce the share of regional $PM_{2.5}$ emissions from these vehicles to about 2% by 2010 and 1% by 2025. The share of NOx emissions from onroad HDDVs is forecast to decrease from 14.9% in 2000 to 8.1% in 2010 and 2.4 % in 2025. HDDV exhaust emissions and EMME2/traffic data were also used to predict $PM_{2.5}$ concentrations near roadways. It was estimated that HDDVs contribute 0.5-0.7 $\mu g/m^3$ to annual average ambient $PM_{2.5}$ concentrations on major truck routes within a distance of 20-100 m from the road for 98% of the road links modelled. Maximum predicted annual average $PM_{2.5}$ concentrations at this distance from roads were 10-18 $\mu g/m^3$.

INTRODUCTION

Emission inventories and forecasts prepared by the Greater Vancouver Regional District (GVRD) show that motor vehicles are a significant source of air pollution in the Canadian portion of the Lower Fraser Valley (LFV) airshed extending over the Greater Vancouver area and east to Hope, BC. These emissions contribute to human health effects associated with exposure to fine particulate matter ($PM_{2.5}$), ozone and other pollutants. Emission standards for heavy-duty vehicles have not been reduced in the last decade to the same degree as light-duty vehicles and, consequently, their proportional contribution to regional emissions has increased.

The much more stringent US EPA emission standards for NOx and particulate matter (PM) emissions from HDDV vehicles will be implemented by manufacturers starting formally with the 2007 model year. The same standards will be in effect in Canada. These new emission standards will substantially reduce future diesel exhaust emissions from on-road heavy duty vehicles as old engines and vehicles are removed from service and replaced with new ones. The sulphur content of on-road diesel in the US and Canada will be reduced from current levels near 300 ppm to 15 ppm by 2006 to enable advanced control measures to achieve the new emission standards. HDDVs sold prior to 2004 or 2007 will have significantly higher emissions and, because of the long life of diesel engines, could conceivably continue emitting at these higher levels for many years unless retrofit or rebuilt using improved emission control and engine technologies. The GVRD and its partner agencies recognize the importance of heavy-duty vehicle emissions in the airshed, and the need to investigate the issue. There is growing evidence that human health impacts of diesel emissions are significant, with diesel particulate matter implicated as contributing a high proportion of the air pollution related cancer risk in urban areas, as well as increased asthma attacks, excess deaths and other health issues. Emissions associated with diesel vehicles also contribute to smog formation and degradation of visibility. Programs have been implemented in several jurisdictions in the United States to reduce diesel emissions and the associated health and environmental impacts. These programs look at fuel quality and emission standards, as well as requirements and incentives for retrofitting or replacing high-emitting vehicles.

The overall objective of a broader study[1] was to evaluate the cost-effectiveness and emission reduction potential of alternative fuels, reformulated diesel fuel and retrofit emission control equipment for government and some commercial fleet heavy-duty diesel vehicles operating in the Lower Fraser Valley area of British Columbia. Cost-effectiveness was determined both with and without the economic benefits from reductions in human health effects associated with reduced exposure to $PM_{2.5}$ and toxic air pollutants. This paper describes the fleet characterization and the development of the emission inventory for HDDVs in the LFV and prediction of the effects of vehicle emissions on ambient $PM_{2.5}$ concentrations near major roads and on the average ambient $PM_{2.5}$ concentration within the airshed. The specific tasks involved in this work were:

- Development of data on the characteristics of HDDV fleets that affect emissions, giving priority first to government operated fleets and second to large privately owned fleets.
- Estimation of emission factors for each class of vehicle in the HDDV fleets based on fleet characteristics developed in the study that influences emissions.
- Calculation of "baseline" emissions of criteria air pollutants, greenhouse gases and air toxics for HDDVs for the period from 2000 to 2025 in 5-year intervals, assuming normal turn-over of diesel vehicle technology.
- Estimation of annual average $PM_{2.5}$ concentrations contributed by HDDVs near major roads in community areas and in the LFV as a whole allowing for both primary and secondary PM.

METHODS

Vehicle Fleet Characteristics

Data describing the heavy duty diesel vehicle fleet operating in the LFV were obtained from two different sources. Information specific to HDDV fleet vehicles was obtained by conducting a survey of local governments and private companies that agreed to provide data for use in the study. The second source of information was an extract from the database of motor vehicle registration statistics maintained by the Insurance Corporation of British Columbia (ICBC) for the rate territories covering the Lower Fraser Valley area.

Survey data were collected by distributing a questionnaire to fleet managers within government and large private companies in the LFV. The participation of government fleets in the study was aided by representatives of the Fleet Managers Group, a voluntary organization that includes as members most major government fleets in the LFV. The survey requested a variety of data needed to model vehicle emissions behaviour for heavy-duty diesel vehicles having a gross vehicle weight of 3856 kg or more that are. This included the ICBC fleet identifier code, type of vehicle/use, date of engine rebuild, fuel consumption, average kilometres accumulated per year, normal area of operation and other related information.

The vehicle data provided by ICBC was specific to commercial motor vehicles that were insured as of June 30, 2003 that had a gross vehicle weight of 3856 kg or more. ICBC identifies the rate territory (area) in which a vehicle normally operates which for this study included: D – Lower Mainland; E – Maple Ridge/Pitt Meadows; G – City of Hope (other communities in territory G outside the LFV were excluded); and H – Fraser Valley. Motor vehicles operating in ICBC territory Z, which comprises vehicles operating mostly outside the LFV were excluded from the ICBC dataset.

ICBC provided data on each insured vehicle, including model year, fuel type, rating territory, gross weight, ICBC body style code, rate class and fleet code. The fleet code, which is used by ICBC to identify common vehicle ownership, was included in the data to allow vehicles to be related to data provided by fleet managers in response to the survey. Names of fleet owners were withheld by ICBC to protect the privacy of fleet owners. Most government fleet managers participating in the study agreed to provide their fleet codes so data for their vehicles could be identified in the ICBC dataset.

Emission Factors for Fleet Vehicles

The MOBILE6.2C model (dated May 14, 2003) was used to determine emission factors for each category and age of heavy-duty vehicle from 2000 to 2025 in five-year intervals. The model was provided by Environment Canada[2], which modified the US MOBILE6.2 model to reflect differences in base emission rates for vehicles in Canada prior to harmonization of emission standards. The main changes were: a) to reflect different emission standards in Canada for pre-1988 light duty vehicles and b) to change the default in the US version regarding the effectiveness of Consent Decree rebuilds of older engines from 90% to 0% (i.e., no rebuild program in Canada).

Emission factors were generated for each age of vehicle in a fleet for each calendar year in five-year intervals from 2000 to 2025 for use in a separate emission calculation model that calculates fleet emissions based on the age distribution and the kilometres travelled for the fleet. Default US EPA was used for mileage accumulation rates by age of vehicle and other parameters to develop model year specific emission factors for each target year. The diesel fuel sulphur content was assumed to be 365 ppm in 2000, 194 ppm in 2005 and 15 ppm in 2006 and subsequent years.

The fleet in future years was assumed to have the same age distribution as in the base year. This implies a steady state has been reached in the replacement of retired vehicles with new vehicles.

Emission factors for greenhouse gases were determined for carbon dioxide, methane and nitrous oxide and converted to carbon dioxide equivalent (eCO_2) using global warming potentials of 21 and 310 as the multipliers for methane and nitrous oxide, respectively. Greenhouse gas emission factors were determined for the vehicle only and for the full fuel life-cycle using the GHGenius model developed for Canadian light and heavy duty vehicles (http://www.ghgenius.ca).

Annual Fleet Emissions

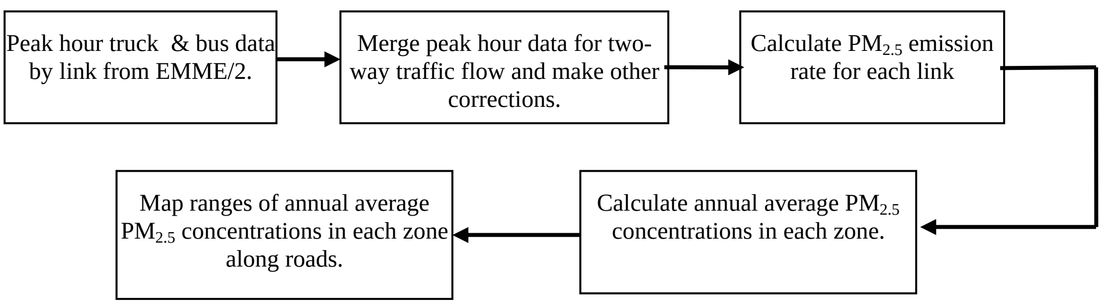
Annual emissions of criteria and toxic pollutants and greenhouse gases from each fleet were calculated for each EPA vehicle classification using the following formula:

No. of vehicles by age in each vehicle classification	**x**	Annual VkmT	**x**	Emission factor for each pollutant	=	Annual emission of each pollutant

The emissions from all vehicles in each vehicle classification were summed to determine the total emissions of each pollutant from the fleet. The annual vehicle kilometres travelled (VkmT) by each vehicle age group and vehicle classification was obtained from survey data provided by fleet managers, where available, or otherwise from EPA default values in MOBILE6.2C.

Estimation of Annual Average $PM_{2.5}$ Concentrations Near Roads

A method was developed to estimate the approximate annual average $PM_{2.5}$ concentration in the vicinity of roads in the Lower Fraser Valley based on modelled AM peak-hour traffic volume and estimated dispersion relationships. This method involves the steps illustrated schematically below:



Peak hour truck and bus traffic data was obtained from TransLink[3] in Geographic Information System file format as produced by EMME/2 from transportation modelling within the region. Traffic volume data was obtained for each of 15,600 links between nodes defined in the EMME/2 transportation model and each of the three Regional Transportation Model (RTM) vehicle types relevant to the study: public transit bus; light truck (4,500-20,000 kg GVWR) and heavy truck (over 20,000 kg GVWR). The data set was for 1999, which is more recent than the 1996 data that was used by the GVRD for the 2000 emission inventory. The data set for trucks agreed well with the data provided to the GVRD previously, while there was a difference in the data set for transit buses, though the difference was not large.

The modelled traffic data applies to the morning peak hour. Two-way traffic was modelled on separately links, and these traffic volumes were combined for modeling of $PM_{2.5}$ concentrations. To develop annual data on emissions for comparison to data developed by other means, the peak-hour values were extrapolated to annual traffic on each link using expansion factors provided by TransLink[3]. These expansion factors are as follows:

RTM Vehicle Class	GVWR (kg)	Expand from AM Peak Hour to Daily (D/H)	Expand from Daily to Annual (A/D)
Light Truck	4500-20,000	14.2	240
Heavy Truck	>20,000	12.7	240

Public Transit Bus		9.0	330

Annual VkmT on each link was calculated using the above expansion factors in the following formula:

Annual VkmT for each link = (AM peak hour traffic) x (link length in km) x (D/H) x (A/D)

The overall VkmT for heavy-duty gasoline and diesel trucks and buses used as the starting point for spatial analysis in this study (1,417,000,000 km) is essentially identical to the VkmT determined with earlier vintage traffic data for the 2000 LFV emission inventory[4,5] (1,420,000,000 km).

Annual $PM_{2.5}$ exhaust emissions on each link were determined using the following formula together with fleet average emission factors for trucks and buses:

Annual Emissions =Annual VkmT by vehicle type x Diesel Fraction x Average Emission Factor.

The incremental annual average $PM_{2.5}$ concentrations near roads from HDDV $PM_{2.5}$ exhaust emissions were approximated by using the form of the theoretical solution in Turner[6] for dispersion from a continuously emitting infinite line source. This approximation is best limited to distances less than 300 meters from a road, wind directions perpendicular to the road, and roads with no intersecting roads. For hypothetical impact zones at some distance perpendicular to the direction of a road link of length L, the simplified form of the equation is:

$$C_Z \text{ (Link L)} = E_i \times F_D / L$$

where,

C_Z (Link L) = Annual average $PM_{2.5}$ concentration in zone Z beside link L ($\mu g/m^3$)
E_i = Annual average emission rate on link L (g/s)
F_D = Dispersion Factor for zone Z ($(\mu g/m^3)/(g/s\text{-}km)$)
L = Link Length (km)

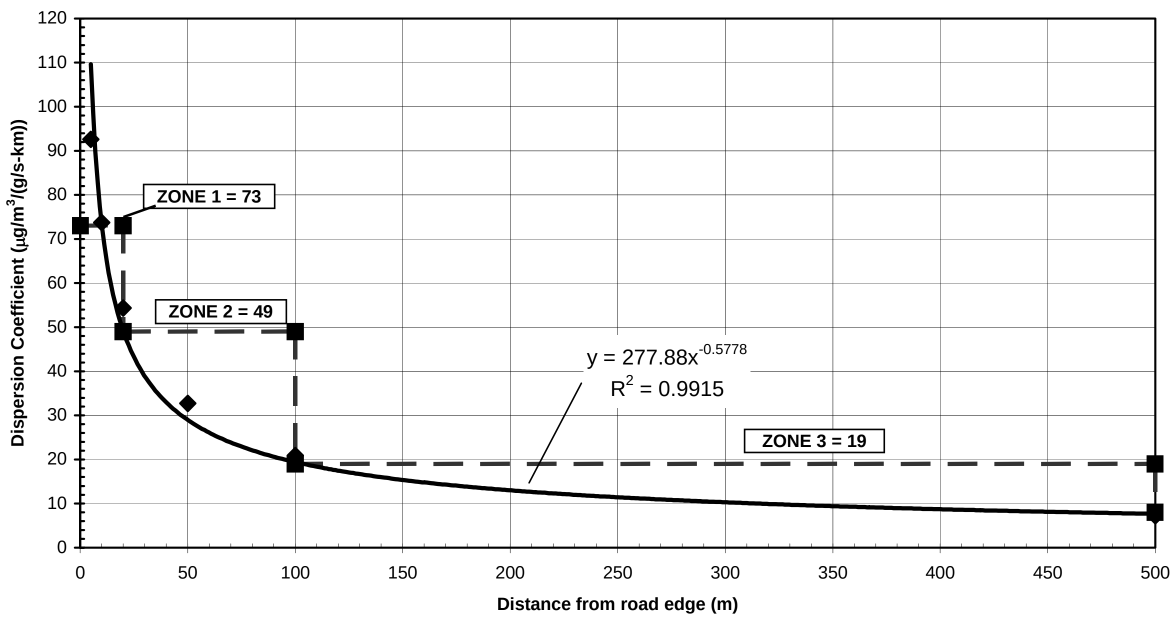
The $PM_{2.5}$ concentrations near roadways were approximated in zones parallel to the direction of the roadway and set back from the road at distances of 0-20m, 20-100m, 100-500m and >500m. The dispersion factor F_D above was estimated from the results of modelling of the pollutant concentrations in the vicinity of the Lougheed Highway in Burnaby. This roadway is oriented generally in an east-west direction and was modelled using the CALINE3 model with approximately 1 year of local meteorology to predict pollutant concentrations at distances from the edge of the road to 1 km away perpendicular to the road. To develop a correlation for the dispersion coefficient that could be applied in this study, the concentrations predicted for both sides of the road were averaged and this average annual concentration was used. Figure 1 shows the data points calculated from the modelled concentrations and the correlation developed to fit these points.

High estimates of the dispersion factors were calculated for each zone to compensate for the contribution of $PM_{2.5}$ from intersecting and nearby links not included explicitly in this simplified method. This was done using the dispersion factor correlation shown in Figure 1 at reference distances located at the edge of the zone nearest to the road, except for the first zone where an intermediate distance was used. The dispersion factors from these approximations are summarized in Table 1.

Table 1. Locations and dispersion factors used for each modelled $PM_{2.5}$ concentration zone.

Zone	Distance from Edge of Road (m)	Reference Distance (m)	Dispersion Factor ($\mu g/m^3$)/(g/s-km)
1	5 - 20	10	73
2	20 - 100	20	49
3	100 - 500	100	19
4	>500	500	8

Figure 1. Approximate dispersion coefficient from CALINE 3 modelling for the annual average pollutant concentrations at distances perpendicular to a road.



RESULTS AND DISCUSSION

HDDV Fleet Profile

The 2003 database of registered and insured vehicles in the LFV included records for a total of 66,255 heavy-duty vehicles that use 17 different fuels or fuel combinations. Of these vehicles, 34,503 are heavy-duty diesel vehicles. The number of diesel vehicles in each of the nine categories defined in the US EPA MOBILE6.2 model, including and excluding nonroad vehicles, is listed in Table 2, along with data used in the 2000 emission inventory by the Greater Vancouver Regional District[5] for the 2000 emission inventory using similar ICBC rate territories. The data for 2000 includes ICBC territory Z that refers to vehicles operating most of the time outside the LFV, as well as nonroad HDDVs.

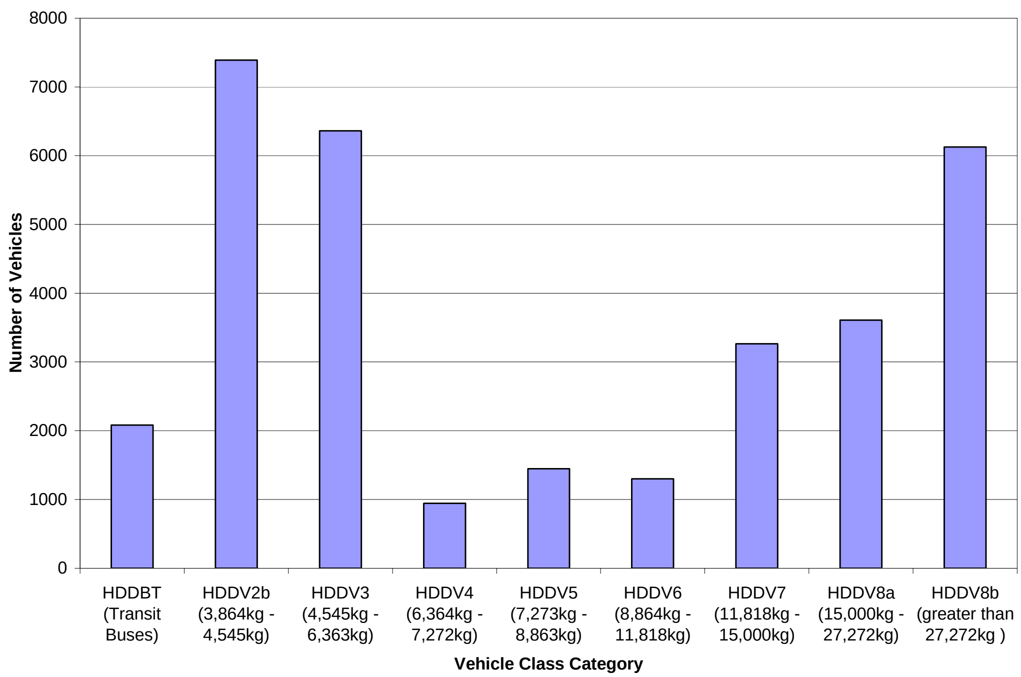
The body style descriptor used by ICBC identifies characteristic types of body styles and was used to identify nonroad vehicles included in the dataset, such as construction or farming vehicles. The different body styles were reviewed and categorized according to onroad or nonroad vehicle use. Filtering of the dataset identified 1,982 nonroad vehicles and reduced the dataset of commercial onroad heavy-duty diesel vehicles to 32,521. Figure 2 illustrates the distribution of these vehicles by EPA vehicle category.

Table 2. HDDVs in the 2003 dataset for this study and in the 2000 dataset used by the GVRD.

Vehicle Class	GVWR (kg)	2003 - Regions D, E, G (Hope) & H This Study				2000 – Regions D, E, H & Z GVRD Inventory	
		Including Nonroad		Excluding Nonroad		Including Nonroad	
		Number	%	Number	%	Number	%
HDDBT* or HDDVBS**		2082	6.0	2082	6.4	2194	5.9
HDDV2b	3,864 - 4,545	7,465	21.6	7,390	22.7	5678	15.2
HDDV3	4,545 - 6,363	6,615	19.2	6,360	19.6	4919	13.2
HDDV4	6,363 - 7,272	1,283	3.7	945	2.9	991	2.7
HDDV5	7,273 - 8,863	1,643	4.8	1,447	4.4	1351	3.6
HDDV6	8,864 - 11,818	1,623	4.7	1,300	4.0	1523	4.1
HDDV7	11,818 - 15,000	3,557	10.3	3,263	10.0	2974	8.0
HDDV8a	15,000 - 27,272	3,950	11.4	3,608	11.1	4593	12.3
HDDV8b	> 27,272	6,285	18.2	6,126	18.8	13065	35.0
Total		34,503	100	32,521	100	37288	100

* Transit or Urban; ** School Bus.

Figure 2. HDDVs by class in the 2003 dataset excluding nonroad vehicles.



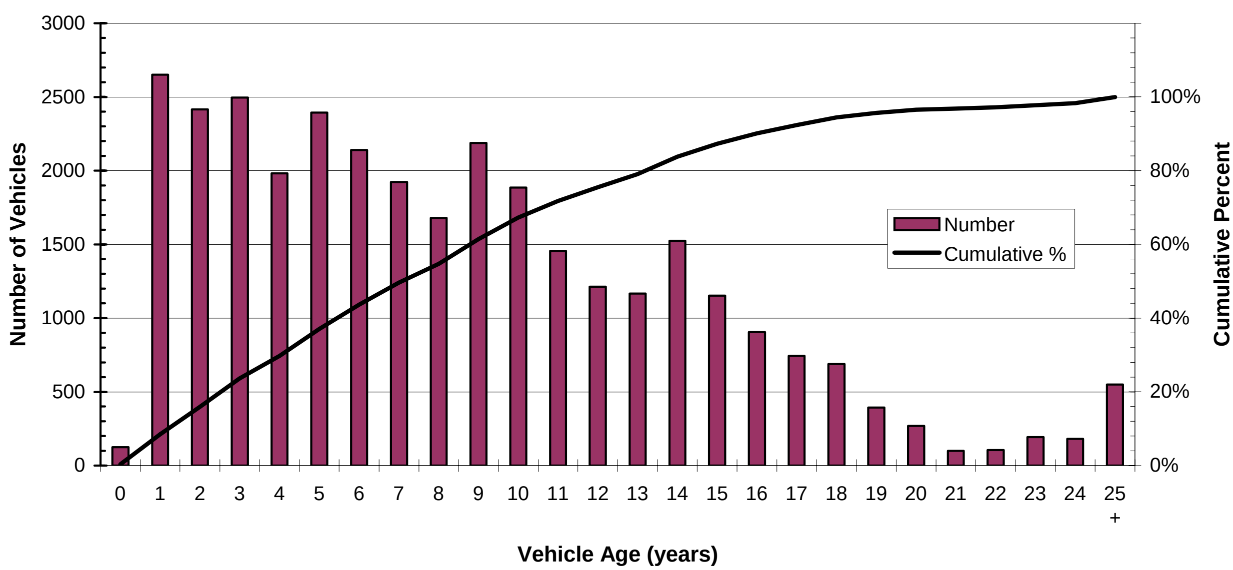
The 2003 dataset contained 20,383 vehicles with no fleet identification codes and hence, presumed to not be part of a commercial vehicle fleet. The remaining vehicles had fleet codes and belonged to 1,583 fleets. The number of fleets of different sizes and the total number of vehicles in each of these fleet groups are listed in Table 3.

Table 3. Distribution of onroad heavy-duty diesel vehicles in the ICBC Dataset identified as part of a fleet

Number of Vehicles in the Fleet	Number of Fleets	Number of Vehicles	Percent of Fleet Vehicles
1	506	506	4.2
2-5	623	1,932	15.9
6-10	227	1,675	13.8
11-25	138	2,192	18.1
26-50	57	2,011	16.6
51-100	22	1,513	12.5
101-200	7	899	7.4
201-500	2	569	4.7
501-1000	1	841	6.9
Total	1,583	12,138	100

The age distribution of commercial HDDVs is shown in Figure 3. These results indicate that 50% of the vehicles are 7 years old or less, 67% of the vehicles are10 years old or less and 96.5% are 20 years old or less. 1.7% of onroad HDDVs are 25 years old or more.

Figure 3. Age distribution of commercial HDDVs in the LFV in 2003.



Fleet Average Emission Factors

Data from the ICBC dataset and responses to the survey distributed to fleet managers were used to calculate baseline emissions for 2000-2025 in five year intervals for a selection of government and private fleets participating in the study. Emission factors for the emission baseline were developed using MOBILE6.2C model as discussed previously with input data appropriate to the local climate, diesel fuel properties and other factors.

The fleets analyzed individually to determine baseline emissions included the following:

Fleet	Number of Vehicles	Vehicle Categories
Combined government vehicle fleets (22 municipal fleets, the GVRD and University of BC)	1,234	HDDV2b to HDDV8b & HDDBT
TransLink (Coast Mountain Bus Company) public transit buses	845	HDDBT
BC Transit	41	HDDV2b to HDDV5 & HDDBT
All other onroad HDDVs	30,386	All categories

Nine municipalities responded to the initial survey with information on the number and ages of the vehicles within each fleet. Of these, five municipalities provided reasonable data on the average annual kilometers travelled and fuel consumed per vehicle. The data provided by these five municipalities was pooled to estimate the typical average annual kilometers travelled and fuel consumption of vehicles operated in a municipal fleet. The kilometers travelled and the average fuel consumption were averaged by vehicle class. These results are shown in Table 4.

Table 4. Pooled average annual kilometers travelled and fuel economy for municipal vehicles.

Vehicle Class	Average Annual Kilometers Travelled	Average Fuel Economy (L per 100 km)
HDDV2b	9,873	26.5
HDDV3	8,488	32.0
HDDV4	15,176	33.4
HDDV5	13,213	32.2
HDDV6	8,574	37.8
HDDV7	7,640	49.5
HDDV8a	9,394	49.7
HDDV8b	16,179	55.8
HDDBT	77,915	52.0

Average emission factors for all 22 municipal fleets, but excluding public transit buses that are part of the West Vancouver vehicle fleet, are presented in Table 5. West Vancouver is the only municipal fleet in the study that included transit buses, as all other transit buses are part of the TransLink fleet.

Tables 6 and 7 summarize data on the number of vehicles and vehicle kilometers travelled (VkmT) for the major fleets and all other HDDVs included in the study. The total VkmT estimated from the number of vehicles and distances travelled agree reasonably well with the independently determined values for VkmT estimated for the GVRD[7] emission forecast. The VkmT used by the GVRD for the 2000 LFV emission inventory was estimated from annual traffic volume and road length output from the EMME/2 transportation model for the LFV. Annual traffic volume in this case was scaled from EMME/2 AM peak hour traffic predictions for the LFV using the expansion factors discussed above that were used in this study to predict $PM_{2.5}$ concentrations near roads. VkmT forecasts were developed by the GVRD from the predicted value for 2000 based in proportion to regional population growth.

Table 5. Fleet average emission factors for 22 municipalities, GVRD and UBC.

Year	Fleet Average Emission Factors (g/km/vehicle)					
	CO	NOx	VOC	SOx	CO_2	
2000	2.774	10.323	0.464	0.220	1218	
2005	1.694	8.062	0.294	0.114	1221	
2010	1.053	5.060	0.222	0.009	1224	
2015	0.586	2.287	0.181	0.009	1219	
2020	0.266	0.984	0.150	0.009	1218	
2025	0.158	0.435	0.139	0.009	1216	
	PM_{10}			$PM_{2.5}$		
Year	Total	Exhaust	Non-exhaust	Total	Exhaust	Non-exhaust
2000	0.401	0.378	0.023	0.356	0.349	0.007
2005	0.205	0.182	0.023	0.175	0.168	0.007
2010	0.111	0.088	0.023	0.088	0.081	0.007
2015	0.070	0.047	0.023	0.050	0.043	0.007
2020	0.047	0.024	0.023	0.029	0.022	0.007
2025	0.039	0.016	0.023	0.022	0.015	0.007
Year	Acrolein	Acetaldehyde	Benzene	1,3 Butadiene	Formaldehyde	Ammonia
2000	0.002	0.014	0.005	0.003	0.038	0.017
2005	0.001	0.009	0.003	0.002	0.024	0.017
2010	0.001	0.007	0.002	0.001	0.018	0.017
2015	0.001	0.005	0.002	0.001	0.015	0.017
2020	0.001	0.005	0.002	0.001	0.012	0.017
2025	0.001	0.004	0.002	0.001	0.011	0.017

Table 6. Vehicle counts and kilometres travelled by year for all onroad HDDVs.

	Number of Vehicles					Average Annual VkmT per Vehicle				
Year	Municipal Vehicles*	TransLink	BC Transit	All Others	Total	Municipal Vehicles	TransLink	BC Transit	All Others	All Vehicles
2000	1234	864	41	30386	32525	13356	60411	52,194	42,193	41595
2005	1263	845	42	32873	35023	13291	60411	52,806	42,191	41602
2010	1343	1118	47	35486	37994	13274	60411	54,000	42,191	41719
2015	1463	1235	54	38126	40878	13153	60411	50,971	42,191	41714
2020	1591	1235	55	40708	43589	12997	60411	51,461	42,195	41657
2025	1716	1235	56	43181	46188	12900	60411	50,694	42,190	41599

* Combined fleet for 22 municipalities, GVRD and UBC.

Table 7. Vehicle counts and VkmT by year for all HDDVs in emission inventory update.

	Total VkmT (1000 km/yr)					GVRD Emission Forecast	Difference from GVRD VkmT
Year	Municipal Vehicles	TransLink	BC Transit	All Others	Total	1000 VkmT	
2000	16,481	52,195	2,140	1,282,062	1,352,879	1,195,986	13.1%
2005	16,787	51,048	2,218	1,386,958	1,457,010	1,391,548	4.7%
2010	17,828	67,540	2,538	1,497,176	1,585,081	1,497,518	5.8%
2015	19,243	74,608	2,752	1,608,587	1,705,190	1,635,613	4.3%
2020	20,678	74,608	2,830	1,717,670	1,815,786	1,744,154	4.1%
2025	22,137	74,608	2,839	1,821,807	1,921,391	1,850,602	3.8%

Emission Results

Emissions of most pollutants generated by heavy-duty diesel vehicles in the Lower Fraser Valley are forecast to decrease dramatically by 2025 as a result of deployment of vehicles meeting the much lower 2007 HDDV emission standards for new vehicles. Table 8 summarizes the emission forecast developed in this study and illustrates the decrease in emissions by 2025 is expected to exceed 90% for CO, NOx, SOx, PM_{10}-exhaust and $PM_{2.5}$-exhaust and be 58% for VOC. The trend for $PM_{2.5}$ from exhaust emissions is illustrated in Figure 4. These changes are consistent with the changes in the sulphur content of diesel fuel and the change in emission standards for new engines. Air toxic emissions are forecast to decline 58%, except for ammonia, which is forecast to increase by 42% over this same period. Emissions of non-exhaust particulate matter from brake and tire wear and greenhouse gases will increase 42% due to the forecast growth in the vehicle-kilometres driven in the LFV.

The forecast of vehicle and full cycle greenhouse gas emissions assumes the average fleet fuel economy remains similar to that for today's fleet. This is equivalent to assuming that increased fuel consumption associated with addition of new emission control technology or changes to larger vehicles to meet buyer preferences are off-set by improvements in the efficiency of vehicles and engines, such as through reduced vehicle weight and deployment of advanced engine or hybrid-electric technology.

Emission estimates for TransLink buses took into account the model years and rebuild years of all the buses. Effectiveness of an engine rebuild for the 1992 and earlier model-year buses was investigated through discussions with the local engine dealer. The dealer confirmed that engine rebuilds for these buses would enable them to achieve the 1993 model-year emission standards, and this assumption was used for the emission estimates. The emission forecast for TransLink assumes that pre-1993 buses are replaced with new diesel buses prior to 2010. All other buses in this fleet are assumed to be replaced every 12 years, on average.

The emission forecast for the public transit bus fleet owned and operated by BC Transit in the FVRD is based on ICBC registration statistics and assumes that buses in this fleet are replaced every 12 years from date of purchase. Nontransit vehicles in the BC Transit fleet were assigned to MOBILE6.2C vehicle classes. Table 9 presents a detailed listing of the updated forecast of emissions of common air contaminants from onroad commercial HDDVs included in the study. Similarly, Table 10 presents results for emissions of greenhouse gases from these vehicles.

Figure 4 $PM_{2.5}$ emission forecast.

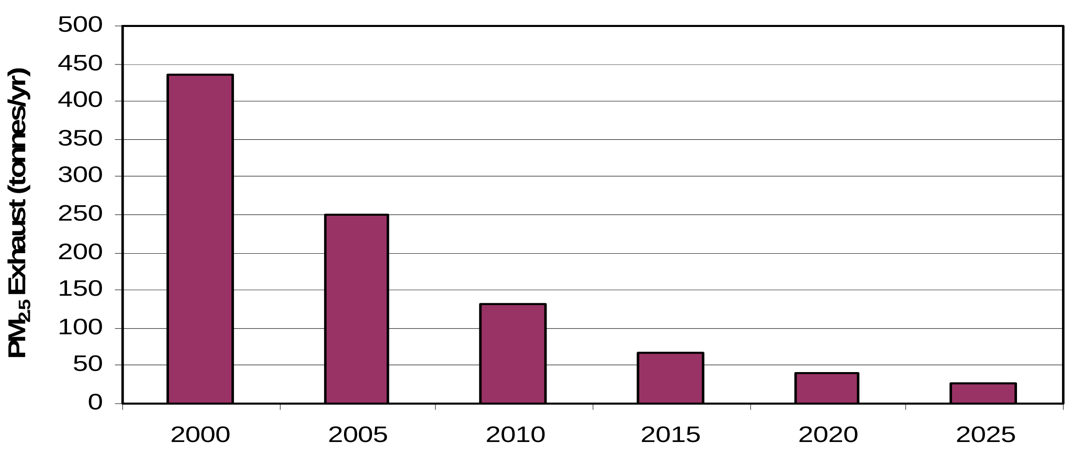


Table 8. Forecast emissions from heavy duty diesel vehicles by year.

Pollutant		2000 (t/yr)	2005 (t/yr)	2010 (t/yr)	2015 (t/yr)	2020 (t/yr)	2025 (t/yr)	Change by 2010 (%)	Change by 2025 (%)
CO		3,673	2,592	1,774	942	512	303	-52	-92
NOx		14,489	11,849	7,887	3,969	1,688	873	-46	-94
VOC		632	448	360	299	272	266	-43	-58
SOx		291	161	14	15	15	16	-95	-94
PM_{10}	Total	503	303	177	111	83	73	-65	-85
	Exhaust	473	271	142	74	43	31	-70	-94
	Non-exhaust	30	32	35	38	40	43	17	42
$PM_{2.5}$	Total	446	260	142	79	52	41	-68	-91
	Exhaust	437	250	131	68	39	28	-70	-94
	Non-exhaust	9	10	11	12	13	13	18	42
Acrolein		2	2	1	1	1	1	-43	-58
Acetaldehyde		19	14	11	9	8	8	-43	-58
Benzene		7	5	4	3	3	3	-43	-58
1,3 Butadiene		4	3	2	2	2	2	-43	-58
Formaldehyde		52	37	30	25	22	22	-43	-58
Ammonia		23	24	27	29	30	32	18	42
CO_2, t/yr		1,227,623	1,277,807	1,416,971	1,503,385	1,597,439	1,687,747	15	37
Full Cycle GHG, t/yr		1,464,103	1,570,613	1,721,786	1,854,445	1,969,401	2,079,157	18	42

Table 9. Criteria air pollutant emission forecast for the LFV by fleet.

Pollutant	Fleet	2000	2005	2010	2015	2020	2025
NOx, t/yr	All Municipal Fleets	181	148	103	48	22	10
	TransLink Buses	624	500	346	193	35	35
	BC Transit Buses	26	19	10	4	1	1
	All other HDDV	13,658	11,182	7,429	3,723	1,631	827
	Total	14,489	11,849	7,887	3,969	1,688	873
VOC, t/yr	All Municipal Fleets	9	5	4	3	3	3
	TransLink Buses	17	11	11	11	11	11
	BC Transit Buses	1	0	0	0	0	0
	All other HDDV	605	432	345	285	258	252
	Total	632	448	360	299	272	266
SOx, t/yr	All Municipal Fleets	4	2	0	0	0	0
	TransLink Buses	18	8	1	1	1	1
	BC Transit Buses	1	0	0	0	0	0
	All other HDDV	268	150	12	13	14	15
	Total	291	161	14	15	15	16
PM_{10}, t/yr Exhaust	All Municipal Fleets	8	3	2	1	0	0
	TransLink Buses	21	12	3	2	2	2
	BC Transit Buses	1	0	0	0	0	0
	All other HDDV	443	256	137	70	41	28
	Total	473	271	142	74	43	31
$PM_{2.5}$, t/yr Exhaust	All Municipal Fleets	8	3	1	1	0	0
	TransLink Buses	19	11	3	2	2	2
	BC Transit Buses	1	0	0	0	0	0
	All other HDDV	409	236	126	65	37	26
	Total	437	250	131	68	39	28

Table 10. Greenhouse gas emission forecast for the LFV by fleet.

Pollutant	Fleet	2000	2005	2010	2015	2020	2025
Vehicle CO_2equiv, t/yr	All Municipal Fleets	20,594	21,020	22,354	24,042	25,794	27,523
	TransLink Buses	84,588	71,732	125,956	117,167	117,220	117,220
	BC Transit Buses	3,005	2,631	2,855	3,332	3,148	3,406
	All other HDDV	1,119,436	1,182,424	1,265,807	1,358,843	1,451,277	1,539,598
	Total	1,227,623	1,277,807	1,416,971	1,503,385	1,597,439	1,687,747
Full Cycle GHG, t/yr	All Municipal Fleets	24,392	24,845	26,385	28,479	30,604	32,763
	TransLink Buses	111,364	108,915	144,103	159,184	159,184	159,184
	BC Transit Buses	3,895	4,037	4,619	5,009	5,151	5,167
	All other HDDV	1,324,453	1,432,816	1,546,679	1,661,773	1,774,463	1,882,044
	Total	1,464,103	1,570,613	1,721,786	1,854,445	1,969,401	2,079,157

Figure 5. Percent of NOx emissions from HDDV classes.

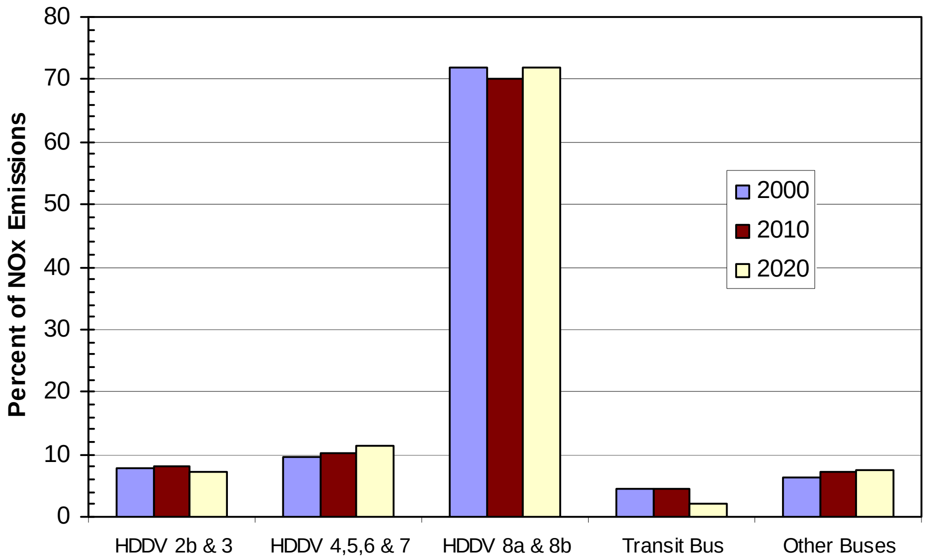
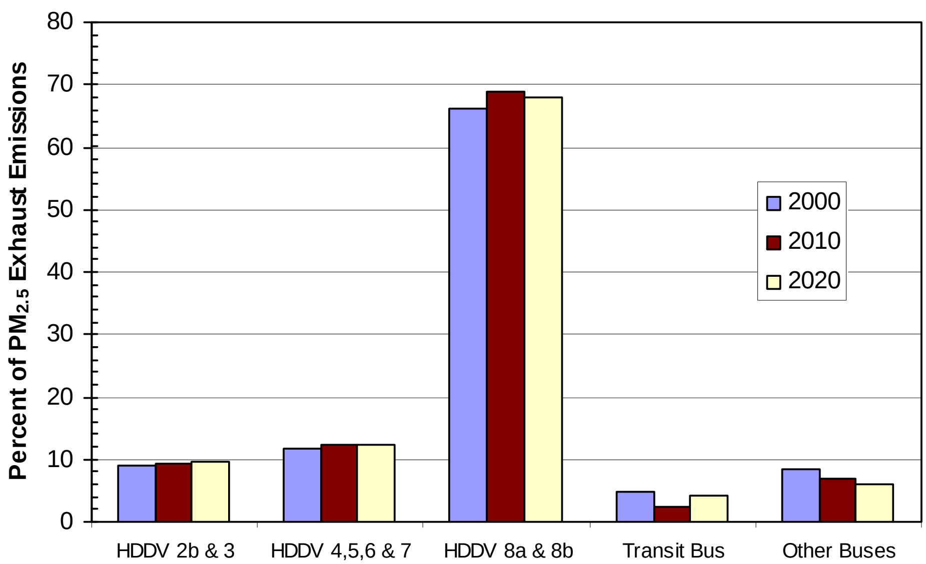


Figure 6. Percent of $PM_{2.5}$ exhaust emissions from HDDV classes.



The largest share of NOx and exhaust $PM_{2.5}$ arises from Class 8a and Class 8b diesel trucks, with this typically being close to 70% for the full forecast period (Figures 5 and 6). The next largest source of these pollutants is Class 4-7 vehicles, followed by Class 2b and 3 vehicles, other buses and transit buses. The contribution of these different vehicle classes remains fairly constant over the forecast period.

Predicted $PM_{2.5}$ Concentrations Near Roads

Table 11 summarizes the predicted maximum, 98th and 95th percentile zonal annual average $PM_{2.5}$ concentrations in 2000 for 8,000 merged links for buses alone, trucks alone and both combined. Two cases are shown, one based on emission factors used by the GVRD for the 2000 emission inventory, net of a 24% reduction from the AirCare OnRoad Program (ACOR) which inspects smoking diesel vehicles, and the other based on updated emission factors developed in this study and used for the updated emission inventory. The highest $PM_{2.5}$ concentrations from HDDVs arise from truck traffic. The contribution of truck emissions to predicted $PM_{2.5}$ concentrations from both vehicle types is less pronounced in the 98th and lower percentile levels of $PM_{2.5}$ than for the maximum. $PM_{2.5}$ concentrations are predicted to be significantly higher with the updated emission factors developed in this study than with the emission factors based on the same assumptions as used in the LFV emission inventory forecast, in proportion to the ratio between these emission factors for each vehicle class modelled. With the updated emission factors, predicted $PM_{2.5}$ concentrations are 22% lower for buses and 76% higher for trucks. The impact of this change for combined emissions from buses and trucks varies, with the change in the maximum $PM_{2.5}$ concentrations controlled by the effects of truck emissions and the lower percentiles of $PM_{2.5}$ concentration increasing 25-40%.

Table 11 Predicted Annual Average $PM_{2.5}$ Concentrations from Bus and Truck Emissions.

	Predicted Annual Average $PM_{2.5}$ Concentration ($\mu g/m^3$)							
	GVRD Emission Factors – 2000 ICBC data & assumed 24% emission reduction from the AirCare Onroad Inspection Program				Updated Emission Factors – 2003 ICBC data with no emission reduction from the AirCare Onroad Inspection Program			
	Zone 1 <20 m	Zone 2 20-100 m	Zone 3 100-500 m	Zone 4 >500 m	Zone 1 <20 m	Zone 2 20-100 m	Zone 3 100-500 m	Zone 4 >500 m
Transit Buses								
Maximum	1.70	1.14	0.44	0.19	1.32	0.88	0.34	0.14
98th Percentile	0.40	0.27	0.10	0.04	0.31	0.21	0.08	0.03
95th Percentile	0.24	0.16	0.06	0.03	0.19	0.13	0.05	0.02
Trucks								
Maximum	15.32	10.28	3.99	1.68	26.94	18.08	7.01	2.95
98th Percentile	0.60	0.40	0.16	0.07	1.05	0.71	0.27	0.12
95th Percentile	0.30	0.20	0.08	0.03	0.51	0.34	0.13	0.06
All HDDV								
Maximum	15.32	10.28	3.99	1.68	26.94	18.08	7.01	2.95
98th Percentile	0.78	0.53	0.20	0.09	1.09	0.73	0.28	0.12
95th Percentile	0.49	0.33	0.13	0.05	0.61	0.41	0.16	0.07

Bus traffic in the LFV is predicted to result in maximum annual average Zone 1 $PM_{2.5}$ concentrations up to 1-2 $\mu g/m^3$, with many bus routes having predicted Zone 1 $PM_{2.5}$ concentrations of 0.4-0.6 $\mu g/m^3$. Truck traffic is predicted to result in maximum annual average Zone 1 $PM_{2.5}$ concentrations of 10-15 $\mu g/m^3$ near a small fraction of roads. Ninety-eight percent of the links had predicted annual average Zone 1 $PM_{2.5}$ concentrations of 0.6 $\mu g/m^3$ or less.

The spatial distribution of elevated annual average $PM_{2.5}$ concentrations from HDDV emissions in 2000 were mapped with ArcView™ software using a corridor mapping technique and the $PM_{2.5}$ concentrations predicted for each zone and link using the GVRD emission factors and assuming an emission reduction for AirCare Onroad Inspection Program. The mapped results for Greater Vancouver (western part of the Lower Fraser Valley) are illustrated in Figure 7, which was mapped using data from all four zones modelled. Annual average incremental $PM_{2.5}$ concentrations above 1 $\mu g/m^3$ in Zone 1 occurs along a number of major roads, including, for example, Granville Street, the Oak Street Bridge, the Iron Worker's Memorial Bridge, and sections of Highway 1 and Highway 99. Wider corridors of 200 m width are predicted to have Zone 2 $PM_{2.5}$ concentrations above 0.4 $\mu g/m^3$ for about 25 km of arterial roads, with the main areas being Granville Street, Kingsway, Knight Street, Highway 1 and all of the major bridges connecting traffic flow to Richmond and the District of North Vancouver. Similar effects on air quality will occur close to the bridges in these adjoining municipalities.

Approximately 196 kilometers of road has predicted incremental annual $PM_{2.5}$ concentrations from HDDVs above 1 $\mu g/m^3$ beyond 20 m of the edge of the road, which is equivalent to an increase of 300 in a million lifetime risk (70 yrs) of cancer based on the California Air Resources Board[8] unit risk factor. This length of road is 5% of the 4,266 km included in the EMME/2 model.

CONCLUSIONS

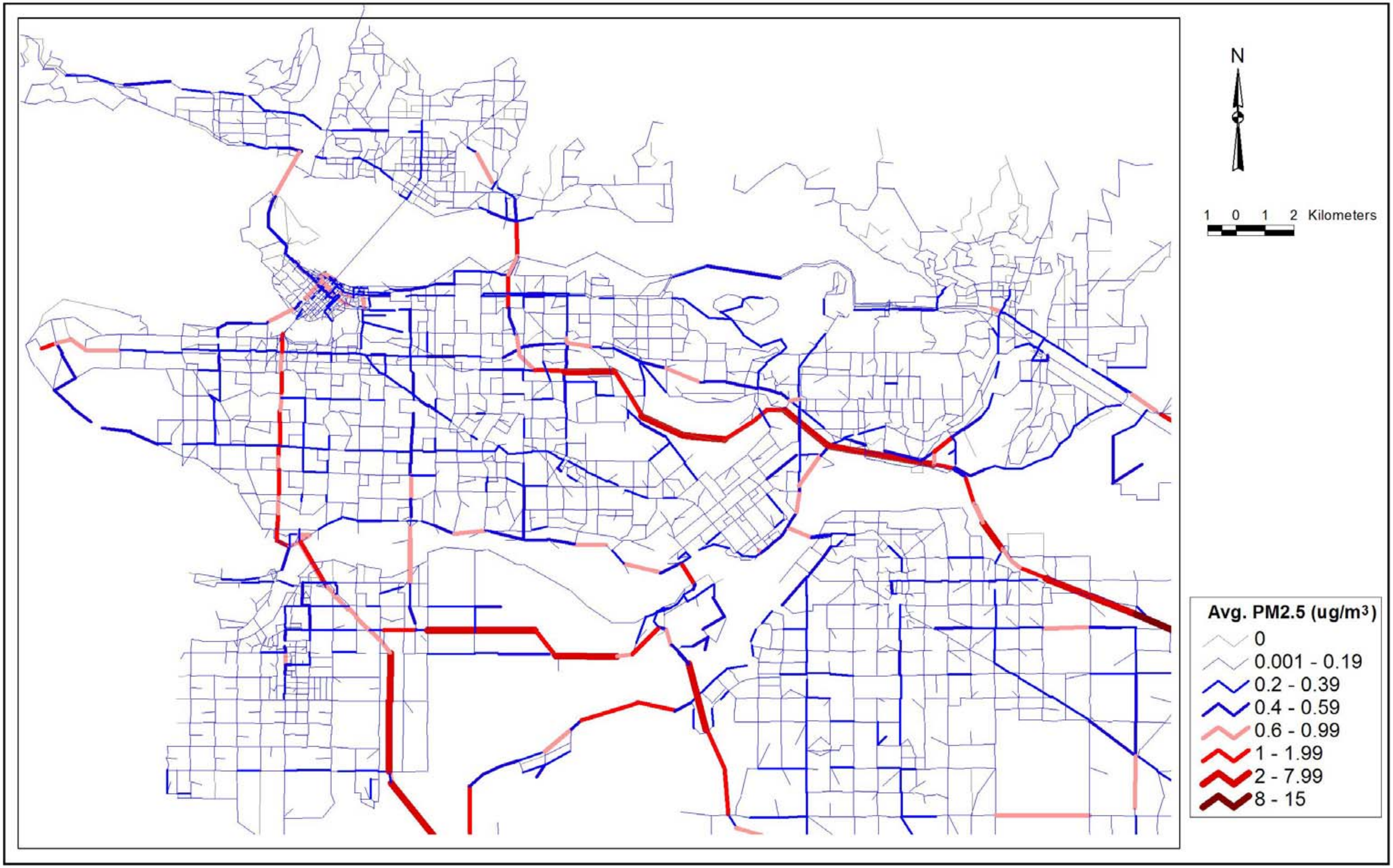
There are 32,521 onroad heavy-duty diesel vehicles operating primarily in the Canadian portion of the Lower Fraser Valley international airshed. Of this total, 12,138 vehicles, or 37%, are specified in the ICBC registration statistics for 2003 to be part of a vehicle fleet. The three largest onroad HDDV categories are Class 8a+b (29.9%), Class 2b (22.7%) and Class 3 (19.6%), which together comprise 72.2% of the heavy duty diesel vehicles

Emissions of criteria air contaminants from HDDVs are forecast to decrease by 60% to 90% between 2000 and 2020, due to introduction of new control technologies and fuel standards. Air toxic emissions, excluding diesel particulate matter and ammonia, are forecast to decrease 57% over this same period. Emissions of greenhouse gases from HDDVs, however, are forecast to increase by 35% during the same period.

Use of EMME/2 traffic modelling output together with simplified dispersion modelling theory allowed estimates to be developed of the impact of HDDV emissions on average annual $PM_{2.5}$ concentrations near roads. The highest Zone 1 $PM_{2.5}$ concentrations from bus and truck HDDV traffic are predicted to occur near major highways and expressways in the LFV where the combined traffic volume is highest. Emissions from heavy trucks tend to have the largest influence on maximum and 98^{th} percentile $PM_{2.5}$ concentrations.

Predicted annual average $PM_{2.5}$ concentrations from HDDV emissions were above 1 $\mu g/m^3$ within 20-100 m of 196 km of roads, with associated potential for increased risk of adverse human health effects. These and associated results can be used for development of localized monitoring programs and assessment of the benefits of implementing emission reduction programs for HDDVs.

Figure 7. Estimated annual average $PM_{2.5}$ concentrations from HDDV traffic in the western part of the Lower Fraser Valley.



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KEY WORD

Heavy-duty diesel vehicles
Fleet characterization
Emissions forecast
$PM_{2.5}$ emissions
$PM_{2.5}$ concentrations
Diesel emissions