GREATER VANCOUVER REGIONAL DISTRICT

REMOTE SENSING DEVICE TRIAL FOR MONITORING HEAVY-DUTY VEHICLE EMISSIONS

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Disclaimer

This report has been reviewed by representatives of Metro Vancouver, Fraser Valley Regional District, BC Ministry of Environment, AirCare, Port Metro Vancouver, and BC Ministry of Transportation and Infrastructure, who commissioned the study, but the interpretation of the results of this study, as expressed in the report, is entirely the responsibility of the consultant authors and does not imply endorsement of specific points of view by Metro Vancouver, Fraser Valley Regional District, BC Ministry of Environment, AirCare, Port Metro Vancouver, or BC Ministry of Transportation and Infrastructure. The findings and conclusions expressed in the report are the opinion of the authors of the study and may not necessarily be supported by Metro Vancouver, Fraser Valley Regional District, BC Ministry of Environment, Air Care, Port Metro Vancouver, or BC Ministry of Transportation and Infrastructure.

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Glossary of Terms and Abbreviations

ACOR	AirCare On-Road
BC	Black Carbon particulate matter
BC	British Columbia
CARB	California Air Resources Board
Clean Screening	The process of using RSD to identify vehicles with low emissions to exempt them from the required emission inspection at an inspection station
CO	Carbon monoxide
CO_2	Carbon dioxide
Cutpoint	An emissions level used to classify vehicles as having met an emissions inspection requirement
CVSE	Commercial Vehicle Safety and Enforcement
Evaporative Emitters	Vehicles releasing gaseous or liquid hydrocarbons from the fuel tank or fuel system
FTP	Federal Test Procedure
g/bhp-hr	Grams of pollutant emissions per brake horsepower hour
g/kg	Grams of pollutant emissions per kilogram of fuel consumed
g/kWh	Grams of pollutant emissions per kilowatt-hour of engine output
GVWR	Gross Vehicle Weight Rating

HC	Hydrocarbons
HD	Heavy-duty
HDV	Heavy-duty vehicle
High-Emitter Identification	The on-road identification of vehicles with high emission levels
ICBC	Insurance Corporation of British Columbia (responsible for vehicle licensing and insurance within the Province)
I/M	Inspection and Maintenance Program
IM240 Test	A loaded-mode transient tailpipe emission test conducted when the vehicle is driven for up to 240 seconds on a dynamometer, following a specific speed trace simulating real world driving conditions
IR	Infrared light
kW/t	Kilowatts per metric ton, the units of measurement for vehicle specific power
LD	Light-duty
LDV	Light-duty vehicle
LFV	Lower Fraser Valley
NMHC	Non-methane hydrocarbons
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen, usually measured by RSD as nitric oxide (NO)

NTE Zone	A defined region of torque and power within which heavy-duty vehicle emissions are not-to-exceed a standard.
OBDII	On Board Diagnostic system to detect emissions related problems required on all 1996 and newer light–duty vehicles
OREMS	On-road Emissions Measurement Systems
PEMS	Portable Emissions Measurement System
$PM_{2.5}$	Particles of ~2.5 micrometers or less
PM_{10}	Particles of ~10 micrometers or less
PMV	Port Metro Vancouver
Positive Power	An operating mode where the engine is generating power to drive the wheels
RSD	Remote Sensing Device
Tag Edit	The transcription of vehicle license plates or tags from images to text
Territory Z	An ICBC designation for vehicles operated in multiple jurisdictions
US	United States
USEPA	United States Environmental Protection Agency
UV	Ultraviolet light
VIN	Vehicle Identification Number
VDR	Vehicle On-road Record
VMT	Vehicle Miles Traveled

VSP	Vehicle Specific Power; estimated engine power divided by the mass of the vehicle

I Executive summary

I-1 Background

Air pollution causes significant health risks, including death from respiratory and cardiovascular causes, inflammation of lung tissue in young, healthy adults and increased hospitalization for asthma among young children.

Environment Canada has declared particulate matter (PM), especially airborne particulate matter equal to or less than 10 microns (called PM10), toxic under the *Canadian Environmental Protection Act (1999)*. California Air Resources Board (CARB) in 1998 also classified diesel exhaust as a toxic air contaminant, finding, "Diesel exhaust includes over 40 substances that are listed by the United States Environmental Protection Agency (USEPA) as hazardous air pollutants and by the CARB as toxic air contaminants. Fifteen of these substances are listed by the International Agency for Research on Cancer (IARC) as carcinogenic to humans, or as a probable or possible human carcinogen" and "Based on available scientific information, a level of diesel exhaust exposure below which no carcinogenic effects are anticipated has not been identified." In 2012, IARC classified diesel engine exhaust as carcinogenic to humans based on evidence that exposure is associated with an increased risk for lung cancer[i].

Oxides of nitrogen (NO_x) are a concern for their role in the formation of harmful low level ozone in the Lower Fraser Valley, which includes Metro Vancouver and the Lower Fraser Valley Regional District. In addition, in 2010 the USEPA announced a national air quality standard for nitrogen dioxide (NO_2) to protect individuals from peak short-term exposures, which primarily occur near major roads. Short-term exposures to NO_2 have been linked to impaired lung function and increased respiratory infections, especially in people with asthma. The USEPA set the new one-hour standard for NO_2 at a level of 100 parts per billion (ppb). USEPA also retained the existing annual average standard of 53 ppb. Environment Canada established National Ambient Air Quality Objectives (NAAQO) for NO_x of an annual maximum desirable level of 60 ppb and an hourly maximum acceptable level of 400 ppb.

On-road transportation is estimated to contribute approximately one quarter of 'smog forming pollutants' in the Lower Fraser Valley. Large, heavy-duty vehicles such as buses and trucks use diesel engines, a significant contributor to emissions of diesel exhaust containing particulate matter and nitrogen oxides that are hazardous to human health. Reductions in heavy-duty emissions have tended to lag behind those of light-duty vehicles. Heavy-duty vehicles, which are nearly all diesel fueled, produce greater quantities of PM and NOx emissions.

Metro Vancouver wished to obtain an assessment of heavy-duty vehicle emissions in the region and selected Envirotest to perform this study. Remote sensing device (RSD) 4600 series units were deployed to acquire on-road remote sensing emissions measurements of active heavy-duty vehicles. In addition a prototype heavy-duty emissions tunnel (HDET) was used to measure heavy-duty vehicle emissions at a weigh-station.

I-2 Goals

The primary objectives for this RSD Trial project were to:

1. **Understand Emissions from Heavy-Duty Vehicles in the Lower Fraser Valley:**

- How many vehicles are higher emitters than their model year counterparts?
- Which vehicles (age/class) have the worst / most offenders?
- Does reality match public perception with respect to the emissions of heavy-duty vehicles?

2. **Understand the Impacts of Different Program / Policy Options:**

- Help design effective programs to target the highest emitting vehicles;
- How many vehicles would be affected by programs established at varying levels of stringency (e.g., opacity limits)?
- What would be the estimated air quality benefit?

3. **Test the Feasibility of Integrating RSD into Program Options:**

- Could RSD play a role in a "gross-emitter" or "clean screen" program?
- Could it help identify vehicles eligible for scrappage incentives?

I-3 Findings

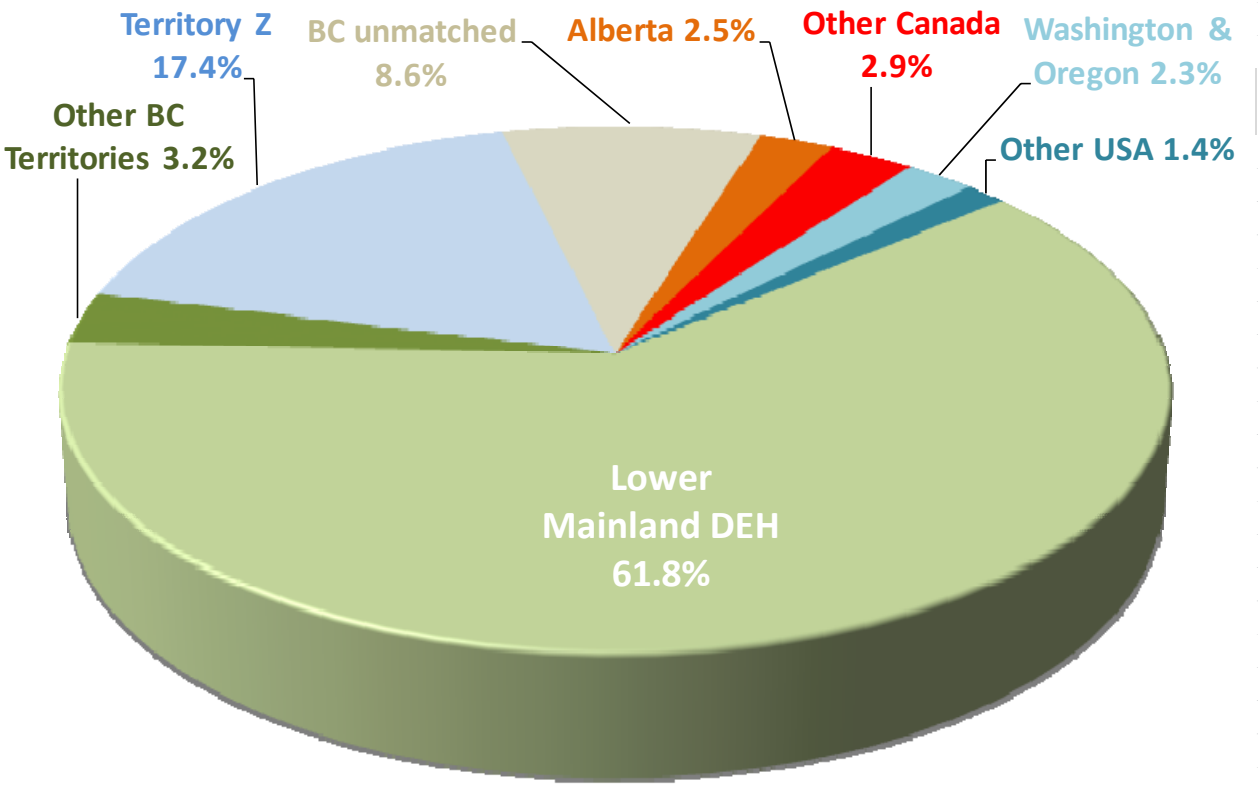
I-3.1 Emissions from HDVs in the Metro Vancouver and the Fraser Valley Regional District

During the 55 days of data collection, a net total of 6,012 individual heavy-duty vehicles were measured by RSD including 17% of all class 8 trucks registered in the region.

Using RSD units deployed at road level and at four meters, Envirotest measured the emissions and captured the license plates of 40,000 heavy-duty and light-duty vehicles driving past the RSD systems at sites such as weigh stations. Over 35,000 of the passing vehicles were matched by license plate to British Columbia registration information and of these 11,700 were heavy-duty and 23,600 were light-duty. These included repeat measurements of the same vehicles at sites where RSD was deployed for several days. In addition, over 900 heavy-duty vehicles were measured as they drove through a tent tunnel designed to capture emissions.

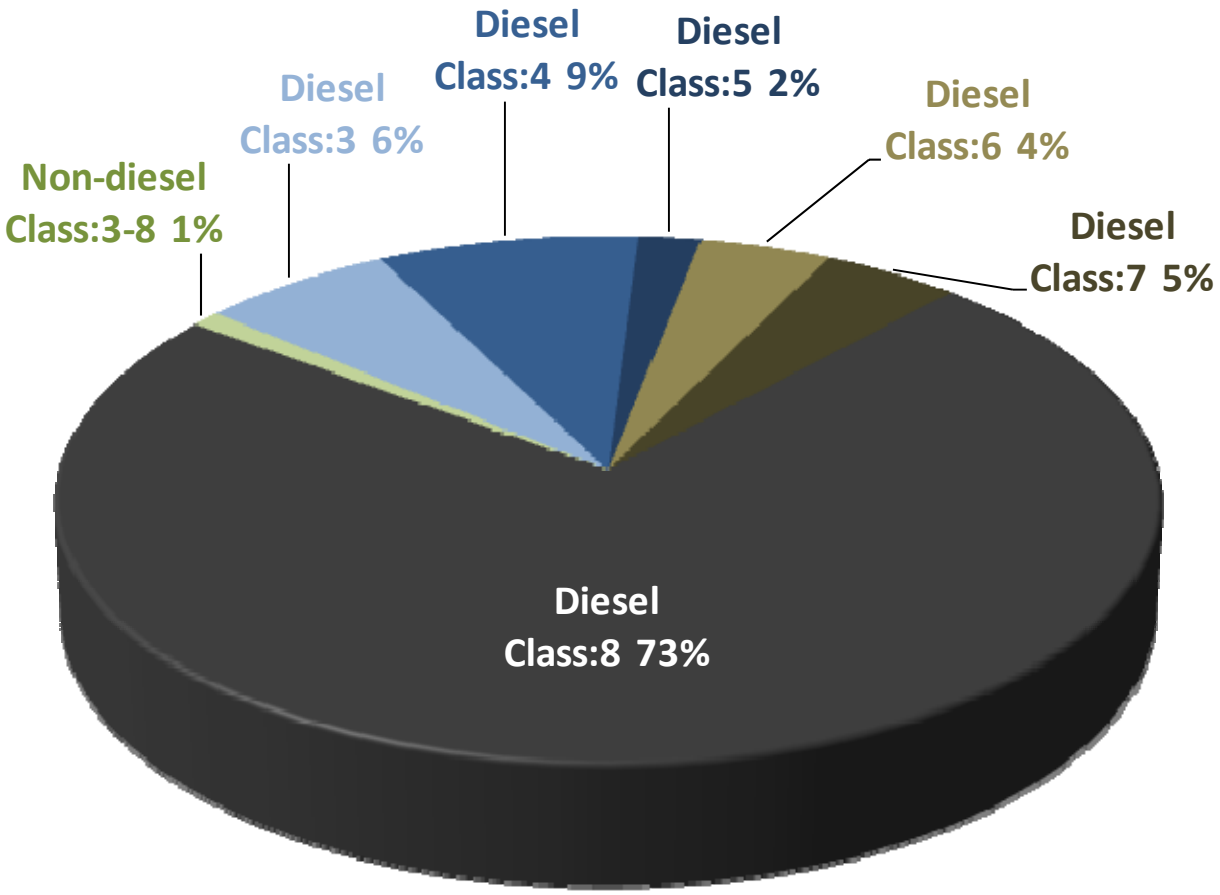
The registration jurisdictions of the heavy-duty vehicles observed operating in the region are shown in Figure I-1. The vast majority were registered in the Lower Fraser Valley region (ICBC lower mainland territories DEH and Z and probably most of the unmatched). Vehicles registered elsewhere were found to have similar emissions.

Figure I-1: Heavy-duty Vehicle Observations by Regional Source



Almost three-quarters of the heavy-duty vehicles observed were Class 8. Observations by weight class are possibly skewed towards Class 8 vehicles by the selection of sites including an emphasis on weigh stations. Figure I-2 shows the split of heavy-duty vehicle observations by weight class. There were not major differences in emissions per unit of fuel across the weight classes. Most of the emissions differences were related to fuel and vehicle age.

Figure I-2: Heavy-duty Vehicle Observations by Weight Class



Emissions of heavy-duty vehicles were more homogeneous than those of light gasoline vehicles. Virtually all (99%) of heavy-duty vehicles were diesel fueled. From an emissions perspective these can be divided into three groups: 1) 2007 & older, 2) 2008-2010 and 3) 2011 and newer.

- The **2007 & older** heavy-duty vehicles had PM and NO_x emissions ten and six times higher respectively per kilogram of fuel consumed than those of 2007 and older light-duty gasoline vehicles. Trucks also use about four times more fuel per kilometer than light vehicles. Nearly all these heavy-duty vehicles had high NO_x emissions but since emission standards were more relaxed for earlier models, it was among the 2004 to 2007 model years that most vehicles exceeded the Canadian adopted USEPA NO_x emissions standards.

- With improved diesel particulate filter systems (DPFs), **the 2008-2010 models** had dramatically lower emissions of PM and modest reductions in NO_x. NO_x standards were phased in for diesel engines between 2007 and 2010 on a percent-of-sales basis: 50% from 2007 to 2009 and 100% in 2010.

- The **2011 and newer** models had low emissions of PM and NO_x.

Federal emission standards in the U.S. and adopted by Canada, have required the use of PM control technologies such as DPF's from 2007, but appears effective on 2008 and later models. NO_x aftertreatment, e.g. lean NO_x catalysts (LNCs) or selective catalytic reduction (SCR) were required from 2010. These NO_x controls appear to have been effectively applied on 2011 and later models. The current heavy-duty standards have effectively reduced NO_x and PM emissions from the newest models to mere fractions of those from older models. Even at these technology levels, however, trucks have higher emissions than light-duty vehicles.

Overall, 24% of heavy-duty vehicles measured were 2008 and newer models.

The emissions of public transit buses were also measured at bus terminals. Many of the measured buses were older and had PM and NO_x emissions consistent with the majority of trucks. This may be a particular concern because they operate in predominantly densely populated areas in close proximity to pedestrians and passengers. Compared to some other urban areas there were relatively few buses fueled by natural gas.

Anecdotally the public believes that most heavy-duty trucks emit smoke. In the study, however, relatively few trucks generated visible smoke as observed by the RSD operators.

The emission averages and trends are illustrated in Table I-1 and Figures I-3 and I-4 for both the RSD and the Tunnel. Both sets of equipment show similar trends and agreement between RSD NO and Tunnel total NOx was very good. Average RSD PM emissions were 0.4 g/kg higher than the Tunnel measurements across all model years, which may be a consequence of the operating mode of the vehicles. Heavy-duty vehicle PM emissions per unit of fuel were higher at idle than when engines were under load and those measured by RSD were often operating at a lower average power than those measured through the Tunnel. Vehicle operating mode needs to be carefully considered when screening heavy-duty vehicles using RSD.

Table I-1: Observations and Average Emissions by Vehicle Age Group

Model Year	Observations	RSD NO g/kg	Tunnel NOx g/kg	NOx Variance (RSD-Tunnel)	RSD PM g/kg	Tunnel PM g/kg	PM Variance (RSD-Tunnel)
2000 & older	6,989	30.5	29.3	1.1	1.2	0.8	0.4
2001-2007	12,768	19.9	20.9	-1.0	1.1	0.6	0.5
2008-2010	3,079	10.9	14.2	-3.3	0.5	0.1	0.4
2011 & newer	2,969	3.6	4.2	-0.6	0.5	0.1	0.4
Total	**25,805**	**19.8**	**20.5**	**-0.6**	**1.0**	**0.6**	**0.4**

Figure I-3: Heavy-duty Vehicle PM Emissions: Tunnel and RSD

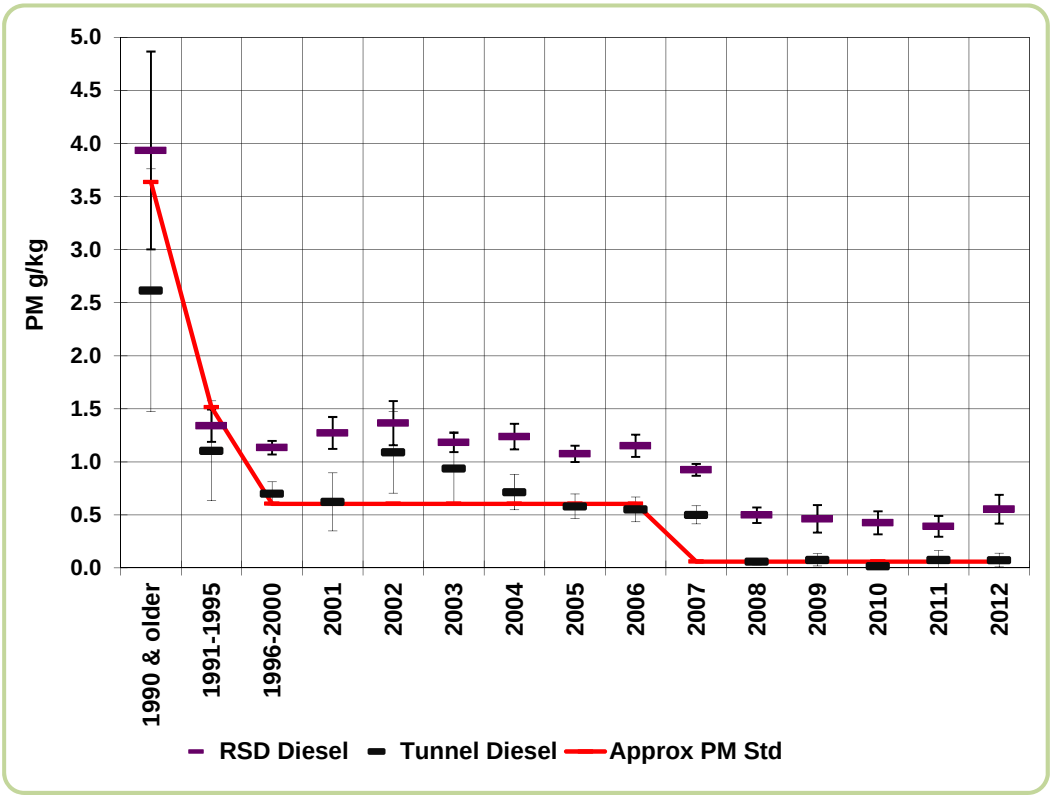


Figure I-4: Tunnel and RSD Heavy-duty Vehicle NO_x Emissions

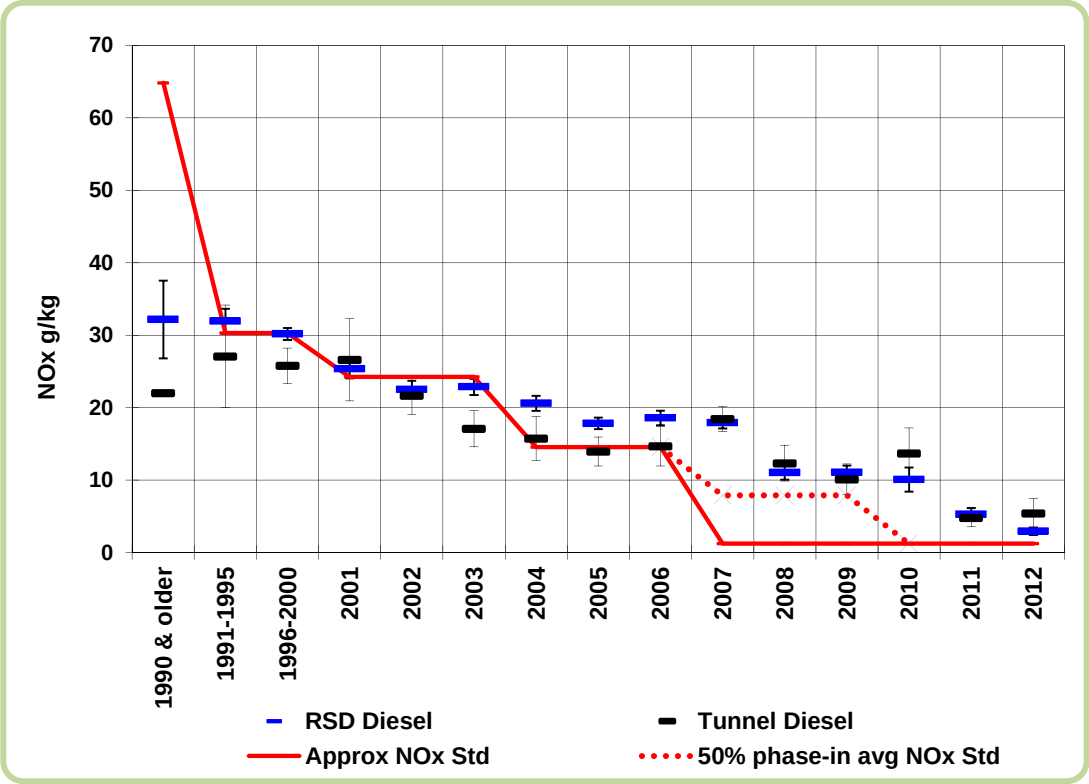


Table I-2 summarizes by four vehicle age groups the percentage of observations of vehicles and the percentage of total NOx and PM emitted by each age group. Seventy-six percent of heavy-duty vehicles observed were 2007 & older models. These emitted 90% of NOx and up to 98% of PM.

Table I-2: Percentage of Observations and Emissions by Vehicle Age Group

Heavy-duty Model Year	% of Observations	% of RSD NO	% of Tunnel NOx	% of RSD PM	% of Tunnel PM
2000 & older	27%	42%	39%	34%	41%
2001-2007	49%	50%	51%	55%	57%
2008-2010	12%	7%	8%	6%	1%
2011 & newer	12%	2%	2%	5%	1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

I-3.2 Impacts of Different Program / Policy Options

Heavy-duty vehicle inspection programs exist in several major metropolitan areas in Canada and the United States. These typically test for opacity only using the "Snap Acceleration Smoke Test Procedure for Heavy-Duty Diesel-powered Vehicles" (SAE J1667)" and may use decentralized facilities or fleet self-testing in combination with limited roadside programs and other audit/enforcement elements.

Canada does little at the federal level with regard to in-use vehicle emissions enforcement because federal jurisdiction stops at the point of first retail sale. Thus, it is up to the provinces to deal with in-use trucks. Diesel trucks and buses in Ontario more than three model years old are required to pass an annual opacity snap acceleration test. Quebec operates an on-road pullover inspection program using the snap acceleration smoke test.

In British Columbia, the AirCare On-Road (ACOR) program[ii] tests a small number of trucks each year using the snap acceleration smoke test. Port Metro Vancouver (PMV) licenses trucks using the port with the goal of bringing the fleet up to 2007 standards. Pre-2007 trucks over ten years old are required to pass a 20% opacity test standard.

Limitations of the current snap acceleration test include: insensitivity to fine PM generated by modern diesel engine systems, standards that are very loose compared to modern truck standards, measurement during unloaded engine operation rather than under load, and no evaluation of NO_x emissions. Tuning for PM by making the fuel-air mixture leaner can increase NO_x emissions. Therefore, an inspection program that controls for opacity but not for NO_x may raise NO_x levels.

In addition to inspections, the USA has made a major investment using public funds to both modernize and retrofit HDVs to reduce their emissions. In 2004, California Air Resources Board adopted a regulation requiring diagnostic systems on all 2007 and subsequent model year heavy-duty engines and vehicles (i.e., vehicles with a gross vehicle weight rating greater than 14,000 lbs.) in California. USEPA and California Air Resources Board subsequently adopted a comprehensive OBD regulation for 2010 and subsequent model year HDVs. In October 2011 similar Canadian regulatory amendments for heavy-duty OBD were proposed. The proposed Amendments only apply to heavy-duty engines of the 2013 and later model years.

Such investments in diesel vehicle retrofits and modernization should be monitored to ensure the equipment is being adequately maintained.

In this context, Envirotest offers a number of suggestions for Metro Vancouver and the Lower Fraser Valley Regional District to consider:

1) A mandatory annual heavy-duty inspection program to protect the public from harmful excess emissions and protect the heavy investment in heavy-duty emission control systems by manufacturers and owners through retrofit/replacement programs.

2) The program should be implemented in a way that is effective but not overly onerous on heavy-duty vehicle operators.

3) The newest model vehicles and those with low mileage accumulation could be exempted.

4) Inspected vehicles should be tested for PM and NO_x emissions. For applicable 2011-2012 models and all 2013 and newer models the inspection should include a scan of the OBD system. The program should collect odometer data.

5) An expanded database of heavy-duty vehicles should be established to record their characteristics including details of original or retrofit emissions control equipment, and inspection results.

Heavy-duty vehicles s observed in the study were nearly all (87%) registered within the Lower Fraser Valley or as territory Z. There were approximately 50,000 vehicles registered in these regions with GVW greater than 5,000 kg and 13% of these were measured during the study.

Potential Air Quality Benefits of an RSD Program:

In looking at the statistics gathered in the study, and extrapolating to the entire fleet, Envirotest ran trials using two sets of RSD emissions cutpoints. One set was conservatively loose with the intent of identifying just the worst emitters and a second set was more directly linked to vehicle standards with an allowance for the variability in operating conditions associated with on-road measurements.

The first set of cutpoints identified 8% percent of vehicles measured as high emitters and these vehicles emitted 16% of the PM and 17% of the NOx from heavy-duty vehicles. If these vehicles were repaired to the average emissions level for their model year the emissions reductions would be 9% of PM and 9% of NOx from HDVs.

With the second set of trial RSD emissions cutpoints, 26% of heavy-duty vehicles were identified as high emitters and these vehicles emitted 42% of the PM and 38% of the NOx from heavy-duty vehicles. If the high emitting vehicles were repaired to the average emissions level for their model year, the emissions reductions would be 23% of PM and 16% of NOx from heavy-duty vehicles.

Greater emissions reductions could be achieved if these vehicles were replaced or retrofit with more effective emissions control systems.

To convert the percentage reductions into tonnes of emissions requires estimates of the kilometers travelled by the heavy-duty vehicles. For this reason, it would be important that the odometer readings be included in the data in any future program. As we have seen in the light-duty vehicle AirCare Program, it is possible to estimate the kilometers travelled from the odometer readings recorded and to make definitive estimates of program benefits.

I-3.3 Feasibility of Integrating RSD into Program Options

The information gathered in the study indicates that both the RSD and the Tunnel are effective tools in identifying the highest and the lowest emitting vehicles. By comparing the data from both methods, RSD indicated a higher level of PM than the same vehicle showed when it went through the tunnel. Other measurements were more closely aligned. It is important to note, however, that the same trends applied with both testing techniques on all measures as illustrated by Figures I-1 and I-2.

Although the weather during the RSD study performed over the summer of 2012 was outstanding (record-breaking dry weather) and it enabled a concentration of effort during the time available for the study, it is understood that this cannot always be expected.

We consider the tunnel test results to be very encouraging. The accuracy, the ability to measure more emissions parameters and the ability to perform testing in the rain makes it a very promising technology for the region. In addition, the control over the test process is reasonably high. If the truck doesn't accelerate properly through the test, the inspector could require it to go through again thus allowing one reading to be used as the screen. We believe the Tunnel technique could be used to cost effectively and conveniently test or screen the HDV fleet.

One issue with the measurements completed in the study was the lower than expected traffic counts at sites. It was perhaps underestimated just how effective the truck driver's communications network is and how much they would consciously avoid the testing locations. This behavior was confirmed by the Commercial Vehicle Safety and Enforcement (CVSE) staff who stated that when they performed surprise roadside safety inspections, a similar scenario exists and the number of trucks observed dropped dramatically and almost instantly. Therefore, screening or testing would have to be part of a mandatory program that required vehicles to be screened or tested annually.

The quick, drive-through nature of the test would be many times more convenient than a requirement for testing at a traditional inspection station. During the 55 days of on-road testing 17% of the class 8 trucks registered in ICBC areas D, E and H were measured. A large number of the vehicles also had repeats indicating that drivers who had "nothing to lose" (like fleet drivers) would not hesitate to go through the RSD or Tunnel.

We estimate that three tunnels (located on convenient sites in the region) would be sufficient to measure the Lower Fraser Valley and territory Z heavy-duty truck fleets annually. Sites could operate 60 hours per week with a throughput capacity of 15 trucks per hour. Three sites would provide the capacity to test or screen 50,000 vehicles annually at 37% utilization. Because the tunnel operation would require some operator interaction with the truck driver, it would only test BC registered trucks. The general population could also be monitored by RSD. If desired ACOR/CVSE teams could direct non-BC trucks to obtain a Tunnel measurement.

An effective use of RSD would be as a complement to the mandatory testing program. RSD can be used in three applications; clean screening, high emitter identification and on-road fleet monitoring. Trucks observed by RSD as being among the cleanest or having emissions well below the standards would not be required to undergo further testing. In the same way, the highest emitters could be flagged as requiring early testing and recruitment into incentivized repair, retrofit and replacement programs. Obtaining adequate funding for heavy-duty vehicle retrofit and replacement programs is a common challenge. Using activity and emissions data to prioritize the vehicles to be retrofit or replaced ensures the most effective use of the limited funds available. Fleet monitoring provides feedback on the effectiveness of the program and the progress made in reducing emissions.

Review of the on-road data could also be used to assess the effectiveness of the decentralized facilities certified for testing – if there are any. The RSD/Tunnel testing techniques would therefore be used to minimize the impact of any emissions testing program to the trucking community.

I-3.1 Next Steps

Suggested next steps are to:

- Integrate the emission results from this study with mileage data from CVSE to develop a more detailed breakdown of the heavy-duty vehicle emissions inventory and the relative contributions from heavy-duty and light-duty vehicles;
- Investigate the cost effectiveness of alternate approaches to reducing heavy-duty vehicle emissions, e.g. repairs, retrofit emissions control equipment, replacement engines or replacement vehicles;
- Establish a working group to consider what legal authority, regulations, equipment and resources would be needed to implement an effective heavy-duty vehicle emissions monitoring and control program.

In summary, we believe there is an opportunity to improve the air quality in the Lower Fraser Valley by monitoring and controlling emissions from heavy-duty vehicle. RSD and Tunnel testing could play a significant role in that effort while minimizing the impact of drivers and operators of these vehicles.

II Project Equipment and Work Plan

II-1 Equipment

Envirotest deployed two remote vehicle emissions measurement technologies to characterize the in-use emissions of the heavy-duty vehicle (HDV) fleet in the Lower Fraser Valley (LFV) that includes Metro Vancouver and the Lower Fraser Valley Regional District:

- Remote Sensing Devices (RSDs) – the principal project measurement technology.
- Heavy Duty Emissions Tunnel (HDET) – a prototype technology being demonstrated.

RSDs were the principal technology used to characterize HDV emissions in the Project Area, and were applied throughout the project. Envirotest, through its predecessor companies and with its research partners, has developed remote sensing technology since the early 1990's and with the University of Denver, has invested more than $20 million in the development of accurate and reliable remote sensing systems. The RSDs used in the study were fourth generation AccuScan™ 4600 series systems that measured HC, CO, NO_x, CO_2 and PM, as well as vehicle speed and acceleration. RSDs were previously used to assess LDV emissions in the region[iii] and in Alberta[iv].

Envirotest's AccuScan™ RSD instantly measures tailpipe emissions as motor vehicles pass through ultraviolet and infrared beams of light. This state-of-the-art technology provides convenient, unobtrusive, reliable and cost-effective emissions measurements in less than a second without impeding a vehicle's progress.

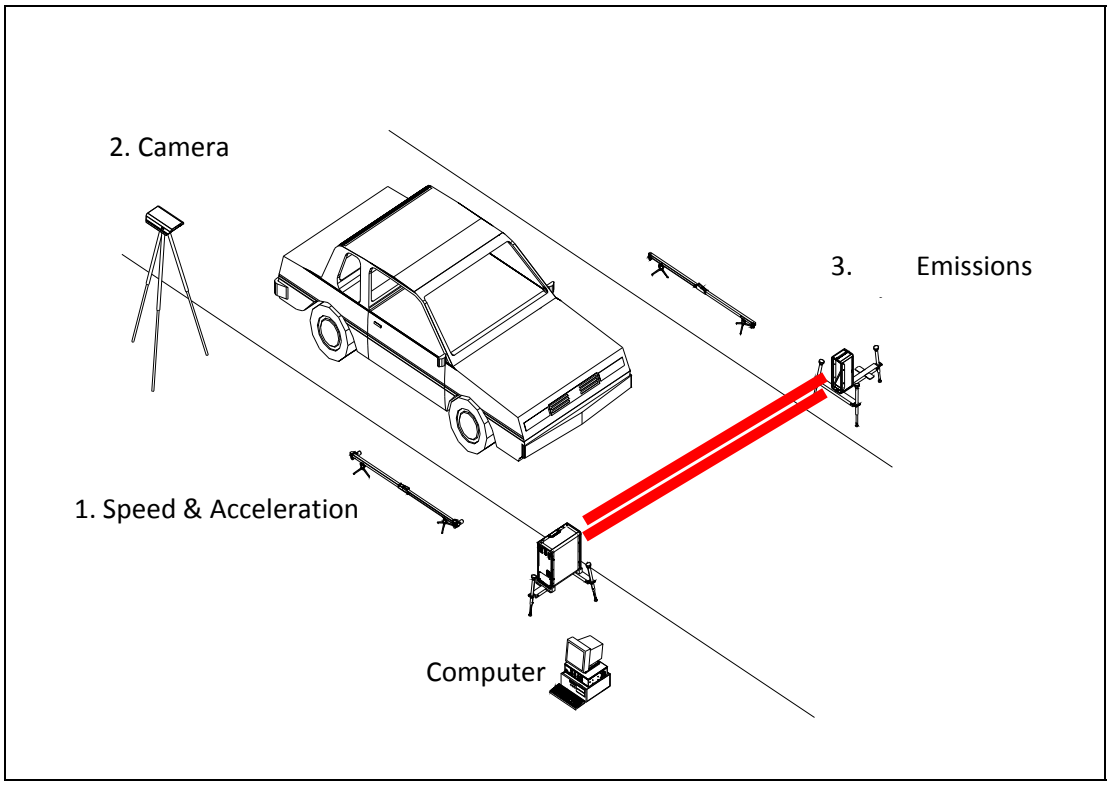
The HDET is a patented emerging technology being developed at the University of Denver in conjunction with Envirotest that holds great promise as an individual vehicle inspection methodology. A prototype HDET was deployed for one week at Nordel.

The HDET Test and RSD programs were physically independent demonstrations of methods to monitor the in-use emissions of HDVs far less obtrusively on-road than traditional methods. Scientifically, it was anticipated a comparison of the two datasets would prove useful, and the results of one might help validate the other. These were hoped-for outcomes, not stated goals of this project. Both techniques were capable of detecting the worst smoking vehicles in need of repair. Envirotest ran both RSD and the HDET at the same time over several days in order to capture measurements from both sets of equipment on a subset of vehicles. The comparative results are presented in Section V.

II-1.1 RSD system

RSD System Set-up: The RSD system, its technical specifications (with a focus on particulate matter measurement), and its on-road deployment are discussed in this subsection. RSDs direct infrared (IR) and ultraviolet (UV) light across a single lane of road at tailpipe height to instantly measure tailpipe exhaust emissions as motor vehicles are driven past roadside installations. RSDs apply measurement technology commonly used in more traditional station analyzers, but unlike emissions testing equipment used in emissions testing centers, RSDs do not need a physical connection to the vehicle.

Figure II-1: On-road set-up of a remote sensing device for a low tailpipe vehicle.



As shown in Figure II-1, an RSD is comprised of three main components linked to a computer: (1) a speed and acceleration system, (2) a camera for license plate capture, and (3) an emissions analyzer that measures fuel-specific carbon monoxide (CO), carbon dioxide (CO2), hydrocarbons (HC), nitric oxide (NO) and particulate matter (PM) as a smoke factor. RSDs are traditionally deployed from a trailer or van and attended to throughout the day by a trained operator whose primary objective after set-up is to periodically audit the system, ensure high data quality, recalibrate as required, and ensure motorist safety.

The RSD trailer used for this project was customized to measure both low tailpipe vehicles and high tailpipe HDVs simultaneously using two independent RSDs. One RSD was deployed on the road surface while the emissions analyzer of the second RSD was elevated by lifts to capture the exhaust from high tailpipes HDVs.

Figure II-2: Example On-road set-up of RSD for High Tailpipe Transit Bus

Figure II-3: On-road set-up of RSD for a High or Low Tailpipe Vehicle

Measurement of Emissions: IR and UV light is directed across the road and passively reflected back to detectors that monitor light intensity at characteristic wavelengths. The amount of characteristic infrared or ultraviolet light absorbed is translated into the exhaust concentration of pollutants. Envirotest's Accuscan RSDs measure CO, HC, and CO2 via non-dispersive infrared spectroscopy and NO via dispersive ultraviolet spectroscopy over 0.5 seconds in the trailing exhaust of vehicles as they drive by. In a total of 0.7 seconds, RSD software algorithms determine the ratios of CO/CO2, HC/CO2, and NO/CO2 in the diluted and dispersed exhaust plumes and apply the combustion equation to calculate gaseous pollutant concentrations.

The RSD uses UV light (~230nm) to measure opacity because of its far greater sensitivity to fine particle matter than the traditional green light (550nm) used in opacimeters, and because at that wavelength the channel is more sensitive to the particles comprising most of the particulate mass emitted by today's diesel vehicles. RSD pollutant measurements of the dilute exhaust behind the vehicle must be ratioed to the amount of fuel burned at the time of measurement. Therefore, the RSD particulate measurement is a ratio of the measured UV exhaust opacity to the sum of the carbon-based gases of the exhaust (i.e. CO2, CO, and HCs). For example, an RSD Smoke Factor (SF) measurement of 2.0 means that 2.0% of the mass of fuel being consumed by the vehicle is being emitted as particulate matter. For diesel black soot emissions, an RSD SF of 1 represents 10g of PM per kilogram of fuel consumed. Envirotest reports diesel particulate matter as RSD SF and in g/kg fuel.

Every RSD is certified prior to field deployment to the accuracy and precision of the California On-Road Emissions Measurement System (OREMS) specifications[v].

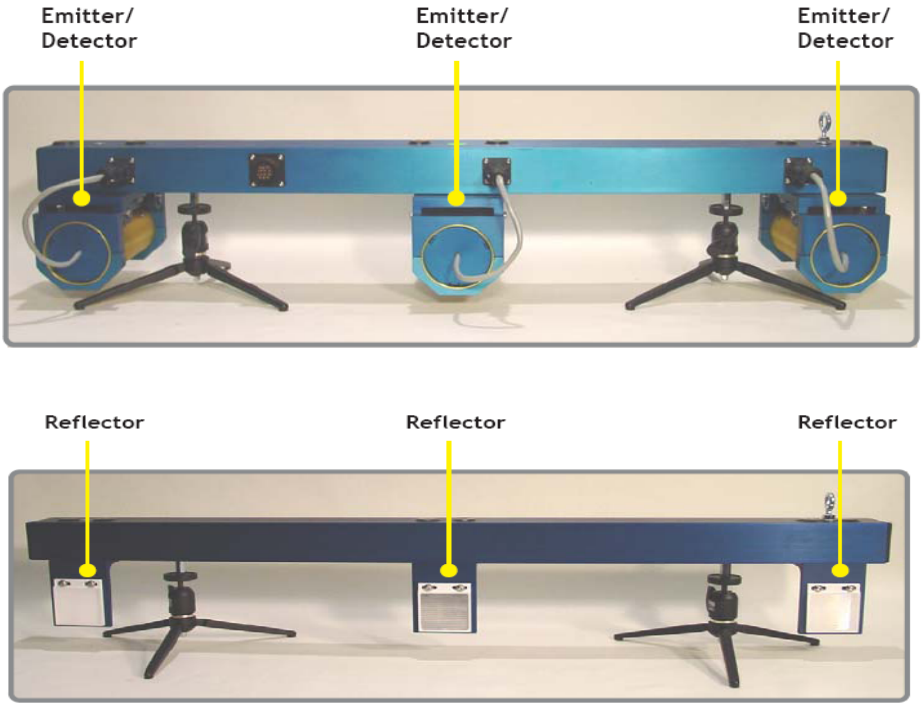
The accuracy and precision of the remote sensing spectrometer has been demonstrated in experiments conducted by several independent organizations in North America, Asia, and Europe. In each, RSD native ratios were directly compared to ratios from laboratory instruments while two analytical systems were set-up to measure the same exhaust stream of a vehicle being run through a transient dynamometer cycle. The most recent of these independent experiments conducted by the Japan Clean Air Program[vi] found that the basic remote sensing analytical instrumentation was accurate, had good resolution and clearly tracked all transient dynamometer events in the laboratory environment.

Speed Measurement Device

Envirotest uses an accurate vehicle speed and acceleration measurement system that measures the vehicle's speed and acceleration. Low power and harmless lasers measure speed within +/- 1 MPH and acceleration within ± 0.3 MPH/second up to 50 MPH and within ± 0.5 MPH/second at speeds between 50 and 75 MPH. This level of accuracy is required to characterize the operating condition of the vehicle at the time of emissions generation, which is approximately a second prior to its discharge from the tailpipe. For

this reason the speed and acceleration is measured several meters in advance of the emissions measurement.

Figure II-4 – Speed and Acceleration Bar



License Plate Imaging

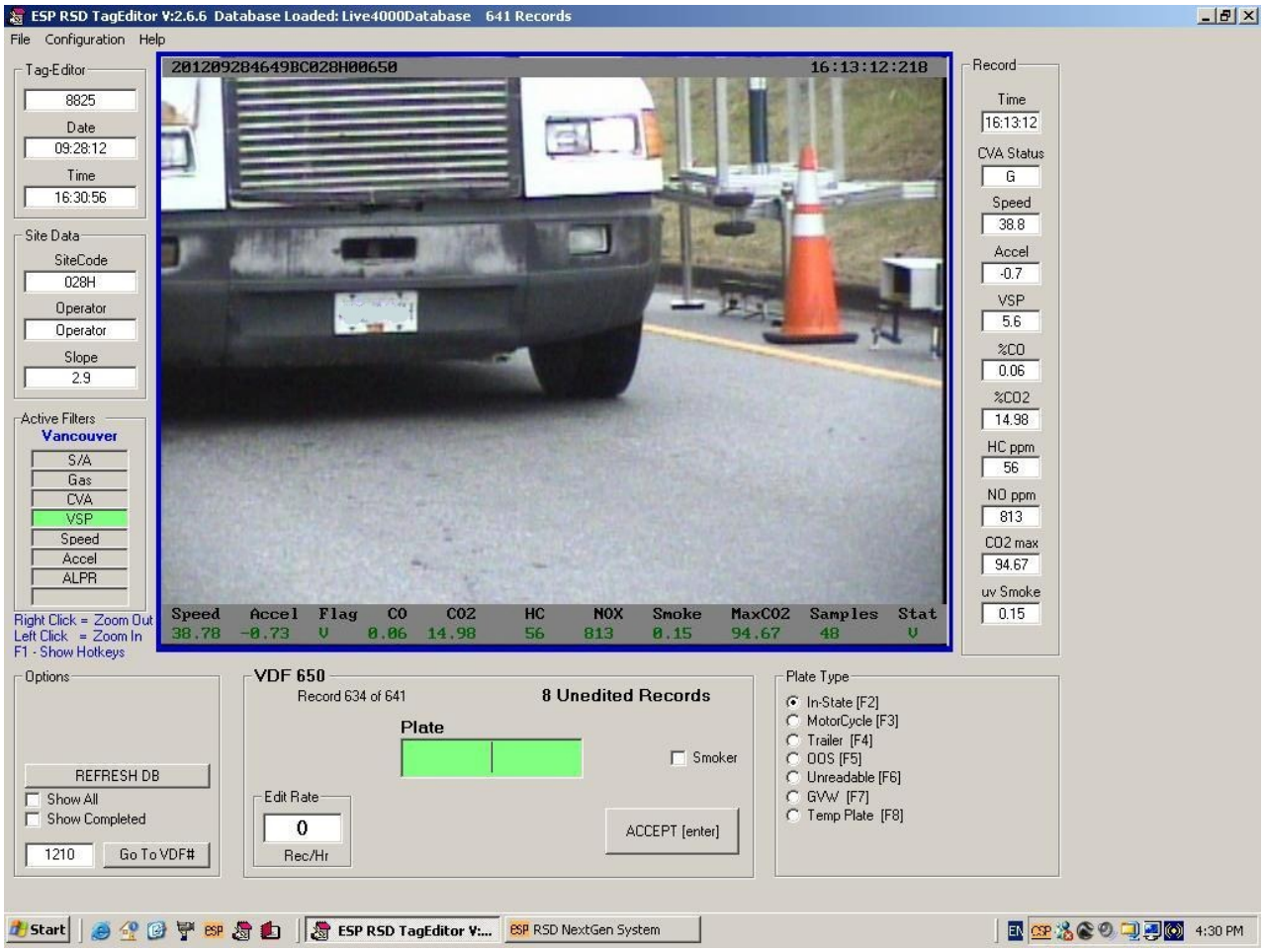
Envirotest's Tag Edit™ software was used by operators to manually transcribe license plates. Figure II-5 shows an example of a Tag Edit™ screen (the plate has been blanked out). The license plate editing software ensured:

- All video images associated with valid emissions data were processed.
- Vehicles with special plates were also processed. This is especially important in areas with many unique license plates issued. Failure to process all plate types can create a statistically skewed database.
- The Tag Edit™ system captures virtually 100% of visually readable and unobstructed vehicle license plates.

Measurements without a gas or speed measurement were tag edited for this trial. Envirotest stores images in individual JPG files allowing them to be easily purged when no longer required.

Vehicle measurements and plate images were stored on removable media in the AccuScan™ vans. These data (along with unit calibration records) were subsequently loaded to a project Vehicle Information Database (VID).

Figure II-5 – Sample Tag Edit™ Screen



II-1.2 Heavy Duty Emissions Tunnel (HDET)

The exhaust emissions of light-duty vehicles (LDVs) are routinely measured on a chassis dynamometer at emissions testing facilities. Chassis dynamometer exhaust can be measured in real time, be integrated electronically, or be allowed to collect in large gas sampling bags and measured subsequently. Measuring integral vehicular exhaust allows the performance and emission quality of the car to be evaluated over multiple and different cycles that attempt to mimic normal driving as would be observed on the road. These same integral tests for HDVs are more complex and far more expensive. The chassis dynamometer and equipment required for HDVs must manage much greater loads and exhaust gas volumes and need multiple personnel to attach the axles to absorption brakes to measure power and torque. In addition, taking HDVs out of service in order to perform emissions testing potentially costs vehicle owners a substantial loss of revenue.

The HDET test was developed to sample integral HDV exhaust on the road in a simple and inexpensive way, thereby providing a useful tool for monitoring and/or inspection.

The HDET Test program for this study was intended as a demonstration of an innovative technology that could be used as a future HD I/M program element. At the 2012 CRC meeting in San Diego the HDET Test was described as an "IM8" since the instrumentation and interpretation is essentially identical to an 8-second version of the IM240 240-second loaded transient I/M test used on LDVs with the exception that the truck itself provides a realistic load rather than a dynamometer.

The HDET Test used a long tent as a sampling chamber and some of the same analyzers used at LDV dynamometer testing facilities to collect and integrate an exhaust sample of a 7-10 second real-world drive cycle.

The sampling tent was 50 feet long, 15 feet wide and 18 feet high at its apex. The structure overlay a section of road populated with HDV traffic – in this case at a weigh station. The length of the tunnel allowed exhaust from an accelerating high-tailpipe HDV to be contained and collected. At the apex of the tunnel there was a pipe about 16 feet above the roadway with 50 holes drilled one foot apart. An inline air fan drew air from inside the tent (along with truck exhaust) through the holes and down the pipe to a set of emission analyzers for integral measurement. The collected exhaust sample included the emissions from multiple accelerator positions as the HDV up-shifted gears while gaining speed. The HDET set-up is shown in Figure II-6.

Figure II-6: HDET Test Tunnel

Gaseous Measurements (CO, HC, CO_2, NO, NO_2): The HDET Test used two Horiba analyzers to measure CO and CO_2 via IR spectroscopy, total HC using a flame-ionization detector, and NO via a chemiluminescence analyzer. NO_2 was measured by another Horiba analyzer so the NO/NO_2 ratio could be determined.

Particulate Measurement: The HDET was equipped with a Dekati Mass Monitor to measure PM mass and a Droplet Measurement Technologies PAX to measure black carbon. The gaseous and particulate matter measurements were ratioed to CO_2 to facilitate comparison to RSD data and reported as emissions per kg of fuel.

The HDET was deployed at the Nordel Scale for one week. The HDET was set-up on a Sunday evening in about 3 hours, in advance of a Monday morning start and left set-up throughout the week. The HDET required 110v power to operate.

II-2 Reported Units of Measurement

Reporting RSD Measurements as g/kg-fuel: RSD concentration measurements of gaseous pollutants can be directly converted to g/kg or g/liter of fuel using combustion equations. The database contained both the emissions concentrations (ppm, %) and g/kg fuel. RSD emissions calculations are described in Appendix A. Note that RSD NO emissions when reported in g/kg are reported as though the NO had been oxidized to NO_2. This is in order to be consistent with NO_x standards and values reported by other analyzers. NO emissions oxidize to NO_2 in the atmosphere.

Relating RSD Measurements to HDV Standards: Government standards for HDVs are in units of g/bhp-hr. The bhp-hr per kg of fuel depends on diesel engine efficiency and, while not constant, is quite close to constant at about 165 g fuel/bhp-hr for HDVs manufactured in the last decade. RSD measurements can be converted from g/kg to equivalent g/bhp-hr estimates based on this assumption for diesel HDVs. One bhp-hr is equivalent to 0.746 kW-hr

Relating RSD and HDET Measurements: The RSD and HDET equipment were run at the same time over three days in order to capture measurements from both sets of equipment on a subset of vehicles. This allowed results from both sets of equipment to be compared (Section V).

Relating RSD and HDET to Snap Acceleration Measurements: The AirCare On-Road (ACOR) mobile inspection program, operated by the BC Ministry of Transportation, uses the snap acceleration test to measure the opacity of diesel emissions. Teams of certified ACOR inspectors run roadside tests of diesel HDVs, looking for excessive smoke emissions. An ACOR team was not present during the period of simultaneous RSD and HDET. However, Envirotest previously made a comparison of RSD vs. snap acceleration opacity for the Singapore National Environment Agency in 2009[vii].

Opacity testing in the AirCare On-Road (ACOR) mobile inspection program has some limitations; green light has limited sensitivity to today's fine particle emissions and is subject to NO_2 interference. The snap acceleration opacity test can vary with ambient conditions and placement of the optical beam.

II-3 Heavy-duty Diesel Vehicle Standards and Not-to-Exceed (NTE) Zone

Canada Gazette Part II, Vol. 131, No. 17 Aug 20, 1997 page 2405 et seq defines heavy-duty as a vehicle rated at more than 8,500 lbs (3,856kg) GVWR or that has a curb weight of more than 6000 lbs (2722kg). The existing AirCare program already tests vehicles up to 11,025lbs (5,000kg) GVWR and has collected a large database of emissions data. This study focuses on vehicles over 11,025lbs (5,000kg) GVWR.

Canada has generally harmonized HD engine emissions standards with those of the US starting from July 28, 1997 and becoming effective for diesel fueled vehicles January 1, 1998 (Canada Gazette Part II, Vol. 131, No. 17 Aug 20, 1997 page 2405 et seq).

In addition, in 1993, the Minister of Transport signed a Memorandum of Understanding (MOU) with manufacturers of HDVs and engines. In the MOU, manufacturers agreed to market and sell in Canada HDVs and engines in the 1995 to 1997 model years that meet US federal emission standards.

Beyond the standards met on a voluntary basis through this MOU, the amendment reduced the allowable level of NO_x in HDV exhaust emissions from 1.9 g/MJ (5.0 g/bhp-hr) under the voluntary standard to 1.49 g/MJ (4.0 g/bhp-hr).

II-3.1 Model Year 1988-2003

Model year 1988-2003 USEPA and 1987-2003 CARB emission standards for heavy-duty diesel truck and bus engines are summarized in Table II-1.

Table II-1: US EPA Emission Standards for Heavy-Duty Diesel Engines, g/bhp·hr

Year	HC	CO	NO_x	PM
	Heavy-Duty Diesel Truck Engines			
1988	1.3	15.5	10.7	0.60
1990	1.3	15.5	6.0	0.60
1991	1.3	15.5	5.0	0.25
1994	1.3	15.5	5.0	0.10
1998	1.3	15.5	4.0	0.10
	Urban Bus Engines			
1991	1.3	15.5	5.0	0.25
1993	1.3	15.5	5.0	0.10
1994	1.3	15.5	5.0	0.07
1996	1.3	15.5	5.0	0.05*

1998	1.3	15.5	4.0	0.05*

* - in-use PM standard 0.07

II-3.2 Model Year 2004 and Later

In October 1997, USEPA adopted new emission standards for model year 2004 and later heavy-duty diesel truck and bus engines. These standards reflect the provisions of the Statement of Principles (SOP) signed in 1995 by the USEPA, CARB, and the manufacturers of heavy-duty diesel engines. The goal was to reduce NOx emissions from highway heavy-duty engines to levels approximately 2.0 g/bhp·hr beginning in 2004.

On December 21, 2000 the EPA signed emission standards for model year 2007 and later heavy-duty highway engines. The rule includes two components: (1) emission standards, and (2) diesel fuel regulations.

The first component of the regulation introduced new, very stringent emission standards, as follows:

- PM—0.01 g/bhp-hr
- NO_x —0.20 g/bhp-hr
- NMHC—0.14 g/bhp-hr

The PM emission standard took full effect in the 2007 heavy-duty engine model year. The NO_x and NMHC standards were phased in for diesel engines between 2007 and 2010.

Canada, by aligning with updated U.S. emission standards for the 2004 and later model years, ensured that vehicles and engines meeting new more stringent exhaust emission standards would begin entering the Canadian market in the 2004 model year and would be phased-in over the 2004 to 2010 model year period (The Canada Gazette Part II, Vol. 137, No. 1 page 35 et seq).

Canadian exhaust emission standards for heavy-duty engines included the additional standards designed to control exhaust emissions under modes of operation not covered by the Federal Test Procedure (FTP) for heavy-duty engines, such as:

- The opacity of smoke emitted from diesel heavy-duty engines during engine acceleration and lugging modes of operation; and
- Beginning in the 2007 model year, a steady-state “Supplemental Emission Test” and, for in-use engines, a “Not-to-Exceed” test procedure both designed to more closely represent the range of real-world driving conditions of diesel HDVs.

As with the USEPA, there were two options for combined NMHC + NO_X limits and tighter standards for urban busses. Phase 2 standards applied starting with the 2007 model year.

In the USA, the Phase 2 NMHC, CO and PM standards applied in 2007 and the NO_X standard was phased in from 2007-2010. In the case of a US standard that was phased in over a period of time, the standard became effective in Canada in the model year for which the US regulation specified that the standard applied to 100% of the class. This created a difference in Canadian and US standards during the phase in period. However, because every engine that was covered by a USEPA certificate and that was sold concurrently in Canada and the US had to conform to the EPA certification and in-use standards, the differences in emission profiles of engines sold during this period were expected to be small.

Manufacturers had the flexibility to certify their engines to one of the two options shown in Table II-2. All emission standards other than NMHC and NO_x applying to 1998 and later model year heavy duty engines (Table II-1) continued at their 1998 levels.

Table II-2: EPA NO_x and NMHC Standards for MY 2004 and Later HD Diesel Engines, g/bhp·hr

Option	NMHC + NO_x	NMHC
1	2.4	n/a
2	2.5	0.5

II-3.3 NTE Zone

In October 1998, a court settlement was reached between the USEPA, the US Department of Justice, CARB and engine manufacturers (Caterpillar, Cummins, Detroit Diesel, Volvo, Mack Trucks/Renault and Navistar) over the issue of high NO_x emissions from heavy-duty diesel engines during certain driving modes. Since the early 1990's, the manufacturers used engine control software that caused engines to switch to a more fuel efficient (but higher NO_x) driving mode during steady highway cruising. The USEPA considered this engine control strategy an illegal "emission defeat device". Provisions of the Consent Decree included the following:

- Civil penalties for engine manufacturers and requirements to allocate funds for pollution research
- Upgrading existing engines to lower NO_x emissions

- Supplemental Emission Test (steady-state) with a limit equal to the FTP standard and NTE limits of 1.25 × FTP
- Meeting the 2004 emission standards by October 2002, 15 months ahead of time

The Not-To-Exceed (NTE) requirements proposed by the USEPA in 1998 were designed to ensure that heavy-duty engine emissions were controlled over the full range of speed and load combinations commonly experienced in use. NTE established an area (the "NTE zone") under the torque curve of an engine where emissions must not exceed a specified value for any of the regulated pollutants. The NTE test procedure did not involve a specific driving cycle of any specific length (mileage or time). Rather it involved driving of any type that could occur within the bounds of the NTE control area, including operation under steady-state or transient conditions and under varying ambient conditions. Emissions were averaged over a minimum time of thirty seconds and then compared to the applicable NTE emission limits.

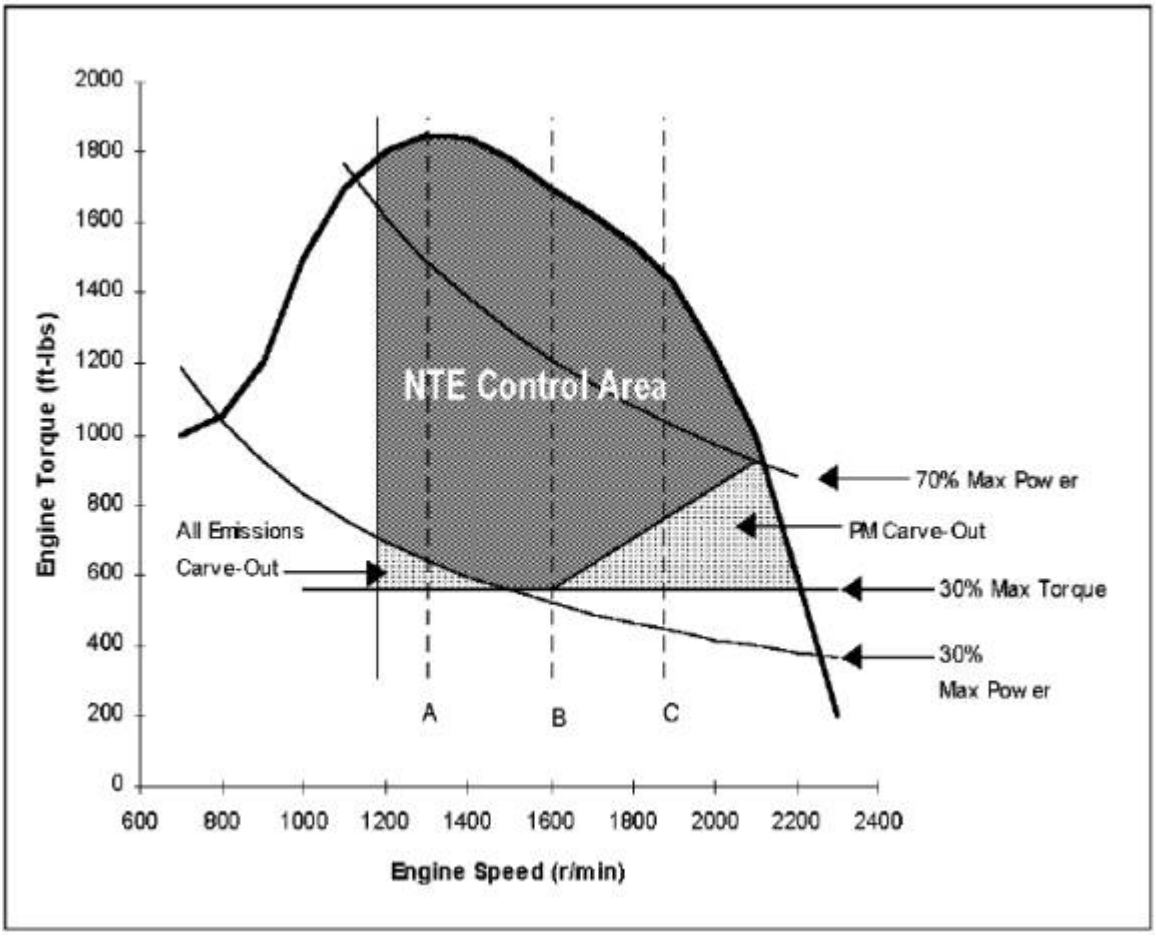
In 2001, engine manufacture and trucking associations challenged the EPA NTE regulations. In June 2003, a settlement agreed upon a detailed outline for a subsequent 2005 regulation requiring manufacturers to run heavy-duty in-use NTE testing programs for diesel-fueled engines and vehicles[viii]. Key elements included:

- Enforceable program beginning in the 2007 model year for gaseous emissions, when new NTE and tailpipe emission standards for NO_x and PM would take effect.
- Enforceable and pilot programs for PM to begin one year after the gaseous programs begin.
- Monitoring in-use emissions of diesel vehicles with portable emission measurement systems (PEMS). Pollutants to be measured: HC, CO, NO_x and PM.
- Testing to be conducted on in-use vehicles, under real-world driving conditions, within the engine's useful life to monitor for NTE compliance and to help ensure overall compliance with the emission standards.
- Measurement "accuracy" margins established to account for the emissions measurement variability associated with these units in the field.
- Addressed a serious, long-standing need for "real-world" in-use testing data.

The Portable Emissions Measurement System (PEMS) described, even though far less expensive than truck dynamometer testing, still requires several hours of preparation and testing per vehicle[ix]. This makes it impractical for widespread testing to determine if vehicles are being properly maintained and the EPA requirement for engine manufacturers is to self-test only 5 to 10 engines from each engine family and 25% of engine families a year[x]. An RSD screening program or Tunnel would independently measure many

thousands of trucks per year. A question is whether vehicles need to be in the NTE zone when measured or whether emissions outside of the zone are sufficient for screening purposes.

Figure II-7: NTE Control Zone



II-3.4 Vehicle Specific Power (VSP)

VSP takes into account aerodynamic drag, tire rolling resistance and road grade. VSP is defined as power per unit mass of the vehicle and for a class of vehicles can be approximated as a function of vehicle speed, acceleration, and road grade. Given a relationship between emissions and VSP it is possible to estimate emissions oven any combination of driving cycles. It is useful for RSD because it provides an estimate of engine power from roadside measurements of road grade, speed and acceleration. For trucks, however,

the mass of the vehicle is dependent on the cargo load and VSP cannot be accurately determined without knowing the gross weight of the truck, e.g. from weigh-in-motion scales.

VSP for light vehicles[xi] is typically calculated as:

$$VSP_{kW/t} = 4.39*\sin(grade)*v+0.22*v*a+0.0954*v+0.0000272*v^3$$

Where 'a' is vehicle acceleration in mph/s, 'v' is vehicle speed in mph, and slope is the road grade in degrees.

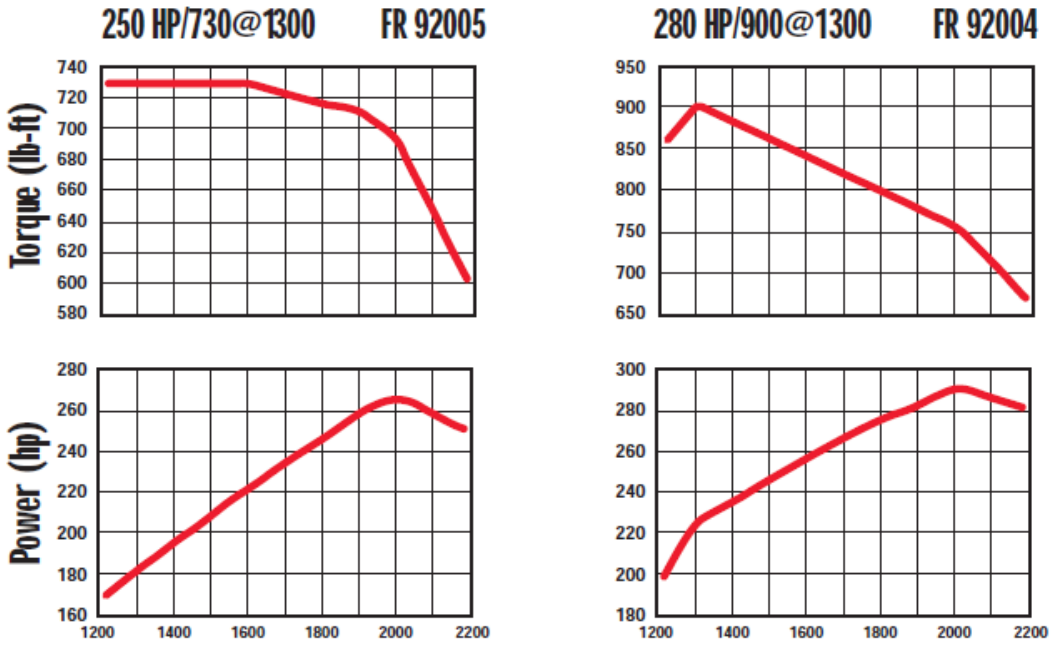
For km/hr and km/hr/s the equivalent equation is:

$$VSP_{kW/t} = 2.7278*\sin(grade)*v+0.08494*v*a+0.059278*v+0.00000653*v^3$$

Where 'a' is vehicle acceleration in kph/s, 'v' is vehicle speed in kph, and slope is the road grade in degrees.

In order to be within the NTE zone, vehicle engine output should be above the 30% maximum power curve in Figure II-7 above. Figure II-8 illustrates the Torque and Power curves vs. engine speed for two Cummins ISL Urban Transit bus engines.

Figure II-8: Example Urban Transit Bus Engine Power and Torque



To understand what VSP range is required, a bus and a truck example were considered:

- Transit Bus example: The 40' New Flyer Excelsior with a Cummins ISL 280 has a curb weight of 14.25 tons (28,500lbs) and a maximum power of 210 kW (280HP) with 900 lb-ft torque at 1300 rpm. Its maximum VSP is approximately 14kW/t. To be above the 30% power curve, a VSP of 4kW/t or higher may be desirable.

- Class 8 truck example: 2007 Peterbilt 387 with a Cummins ISX 450HP engine and a 63,500 lbs GVW rating and a tractor curb weight of 8000lbs. The rated power engine output is 336 kW. When 50% loaded, total weight is 39,750lbs or 20 tons its maximum VSP would be 17. To be above the 30% power curve, a VSP of 5kW/t or higher may be desirable.

At low speeds the inertial forces defined in the first two terms predominate and these will be the same for buses and trucks. HDV emissions vs. VSP are reviewed in Section III.

II-4 Testing Matrix and Sites

All diesel powered vehicles that are not currently captured by the AirCare Program were a subject of this study. AirCare tests vehicles under 5000 kg so the target of the study included the portion of Class 3 vehicles over 5000 kg and all Class 4 through 8 medium and heavy duty trucks and buses. RSD on-road sites were chosen in order to characterize as many relevant classes of HDVs as possible in the available tests days. The sites chosen for on-road measurements, the HDV classes being targeted, the sample sizes expected, and the impact of sites on data are discussed in this subsection.

At weigh scales and bus terminals, vehicles were encouraged to accelerate past the RSD unit. However, despite enthusiastic encouragement, many trucks accelerated only modestly or not at all. On-road sites were selected where the HDV were operating within a range of speeds and accelerations likely to place vehicles inside the NTE Zone. Although gross vehicle weight (GVW) were not known, measurements were reviewed to identify the appropriate minimum envelope of speed, grade and acceleration for obtaining sufficient engine power output to either place it in the NTE Zone or sufficient power to obtain a measurement of emissions that would be consistent with the normal performance of the vehicle. At low speeds, the engine power is proportional to speed times acceleration where acceleration includes the effect of road grade.

For LDVs, Envirotest used an estimate of VSP kW/t calculated from speed, acceleration and road grade to screen measurements for an appropriate vehicle operating mode.

Proposed sites were chosen with the following criteria in mind:

- Truck traffic
- Single lane
- Slight uphill incline or level with the trucks under power
- Adequate space for setting up the equipment
- Multiple sites throughout the Lower Fraser Valley
- Attempts to capture a variety of truck categories

Each of the sites required the participation of various authorities including:

- Commercial Vehicle Safety and Enforcement (CVSE)
- Provincial Highways
- TransLink
- Municipal governments
- The Port Authority
- RCMP and local law enforcement authorities

The attached Figure II-9 and Table II-3 show the 30 proposed sites. GVRD's assistance in gaining the cooperation of the various authorities was critical to the success of the study. The location inside Vancouver port was not used for testing due to logistical and operational issues.

As discussed, the sites included a variety of vehicle operating conditions, fleet mixes and traffic counts. They were also distributed over ten municipalities in the Lower Fraser Valley in an attempt to capture the widest possible sample of the fleet. Appendix C contains descriptions and pictures of specific sites.

Sites were categorized into three types: A - vehicles which accelerate from a stop, B - vehicles which drive-by at low speed and are accelerating, C - vehicles which drive-by at moderate speeds and typically have some positive acceleration. While differences in emissions level from different sites were anticipated, having data from comparable vehicles measured under different operating conditions was anticipated to be valuable for:

- Developing a more accurate estimate of composite emissions over the normal operational driving cycle for the type of vehicle by measuring vehicles under different operating conditions; and
- Determining the range of operating modes that would be suitable for screening vehicle emissions.

Figure II-9: Proposed Site Locations

Table II-3 Proposed Site Locations

Site #	Type of Site	Name	**Location**	**Used**
1	A	Vancouver Port	inside port gate off McGill	N
2	C	Deltaport Way	Deltaport way approach onto Hwy 17	Y
3	B	Nordel Weigh Scale	South end of Alex Fraser Bridge	Y
4	A	Border Weigh Scale	Hwy 15 at 176th Street Truck Crossing	Y
5	B	Massey Tunnel Scale**	Closed scale at the Massey Tunnel	Y
6	B	Annacis Island E	on ramp to Hwy 91 from East end of Annacis	Y
7	C	Annacis Island W	on ramp to Hwy 91 from West end f Annacis	Y
8	A	16th Avenue	Surrey near 192nd Street	Y
9	C	Front Street	New Westminster near parkade	N
10	B	Front Street	Front Street in New Westminster under parkade	Y
11	B	TransLink bus facility	Richmond: as the buses leave the yard	Y
12	B	Truck Pull-Out Hwy 91	Delta: commercial vehicles pulled in by CVSE	Y
13	A	Vancouver Landfill	Delta: as the trucks approach the scale	N
14	B	Lake City	Burnaby: Lake City Way	Y
15	B	Truck pull out Hwy 7	West of Albion	N
16	B	Truck pull-out Hwy 7	East of Albion	Y
17	A	HWY 1 Weigh Scale	Hunter Creek	Y
18	A	Hwy 1 Weigh Scale	Hunter Creek	Y
19	C	Atkinson Road	Gravel truck on ramp to Hwy 1 W from Sumas Mt	N
20	B	TransLink bus facility	Burnaby: Boundary Road	Y
21	B	TransLink bus facility	Port Coquitlam	Y
22	C	River Road	Delta: River Road on one lane section	Y
23	A	Brake Check West Van	Upper Levels Highway above Horseshoe Bay	Y
24	B	Blundell Road	Richmond industrial park near Nelson	Y
25	A	Pattullo Bridge	With CVSE during their safety check blitz	N
26	C	Hwy 99 ramp to 8th Ave	South Surrey	Y
27	A	CP Intermodal Terminal	Pitt Meadows	Y
28	C	McGill ramp off Hwy 1	Vancouver	Y
29	C	Hwy 99 Ramp to Hwy 91	Richmond	Y
30	B	Surrey Bus	Surrey	Y

II-5 Quality Assurance

RSD Certification: The two RSDs were certified at Envirotest's Tucson technology center facility prior to being deployed on the project. In-house certification involved optical alignment of the analytical bench to maximize signal and minimize noise, factory re-calibration, and accuracy/precision measurement using known dry gas mixtures to ensure operation within a range tighter than the California Bureau of Automotive Repair (BAR) On-road Emissions Measurement Standard (OREMS).

RSD Calibration and Auditing: Each day started with a field calibration of the RSDs. Then, periodically throughout the test day, a known mixture of CO, HC, NO, and CO_2 was released into the RSD beam path to ensure the instrument was measuring accurately and the calibration was still valid. A failing audit generally required instrument recalibration followed by a passing audit.

RSD Data Validation: As previously noted, RSD units were certified prior to use, calibrated at the beginning of each day, and audited periodically throughout the day. RSDs data were also subject to real-time and post-data collection review to ensure that only quality data is carried forward to analysis.

Real-Time Review: RSDs continuously sampled each exhaust plume to develop up to 50 sets of values from which the quality of the observed exhaust plume was evaluated and exhaust emissions were calculated in real-time. Exhaust plume measurements were required to meet several criteria before being accepted, including:

- Strength: sufficient CO_2 signal is measured from the RSD beam passing through the exhaust plume.
- Samples: a sufficient number of samples of the exhaust plume were achieved before it dispersed.
- Background: background values are sufficiently stable.

Post-Data Collection Review:

Post-data collection review was performed:

- Emission values were checked to confirm they are within appropriate limits;
- Tables were developed showing:
    - Hourly mean temperature and humidity
    - Day-to-day average values: speed, acceleration, emissions

Tables are provided in Appendix B.

During the data analysis phase, day-to-day decile emission values for the cleanest 90% of 2007 and newer vehicles were compared to ensure there was no significant day-to-day set-up bias in the measured

emissions of what are presumed to be clean vehicles. Figures II-10 through II-13 display these results. For each daily RSD session, emissions measurements by fuel type were ordered from cleanest to dirtiest and 10% of measurements were placed in each of ten bins. The charts show the bin averages for the cleanest 90% of vehicles. The horizontal-axis legend shows fuel (Diesel or Gasoline), date, site code, whether the unit was high or low, and the RSD unit number. Sessions were included only if at least 20 vehicles were measured for the fuel. There were virtually no gasoline vehicles with high exhausts.

Negative values represent system noise but are necessarily retained in statistical results because they are offset by noise in positive values. A negative value means the emission exhaust plume was interpreted as having lower concentrations of pollutants than the ambient background and the vehicle emissions were not measurable, i.e. effectively zero.

The charts highlight any bias in daily emissions from daily calibration or unanticipated events. Newer gasoline vehicles, shown on the right side of the charts typically had very low emissions with median emissions close to zero, which was expected.

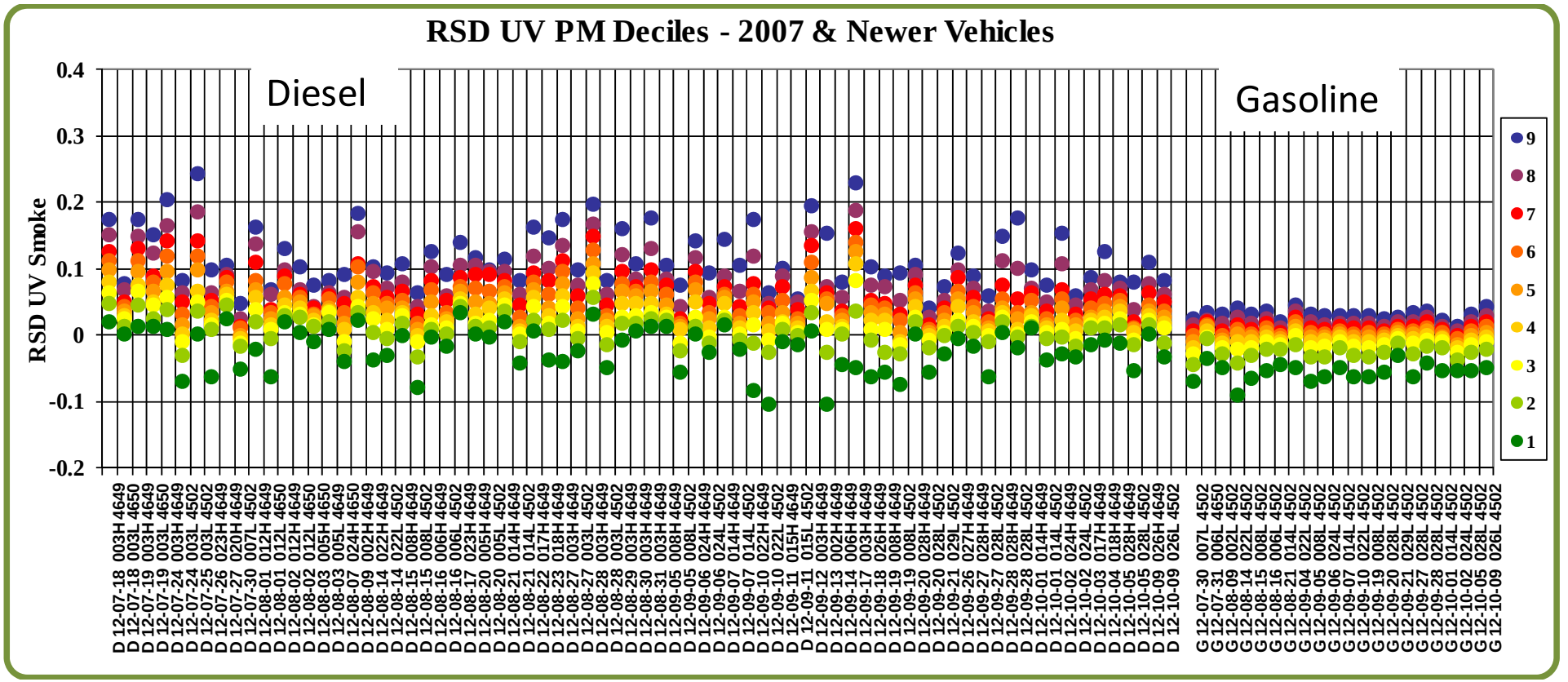
UV PM emissions (Figure II-10) were higher and more variable for diesel vehicles, which could indicate the differences in vehicles measured by the high and low RSD units and site related (vehicle operation) differences.

In the case of NO emissions (Figure II-11), there was a wide spread of NO emissions for diesel vehicles shown on the left side of the charts, which was characteristic for diesel trucks. Gasoline vehicle NO emissions were much more tightly defined.

Modern HDV vehicles 2007 and newer exhibited a wider variation in PM and NOx emissions than light-duty gasoline vehicles.

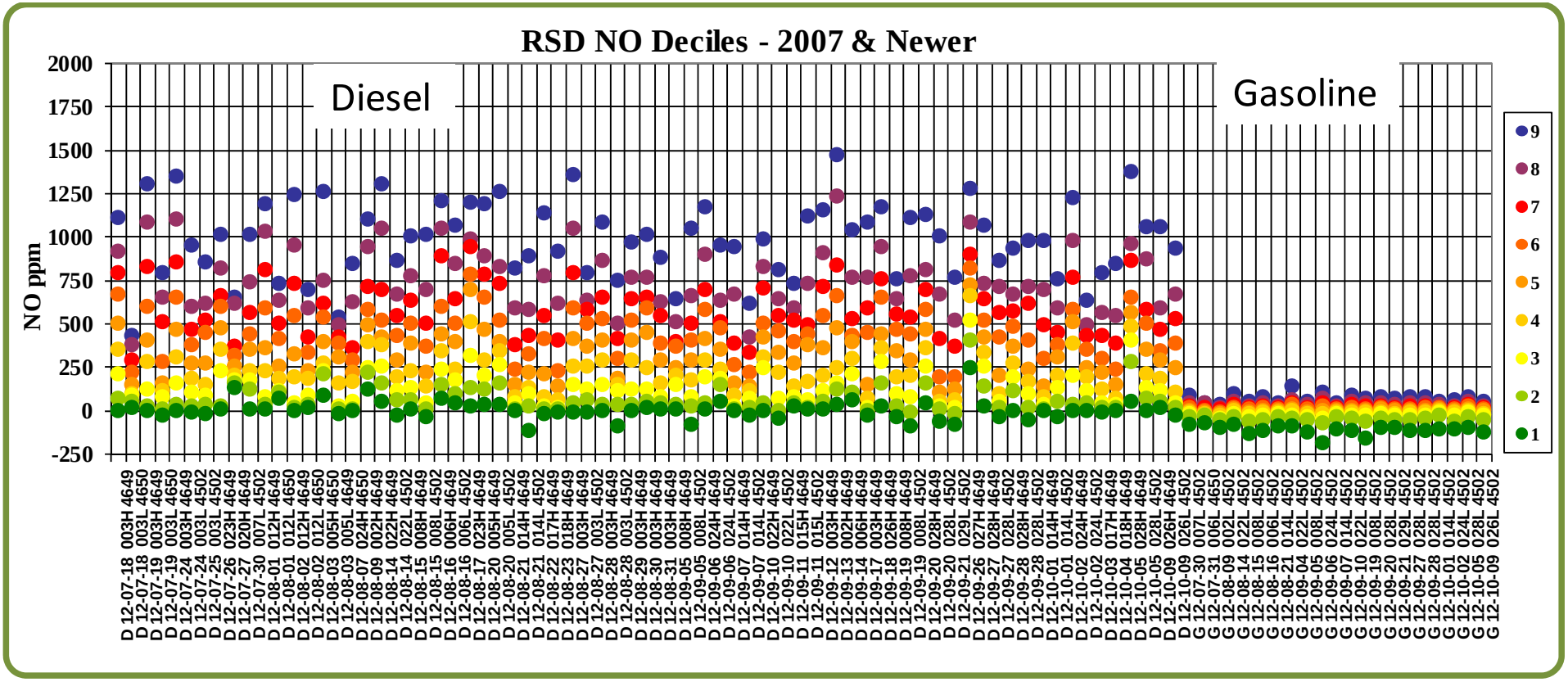
Diesel PM may be quite sensitive to the speed and engine load at different sites.

Figure II-10: Daily UV PM Deciles



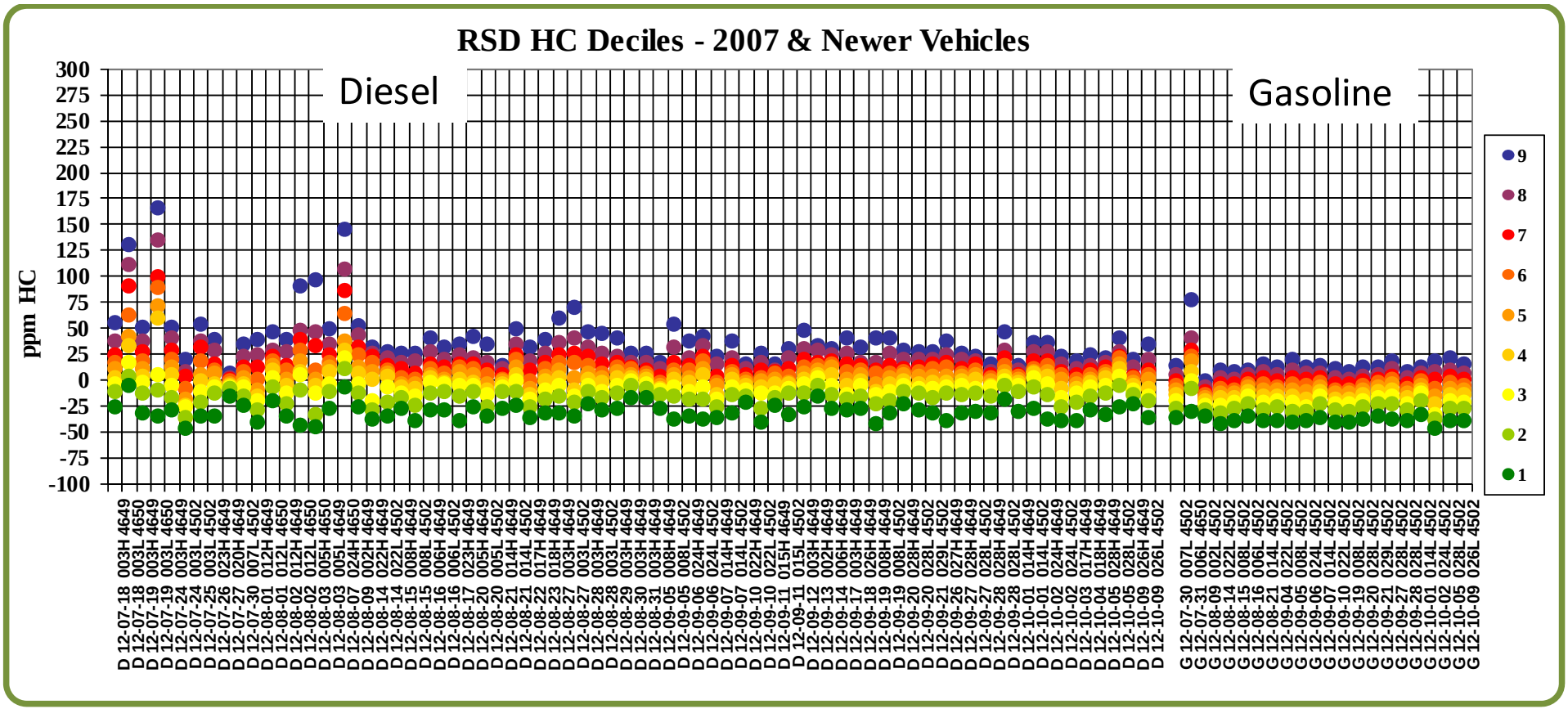
Horizontal-axis legends: **D/G** (Diesel/Gasoline) **Date** (yy-mm-dd) **Site H/L** (high/low RSD) **RSD unit number**

Figure II-11: Daily NO Deciles



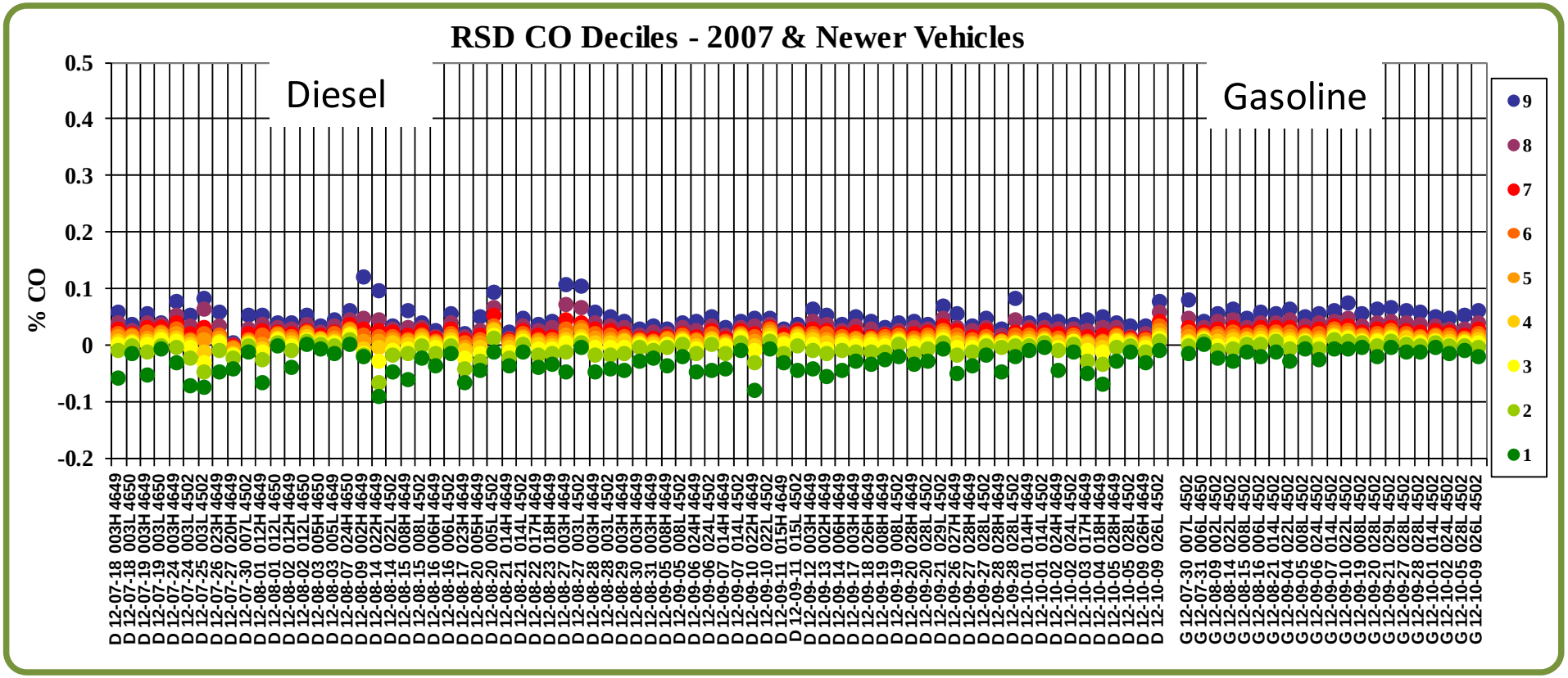
Horizontal-axis legends: **D/G** (Diesel/Gasoline) **Date** (yy-mm-dd) **Site H/L** (high/low RSD) **RSD unit number**

Figure II-12: Daily HC Deciles



Horizontal-axis legends: **D/G** (Diesel/Gasoline) **Date** (yy-mm-dd) **Site H/L** (high/low RSD) **RSD unit number**

Figure II-13: Daily CO Deciles



Horizontal-axis legends: **D/G** (Diesel/Gasoline) **Date** (yy-mm-dd) **Site H/L** (high/low RSD) **RSD unit number**

II-6 Data Sources and the Vehicle Information Database (VID)

Vehicle emissions measurements and plates were compared to vehicle registrations to obtain the characteristics of vehicles measured. The data were uploaded to a database that was used for reporting results. Major database tables included:

- Sites
- Sessions
- Emissions, and
- Vehicle Information

The contents of the tables used for reporting are summarized below.

Site table: Site reference, cross streets/description, city, postal code, latitude & longitude.

Daily session statistics: Date, site, RSD unit, grade, count of vehicles passing, count of vehicles with measured pollutants, count of vehicles with measured speed and acceleration, count of vehicles with readable plate information, count of complete records.

Emissions Database: One record per measurement. The key data elements are listed below:

- Record Number
- RSD Unit ID
- Date
- Time
- Site ID
- Site Slope
- Van ID
- Record Status
- Speed Acceleration Valid Flag
- Speed km/s
- Acceleration km/s/s
- Gases Valid Flag
- Percent CO
- Percent CO2
- PPM HC propane
- PPM HC hexane
- PPM NO
- maxCO2 (exhaust plume CO2 concentration observed)

- Samples (number of times exhaust plume was sampled)
- UV Smoke Factor (100g/kg fuel)
- Vehicle Specific Power (applicable to light vehicles)
- Temperature
- Relative Humidity
- Barometer
- Wind speed
- Wind direction
- Tag Edit Plate
- Tag Edit Plate Type
- Tag Edit Plate Info
- Tag Edit State
- Tag Edit Status
- Tag Edit ESP Code
- Plate image file name

Emissions information in grams per kilogram of fuel:

- HC g/kg
- CO g/kg
- NO g/kg
- PM g/kg (from UV Smoke Factor)
- CO2 g/kg

Derived emissions information assuming a diesel engine efficiency factor:

- HC g/bhp·hr
- CO g/bhp·hr
- NO g/bhp·hr
- PM g/bhp·hr
- CO2 g/bhp·hr

Vehicle Information:

The vehicle information table was initially be populated with information from ICBC registration records by plate matching. Once the vehicle VIN was established, the Polk VIN decoder was used to obtain additional information. The Polk information and/or the registration information will be used to assign the MOVES and MOBILE 6.2 vehicle types.

1) ICBC provided registration information:

- License Plate
- VIN
- Make
- Model
- Body style
- Vehicle class
- Vehicle weight
- Fleet owner name (if available)
- Fuel
- Engine

2) Polk Decoded Information:
   - Make
   - Model
   - Body Style
   - Model year
   - Vehicle Type
   - Engine Displacement
   - GVWR code
   - Fuel
   - Transmission

Not all data elements were complete for all vehicles.

3) Out-of-province vehicles:

Registration information was not available for vehicles not registered in BC. Out-of-province vehicles were compared to fleet average emissions, but without information as to the vehicle type, class, age, etc. more detailed emissions comparisons were not possible.

Pictures:

Envirotest also provided the .jpg pictures of each vehicle measured by RSD

HDET Data:

Tunnel data were reported as emissions per Kg of fuel.

III Data Collection

This section of the report contains:

- Overall collection statistics;
- Daily collection statistics;
- Table of vehicles measured by class/type, age group and jurisdiction at each site;
- Numbers of vehicles by class and multiple measurements;
- HDV fleet coverage;
- Emissions by vehicle specific power.

III-1 Overall Collection Statistics

Table III-1 summarizes the remote sensing measurement activity. Units were deployed at 24 sites for 56 days in total and 98,000 vehicle measurements were attempted. Typically two units were deployed, one at a height of 4m to measure vehicles with high exhaust pipes and one at 0.3m to measure vehicles with low exhaust pipes. The low unit was not deployed at bus terminals where no low exhaust vehicles were intended to be measured.

Plates were recorded for 77,492 (79%) of vehicles and 66,839 of these were matched to ICBC registrations. Of the vehicles matched to ICBC registrations, 38% were heavy-duty, 6% were light-duty diesel and 55% were other LDVs. This includes vehicles with high exhausts that were recorded by both the high and low RSD units.

Emissions and speed were measured on 46,487 (47%) of the total records. Approximately, 40,500 (41%) measurements acquired complete information (speed, acceleration, emission measurements and a plate) and 35,000 of these were matched to ICBC registrations.

The apparent successful measurement percentage was lower than normal in part because the 'low' RSD unit detected passage of vehicles with high exhausts and recorded an invalid measurement. Table III-2 reviews success rates for vehicles having matching ICBC registrations, which was required to obtain weight class and fuel information. The high RSD unit measured emissions and speed for 64% of passing diesel HDVs vs. 21% for vehicles detected by the low RSD unit.

Table III-1: Data Collection Summary

Activity	Qty	%
Sites	24	
Days	56	
Active Site Hours	438	
Unit Sessions	103	
Unit Hours	792	
Net observations attempted	98,337	

Plates Recorded	Qty	%
Net observations attempted	98,337	
Plates Recorded	77,492	79%
Matched to BC Registration	66,839	68%

Matched Plates by Weight & Fuel	Qty	%
Heavy-duty diesel	25,559	38%
Heavy-duty non-diesel	246	0%
Light-duty diesel	4,129	6%
Light-duty non-diesel	36,905	55%
Total	66,839	100%

Emissions Measured	Qty	%
Net measurements attempted	98,337	
Measurements with Valid Emissions	50,932	52%
Valid Emissions and Speed	46,487	47%

Emissions & Plate Recorded	Qty	%
Net measurements attempted	98,337	
Valid Emissions, Speed & Plate	40,502	41%
Valid Emissions, Speed, Plate & Matched	35,337	36%

Table III-2: Vehicle Measurements Matched to ICBC Registrations

Diesel_non	Type	High / Low Exhaust	RSD Active Matched	Valid Gases	Valid Gas and Speed	HC g/kg	CO g/kg	NO g/kg	UV PM g/kg	% Valid Gas	% Valid Gas & Speed
Diesel	HD	H	14,588	10,381	9,350	2.6	6.0	21.8	1.2	71%	64%
Diesel	HD	L	10,971	2,510	2,266	3.6	6.9	18.3	1.1	23%	21%
Diesel	LD	H	81	52	47	5.2	22.1	25.0	1.6	64%	58%
Diesel	LD	L	4,048	2,443	2,292	2.8	5.6	16.9	0.8	60%	57%
Non-diesel	HD	H	139	111	89	4.5	3.2	17.8	1.4	80%	64%
Non-diesel	HD	L	107	16	16	1.2	20.4	13.6	0.3	15%	15%
Non-diesel	LD	H	250	123	110	3.5	14.4	23.0	1.2	49%	44%
Non-diesel	LD	L	36,650	22,436	21,176	0.4	12.6	2.4	0.1	61%	58%
Unknown	LD	H	2	1	1	0.6	3.9	15.4	1.6	50%	50%
Unknown	LD	L	3	0	0						
Total			**66,839**	**38,073**	**35,347**	**1.4**	**10.0**	**9.6**	**0.5**	**57%**	**53%**
Total Heavy-duty	**HD**		**25,805**	**13,018**	**11,721**	**2.8**	**6.2**	**21.1**	**1.2**	**62%**	**56%**
Total Light-duty	**LD**		**41,034**	**25,055**	**23,626**	**0.7**	**11.9**	**3.9**	**0.2**	**61%**	**58%**

Table III-3 Daily Activity

Date	Site & Unit Height	Location	RSD Unit	Start	End	Hours	RSD* Active	Valid	Valid with Speed	Plates	Plates Matched	Valid with Plate	Valid with VIN
2012-07-18	003H	Nordel Weigh Scale	4649	7:50	15:26	7.6	995	703	627	655	536	454	373
2012-07-18	003L	Nordel Weigh Scale	4650	8:02	15:30	7.5	801	186	127	429	385	91	83
2012-07-19	003H	Nordel Weigh Scale	4649	8:17	13:49	5.5	906	697	648	590	483	449	365
2012-07-19	003L	Nordel Weigh Scale	4502	13:01	14:07	1.1	110	16	10	26	20	3	2
2012-07-19	003L	Nordel Weigh Scale	4650	8:24	12:27	4.1	446	100	86	279	244	72	64
2012-07-20	003H	Nordel Weigh Scale	4649	8:04	8:49	0.8	83	47	34	47	44	21	20
2012-07-24	003H	Nordel Weigh Scale	4649	7:29	16:27	9.0	1149	888	863	840	671	652	513
2012-07-24	003L	Nordel Weigh Scale	4502	8:49	16:24	7.6	1471	244	212	888	796	188	172
2012-07-25	003L	Nordel Weigh Scale	4502	8:08	16:26	8.3	1887	352	307	1187	1017	257	225
2012-07-26	023H	Brake Check West Van	4649	7:25	16:55	9.5	205	135	133	152	133	106	94
2012-07-26	023L	Brake Check West Van	4502	7:28	16:55	9.5	470	115	91	297	261	74	66
2012-07-27	020H	TransLink bus facility	4649	17:14	21:00	3.8	132	123	80	130	124	80	76
2012-07-30	007H	Annacis Island W	4649	7:25	11:38	4.2	94	53	52	71	59	40	35
2012-07-30	007L	Annacis Island W	4502	7:25	11:35	4.2	820	492	469	745	699	448	423
2012-07-31	006H	Annacis Island E	4649	7:18	11:23	4.1	188	112	93	133	118	75	70
2012-07-31	006L	Annacis Island E	4650	7:37	11:24	3.8	332	196	188	257	239	163	151
2012-08-01	012H	Truck Pull-Out Hwy 91	4649	7:50	15:59	8.2	438	243	234	342	241	194	137
2012-08-01	012L	Truck Pull-Out Hwy 91	4650	7:31	16:00	8.5	464	132	127	348	291	106	86
2012-08-02	012H	Truck Pull-Out Hwy 91	4649	8:21	15:58	7.6	389	238	230	311	224	183	128
2012-08-02	012L	Truck Pull-Out Hwy 91	4650	8:11	15:59	7.8	426	122	117	326	268	100	84
2012-08-03	005H	Massey Tunnel Scale**	4650	7:54	13:21	5.4	406	161	145	313	258	108	91
2012-08-03	005L	Massey Tunnel Scale**	4649	7:32	13:28	5.9	275	171	160	208	171	135	109
2012-08-07	024H	Blundell Road	4650	8:49	12:57	4.1	431	201	161	381	322	153	131
2012-08-07	024L	Blundell Road	4649	9:00	12:41	3.7	309	188	123	240	217	106	96
2012-08-08	011H	TransLink bus facility	4649	7:41	10:53	3.2	20	10	9	17	17	9	9
2012-08-09	002H	Deltaport Way	4649	8:12	17:39	9.4	403	205	167	318	287	133	122
2012-08-09	002L	Deltaport Way	4502	12:01	18:02	6.0	747	177	168	623	591	149	145
2012-08-09	002L	Deltaport Way	4650	8:35	10:52	2.3	107	28	26	80	71	26	21
2012-08-10	004H	Border Weigh Scale	4502	9:08	17:34	8.4	153	118	112	100	65	80	51
2012-08-10	004L	Border Weigh Scale	4649	9:12	17:34	8.4	83	45	38	69	39	31	16
2012-08-13	021H	TransLink bus facility	4649	16:15	20:44	4.5	50	34	29	38	35	25	24
2012-08-13	021L	TransLink bus facility	4502	16:19	20:48	4.5	107	51	36	75	63	28	22
2012-08-14	022H	River Road	4649	7:24	17:35	10.2	417	215	173	332	268	141	118
2012-08-14	022L	River Road	4502	7:44	17:43	10.0	3587	994	733	2990	2776	620	581
2012-08-15	008H	16th Avenue	4649	7:03	18:08	11.1	388	144	132	243	201	99	86
2012-08-15	008L	16th Avenue	4502	7:41	18:10	10.5	4392	2327	2260	3846	3527	2011	1846
2012-08-16	006H	Annacis Island E	4649	7:47	16:59	9.2	495	382	332	393	336	283	238
2012-08-16	006L	Annacis Island E	4502	7:36	17:03	9.5	2187	1364	1256	1748	1615	1102	1019
2012-08-17	023H	Brake Check West Van	4649	8:13	12:04	3.9	95	69	68	64	55	52	45
2012-08-17	023L	Brake Check West Van	4502	8:14	12:05	3.8	185	53	46	107	87	31	26
2012-08-20	005H	Massey Tunnel Scale**	4649	9:23	13:20	4.0	476	319	304	358	305	247	212
2012-08-20	005L	Massey Tunnel Scale**	4502	8:43	13:21	4.6	684	133	120	491	413	99	83
2012-08-21	014H	Lake City	4649	6:56	16:58	10.0	319	191	184	224	184	161	128
2012-08-21	014L	Lake City	4502	6:56	17:01	10.1	2496	1948	1822	2309	2168	1752	1661
2012-08-22	017H	HWY 1 Weigh Scale	4649	8:29	16:39	8.2	573	278	267	381	250	190	124
2012-08-22	017L	HWY 1 Weigh Scale	4502	8:34	16:39	8.1	683	62	53	400	288	34	26
2012-08-23	018H	Hwy 1 Weigh Scale	4649	8:16	16:56	8.7	542	295	276	373	247	217	137
2012-08-23	018L	Hwy 1 Weigh Scale	4502	9:56	16:50	6.9	403	85	77	200	153	54	44
2012-08-24	010H	Front Street	4649	7:13	11:30	4.3	186	70	53	123	72	32	21
2012-08-24	010L	Front Street	4502	7:17	11:35	4.3	1365	438	211	1026	543	170	119
2012-08-27	003H	Nordel Weigh Scale	4649	7:18	15:32	8.2	1100	720	698	837	620	552	398
2012-08-27	003L	Nordel Weigh Scale	4502	7:09	15:42	8.5	1672	364	317	1060	799	247	203

Table III-3 Daily Activity cont'd

Date	Site & Unit Height	Location	RSD Unit	Start	End	Hours	RSD* Active	Valid	Valid with Speed	Plates	Plates Matched	Valid with Plate	Valid with VIN
2012-08-28	003H	Nordel Weigh Scale	4649	7:03	14:52	7.8	1387	983	950	1071	857	769	620
2012-08-28	003L	Nordel Weigh Scale	4502	7:02	14:53	7.8	2206	407	348	1558	1275	294	252
2012-08-29	003H	Nordel Weigh Scale	4649	8:00	16:52	8.9	531	440	430	439	364	371	309
2012-08-30	003H	Nordel Weigh Scale	4649	7:54	16:55	9.0	372	321	292	307	249	254	208
2012-08-30	003L	Nordel Weigh Scale	4650	7:47	16:55	9.1	210	60	37	114	90	27	18
2012-08-31	003H	Nordel Weigh Scale	4649	7:20	14:27	7.1	282	239	235	227	193	197	169
2012-08-31	003L	Nordel Weigh Scale	4650	7:20	13:55	6.6	102	38	30	62	49	24	20
2012-09-04	022H	River Road	4649	9:14	12:38	3.4	174	72	48	125	106	42	33
2012-09-04	022L	River Road	4502	9:25	12:45	3.3	1055	246	237	919	834	223	204
2012-09-05	008H	16th Avenue	4649	7:21	16:52	9.5	223	114	100	158	135	79	65
2012-09-05	008L	16th Avenue	4502	7:21	17:00	9.7	3908	2040	1954	3284	3073	1711	1605
2012-09-06	024H	Blundell Road	4649	6:59	17:00	10.0	1169	621	471	764	637	348	290
2012-09-06	024L	Blundell Road	4502	6:58	16:59	10.0	1509	536	402	856	756	324	283
2012-09-07	014H	Lake City	4649	7:09	17:28	10.3	250	157	154	171	136	119	93
2012-09-07	014L	Lake City	4502	6:53	17:31	10.6	2826	2235	2095	2586	2385	2001	1866
2012-09-10	022H	River Road	4649	7:25	16:59	9.6	517	218	185	386	313	156	123
2012-09-10	022L	River Road	4502	7:23	17:01	9.6	3717	1136	1094	3041	2701	962	876
2012-09-11	015H	Truck pull out Hwy 7	4649	8:28	14:57	6.5	143	102	97	106	92	81	72
2012-09-11	015L	Truck pull out Hwy 7	4502	7:56	14:58	7.0	275	98	91	202	178	84	79
2012-09-12	003H	Nordel Weigh Scale	4649	7:18	15:32	8.2	1519	1034	988	1129	883	782	611
2012-09-13	002H	Delta Port	4649	7:28	17:01	9.5	427	298	233	379	317	216	176
2012-09-14	006H	Annacis Island E	4649	7:09	16:52	9.7	444	317	280	308	249	206	173
2012-09-17	003H	Nordel Weigh Scale	4649	7:16	11:36	4.3	398	275	263	242	192	169	134
2012-09-18	026H	Hwy 99 ramp to 8th Ave	4649	9:31	17:03	7.5	364	228	211	243	137	158	94
2012-09-19	008H	16th Avenue	4649	7:08	16:35	9.4	274	180	153	199	158	116	90
2012-09-19	008L	16th Avenue	4502	6:51	16:43	9.9	4115	2132	2080	3660	3317	1933	1767
2012-09-20	028H	McGill ramp off Hwy 1	4649	6:52	17:02	10.2	736	581	497	645	537	451	377
2012-09-20	028L	McGill ramp off Hwy 1	4502	6:50	17:06	10.3	2690	1563	1485	2328	2080	1370	1235
2012-09-21	029H	Hwy 99 Ramp to Hwy 91	4649	6:41	17:01	10.3	134	89	75	80	60	52	37
2012-09-21	029L	Hwy 99 Ramp to Hwy 91	4502	6:31	17:13	10.7	7407	4551	4370	6671	6043	4011	3635
2012-09-24	030H	Surrey Bus	4649	17:55	21:32	3.6	65	26	26	61	54	23	20
2012-09-24	030L	Surrey Bus	4502	16:57	21:33	4.6	140	23	23	104	87	22	18
2012-09-25	011H	TransLink bus facility	4649	16:57	23:06	6.1	202	166	165	202	199	165	163
2012-09-26	027H	CP Intermodal Terminal	4649	6:10	16:59	10.8	312	243	235	260	203	193	154
2012-09-26	027L	CP Intermodal Terminal	4502	6:09	16:59	10.8	168	44	42	82	67	32	28
2012-09-27	028H	McGill ramp off Hwy 1	4649	6:11	17:25	11.2	754	610	491	629	511	430	348
2012-09-27	028L	McGill ramp off Hwy 1	4502	6:11	17:26	11.2	2936	1739	1506	2532	2259	1414	1285
2012-09-28	028H	McGill ramp off Hwy 1	4649	6:33	17:10	10.6	645	532	410	547	448	375	298
2012-09-28	028L	McGill ramp off Hwy 1	4502	6:33	16:35	10.0	2448	1348	1269	2110	1885	1175	1066
2012-10-01	014H	Lake City	4649	6:21	14:10	7.8	154	121	116	111	95	91	76
2012-10-01	014L	Lake City	4502	6:15	14:12	8.0	1798	1515	1417	1620	1490	1323	1223
2012-10-02	024H	Blundell Road	4649	7:10	17:59	10.8	1141	748	557	795	642	495	393
2012-10-02	024L	Blundell Road	4502	7:10	18:00	10.8	1832	504	405	1090	941	325	296
2012-10-03	017H	HWY 1 Weigh Scale	4649	7:18	17:00	9.7	601	236	209	349	214	155	98
2012-10-03	017L	HWY 1 Weigh Scale	4502	7:05	17:01	9.9	800	99	88	414	258	52	39
2012-10-04	018H	Hwy 1 Weigh Scale	4649	7:49	17:32	9.7	587	408	378	489	290	330	193
2012-10-04	018L	Hwy 1 Weigh Scale	4502	7:43	17:28	9.7	734	100	91	423	266	70	43
2012-10-05	028H	McGill ramp off Hwy 1	4649	6:49	16:15	9.4	614	489	395	499	408	325	259
2012-10-05	028L	McGill ramp off Hwy 1	4502	6:56	16:30	9.6	2324	1218	1162	2017	1815	1093	986
2012-10-09	026H	Hwy 99 ramp to 8th Ave	4649	8:01	17:26	9.4	543	432	407	383	226	302	175
2012-10-09	026L	Hwy 99 ramp to 8th Ave	4502	7:50	17:08	9.3	3033	1986	1926	2495	2166	1749	1543
Total	**103**					**791.6**	**98337**	**50932**	**46487**	**77492**	**66816**	**40502**	**35337**
Percentage of attempted measurements								**52%**	**47%**	**79%**	**68%**	**41%**	**36%**

III-2 Unique Vehicles and Emissions Measurements

Vehicles were binned by gross weight into those less than or equal to 5000kg, which are inspected in the existing I/M program and those greater than 5000 kg. Vehicles were also binned by fuel and weight class. Table III-4 lists:

- Unique vehicles observed and matched to a registration and the number of observations;
- Unique vehicles whose emissions were measured and the number of measurements;
- The average emissions, acceleration and VSP.

Over 8,600 unique HDVs were observed and emissions from 6,012 of the vehicles were measured.

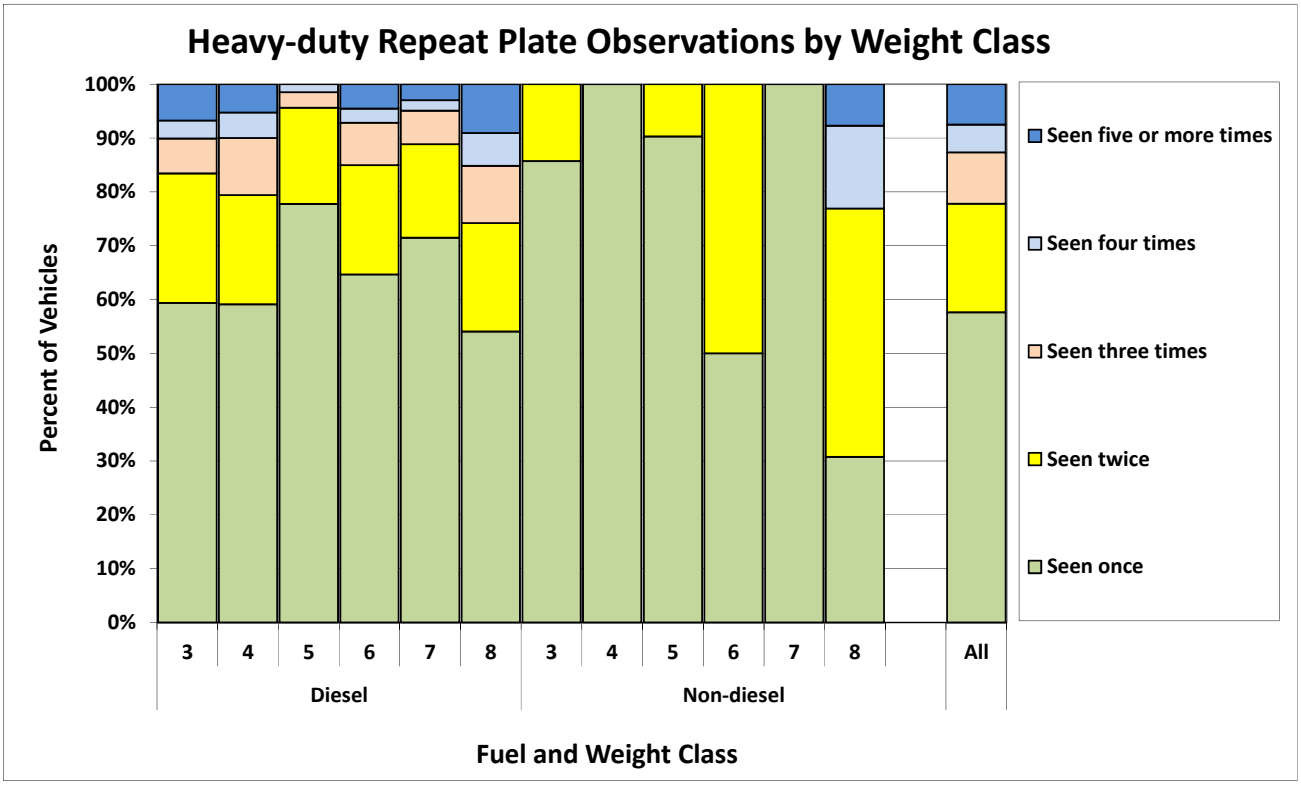
Table III-4 Vehicles, Observations and Measurements

			Observed		Emissions Measured		
Division	Fuel	GVW Code	Unique Vehicles	Observations	Unique Vehicles	Emissions Measurements	Average Measurements Per Vehicle
Greater than 5000kg	Diesel	3	680	1,639	507	914	1.8
		4	917	2,204	670	1,209	1.8
		5	348	524	207	265	1.3
		6	449	1,106	266	465	1.7
		7	513	1,164	305	461	1.5
		8	5,618	18,922	3,975	8,302	2.1
	Non-diesel	3	12	17	7	8	1.1
		4	14	24	9	9	1.0
		5	59	74	31	34	1.1
		6	5	8	2	3	1.5
		7	27	41	20	20	1.0
		8	20	82	13	31	2.4
Subtotal heavy-duty			**8,662**	**25,805**	**6,012**	**11,721**	**1.9**
Less than or equal to 5000kg	Diesel	0	505	609	286	327	1.1
		1	1,409	1,764	864	1,035	1.2
		2	945	1,578	644	869	1.3
		3	93	178	67	108	1.6
	Non-diesel	0	24,117	28,948	14,436	16,571	1.1
		1	6,277	7,718	3,919	4,578	1.2
		2	140	195	98	119	1.2
		3	10	16	6	8	1.3
	Unclassified	1	4	5	1	1	1.0
Subtotal light-duty			**33,500**	**41,011**	**20,321**	**23,616**	**1.2**
Total			**42,162**	**66,816**	**26,333**	**35,337**	**1.3**

Figure III-1 shows the percentages of vehicles by fuel and weight class observed once only, twice, three times, four times or more than four times. Only valid measurements were used to avoid counting duplicate high/low RSD unit observations of the same high vehicle (the measurement attempted at the wrong height was flagged by the RSD unit as invalid).

A majority of vehicles were observed only once and 43% of diesel vehicles in weight classes 3-8 were measured more than once.

Figure III-1 Repeat Observations by Weight Class



III-3 Vehicles Measured Compared to Registrations

Table III-5 compares the number of BC plated HDVs measured to HDVs registered in three regions.

- LFV - Lower Fraser Valley,
- RestPr - Rest of the province, and
- Terriz - Territory Z.

Vehicle class description codes are shown below. The third character in the registered class code referred to the fuel; D-diesel, G-gasoline and O-other. GVW is the gross vehicle weight rating, which is the total allowable combined weight of truck and trailer, including all passengers, fuel, fluids and cargo.

Truck Weight Classes	Empty Weight	GVW min	GVW max
HD_V2B		gt 8500	le 10000
HD_V3		gt 10000	le 14000
HD_V4		gt 14000	le 16000
HD_V5		gt 16000	le 19500
HD_V6		gt 19500	le 26000
HD_V7		gt 26000	le 33000
HD_V8A		gt 33000	le 60000
HD_V8B		gt 60000	
LD_T1	le 3750		le 6000
LD_T2	gt 3750		le 6000
LD_T3	le 3750	gt 6000	le 8500
LD_T4	gt 3750	gt 6000	le 8500

Other classes	
LD_V	passenger vehicle
MC_	motorcycle
MH_	motorhome
OT_B	other bus
SC_B	school bus
TR_B	transit bus

The study measured 13% of LFV HDVs and 16% of Territory Z HDVs. Less than 1% of HDVs registered in the rest of the province were measured, which suggests most of these did not frequently travel within the LFV.

The HDVs registered in the LFV were, on average, measured twice during the 55 day study. Vehicles from outside the region were measured 1.6 times.

18% of LFV diesel vehicle class 8 (HDDV8) trucks were measured. Few of the registered HDDV5 and HDDV7 vehicles were observed. School buses were not covered by the study and were omitted from the table.

A majority of registered HD_V3 trucks were less than 5000 kg and already subject to inspection by the AirCare program. However the actual numbers of registered HD_V3 trucks with weights above and below 5,000 kg was unknown. The HD_V3 vehicles measured in the study were more likely to be those over 5000 kg. In the table, the percentages of HD_V3 vehicles measured do not reflect the percentage of the HD_V3

over 5,000 kg that were measured and were the subject of the study. For this reason they were placed in a separate section at the end of the table.

Table III-5 Registered Vehicles and Measurements

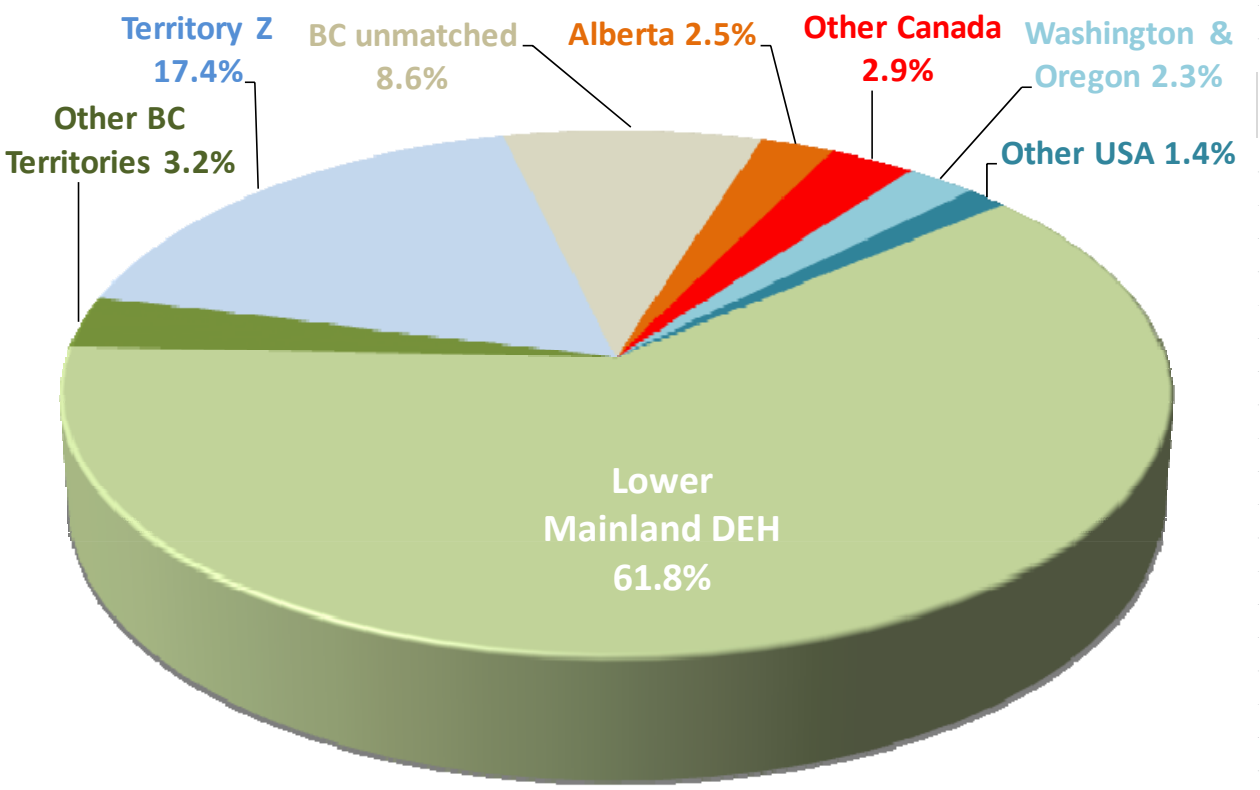
	Registered			Unique Veh Measured			% Measured			Measurements / Veh		
Class	**LFV**	**Restpr**	**Terriz**	**LFV**	**Restpr**	**TerrZ**	**LFV**	**Restpr**	**TerrZ**	**LFV**	**Restpr**	**TerrZ**
Diesel												
HDDV4	2,122	2,431	78	618	17	34	29%	1%	44%	1.8	1.4	1.5
HDDV5	4,327	6,918	302	55	6	2	1%	0%	1%	1.4	1.2	2.0
HDDV6	2,666	4,372	305	238	6	17	9%	0%	6%	1.8	1.2	1.6
HDDV7	4,624	5,572	502	236	11	2	5%	0%	0%	1.6	1.1	1.0
HDDV8A/B	13,350	19,392	8,082	2,331	167	1,457	17%	1%	18%	2.4	1.6	1.6
TRDB	1,230	553	2	35	1		3%	0%		1.1	1.0	
OTDB	777	897	305	168	1	1	22%	0%	0%	1.2	1.0	1.0
Subtotal	29,096	40,135	9,576	3,681	209	1,513	13%	1%	16%	2.1	1.6	1.6
Gasoline												
HDGV4	947	897	21	9			1%			1.0		
HDGV5	948	1,621	64	1			0%			1.0		
HDGV6	257	500	9	2			1%			1.5		
HDGV7	177	399	3	2			1%			1.0		
HDGV8A/B	152	220	19	10		3	7%		16%	2.1		3.3
TRGB	44	66	2									
OTGB	654	724	87									
Subtotal	3,179	4,427	205	24	0	3	1%	0%	1%	1.5		3.3
Other fuels												
HDOV4	177	101										
HDOV5	100	157										
HDOV6	96	89		1			1%			1.0		
HDOV7	64	77	1	3			5%			1.0		
HDOV8A/B	46	63	19	1	1	18	2%	2%	95%	3.0	4.0	2.9
TROB	496	26	2	41			8%			1.0		
OTOB	42	62	2	4			10%			1.8		
Subtotal	1,021	575	24	50	1	18	5%	0%	75%	1.1	4.0	2.9
HDV3 (most less than 5000 kg)												
HDDV3	20,337	42,045	1,304	518	20	35	3%	0%	3%	1.8	1.2	2.1
HDGV3	15,525	16,029	413	9			0%			1.1		
HDOV3	1,184	856	14	4			0%			1.5		
Subtotal	37,046	58,930	1,731	531	20	35	1%	0%	2%	1.8	1.2	2.1
Total	**70,342**	**104,067**	**11,536**	**4,286**	**230**	**1,569**	6%	0%	14%	2.1	1.5	1.6

III-4 HDV Activity by Regional Source

Figure III-2 shows the regional source of the HDV activity observed on-road. Vehicles were included as heavy-duty if they were matched to an ICBC registration with a gross weight greater than 11,025 lbs (5,000kg) or they were observed by the high RSD unit. This might omit a few low exhaust HDVs from other regions but their numbers are most likely not material.

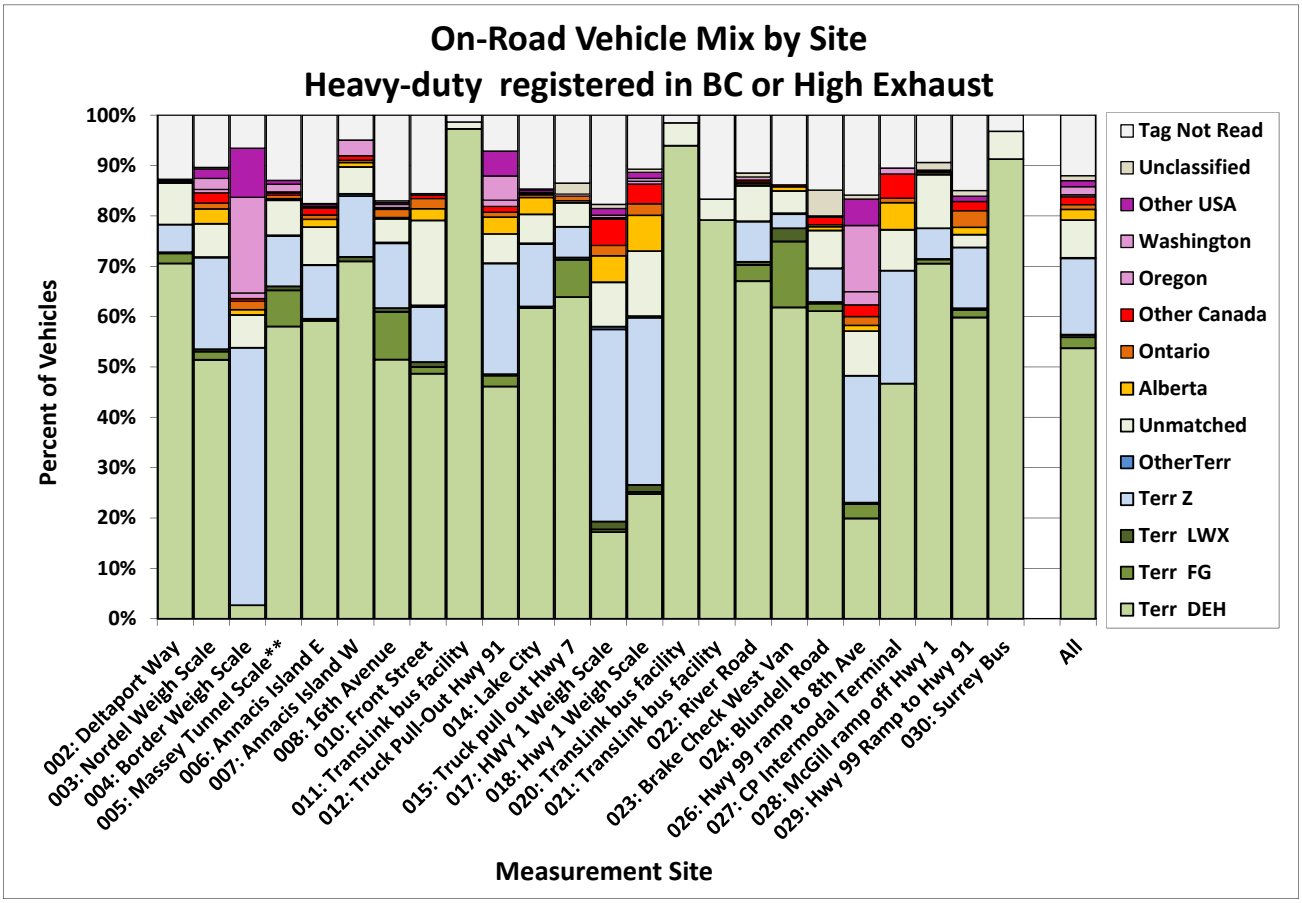
Figure III-3 shows the regional source by site including the percentage of license tags that were not read. The weigh scale sites had large percentages of territory Z vehicles. As anticipated, the Border weigh scale had the largest percentage of trucks from the USA and Translink terminal buses were all registered in the lower mainland.

Figure III-2 Measurements of Heavy-Duty Vehicles by Region



Lower Mainland DEH: ICBC Territories covering the Lower Fraser Valley, Territory Z: insurance for vehicles also driven outside British Columbia.

Figure III-3 Site Mix of Heavy-Duty Vehicles by Region



III-5 HDV Activity by Weight Class

Virtually all HDVs were fueled with diesel. Only 1% of weight classes 3 to 8 were non-diesel fueled. As indicated in Figure III-4 a majority of HDVs (73%) were weight class 8.

Figure III-4 Measurements of Heavy-duty Vehicles by Weight Class

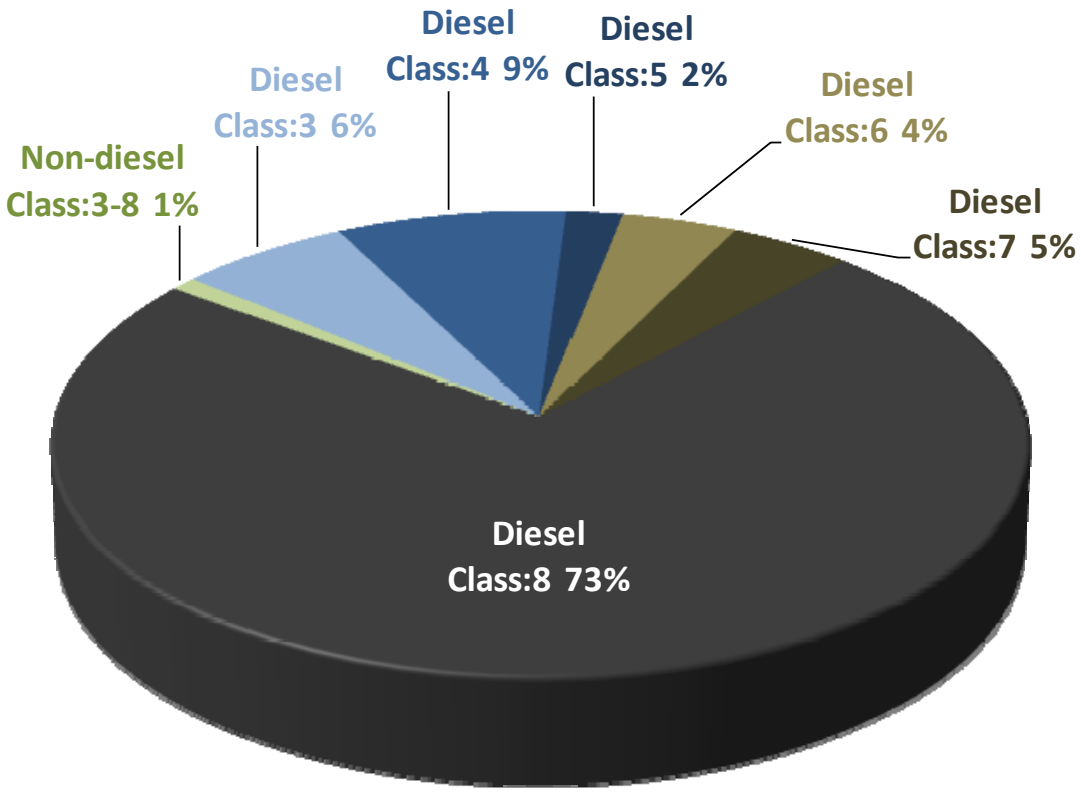


Figure III-5 and Table III-6 show the mix by site. Sites near ports and the weigh scales saw predominantly class 8 trucks. Twenty to fifty percent of trucks observed at other on-road sites were classes 3 to 7. Buses at transit terminals were of various weight classes and a moderate number were non-diesel fueled.

Figure III-5 Site Mix of Heavy-Duty Vehicles by Weight Class

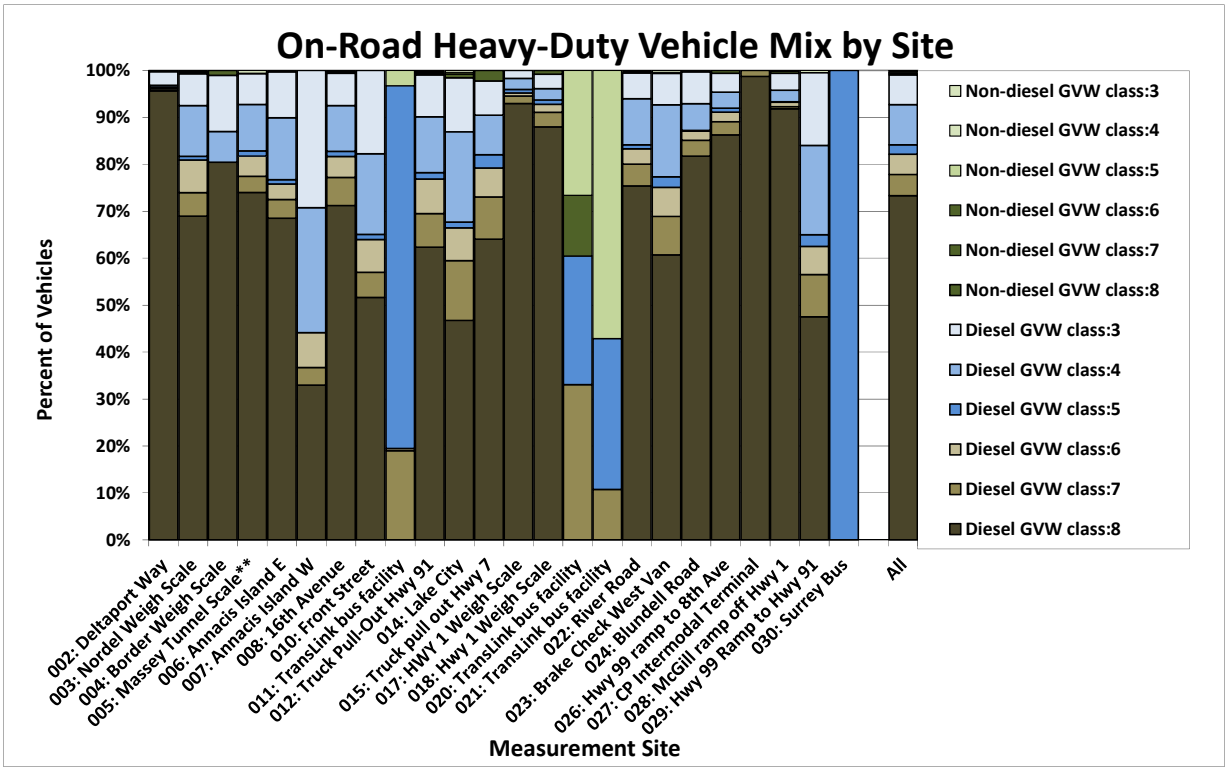


Table III-6 Vehicles Observed by Site and Weight Class

	Heavy-duty Diesel Weight Class						Heavy-duty Non-diesel Weight Class						
Site	3	4	5	6	7	8	3	4	5	6	7	8	Total
002: Deltaport Way	22	3	2	3	1	723						2	756
003: Nordel Weigh Scale	603	957	73	616	445	6,124	6	10		5	13	30	8,882
004: Border Weigh Scale	11	6				74						1	92
005: Massey Tunnel Scale**	66	100	11	43	35	745		6				1	1,007
006: Annacis Island E	94	127	9	32	38	660	1					2	963
007: Annacis Island W	55	50		14	7	62							188
008: 16th Avenue	77	109	12	50	67	796	1	2	1			3	1,118
010: Front Street	33	32	2	13	10	96							186
011: TransLink bus facility			167	1	41				7				216
012: Truck Pull-Out Hwy 91	75	100	11	62	60	523	2	2		1	1	2	839
014: Lake City	102	171	11	62	113	415	4				3	7	888
015: Truck pull out Hwy 7	13	15	5	11	16	114						4	178
017: Hwy 1 Weigh Scale	16	22	7	6	15	871							937
018: Hwy 1 Weigh Scale	27	21	8	15	27	768						7	873
020: TransLink bus facility			34		41				33		16		124
021: TransLink bus facility			18		6				32				56
022: River Road	84	150	13	50	71	1,151	2	1		1	3	1	1,527
023: Brake Check West Van	30	69	10	28	37	273		2			1		450
024: Blundell Road	174	146	4	50	86	2,098				1	2	5	2,566
026: Hwy 99 ramp to 8th Ave	20	17	4	10	14	427						3	495
027: CP Intermodal Terminal					3	228							231
028: McGill ramp off Hwy 1	106	71	3	28	13	2,679	1		1		2	14	2,918
029: Hwy 99 Ramp to Hwy 91	31	38	5	12	18	95		1					200
030: Surrey Bus			115										115
Total	1,639	2,204	524	1,106	1,164	18,922	17	24	74	8	41	82	25,805

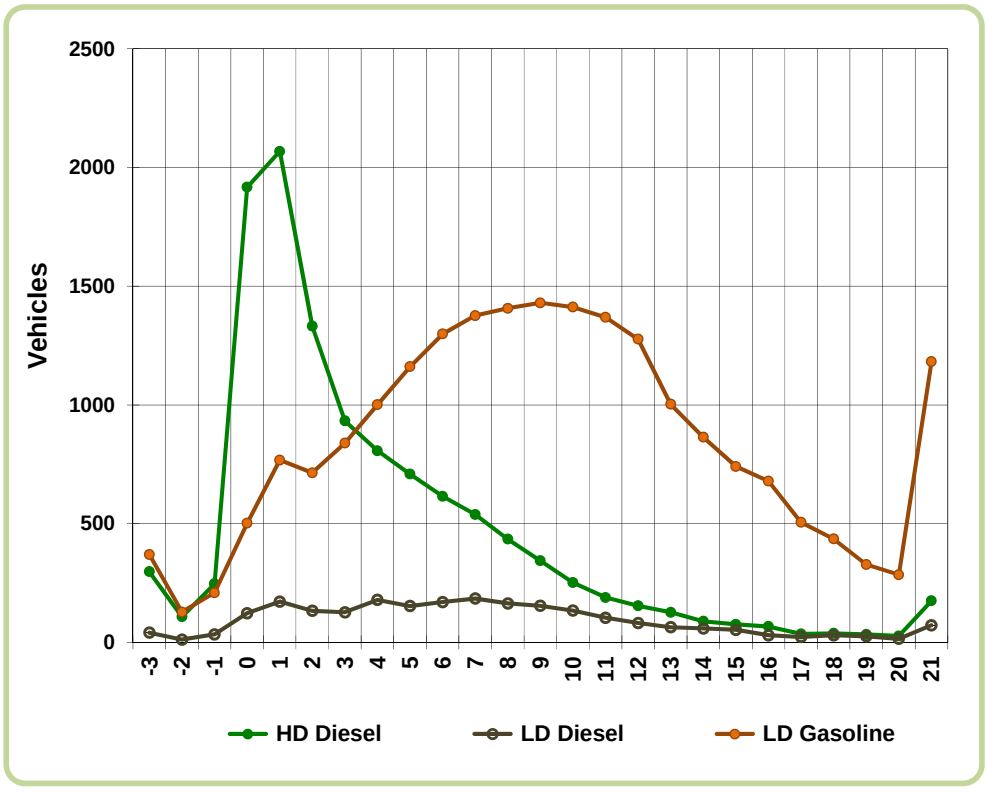
III-6 Emissions vs. Vehicle Specific Power

Figures III-6 and III-7 display vehicles and emissions vs. vehicle specific power (VSP), which was described in section II. VSP accounts for road slope, speed and acceleration and is therefore a better indicator of positive engine power than acceleration alone.

Vehicle measurements were divided into three series; heavy-duty diesel, light-duty diesel and light-duty non-diesel. These three groups accounted for 99% of measurements. The vast majority of non-diesel vehicles were fueled by gasoline. The first and last values in each series include all vehicles with lower or higher values than the horizontal-axis range.

The VSP distribution of light-duty non-diesel vehicles was roughly centered on a mode of 9kW/t. The VSP distribution of light-duty diesel vehicles was similar to that of the non-diesel vehicles but skewed toward lower values. Many diesel HDVs were measured with VSP in the 0-3 kW/t range, which may indicate lower than desired engine load. This was the result of measuring many HDVs at flat weigh stations and low speeds rather than at on-road locations with an uphill slope and higher speeds.

Figure III-6 Measurements vs. VSP (kw/t)

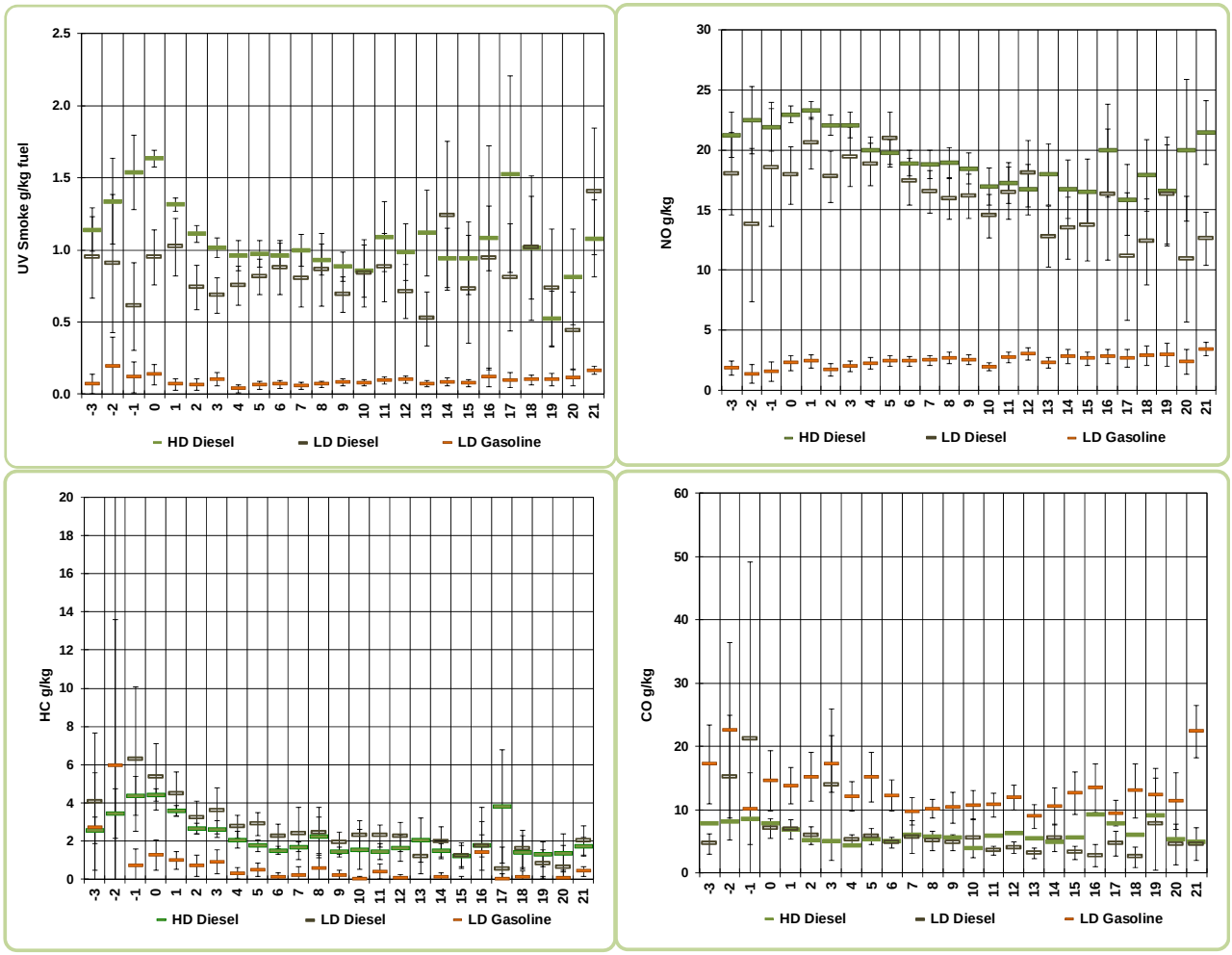


In Figure III-7, the set of four charts of emissions vs. VSP show:

- Top left: PM g/kg (RSD UV Smoke)
- Top right: NO as NO2 g/kg
- Bottom left: HC g/kg, and
- Bottom right: CO g/kg

In the emissions charts, vertical bars indicate the 95% confidence interval of the mean value. The wide range of the confidence intervals for diesel vehicles at the higher VSP values resulted from the small numbers of diesel vehicle measurements in these higher VSP bins.

Figure III-7 Emissions vs. VSP (kw/t)



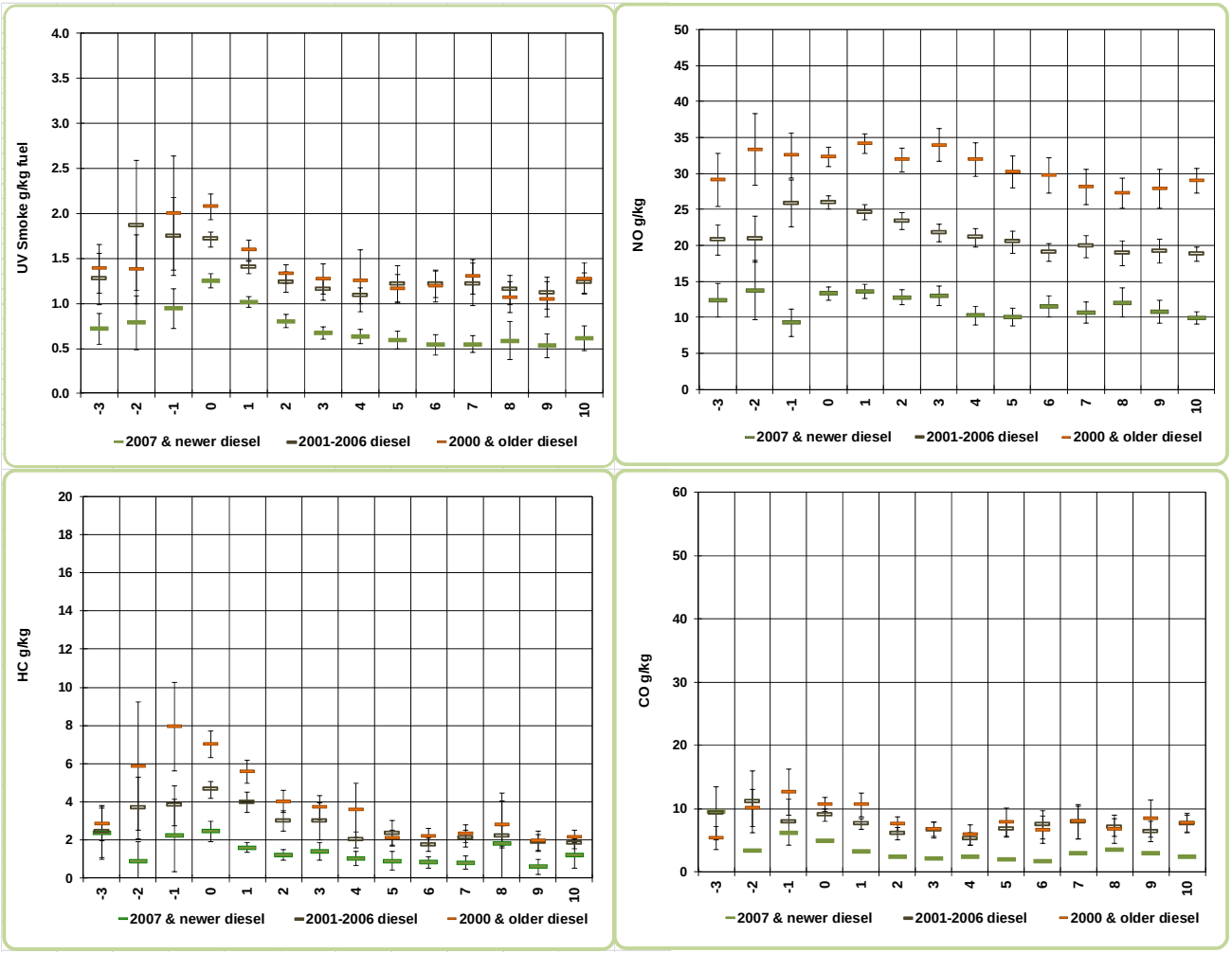
The diesel vehicles had notably higher PM, NO and HC emissions than non-diesel fueled vehicles. PM emissions were higher in the VSP range of -2 to +2 kW/t and roughly flat across the VSP range above 2 kW/t.

NO emissions were flatter across the entire VSP range and, in contrast to gasoline vehicles, trended downward with increasing VSP.

Figure III-8 shows heavy duty diesel emissions vs. VSP for three age groups; 2007 & newer, 2001-2006, and 2000 and older. The 2007 and newer model range was selected to be coincident with the change in heavy-duty emissions standards. The 2000/2001 division was selected for convenience. The percentages of measurements within the age series from newest to oldest were 36%, 37% and 27% respectively. The distributions of measurements with respect to VSP were almost identical for the three groups.

The 2007 & newer models had substantially lower emissions than older models.

Figure III-8 Heavy-duty Diesel Emissions vs. VSP by Age



Based on the RSD emissions vs. VSP, Envirotest elected to use the 60% of RSD HDV measurements made at VSP greater than 2 when reporting heavy-duty vehicle RSD emissions in subsequent sections.

IV Heavy-Duty Fleet Characterization and Emissions

This section characterizes the emissions of the HDV fleet using RSD measurements. Average emissions were examined by:

- Vehicle Year
- Body Style and Make
- Vehicle GVW class
- Jurisdiction / Territory

Emissions of vehicles with multiple measurements were also reviewed.

IV-1 Heavy-duty Measurements and Emissions by Vehicle Year

RSD emissions measurements of HDVs with VSP greater than 2kW/t were binned by fuel (diesel and non-diesel) and by model year. Figure IV-1: 'Heavy-duty Diesel Average Emissions by Model Year' compares average emissions to vehicle emissions standards.

In section II it was noted the bhp-hr per kg of fuel depends on diesel engine efficiency and, while not constant, is quite close to constant at about 165 g fuel/bhp-hr. To compare measured emissions to vehicle standards, the standards have been converted to their equivalent g/kg by multiplying by a factor of 6.06 (1000/165).

Particulate matter emissions for diesel vehicles were:

- 4 g/kg (0.7 g/bhp-hr) for the few 1990 and older models,
- 1.0 to 1.4 g/kg (0.2 g/bhp-hr) for 1991-2007 models, and
- 0.5 g/kg (0.1 g/bhp-hr) for 2008 and newer vehicles.

Average RSD diesel vehicle PM emissions were typically about 0.5 g/kg (0.1 g/bhp-hr) above the standard.

Diesel NOx emissions were in the range of:

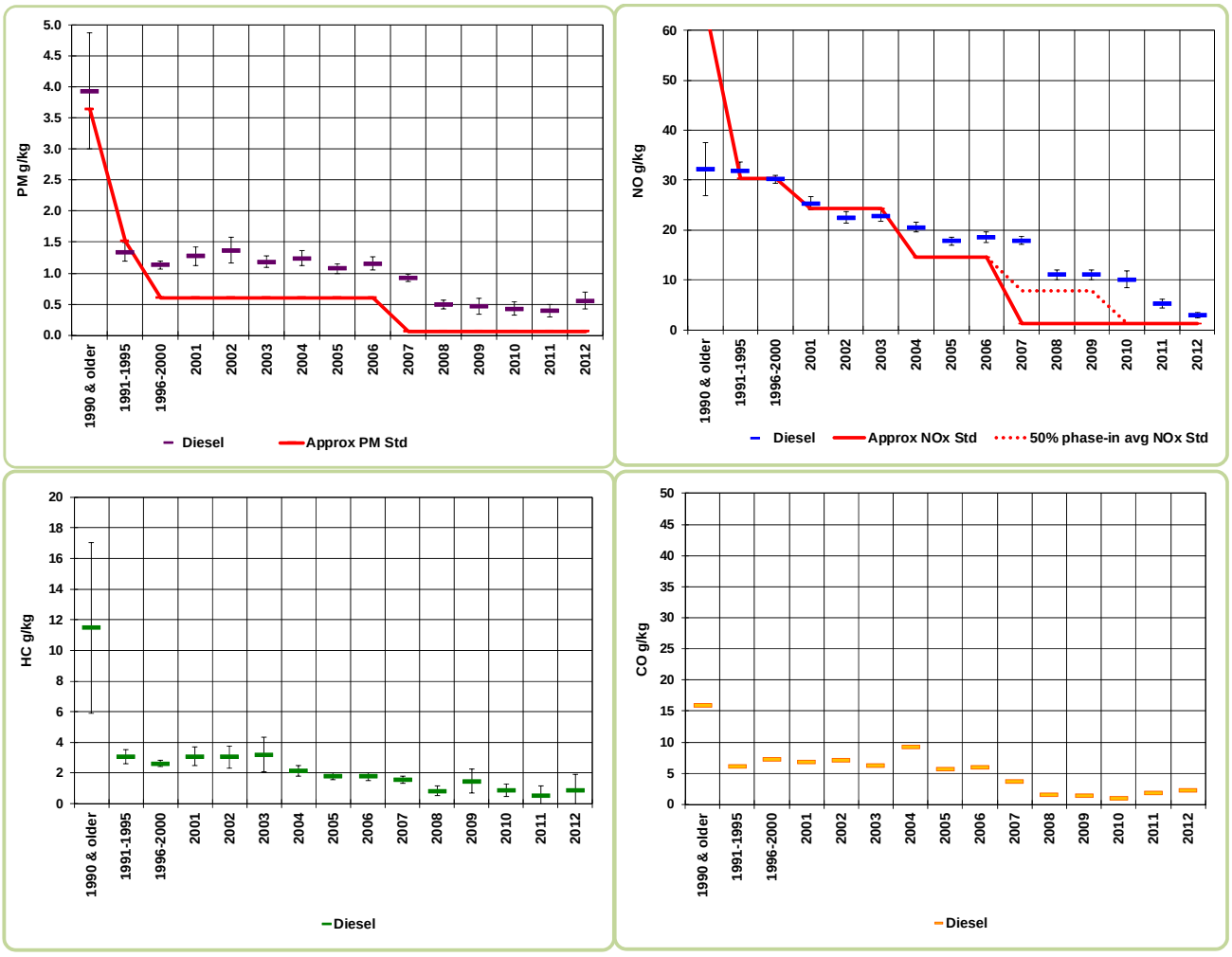
- 20 to 30 g/kg (3 to 5 g/bhp-hr) range for 2007 and older models; and
- declining emissions from 10 g/kg (2 g/bhp-hr) for 2008 models to 3 g/kg (0.5 g/bhp-hr) for 2012 models.

Step reductions in PM and NO emissions were evident following changes in certification standards. Average RSD PM emissions were 0.5 g/kg higher than certification standards. Reductions in average 2004 and newer model RSD NO appear to lag reductions in certification standards. An RSD measurement is not the same as a certification test comprising multiple combinations of engine speeds and loads.

The few non-diesel vehicles appeared to have NO emissions similar to those of diesel vehicles of the same age but the sample was too small to be definitive. Non-diesel HDVs 1996 and newer had lower average PM emissions of 0.9 g/kg (0.15 g/bhp-hr) and average NO emissions of 15 g/kg (3 g/bhp-hr).

As expected for diesel vehicles, HC and CO emissions were less significant. Newer diesel vehicles had lower HC emissions, which trended downward from 3 g/kg for 1991-2003 models to less than 1 g/kg for the newest models. CO emissions declined from 6 g/kg to less than 2 g/kg over the same age range.

Figure IV-1 Heavy-duty Diesel Average Emissions by Model Year



IV-2 Heavy-duty Measurements and Emissions by Body Style

Vehicles measured and emissions by body style are shown in Table IV-1 and Figures IV-2 through IV-5. Buses were notably old but had low HC & CO emissions and typical NO and PM emissions. The TRANS category contained newer transit buses and these had lower NO and lower PM than other body styles.

Table IV-1 Observations and Average Emissions by Body Style

Type	Vehicles Measured	Emissions and VSP>2	Avg Years Old	GVW kg	CO g/kg	HC g/kg	NO g/kg	PM g/kg	VSP kW/t
BOX	383	246	7.6	6,841	4.6	2.0	15.8	0.9	6.3
BUS	218	128	13.6	9,516	0.9	0.8	19.7	1.1	6.8
DUMP	748	460	7.8	21,102	5.8	2.0	16.8	1.1	7.5
FLDCK	466	289	9.4	9,835	6.8	2.8	19.6	1.2	7.0
GRBGE	97	52	8.7	11,354	4.0	3.4	19.9	1.1	7.1
LOGTR	14	11	11.6	23,171	9.6	4.4	24.1	1.2	4.4
MIXER	126	77	7.6	17,822	3.7	2.3	14.2	1.1	7.0
TANK	100	56	7.1	12,848	8.1	1.9	17.9	1.0	7.7
TRACT	7709	4,477	8.5	21,496	5.3	2.0	21.1	1.0	7.1
TRANS	79	58	5.3	10,475	0.0	2.6	13.5	0.8	10.3
TRCTR	159	100	7.9	21,128	5.3	1.9	21.0	0.9	7.7
TRUCK	166	106	9.4	11,546	5.0	2.4	23.6	1.0	7.1
UTLTY	10	8	9.5	5,924	3.0	2.2	17.4	1.0	7.0
VAN	1288	871	8.1	6,770	5.5	2.2	16.9	0.9	6.6
WRCKR	26	19	7.8	6,176	8.6	2.6	20.2	1.0	7.8
OTHER	132	82	6.2	9,475	4.9	2.3	16.2	0.8	8.2
Total	11,721	7,040	8.4	17,814	5.29	2.1	19.8	1.0	7.0

BOX: Box truck, BUS: bus, DUMP: Dump Truck, FLDCK: Flat Deck, GRBGE: Garbage, LOGTR: Logging Truck, MIXER: Cement Mixer, TANK: Tank, TRACT: Truck Tractor, TRANS: Public Transit Bus, TRCTR: Farm/Industrial Tractor, TRUCK: Truck (includes tow truck), UTLTY: Utility, VAN: Van, WRCKR: Wrecker.

Figure IV-2 Heavy-duty Vehicles by Body Style: Years Old

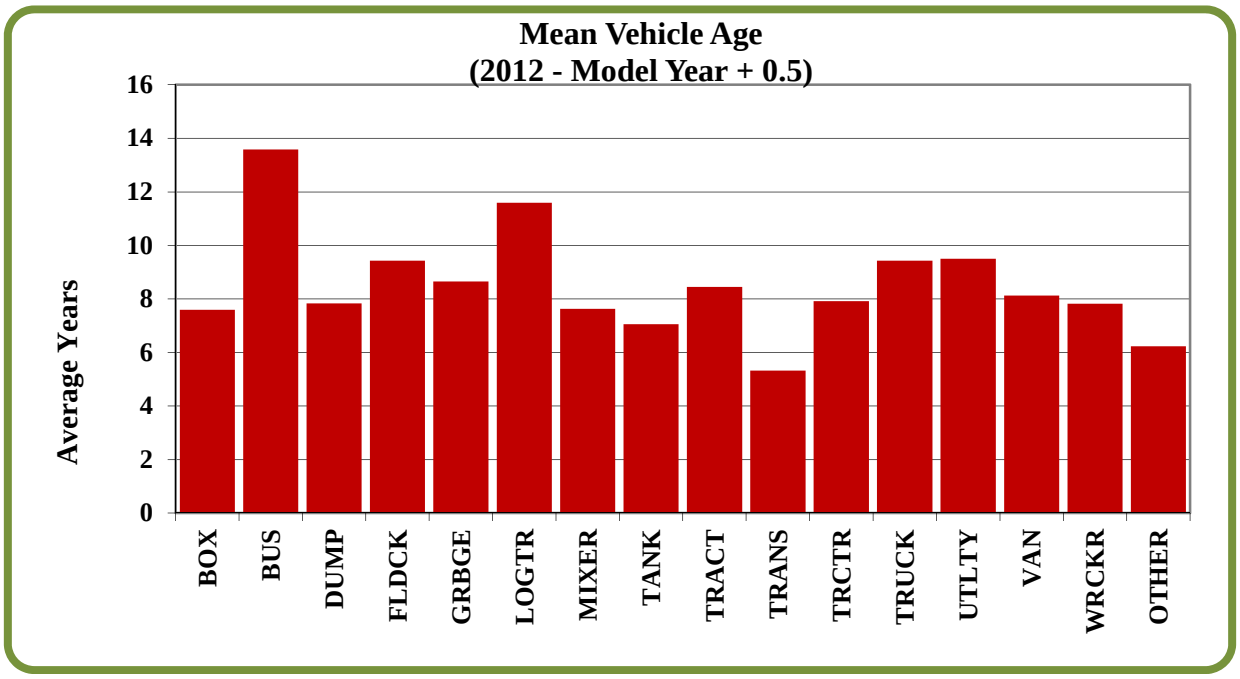


Figure IV-3 Heavy-duty Vehicles by Body Style: VSP kW/t

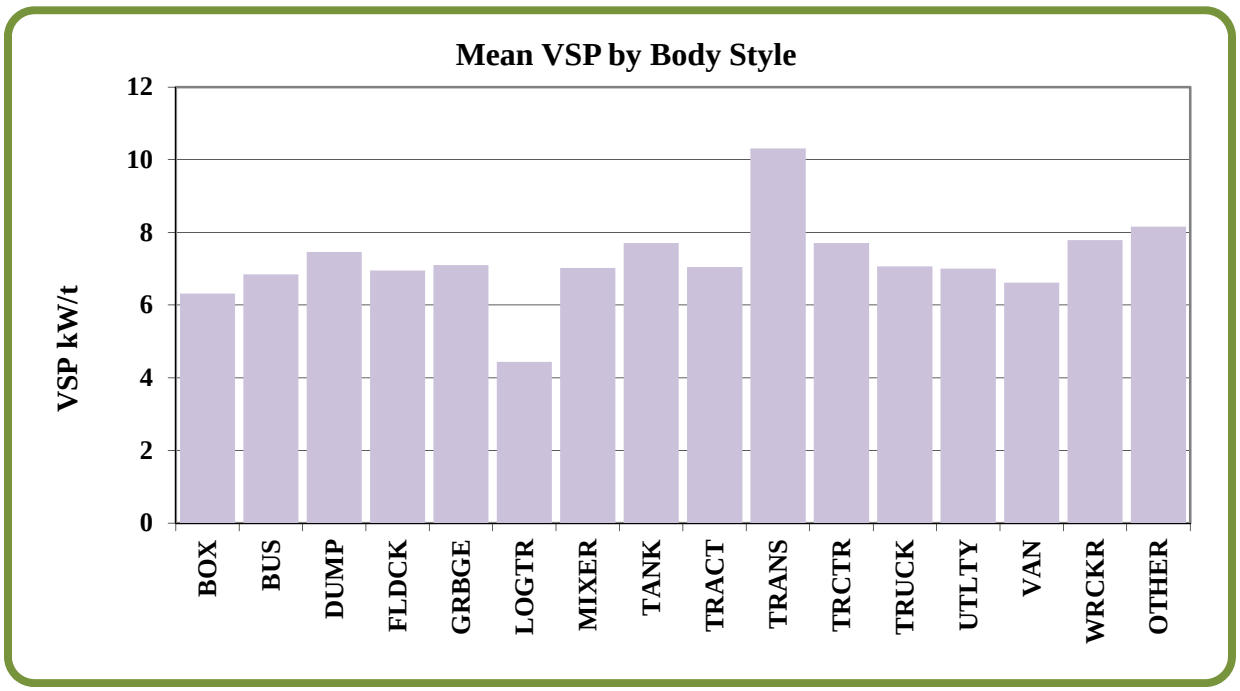


Figure IV-4 Heavy-duty Vehicles by Body Style: PM g/kg

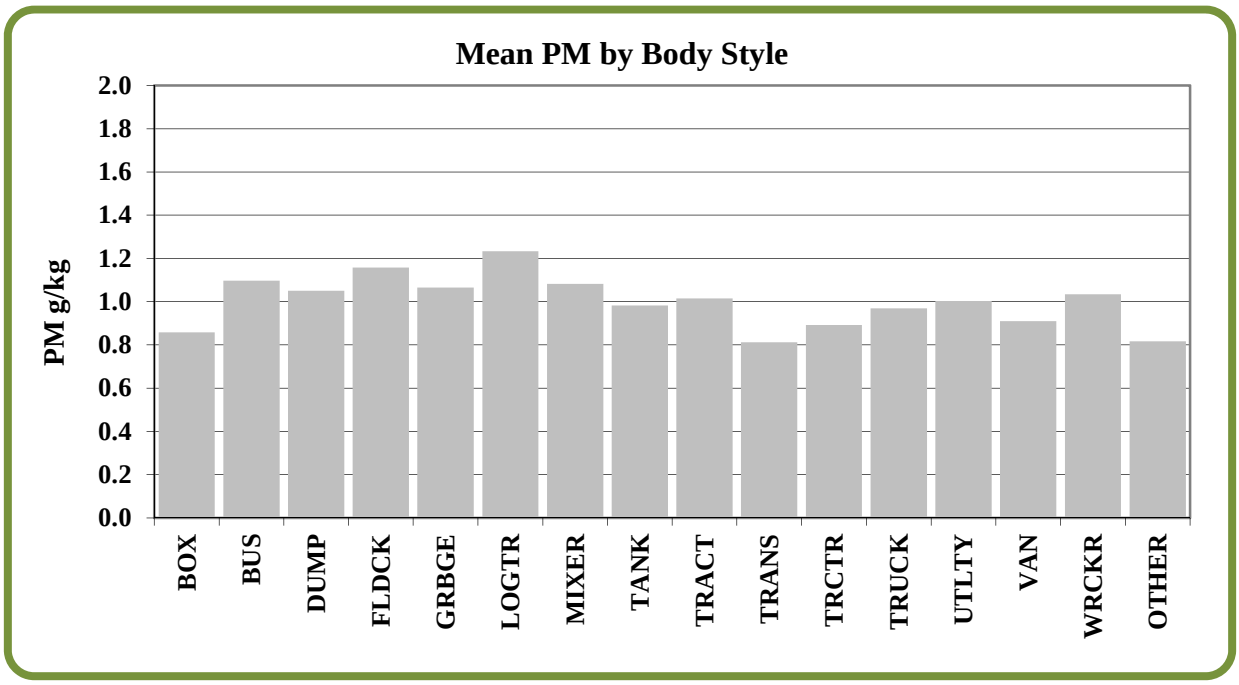
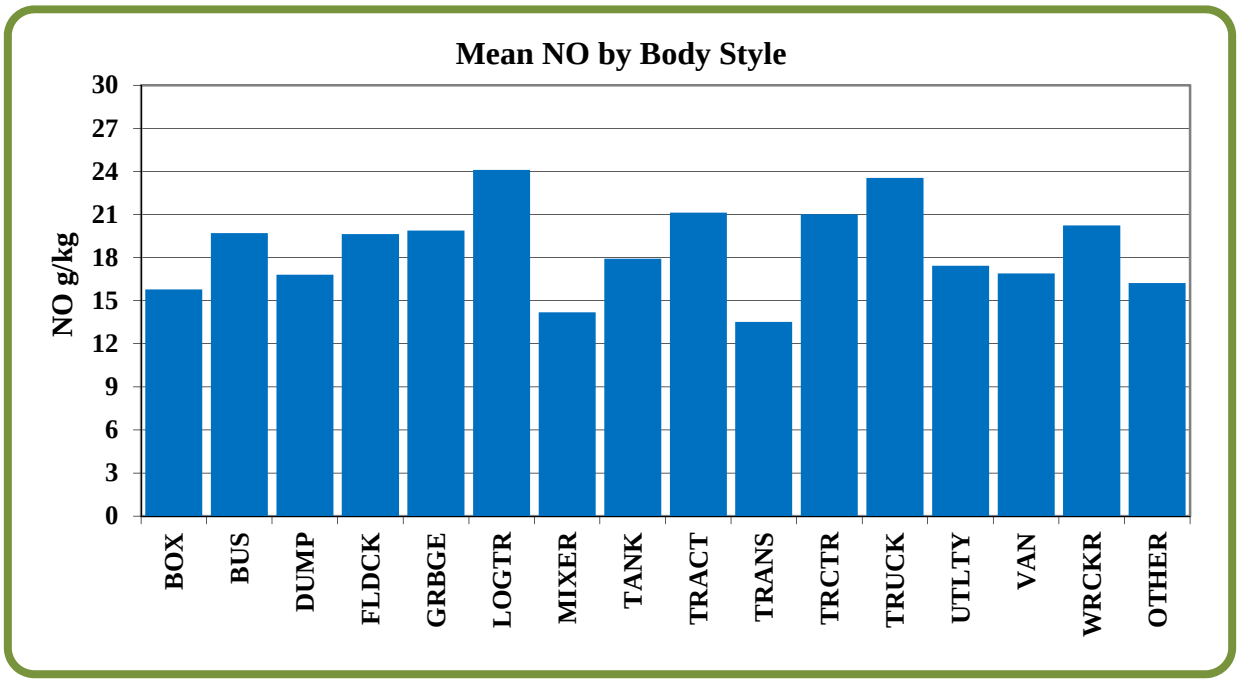


Figure IV-5 Heavy-duty Vehicles by Body Style: NO g/kg



IV-3 Heavy-duty Measurements and Emissions by Make

Vehicles measured and emissions by make are shown in Table IV-2 and Figures IV-6 through IV-9. Ford, New Flyer and Orion V makes were the oldest and Novabus were the newest. Table IV-3 shows makes measured by body style, which confirms that New Flyer, Novabus and Orion V were all buses. The Orion V buses appeared to have high PM emissions.

Table IV-2 Observations and Average Emissions by Make

Type	Vehicles Measured	Emissions and VSP>2	Avg Years Old	GVW kg	CO g/kg	HC g/kg	NO g/kg	PM g/kg	VSP kW/t
FORD	159	106	11.9	8,731	8.0	3.4	25.4	1.3	7.5
FREIGHTLIN	3,462	2,167	8.7	19,239	5.8	1.9	20.1	1.1	7.2
GMC	564	360	9.5	6,541	5.8	2.4	16.9	1.0	6.4
HINO	391	271	7.4	6,353	5.5	2.3	14.6	1.0	6.1
INTERNATIO	346	211	9.5	11,571	5.8	2.5	21.0	0.9	7.0
INTERNATNA	1,038	636	7.1	15,495	5.2	2.7	19.4	0.8	7.2
ISUZU	35	23	8.8	6,387	4.0	2.6	15.8	1.3	6.4
KENWORTH	1,518	888	9.0	21,141	5.5	2.1	21.1	1.0	6.9
MACK	290	159	6.4	20,926	3.3	2.6	18.4	0.8	7.1
NEW FLYER	203	123	12.0	10,513	0.0	1.2	18.9	0.9	7.8
NOVABUS	29	21	4.5	8,326	0.0	0.6	13.3	1.0	13.8
ORION V	58	37	11.7	8,368	2.6	2.2	17.7	1.6	5.2
PETERBILT	1,057	585	7.3	22,788	5.4	1.6	18.2	0.9	6.7
STERLING	402	236	6.8	15,807	5.4	2.2	16.3	1.0	7.2
VOLVO	1,714	949	8.4	21,053	4.6	1.9	23.4	1.0	7.2
WESTERN ST	350	198	7.5	22,967	4.5	1.5	15.1	0.9	6.7
OTHER	105	70	10.7	11,479	7.0	3.6	23.9	1.6	8.7
Total	11,721	7,040	8.4	17,814	5.29	2.1	19.8	1.0	7.0

Table IV-3 Measurements by Make and Body Style

MAKE \ BODY	BOX	BUS	DUMP	FLDCK	GRBGE	LOGTR	MIXER	OTHER	TANK	TRACT	TRANS	TRCTR	TRUCK	UTLTY	VAN	WRCKR	Total
FORD	9		26	42	3			9	8	19			6	4	33		**159**
FREIGHTLIN	46	1	39	78	17	1	3	23	15	2,876		56	51		250	6	**3,462**
GMC	121		16	71				14	3	3			16	3	316	1	**564**
HINO	71		7	57				7	1	1			13		232	2	**391**
INTERNATIO	33		11	27	7			2	2	106		2	13	1	141	1	**346**
INTERNATNA	55		15	62	21		26	14	11	589		16	24	1	196	8	**1,038**
ISUZU	8		3	3											21		**35**
KENWORTH	14		278	32	5	5	11	8	25	1,063		31	10		34	2	**1,518**
MACK	2		26	6	13		15	13	4	200		7			4		**290**
NEW FLYER		155									48						**203**
NOVABUS											29						**29**
ORION V		57									1						**58**
OTHER	5	5	9	10	1	1	4	26	1	23	1		3		15	1	**105**
PETERBILT	3		116	22	7	2	2	4	17	832		6	16	1	28	1	**1,057**
STERLING	15		137	36	14		50	3	1	105		12	9		16	4	**402**
VOLVO			4	7	7			9	4	1,652		26	3		2		**1,714**
WESTERN ST	1		61	13	2	5	15		8	240		3	2				**350**
Total	**383**	**218**	**748**	**466**	**97**	**14**	**126**	**132**	**100**	**7,709**	**79**	**159**	**166**	**10**	**1,288**	**26**	**11,721**

Figure IV-6 Heavy-duty Vehicles by Make: Years Old

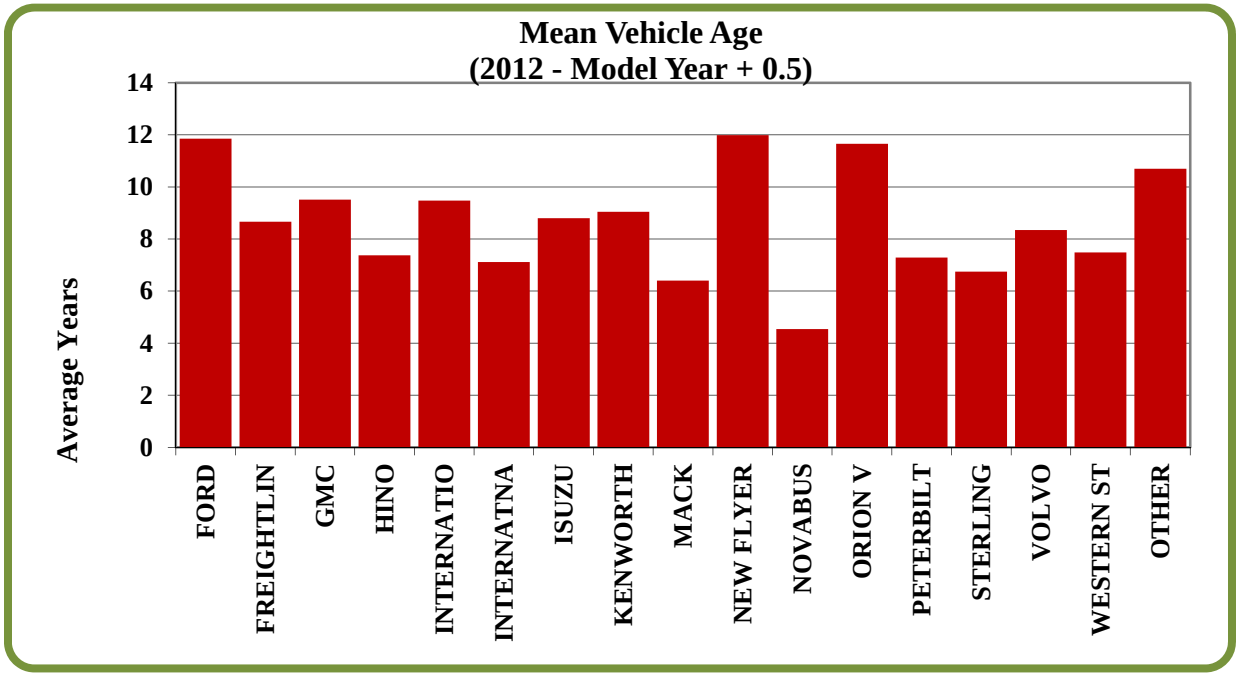


Figure IV-7 Heavy-duty Vehicles by Make: VSP kW/t

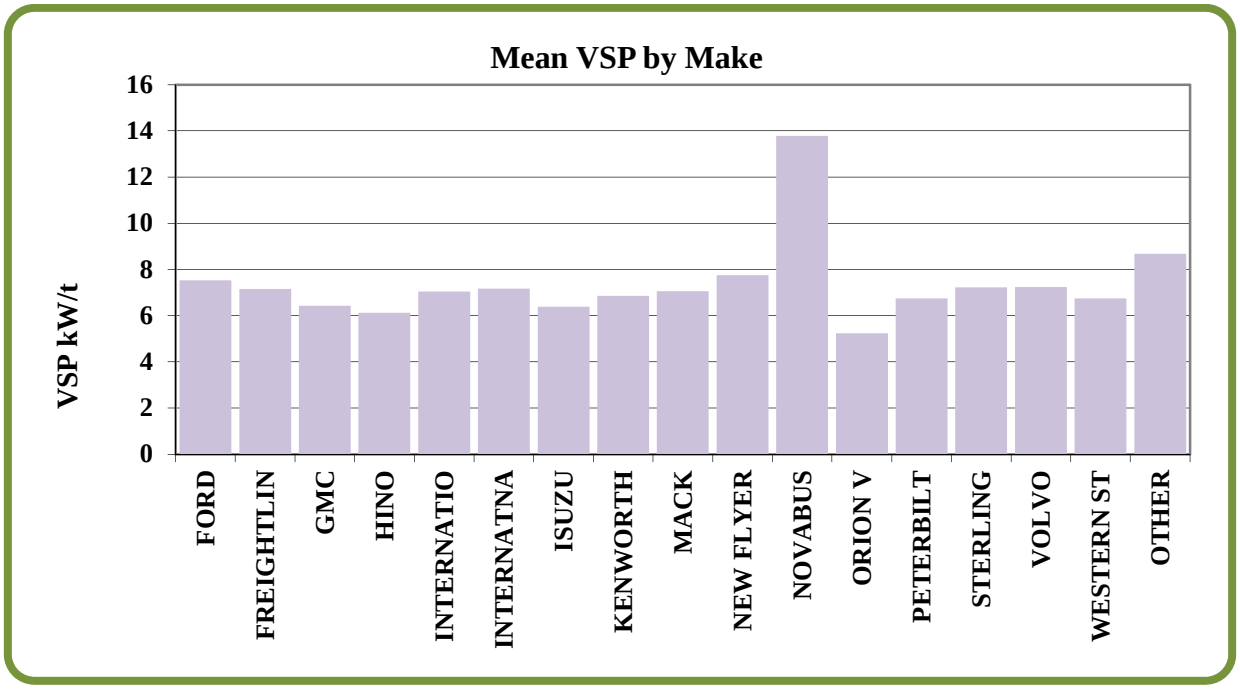


Figure IV-8 Heavy-duty Vehicles by Make: PM g/kg

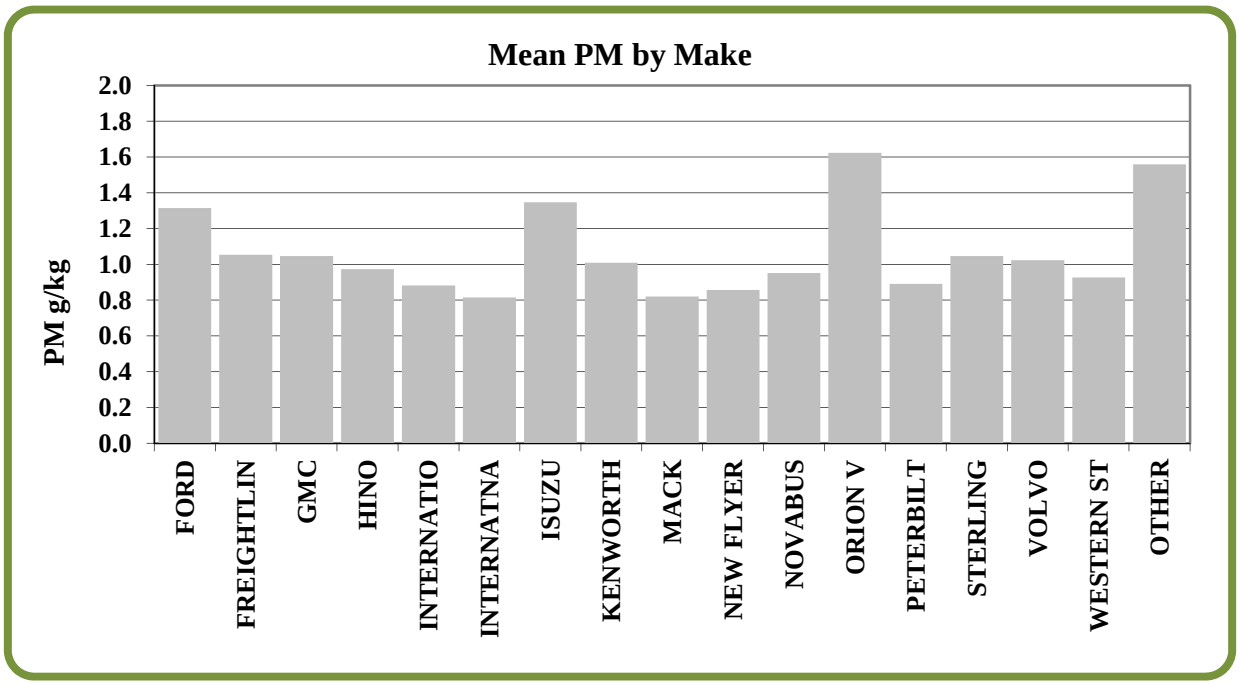
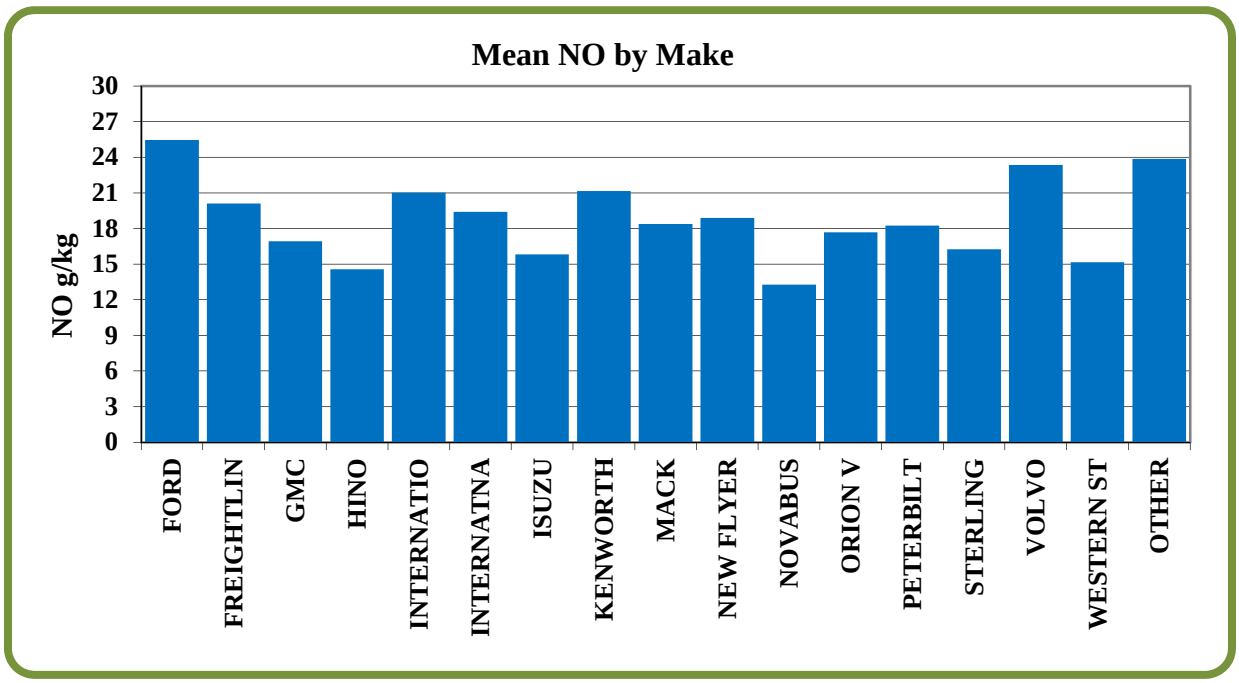


Figure IV-9 Heavy-duty Vehicles by Make: NO g/kg



IV-4 Measurements and Emissions by Fuel and Weight Class

Vehicles measured and emissions by weight class are shown in Table IV-4 and Figures IV-10 through IV-13. Diesel class 5 vehicles were the oldest but had lower emissions of CO and HC and typical emissions of NO and PM. Transit buses made up a majority of this weight class. Class 8 trucks had the highest average NO emissions. Non-diesel class-7 vehicles were the newest and had the lowest NO emissions.

Average emissions are not shown for Non-diesel class 6 vehicles. Three of these were measured but at VSP of less than two.

Table IV-4 Vehicles by Fuel and Weight Class

Type	Vehicles Observed	Emissions and VSP>2	Avg Years Old	GVW kg	CO g/kg	HC g/kg	NO g/kg	PM g/kg	VSP kW/t
Diesel-3	914	627	8.8	5,812	5.6	2.3	17.6	1.0	6.7
Diesel-4	1,209	800	8.2	6,691	5.5	2.3	18.2	0.9	6.6
Diesel-5	265	154	10.9	8,007	2.9	1.5	19.3	1.1	6.6
Diesel-6	465	278	8.5	10,957	5.6	2.7	17.9	1.1	7.0
Diesel-7	461	274	8.6	13,117	3.8	1.7	17.1	1.0	7.7
Diesel-8	8,302	4,827	8.4	22,271	5.4	2.0	20.8	1.0	7.1
Non-diesel-3	8	6	8.5	5,816	3.2	0.0	14.1	0.3	7.0
Non-diesel-4	9	6	9.8	6,701	45.1	2.5	15.7	0.4	6.7
Non-diesel-5	34	28	6.4	8,550	0.0	5.8	19.5	1.0	10.7
Non-diesel-7	20	18	4.9	13,655	3.6	2.0	8.2	0.7	7.9
Non-diesel-8	31	22	5.5	21,591	4.8	1.1	16.1	1.4	7.7
Total	11,718	7,040	8.4	17,814	5.29	2.1	19.8	1.0	7.0

Figure IV-10 Heavy-duty Vehicles by Fuel & Weight Class: Years Old

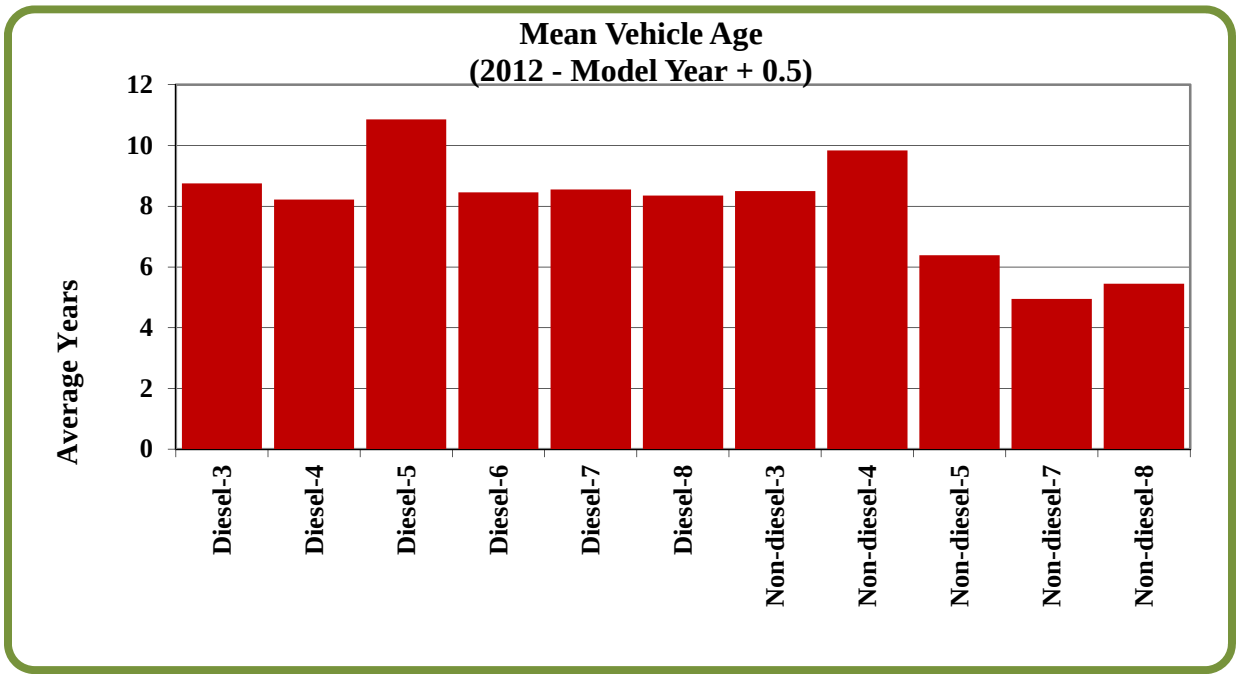


Figure IV-11 Heavy-duty Vehicles by Fuel & Weight Class: VSP kW/t

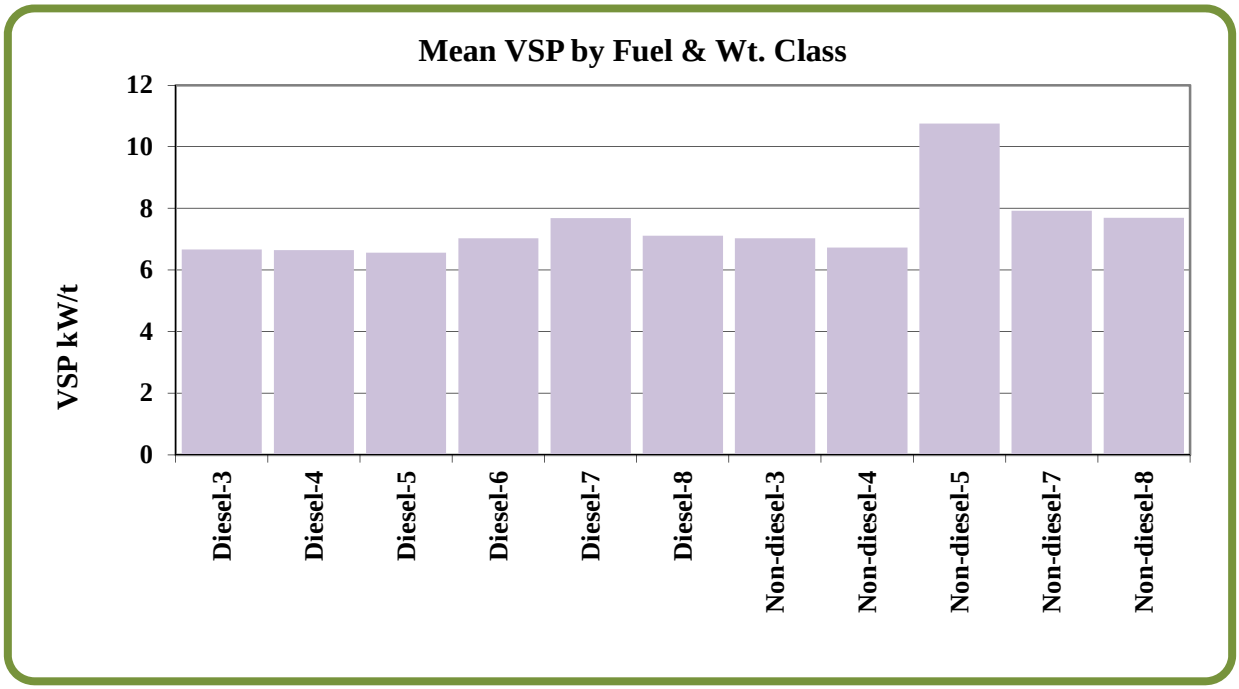


Figure IV-12 Heavy-duty Vehicles by Fuel & Weight Class: PM g/kg

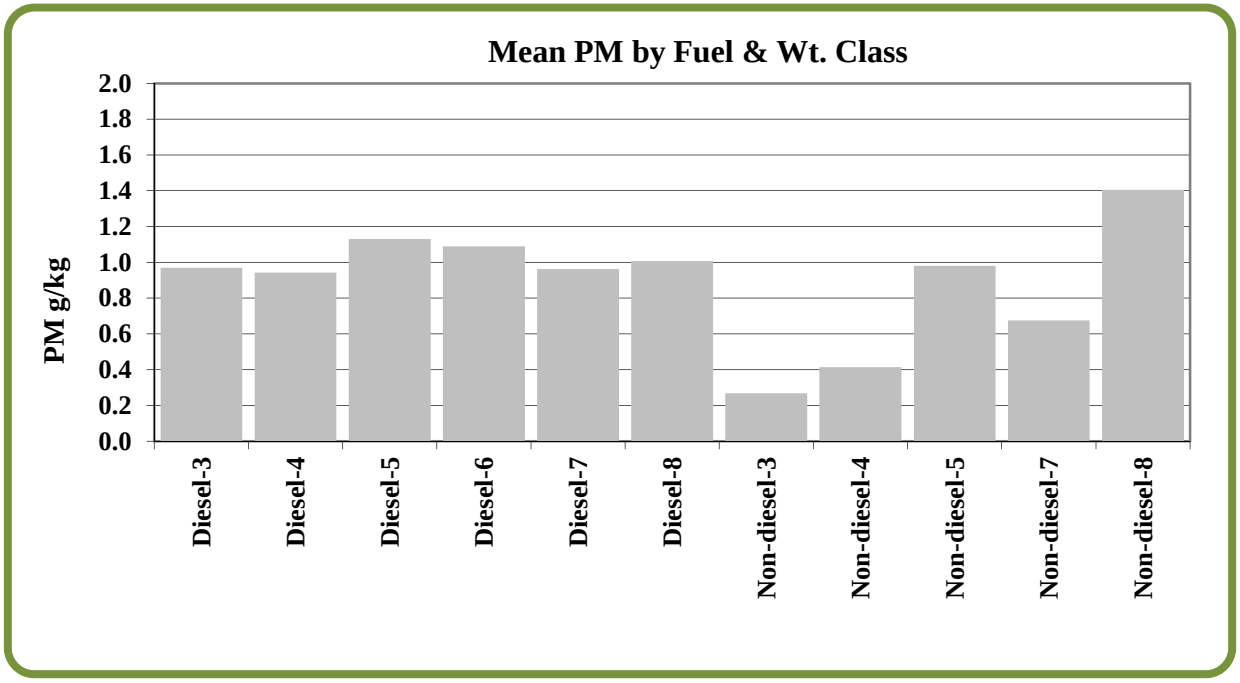
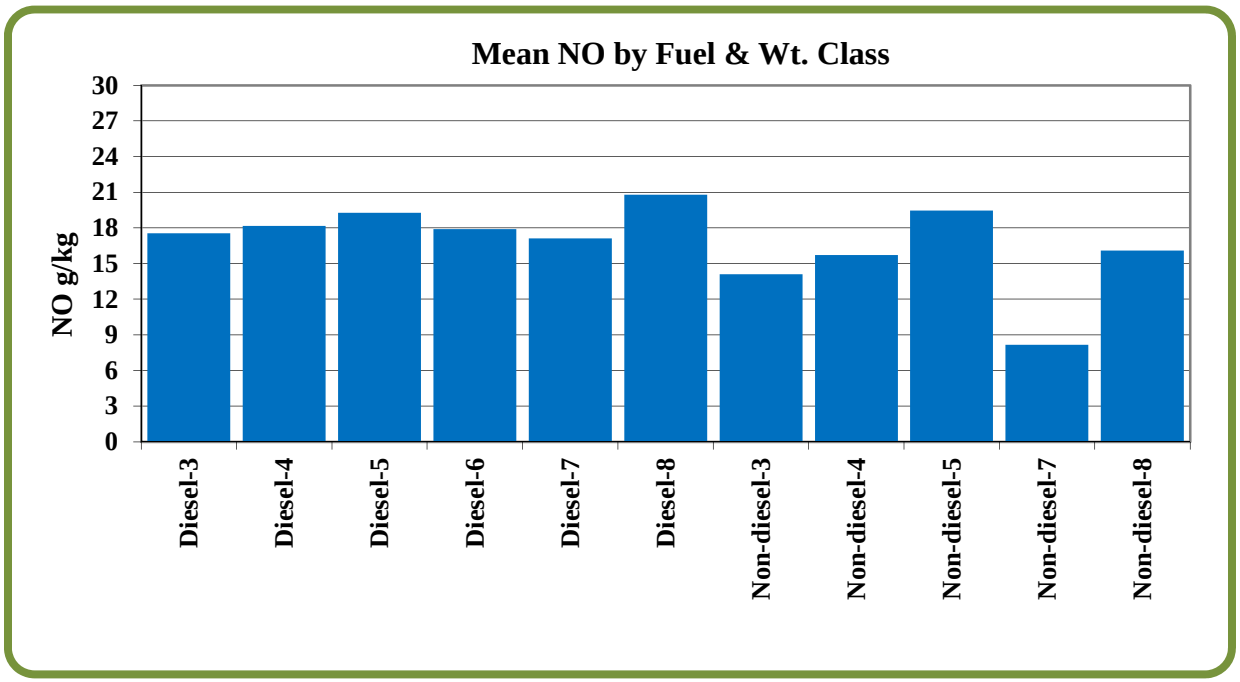


Figure IV-13 Heavy-duty Vehicles by Fuel & Weight Class: NO g/kg



IV-5 Emissions by Territory

Vehicles measured were binned by territory or other jurisdiction. The territory or jurisdiction was obtained from license plates matched to registrations or, for vehicles registered in other Provinces or States, from the jurisdiction indicated on the vehicle plate. Since no vehicle model information was available for those registered outside British Columbia, only measurements of high exhaust vehicles were included and these were assumed to be mostly diesel fueled HDVs. TableIV-5 indicates the number and percentage of vehicles observed from each jurisdiction. A majority of the vehicles were registered in territory D and Z or were unmatched to a registration. A further 4,000 vehicles had plates that were not in the RSD picture or could not be read.

Table IV-5 High Exhaust Observations by Registered Jurisdiction

Jurisdiction	Observed	%
DEH	10,821	52%
FG	435	2%
LWX	126	1%
Other	80	0%
Z	3,598	17%
Unmatched	2,738	13%
Alberta	818	4%
Ontario	375	2%
Other Canada	640	3%
Oregon	147	1%
Washington	598	3%
Other USA	461	2%
Total	**20,837**	**100%**

Figure IV-14 compares the emissions of vehicles registered to the different jurisdictions. PM emissions were similar across the jurisdictions.

The NOx emissions of vehicles registered in British Columbia territories and territory Z were similar. Vehicles from Alberta and Ontario appear to have had lower NO emissions than British Columbia registered vehicles. Vehicles with unread plates had much higher average HC.

Figure IV-14 Emissions by Jurisdiction: Vehicles with High Exhausts

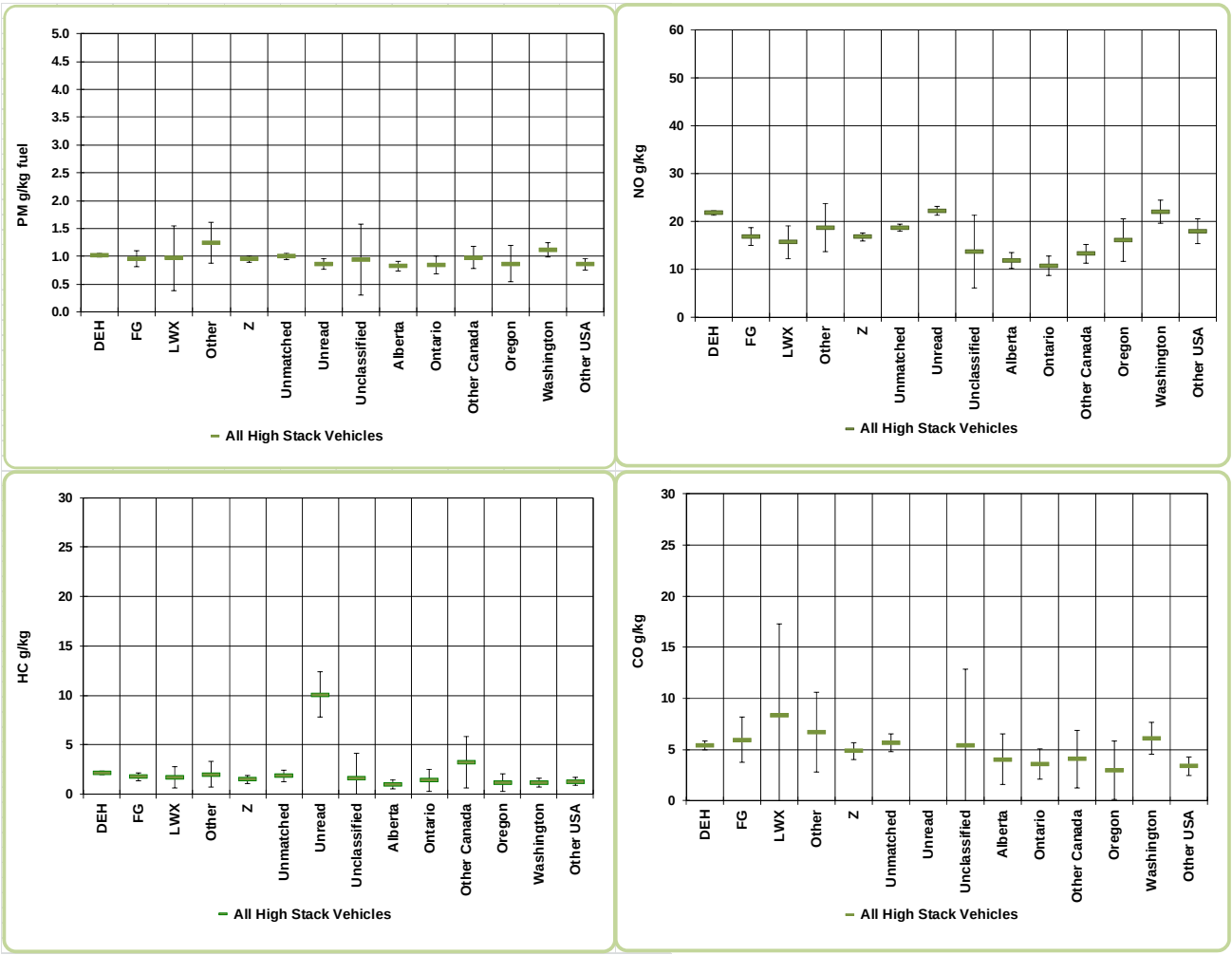


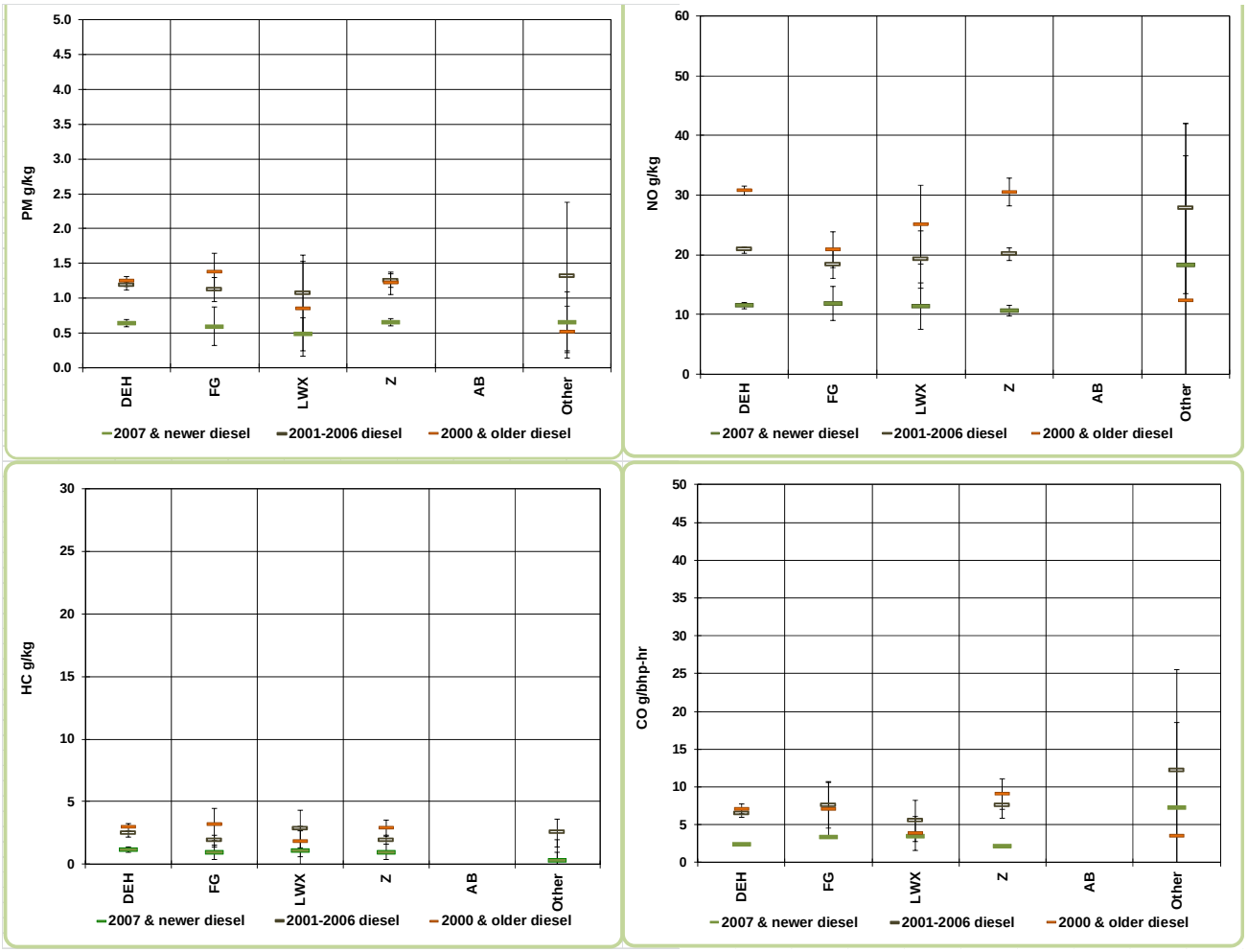
Table IV-6 shows the number of vehicles measured and Figure IV-15 shows the emissions of vehicles registered in British Columbia Territories for three age groups. Both Lower Fraser Valley vehicles (Territories D, E and H) and Territory Z vehicles had similar emissions.

Overall, 36% of HDVs measured were 2007 and newer models. Territory Z registered HDVs measured were newer with 51% being 2007 and newer.

Table IV-6 Heavy-duty Vehicle Measurements by Territory

Fuel	Model Year	Vehicles	D	E	F	G	H	L	W	X	Z	Other
Diesel	2000 & older	3,157	2,655	3	45	0	35	4	6	6	398	5
Diesel	2001-2006	4,266	3,205	1	120	3	46	5	9	8	863	6
Diesel	2007 & Newer	4,193	2,724	2	94	2	29	18	8	9	1,304	3
Non-diesel	2000 & older	16	16	0	0	0	0	0	0	0	0	0
Non-diesel	2001-2006	28	27	0	0	0	0	0	0	0	1	0
Non-diesel	2007 & Newer	61	51	1	0	0	0	0	0	0	9	0
Total		**11,721**	**8,678**	**7**	**259**	**5**	**110**	**27**	**23**	**23**	**2,575**	**14**

Figure IV-15 Diesel Emissions by Territory



IV-6 Multiple Measurements of the Same Vehicle

Figures IV-16 to IV-19 plot the NO and PM emissions of vehicles with at least four RSD measurements with VSP greater than 2kW/t.

Vehicles were grouped by fuel, weight class and three vehicle year ranges (2007 & newer, 2001-2006, and 2000 and older). Within the groups, vehicles were ordered by average emissions from highest to lowest. X-axis labels indicate the fuel (D: Diesel, F: Diesel-Butane, G: Gasoline, R: Diesel-Natural, etc.), vehicle year, weight class and make. The x-axis labels show every second or third vehicle on some charts because of space limitations.

Each column of points represents the four or more individual measurements of a vehicle. The red squares indicate the average emissions of each vehicle.

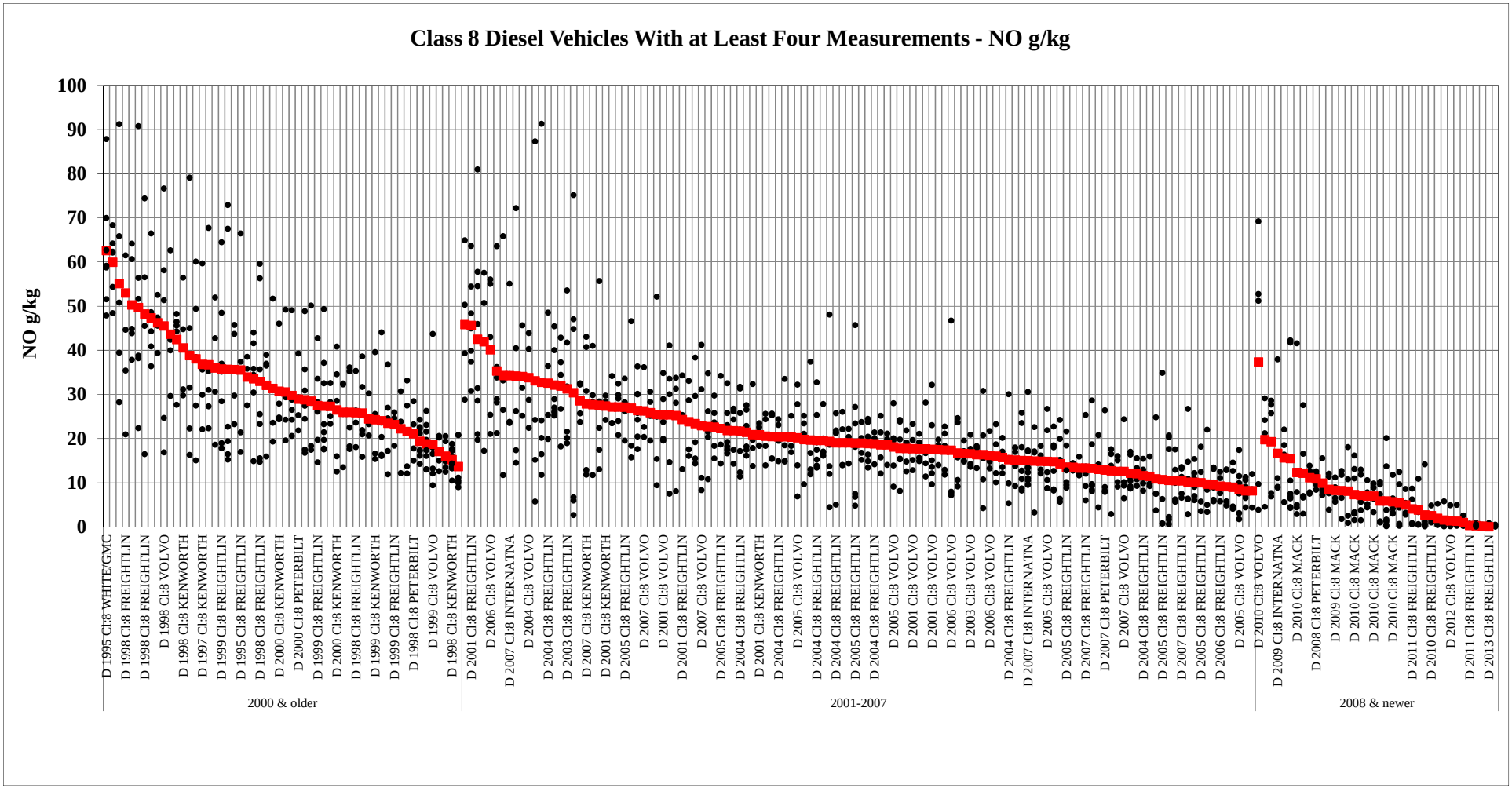
The standard deviations of measurements for each vehicle were roughly proportional to the average emissions value. Average standard deviations were 8 g/kg NO (46%) and 0.68 g/kg PM (60%).

Thus RSD screening cutpoints need to have an appropriate margin to allow for variability in vehicle operating conditions. The standard error or 95% confidence interval for the mean emissions is:

1.96 X Standard Deviation/ (Number of measurements)$^{(1/2)}$

Having multiple measurements of each vehicle improves the accuracy of the average emissions.

Figure IV-16: Class 8 Diesel Vehicles with Multiple NO Measurements



Horizontal axis labels: Vehicle Fuel, Year, Class and Make.

Each column represents one vehicle: a red square indicates the average emissions of the vehicle and black dots show individual RSD measurements.

Figure IV-17: Class 8 Diesel Vehicles with Multiple UV Smoke Measurements

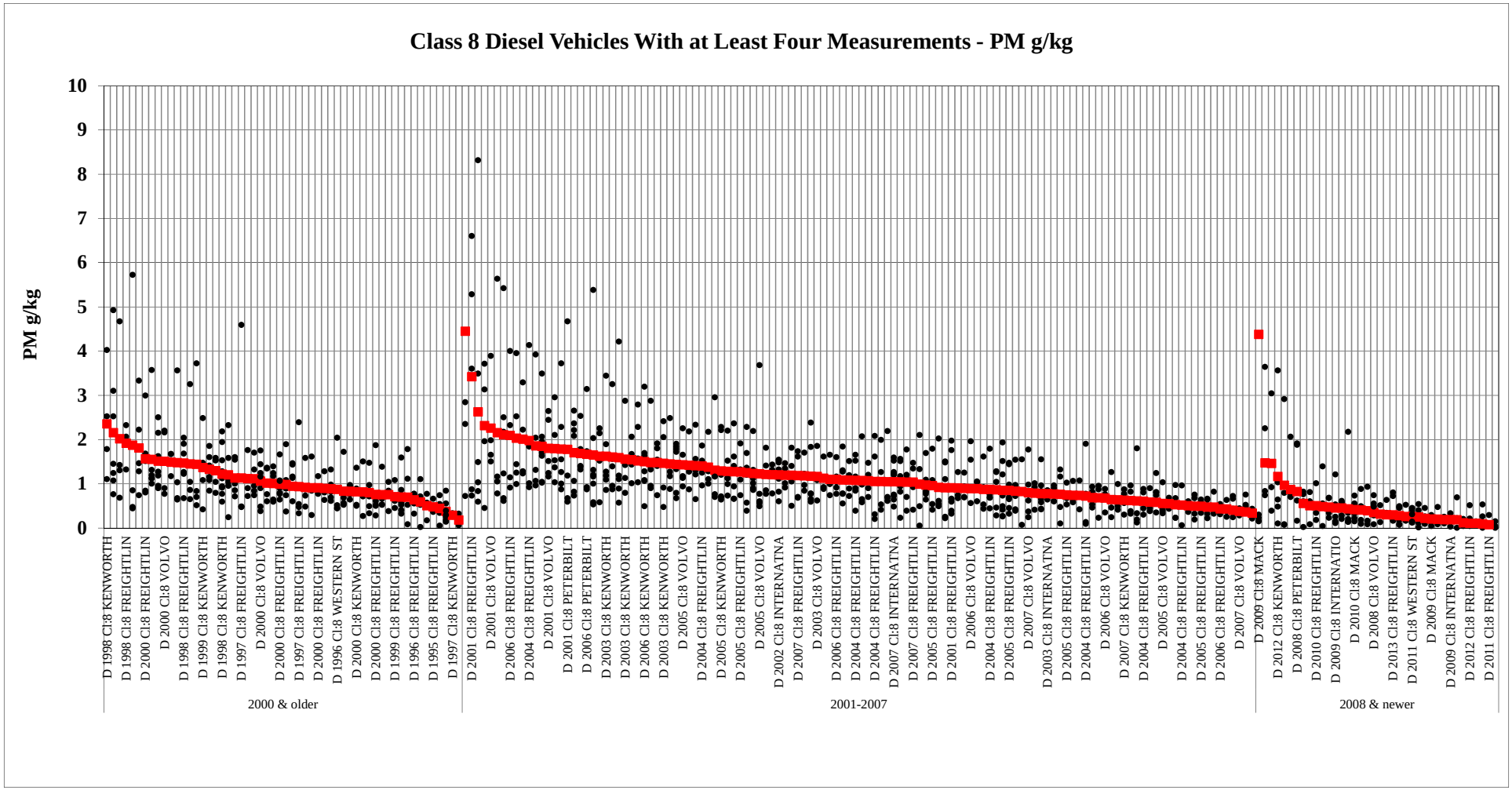


Figure IV-18: Other Fuels and Diesel Class 2-7 with Multiple NO Measurements

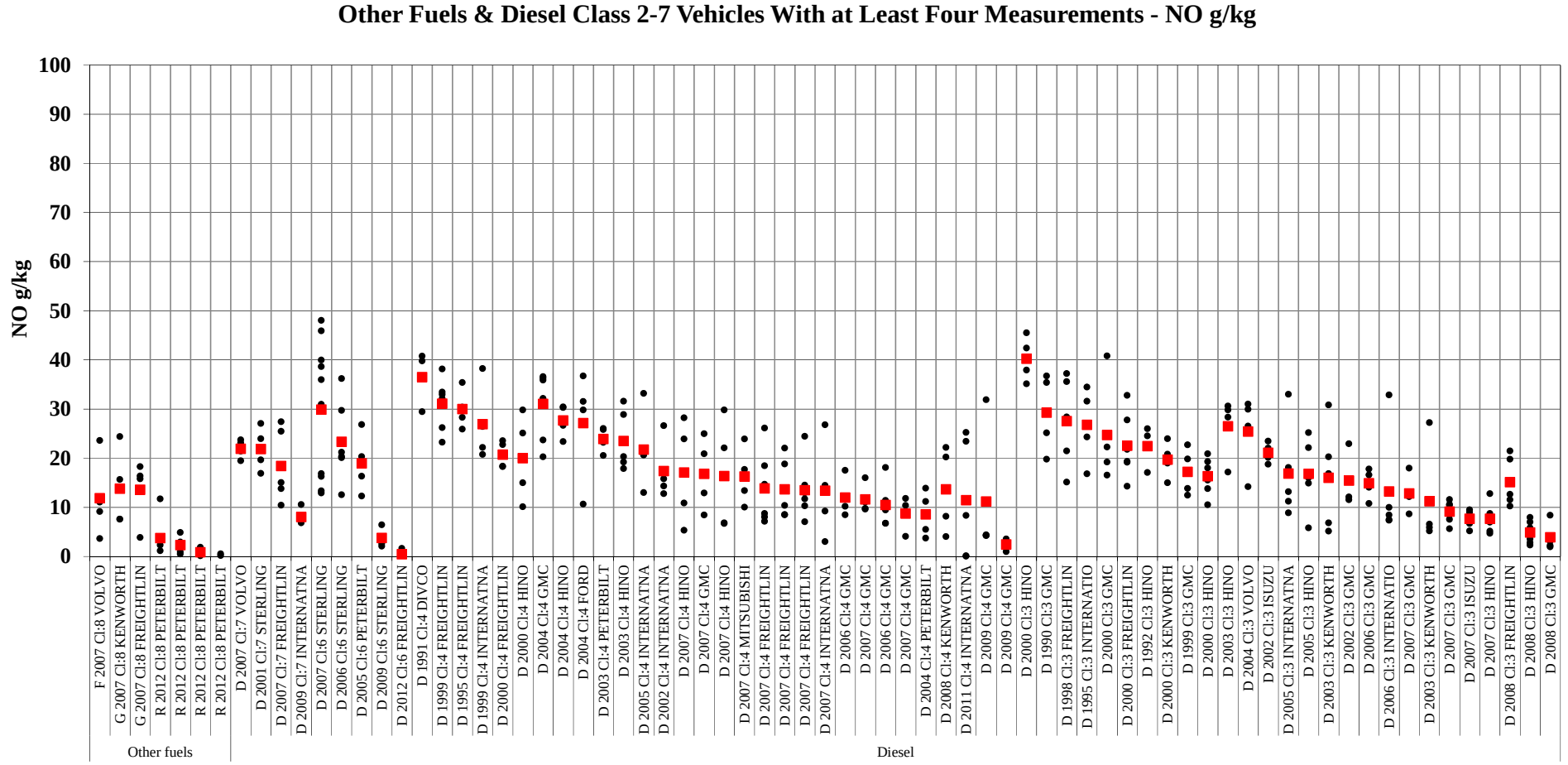
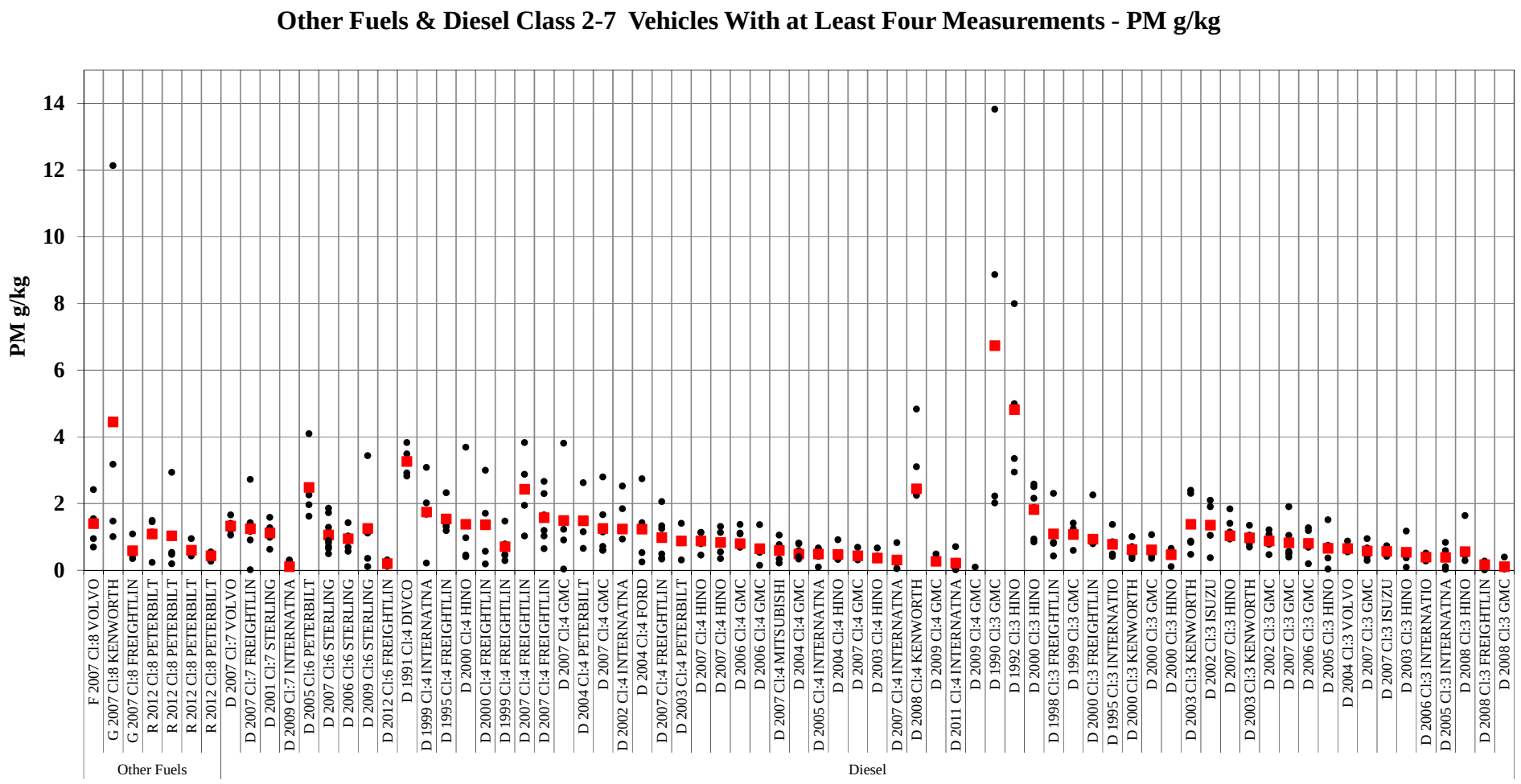


Figure IV-19: Other Fuels and Diesel Class 2-7 with Multiple UV Smoke Measurements



IV-7 Emissions Distributions of Unique Vehicles

Figure IV-20 shows the distribution of emissions for heavy-duty diesel and light-duty gasoline vehicles. Dashed lines show the percentage of the pollutant emitted for a given percentage of the vehicles. Diesel HDVs had PM and NO emissions that were on average 11 and 7 times higher than those of light-duty gasoline vehicles.

A trial cutpoint of 2.8 g/kg PM would identify 4% of diesel HDVs emitting 19% of total heavy-duty PM as high emitters. A trial cutpoint of 48 g/kg NO would identify 5% of diesel HDVs emitting 15% of total heavy-duty NO as high emitters. The high emitter section of the report discusses the potential of using multiple cutpoints for different age and technology models.

The diesel HDVs were divided into four age groups; 1997 & older, 1998-2007, 2008-2010 and 2011-2012, to look in more detail at the emissions distributions of each age group. Figures IV-21 shows the NO and PM emissions distributions of the newer models and IV-22 the older models.

In Figure IV-22, the PM distribution for 2008-2010 models was similar to that of 2011-2013 models.

Vehicles were grouped by fuel, weight and model year. Vehicles within each group were rank ordered by emissions and divided into ten bins. Figures IV-23 and IV-24 illustrate the average emissions of the bins for PM and NO. Most 2008 and newer models had lower PM emissions than older models. NO emissions were lowest for the majority of 2011 and 2012 models, increased with age from 2010 to 2008 models and were higher for 2007 and older models.

Figure IV-20: HD Diesel and LD Non-diesel Emissions Distributions

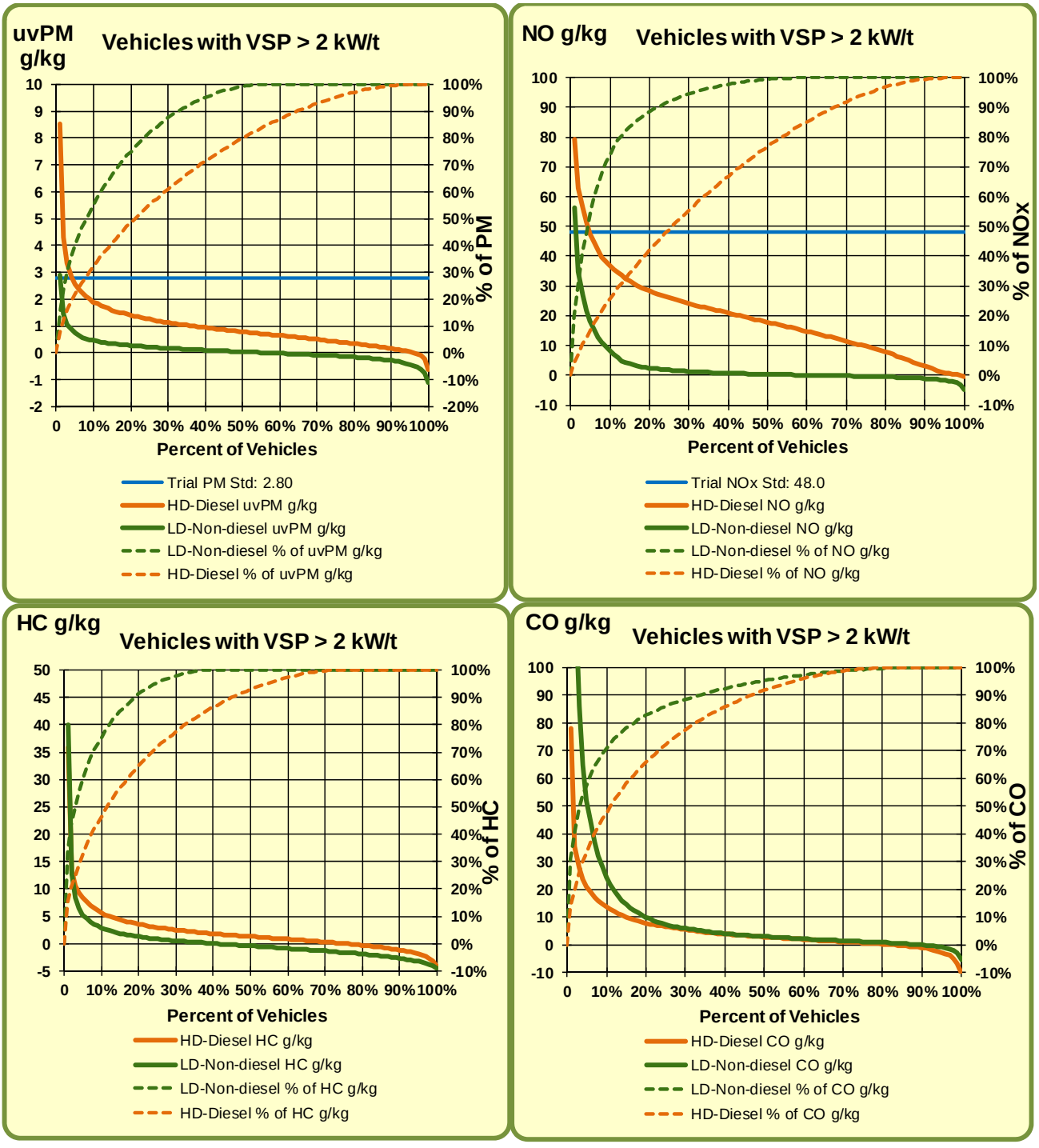


Figure IV-21: HD Diesel Emissions Distributions: MY 2008-2010 and MY 2011-2012

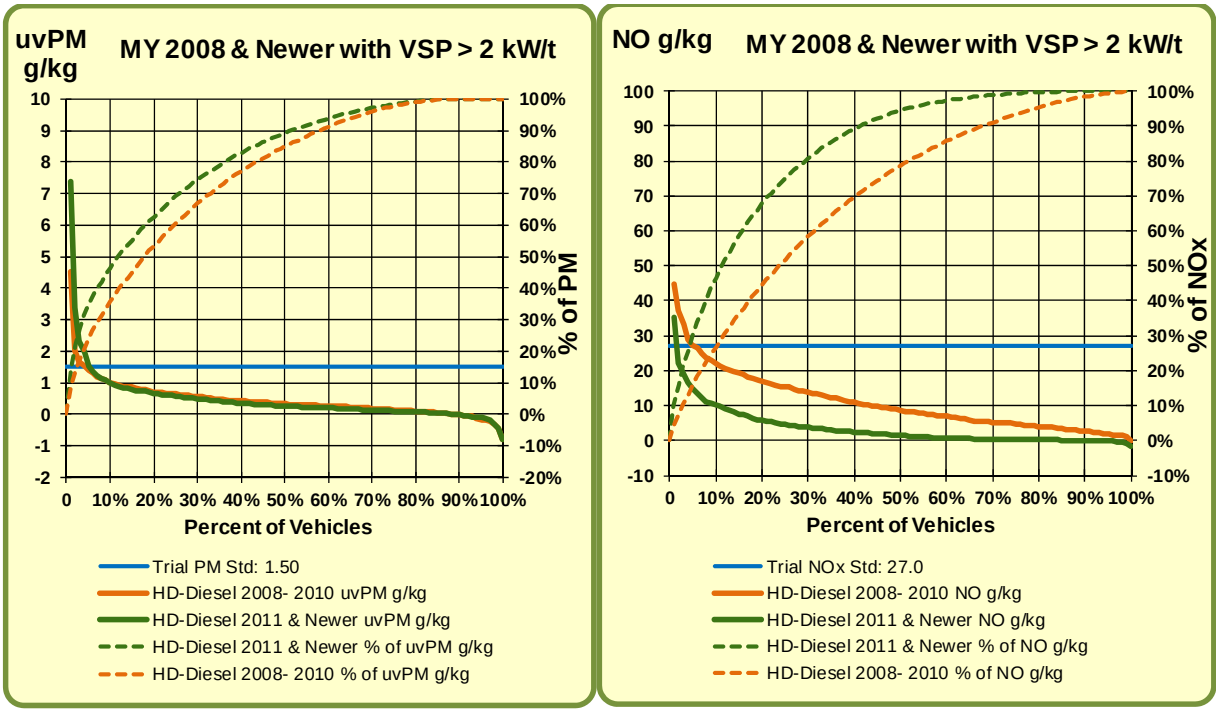


Figure IV-22: HD Diesel Emissions Distributions: MY 1997 & older and MY 1998-2007

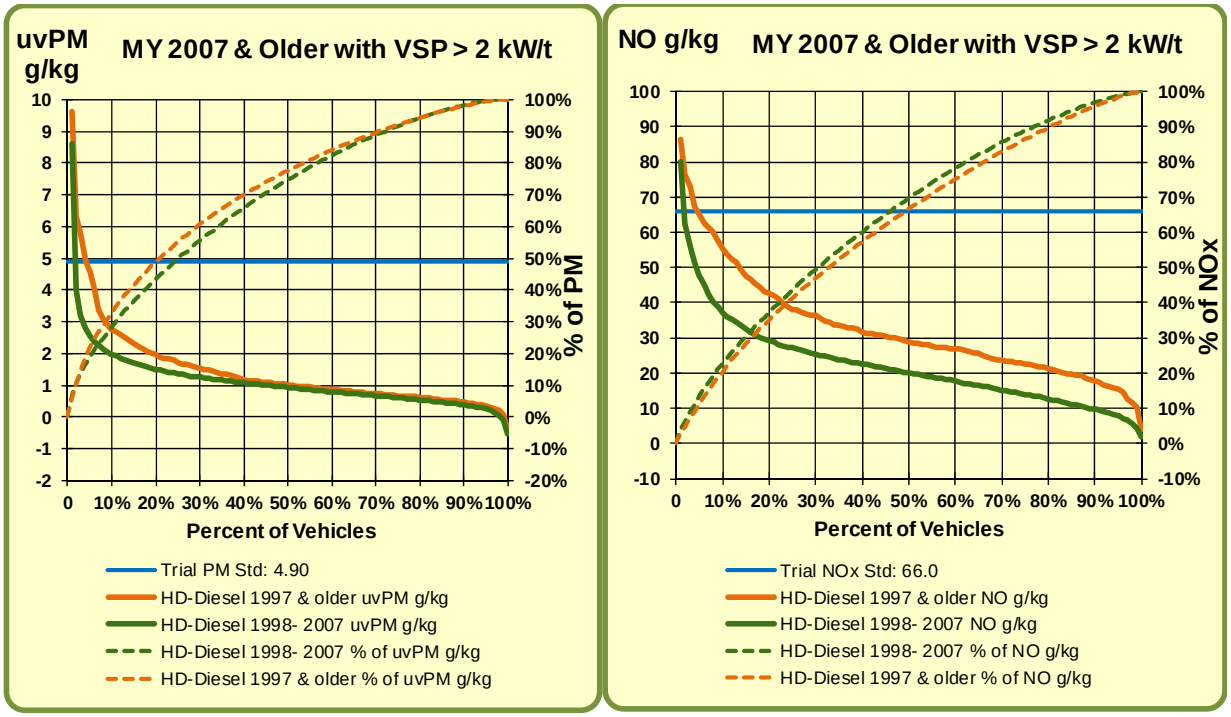


Figure IV-23: Heavy-duty Vehicle PM Deciles

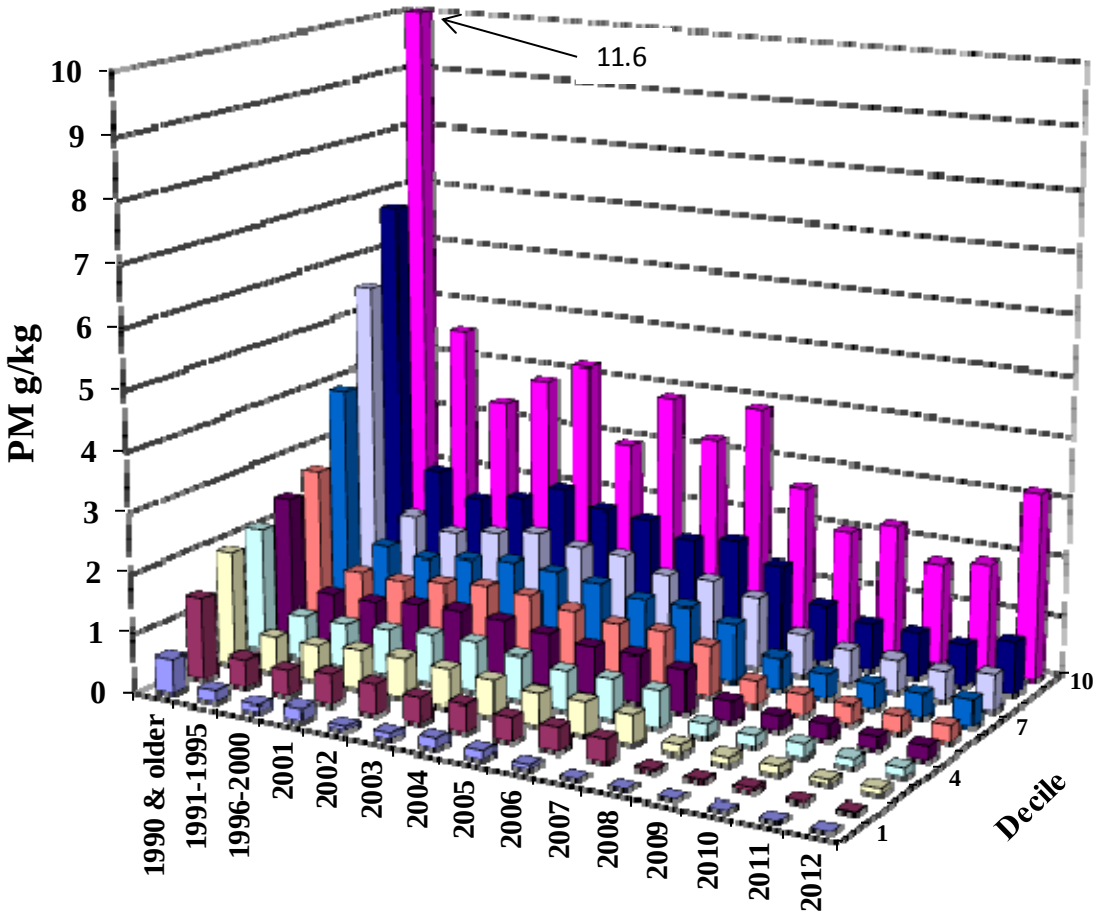
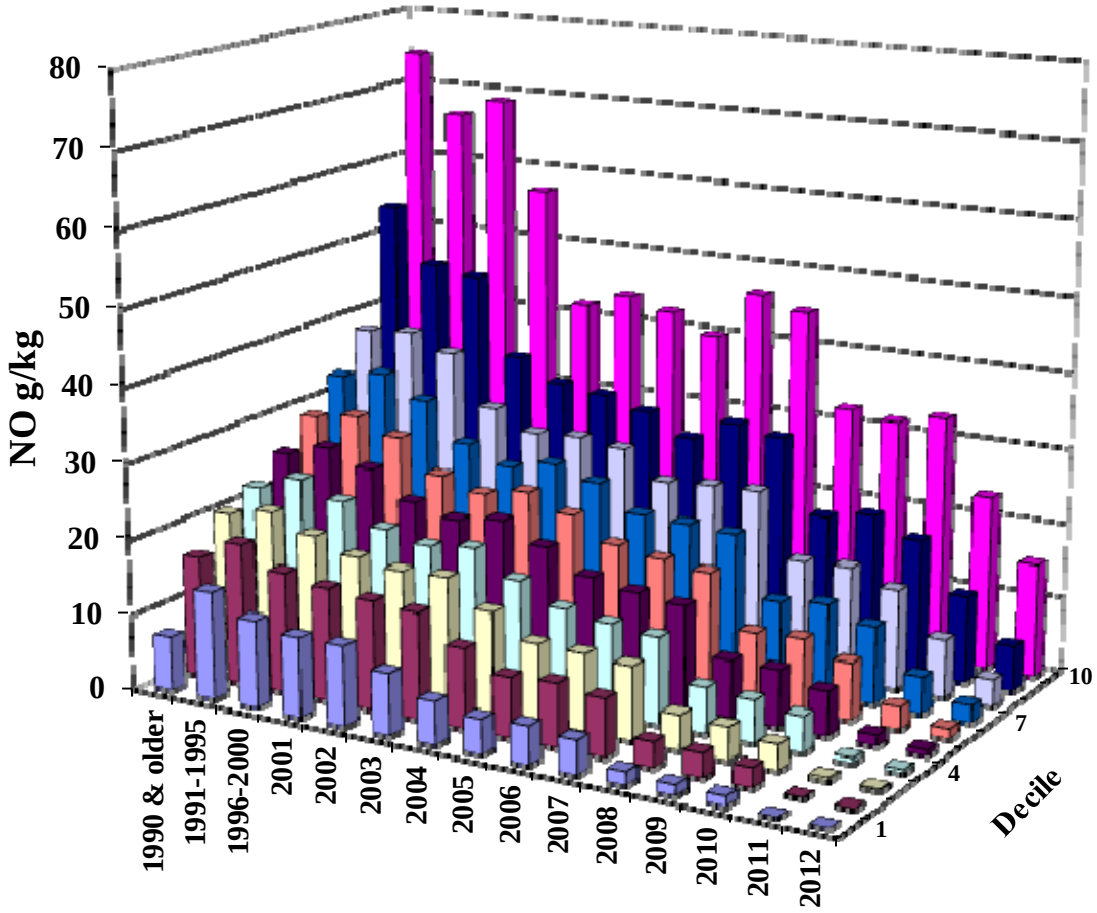


Figure IV-24: Heavy-duty Vehicle NO Deciles



V Tunnel Results

This section presents the results from the 'Tunnel' testing and compares Tunnel results with RSD measurements. Out of 1054 attempts, 929 HDVs and 8 LDVs were successfully measured – an 89% success rate. LDVs were omitted from Table V-1.

Emissions measured were HC, CO, NO, NO_x, overall PM and black carbon (BC) PM. Average emissions by fuel group and vehicle model year are shown in Table V-1. As with the RSD NO measurements, NO g/kg values were calculated using the molecular weight of NO_2 in order to be consistent with NO_x standards and other NO_x analyzers.

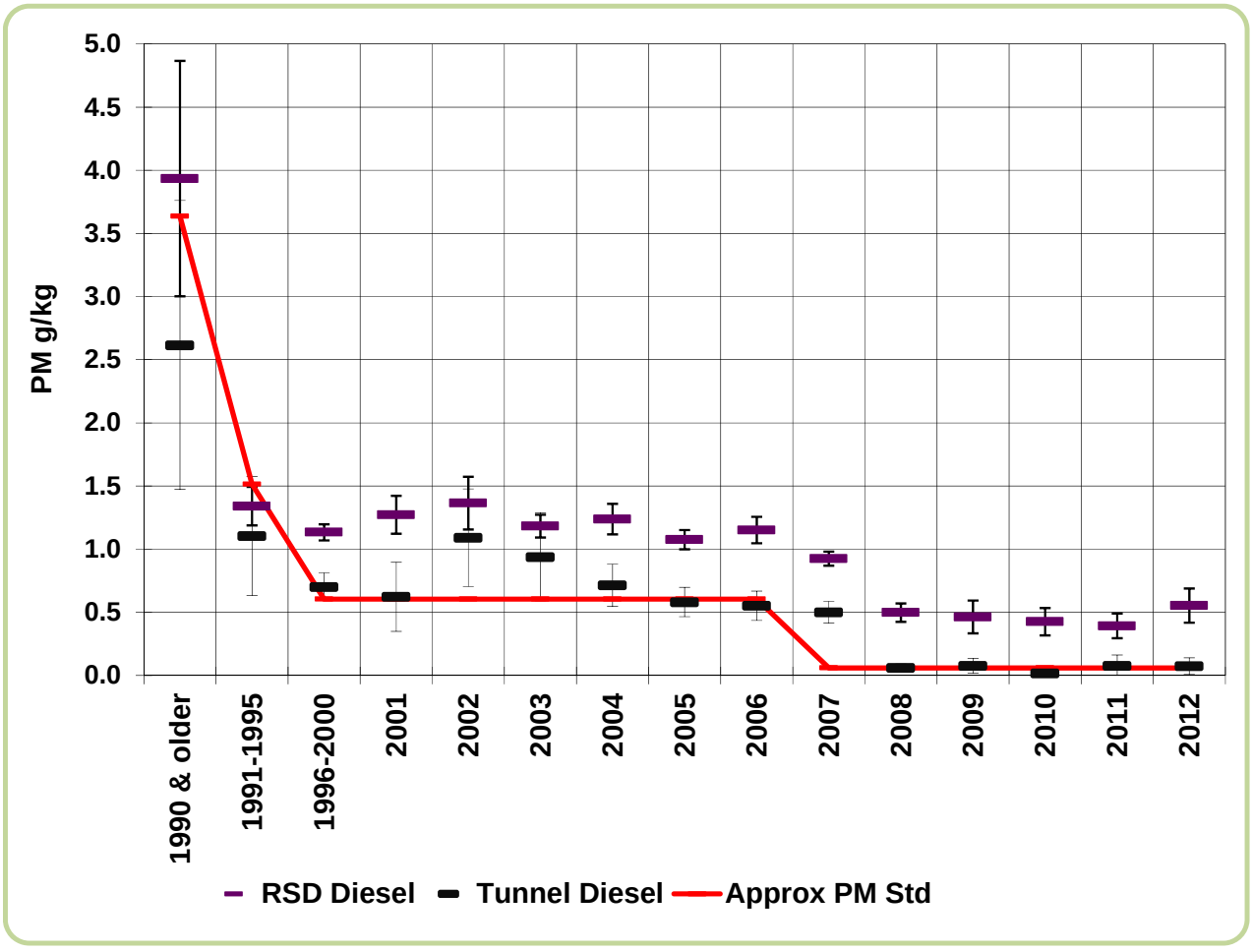
Table V-1 Heavy-duty Vehicles Measured Using the Emissions Tunnel

Fuel	Model Year	N	GVW kg	HC g/kg	CO g/kg	NO g/kg	NOx g/kg	PM g/kg	BC g/kg	NO/NOx	BC/PM
Diesel	1990 & older	6	13,427	0.9	15.5	21.6	25.0	2.62	1.33	87%	51%
Diesel	1991-1995	37	15,513	1.0	7.5	23.6	29.7	1.11	0.41	79%	37%
Diesel	1996-2000	173	19,108	0.8	5.8	24.3	29.2	0.70	0.22	83%	32%
Diesel	2001	52	19,591	0.8	4.0	23.8	27.2	0.62	0.21	88%	33%
Diesel	2002	34	18,980	0.9	5.9	20.2	23.7	1.09	0.54	85%	49%
Diesel	2003	47	20,071	0.7	4.8	18.4	21.2	0.94	0.41	87%	43%
Diesel	2004	54	18,787	0.6	7.4	17.8	19.9	0.71	0.32	89%	45%
Diesel	2005	76	20,275	0.4	4.2	15.5	18.3	0.58	0.29	85%	50%
Diesel	2006	83	19,937	0.4	3.1	17.3	19.8	0.55	0.27	87%	50%
Diesel	2007	130	19,752	0.4	3.5	17.6	20.1	0.50	0.23	88%	47%
Diesel	2008	50	18,399	0.2	2.4	9.3	15.1	0.06	0.03	61%	50%
Diesel	2009	54	18,964	0.3	2.3	8.1	12.8	0.08	0.02	64%	31%
Diesel	2010	22	19,392	0.2	1.8	9.0	15.2	0.02	0.01	59%	50%
Diesel	2011	45	21,842	0.2	1.3	4.4	5.3	0.08	0.03	82%	39%
Diesel	2012	44	20,514	1.0	0.4	2.9	3.6	0.07	0.04	79%	48%
Diesel	2013	16	22,906	0.1	0.7	2.8	2.7	0.01	0.01	101%	62%
Subtotal Diesel		923	19,467	0.6	4.1	16.6	20.0	0.54	0.23	82%	42%
Non-diesel	1990 & older	1	9,888	1.0	6.8	16.7	19.1	5.67	1.54	87%	27%
Non-diesel	1996-2000	1	17,463	0.6	4.9	46.1	55.0	0.08	0.04	84%	45%
Non-diesel	2005	1	19,958	0.4	4.3	17.0	18.3	0.69	0.36	93%	53%
Non-diesel	2008	1	14,560	0.0	0.1	6.4	17.3	0.00	0.00	37%	3%
Non-diesel	2009	1	28,803	0.3	0.6	16.9	19.5	0.01	0.00	87%	0%
Non-diesel	2011	1	13,320	23.9	0.0	0.0	0.3	0.01	0.00	0%	23%
Subtotal Non-Diesel		6	17,332	4.4	2.8	17.2	21.6	1.08	0.32	65%	25%
Total		929	19,453	0.6	4.1	16.6	20.0	0.55	0.23	82%	42%

Figure V-2 and V-3 compare RSD and Tunnel average emissions by model year for diesel HDVs. This comparison used all valid RSD measurements from all sites having VSP greater than 2 kW/t.

In Figure V-2, the RSD PM values were typically about 0.4 g/kg higher than the Tunnel value. Both sets of measurements show that reduction in PM between the 2007 and 2008 models but in the case of the Tunnel the average emissions of 2008 to 2012 models were much closer to zero with an average of 0.06 g/kg. The average PM emissions measured by the Tunnel fairly closely tracked the PM standards. Heavy-duty vehicle PM emissions per unit of fuel were higher at idle than when engines were under load and those measured by RSD were believed to often be operating at a lower average power than those measured through the Tunnel. Vehicle operating mode needs to be carefully considered when screening heavy-duty vehicles using RSD.

Figure V-1: Heavy-duty Vehicle PM Emissions: Tunnel and RSD



In Figure V-2 it can be seen that average Tunnel and RSD emissions were similar. RSD was measuring NO while the Tunnel measured both NO and NO_2. The subset of heavy-duty vehicles measured by both the Tunnel and RSD had slightly lower than average NOx emissions.

Newer vehicles may have emissions control technology that can affect NO/NO_x ratios. Control systems may include diesel oxidation catalysts (DOCs) that reduce PM emissions, diesel particulate filters (DPFs), Lean NO_x Catalysts (LNCs) and selective Catalytic Reduction (SCR). These technologies are described in detail on the EPA website: at: http://www.epa.gov/cleandiesel/technologies/retrofits.htm.

Lean NO_x Catalysts (LNC) use diesel fuel injected into the exhaust stream to create a catalytic reaction and reduce pollution. LNCs are paired with either a DPF or a DOC.

SCR is a method of converting harmful diesel oxides of nitrogen (NO_x) emissions, by catalytic reaction, into benign nitrogen gas and water. SCRs can deliver near-zero emissions of NO_x.

We have not yet identified a good source of data on the penetration of these newer emissions control technologies in the heavy-duty diesel fleet. A database with information on the emissions control systems installed on each registered HDV would be a very useful tool to help manage and monitor heavy-duty emissions reductions. This information could be collected during CVSE inspections and added to the CVSE inspection database.

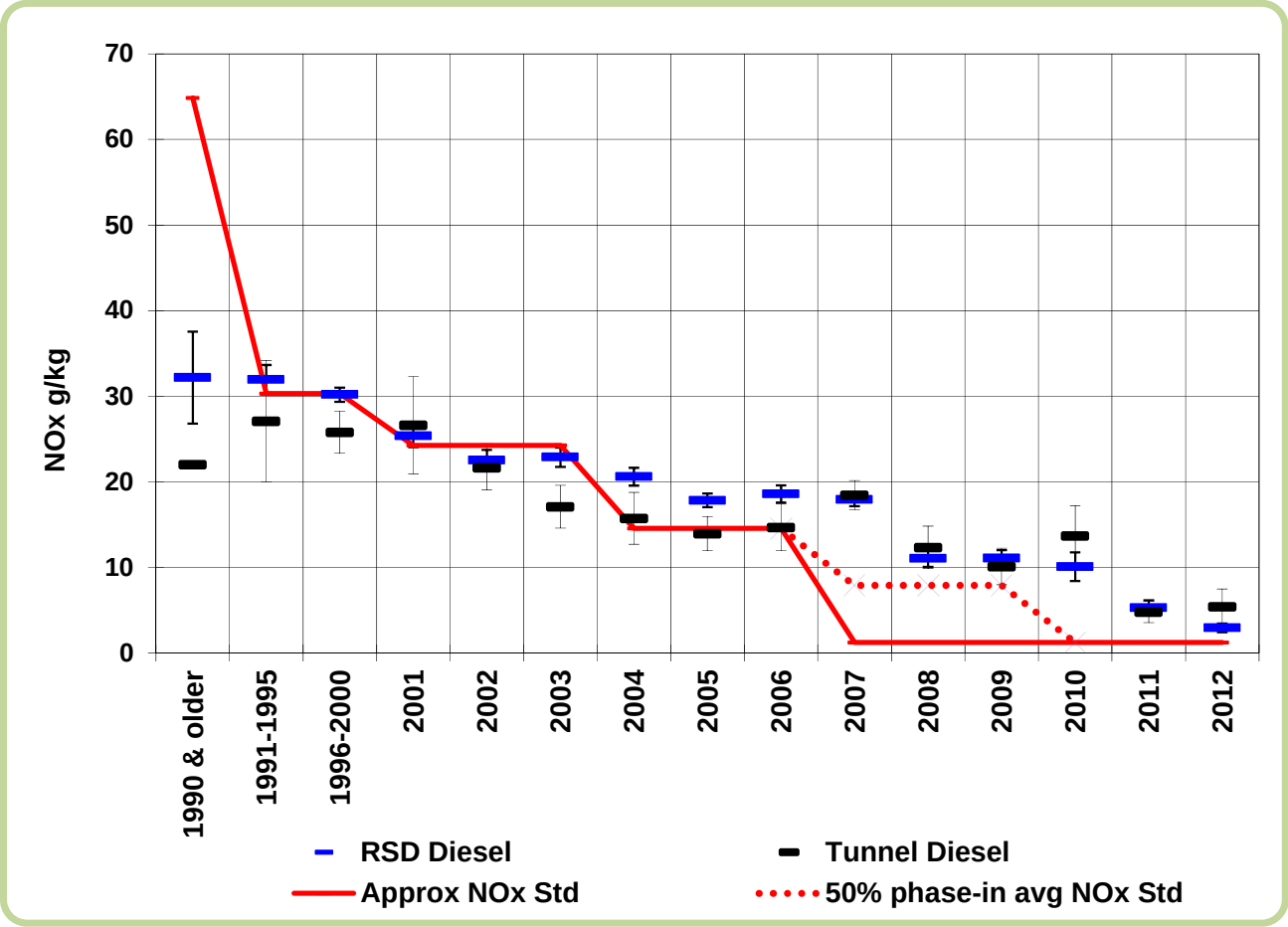
2008 to 2010 models had lower NO_x than earlier models but the Tunnel equipment recorded higher total NO_x than RSD. Since these models had low PM, we assume most, if not all, were equipped with DPFs that may have oxidized some NO to NO_2. In table V-1, the NO/NO_x percentages were lower for these models.

Both RSD and Tunnel reported emissions values for 2007 to 2010 models were higher than the average 50% NO_x phase-in certification standard, which leads one to suspect many of these vehicles may be operating with higher NO_x emissions than intended. However, the details of the implementation of the 50% phase-in are unknown and it would require knowledge of the certification standards of each individual vehicle to be definitive.

It should be also be noted that the certification dynamometer driving cycle is quite different than the snapshot RSD and 8-second Tunnel measurements.

Both the Tunnel and RSD recorded much lower NO and NO_x for 2011 and 2012 models. These models were likely equipped with SCR.

Figure V-2: Tunnel and RSD Heavy-duty Vehicle NO_x Emissions



Vehicles were grouped by fuel, weight and model year. Vehicles within each group were rank ordered by emissions and divided into ten bins. Figures V-3 through V-9 illustrate the average emissions of the bins for PM, BC, CO, NOx, NO2 and HC.

Almost all 2008 and newer models had low PM emissions. The distributions of BC and CO emissions look similar to that of PM.

NO_x emissions were lowest for the majority of 2011 and 2012 models, increased with age from 2010 to 2008 models and were higher for 2007 and older models. The distribution is very similar to the RSD NO distribution (Figure IV-24).

NO_2 emissions were highest among the 2008-2010 models and, as noted above, we speculate these use emissions controls that were oxidizing NO to NO_2 in the exhaust system. Total NO_x was higher for some of these vehicles than for earlier models.

Figure V-3: Heavy-duty Tunnel Vehicle PM Deciles

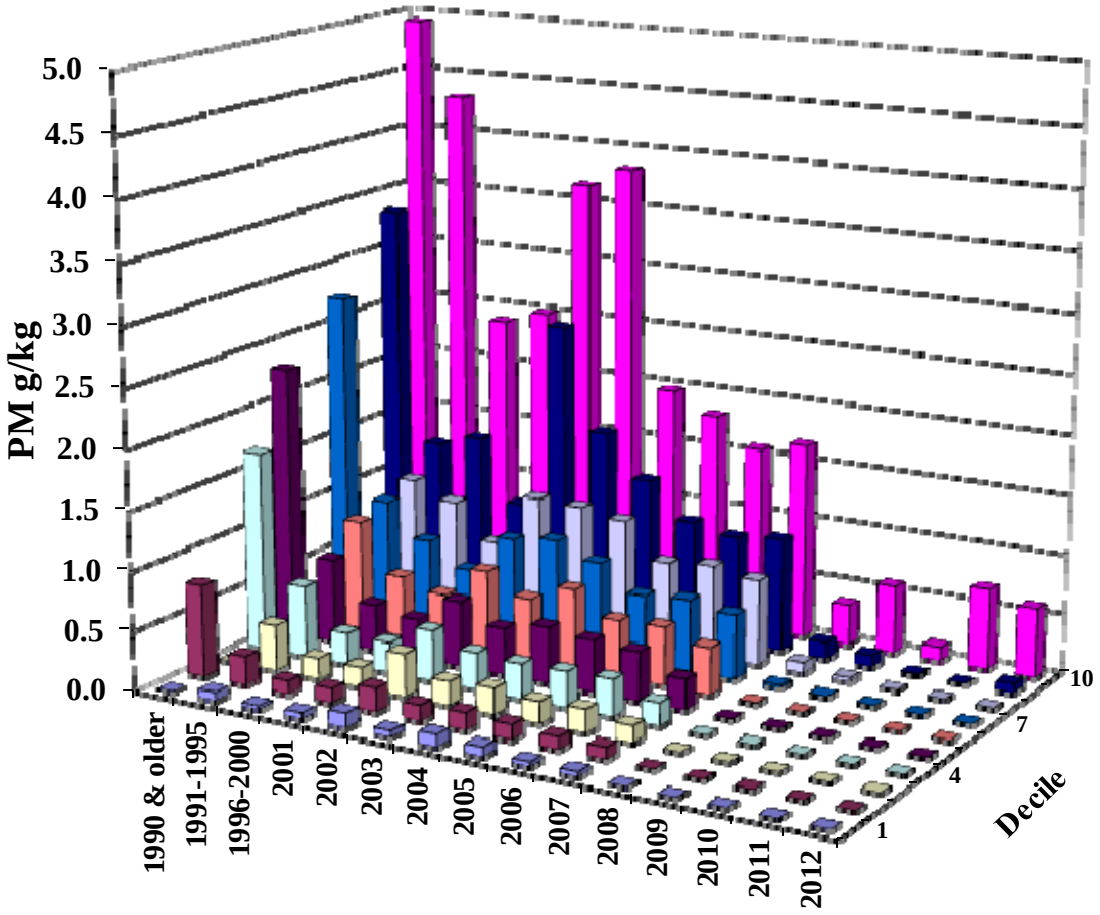


Figure V-4: Heavy-duty Tunnel Vehicle Black Carbon Deciles

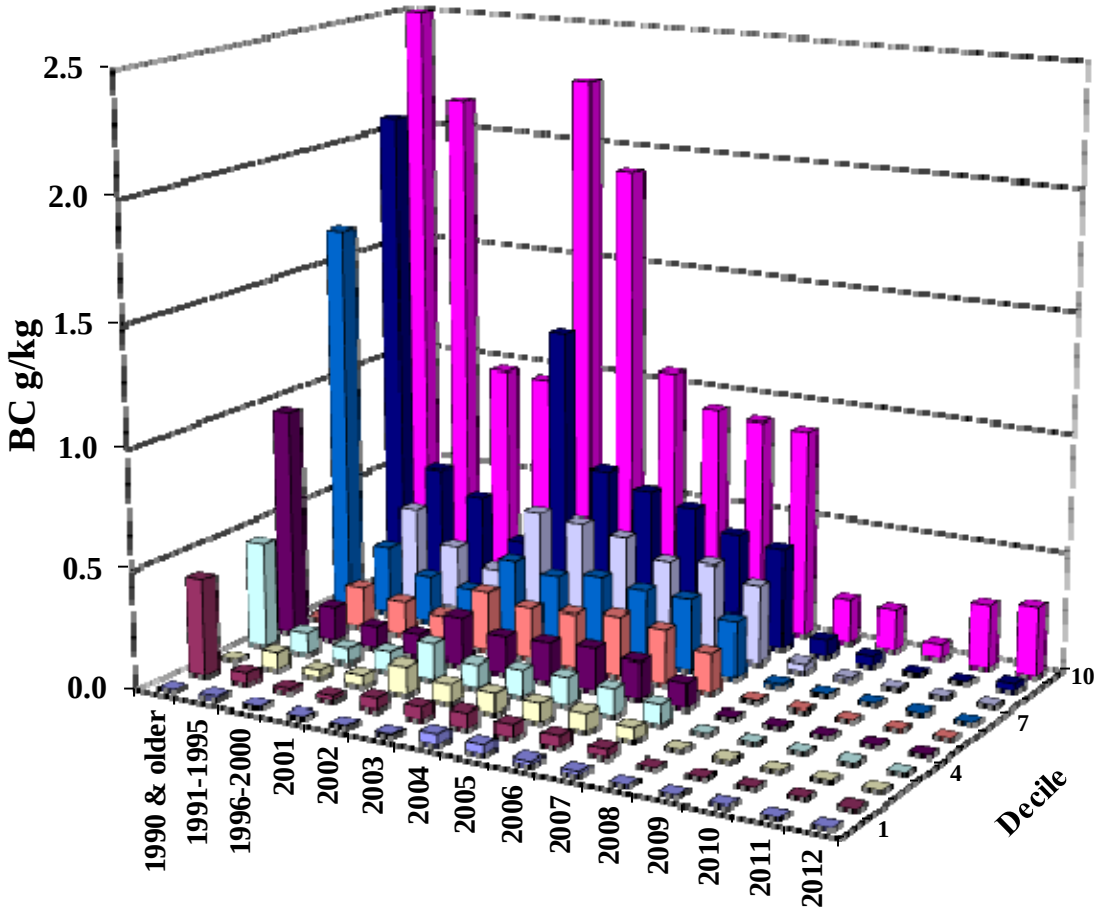


Figure V-5: Heavy-duty Tunnel Vehicle CO Deciles

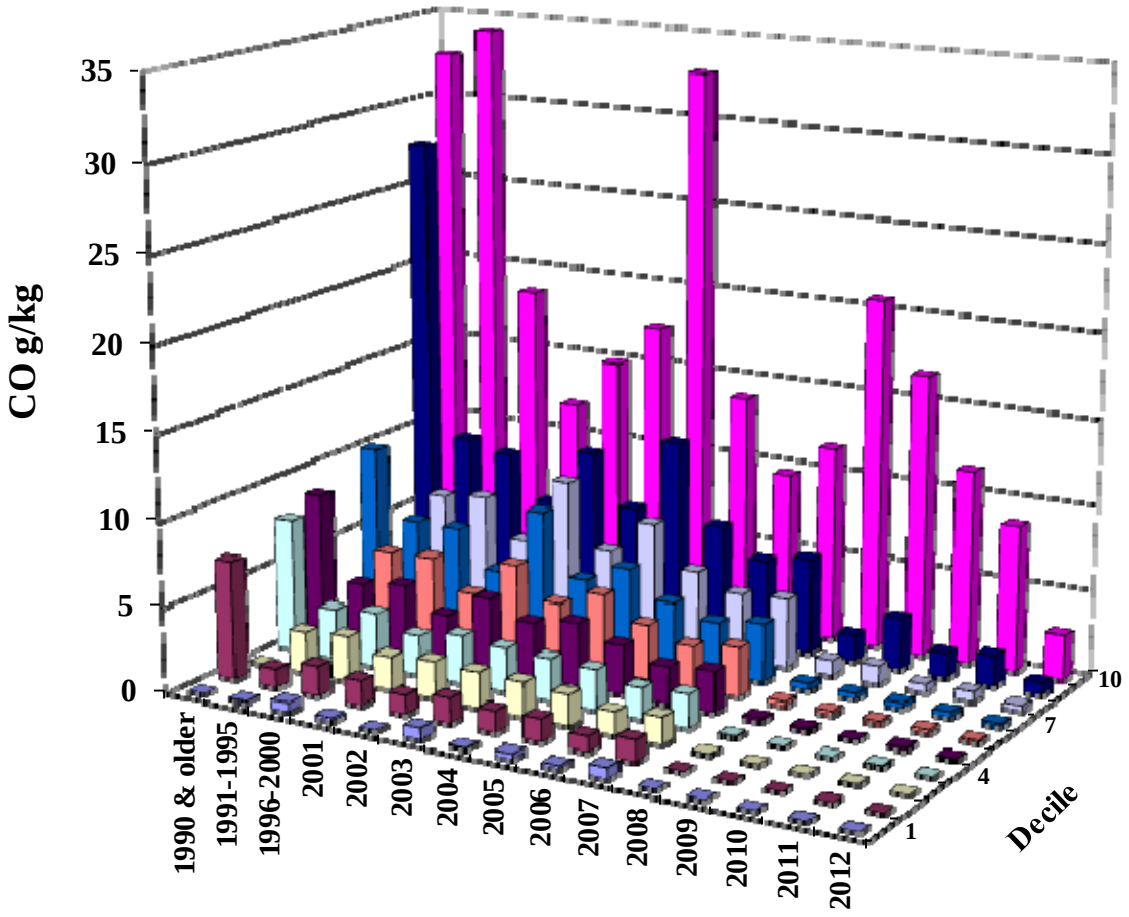


Figure V-6: Heavy-duty Tunnel Vehicle NOx Deciles

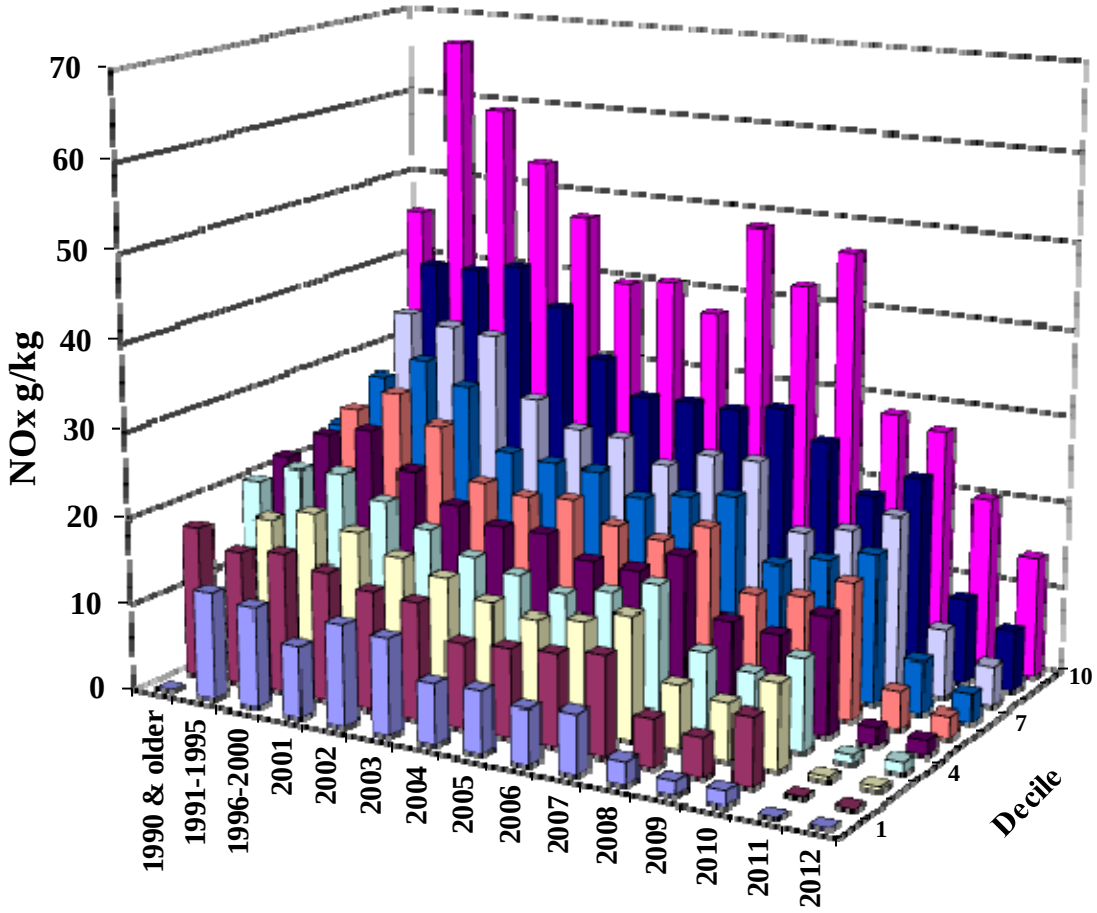


Figure V-7: Heavy-duty Tunnel Vehicle NO2 Deciles

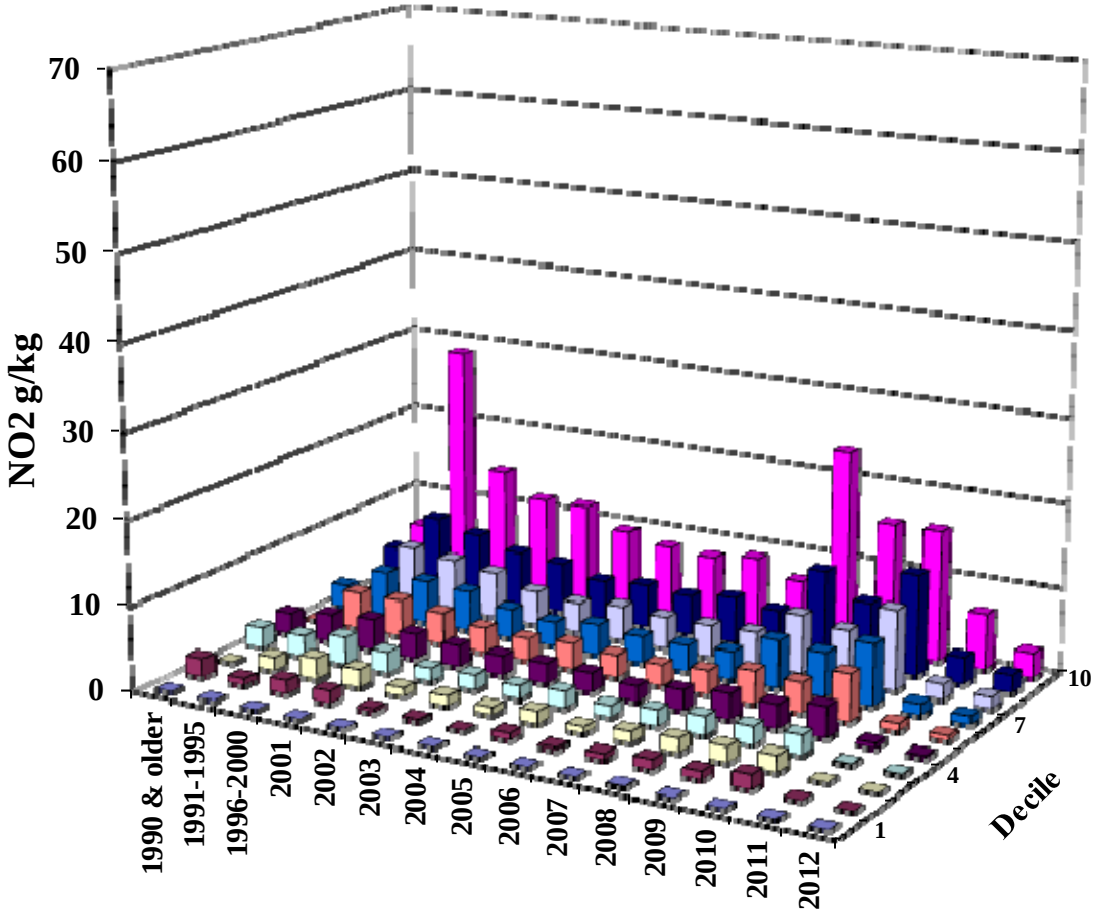


Figure V-8: Heavy-duty Tunnel Vehicle NO Deciles

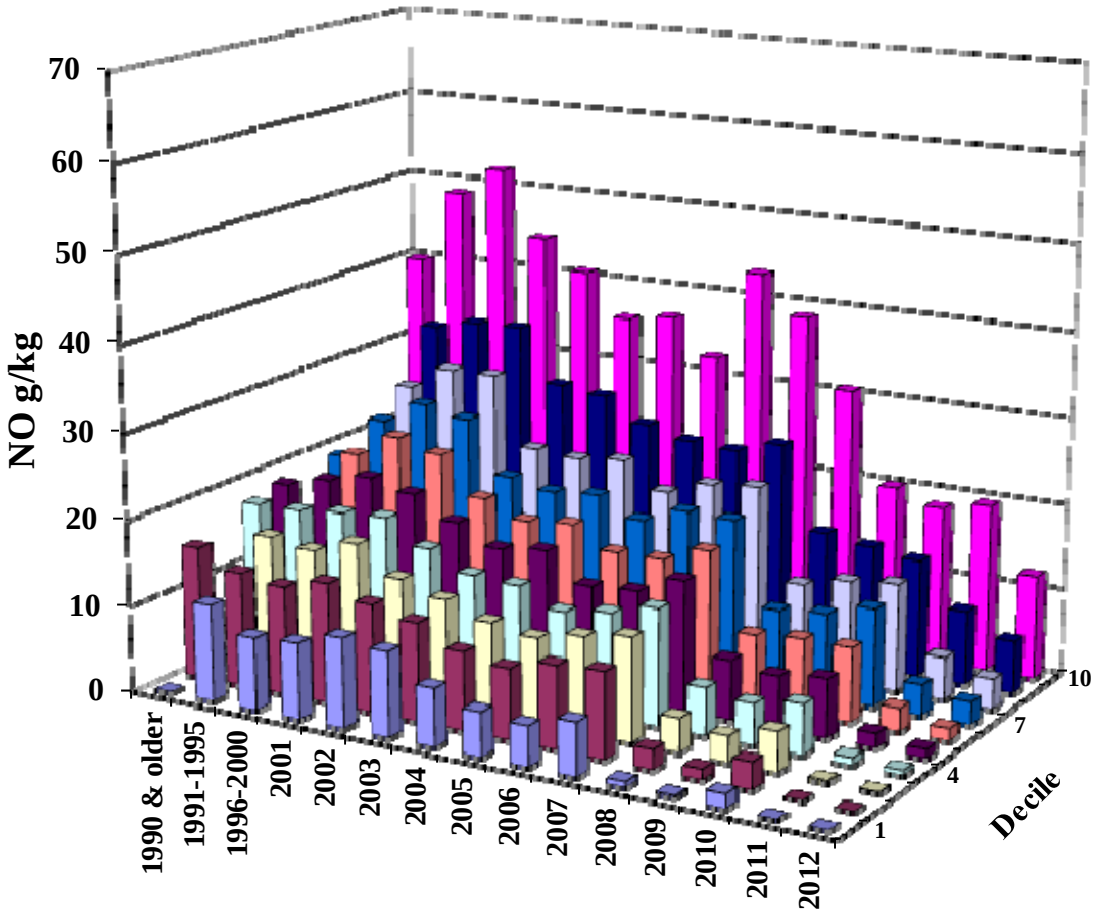
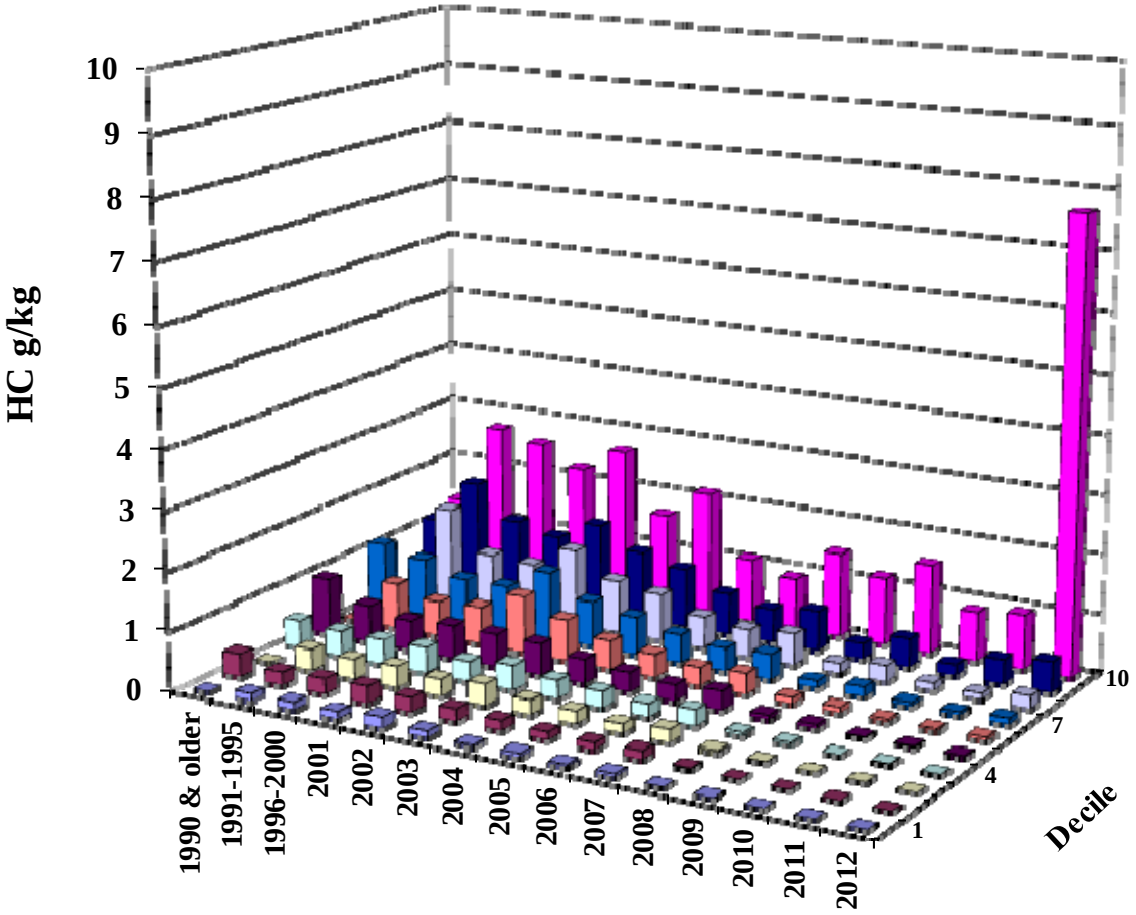


Figure V-9: Heavy-duty Tunnel Vehicle HC Deciles



The high 2012 HC g/kg decile value resulted from a 2012 Peterbilt class 8 tractor with fuel type of R (Diesel-Natural Gas) emitting 18 g/kg HC, 4 g/kg CO, 4 g/kg NOx and 0 g/kg PM.

VI Emissions Contributions

Remote sensing of light vehicles across a representative sample of sites provides data that can be used to estimate the activity of different types and models of vehicle. The activity profile when combined with vehicle emissions can be used to generate a detailed model of the composition and emissions contribution of the active on-road fleet.

With HDVs this is a more challenging task. The study data have provided information about the types and age of HDVs observed at different locations, e.g. weigh stations, bus terminals and selected on-road locations. However because specialist sites were selected to obtain a high concentrations of HDVs, the observation counts of different types of vehicle are unlikely to be representative of total HDV activity.

Given that emissions were fairly homogeneous among different weight classes and body styles and the major differences related to age and emissions control technologies, it is possible to approximately estimate the relative emissions contributions from each age group.

NO/NOx and PM emission averages are shown by age group in Table VI-1 for both the RSD and the Tunnel. For light-duty vehicles, the number of observations of vehicles within age groups is typically proportional to the kilometers driven. If this were to hold true for heavy-duty vehicles, the relative proportions of NOx and PM emissions are shown in Table VI-2, which summarizes by four vehicle age groups the projected percentage of observations of vehicles and the percentage of total NOx and PM emitted by each group. Seventy-six percent of heavy-duty vehicles observed were 2007 & models. These emitted 90% of NOx and up to 98% of PM.

Table VI-1: Observations and Average Emissions by Vehicle Age Group

Model Year	Observations	RSD NO g/kg	Tunnel NOx g/kg	NOx Variance (RSD-Tunnel)	RSD PM g/kg	Tunnel PM g/kg	PM Variance (RSD-Tunnel)
2000 & older	6,989	30.5	29.3	1.1	1.2	0.8	0.4
2001-2007	12,768	19.9	20.9	-1.0	1.1	0.6	0.5
2008-2010	3,079	10.9	14.2	-3.3	0.5	0.1	0.4
2011 & newer	2,969	3.6	4.2	-0.6	0.5	0.1	0.4
Total	**25,805**	**19.8**	**20.5**	**-0.6**	**1.0**	**0.6**	**0.4**

Table VI-2: Percentage of Observations and Emissions by Vehicle Age Group

Heavy-duty Model Year	% of Observations	% of RSD NO	% of Tunnel NOx	% of RSD PM	% of Tunnel PM
2000 & older	27%	42%	39%	34%	41%
2001-2007	49%	50%	51%	55%	57%
2008-2010	12%	7%	8%	6%	1%
2011 & newer	12%	2%	2%	5%	1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

To obtain better estimates of HDV activity the odometer data for BC registered vehicles collected by the commercial vehicle safety inspection program since 2009 can be analyzed to estimate the annual km driven by each vehicle.

If the agency is able to provide fuel economy estimates and vehicle kilometers travelled (VKMT) or heavy-duty fuel sales, it will be possible to develop an approximate estimate of the emissions inventory using either or both of two methods:

1) Annual emissions tonnes = emissions g/kg x kg fuel/km x annual million VKMT
2) Annual emissions tonnes = fleet composite g/kg x kg fuel sales

The first method can provide estimates by vehicle class or other subgroups provided estimates of fuel economy and VKMT are available for each class or group of vehicles.

The second method using fuel sales can provide an independent verification of the total emissions if a reasonable assessment of fleet composite g/kg emissions can be obtained by weighting emissions measurements by registrations and estimated VKMT.

Emissions vs. VSP and the operating cycles of the HDV vehicles must also be factored into the estimates of emissions tonnes.

VII High Emitters and Impacts of Different Program / Policy Options

This section of the report provides information to help design effective programs to target the highest emitting engines. It helps to answer questions such as:

- How many vehicles would be affected by programs established at varying levels of stringency (e.g., opacity limits)?
- What would be the estimated air quality benefit?

Envirotest selected alternative sets of trial RSD high emitter cutpoints that have been applied to the emissions database to identify:

- The number and percentage of high emitters;
- The fraction of total emissions coming from high emitters;
- Estimated or assumed after repair emissions;
- Potential percentage emission reductions.

VII-1 Conservative High Emitter Cutpoints

Using the emissions distributions discussed in Section IV, Envirotest selected the trial RSD high emitter cutpoints shown in Table VII-1 as simple and conservative cutpoints. Only two sets of NO and PM cutpoints were used, one for 2007 and older models and one for 2008 and newer models. These cutpoints were intended to identify the worst emitters that could be targeted for mandatory or incentive based repair, replacement or retrofit.

As noted in Section II, the engine emissions standards for 2008 and newer vehicles are 0.2 g/bhp-hr NO_x, 0.01 g/bhp-hr for PM and 0.14 g/bhp-hr MNHC. The trial cutpoints of 24 g/kg (4 g/bhp-hr) NO and 2.4 g/kg (0.4 g/bhp-hr) PM far exceed the standards for these vehicles.

The situation for 2007 and older models is more complicated. US heavy-duty standards ranged from 10.7 g/bhp-hr for 1988/1989 engines to 4.0 g/bhp-hr for 1998-2003 models. Therefore the cutpoint 45 (7.5 g/bhp-hr) NO is restrictive for 1988/1989 engines and 25% to 87% above the standard for the 1991-2006 engines. The 3.6 g/kg (0.6 g/bhp-hr) cutpoint is the same as the standard for 1988-1990 models and six times the 0.1 g/bhp-hr standard for 1994-2006 models.

Vehicles with a single measurement were classified as high emitters if either NO or PM exceeded the cutpoint. Vehicles with multiple measurements were classified as high emitters if either NO or PM exceeded the cutpoint on more than 50% of measurements; e.g. vehicles with two measurements had to exceed the

cutpoint for a specific pollutant on both measurements, vehicles with three measurements had to exceed the cutpoint on two out of the three measurements, etc.

Table VII-1 Conservative Trial High Emitter Cutpoints

Trial	Model Year Low	Model Year High	NO g/kg Cutpoint	PM g/kg Cutpoint
A	1900	1997	45	3.6
A	1998	2007	45	3.6
A	2008	2010	24	2.4
A	2011	2012	24	2.4

Figure VII-1 shows the number of high emitters by model year and (on the right y-axis) the percentages of each model year that were classified as high emitters. The break between 2007 and 2008 models indicates the change in cutpoints applied.

Table VII-2 also shows the fraction of the total emissions coming from high emitters. Eight percent of vehicles measured were classified as high emitters and these vehicles emitted 16% of total PM and 17% of total NO.

Table VII-3 estimates potential emissions reductions of 9% PM and 9% NO.

Figure VII-1: Heavy-duty High Emitters

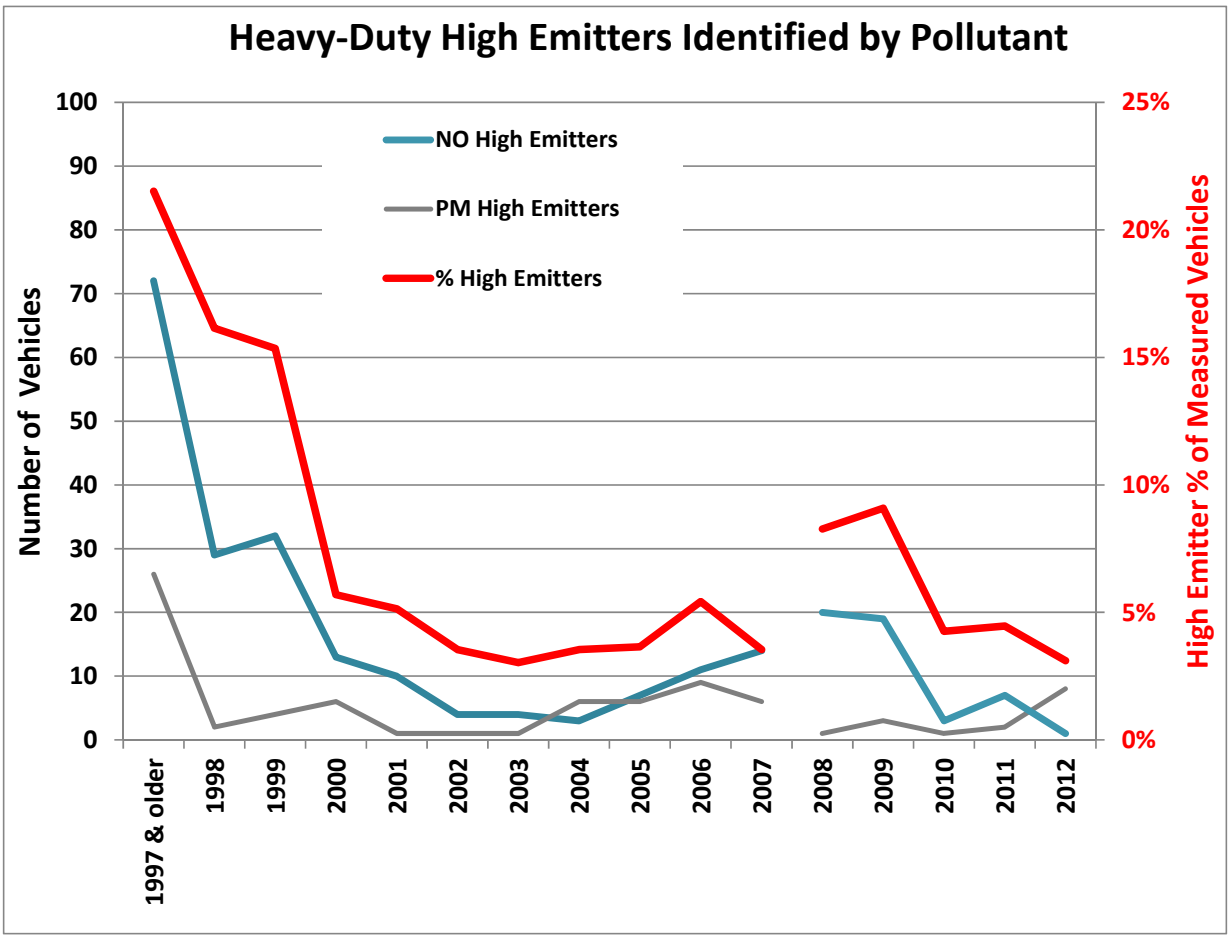
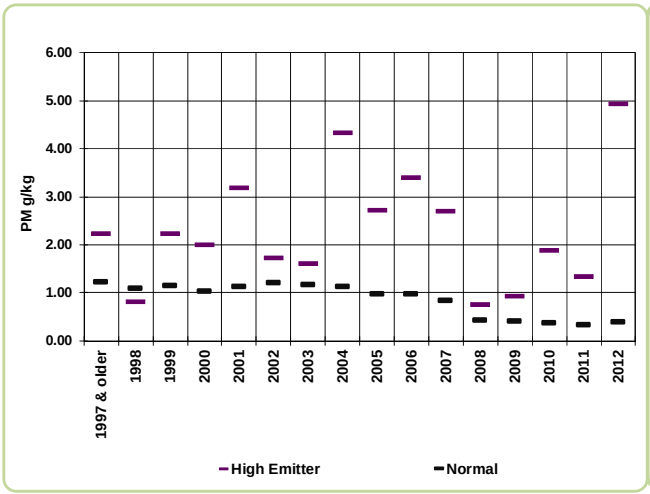


Figure VII-2: Conservative Trial Normal and High Emitter Average PM and NO



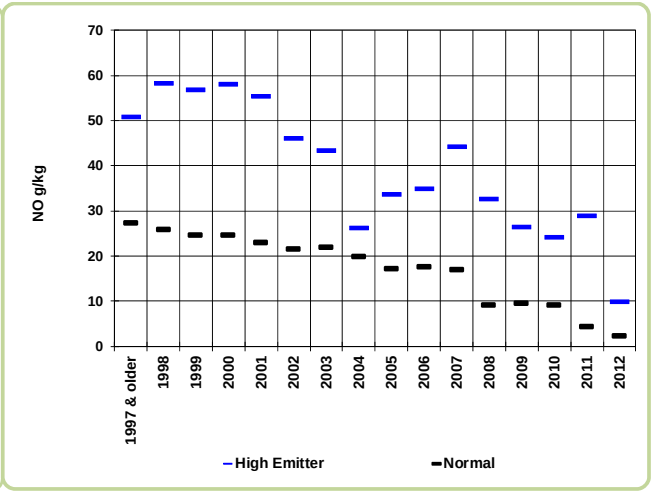


Table VII-2 Conservative Trial High Emitter Results

Model Year	Heav-duty Vehicles			Sum of Vehicle Emissions g/kg					
	All Vehicles	High Emitters	% High Emitters	All PM	High Emitter PM	High Emitter %	All NO	High Emitter NO	High Emitter %
1997 & older	423	91	22%	615	203	33%	13751	4630	34%
1998	192	31	16%	202	25	12%	6004	1808	30%
1999	228	35	15%	304	78	26%	6756	1985	29%
2000	281	16	6%	311	32	10%	7468	928	12%
2001	214	11	5%	266	35	13%	5297	609	11%
2002	141	5	4%	176	9	5%	3169	231	7%
2003	165	5	3%	199	8	4%	3745	217	6%
2004	254	9	4%	318	39	12%	5148	236	5%
2005	356	13	4%	375	35	9%	6400	438	7%
2006	369	20	5%	415	68	16%	6920	699	10%
2007	564	20	4%	522	54	10%	10235	883	9%
2008	254	21	8%	120	16	13%	2831	687	24%
2009	242	22	9%	113	21	18%	2696	581	22%
2010	94	4	4%	41	8	18%	928	96	10%
2011	179	8	4%	70	11	15%	1006	230	23%
2012	290	9	3%	157	44	28%	789	89	11%
Total	**4246**	**320**	**8%**	**4202**	**685**	**16%**	**83143**	**14347**	**17%**

Table VII-3 Conservative Trial Emissions Reductions

Model Year	Sum of Vehicle Emissions g/kg					
	Initial PM	PM After Repair	% Reduction	Initial NO	NO After Repair	% Reduction
1997 & older	615	525	15%	13751	11620	15%
1998	202	211	-4%	6004	5003	17%
1999	304	266	12%	6756	5637	17%
2000	311	296	5%	7468	6934	7%
2001	266	243	8%	5297	4943	7%
2002	176	173	1%	3169	3046	4%
2003	199	196	1%	3745	3638	3%
2004	318	290	9%	5148	5093	1%
2005	375	352	6%	6400	6188	3%
2006	415	366	12%	6920	6577	5%
2007	522	485	7%	10235	9696	5%
2008	120	113	5%	2831	2337	17%
2009	113	101	10%	2696	2327	14%
2010	41	35	15%	928	869	6%
2011	70	62	11%	1006	812	19%
2012	157	116	26%	789	722	8%
Total	**4202**	**3833**	**9%**	**83143**	**75443**	**9%**

VII-1 Standards Based High Emitter Cutpoints

Using the heavy-duty emissions standards discussed in Section II, Envirotest selected the trial RSD high emitter cutpoints shown in Table VII-4. These were intended to be about 1.5X the vehicle standard plus an allowance for RSD variation. However based on results, the cutpoints were relaxed for 2004-2007 vehicles and 2007 models were included with the 2004-2006 models rather than with 2008 and newer models. These cutpoints were intended to identify the high emitters that could be targeted over time for mandatory or incentive based repair, replacement or retrofit. Cutpoints in g/kg can be divided by 6 to convert to g/bhp-hr.

As before, vehicles with a single measurement were classified as high emitters if either NO_x or PM exceeded the cutpoint. Vehicles with multiple measurements were classified as high emitters if either NO_x or PM exceeded the cutpoint on more than 50% of measurements; e.g. vehicles with two measurements had to exceed the cutpoint for a specific pollutant on both measurements, vehicles with three measurements had to exceed the cutpoint on two out of the three measurements, etc.

Table VII-4 Standards Based Trial High Emitter Cutpoints

Trial	Model Year Low	Model Year High	NO g/kg Cutpoint	PM g/kg Cutpoint
B	1900	1990	90	6
B	1991	1997	45	2.4
B	1998	2003	36	1.8
B	2004	2007	30	1.5
B	2008	2099	12	0.9

Figure VII-3 shows the number of high emitters by model year and (on the right y-axis) the percentages of each model year that were classified as high emitters. The chart lines were broken between the 2007 and 2008 models to mark the significant change in cutpoint

Table VII-5 shows the fraction of the total emissions coming from high emitters. Twenty-six percent of vehicles measured were classified as high emitters and these vehicles emitted 42% of total PM and 38% of total NO.

If the high emitting vehicles were repaired to the average emissions level for the model year, PM and NO emissions would be reduced by 23% and 16% (Table VII-6).

Figure VII-3: Standards Based Trial Heavy-duty High Emitters

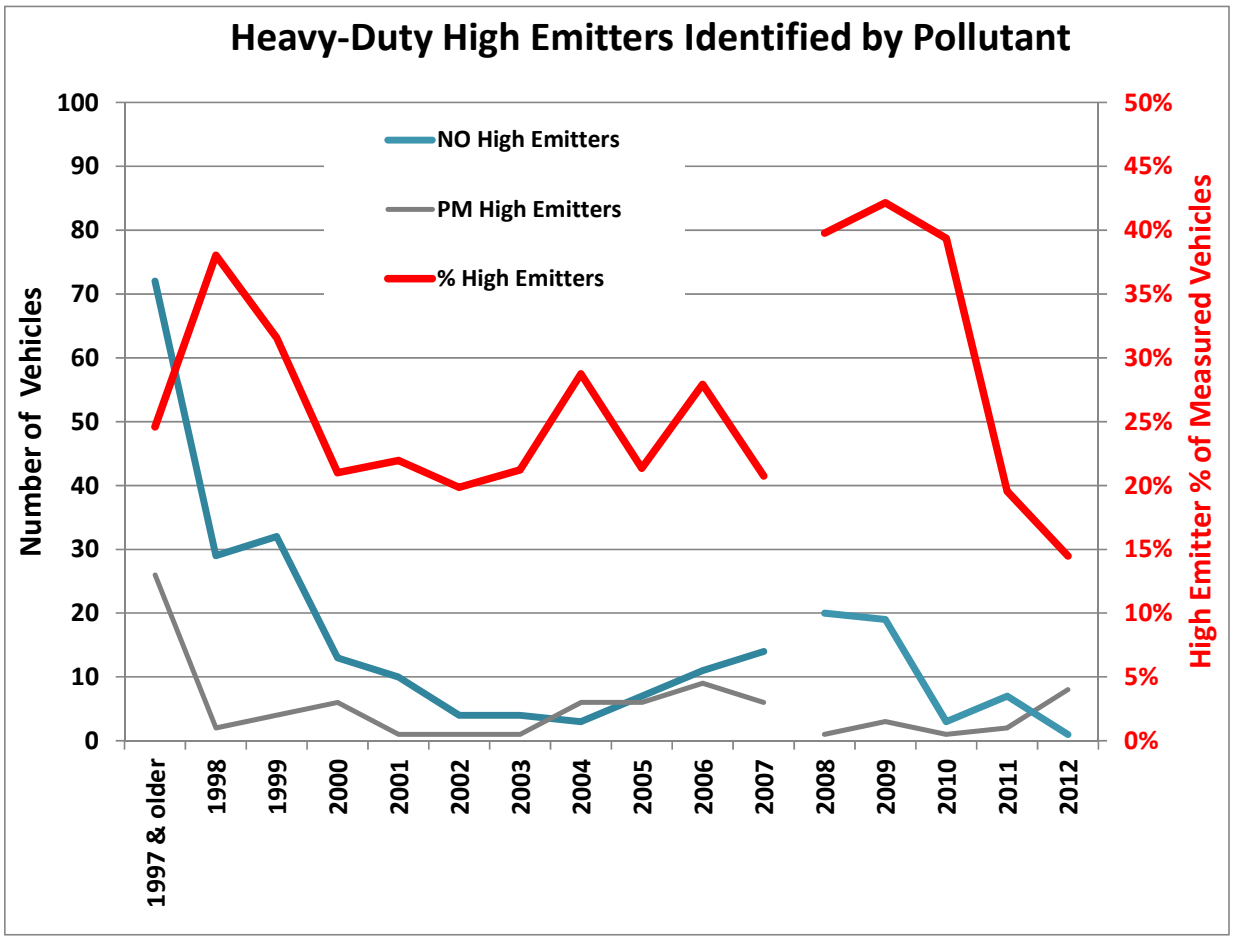
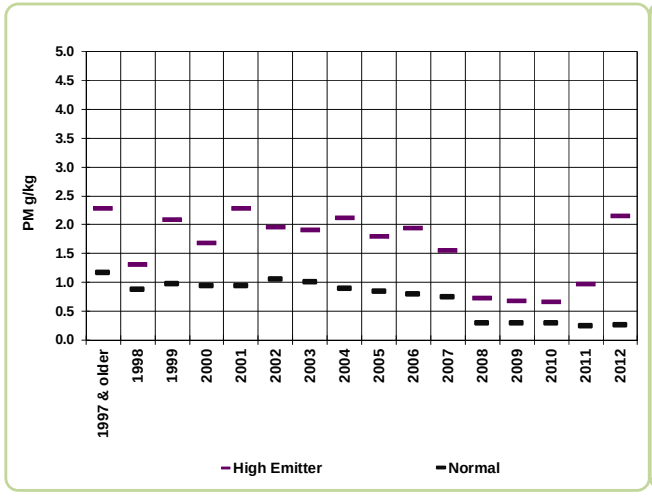


Figure VII-4: Standards Based Trial Normal and High Emitter Average PM and NO



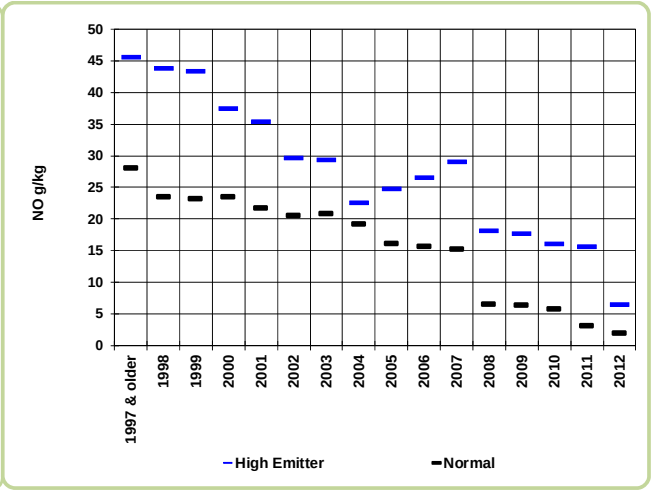


Table VII-5 Standards Based Trial High Emitter Results

Model Year	Heav-duty Vehicles			Sum of Vehicle Emissions g/kg					
	All Vehicles	High Emitters	% High Emitters	All PM	High Emitter PM	High Emitter %	All NO	High Emitter NO	High Emitter %
1997 & older	423	104	25%	615	237	39%	13751	4743	34%
1998	192	73	38%	202	96	47%	6004	3201	53%
1999	228	72	32%	304	150	49%	6756	3125	46%
2000	281	59	21%	311	99	32%	7468	2215	30%
2001	214	47	22%	266	107	40%	5297	1662	31%
2002	141	28	20%	176	55	31%	3169	829	26%
2003	165	35	21%	199	67	34%	3745	1025	27%
2004	254	73	29%	318	154	48%	5148	1641	32%
2005	356	76	21%	375	137	36%	6400	1879	29%
2006	369	103	28%	415	199	48%	6920	2731	39%
2007	564	117	21%	522	181	35%	10235	3392	33%
2008	254	101	40%	120	74	62%	2831	1824	64%
2009	242	102	42%	113	69	61%	2696	1801	67%
2010	94	37	39%	41	24	59%	928	595	64%
2011	179	35	20%	70	34	49%	1006	545	54%
2012	290	42	14%	157	91	58%	789	272	34%
Total	**4246**	**1104**	**26%**	**4202**	**1774**	**42%**	**83143**	**31479**	**38%**

Table VII-6 Standards Based Trial Emissions Reductions

Model Year	Sum of Vehicle Emissions g/kg					
	Initial PM	PM After Repair	% Reduction	Initial NO	NO After Repair	% Reduction
1997 & older	615	501	19%	13751	11945	13%
1998	202	172	15%	6004	4522	25%
1999	304	224	26%	6756	5308	21%
2000	311	268	14%	7468	6649	11%
2001	266	204	23%	5297	4658	12%
2002	176	151	14%	3169	2920	8%
2003	199	167	16%	3745	3452	8%
2004	318	231	28%	5148	4921	4%
2005	375	303	19%	6400	5749	10%
2006	415	299	28%	6920	5811	16%
2007	522	430	18%	10235	8635	16%
2008	120	76	36%	2831	1671	41%
2009	113	75	33%	2696	1546	43%
2010	41	28	32%	928	550	41%
2011	70	45	36%	1006	574	43%
2012	157	77	51%	789	604	23%
Total	**4202**	**3250**	**23%**	**83143**	**69514**	**16%**

VIII Feasibility of Integrating RSD into Program Options

VIII-1 Existing Heavy-Duty Emissions Inspection Programs

Heavy-duty vehicle inspection programs exist in several major metropolitan areas in Canada and the United States (US)[xii]. These typically test for opacity only using the "Snap Acceleration Smoke Test Procedure for Heavy-Duty Diesel-powered Vehicles" (SAE J1667)" and may use decentralized facilities or fleet self-testing in combination with limited roadside programs and other audit/enforcement elements.

Canada does little at the federal level with regard to in-use vehicle emissions enforcement because federal jurisdiction stops at the point of first retail sale. Thus, it is up to the provinces to deal with in-use trucks. As of September 30, 1999, all diesel trucks and buses in Ontario more than three model years old with registered gross weights over 4,500 kg, are required to pass an annual emissions test. All resale trucks and buses, no matter how old they are, are required to pass an emissions test before they can be licensed for the road under new ownership. Diesel vehicles are tested using the same snap acceleration test noted above. Non-diesel powered vehicles undergo a two-speed idle test where hydrocarbon and carbon monoxide emissions are measured at two pre-determined RPM settings. There are approximately 200,000 heavy-duty trucks and buses licensed for on-road use in Ontario.

Quebec operates an on-road pullover inspection program using an opacity snap acceleration test.

In British Columbia, the AirCare On-Road (ACOR) program[xiii] tests a small number of trucks each year using the snap acceleration test. Port Metro Vancouver (PMV) licenses trucks using the port. New trucks into the system have to be 2007 or newer, and older existing trucks have to be retrofitted with emission reduction measures. Pre-2007 trucks over ten years old are required to pass a 20% opacity test standard[xiv].

Limitations of the current snap acceleration test include: insensitivity to fine PM generated by modern diesel engine systems, standards that are very loose compared to modern truck standards, measurement during unloaded engine operation rather than under load, and no evaluation of NO_x emissions. Tuning for PM by making the fuel-air mixture leaner can increase NO_x emissions. Therefore, an inspection program that controls for opacity but not for NO_x may raise NO_x levels.

In addition to inspections, the USA has made a major investment to both modernize and retrofit HDVs to reduce their emissions. This approach recognized that emissions from older HDVs cannot otherwise be adequately controlled. Billions of public dollars were committed to upgrade diesel trucks and buses through retrofits and replacements, including $200 million dollars of Federal funds through the Diesel Emissions

Reduction Act (DERA) and an increasing portion of the $8.6bn allocated from 2005-2009 to the Congestion Mitigation and Air Quality Improvement Program (CMAQ) .

In 2004, CARB adopted a regulation requiring diagnostic systems on all 2007 and subsequent model year heavy-duty engines and vehicles (i.e., vehicles with a gross vehicle weight rating greater than 14,000 lbs.) in California. USEPA and CARB subsequently adopted a comprehensive OBD regulation for 2010 and subsequent model year HDVs. All major emissions control systems were required to be monitored and malfunctions detected prior to emissions exceeding a set of emissions thresholds. Most notably, aftertreatment devices— e.g., the diesel particulate filters and NO_x reducing catalysts—used on highway diesel engines must be monitored and their failure detected and noted to the driver. All emission-related electronic sensors and actuators were required to be monitored for proper operation. In October 2011 similar Canadian regulatory amendments for heavy-duty OBD were proposed. The proposed Amendments only apply to heavy-duty engines of the 2013 and later model years.

Such investments in diesel vehicle retrofits and modernization should be monitored to ensure the equipment is being adequately maintained.

VIII-2 RSD and Tunnel Performance

The information gathered in the study indicates that both the RSD and the Tunnel are effective tools for identifying the highest and the lowest emitting vehicles. By comparing the data from both methods, RSD indicated a higher level of PM than the same vehicle showed when it went through the tunnel but other measurements were more closely aligned. It is important to note, however, that the same trends applied with both testing techniques on all measures as illustrated by Figures in section V and Figures IV-23, IV-24.

The tunnel test results appeared to be excellent. The accuracy, the ability to measure more emissions parameters and the ability to perform testing in the rain makes it a very promising technology for the region. In addition, the control over the test process is reasonably high. If the truck doesn't accelerate properly through the test, the inspector could require it to go through again thus allowing one reading to be used as the screen. We believe the Tunnel technique could be used to cost effectively and conveniently test or screen the heavy-duty fleet.

Because the tunnel operation would require some operator interaction with the truck driver, it could be limited to testing BC registered trucks. If desired ACOR/CVSE teams could direct non-BC trucks to obtain a Tunnel measurement. The general population of trucks could also be monitored by RSD.

VIII-3 Other Considerations

Although the weather in the summer of 2012 during the RSD study was outstanding (record-breaking dry weather) and it enabled a concentration of effort during the time available for the study, it is understood

this cannot always be expected. The ability to perform testing in the rain makes the Tunnel a very promising technology for the region.

One issue with the measurements completed in the study was the lower than expected traffic counts at sites. It was perhaps underestimated just how effective the truck driver's communications network is and how much they would consciously avoid the testing locations. This behavior was confirmed by the Commercial Vehicle Safety and Enforcement (CVSE) who stated that when they performed surprise roadside safety inspections, a similar scenario exists and the number of trucks observed dropped dramatically and almost instantly. Therefore, any screening or testing program would be most effective if it were part of a mandatory program that required vehicles to be screened or tested annually.

We have not investigated what legal authority, legislation or regulations would be required to authorize and implement a mandatory heavy-duty inspection program.

VIII-4 Tunnel Application

The quick, drive-through nature of the Tunnel test would be many times more convenient than a requirement for testing at a traditional inspection station. During the 55 days of on-road testing 17% of the class 8 trucks registered in ICBC areas D, E and H were measured. A large number of the vehicles also had repeat measurements indicating that drivers who had "nothing to lose" (like fleet drivers) would not hesitate to go through the RSD or Tunnel.

Tunnel sites could operate 60 hours per week with a throughput capacity of at least 15 trucks per hour or more. Each site would have the theoretical capacity to test or screen 45,000 vehicles annually.

Three tunnels (located on convenient sites in the region) would be sufficient to measure the approximately 50,000 HDVs registered in the Lower Fraser Valley and territory Z annually with a 37% annual utilization. Drive through I/M inspection lanes such as those in AirCare typically operate at 40-60% annual utilization.

VIII-5 RSD Applications

An effective use of RSD would be as a complement to a mandatory testing program. RSD can be used in three applications; clean screening, high emitter identification and on-road fleet monitoring. HDVs observed by RSD as being among the cleanest or having emissions well below the standards would not be required to undergo further testing. In the same way, the highest emitters could be flagged as requiring early testing and recruitment into incentivized repair, retrofit and replacement programs.

Obtaining adequate funding for HDV retrofit and replacement programs is a common challenge. Using activity and emissions data to prioritize the vehicles to be retrofit or replaced should help ensure the most effective use of limited funds available.

Fleet monitoring provides feedback on the effectiveness of the program and the progress made in reducing emissions. Review of the on-road data could also be used to assess the effectiveness of the decentralized facilities certified for testing – if there are any.

Both RSD/Tunnel testing techniques could therefore be combined to provide an effective HDV inspection program that minimizes inconvenience and cost for the trucking community.

VIII-6 Next Steps

Several follow-on activities are suggested.

VIII-6.1 Heavy-Duty Vehicle Emissions Inventory Review and Update

Metro Vancouver previously estimated that 11% of total NOx emissions were from heavy-duty vehicles compared to 24% from light-duty vehicles in 2005[xv]. For greenhouse gases the percentages were 7% from heavy-duty vehicles and 27% for light-duty. The heavy-duty contributions of PM were not separately identified in the report.

By integrating the emission results from this study with mileage data from CVSE, it would be possible to develop a more detailed breakdown of the heavy-duty vehicle emissions inventory and the relative contributions from heavy-duty and light-duty vehicles. This will provide greater perspective on the importance of heavy-duty vehicle emissions.

VIII-6.2 Heavy-duty Repairs and Retrofits

In order to develop a plan for reducing heavy-duty vehicle emissions, and to determine if a cost-effective plan is feasible, we suggest further investigation of the cost effectiveness of alternate approaches to reducing heavy-duty vehicle emissions is performed, e.g. heavy-duty vehicle repairs, retrofit emissions control equipment, replacement engines or replacement vehicles. The goal would be to develop a matrix of the most cost effective approaches for reducing emissions from the in-use heavy-duty vehicle fleet appropriate for the age and original emissions control technologies of the vehicles. This would provide the basis for reviewing existing plans and, perhaps, enhancing plans for dealing with heavy-duty vehicle emissions.

VIII-6.3 Steps Required to Implement a Heavy-Duty I/M Program

The implementation of a heavy-duty program requires considerable planning. We suggest a task force consider what legal authority, regulations, equipment and resources would be needed to implement a heavy-duty I/M program.

References

[i] International Agency for Research on Cancer, World Health Organization, Press Release N° 213, "Diesel Engine Exhaust Carcinogenic" 12 June 2012

[ii] AirCare On-Road: http://www.th.gov.bc.ca/ACOR/index.htm#what

[iii] "Draft Preliminary Analysis of Remote Sensing Device Feasibility in the Greater Vancouver Regional District", Prepared for the AirCare Steering Committee, May 2004

[iv] "The Alberta ROVER II On-road Vehicle Emissions Survey", prepared for Clean Air Strategic Alliance of Alberta, Envirotest, June 2007

[v] "On road Emissions Measurement System (OREMS) Specifications Version O", California Bureau of Automotive Repair, May 2003

[vi] "Measurement and Analysis of Exhaust Emissions from Diesel Trucks Using Remote Sensing Device". Yohei Oya, Annual Meeting of Japan Society for Atmospheric Environment, September 7, 2005 (Nagoya, Japan)

[vii] "Singapore HDV Remote Sensing Pilot", prepared for Singapore National Environment Agency, Envirotest, August 2009

[viii] EPA420-F-05-021 Regulatory Announcement Final Rule on In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles June 2005

[ix] "Cross Border In-Use Emissions Study For Heavy Duty Vehicles, Nogales, AZ", prepared for Arizona DEQ and US EPA, September 2006

[x] Title 40 US C.F.R. PART 86—Control of Emissions from New and In-use Highway Vehicles and Engines, Subpart T—Manufacturer-Run In-Use Testing Program for Heavy-Duty Diesel Engines

[xi] EPA420-B-02-001 "Guidance on Use of Remote Sensing for Evaluation of I/M Program Performance", July 2002

[xii] "State Diesel Emission Inspection Programs: Trends and Outcomes" prepared for the Diesel Technology Forum Washington DC, Energy and Environmental Analysis, Inc. March 2004

[xiii] AirCare On-Road: http://www.th.gov.bc.ca/ACOR/index.htm#what

[xiv] Port of Metro Vancouver TLS Environmental Requirements 2012 Program Overview https://www1.pacificgatewayportal.com/tls4/Application/ShowFile.aspx?FileName=2012-02-13%202012%20Environment%20overview

[xv] "2005 Lower Fraser Valley Air Emissions Inventory & Forecast and Backcast", Metro Vancouver, December 2007

Appendix A

RSD Mass Emissions Calculations

PMM December 2012

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Emissions grams per kilowatt hour = (grams per liter * diesel liters per kw-hr) 4

3.4 Calculate Grams per bhp-hr from g/kg (diesel only): 4

3.5 Calculate Grams per km 4

Grams per kilometer = (grams per liter / kilometers per liter) 4

3.5.1 Fuel Kilometers per liter from grams per kilometer 5

1 Basic equations:

To calculate grams per liter, the following equations provided by Bishop[i] were used to first convert from concentration percentages to grams per kilogram:

$$\text{gm CO/kg} = (28 \times \%CO/\%CO_2 / (\%CO/\%CO_2 + 1 + 3 \times \%HC / \%CO_2)) / 0.014$$

$$\text{gm HC/kg} = (44 \times \%HC/\%CO_2 / (\%CO/\%CO_2 + 1 + 3 \times \%HC / \%CO_2)) / 0.014$$

$$\text{gm NO/kg} = (30 \times \%NO/\%CO_2 / (\%CO/\%CO_2 + 1 + 3 \times \%HC / \%CO_2)) / 0.014$$

Where the 28, 44 and 30 are grams/mole for CO, HC (as propane) and NO respectively and 0.014 is the kg of fuel per mole of carbon assuming gasoline is stoichiometrically CH2.

2 Adjustments and Conversions

2.1 HC response factor (HCRF):

In a comparison of Non-dispersive Infra-red (NDIR) analyzers vs. Flame ionization detectors (FIDs), Singer and Harley[ii] noted that NDIR analyzers are not sensitive to all species of exhaust hydrocarbons. Their results indicate that hydrocarbon concentrations measured by remote sensors with 3.4 micron filters should be multiplied by a factor of 2.0 for light duty vehicles using US reformulated gasoline blends and by 2.2 when conventional gasoline is used. Therefore, %HC values were multiplied by an additional factor of 2.2 when estimating g/kg HC. The limited data on diesel vehicles suggests a factor in the same range and the same factor was used.

HCRF:

Conventional Gasoline: 2.2

Reformulated Gasoline: 2.0

Diesel: 2.0

CNG: 3.33

LPG: 1.0

2.2 Fuel Kg per Mole of Carbon (FKgpMC)

Don Stedman[iii]: "The factor 0.014 is the kg of fuel per mole of carbon in the fuel. For a CNG vehicle this factor is 0.016 and for an LPG vehicle the factor is approximately 0.0147, but this is for pure propane. To the extent that the LPG contains butane (factor 0.0145) then small adjustments are needed.

Courtesy of the Singer *et al*. experiments noted above, there is more to be said when measuring LPG and CNG vehicles. If they do not emit HC, then they are correctly measured and reported by RSD. If they are reported by the RSD as high HC emitters then, to the extent that their emissions are actually unburned fuel, the correction noted above to the HC readings alone need to be altered. Basically for LPG the factor of 2 multiplying the 44*Q' becomes one and the denominator for all pollutants should use 3*Q' not 6* Q'."

FKgpMC values:

Gasoline: 0.014

Diesel: 0.014

CNG: 0.016

2.3 Fuel density (FKgpl)

Use fuel density to calculate grams/liter instead of grams/kilogram of fuel

Light vehicle emissions are normally required in g/km. Most fuel is purchased by volume and fuel economies are normally expressed in km/liter (or liters/100km). It is, therefore, sometimes convenient to report emissions results in grams per liter. Emissions g/kg are converted to g/l by multiplying by the fuel density(kg/l).

Fuel Kg per liter (FKgpl):

Gasoline: 0.73
Diesel: 0.81
CNG: 0.46

Looking for a better reference for liquid kg/l but here are two sources:
http://www.simetric.co.uk/si_liquids.htm
http://www.eppo.go.th/ref/UNIT-OIL.html

2.4 Calculate NO_2 mass instead of NO:

Don Stedman: "In many countries, including the USA, government NOx emission standards are written as mass of NO_2, even though NO is the molecule emitted." Hence, in the equations below, the molecular weight of NO_2 (46) is used as the multiplier to calculate NO_2_gpl.

Also, RSD detects NO but not NO_2. NOx is the estimated ratio of ($NO+NO_2$)/NO at the tailpipe. For light gasoline vehicles this is 1.03. So the NO_2_gpl could be multiplied by 1.03 to report estimated NO_x for light gasoline vehicles. Could add another field to the EuroStandards table for an NO->NO_x multiplier.

2.5 Calculate using HC hexane instead of HC Propane

Assume hexane value is half the propane value.

3 Adjusted Equations:

3.1 Calculate Grams per Kg

HC g/kg =HCRF*(44*(2*[ppmHchex]/(10000*[perCO_2]))
/(([perCO]/[perCO_2])+1+(6*[ppmHchex]/(10000*[perCO_2])))/ **FKgpMC**

CO g/kg= (28*([perCO]/[perCO_2]) /(([perCO]/[perCO_2])+1+(6*[ppmHchex]/(10000*[perCO_2])))/**FKgpMC**

NO2 g/kg= (46*([ppmNO]/(10000*[perCO_2]))
/(([perCO]/[perCO_2])+1+(6*[ppmHchex]/(10000*[perCO_2])))/ **FKgpMC**

PM g/kg = [uvSmoke]*1000/100,

CO2 g/kg = (44*([perCO_2]/[perCO_2]) /(([perCO]/[perCO2])+1+(6*[ppmHchex]/(10000*[perCO2])))/
FKgpMC

3.2 Calculate Grams per Liter

HC g/l = FKgpl*HCRF*(44*(2*[ppmHChex]/(10000*[perCO_2]))
/(([perCO]/[perCO_2])+1+(6*[ppmHChex]/(10000*[perCO_2])))/ **FKgpMC**

CO g/l=Fkgpl*(28*([perCO]/[perCO_2])
/(([perCO]/[perCO_2])+1+(6*[ppmHChex]/(10000*[perCO_2])))/**FKgpMC**

NO2 g/l = FKgpl* (46*([ppmNO]/(10000*[perCO$_2$]))
/(([perCO]/[perCO$_2$])+1+(6*[ppmHChex]/(10000*[perCO$_2$])))/ **FKgpMC**

Smoke g/l = Fkgpl*[uvSmoke]*1000/100,

CO$_2$ g/l = FKgpl*(44*([perCO$_2$]/[perCO$_2$]) /(([perCO]/[perCO$_2$])+1+(6*[ppmHchex]/(10000*[perCO$_2$])))/
FKgpMC

3.3 Calculate Grams per kw-hr (diesel only):

Emissions grams per kilowatt hour = (grams per liter * diesel liters per kw-hr)
Diesel l/kw-hr depends on diesel engine efficiency and is estimated to be 0.26 l/kw-hr for modern diesels. Modified values could be stored by vehicle type/age.

Volvo truck values can be calculated from
200909002_Volvo_Fuel_Econ_and_Emis_eng_20640_03017.pdf, Tables 1 and 2 e.g. NO$_x$ g/l=18, NOx g/kWh=4.7, therefore l/kWh=4.7/18.

HC g/kw-hr = [HC g/l]*diesel l/kw-hr,
CO g/kw-hr = [CO g/l]* diesel l/kw-hr,
NO$_2$ g/kw-hr =[NO$_2$ g/l]* diesel l/kw-hr,
PM_g/kw-hr = [PM gpl]* diesel l/kw-hr,
CO$_2$ g/kw-hr = [CO$_2$ g/l]* diesel l/kw-hr

3.4 Calculate Grams per bhp-hr from g/kg (diesel only):

Emissions g/bhp-hr = emissions g/ kg * (kg diesel/ bhp-hr)

From above : 1 kw-hr = 0.26 l
Diesel fuel density[iv] = 848 g/l
1 kw-hr = 220.48 g diesel fuel
1 bhp-hr = 0.746 kw-hr
1 bhp-hr = 165 g diesel fuel

Emissions g/bhp-hr = emissions g/kg * (165/1000)
Emissions g/bhp-hr = emissions g/kg / 6.06

3.5 Calculate Grams per km

Grams per kilometer = (grams per liter / kilometers per liter)

HC g/km = [HC g/l] / [km/l],
CO g/km = [CO g/l] /[km/l],
NO$_2$ g/km = [NO$_2$ g/l] / [km/l],

PM g/km = [PM g/l] / [km/l],
CO_2 g/km = [CO_2 g/l] / [km/l]

3.5.1 Fuel kilometers per liter from grams per kilometer

Fuel consumption is sometimes provided as fuel grams per kilometer. To convert to kilometers per liter, divide the fuel density grams per liter (see earlier) by grams per kilometer [km/l = (g/l) / (g/km)]:

km/l = Fuel Kg/l*1000 / Fuel Cons g/km

For example, a gasoline vehicle using 65 g/km of fuel with density 0.73 kg/l has a fuel economy of:

(0.73 kg/l *1000 g/kg) / 65 g/km = 11.23 km/l

[i] On-road Remote Sensing of Automobile Emissions in the Los Angeles Area: Year 1; Bishop, Gary A., Pokharel, Sajal S. and Stedman, Donald H., Coordinating Research Council, January 2000

[ii] Scaling of Infrared Remote Sensor Hydrocarbon Measurements for Motor Vehicle Emission Inventory Calculations; Singer B., Harley R., Littlejohn D., Ho J. and Vo T., Env. Sci & Tech. Vol 32, No 21, 1998

[iii] 20050428_DonStedman_CNG_and_LPG calculations.doc

[iv] http://www.deltaindustrial.com/MSDS/FuelsLubesAntifreeze/DieselFuelNo2.pdf

Appendix B

Daily Emissions Averages

							Light Duty Matched to ICBC						Heavy Duty Matched to ICBC					
Day	Site	Name	RSD Unit	Start Time	End Time	Hours	Count	VSP kW/t	PM g/kg	NO g/kg	CO g/kg	HC g/kg	Count	VSP kW/t	PM g/kg	NO g/kg	CO g/kg	HC g/kg
7/18/2012	003H	Nordel Weigh Scale	4649	8:08	15:05	6.9	1	1.8	1.4	59.6	8.0	-3.1	372	1.4	1.3	24.0	6.1	3.4
7/18/2012	003L	Nordel Weigh Scale	4650	8:33	15:06	6.5	18	0.9	0.7	18.6	6.8	10.3	65	0.8	0.9	18.7	8.0	10.0
7/19/2012	003H	Nordel Weigh Scale	4649	8:24	13:49	5.4	2	2.2	1.2	22.7	9.2	8.9	363	1.1	1.5	22.4	5.2	3.2
7/19/2012	003L	Nordel Weigh Scale	4502	13:18	14:01	0.7	0						2	0.9	1.0	17.5	6.2	3.9
7/19/2012	003L	Nordel Weigh Scale	4650	9:00	12:26	3.4	22	1.0	0.8	10.7	6.4	11.8	42	1.6	1.2	18.3	6.7	10.0
7/20/2012	003H	Nordel Weigh Scale	4649	8:08	8:48	0.7	0						20	2.1	1.3	20.5	11.2	3.7
7/24/2012	003H	Nordel Weigh Scale	4649	7:32	16:24	8.9	16	0.9	2.0	31.4	11.5	4.7	497	1.0	1.5	25.5	7.7	3.2
7/24/2012	003L	Nordel Weigh Scale	4502	8:52	16:24	7.5	41	1.4	0.5	16.7	5.4	1.3	131	0.9	0.7	20.6	6.5	2.6
7/25/2012	003L	Nordel Weigh Scale	4502	8:12	16:13	8.0	62	3.9	1.3	14.3	5.5	2.7	163	2.2	1.8	18.2	7.6	3.3
7/26/2012	023H	Brake Check West Van	4649	7:27	16:55	9.5	3	1.5	0.3	10.7	5.0	3.1	91	2.3	1.0	19.1	5.7	2.8
7/26/2012	023L	Brake Check West Van	4502	7:31	16:55	9.4	27	3.1	0.5	6.0	58.6	2.5	39	2.8	1.2	13.1	9.2	3.6
7/27/2012	020H	TransLink bus facility	4649	17:37	20:58	3.3	0						76	9.5	0.9	13.0	-1.0	-0.1
7/30/2012	007H	Annacis Island W	4649	7:30	11:38	4.1	1	3.6	1.8	21.2	12.1	4.4	34	3.2	1.8	20.4	10.2	2.5
7/30/2012	007L	Annacis Island W	4502	7:39	11:35	3.9	351	4.3	0.1	4.5	14.5	0.4	72	3.1	1.1	21.0	7.3	2.1
7/31/2012	006H	Annacis Island E	4649	7:39	11:18	3.6	1	0.2	2.3	29.0	7.4	3.5	69	6.7	1.2	19.1	3.3	2.3
7/31/2012	006L	Annacis Island E	4650	7:42	9:51	2.1	103	5.7	0.4	5.7	12.1	5.6	48	5.7	1.2	20.3	4.6	5.4
8/1/2012	012H	Truck Pull-Out Hwy 91	4649	8:17	15:56	7.7	4	5.6	2.3	26.7	10.7	6.9	133	2.8	1.2	19.1	5.1	1.7
8/1/2012	012L	Truck Pull-Out Hwy 91	4650	7:33	16:00	8.5	44	6.8	0.4	9.8	11.5	6.6	42	2.5	1.2	15.0	5.8	6.5
8/2/2012	012H	Truck Pull-Out Hwy 91	4649	8:21	15:56	7.6	1	4.7	1.6	7.2	2.0	-0.8	127	3.7	1.3	20.2	6.3	2.1
8/2/2012	012L	Truck Pull-Out Hwy 91	4650	8:17	15:59	7.7	50	6.8	0.7	9.8	22.2	9.2	34	3.8	1.2	14.3	5.4	8.8
8/3/2012	005H	Massey Tunnel Scale	4650	8:28	13:21	4.9	6	2.7	0.8	15.3	4.0	3.8	85	3.4	1.0	21.0	7.2	9.5
8/3/2012	005L	Massey Tunnel Scale	4649	7:43	13:28	5.7	45	3.2	0.8	14.8	20.9	5.0	64	2.1	1.2	17.0	5.4	3.9
8/7/2012	024H	Blundell Road	4650	9:41	12:57	3.3	0						131	4.1	0.7	18.8	8.8	13.1
8/7/2012	024L	Blundell Road	4649	9:03	12:35	3.5	50	2.9	0.2	7.3	8.0	1.4	46	3.6	1.0	17.7	3.3	4.1
8/8/2012	011H	TransLink bus facility	4649	8:25	10:53	2.5	0						9	6.1	1.0	18.9	2.4	0.7
8/9/2012	002H	Deltaport Way	4649	8:27	17:22	8.9	4	1.5	1.8	32.7	11.8	2.9	118	5.5	1.3	28.4	6.1	2.7
8/9/2012	002L	Deltaport Way	4502	12:13	17:59	5.8	136	10.4	0.1	3.7	7.1	-0.7	9	4.6	0.9	24.5	2.4	1.1
8/9/2012	002L	Deltaport Way	4650	9:42	10:52	1.2	19	6.8	0.2	3.6	8.4	3.2	2	3.2	0.9	14.1	4.1	3.5
8/10/2012	004H	Border Weigh Scale	4502	9:19	17:34	8.2	0						51	0.9	1.3	27.2	12.9	6.0
8/10/2012	004L	Border Weigh Scale	4649	9:27	17:27	8.0	6	5.9	0.2	2.4	12.8	-0.2	10	4.9	1.7	12.5	26.5	3.3
8/13/2012	021H	TransLink bus facility	4649	16:57	20:44	3.8	1	27.5	1.7	41.7	11.7	1.3	23	5.5	0.8	15.7	0.1	6.8
8/13/2012	021L	TransLink bus facility	4502	16:38	20:48	4.2	22	8.9	0.4	8.4	13.8	4.7	0					
8/14/2012	022H	River Road	4649	7:31	17:28	9.9	2	-0.8	0.1	0.3	1.1	2.1	116	6.9	1.0	26.1	9.0	2.4
8/14/2012	022L	River Road	4502	7:54	17:40	9.8	540	9.2	0.1	4.0	11.1	0.1	41	9.5	1.3	20.1	8.8	3.1
8/15/2012	008H	16th Avenue	4649	7:48	18:03	10.2	2	4.8	0.3	2.0	-0.3	-1.0	84	4.6	0.9	19.7	5.3	1.6
8/15/2012	008L	16th Avenue	4502	7:43	18:10	10.4	1,807	6.7	0.1	2.9	12.4	0.7	39	4.0	0.6	14.8	8.4	1.5
8/16/2012	006H	Annacis Island E	4649	7:50	16:59	9.1	2	7.4	1.0	24.2	0.7	0.9	236	6.8	1.2	21.1	4.7	2.6
8/16/2012	006L	Annacis Island E	4502	7:40	17:03	9.4	900	8.6	0.3	5.4	18.4	3.0	119	4.8	1.1	21.2	5.7	3.0
8/17/2012	023H	Brake Check West Van	4649	8:16	12:04	3.8	2	2.2	0.7	47.4	3.1	3.3	43	3.2	1.2	18.1	1.7	1.4
8/17/2012	023L	Brake Check West Van	4502	8:30	12:02	3.5	9	5.1	0.4	8.1	8.9	2.0	17	3.4	1.4	11.4	4.5	3.6
8/20/2012	005H	Massey Tunnel Scale	4649	9:37	13:20	3.7	4	1.8	1.0	16.6	0.8	0.1	208	2.9	1.2	22.5	6.3	4.0
8/20/2012	005L	Massey Tunnel Scale	4502	8:45	13:19	4.6	31	4.4	0.9	12.0	44.3	4.8	52	2.0	1.3	21.4	10.7	4.9
8/21/2012	014H	Lake City	4649	7:02	16:58	9.9	0						128	5.7	1.0	15.7	2.0	0.5
8/21/2012	014L	Lake City	4502	6:58	17:00	10.0	1,570	9.3	0.1	3.9	11.8	0.9	91	7.0	1.3	16.3	6.1	2.9
8/22/2012	017H	HWY 1 Weigh Scale	4649	8:33	16:38	8.1	0						124	4.0	1.2	17.5	7.4	2.4
8/22/2012	017L	HWY 1 Weigh Scale	4502	8:57	16:16	7.3	11	8.0	0.6	7.5	4.0	3.2	15	5.9	0.4	15.4	5.3	3.6
8/23/2012	018H	Hwy 1 Weigh Scale	4649	8:22	16:55	8.5	3	1.5	1.7	1.4	4.5	-0.7	134	3.7	1.0	15.1	4.1	2.2
8/23/2012	018L	Hwy 1 Weigh Scale	4502	10:12	16:36	6.4	22	5.7	0.5	10.7	13.2	1.9	22	3.0	0.6	16.9	4.5	1.8
8/24/2012	010H	Front Street	4649	7:25	11:28	4.0	1	11.0	1.2	20.2	2.8	-0.1	20	2.5	0.8	22.7	8.1	2.4
8/24/2012	010L	Front Street	4502	7:21	11:35	4.2	92	2.0	0.1	4.0	7.9	1.5	27	1.0	0.7	23.9	6.3	4.5
8/27/2012	003H	Nordel Weigh Scale	4649	7:35	15:32	8.0	7	2.3	0.7	19.9	8.4	4.0	391	1.7	1.3	22.4	8.1	3.2
8/27/2012	003L	Nordel Weigh Scale	4502	7:11	15:42	8.5	65	1.7	0.8	18.7	7.0	3.1	138	1.3	0.8	19.3	10.3	4.0
8/28/2012	003H	Nordel Weigh Scale	4649	7:06	14:51	7.7	3	1.6	2.1	16.6	9.0	1.7	617	1.3	1.6	20.8	6.2	2.8
8/28/2012	003L	Nordel Weigh Scale	4502	7:12	14:51	7.7	84	2.0	0.5	15.4	4.5	3.4	168	2.2	0.7	17.8	7.6	4.2
8/29/2012	003H	Nordel Weigh Scale	4649	8:00	16:52	8.9	3	1.0	2.1	13.9	5.9	6.6	306	2.1	1.2	19.2	5.6	3.1
8/30/2012	003H	Nordel Weigh Scale	4649	8:07	16:55	8.8	3	1.8	0.9	16.5	3.5	3.7	205	3.8	1.2	17.4	4.2	2.3
8/30/2012	003L	Nordel Weigh Scale	4650	9:49	16:30	6.7	10	9.9	0.2	6.3	14.7	2.5	8	6.2	0.8	16.3	8.3	6.5
8/31/2012	003H	Nordel Weigh Scale	4649	8:05	14:27	6.4	0						169	3.4	1.6	17.2	5.5	2.4
8/31/2012	003L	Nordel Weigh Scale	4650	7:25	12:16	4.8	9	6.7	0.9	7.5	3.7	2.6	11	5.9	1.1	10.5	4.2	6.8

Appendix B

Daily Emissions Averages

							Light Duty Matched to ICBC						Heavy Duty Matched to ICBC					
Day	Site	Name	RSD Unit	Start Time	End Time	Hours	Count	VSP kW/t	PM g/kg	NO g/kg	CO g/kg	HC g/kg	Count	VSP kW/t	PM g/kg	NO g/kg	CO g/kg	HC g/kg
9/4/2012	022H	River Road	4649	9:25	12:38	3.2	0						33	11.3	1.1	19.6	4.9	2.0
9/4/2012	022L	River Road	4502	10:24	12:45	2.3	172	7.6	0.3	5.0	12.3	0.7	32	7.7	1.1	22.0	5.7	1.1
9/5/2012	008H	16th Avenue	4649	8:13	16:45	8.5	1	-10.0	-0.1	0.6	0.4	0.1	64	5.7	1.3	15.2	5.1	0.7
9/5/2012	008L	16th Avenue	4502	7:23	17:00	9.6	1,573	7.9	0.1	3.4	11.0	0.6	32	5.8	1.2	15.8	9.8	3.2
9/6/2012	024H	Blundell Road	4649	7:01	16:58	9.9	5	5.2	1.0	20.4	2.8	1.3	285	5.5	1.1	23.3	3.8	1.3
9/6/2012	024L	Blundell Road	4502	7:03	16:59	9.9	198	7.2	0.3	8.0	9.3	2.1	85	5.5	0.8	20.3	5.0	3.7
9/7/2012	014H	Lake City	4649	7:11	17:28	10.3	0						93	6.8	1.0	16.7	3.0	0.9
9/7/2012	014L	Lake City	4502	6:56	17:30	10.6	1,789	8.6	0.1	3.2	11.6	0.4	77	8.1	0.8	13.0	5.3	2.0
9/10/2012	022H	River Road	4649	7:32	16:55	9.4	3	6.2	2.3	17.6	3.4	2.0	120	6.3	1.2	21.9	6.2	1.0
9/10/2012	022L	River Road	4502	7:34	17:01	9.5	806	11.0	0.1	4.9	13.1	-0.1	70	8.8	1.7	22.6	9.0	2.2
9/11/2012	015H	Truck pull out Hwy 7	4649	8:28	14:57	6.5	5	8.9	2.3	21.2	11.4	3.0	67	6.2	1.1	15.3	4.9	1.2
9/11/2012	015L	Truck pull out Hwy 7	4502	7:57	14:58	7.0	56	8.8	0.7	14.0	9.6	3.2	23	7.7	0.5	15.7	4.9	0.8
9/12/2012	003H	Nordel Weigh Scale	4649	7:20	15:32	8.2	13	4.5	1.2	25.7	4.4	1.9	598	2.7	1.4	23.4	6.7	2.8
9/13/2012	002H	Deltaport Way	4649	7:45	17:00	9.2	5	7.4	1.1	24.0	5.9	3.3	171	10.1	1.1	31.2	7.1	2.8
9/14/2012	006H	Annacis Island E	4649	7:26	16:52	9.4	7	9.9	1.3	20.1	5.3	3.0	166	7.6	0.9	22.0	4.4	2.4
9/17/2012	003H	Nordel Weigh Scale	4649	7:38	11:31	3.9	3	1.1	1.5	32.1	16.4	4.6	131	1.4	1.9	22.3	6.6	3.5
9/18/2012	026H	Hwy 99 ramp to 8th Ave	4649	9:35	17:03	7.5	2	3.6	6.0	31.2	337.1	36.7	92	5.9	0.9	25.7	7.2	1.4
9/19/2012	008H	16th Avenue	4649	7:15	16:23	9.1	7	7.7	0.8	21.5	66.8	9.8	83	5.4	0.8	19.3	4.6	1.8
9/19/2012	008L	16th Avenue	4502	6:52	16:43	9.9	1,725	9.6	0.1	4.0	13.3	0.1	42	7.3	0.9	15.0	3.1	2.7
9/20/2012	028H	McGill ramp off Hwy 1	4649	6:59	17:02	10.1	4	7.6	0.8	25.9	2.9	2.0	373	6.3	1.1	21.9	8.3	1.8
9/20/2012	028L	McGill ramp off Hwy 1	4502	6:52	17:03	10.2	1,203	11.7	0.1	3.0	13.9	0.2	32	5.2	1.0	18.7	6.0	2.7
9/21/2012	029H	Hwy 99 Ramp to Hwy 91	4649	6:57	17:01	10.1	1	-5.7	1.9	20.6	6.2	4.4	36	8.5	1.1	15.9	7.1	1.7
9/21/2012	029L	Hwy 99 Ramp to Hwy 91	4502	6:33	17:10	10.6	3,573	12.9	0.1	2.9	10.4	0.1	62	10.1	1.2	17.4	9.7	2.7
9/24/2012	030H	Surrey Bus	4649	18:06	21:32	3.4	0						20	-1.4	1.2	17.4	3.2	0.7
9/24/2012	030L	Surrey Bus	4502	16:59	21:33	4.6	18	6.1	0.1	9.7	2.2	0.9	0					
9/25/2012	011H	TransLink bus facility	4649	17:42	23:06	5.4	0						163	-0.3	1.1	20.3	1.3	1.1
9/26/2012	027H	CP Intermodal Terminal	4649	6:14	16:59	10.8	3	1.8	1.2	44.1	8.2	5.4	151	2.6	1.7	28.1	9.4	4.8
9/26/2012	027L	CP Intermodal Terminal	4502	6:39	16:33	9.9	25	4.9	0.6	6.9	18.2	4.2	3	1.6	2.1	42.0	31.9	8.0
9/27/2012	028H	McGill ramp off Hwy 1	4649	6:17	17:25	11.1	6	3.0	0.8	27.6	3.3	1.4	342	6.9	1.0	21.5	6.6	1.3
9/27/2012	028L	McGill ramp off Hwy 1	4502	6:13	17:26	11.2	1,248	12.3	0.1	3.0	10.1	0.6	37	11.2	1.4	18.9	11.2	2.3
9/28/2012	028H	McGill ramp off Hwy 1	4649	6:41	17:10	10.5	0						298	7.1	1.1	22.1	5.1	1.3
9/28/2012	028L	McGill ramp off Hwy 1	4502	6:34	16:28	9.9	1,042	11.8	0.2	3.2	13.5	0.0	24	7.3	0.9	19.8	4.0	2.0
10/1/2012	014H	Lake City	4649	6:30	14:10	7.7	2	2.6	0.5	62.5	4.1	2.2	74	5.4	0.8	19.7	3.3	1.1
10/1/2012	014L	Lake City	4502	6:18	14:12	7.9	1,175	9.8	0.1	3.1	8.2	0.5	48	7.6	1.1	13.5	4.9	1.9
10/2/2012	024H	Blundell Road	4649	7:12	17:47	10.6	6	4.3	1.8	24.6	8.2	5.6	387	6.6	1.0	27.9	3.7	2.7
10/2/2012	024L	Blundell Road	4502	7:13	18:00	10.8	199	7.1	0.1	6.9	7.1	0.8	97	6.6	0.9	16.5	6.5	2.3
10/3/2012	017H	HWY 1 Weigh Scale	4649	7:24	17:00	9.6	1	3.8	0.5	49.0	5.1	1.5	97	6.3	1.0	14.0	10.1	4.7
10/3/2012	017L	HWY 1 Weigh Scale	4502	7:17	16:57	9.7	16	13.3	0.6	6.8	36.7	7.3	23	10.0	0.9	17.5	4.2	1.6
10/4/2012	018H	Hwy 1 Weigh Scale	4649	7:51	17:32	9.7	6	9.3	0.7	7.4	10.7	0.6	187	8.8	1.1	13.9	3.9	1.5
10/4/2012	018L	Hwy 1 Weigh Scale	4502	7:56	17:14	9.3	22	9.2	0.8	14.8	23.3	2.3	21	8.2	0.9	15.1	4.1	1.0
10/5/2012	028H	McGill ramp off Hwy 1	4649	6:58	16:15	9.3	6	13.5	0.4	30.8	88.1	9.8	253	9.3	0.9	25.9	8.2	1.4
10/5/2012	028L	McGill ramp off Hwy 1	4502	6:56	16:30	9.6	957	12.3	0.1	3.1	9.7	0.6	29	7.3	0.9	24.6	3.8	3.0
10/9/2012	026H	Hwy 99 ramp to 8th Ave	4649	8:06	17:26	9.3	0						175	6.2	0.8	21.0	5.9	1.1
10/9/2012	026L	Hwy 99 ramp to 8th Ave	4502	7:53	17:08	9.2	1,515	10.0	0.2	3.2	13.6	0.4	28	5.5	0.9	18.9	6.7	1.7
Total							**23,616**	**9.8**	**0.2**	**3.9**	**11.9**	**0.7**	**11,721**	**4.3**	**1.2**	**21.1**	**6.2**	**2.8**

Appendix B

Hourly Temperature

Day	Unit	Site	06 & earlier	07	08	09	10	11	12	13	14	15	16	17	18 & later
18-Jul-12	__08054649	003H		18	18	19	20	20	20	22	23	24			
18-Jul-12	__09084650	003L			18	19	20	20	20	22	24	24			
19-Jul-12	__07034502	003L								26	27				
19-Jul-12	__08054649	003H			21	22	23	24	25	26					
19-Jul-12	__09084650	003L			21	22	23	24	25						
20-Jul-12	__08054649	003H			19										
24-Jul-12	__07034502	003L			17	18	20	21	22	23	23	23	25		
24-Jul-12	__08054649	003H		15	16	18	19	21	22	23	23	23	24		
25-Jul-12	__07034502	003L			19	21	22	23	24	25	27	28	30		
26-Jul-12	__07034502	023L		16	18	22	26	29	30	31	33	34	34		
26-Jul-12	__08054649	023H		16	18	25	27	30	31	32	33	33	32		
27-Jul-12	__08054649	020H												21	20
30-Jul-12	__07034502	007L		17	18	19	19	20							
30-Jul-12	__08054649	007H		16	18	19	19	20							
31-Jul-12	__08054649	006H		17	17	20	24	26							
31-Jul-12	__09084650	006L		17	17	20	23	25							
1-Aug-12	__08054649	012H		15	17	19	21	23	24	25	26	26			
1-Aug-12	__09084650	012L		15	17	19	20	22	23	24	26	26	26		
2-Aug-12	__08054649	012H			16	18	19	20	23	26	27	27			
2-Aug-12	__09084650	012L			16	18	19	20	22	25	27	27			
3-Aug-12	__08054649	005L		25	28	26	26	26	26	26					
3-Aug-12	__09084650	005H		25	28	25	25	25	25	25					
7-Aug-12	__08054649	024L				23	24	28	28						
7-Aug-12	__09084650	024H			22	24	24	29	27						
8-Aug-12	__08054649	011H		17	17	17	17								
9-Aug-12	__07034502	002L							23	25	26	27	28	28	
9-Aug-12	__08054649	002H			18	20	21	22	23	25	26	27	28	28	
9-Aug-12	__09084650	002L			18	21	21								
10-Aug-12	__07034502	004H				20	21	20		23	25	27	28	28	
10-Aug-12	__08054649	004L				21	21	21	22	23	25	26	27	27	
13-Aug-12	__07034502	021L											30	29	27
13-Aug-12	__08054649	021H											30	30	27
14-Aug-12	__07034502	022L		17	18	19	20		24	26	26	28	27	28	
14-Aug-12	__08054649	022H		16	17	18	21	22	23	25	26	28	27	28	
15-Aug-12	__07034502	008L		17	20	25	30	35	37	38	39	38	38	36	35
15-Aug-12	__08054649	008H		16	22	27	32	35	37	39	39	38	37	34	34
16-Aug-12	__07034502	006L		20	22	26	29	32	34	35	36	37	36	35	
16-Aug-12	__08054649	006H		21	25	28	31	33	35	35	36	36	35		
17-Aug-12	__07034502	023L			22	27	31	33	34						
17-Aug-12	__08054649	023H			23	29	32	33	35						
20-Aug-12	__07034502	005L			19	21	24	28	28	27					
20-Aug-12	__08054649	005H				21	24	26	27	26					
21-Aug-12	__07034502	014L	18	18	19	20	22	23	24	24	25	24	22	22	
21-Aug-12	__08054649	014H	18	18	18	20	22	23	24	24	25	23	22		
22-Aug-12	__07034502	017L			17	17	18	20	22	23	23	24	23		
22-Aug-12	__08054649	017H			17	17	18	20	22	22	23	24	23		
23-Aug-12	__07034502	018L				18	19	21	20	21	20	20	20		
23-Aug-12	__08054649	018H			16	18	19	22	20	21	20	20	19		
24-Aug-12	__07034502	010L		15	16	17	19	18							
24-Aug-12	__08054649	010H		15	15	17	18	18							
27-Aug-12	__07034502	003L		15	17	19	21	22	24	24	26	28			
27-Aug-12	__08054649	003H		15	17	19	21	22	24	24	27	28			
28-Aug-12	__07034502	003L		15	16	17	19	19	20	19	21				
28-Aug-12	__08054649	003H		15	16	17	19	19	20	19	22				

Appendix B

Hourly Temperature

Day	Unit	Site	06 & earlier	07	08	09	10	11	12	13	14	15	16	17	18 & later
29-Aug-12	__08054649	003H			19	20	19	19	21	21	22	22	22		
30-Aug-12	__08054649	003H		20	25	21	19	22	23	24	24	23	23		
30-Aug-12	__09084650	003L		20		19	19	22	24		26		23		
31-Aug-12	__08054649	003H		13	15	18	20	23	23	23	22				
31-Aug-12	__09084650	003L		13	15	18	20	22	24	24					
4-Sep-12	__07034502	022L					19	19	20						
4-Sep-12	__08054649	022H				18	19	19	20						
5-Sep-12	__07034502	008L		13	15	16	17	19	23	27	26	27	26	25	
5-Sep-12	__08054649	008H		13	16	16	17	19	24	27	26	27	26		
6-Sep-12	__07034502	024L		15	17	19	22	24	26	28	29	30	30		
6-Sep-12	__08054649	024H		14	17	20	22	25	27	28	29	29	29		
7-Sep-12	__07034502	014L	13	13	15	18	20	23	27	30	32	34	35	35	
7-Sep-12	__08054649	014H		13	14	18	20	24	27	31	33	36	36	36	
10-Sep-12	__07034502	022L		12	13	16	17	18	19	19	19	17	20	20	
10-Sep-12	__08054649	022H		12	12	15	17	18	19	19	19	17	21		
11-Sep-12	__07034502	015L		7	9	13	15	18	22	26	24				
11-Sep-12	__08054649	015H			10	12	15	20	24	27	26				
12-Sep-12	__08054649	003H		7	9	13	16	17	18	21	23	24			
13-Sep-12	__08054649	002H		9	12	16	18	21	23	25	26	27	27	26	
14-Sep-12	__08054649	006H		13	16	21	25	28	29	29	30	29	27		
17-Sep-12	__08054649	003H		10	13	17	21	22							
18-Sep-12	__08054649	026H				18	20	21	21	22	22	23	25	25	
19-Sep-12	__07034502	008L	9	10	12	18	22	21	23	27	27	29	28		
19-Sep-12	__08054649	008H		10	14	19	24	21	25	27	27	28	27		
20-Sep-12	__07034502	028L	13	13	16	21	26	28	29	29	32	33	32	31	
20-Sep-12	__08054649	028H	13	13	17	22	27	29	30	29	32	32	31	29	
21-Sep-12	__07034502	029L	13	14	14	15	16	17	18	18	18	18	18	17	
21-Sep-12	__08054649	029H	13	13	14	15	16	16	18	18	18	17	17	17	
24-Sep-12	__07034502	030L											20	20	17
24-Sep-12	__08054649	030H												18	17
25-Sep-12	__08054649	011H											20	18	13
26-Sep-12	__07034502	027L	9	9	11	14	19	21	24	23	21	22	24		
26-Sep-12	__08054649	027H	9	9	11	14	20	23	25	23	21	22	23		
27-Sep-12	__07034502	028L	10	10	13	18	23	27	30	31	30	30	30	28	
27-Sep-12	__08054649	028H	10	10	14	20	25	28	31	31	30	30	29	27	
28-Sep-12	__07034502	028L	13	14	15	18	21	24	24	24	22	19	19		
28-Sep-12	__08054649	028H	13	14	15	18	22	24	24	24	20	18	19	19	
1-Oct-12	__07034502	014L	12	13	14	15	17	19	19	20	21				
1-Oct-12	__08054649	014H	11	12	14	16	17	19	19	20	21				
2-Oct-12	__07034502	024L		11	11	13	13	15	18	23	23	22	25	22	18
2-Oct-12	__08054649	024H		11	11	13	13	15	18	24	24	21	24	21	
3-Oct-12	__07034502	017L		8	8	9	11	15	17	19	20	22	23		
3-Oct-12	__08054649	017H		7	8	9	11	15	17	18	20	22	24	24	
4-Oct-12	__07034502	018L		8	8	9	10	20	22	26	27	25	22	19	
4-Oct-12	__08054649	018H		8	8	8	10	20	23	25	25	24	21	18	
5-Oct-12	__07034502	028L	7	7	10	16	22	26	28	29	28	29	27		
5-Oct-12	__08054649	028H	7	7	10	17	24	27	29	29	28	29	26		
9-Oct-12	__07034502	026L		10	10	12	13	14	15	15	16	16	17	16	
9-Oct-12	__08054649	026H			10	12	13	14	15	15	16	16	18	16	

Appendix B

Hourly Relative Humidity

Day	Unit	Site	06 & earlier	07	08	09	10	11	12	13	14	15	16	17	18 & later
18-Jul-12	__08054649	003H		71	70	67	60	59	59	54	50	48			
18-Jul-12	__09084650	003L			71	69	61	59	60	55	51	49			
19-Jul-12	__07034502	003L								48	44				
19-Jul-12	__08054649	003H			61	59	55	50	49	47					
19-Jul-12	__09084650	003L			61	58	54	49	50						
20-Jul-12	__08054649	003H			80										
24-Jul-12	__07034502	003L			75	72	62	56	54	52	52	52	48		
24-Jul-12	__08054649	003H		79	76	71	61	55	54	51	51	50	47		
25-Jul-12	__07034502	003L			72	64	59	59	56	51	47	41	38		
26-Jul-12	__07034502	023L		83	81	63	51	44	40	36	34	33	33		
26-Jul-12	__08054649	023H		83	79	53	45	41	38	35	34	34	34		
27-Jul-12	__08054649	020H												57	57
30-Jul-12	__07034502	007L		67	63	60	60	59							
30-Jul-12	__08054649	007H		65	61	58	58	57							
31-Jul-12	__08054649	006H		66	65	57	44	40							
31-Jul-12	__09084650	006L		68	67	59	47	44							
1-Aug-12	__08054649	012H		73	67	60	58	52	47	44	40	39			
1-Aug-12	__09084650	012L		73	68	62	60	56	50	47	42	40	41		
2-Aug-12	__08054649	012H			72	69	65	64	54	47	45	44			
2-Aug-12	__09084650	012L			73	69	67	64	57	49	47	45			
3-Aug-12	__08054649	005L		54	44	48	48	48	46	46					
3-Aug-12	__09084650	005H		51	44	49	50	50	47	48					
7-Aug-12	__08054649	024L				62	60	46	47						
7-Aug-12	__09084650	024H			67	55	56	45	46						
8-Aug-12	__08054649	011H		73	71	73	74								
9-Aug-12	__07034502	002L							56	50	45	38	34	35	
9-Aug-12	__08054649	002H			74	66	61	59	56	47	43	39	34	35	
9-Aug-12	__09084650	002L			72	63	62								
10-Aug-12	__07034502	004H				65	63	65		55	47	43	41	41	
10-Aug-12	__08054649	004L				64	64	66	60	58	49	46	44	44	
13-Aug-12	__07034502	021L											40	40	44
13-Aug-12	__08054649	021H											40	38	41
14-Aug-12	__07034502	022L		80	79	76	71		56	54	52	49	53	49	
14-Aug-12	__08054649	022H		81	78	75	68	61	57	54	52	48	50	46	
15-Aug-12	__07034502	008L		86	77	58	37	23	20	18	20	23	22	22	22
15-Aug-12	__08054649	008H		86	71	50	34	22	20	18	20	23	23	23	23
16-Aug-12	__07034502	006L		67	57	44	33	30	27	23	21	20	21	23	
16-Aug-12	__08054649	006H		63	49	39	30	28	25	23	21	21	22		
17-Aug-12	__07034502	023L			59	42	32	31	27						
17-Aug-12	__08054649	023H			54	38	29	30	27						
20-Aug-12	__07034502	005L			62	56	48	38	38	40					
20-Aug-12	__08054649	005H				54	47	40	40	40					
21-Aug-12	__07034502	014L	65	64	63	59	54	49	48	49	47	48	54	55	
21-Aug-12	__08054649	014H	65	63	62	58	52	47	47	48	46	48	52		
22-Aug-12	__07034502	017L			71	68	64	57	52	48	48	46	50		
22-Aug-12	__08054649	017H			70	67	63	57	50	48	47	46	50		
23-Aug-12	__07034502	018L				62	60	53	55	55	57	57	62		
23-Aug-12	__08054649	018H			67	63	58	49	54	54	54	57	62		
24-Aug-12	__07034502	010L		70	69	63	59	59							
24-Aug-12	__08054649	010H		69	69	63	57	59							
27-Aug-12	__07034502	003L		73	63	58	54	48	43	41	33	30			
27-Aug-12	__08054649	003H		72	62	56	52	47	42	40	33	28			
28-Aug-12	__07034502	003L		79	77	78	67	62	60	66	57				
28-Aug-12	__08054649	003H		77	75	77	65	60	57	64	53				

Appendix B

Hourly Relative Humidity

Day	Unit	Site	06 & earlier	07	08	09	10	11	12	13	14	15	16	17	18 & later
29-Aug-12	__08054649	003H			60	57	61	60	54	51	49	49	51		
30-Aug-12	__08054649	003H		57	44	50	55	46	44	39	38	41	47		
30-Aug-12	__09084650	003L		59		59	58	50	44		40		47		
31-Aug-12	__08054649	003H		77	73	64	55	48	47	45	45				
31-Aug-12	__09084650	003L		79	74	65	57	51	47	42					
4-Sep-12	__07034502	022L					65	66	64						
4-Sep-12	__08054649	022H				64	65	65	63						
5-Sep-12	__07034502	008L		84	80	79	75	70	56	47	47	42	44	48	
5-Sep-12	__08054649	008H		83	77	78	74	69	53	45	46	42	43		
6-Sep-12	__07034502	024L		83	76	65	55	47	40	35	31	28	25		
6-Sep-12	__08054649	024H		82	71	60	52	44	38	33	30	27	25		
7-Sep-12	__07034502	014L	71	74	71	58	49	41	34	27	24	20	20	19	
7-Sep-12	__08054649	014H		72	70	56	49	40	34	26	23	19	18	18	
10-Sep-12	__07034502	022L		76	77	62	54	49	44	39	42	49	40	40	
10-Sep-12	__08054649	022H		75	76	61	54	48	44	39	43	50	39		
11-Sep-12	__07034502	015L		83	85	73	61	50	37	27	29				
11-Sep-12	__08054649	015H			84	73	59	42	32	26	25				
12-Sep-12	__08054649	003H		77	76	67	53	47	42	38	35	31			
13-Sep-12	__08054649	002H		85	83	69	58	50	42	38	35	29	28	29	
14-Sep-12	__08054649	006H		77	64	50	39	32	31	30	26	28	32		
17-Sep-12	__08054649	003H		78	80	72	59	53							
18-Sep-12	__08054649	026H				65	56	52	55	51	48	44	40	42	
19-Sep-12	__07034502	008L	84	84	79	66	53	57	51	42	40	37	37		
19-Sep-12	__08054649	008H		81	74	59	47	53	46	40	40	38	38		
20-Sep-12	__07034502	028L	82	82	74	58	44	38	35	38	32	28	28	30	
20-Sep-12	__08054649	028H	81	80	67	52	40	35	34	37	31	29	29	32	
21-Sep-12	__07034502	029L	81	80	78	75	71	69	64	62	62	64	65	65	
21-Sep-12	__08054649	029H	80	79	77	73	70	68	63	60	61	63	63	63	
24-Sep-12	__07034502	030L											52	52	69
24-Sep-12	__08054649	030H												57	64
25-Sep-12	__08054649	011H											53	57	76
26-Sep-12	__07034502	027L	86	86	86	77	62	54	47	49	56	54	45		
26-Sep-12	__08054649	027H	85	85	82	73	56	48	42	47	55	52	47		
27-Sep-12	__07034502	028L	87	88	80	64	48	38	33	31	32	29	30	32	
27-Sep-12	__08054649	028H	86	87	76	57	43	34	31	29	31	30	31	33	
28-Sep-12	__07034502	028L	82	81	76	65	53	47	44	43	52	76	75		
28-Sep-12	__08054649	028H	82	81	74	63	50	43	43	42	60	74	72	73	
1-Oct-12	__07034502	014L	81	79	75	70	65	58	54	48	46				
1-Oct-12	__08054649	014H	81	78	74	68	63	56	53	47	45				
2-Oct-12	__07034502	024L		68	63	55	49	46	41	35	34	36	29	32	43
2-Oct-12	__08054649	024H		67	61	52	48	44	40	32	32	37	29	33	
3-Oct-12	__07034502	017L		54	55	53	43	33	29	27	25	22	22		
3-Oct-12	__08054649	017H		53	53	52	42	31	27	26	24	21	20	21	
4-Oct-12	__07034502	018L		47	48	45	43	24	21	20	18	16	20	27	
4-Oct-12	__08054649	018H		46	46	44	42	25	21	20	19	18	20	28	
5-Oct-12	__07034502	028L	69	70	64	45	31	25	24	24	24	22	22		
5-Oct-12	__08054649	028H	69	68	60	41	27	23	23	22	23	22	23		
9-Oct-12	__07034502	026L		89	87	83	78	73	68	67	65	64	60	62	
9-Oct-12	__08054649	026H			86	82	76	72	67	66	63	62	55	60	

Appendix C

Proposed Site Details

1. Vancouver Port

- Just inside the Port gate
- Trucks must stop and check in with Port Authorities
- The HD RSD Would be set up as close as practical to the gate
- The vehicles will be under acceleration from a stop as they enter Port property
- Virtually all of the vehicles seen here will be class 8 HD diesel powered semi tractors pulling container trailers
- There should be space available for the tunnel equipment
- CVSE would be asked to perform a sample of snap idle tests on some vehicles that were tested by RSD and the tunnel
- Site was not used after concerns expressed by Port Metro Vancouver

2. Deltaport Way, Delta

- On the exit road from the port, as the road goes under Hwy 17 and as the trucks accelerate to merge into traffic coming from the Ferry terminal
- Vehicles travelling under load at about 40 km/h
- Virtually all of the vehicles seen here were class 8 HD diesel powered semi tractors pulling container trailers

3. Nordel Weigh Scale, Delta

- On the south end of the Alex Fraser Bridge, during certain times of the day, all vehicles with a GVW greater than 5500 kg must report to the scales
- Vehicles come off the access road and turn sharply to the right as they approach the queue to the scales. After the location for the HD RSD equipment, the vehicles select a lane: one for loaded and to be weighed and one unloaded and to use the bypass lane
- Vehicles are accelerating at the time off the access road and are travelling at between 10 and 30 km/h
- About 70% of the trucks observed are class 8 and 30% are class 4 through 7
- There is room available at the site for the tunnel equipment
- Truck drivers were encouraged to accelerate through the equipment but many were hesitant resulting in many negative accelerations and discarded readings
- The scale generally closes after 5 or 6 pm

4. Border Weigh Scale, Surrey

- Located on 176 St northbound in Surrey
- All traffic for the scale must come through the border from the USA
- The RSD unit was set up just after the trucks leave the scales from a stop and accelerate to leave the property
- A mix of class 8 and medium duty trucks were observed

5. Massey Tunnel Scale, Richmond

- This facility is no longer open as a weigh scale but the property is almost untouched from when it was operational
- The assistance of the Commercial Vehicle Safety Enforcement (CVSE) group was necessary to direct commercial vehicles to the closed scale and drive through the RSD equipment
- The vehicles must be accelerating to merge back in with tunnel traffic but pass through the RSD unit at between 10 and 30 km/h
- A mix of class 8 and medium duty trucks were observed
- The timing of the observations was critical as during morning rush hour, traffic is at a virtual standstill going southbound. The RSD reads were performed between rush hours.
- There were some issues of backup when the tested vehicles merge back into traffic resulting in reduced hours of data collection.

6. Annacis Island East, Richmond

- This site captured the trucks leaving the east end of the industrial park heading north onto Hwy 91
- The on-ramp has a slight uphill slope where the equipment was located
- A mix of class 8 and medium duty trucks were observed
- Trucks passed by the RSD unit at between 10 and 30 km/h

7. Annacis Island West, Richmond

- This site captured the trucks leaving the west end of the industrial park heading north onto Hwy 91
- The cloverleaf on-ramp had sufficient space to set up the RSD equipment
- The trucks will be accelerating towards a merge at 30-70 km/h
- A mix of class 8 and medium duty trucks were observed
- The speeds observed were too high to register acceleration and the site was only used for one day

8. 16th Avenue, Surrey, westbound

- A two-lane rural truck route heavily populated with dump trucks
- The subject site, located just West of 192nd Street in Surrey, has a slight uphill grade and is just past a controlled intersection
- Vehicles could be under light load if they proceed through a green light at speeds near 30 km/h
- If the vehicle is proceeding off a light, it was under heavier load
- Many drivers were apprehensive of the testing site and slowed through the beams, rendering the readings useless

9. Front Street, New Westminster, westbound

- This truck route is a main truck east-west arterial located just on the north side of the Fraser River
- As the trucks pass under the Patullo railway bridge approach, a painted median and a pull out allows the equipment to be positioned, but is very tight.
- There is no uphill grade so it is expected that the trucks will proceed at a constant speed of about 30-40 km/h
- This site will see a mixed fleet of class 8 and medium duty trucks
- The site was deemed too intrusive by the city of New Westminster and not used

10. Front Street, New Westminster, eastbound

- As trucks approach the designated truck route, the two-lane road becomes 1 lane eastbound
- There is a painted median that will be used for the trailer and a slim grass curb for the mirror unit.
- This site will see a mixed fleet of HD and Medium Duty trucks
- The trucks are expected to proceed past the RSD unit at between 10 and 30 km/h
- The site was deemed too intrusive and not used.
- The replacement site was located under the parking garage and was covering two lanes of traffic.
- This two-lane technique, designed to deal with rain days (as it was covered) was only marginally successful because of the uncertain readings when two vehicles passed in opposite directions at the point of the beams.

11. TransLink bus facility, Richmond

- The transit maintenance and parking facility has space for about 350 buses

- The RSD unit was set-up within the facility and capture buses as they depart the yard in the morning and as they return after their shift
- All buses will be diesel powered with a variety of model years represented
- The buses proceeded through the system at between 10 and 30 km/h

12. Truck pull-out Hwy 91, Delta, northbound

- It was necessary for the CVSE to order commercial vehicles to pass through this popular truck rest area
- The RSD unit was positioned so as to require an acceleration as the trucks return to the active roadway
- A variety of HD and MD trucks were seen along with a few highway buses
- Trucks proceeded through the RSD beams at 10-30 km/h
- It was evident by the traffic flows that truckers were advising others to avoid the site

13. Vancouver Landfill, Delta

- All city of Vancouver garbage transfer trucks must use this facility.
- Relatively low volume but very focused fleet
- Private refuse haulers use the facility with smaller trucks
- This site is only used in option 1
- Trucks will proceed through the RSD unit either before or after the weigh scales from a standing start
- Site not used

14. Lake City, Burnaby

- An urban industrial park where a large number of medium duty trucks are seen
- A slight uphill grade off Lougheed Hwy assures a valid reading
- Speed was 10-30 km/h
- Very successful for positive acceleration netting sound readings

15. Truck pull-out Hwy 7 westbound near Albion

- The CVSE would be needed to divert commercial traffic into the site where the RSD equipment would be set up
- A variety of trucks from logging trucks to local delivery trucks are evident
- Trucks will start from a standstill after being directed onto the site
- Site not used after disappointing results eastbound at site 16

16. Truck pull-out Hwy 7 eastbound near Albion.

- The CVSE were needed to divert commercial traffic into the site where the RSD equipment was set up.
- A variety of trucks from logging trucks to local delivery trucks are evident
- Trucks started from a standstill after being directed onto the site
- Relatively low volume but these trucks may not be seen elsewhere
- With proper direction, these trucks will proceed at between 10 and 30 km/h
- Relatively low volume as it was suspected that drivers were warning each other

17. Hwy 1 Weigh Scale near Hunter Creek eastbound

- Located in the eastern end of the Lower Fraser Valley, this very busy highway weigh scale captured loaded trucks heading east out of Vancouver
- Although operated by the CVSE, it wasn't be necessary to have the trucks specifically diverted as they are already required to present themselves for weight verification
- With proper direction, these trucks proceeded at between 10 and 30 km/h
- Very successful site as the drivers had no opportunity to divert

18. Hwy 1 Weigh Scale near Hunter Creek westbound

- Across the street from loc #17
- Captured HD trucks arriving into the Lower Fraser Valley airshed headed for Vancouver
- The trucks proceeded through the RSD unit from a standstill
- Very successful site

19. Atkinson Road, Abbotsford

- An on-ramp westbound on Hwy 1 designed to accommodate gravel trucks from a very large operation
- Good acceleration
- Speed estimated at 30-70 km/h
- Site not used

20. TransLink Facility, Burnaby

- Transit maintenance and parking facility for approximately 200 buses
- Home to the hybrid bus fleet
- The RSD unit was set up within the facility and capture buses as they return after their shift

- The buses passed by the RSD unit between 10 and 30 km/h

21. TransLink facility, Port Coquitlam

- Transit maintenance and parking facility for approximately 150 buses
- This transit yard is home to all of the CNG powered TransLink fleet
- This transit yard also houses some of TransLink's community shuttle buses
- The fleet housed here is generally older than some other facilities
- The RSD unit was set up within the facility and capture buses as they depart the yard in the morning and as they return after their shift
- The buses would pass by the RSD unit between 10 and 30 km/h

22. River Road, Delta

- Eastbound on a single lane section
- Slight uphill grade
- Full flow traffic at about 50-70 km/h speed
- High percentage of light duty vehicles but both high and low stack trucks as well

23. Brake Check, West Vancouver

- On upper levels highway westbound
- All trucks must stop to check brakes before a large hill toward the ferry terminal
- Unit set up just after the stop area, so consistent acceleration was seen

24. Blundell Road Richmond

- Two lane road Westbound in industrial park
- Used extensively by container trucks heading to and from "stuffing houses" where cargo is offloaded from containers and put onto other trucks
- Located just after a 90 degree turn and set up to allow single lane traffic with all of the necessary traffic control equipment
- Although encouraged to accel through the sensors, many drivers were very apprehensive and decelerated. It was noted that most trucks who did not accel were owner-operators and had older trucks .

25. Pattulo Bridge Eastbound

- Surrey side of bridge
- Set up in conjunction with CVSE during safety check

- After discussions with CVSE, it was decided that the site was not safe and wasn't used.

26. Hwy 99 to 8th Avenue

- South surrey approaching the border
- Trucks are required to use this exit off Hwy 99 and proceed to truck border crossing
- Uphill grade and sweeping curve
- Positive accel was observed in most cases
- Many light duty vehicles interspersed with the trucks
- Most trucks were HD high stack

27. CP Intermodal yard

- Private property operated by CP rail located in Pitt Meadows
- All trucks with containers that must exit through gate
- Unit set up near gate to encourage accel
- Most drivers who did not accelerate were in older owner-operated trucks

28. McGill Ramp off Hwy 1

- Exit off Hwy 1 just as the highway approaches the Ironworker's Memorial Bridge in Vancouver
- Slight uphill grade on a curve
- Most drivers were unaware that the unit was set up until it was too late to decel
- Positive acceleration was seen on most trucks
- Many light duty vehicles interspersed with mainly high stack Hd Trucks headed for the Port with containers

29. Hwy 99 to Hwy 91

- Major trucking route for vehicles headed from the city to Hwy 1 using the East-West connector
- Slight uphill grade on a corner
- Higher average speeds
- Many light duty vehicles
- Disappointing truck traffic volume with the supposition that truckers were warning each other to avoid the site

30. Surrey Bus Barn

- TransLink facility located off 130th avenue in Surrey