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

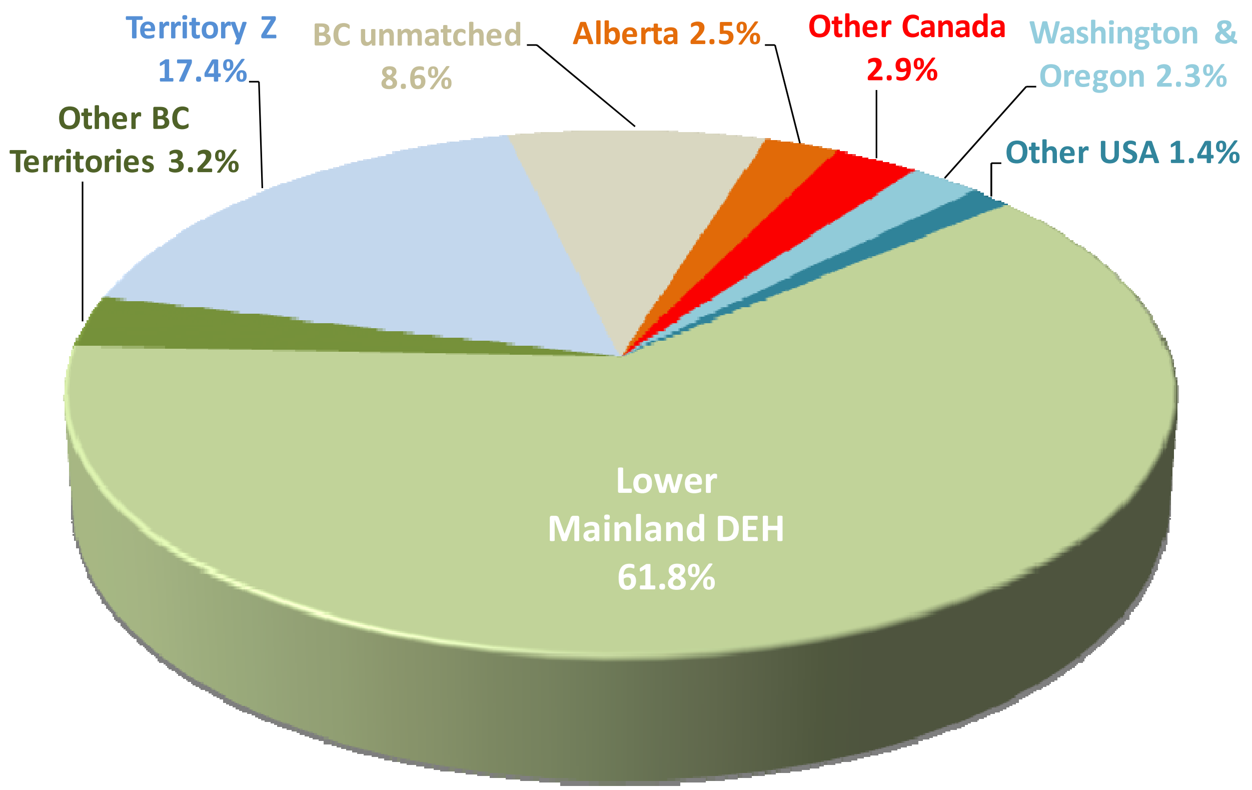
### I-3.1 Emissions from HDVs in the Metro Vancouver and the Fraser Valley Regional District

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.

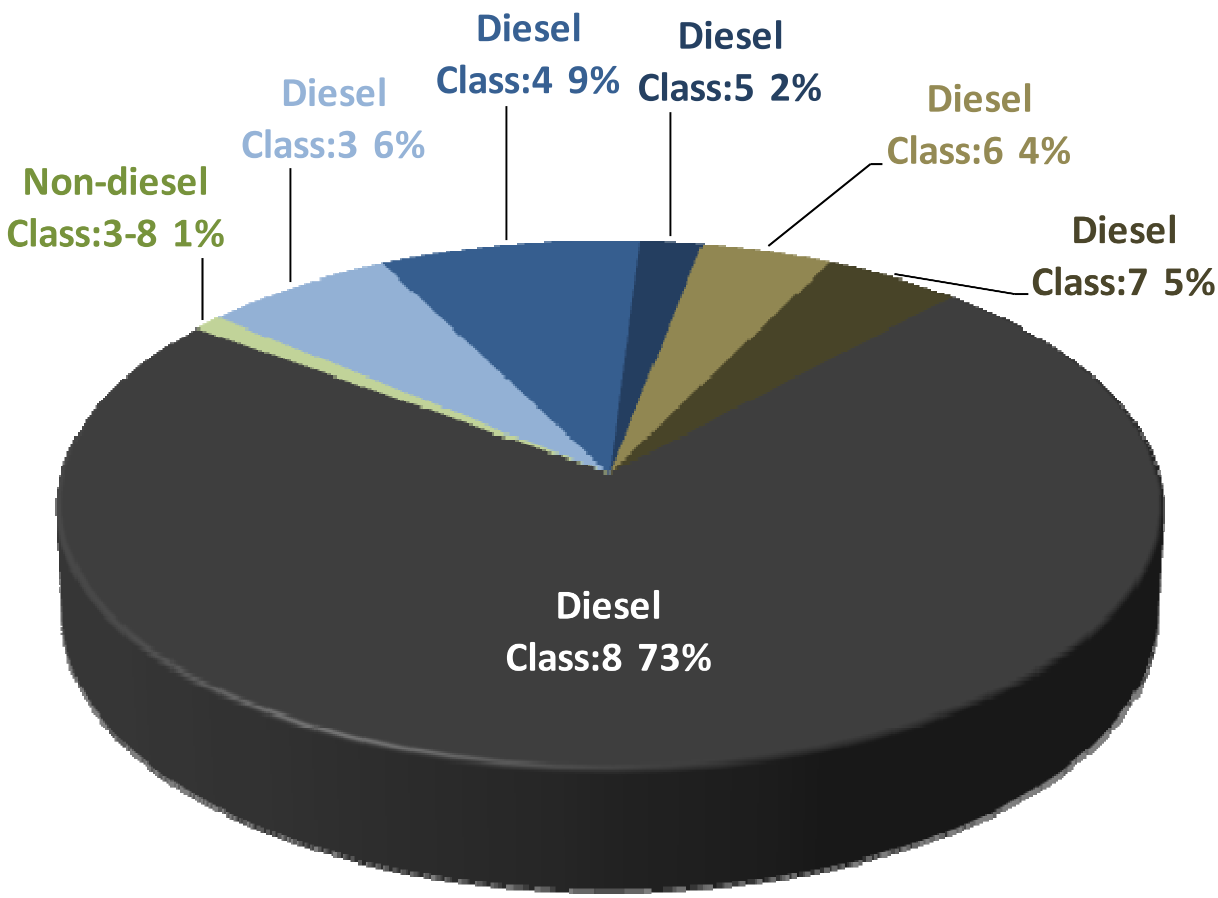
The registration jurisdictions of the heavy-duty vehicles observed operating in the region are shown in Figure I-1. The vast majority were registered in the Lower Fraser Valley region (ICBC lower mainland territories DEH and Z and probably most of the unmatched). Vehicles registered elsewhere were found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

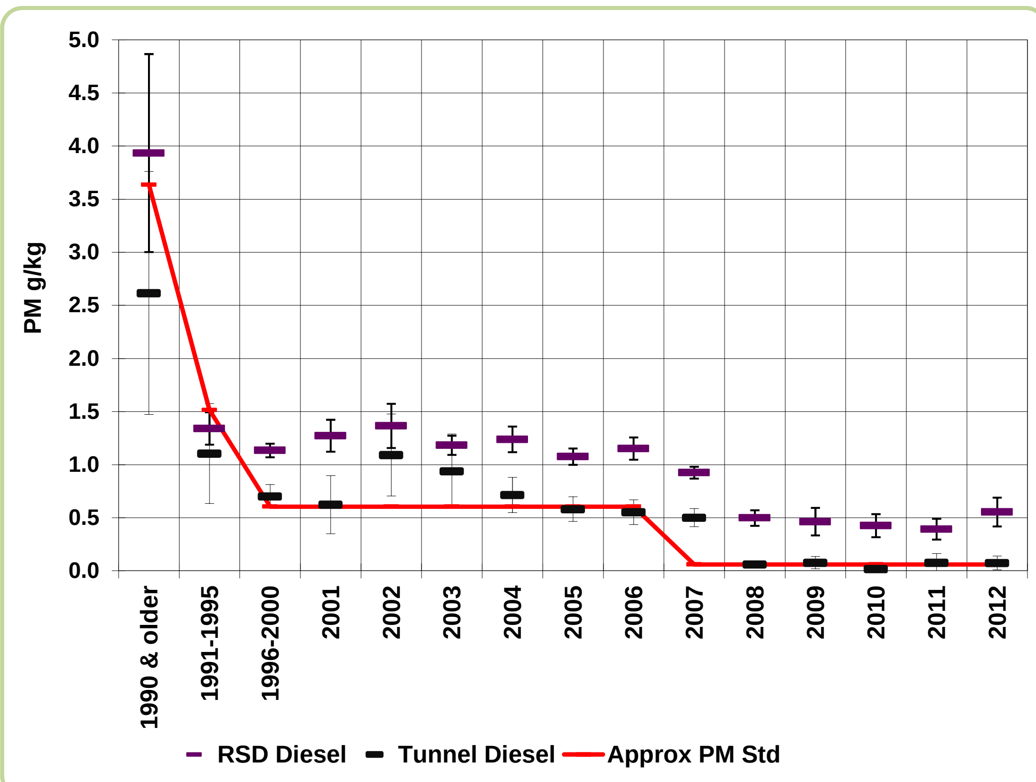


Figure I-4: Tunnel and RSD Heavy-duty Vehicle $NO_x$ Emissions

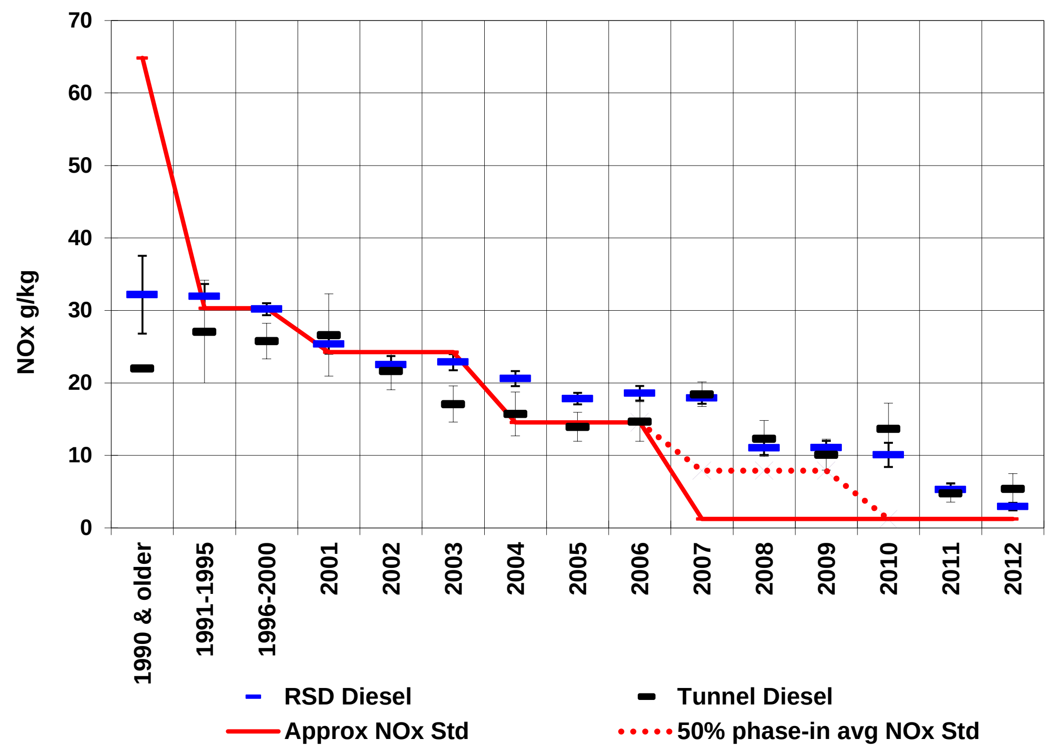



Table I-2 summarizes by four vehicle age groups the percentage of observations of vehicles and the percentage of total NOx and PM emitted by each age group. Seventy-six percent of heavy-duty vehicles observed were 2007 & older models. These emitted 90% of NOx and up to 98% of PM.

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.

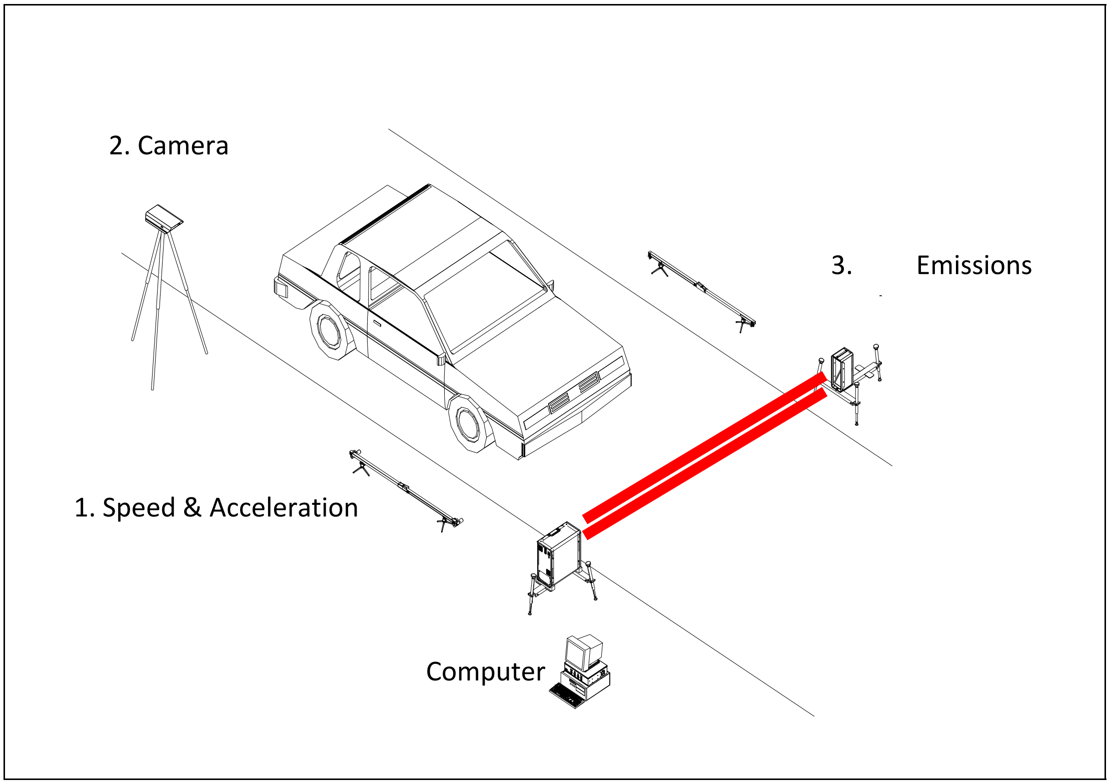
The HDET is a patented emerging technology being developed at the University of Denver in conjunction with Envirotest that holds great promise as an individual vehicle inspection methodology. A prototype HDET was deployed for one week at Nordel.

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].

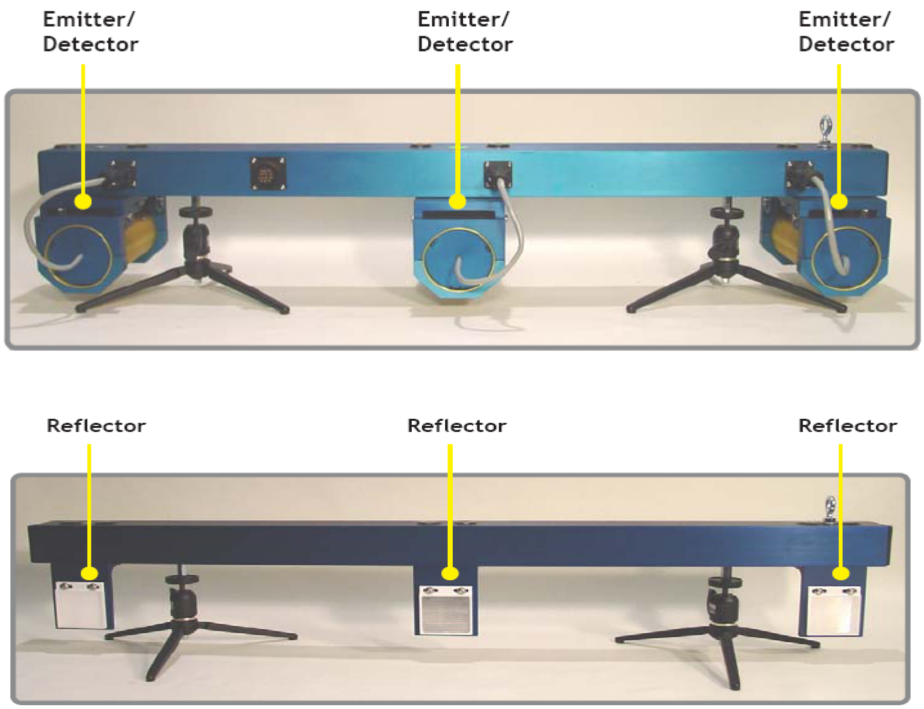
The accuracy and precision of the remote sensing spectrometer has been demonstrated in experiments conducted by several independent organizations in North America, Asia, and Europe. In each, RSD native ratios were directly compared to ratios from laboratory instruments while two analytical systems were 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**

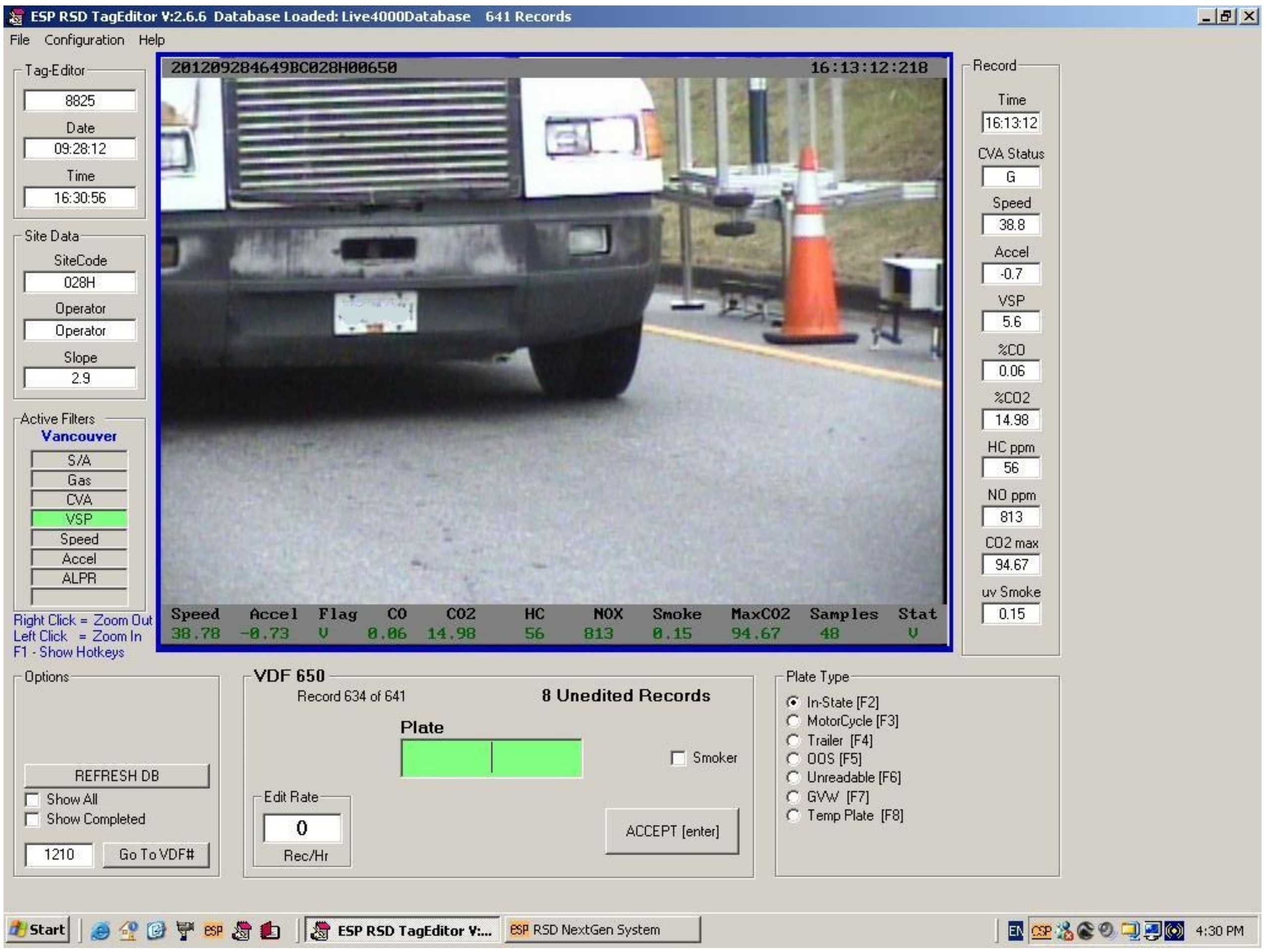
Envirotest's Tag Edit™ software was used by operators to manually transcribe license plates. Figure II-5 shows an example of a Tag Edit™ screen (the plate has been blanked out). The license plate editing software ensured:

- 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.

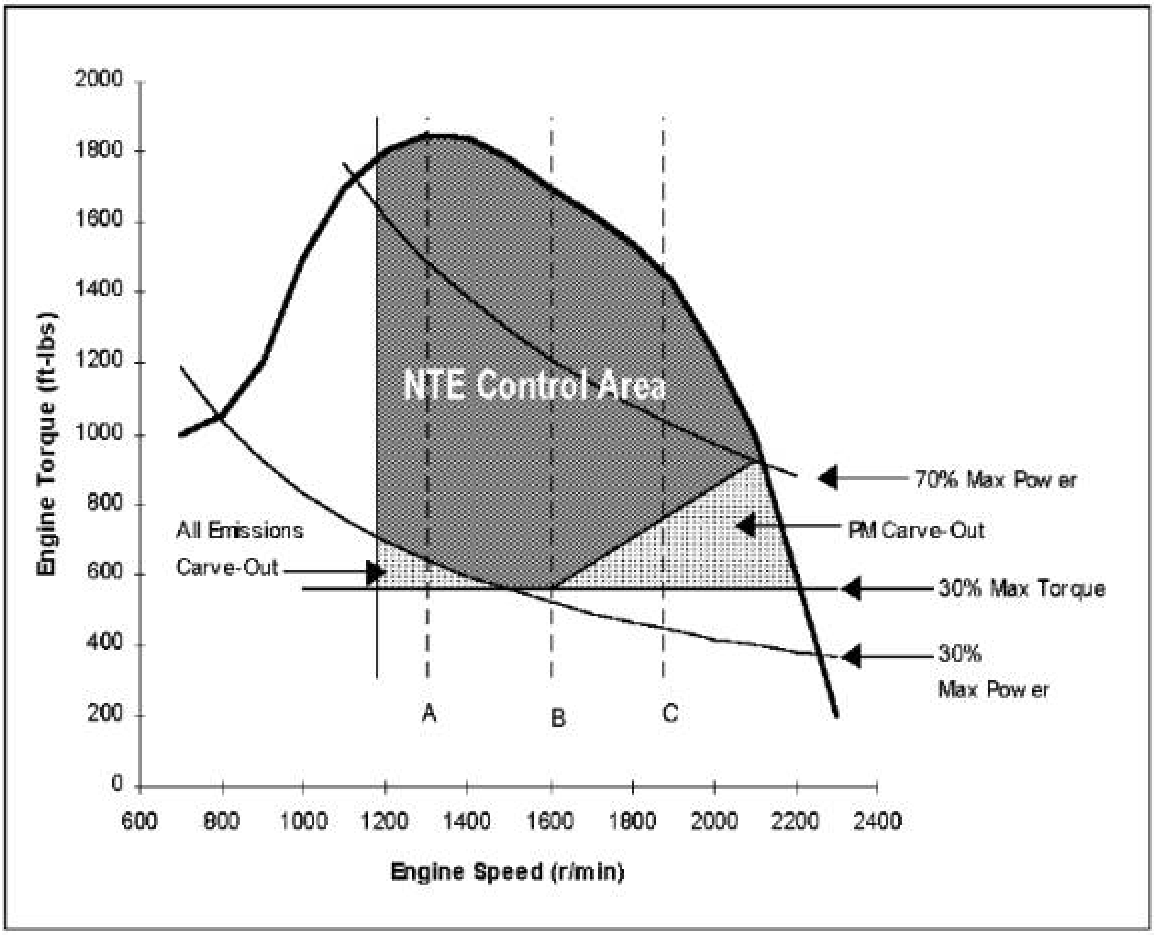
In 2001, engine manufacture and trucking associations challenged the EPA NTE regulations. In June 2003, a settlement agreed upon a detailed outline for a subsequent 2005 regulation requiring manufacturers to run heavy-duty in-use NTE testing programs for diesel-fueled engines and vehicles[viii]. Key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

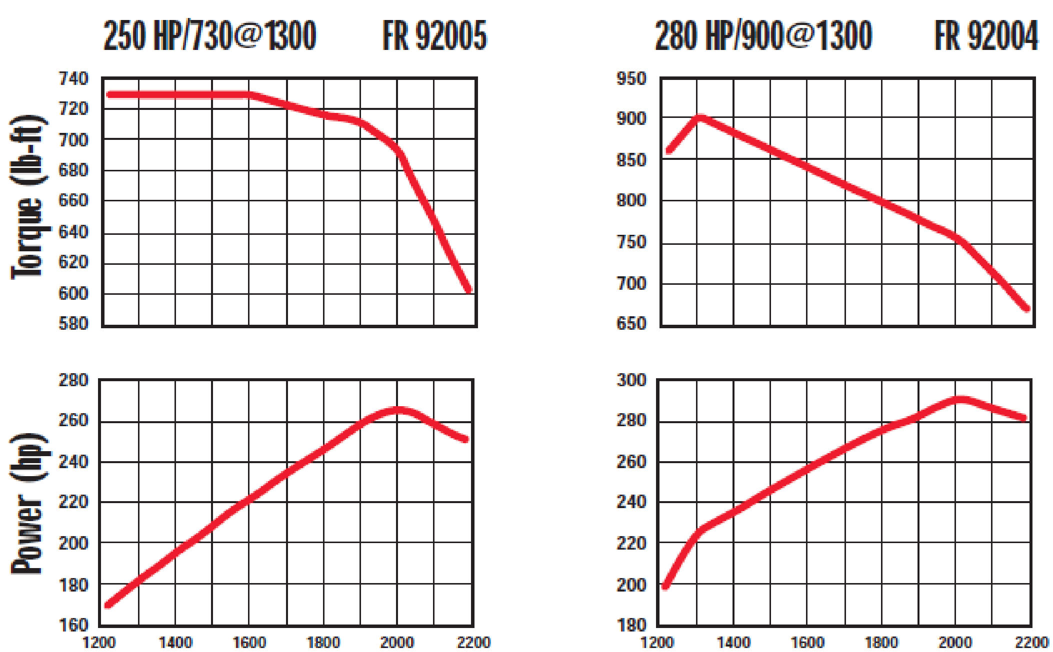
For km/hr and km/hr/s the equivalent equation is:

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

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.

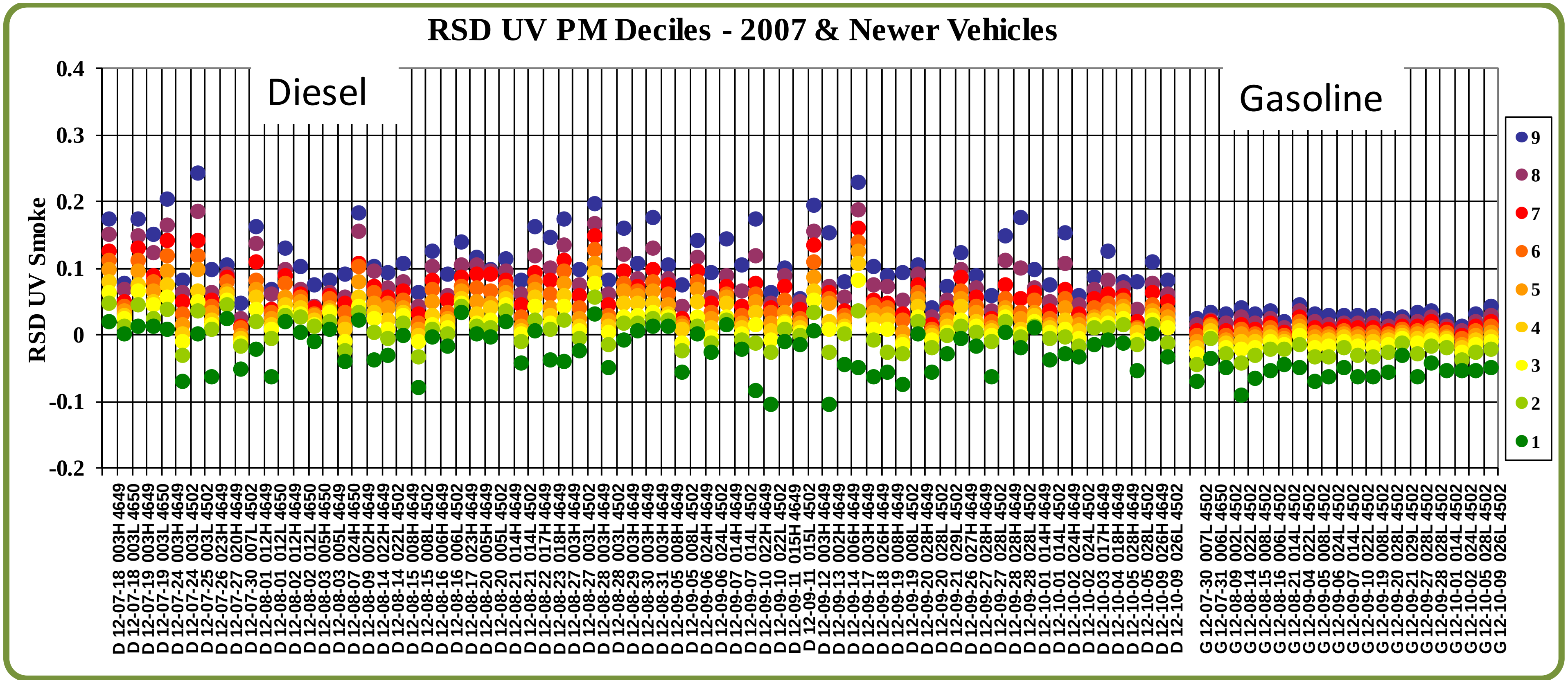
UV PM emissions (Figure II-10) were higher and more variable for diesel vehicles, which could indicate the differences in vehicles measured by the high and low RSD units and site related (vehicle operation) differences.

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.

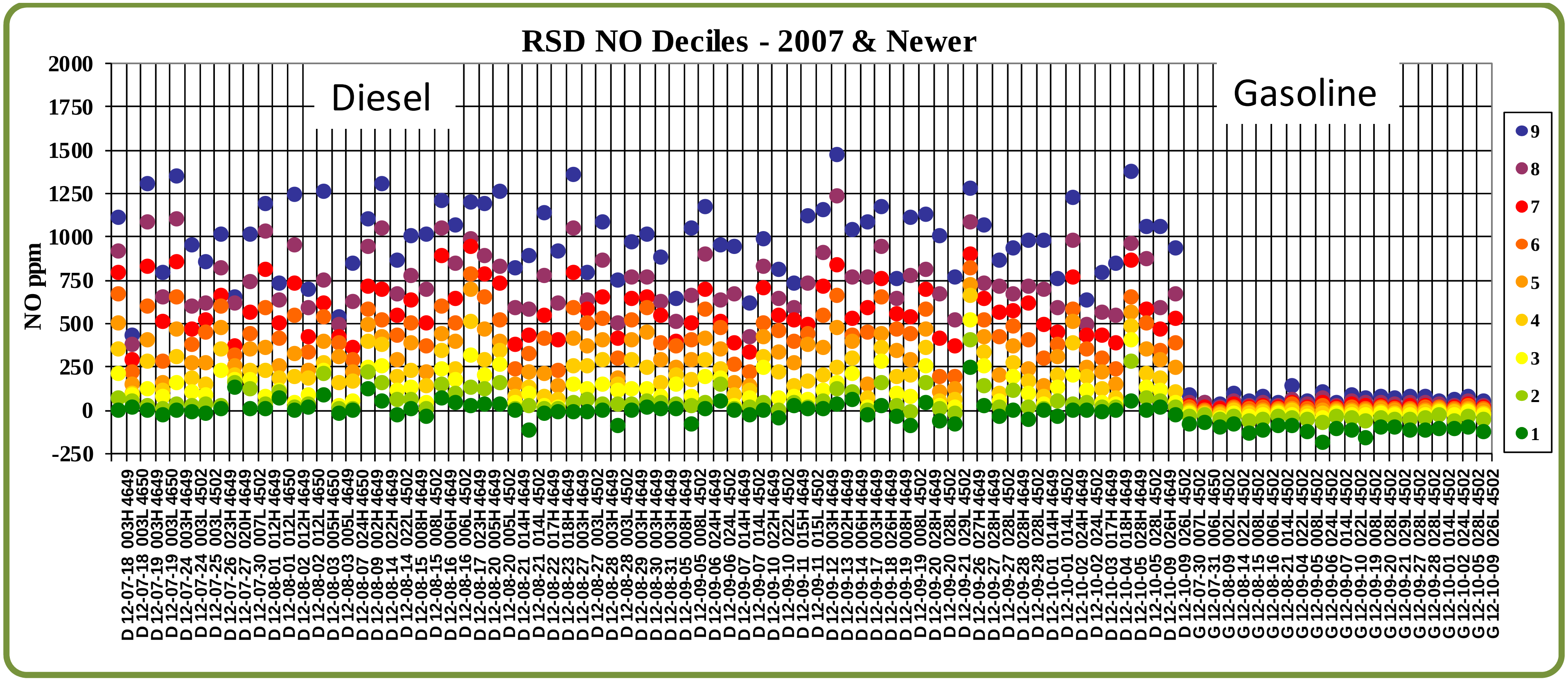
Diesel PM may be quite sensitive to the speed and engine load at different sites.

Figure II-10: Daily UV PM Deciles



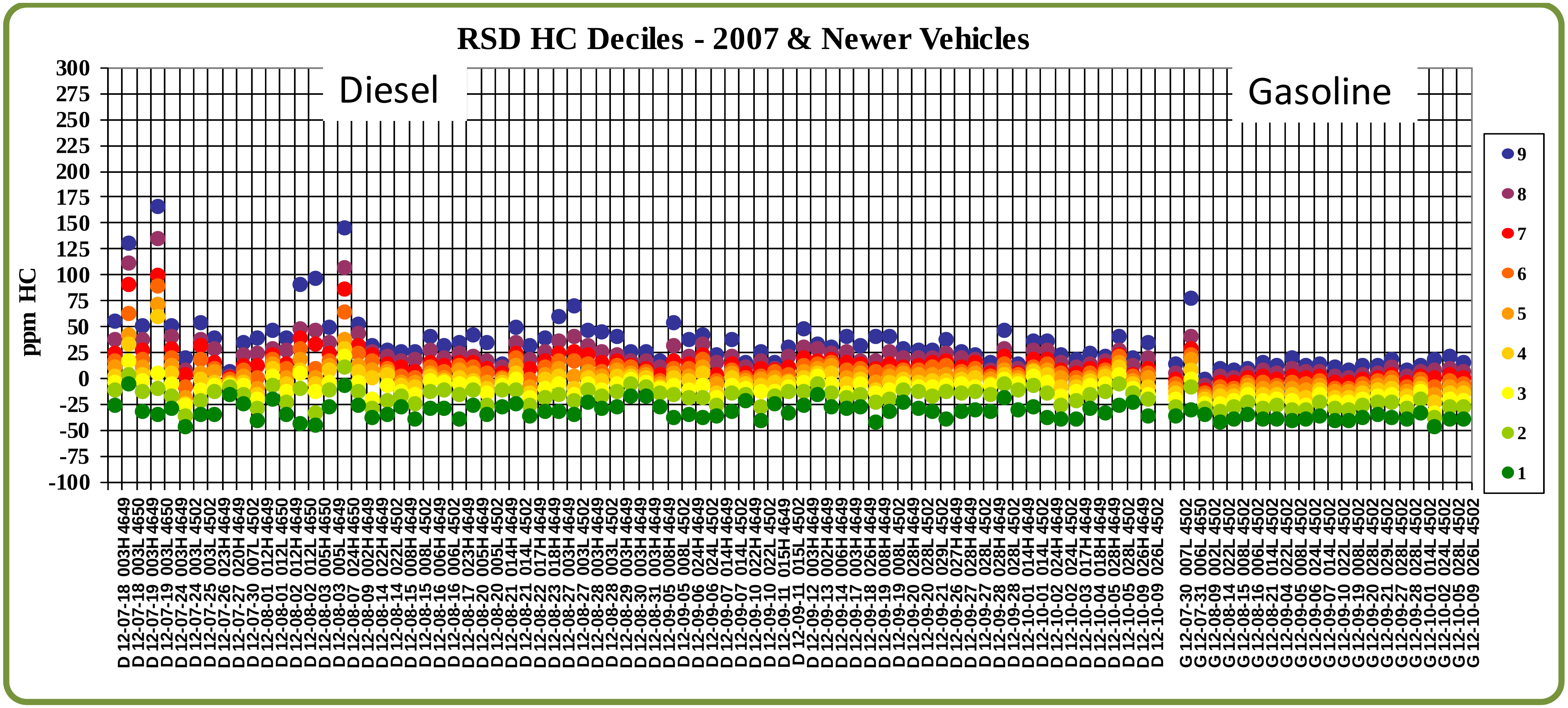

Horizontal-axis legends: **D/G** (Diesel/Gasoline) **Date** (yy-mm-dd) **Site H/L** (high/low RSD) **RSD unit number**

Figure II-11: Daily NO Deciles



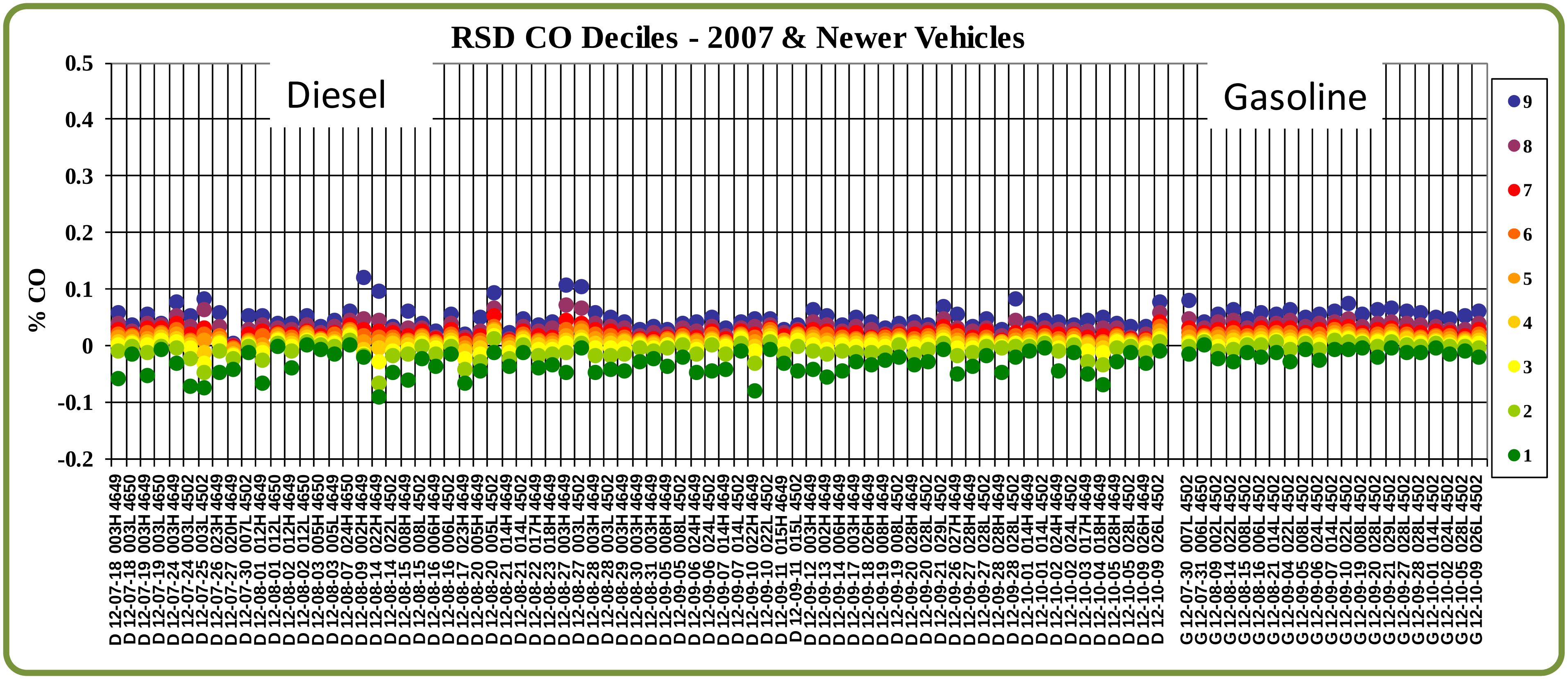

Horizontal-axis legends: **D/G** (Diesel/Gasoline) **Date** (yy-mm-dd) **Site H/L** (high/low RSD) **RSD unit number**

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)
- $CO_2$ 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
- $CO_2$ 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.

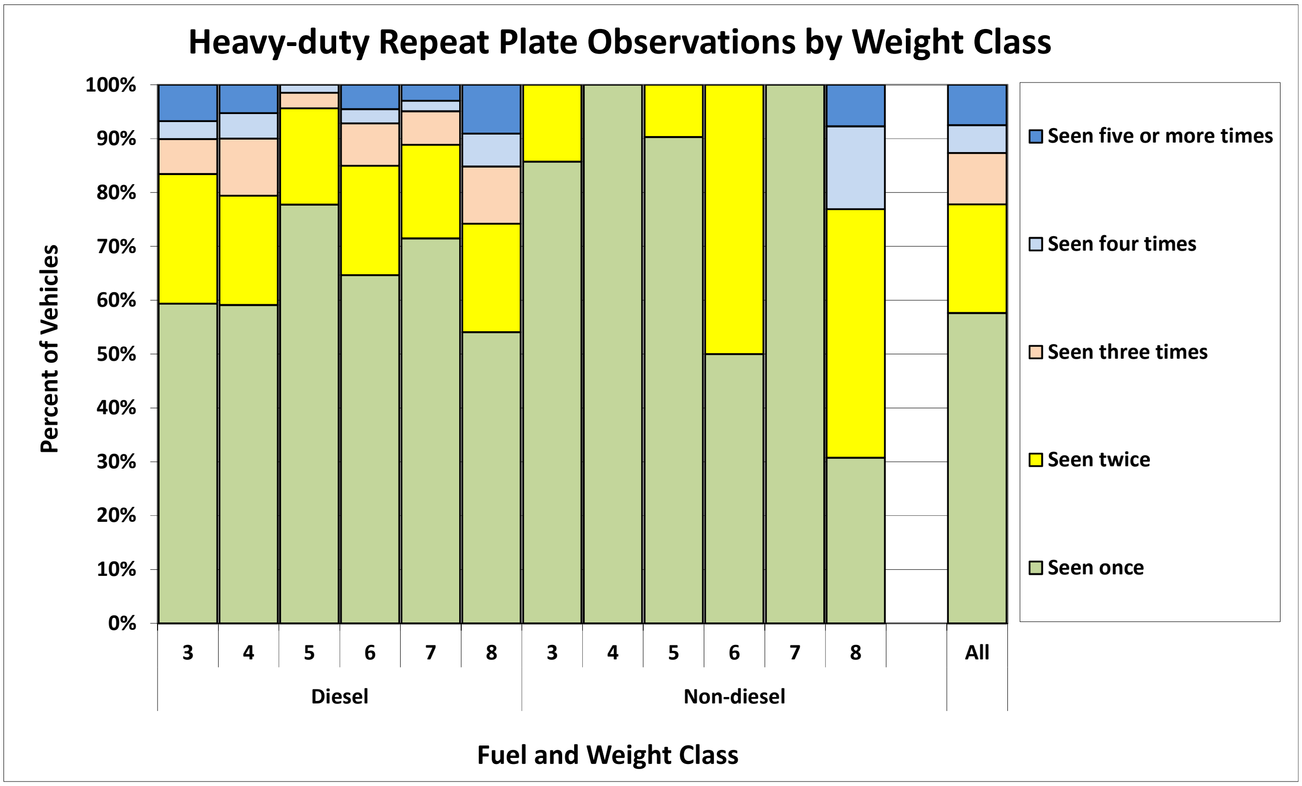
Table III-4 Vehicles, Observations and Measurements

| | | | 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

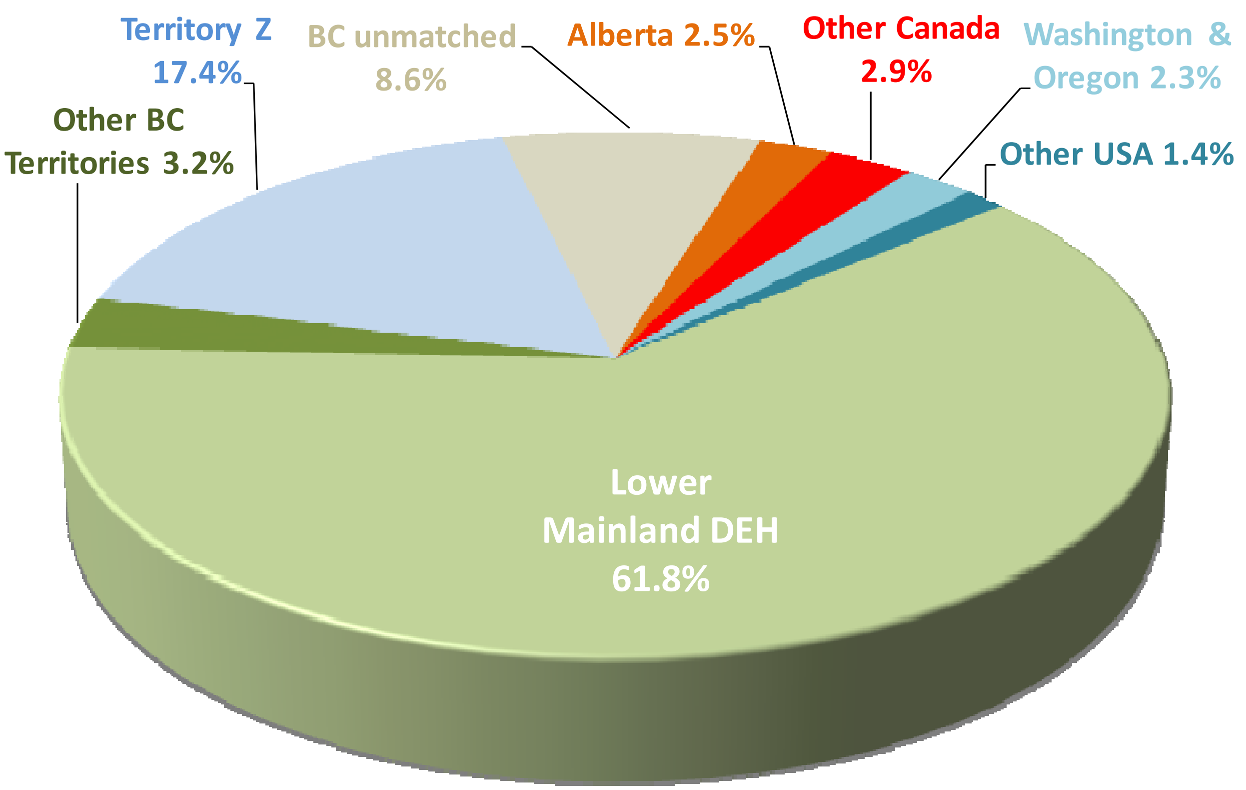
| | Registered | | | Unique Veh Measured | | | % Measured | | | Measurements / Veh | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Class** | **LFV** | **Restpr** | **Terriz** | **LFV** | **Restpr** | **TerrZ** | **LFV** | **Restpr** | **TerrZ** | **LFV** | **Restpr** | **TerrZ** |
| **Diesel** | | | | | | | | | | | | |
| 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.

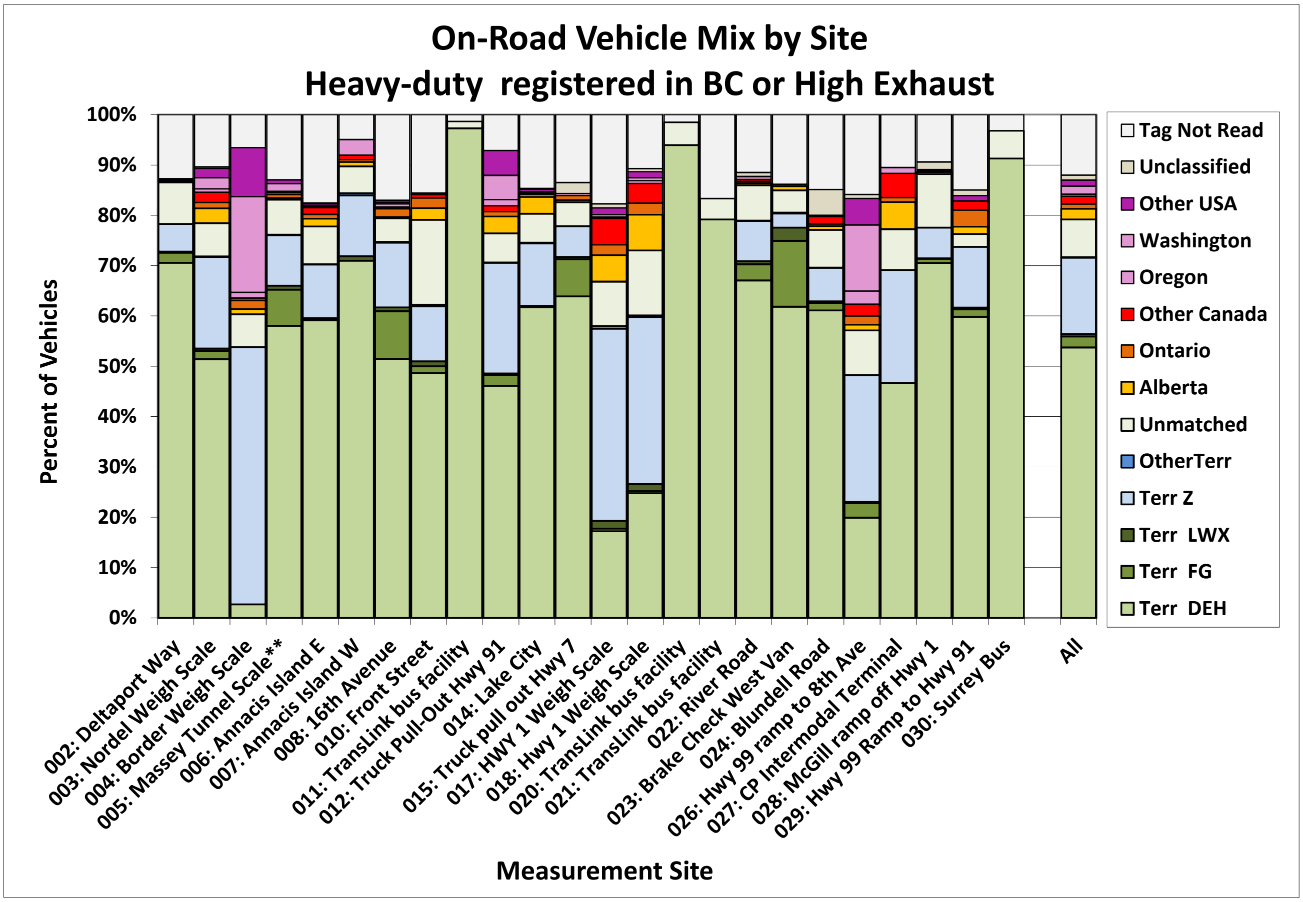
Figure III-3 shows the regional source by site including the percentage of license tags that were not read. The weigh scale sites had large percentages of territory Z vehicles. As anticipated, the Border weigh scale had the largest percentage of trucks from the USA and Translink terminal buses were all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

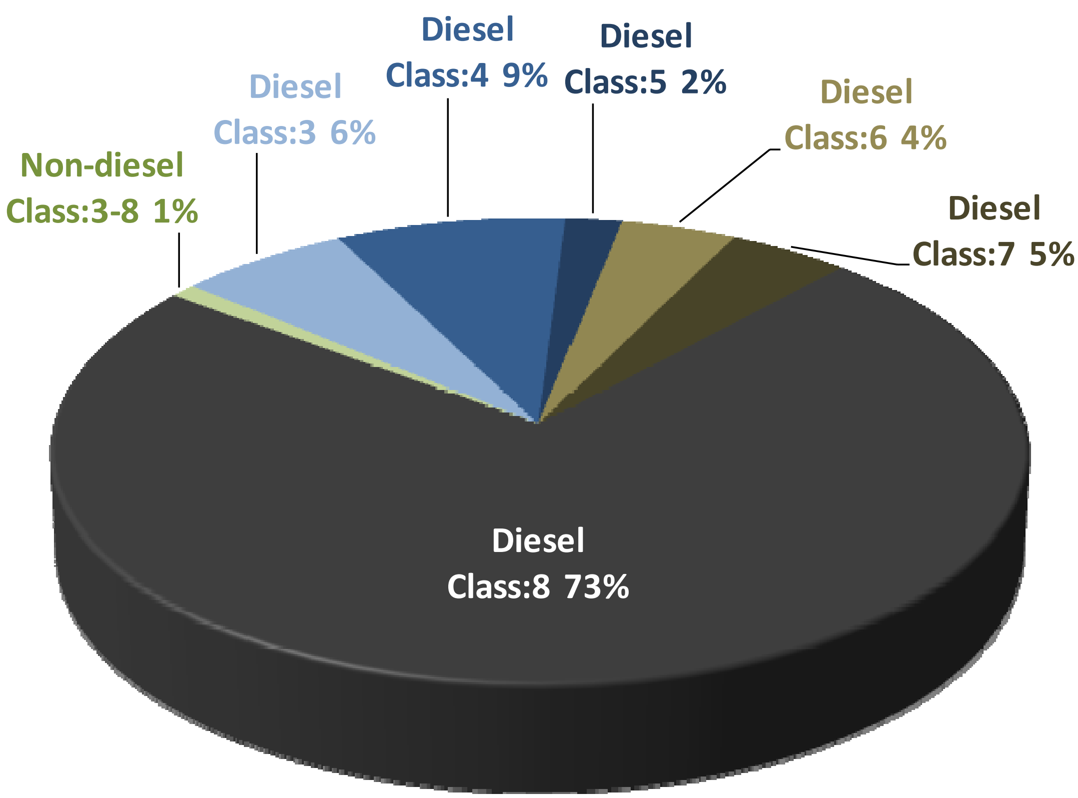
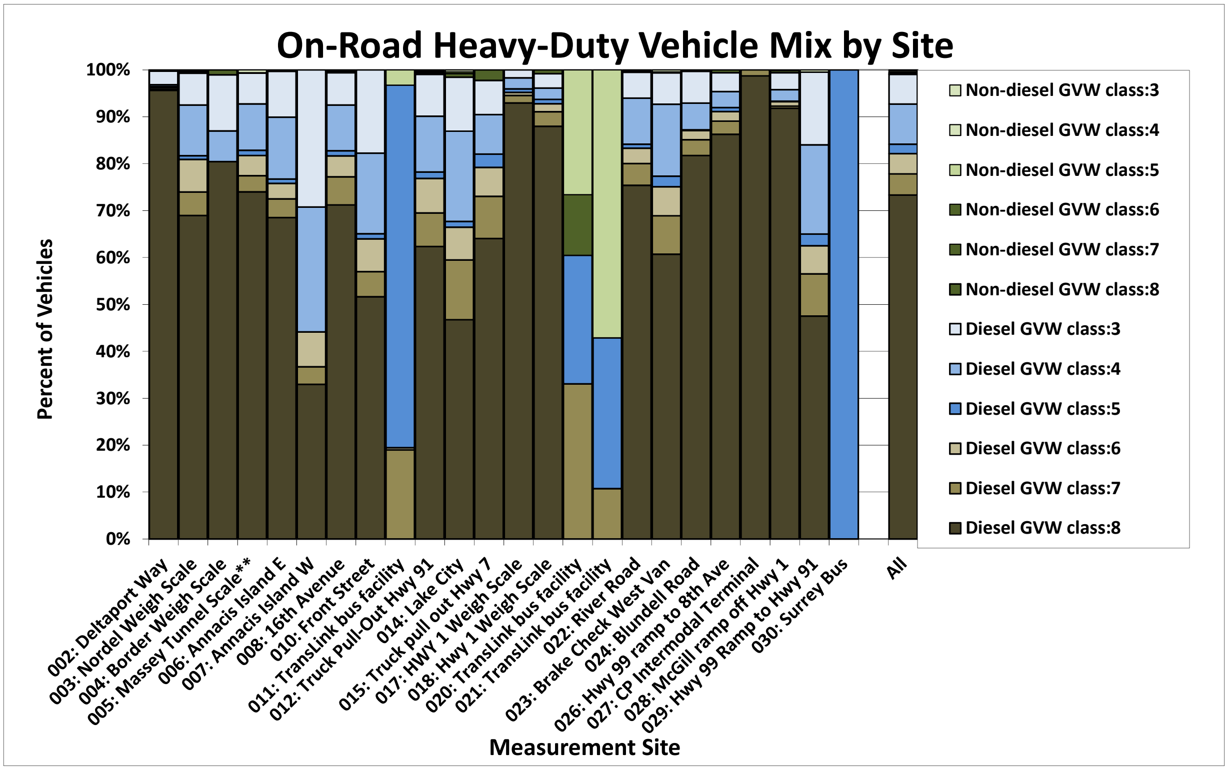



Figure III-5 and Table III-6 show the mix by site. Sites near ports and the weigh scales saw predominantly class 8 trucks. Twenty to fifty percent of trucks observed at other on-road sites were classes 3 to 7. Buses at transit terminals were of various weight classes and a moderate number were non-diesel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

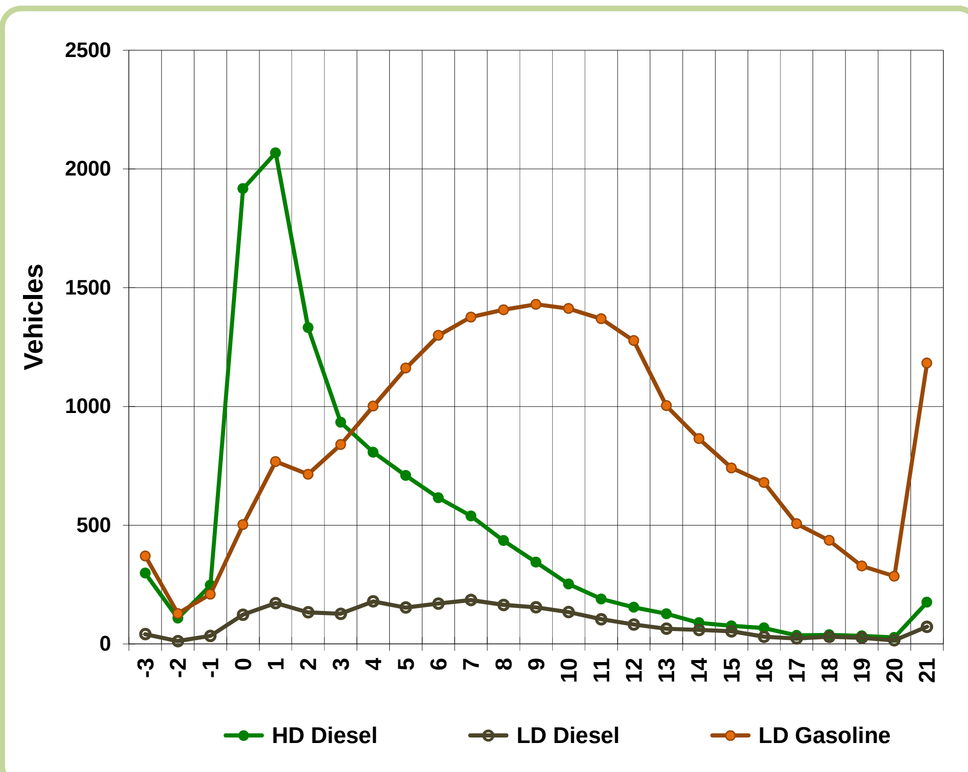
## III-6 Emissions vs. Vehicle Specific Power

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)**

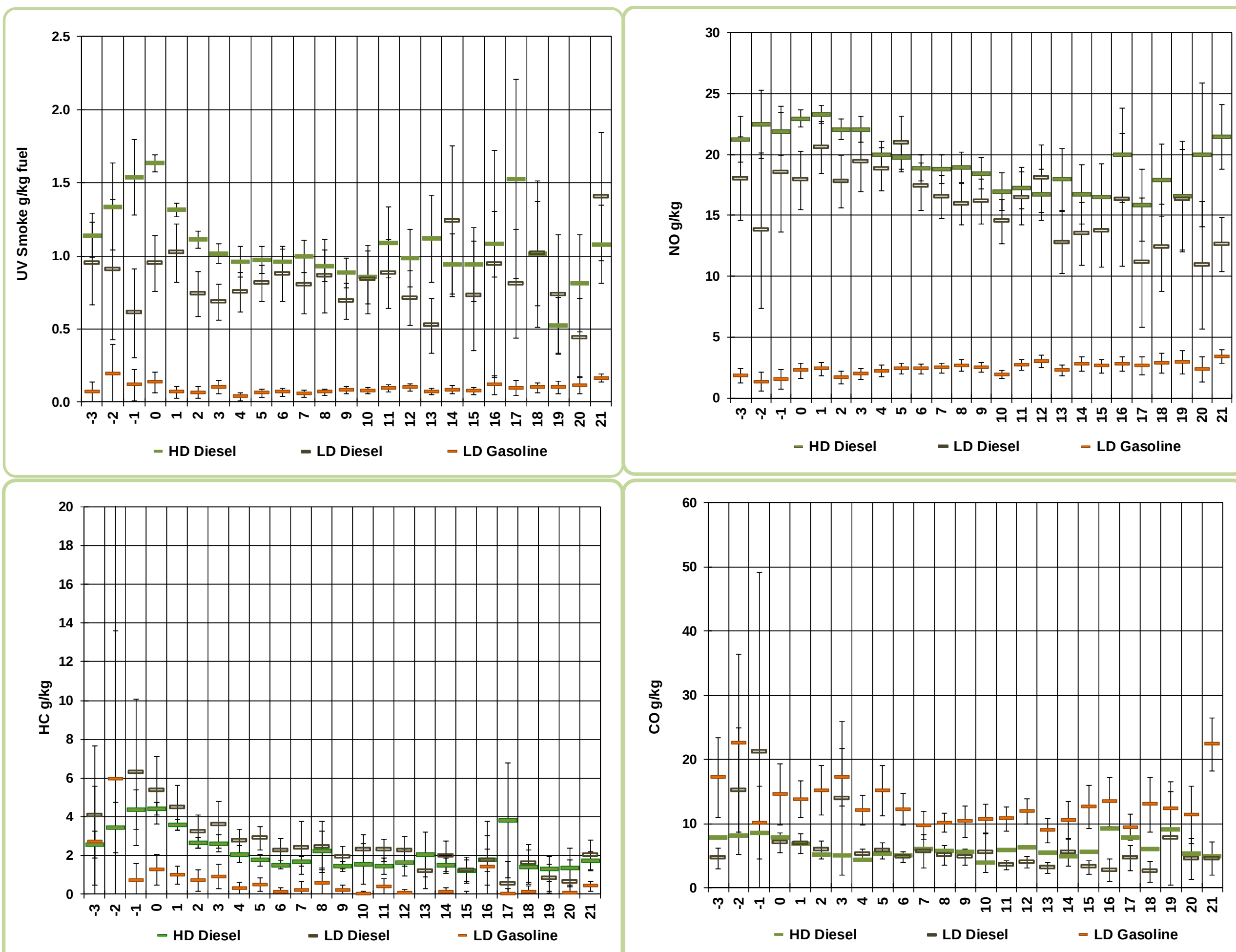


In Figure III-7, the set of four charts of emissions vs. VSP show:

- 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)**



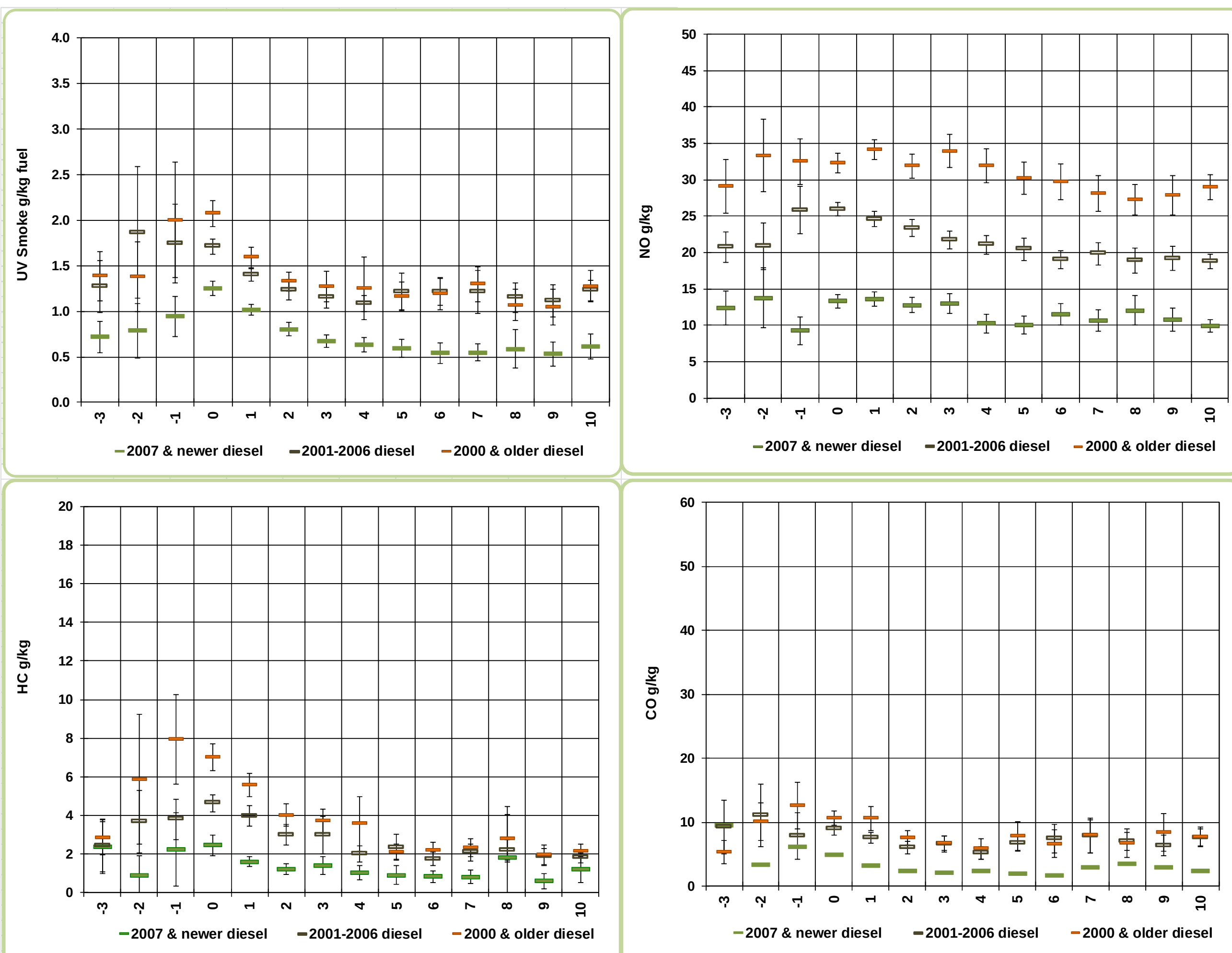

The diesel vehicles had notably higher PM, NO and HC emissions than non-diesel fueled vehicles. PM emissions were higher in the VSP range of -2 to +2 kW/t and roughly flat across the VSP range above 2 kW/t.

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:

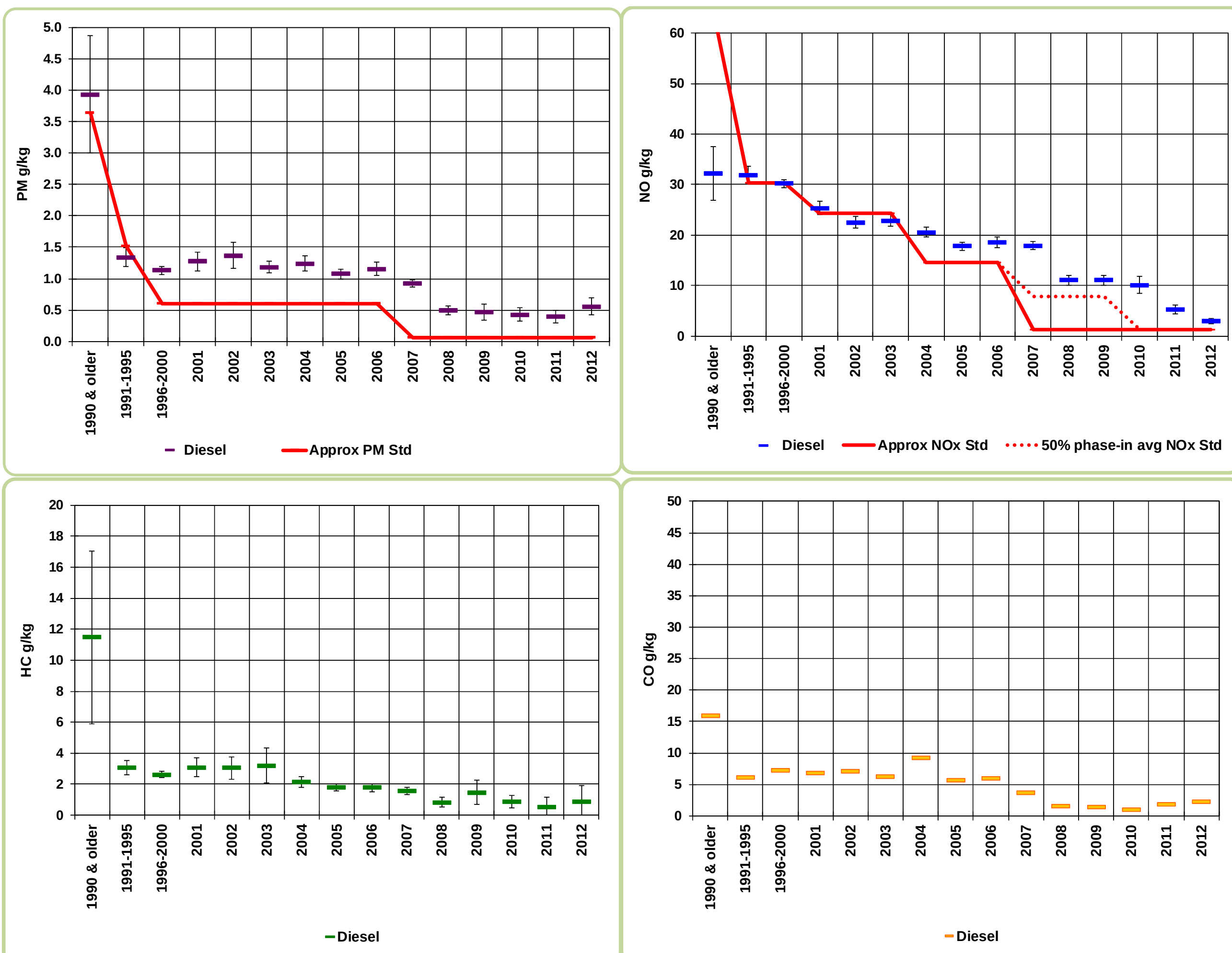
- 20 to 30 g/kg (3 to 5 g/bhp-hr) range for 2007 and older models; and
- declining emissions from 10 g/kg (2 g/bhp-hr) for 2008 models to 3 g/kg (0.5 g/bhp-hr) for 2012 models.

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

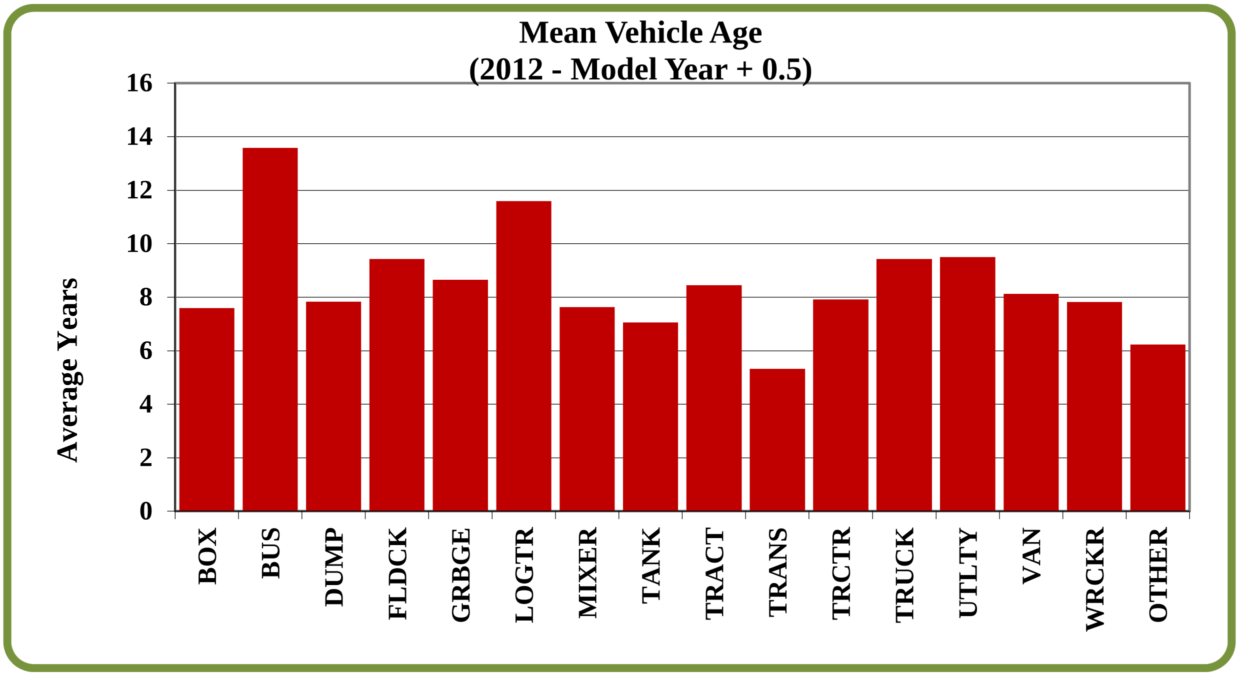



Figure IV-3 Heavy-duty Vehicles by Body Style: VSP kW/t

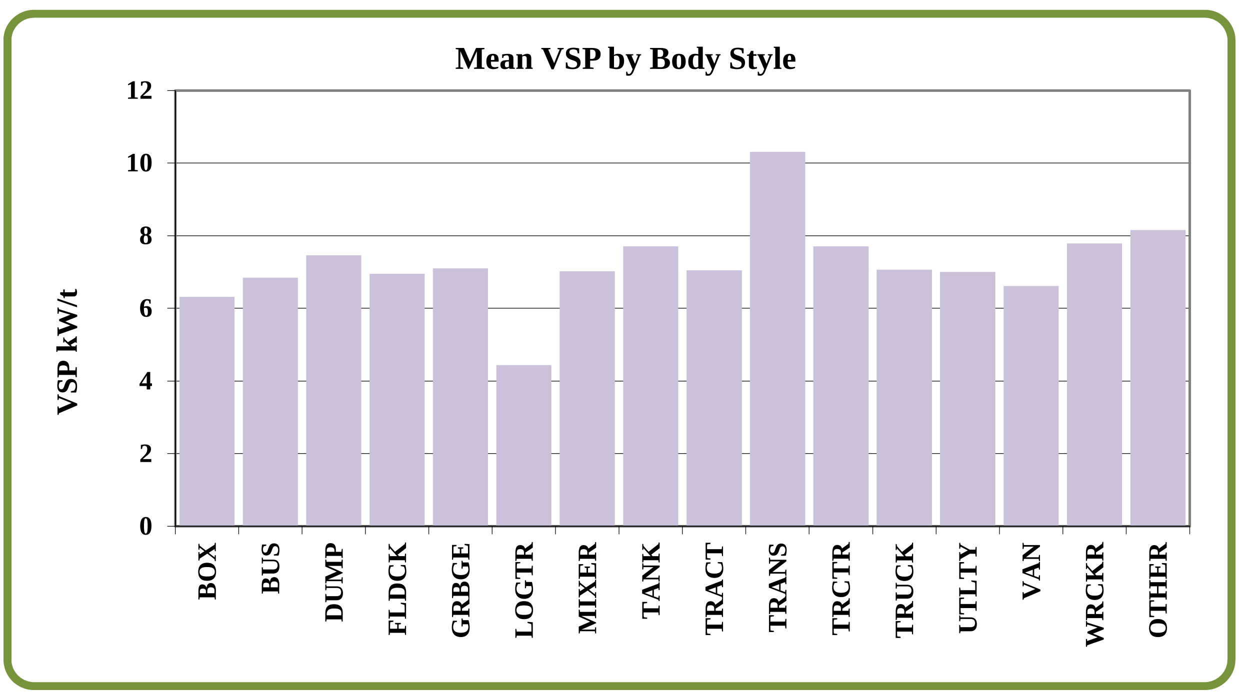


Figure IV-4 Heavy-duty Vehicles by Body Style: PM g/kg

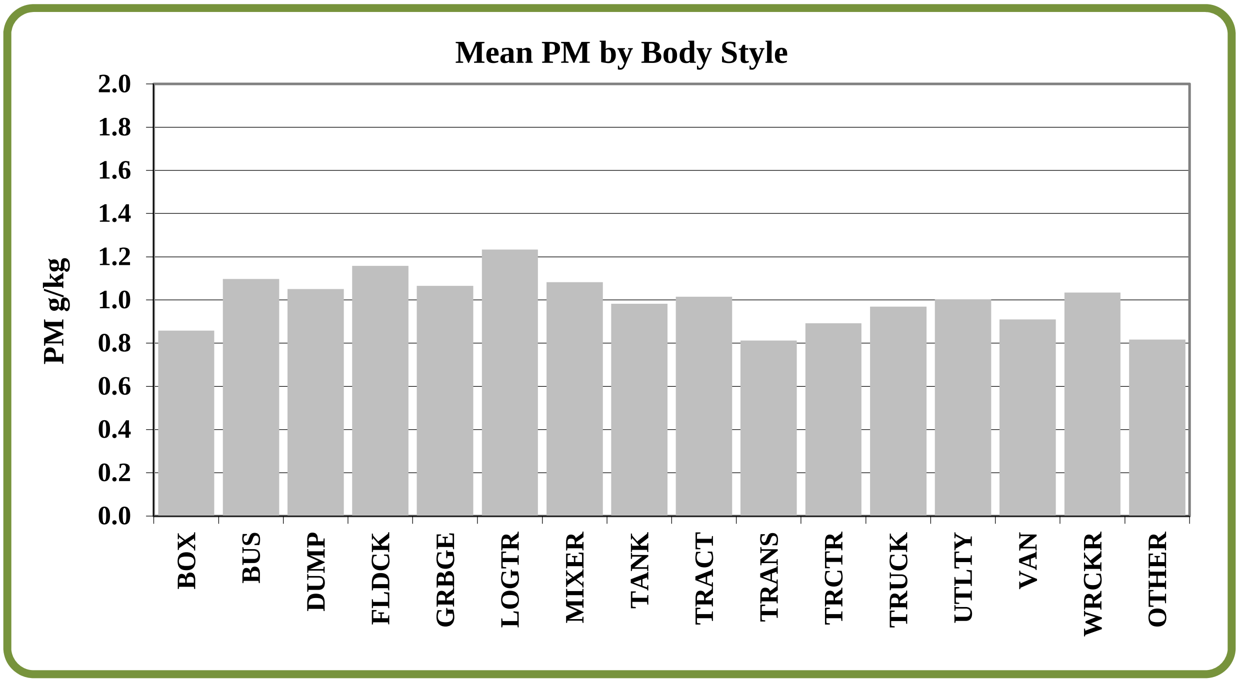
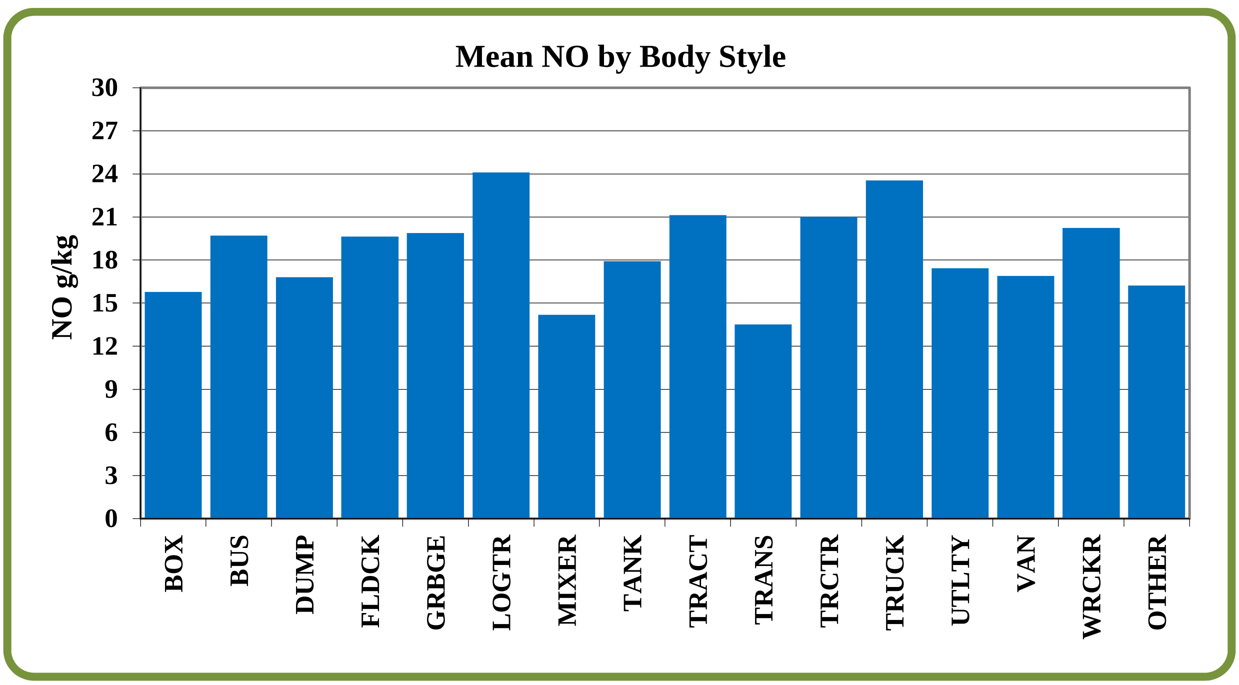



Figure IV-5 Heavy-duty Vehicles by Body Style: NO g/kg



## 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

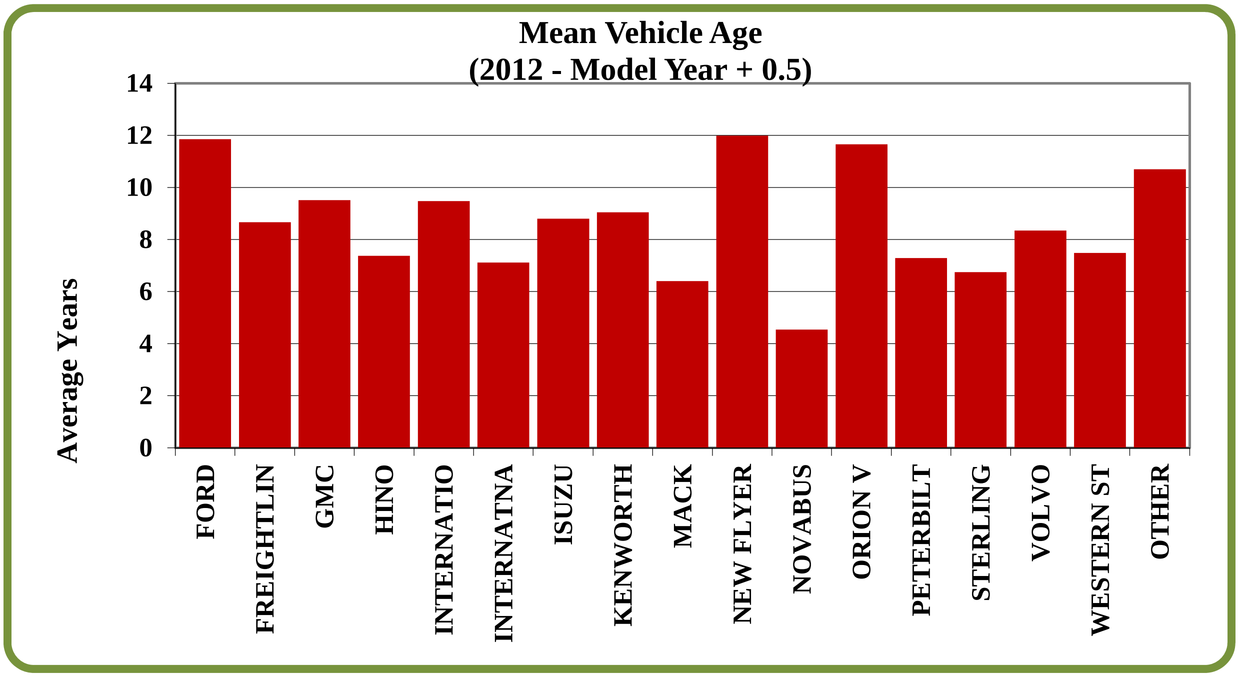
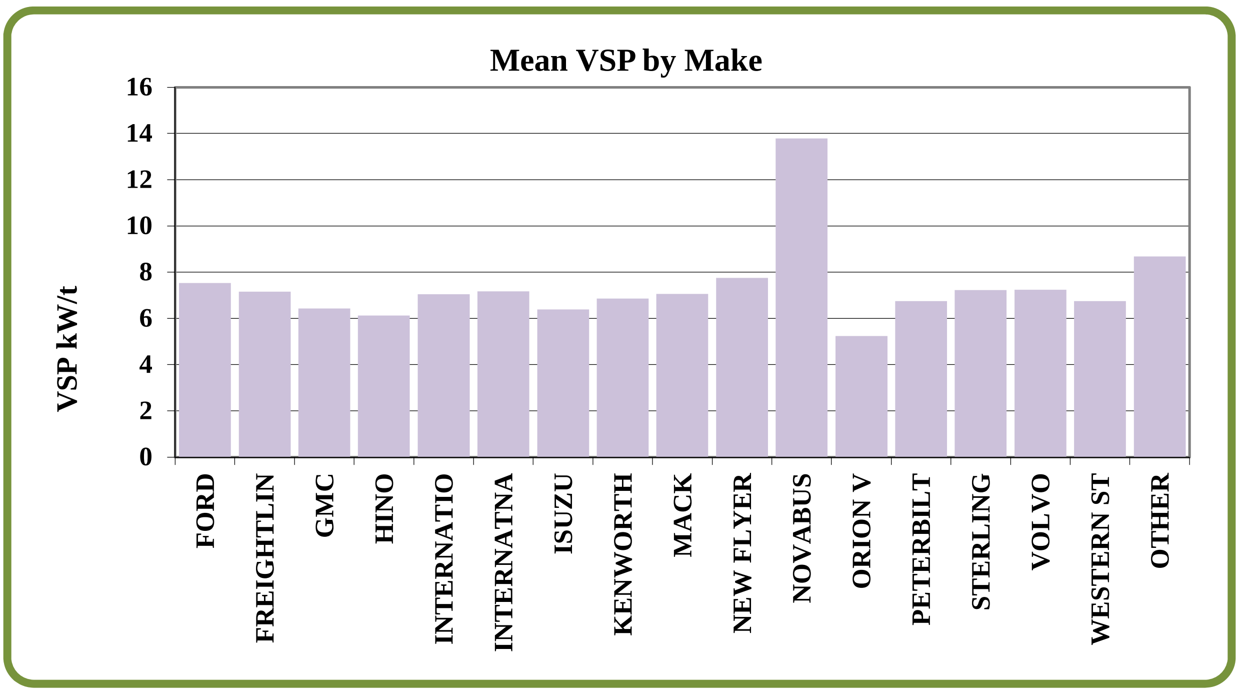
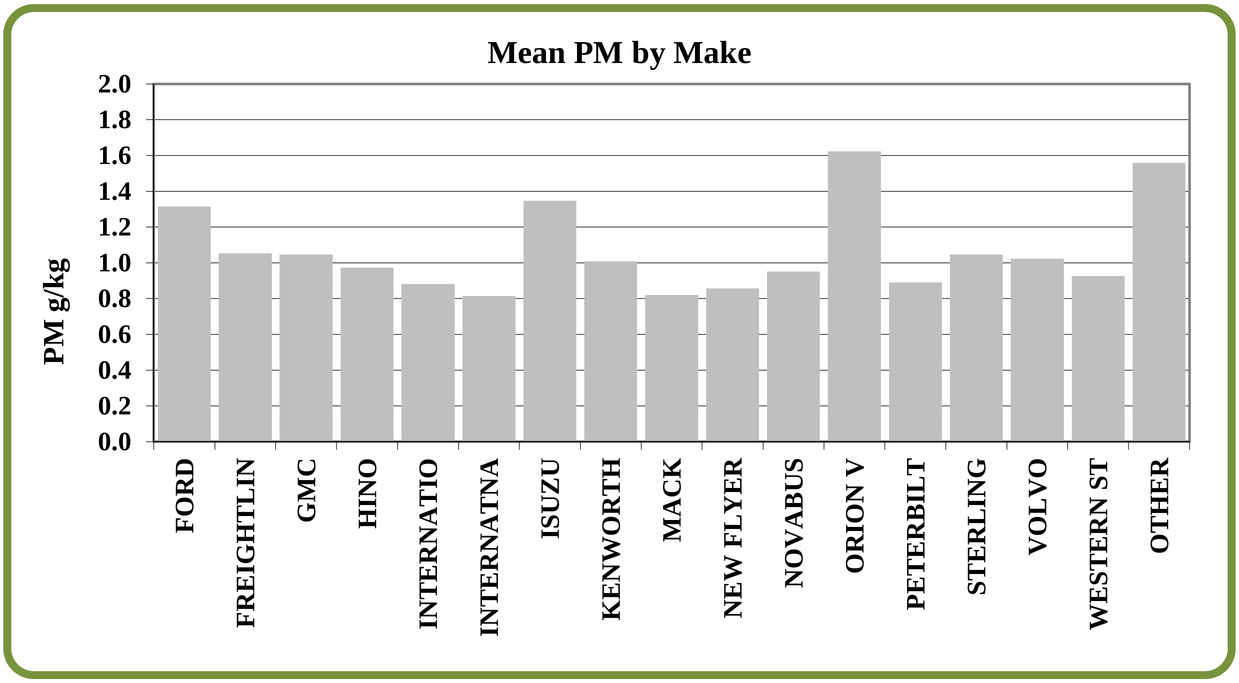


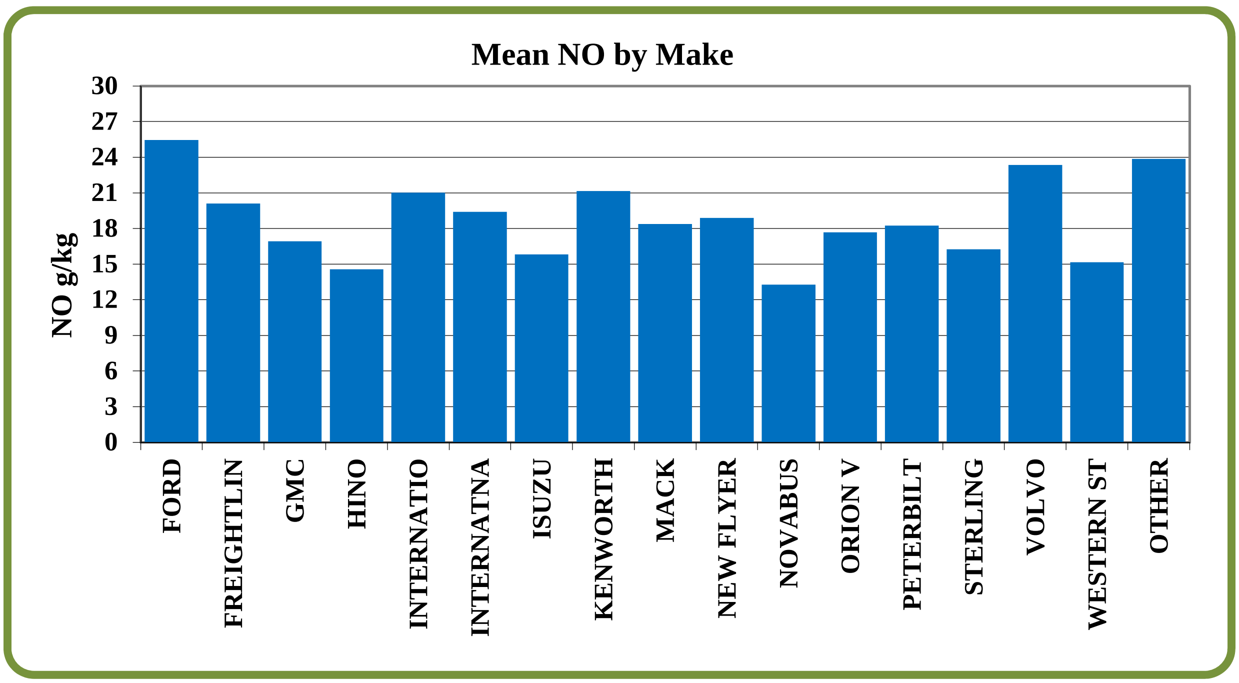

Figure IV-7 Heavy-duty Vehicles by Make: VSP kW/t



## 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

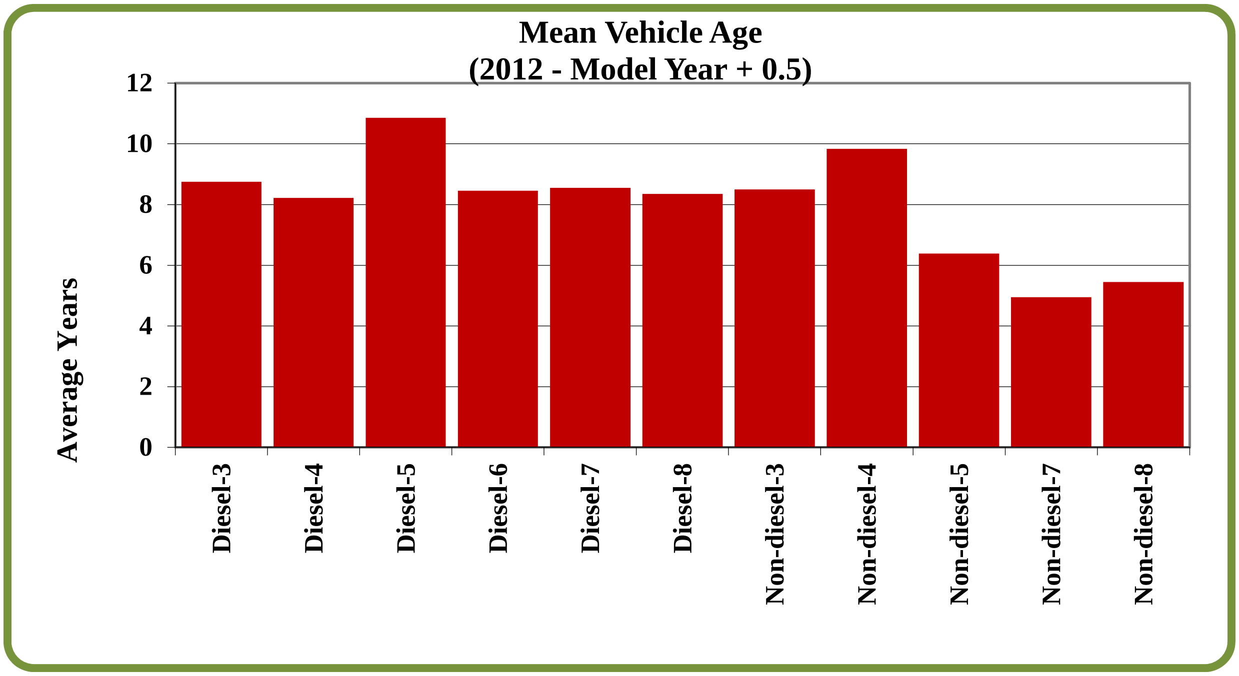



Figure IV-11 Heavy-duty Vehicles by Fuel & Weight Class: VSP kW/t

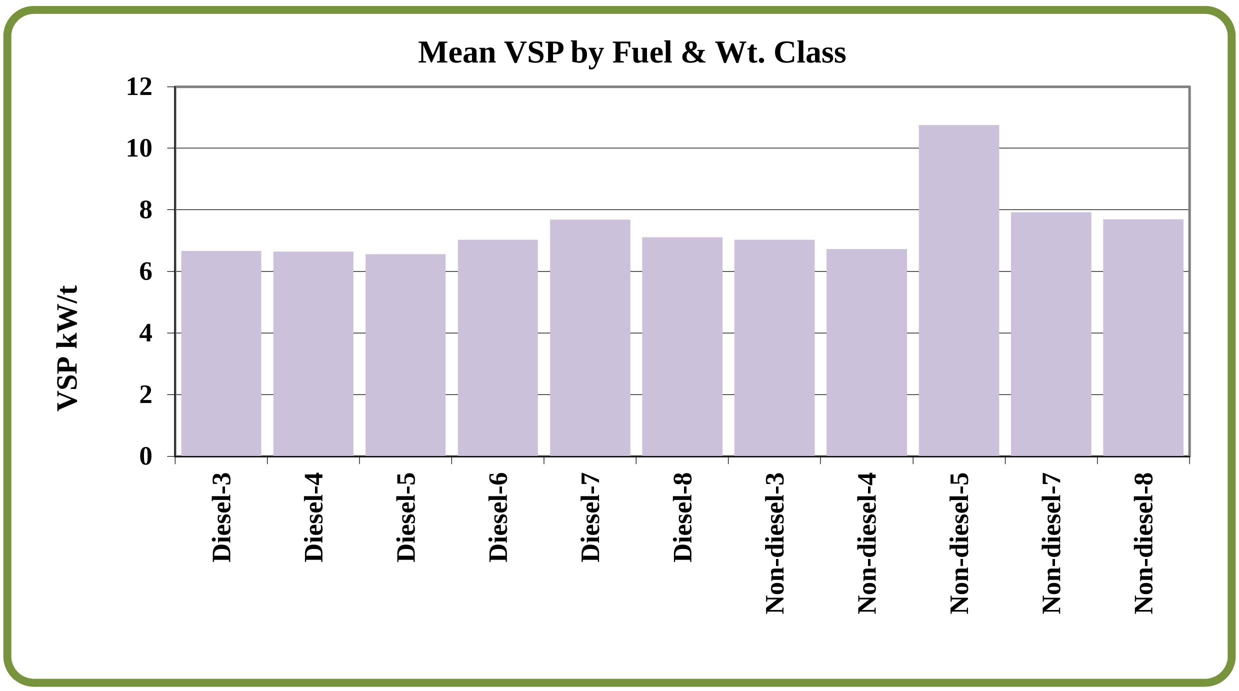


Figure IV-12 Heavy-duty Vehicles by Fuel & Weight Class:  PM g/kg

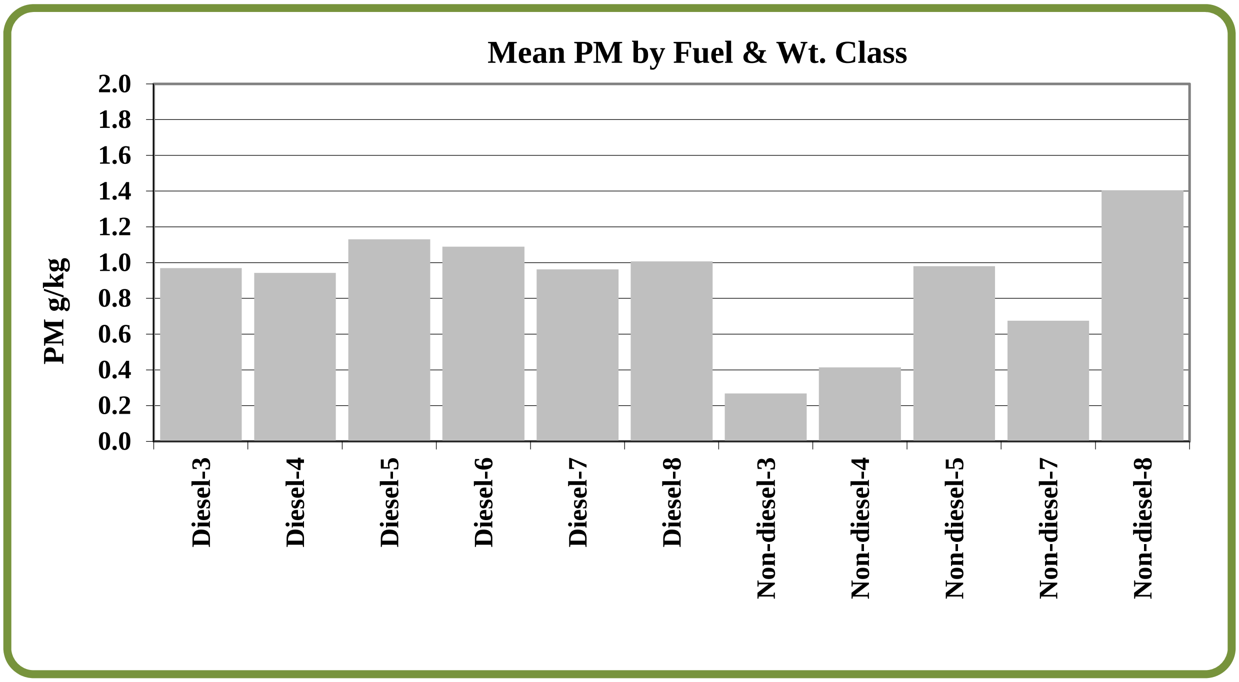
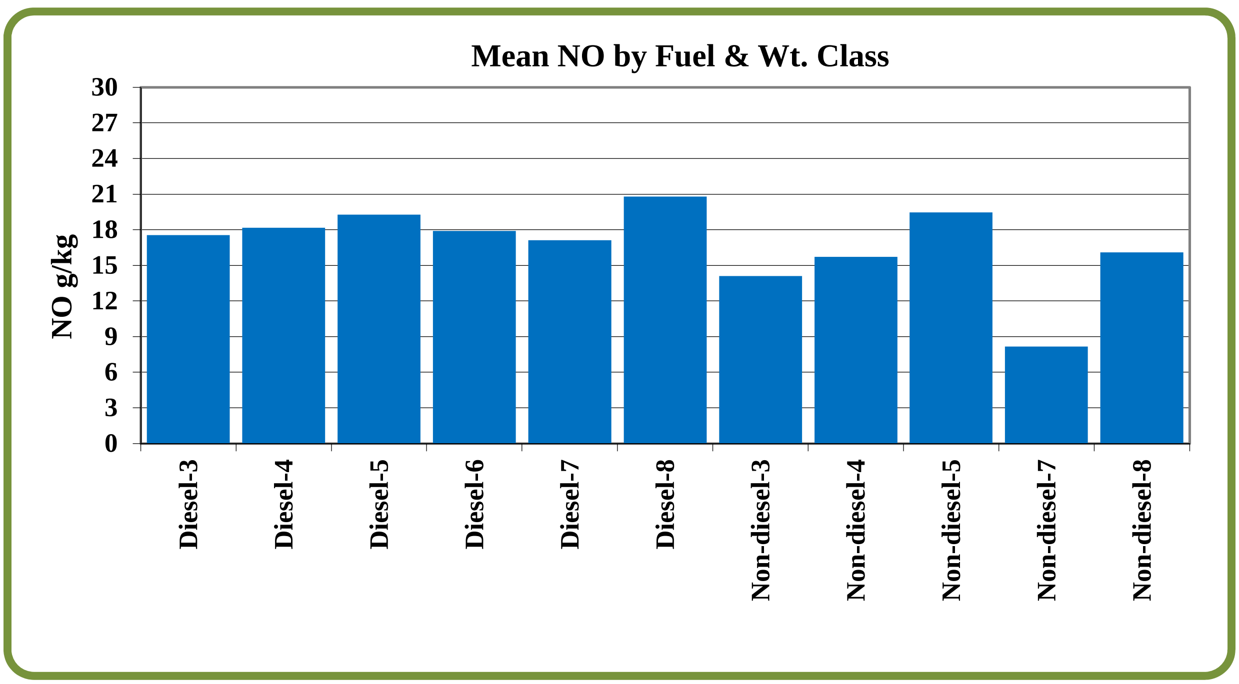



Figure IV-13 Heavy-duty Vehicles by Fuel & Weight Class:  NO g/kg



## 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

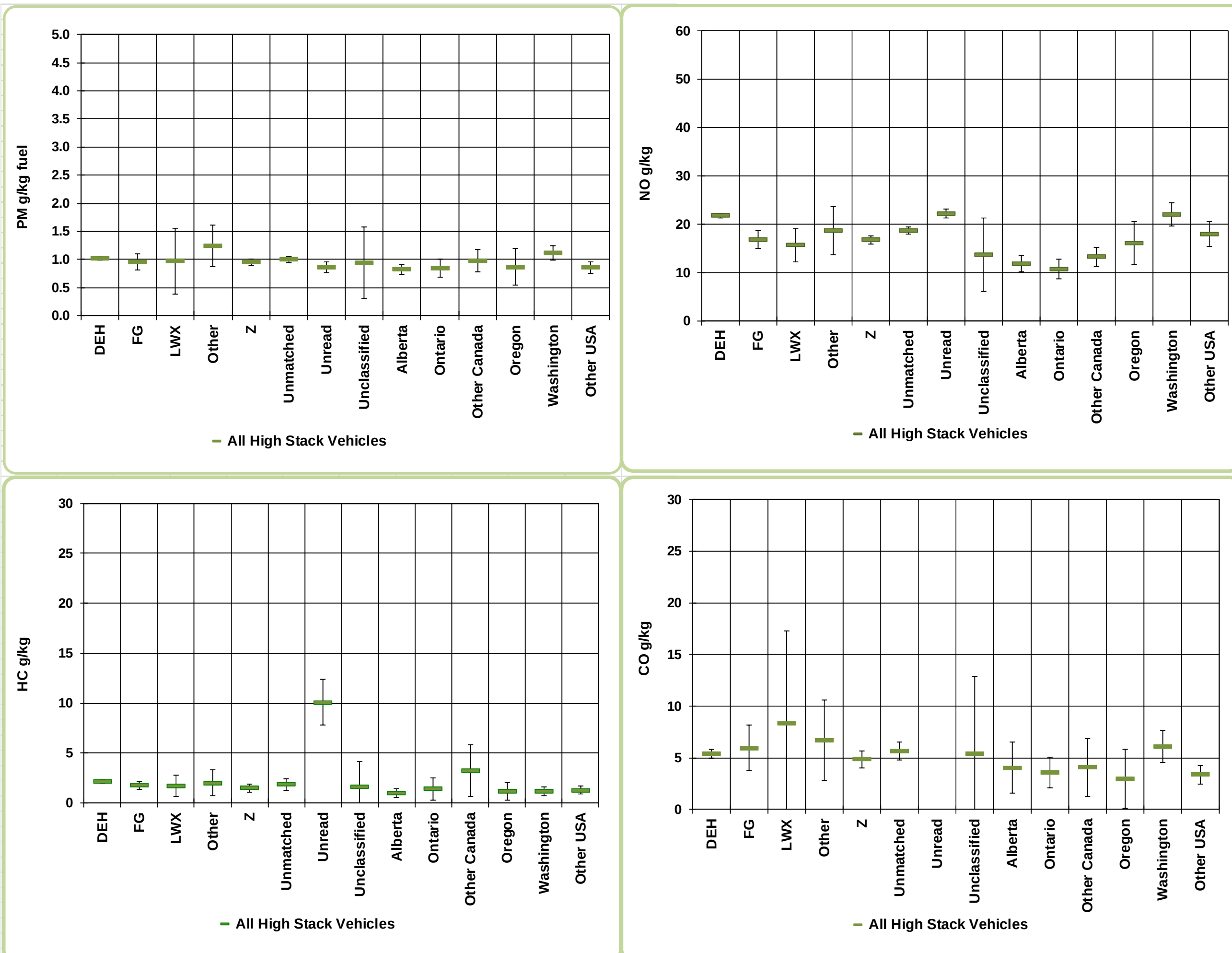


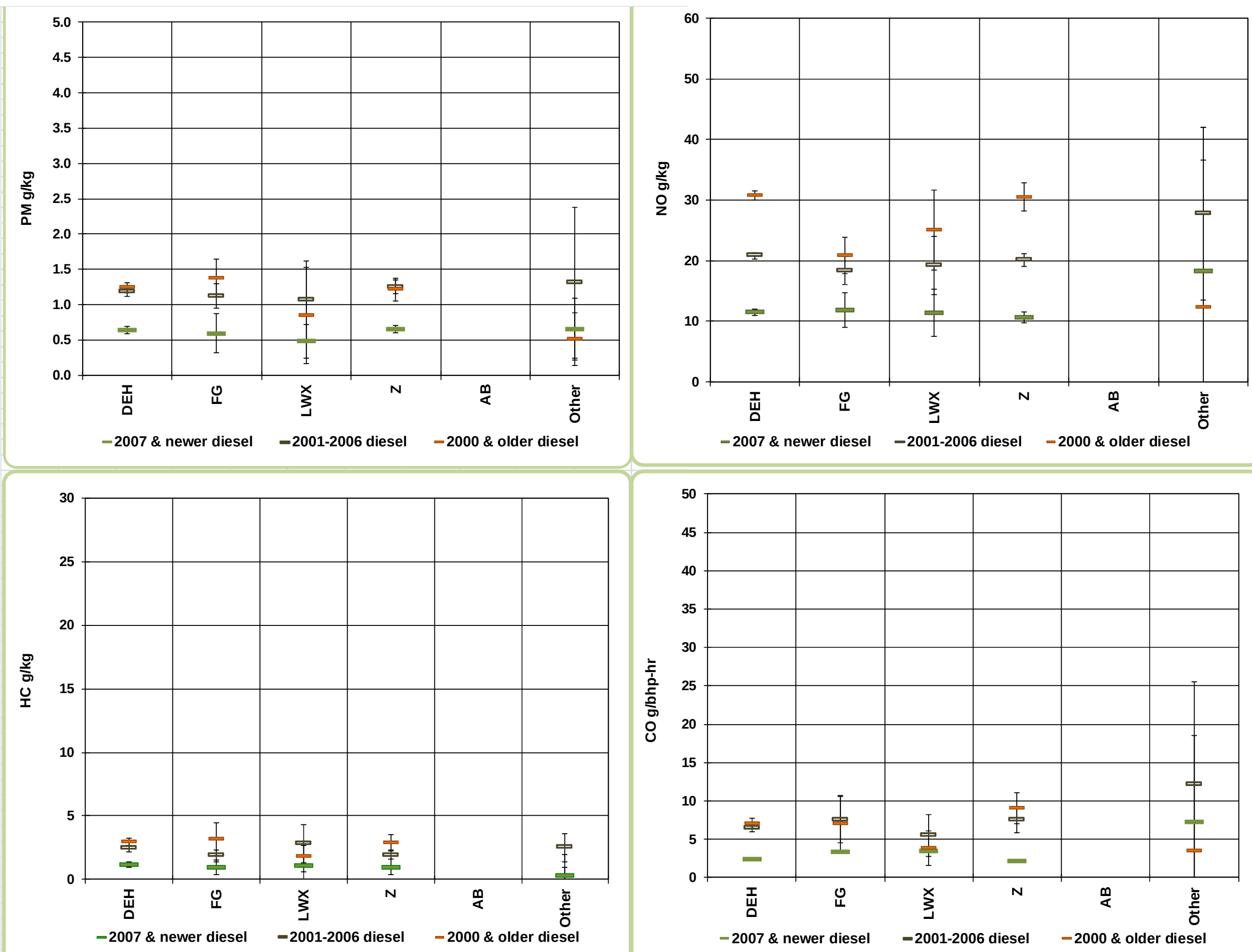

Table IV-6 shows the number of vehicles measured and Figure IV-15 shows the emissions of vehicles registered in British Columbia Territories for three age groups. Both Lower Fraser Valley vehicles (Territories D, E and H) and Territory Z vehicles had similar emissions.

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.

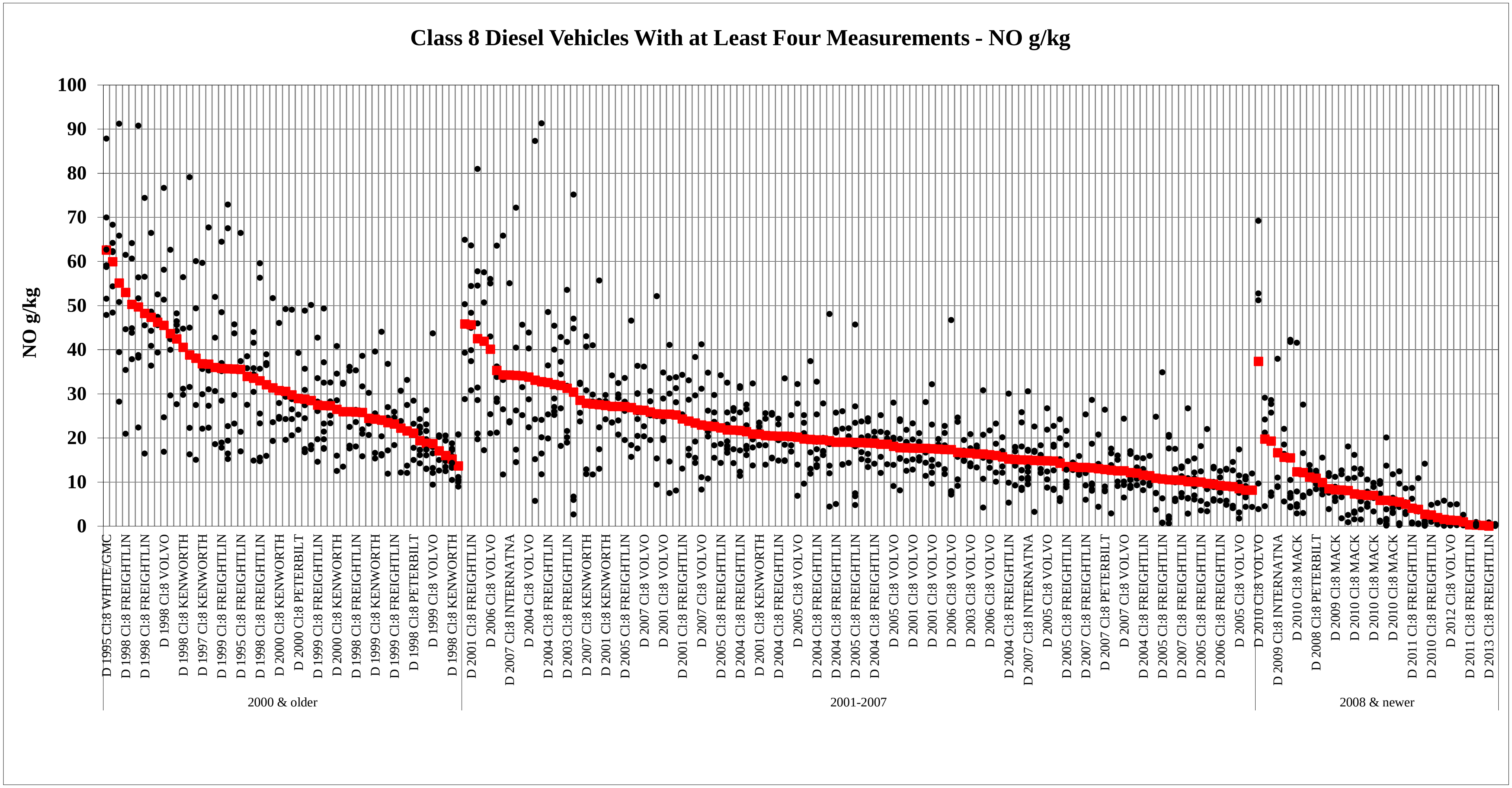
The standard deviations of measurements for each vehicle were roughly proportional to the average emissions value. Average standard deviations were 8 g/kg NO (46%) and 0.68 g/kg PM (60%).

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

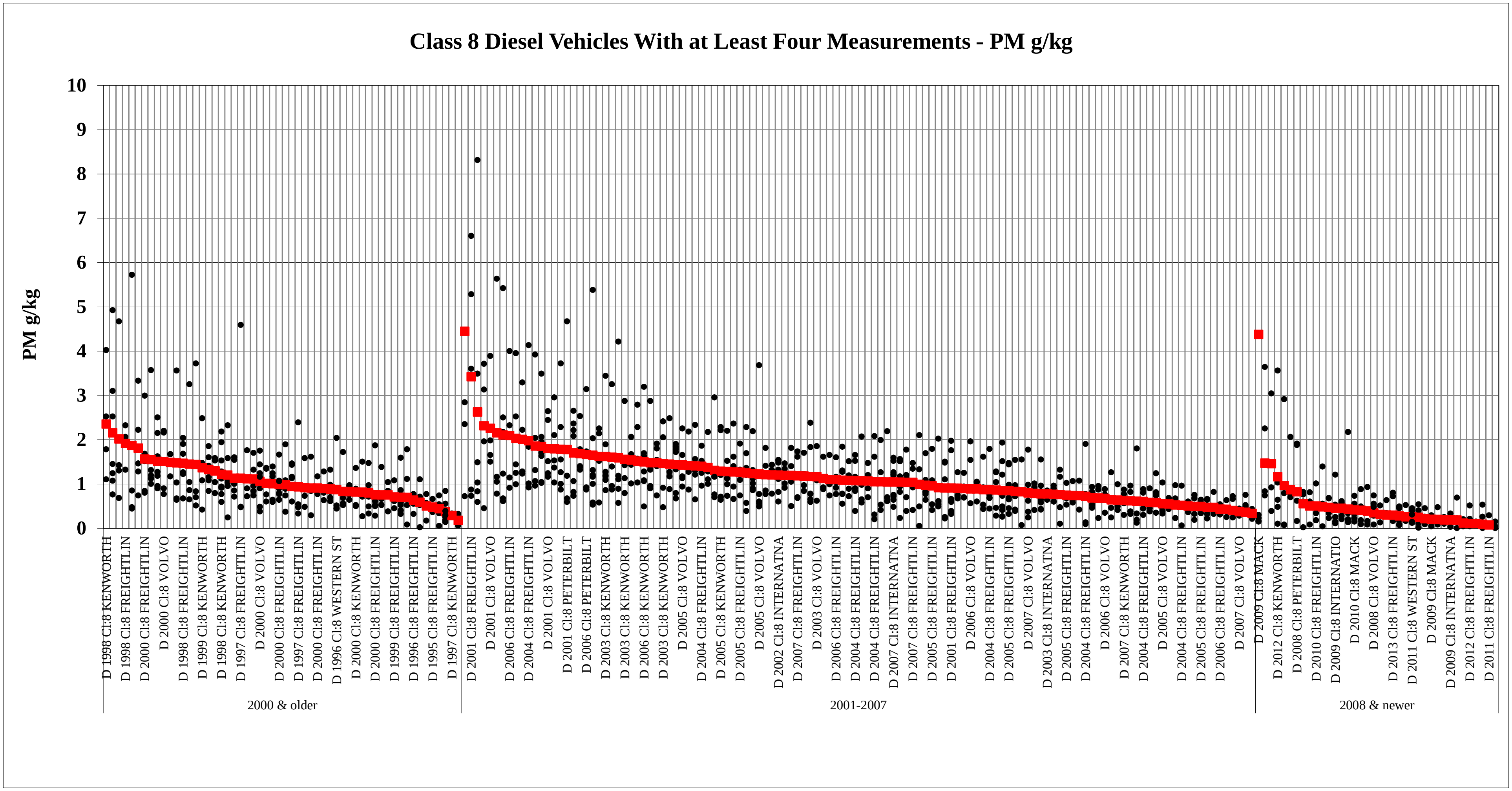


Figure IV-18: Other Fuels and Diesel Class 2-7 with Multiple NO Measurements

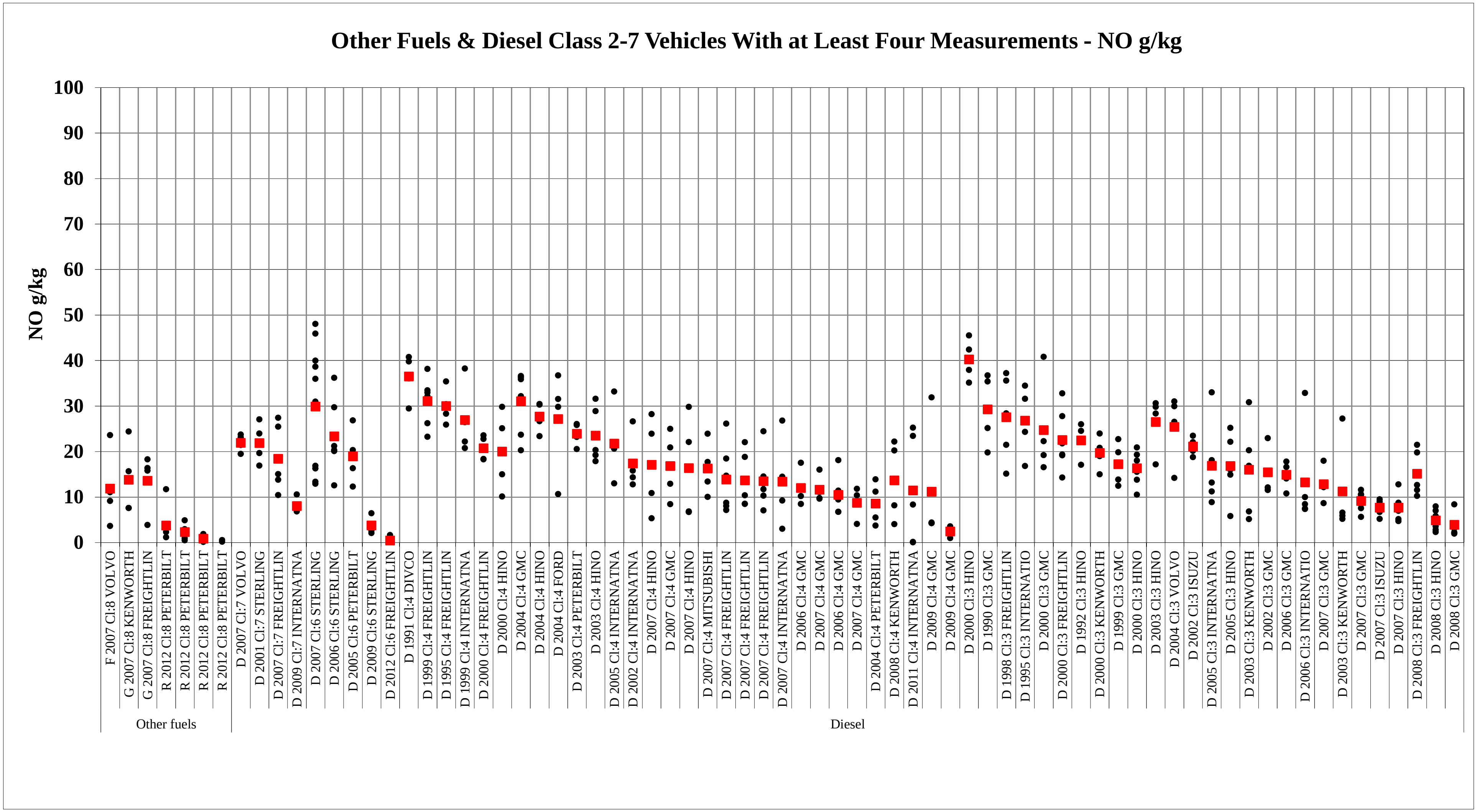
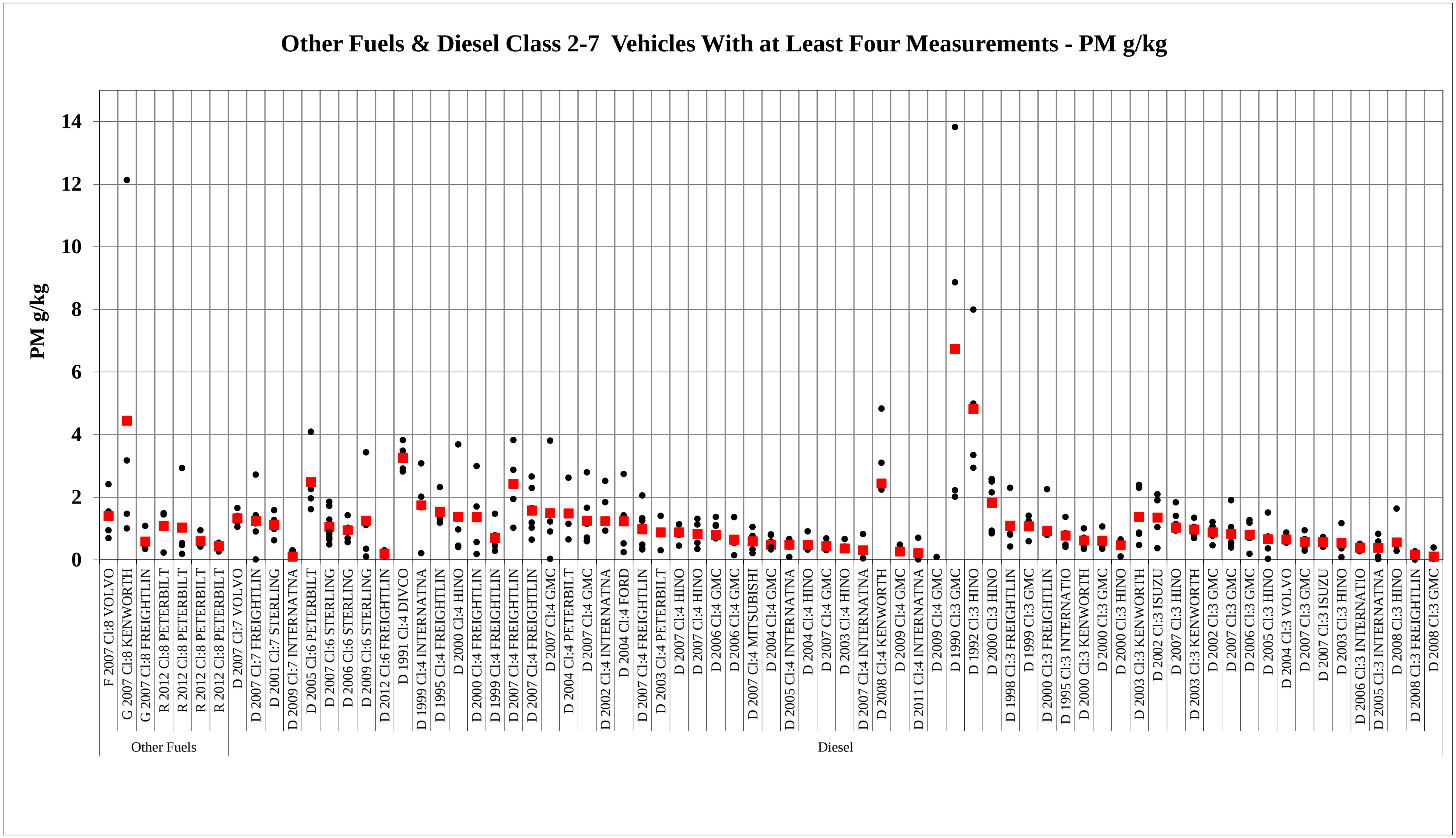


Figure IV-19: Other Fuels and Diesel Class 2-7 with Multiple UV Smoke Measurements



## 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

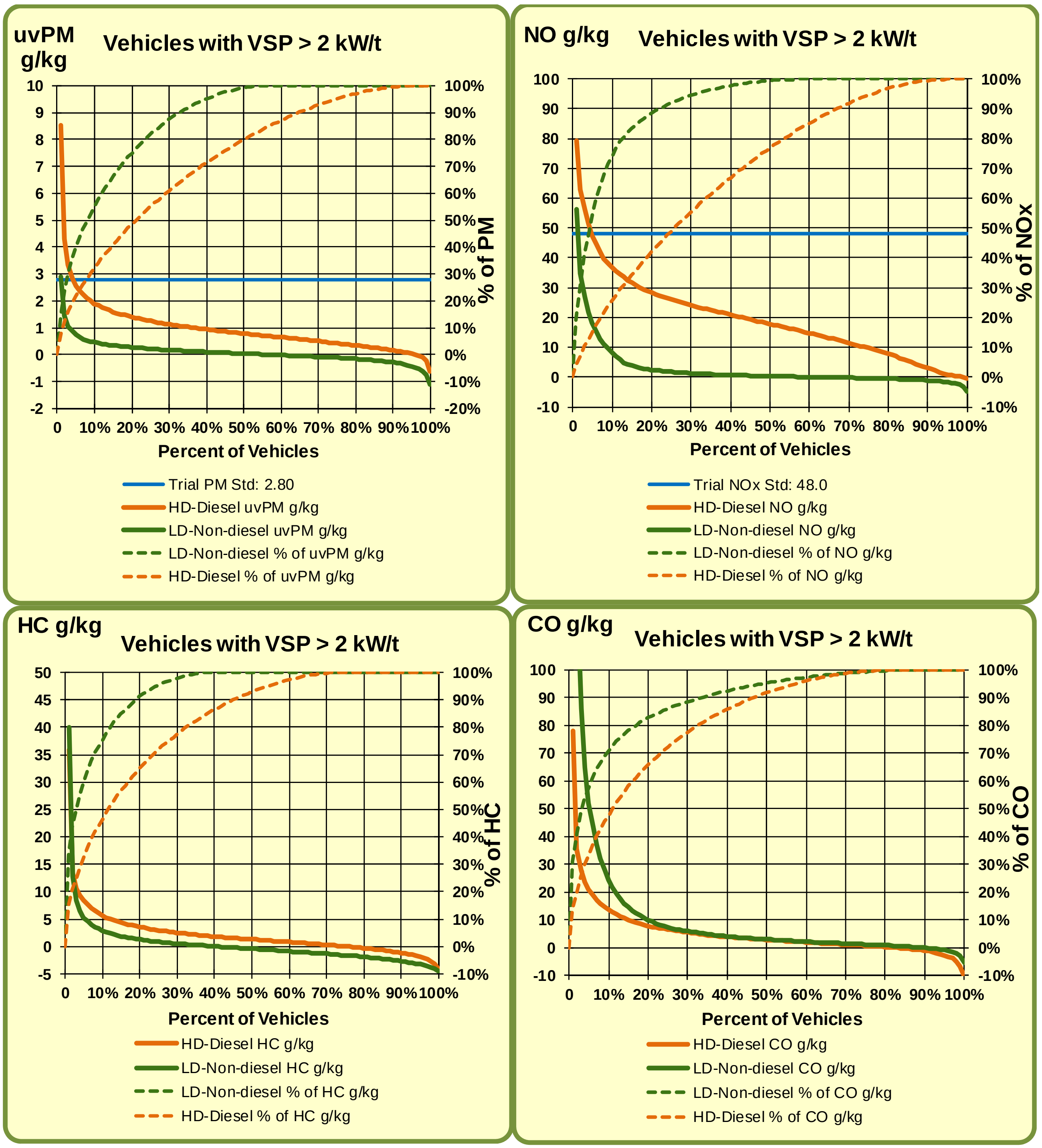


Figure IV-21: HD Diesel Emissions Distributions: MY 2008-2010 and MY 2011-2012

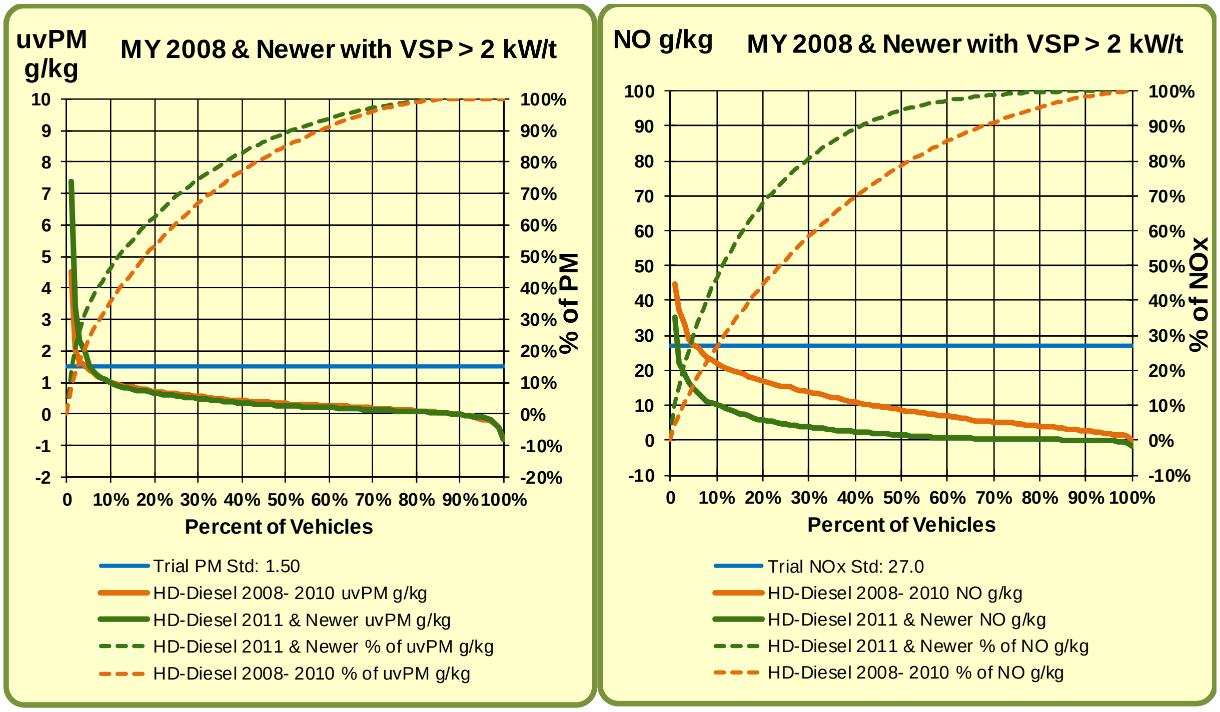



Figure IV-22: HD Diesel Emissions Distributions: MY 1997 & older and MY 1998-2007

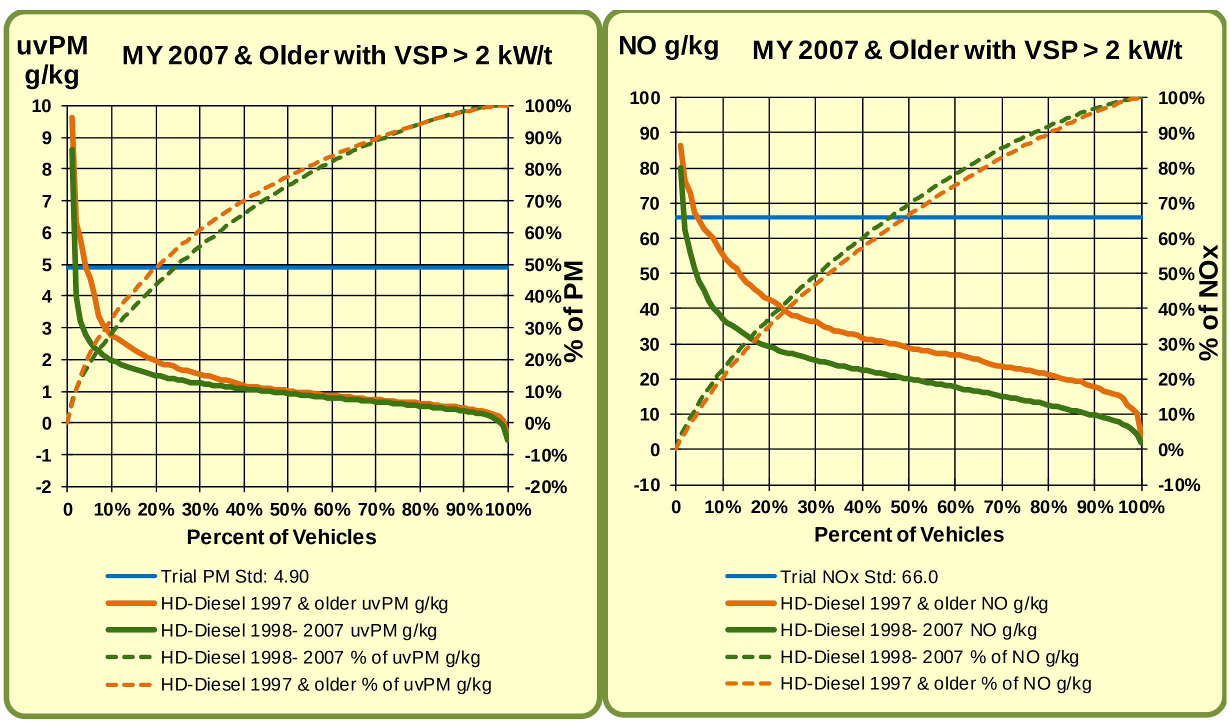


Figure IV-23: Heavy-duty Vehicle PM Deciles

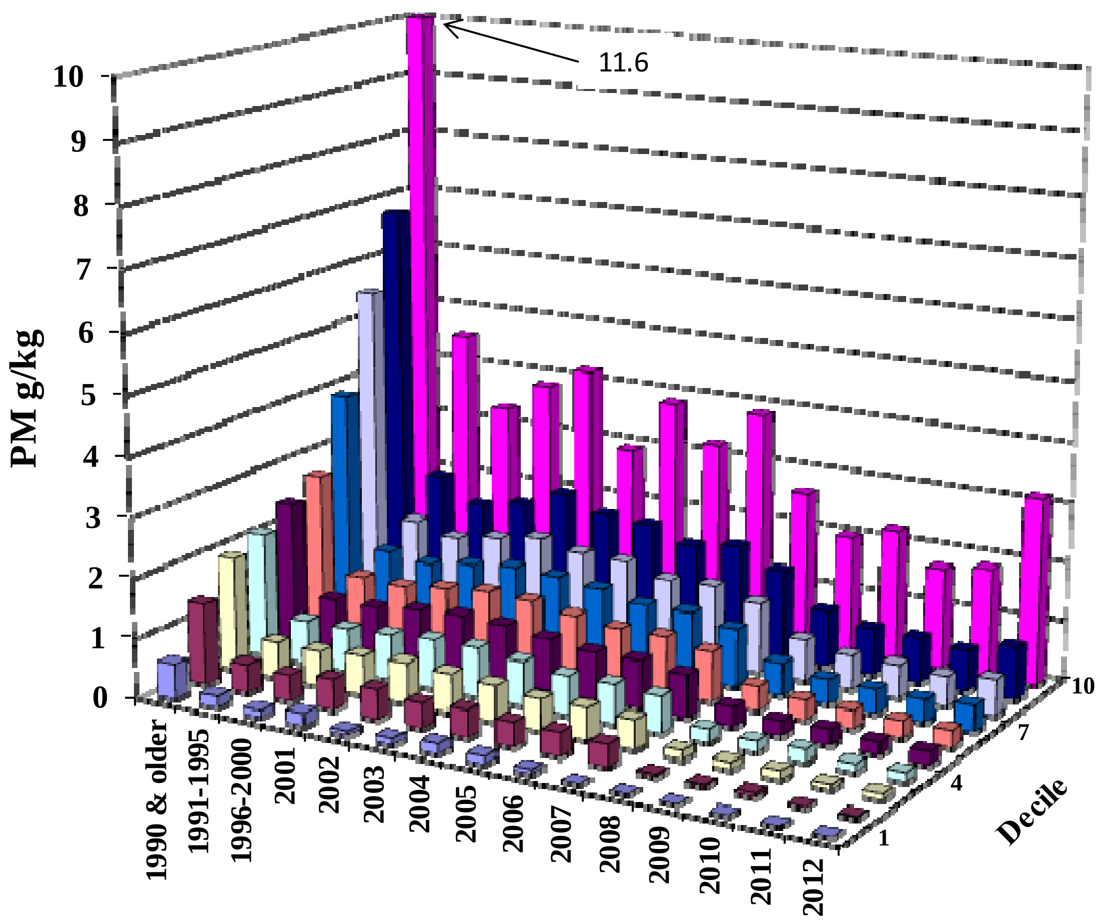
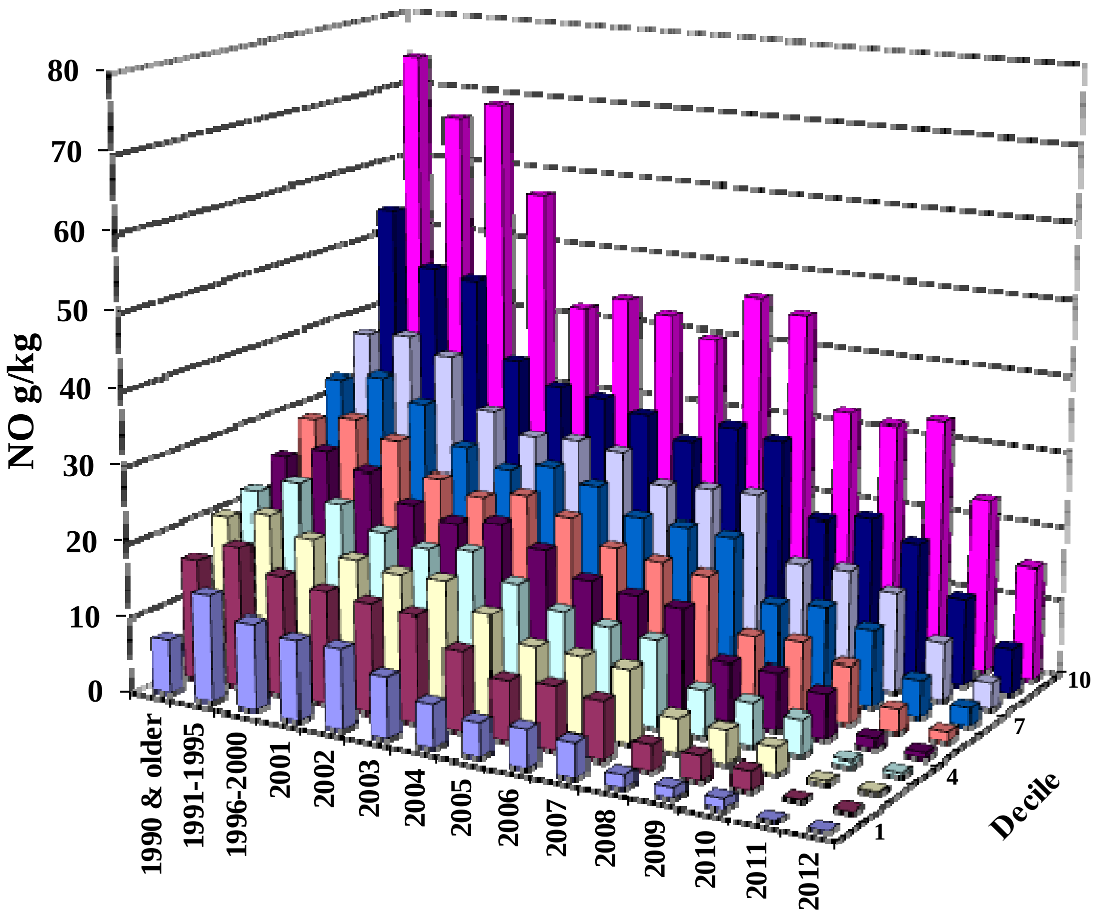


Figure IV-24: Heavy-duty Vehicle NO Deciles



# 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.

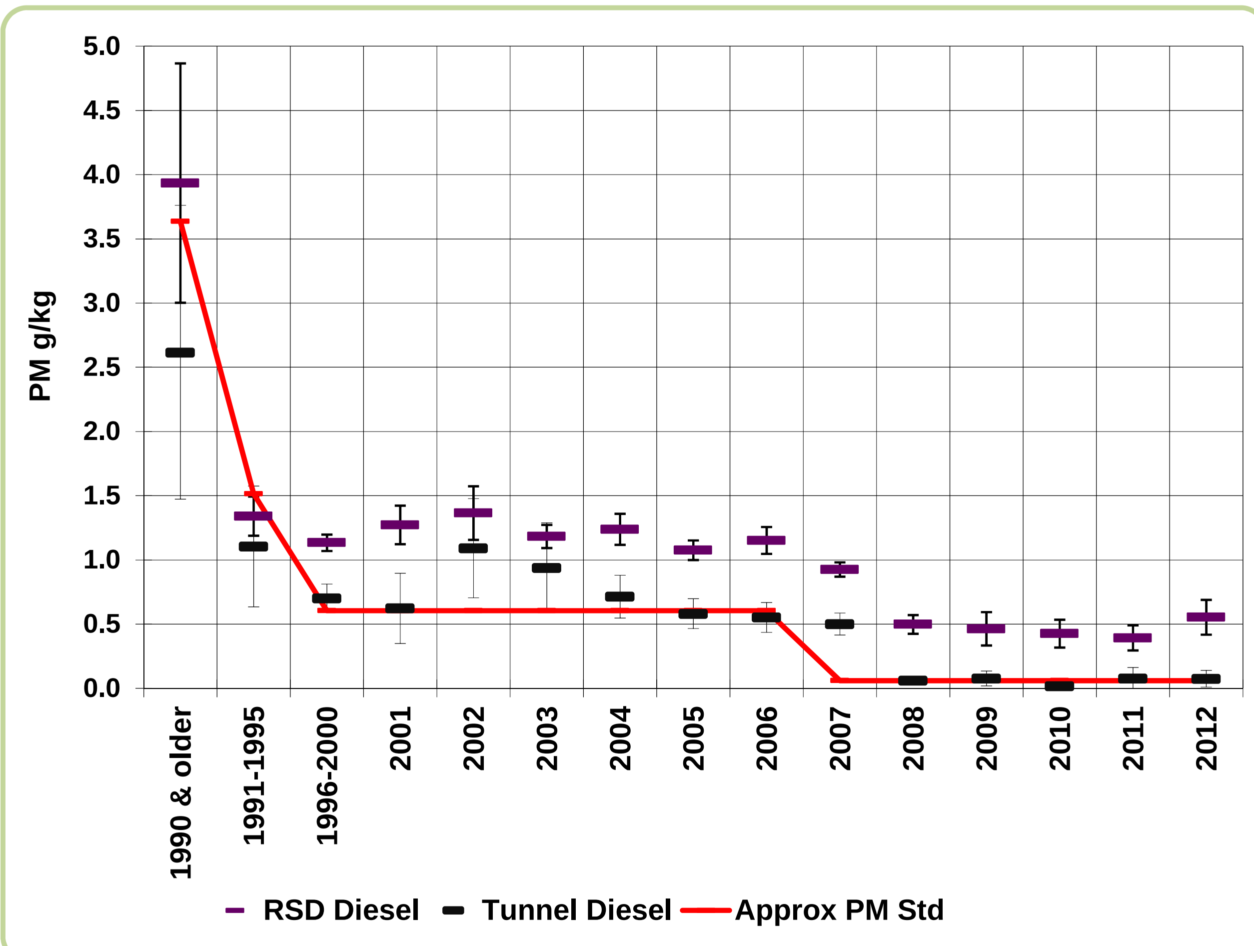
Table V-1 Heavy-duty Vehicles Measured Using the Emissions Tunnel

| 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.

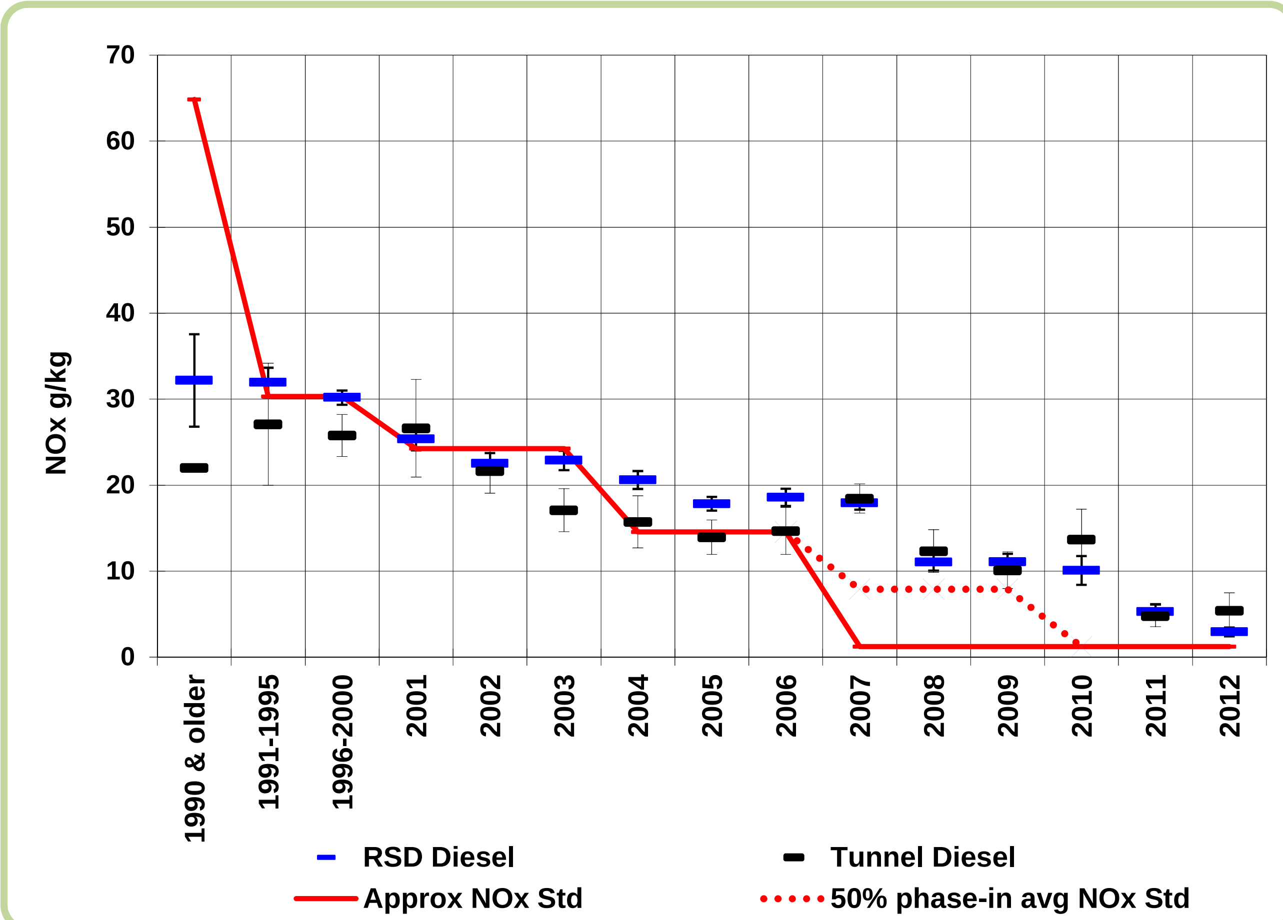
2008 to 2010 models had lower $NO_x$ than earlier models but the Tunnel equipment recorded higher total $NO_x$ than RSD. Since these models had low PM, we assume most, if not all, were equipped with DPFs that may have oxidized some NO to $NO_2$. In table V-1, the NO/$NO_x$ percentages were lower for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

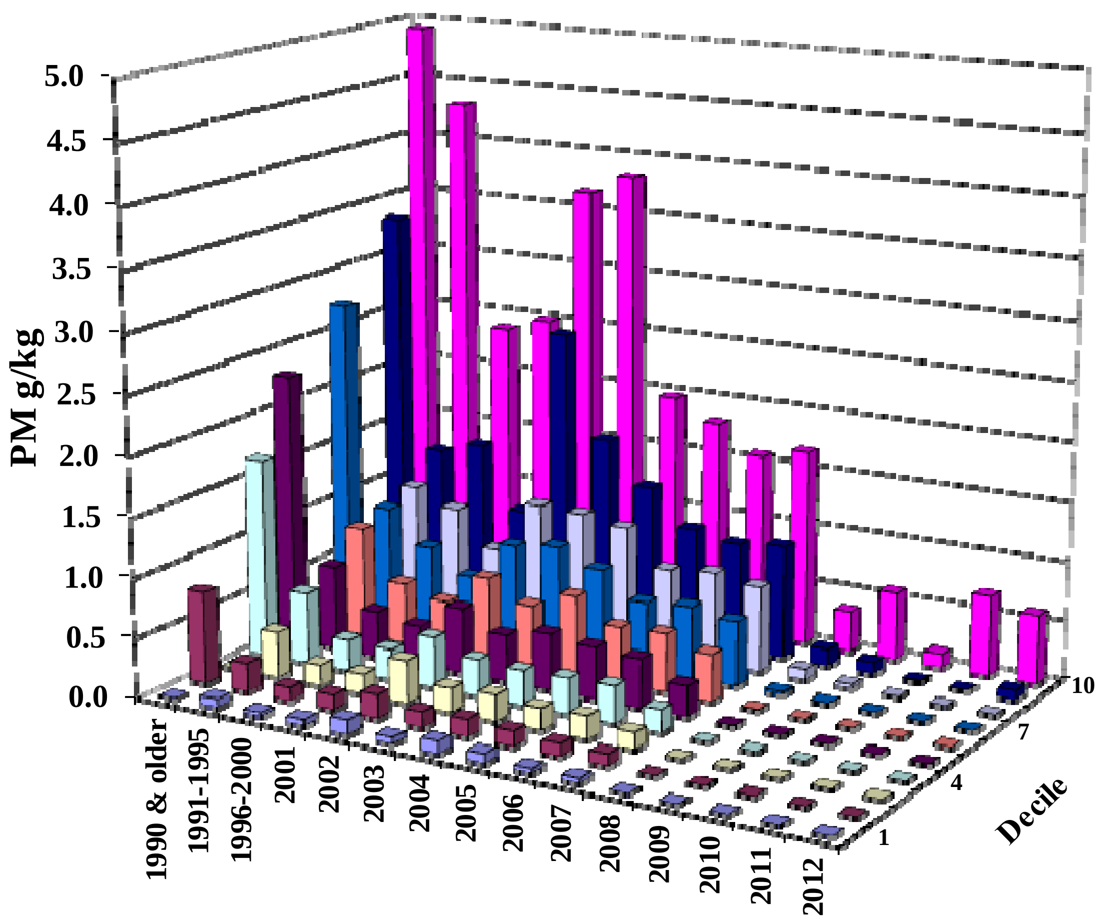


Figure V-4: Heavy-duty Tunnel Vehicle Black Carbon Deciles

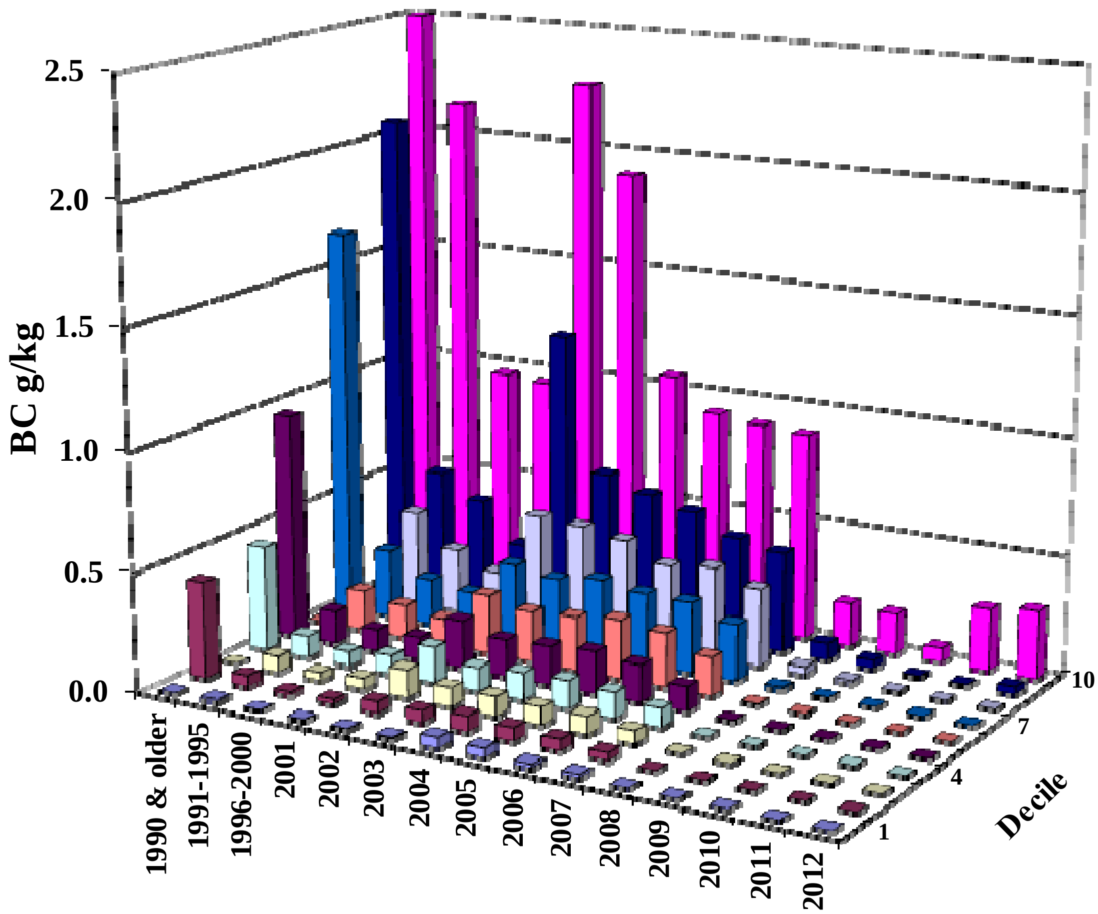


Figure V-5: Heavy-duty Tunnel Vehicle CO Deciles

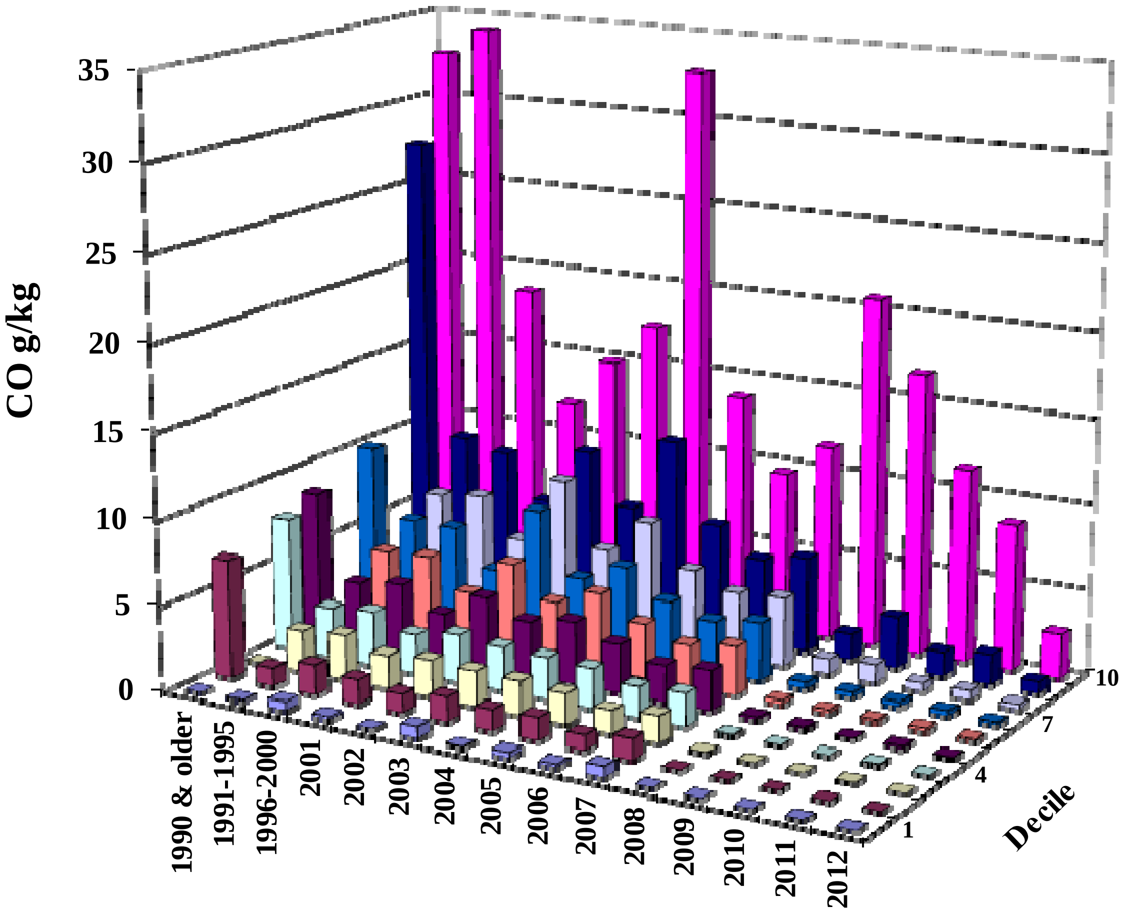


Figure V-6: Heavy-duty Tunnel Vehicle NOx Deciles

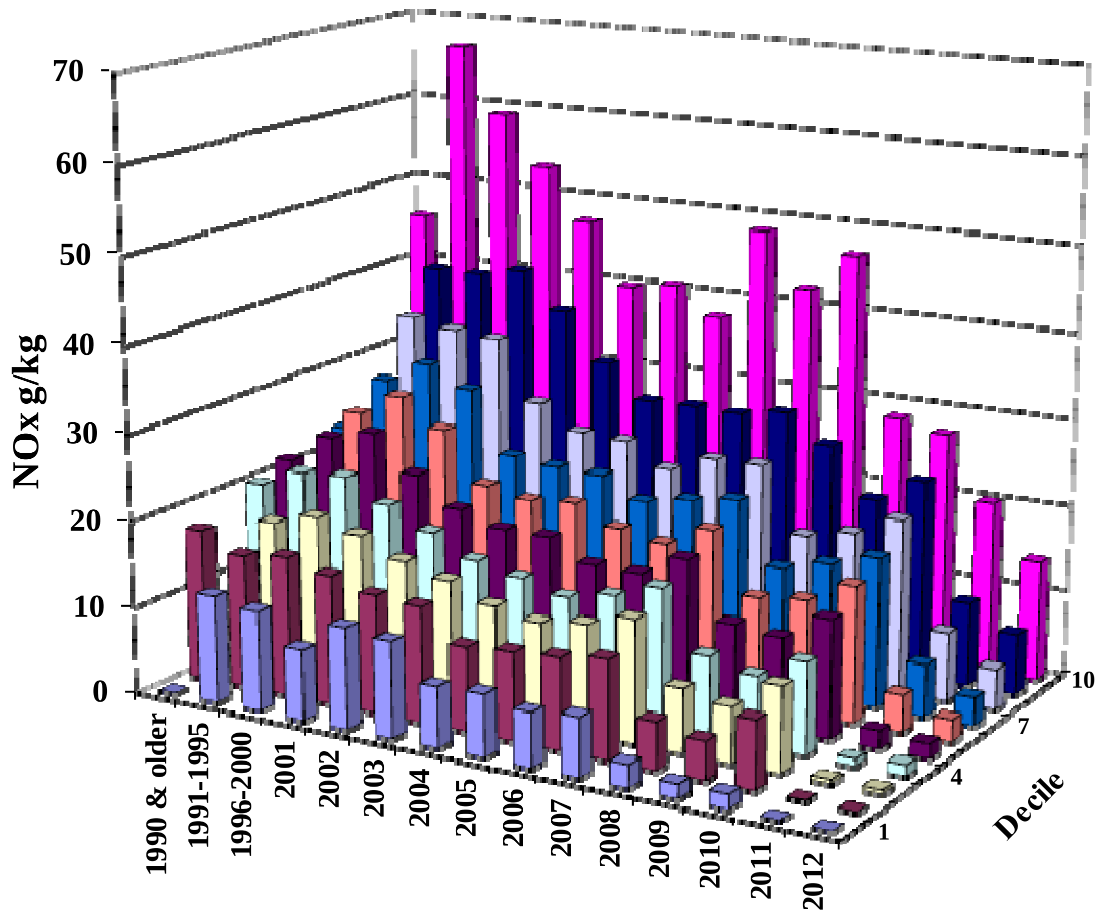


Figure V-7: Heavy-duty Tunnel Vehicle NO2 Deciles

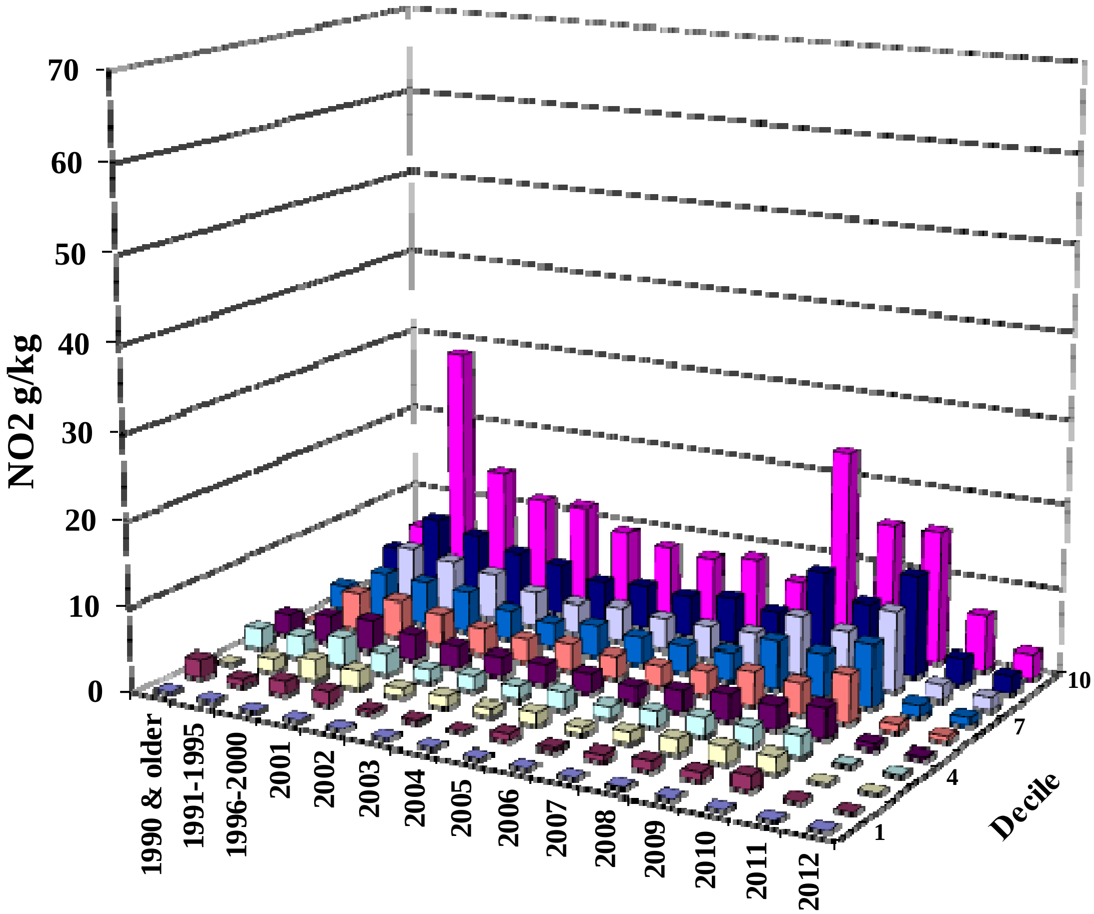


Figure V-8: Heavy-duty Tunnel Vehicle NO Deciles

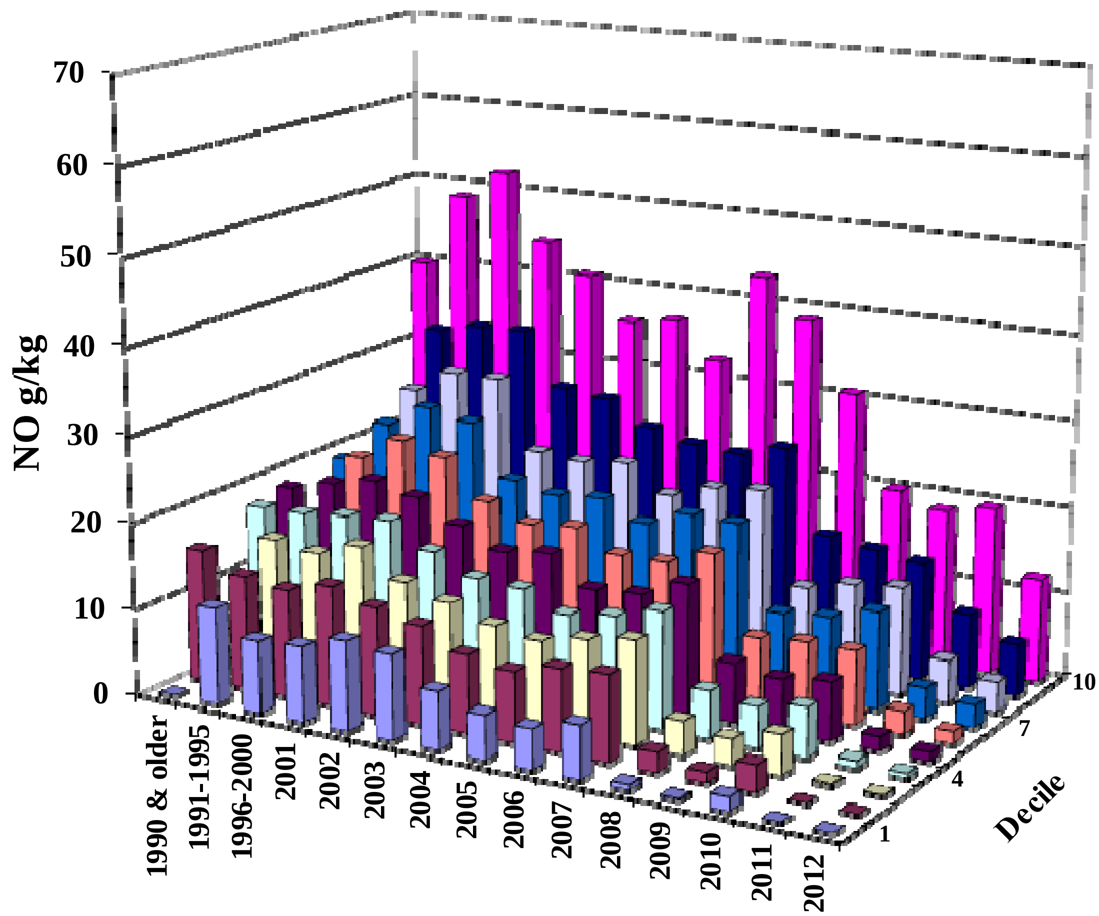
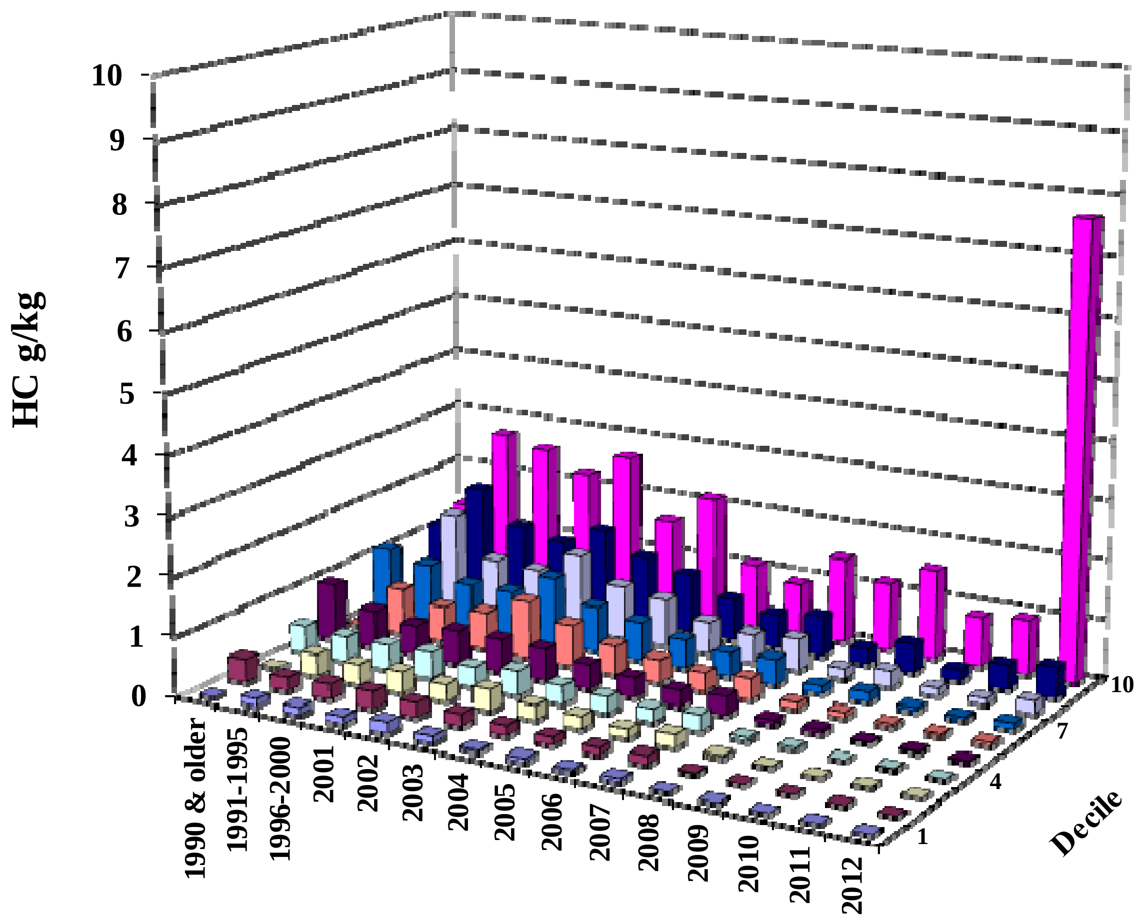


Figure V-9: Heavy-duty Tunnel Vehicle HC Deciles




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

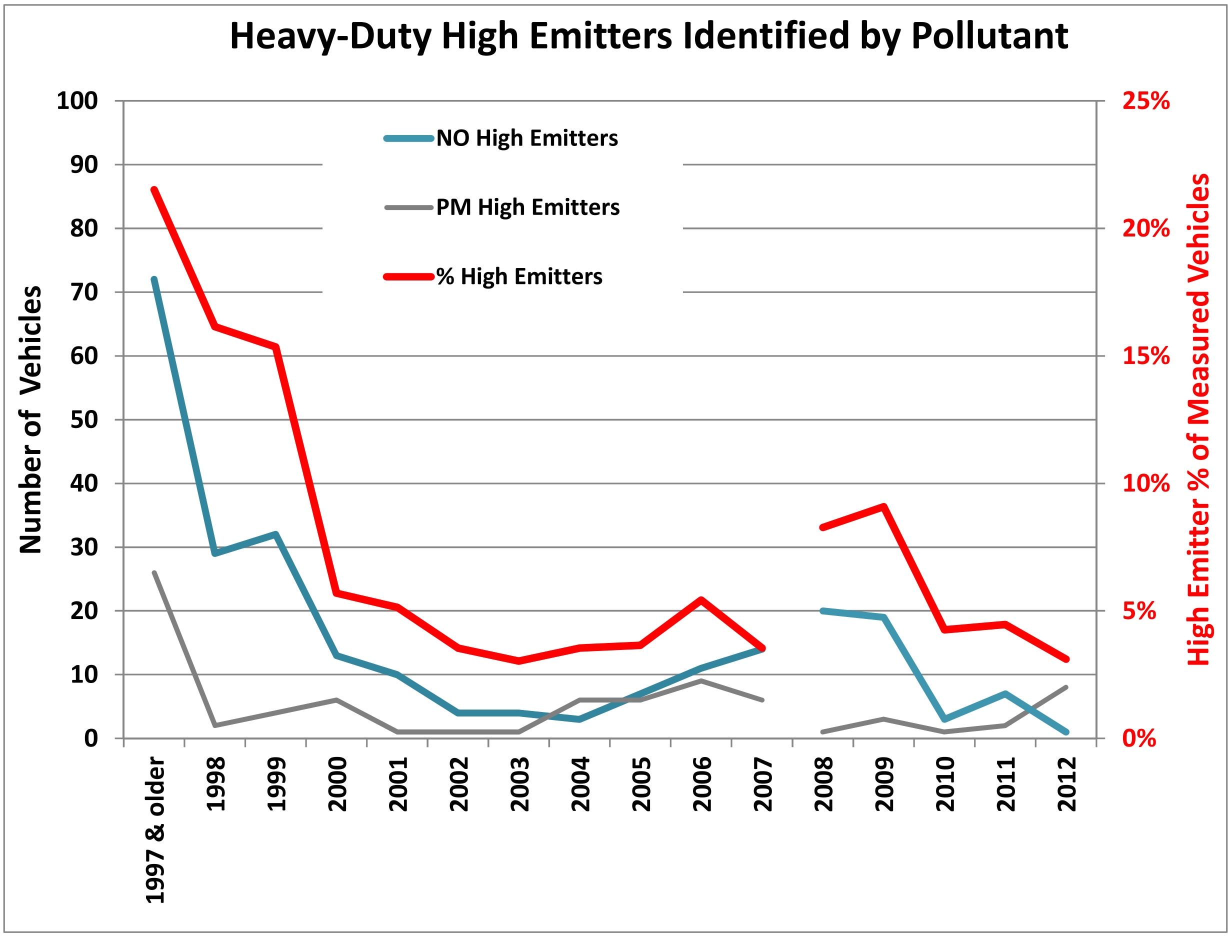



Figure VII-2: Conservative Trial Normal and High Emitter Average PM and NO

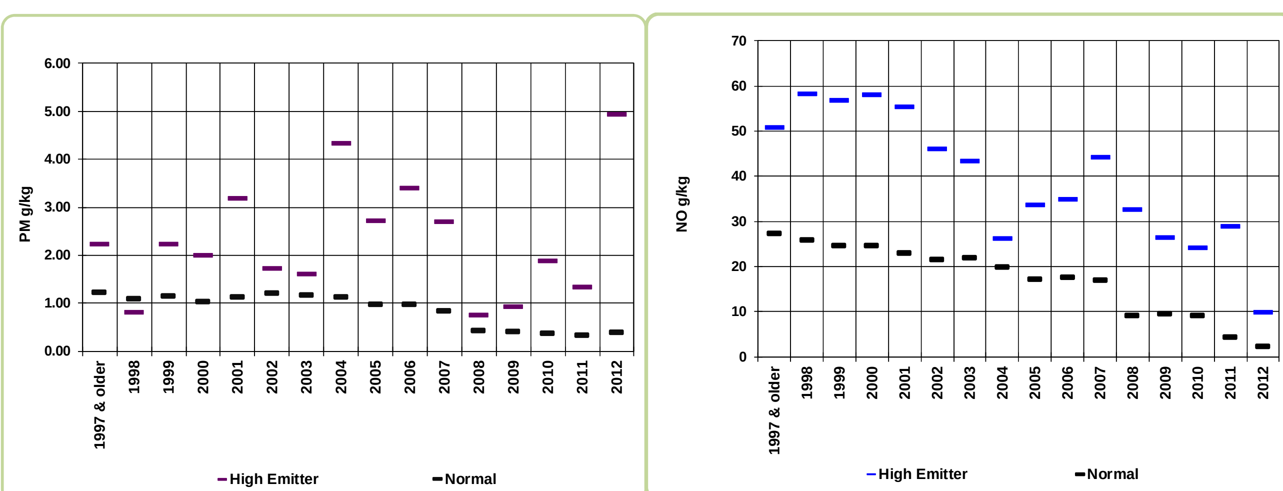


Table VII-2 Conservative Trial High Emitter Results

| 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

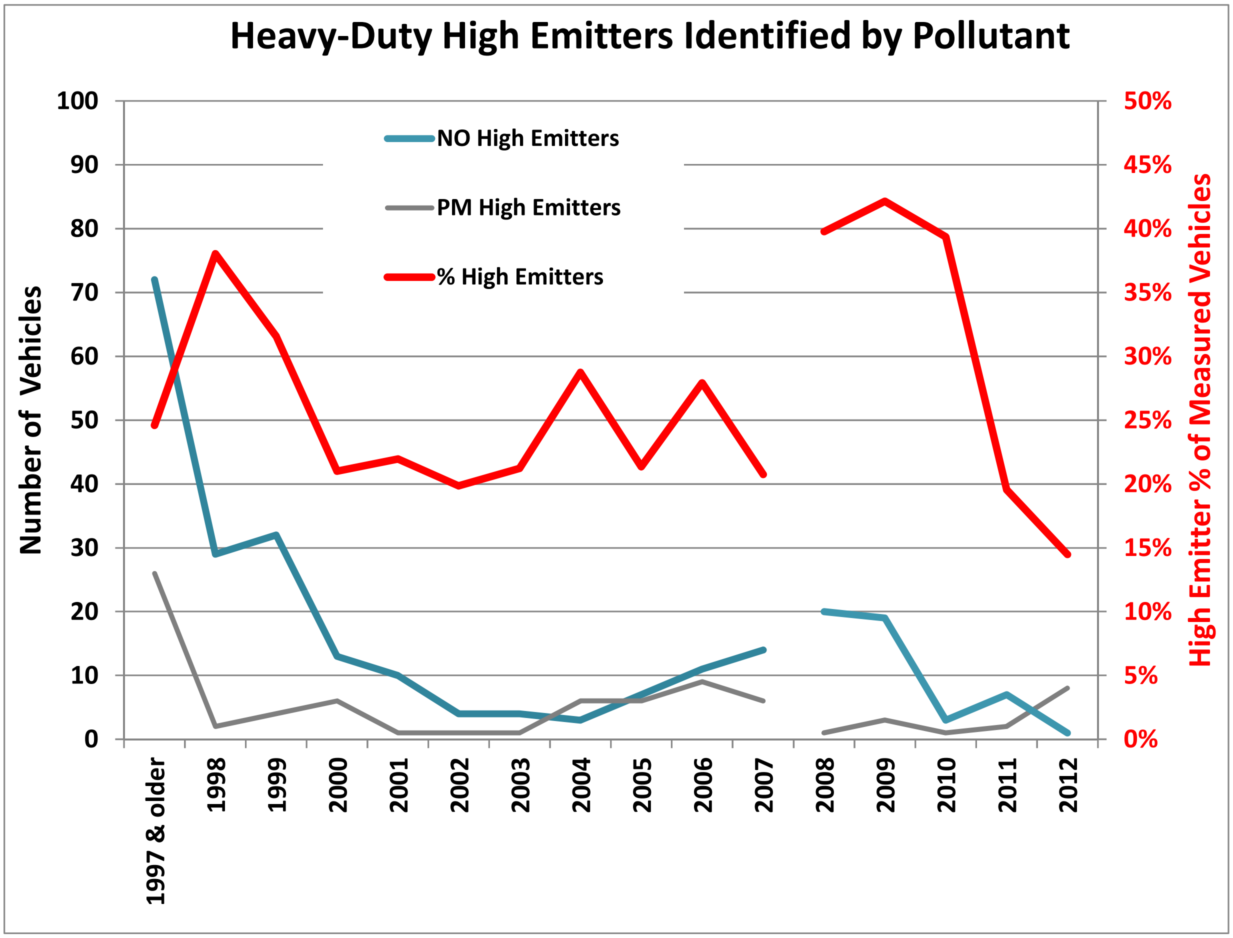
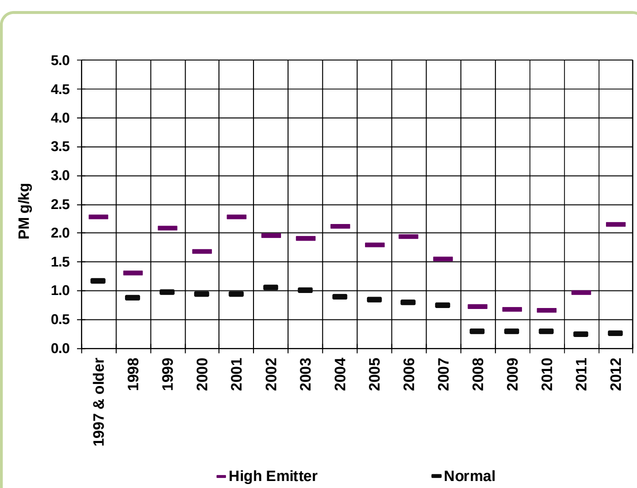



Figure VII-4: Standards Based Trial Normal and High Emitter Average PM and NO



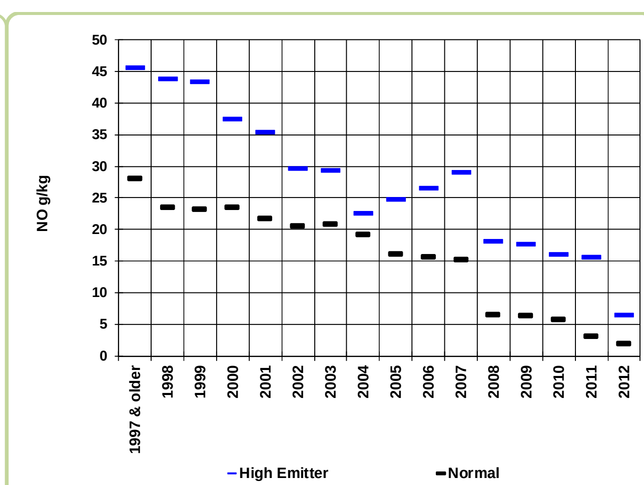



Table VII-5 Standards Based Trial High Emitter Results

| 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**



## 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:

gm CO/kg = (28 x %CO/%$CO_2$ / (%CO/%$CO_2$ + 1 + 3 x %HC / %$CO_2$)) / 0.014

gm HC/kg = (44 x %HC/%$CO_2$ / (%CO/%$CO_2$ + 1 + 3 x %HC / %$CO_2$)) / 0.014

gm NO/kg = (30 x %NO/%$CO_2$ / (%CO/%$CO_2$ + 1 + 3 x %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

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[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