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Virginia Remote Sensing Device Study – Draft Report

Prepared for:

Virginia Department of Environmental Quality

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Glossary of Terms and Abbreviations

ADT	Average Daily Traffic
ASM	Acceleration Simulation Mode
Basic I/M	A set of vehicle I/M program inspection requirements defined by the U.S. EPA that may be used in areas not required to implement an Enhanced I/M program; the inspection procedure usually involves idle testing
Clean Screening	The process of identifying vehicles with low emissions that are then exempt from emission inspection at an inspection station
CO	Carbon monoxide
CO2	Carbon dioxide
Cutpoint	An emissions level used to classify vehicles as having met an emissions inspection requirement
Enhanced I/M	A set of more rigorous vehicle I/M program inspection requirements defined by the U.S. EPA that usually involves IM240 testing
EPA	United States Environmental Protection Agency
Excess Emissions	Vehicle emissions that exceed an I/M cutpoint
FTP	Federal Test Procedure
g/mi	Grams per mile, the units of measurement for FTP and IM240 tests
GIT	Georgia Institute of Technology
GVWR	Gross Vehicle Weight Rating
HC	Hydrocarbons
High Emitter Identification	The on-road identification of vehicles with high emission levels
I/M	Inspection and maintenance program
Idle Test	A tailpipe emission test conducted when the vehicle is idling and the transmission is not engaged
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 that simulates real world driving conditions
KW/t	Kilowatts per metric ton, the units of measurement for vehicle specific power
LDGV	Light-duty Gasoline-powered Vehicle
LDGT	Light-duty Gasoline-powered Truck
NO_X	Oxides of nitrogen, usually measured as nitric oxide (NO)

OBDII	On board diagnostic system to detect emissions related problems that is required on all 1996 and newer light–duty vehicles
Repairable Emissions	The emission reductions that can be obtained by repairing a vehicle. The amount of repairable emissions is equal to or greater than the amount of excess emissions
RSD	Remote Sensing Device
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
VTR	Vehicle Test Record

1. Introduction

The 1990 Federal Clean Air Act Amendments require that I/M Programs be implemented in urbanized areas exceeding the National Ambient Air Quality Standards for ozone and/or carbon monoxide (CO). The Federal Clean Air Act requires implementation of an enhanced I/M Program in the census-defined Washington DC Metropolitan Statistical Area (MSA). In Virginia, this area includes the cities of Alexandria, Fairfax, Falls Church, Manassas, and Manassas Park, and the counties of Arlington, Fairfax, Prince William, Loudoun, and Stafford.

DEQ currently operates a decentralized enhanced I/M program in the northern Virginia area consisting of approximately 415 independently operated inspection stations. All gasoline fueled vehicles less than 25 years old and up to 10,000 pounds gross vehicle weight rating (GVWR) are required to pass an emissions test or receive a waiver biennially before their motor vehicle license plates can be renewed. Currently, vehicles of model year 1981 and newer, and up to 8,500 lbs. GVWR are required to receive a two-mode Acceleration Simulation Mode (ASM-2) test if they are able to be tested on a single axle dynamometer. Other vehicles receive a two-speed idle (TSI) test. In addition, all vehicles must pass a gas cap pressure test, a visual inspection of applicable emissions control equipment components, and a pre- and post-inspection check for visible emissions.

Remote sensing has been included in the I/M State Implementation Plan revisions submitted by DEQ. The goals of the future comprehensive remote sensing program will be:

1) to identify high-emitting light duty vehicles and trucks operating in the program area for out-of-cycle "verification" testing and subsequent repair,

2) to use RSD for "clean screening" of very clean vehicles, enabling these vehicles to avoid the regularly scheduled biennial emissions inspection test,

3) to identify and evaluate the emissions of vehicles regularly driving in the I/M area that have not undergone an emissions inspection at a Virginia Certified Emissions Inspection Facility, and

4) to evaluate fleet emissions and I/M program effectiveness.

The Virginia Department of Environmental Quality (VDEQ) contracted Environmental Systems Products (ESP) to conduct a remote sensing device (RSD) study in the Northern Virginia Enhanced Inspection and Maintenance (I/M) Program area. DEQ intends to use information gathered during this study to:

1) compare the emission test results from the existing I/M program area with the emissions as measured by remote sensing,

2) determine the overall feasibility and cost effectiveness of operating a future comprehensive remote sensing program in the Northern Virginia Enhanced I/M Program area,

3) determine the percent of “transient vehicles” not registered in the I/M program area and determine which of these are habitual commuters,

4) assess fleet emissions in the existing northern Virginia I/M area,

5) draw conclusions as to the effectiveness of the existing I/M program, and

6) assess the vehicle miles traveled (vmt) distribution of vehicles within the I/M area by vehicle age and body style.

To accomplish the study goals, ESP conducted a remote sensing device (RSD) study in an area designated as the Northern Virginia Enhanced Inspection and Maintenance (I/M) Program area. ESP also sampled in the Richmond area for the purpose of establishing a no-I/M baseline emissions profile.

CONCLUSIONS – This document describes the study and its results. Following are the key conclusions drawn from this analysis:

- The study met its data collection goals. Valid RSD measurements were made on 23% of the Northern Virginia I/M fleet.
- Vehicles registered in Virginia’s I/M areas had significantly lower HC, CO, and NOx remote sensing levels than vehicles registered in Virginia’s non-I/M areas.
- Vehicle Specific Power (VSP) is a good measure to judge the conditions that a vehicle should be operating under to generate reliable RSD emission readings. In addition, site/hour combinations with high percentages of new vehicles with high emissions (after VSP screens are applied) are likely to be seeing more vehicles in cold start mode. ESP is considering removing observations from these sites.
- Estimated emission reductions for Virginia’s I/M program based on RSD observations in I/M and non-I/M areas are much greater than emission reductions estimated by EPA’s MOBILE6 model.
- Combining RSD results with high emitter index values can identify most of the high emitters. Vehicles that are classified as high emitters by RSD and are in the dirtiest 25% of the high emitter index have much higher emission levels than the average vehicle.
- A dirty screen program using one hit plus high emitter indexing has similar performance to one using two-hits. Initially, it’s much easier to get one hit on a vehicle than 2 hits, so this scenario would be more cost-effective.

The following section describes the study design. The analysis of data collected is presented in Section 3.0. A forthcoming addendum to this report will address opacity measurements.

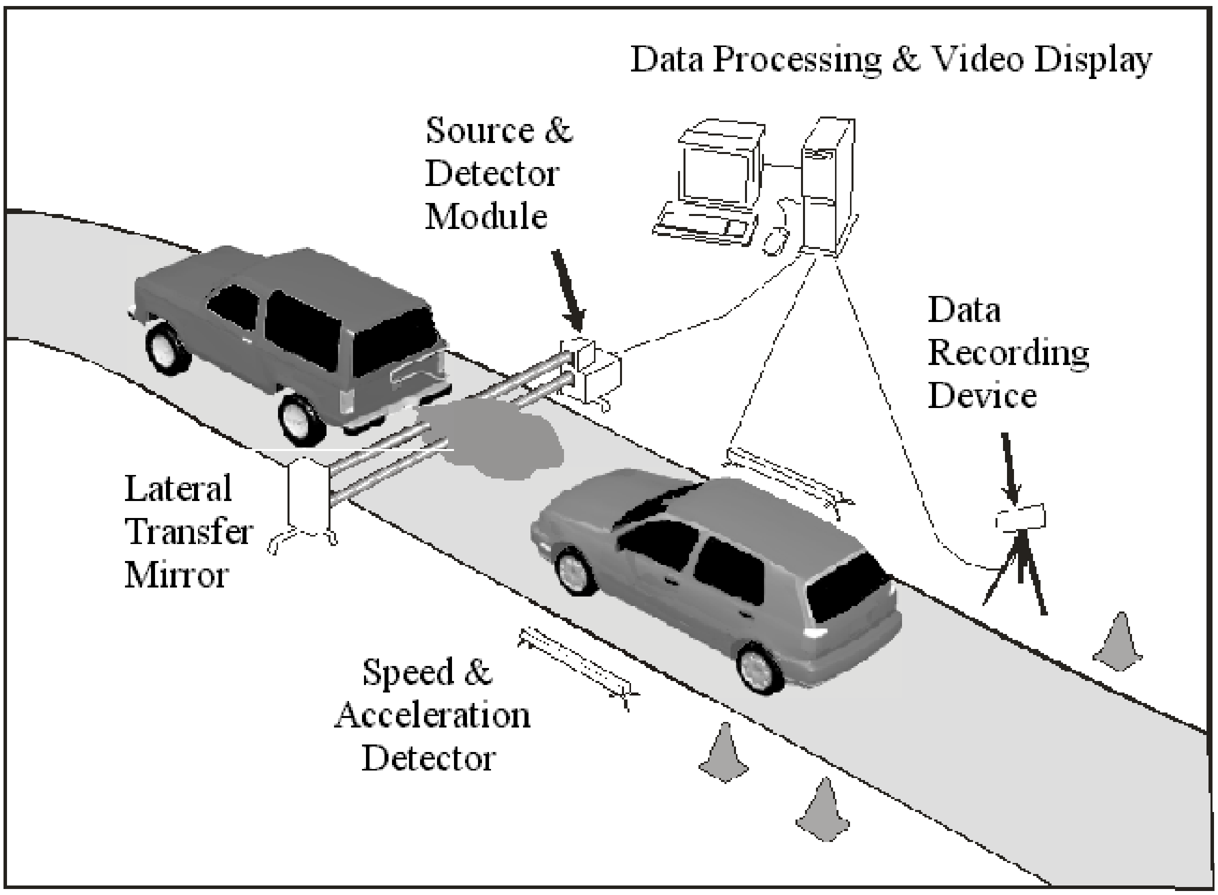
2. STUDY DESIGN

2.1. Equipment Description

The Virginia Study was the first study of it's kind to utilize the newest addition to ESP's line of products, the RSD4000. The RSD4000 is based on the same underlying technology as the predecessor RSD3000 but has completely re-engineered electronics to improve sensitivity. It is a more durable, easily operable, deployable and portable system that significantly improves operator and program effectiveness through greater capture rates of more accurate vehicle emissions readings.

The RSD4000 detects vehicle emissions when a car drives through an invisible light beam the system projects across a roadway. Figure 2-1 illustrates the remote sensing equipment set-up. The process of measuring emissions remotely begins when the RSD4000 Source & Detector Module (SDM) sends an infrared (IR) and ultraviolet (UV) light beam across a single lane of road to a lateral transfer mirror. The mirror reflects the beam back across the street (creating a dual beam path) into a series of detectors in the SDM.

Figure 2-1 On-Road Remote Sensing Set-Up



Fuel specific concentrations of HC, CO, CO2, NOx and smoke are measured in vehicle exhaust plumes based on their absorption of IR/UV light in the dual beam path. During this process, the data-recording device captures an image of the rear of the vehicle, while the Speed & Acceleration Detector measures the speed of each vehicle.

The RSD units are housed in fully outfitted Dodge Maxi vans. These vans are equipped with heating/cooling, a generator, and adequate storage for all components. The vans carry a full compliment of road safety equipment and tools for making small repairs. The vans are equipped with additional lighting for testing during pre-dawn and post dusk hours. The new RSD4000 includes the following improvements over the RSD3000:

1) A longer beam range for safer, more versatile deployment
2) Wider, more stable platform resulting in less operational vibration
3) Simple and easy setup with laser alignment aids
4) Alignment platforms to facilitate a fast and secure alignment result
5) Continuous automatic CO2 for background compensation minimizes the need for field calibration. (Only one or two calibrations are generally required during a full day of data collection.)
6) Fourth generation real-time measurement validation
7) Signal sensitivity and accuracy that significantly exceed 2002 California BAR certification standards
8) Fewer degrees of freedom in alignment resulting in improved optical stability and less noise for increased productivity, yielding more valid records.
9) A Windows operating system for ease of operation and true multi-tasking
10) A fuel specific smoke measurement using a UV wavelength that senses the fine particles invisible to traditional visible light opacity meters
11) Rugged assembles requiring less maintenance and resulting in less downtime

2.2. Equipment QA/QC Audits:

2.2.1. Factory Testing and Certification

When an RSD system is built at the Tucson Technology Center, it undergoes several steps to ensure accuracy. First, the source detector module is bench calibrated. It is then audited using several blends of gas. When the system is fully calibrated and assembled, it is tested again in the parking lot using an audit truck. The unit tests are based on the BAR OREMS specification.

An audit truck is a modified vehicle that uses a long exhaust stack to direct the vehicle engine exhaust upwards and away from the roadway. Audit gases of known concentrations are dispensed through a simulated tailpipe routed to the rear of the audit truck. When the truck is driven past a roadside remote sensing SDM/VTM set of modules, the system measures the pollutant concentrations in the dispensed test gas instead of the vehicle engine exhaust.

The remote sensing unit is setup in a parking lot to avoid interference from other traffic. The auditor drives the audit truck through the remote sensing system 40 times for each gas blend during acceptance testing. ESP detector accuracy, including speed and acceleration, will meet the detector accuracy tolerances shown below for at least 97.5% (39/40) runs for each gas. Six different audit gas blends are used to verify the unit accuracy over a range of pollutant concentrations.

2.2.1.1 Detector Accuracy:

(1) The carbon monoxide (CO%) reading will be within ± 10% of the Certified Gas Sample, or an absolute value of ± 0.25% CO (whichever is greater), for a gas range less than or equal to 3.00% CO. Negative values shall be included and will not be rounded to zero. The CO% reading will be within ± 15% of the Certified Gas Sample for a gas range greater than 3.00% CO. Negative values will be included and will not be rounded to zero.

(2) The hydrocarbon reading (recorded in ppm hexane) will be within ± 15% of the Certified Gas Sample, or an absolute value of ± 250 ppm HC, (whichever is greater). Negative values will be included and will not be rounded to zero.

(3) The nitric oxide reading (ppm) will be within ± 15% of the Certified Gas Sample, or an absolute value of ± 250 ppm NO, (whichever is greater). Negative values shall be included and will not be rounded to zero.

2.2.1.2 Speed and Acceleration Accuracy:

(1) The vehicle speed measurement will be accurately recorded within ± 1.0 mile per hour.

(2) The vehicle acceleration measurement will be accurately recorded within ± 0.5 mile per hour / second.

2.2.2. Daily Set-Up and Calibration

Every scheduled work day, the operator drives to an existing or new test site. The operator's first duty is to provide himself and passing motorists with a safe work area. The next step is to set up the source detector module and allow the electronic components within to warm up for a minimum of 30 minutes. Following the set up and alignment of the other components, the SDM is aligned and ready for Calibration.

A puff audit calibration is a method of testing the equipment without the need to drive an audit truck past the unit. During a gap in the passing traffic, a test gas with a known blend of HC, CO, CO2 and NOx, is puffed into the optical path of the remote sensing beam. If necessary, the instrument set-up is adjusted so that the pollutant values measured by the unit, match the known concentrations of pollutants in the test gas blend.

Calibration for the RSD4000 occurs once at the beginning day and at mid-day if conditions warrant.

2.2.3. Equipment Audits

After each daily calibration, the Operator is required to perform an audit to verify an optimal calibration. This is done in the same manner as the calibration except the audits are "earmarked" in the data file with an "A". If the audit passes a predetermined pass/fail tolerance, the operator is allowed to begin testing vehicles. If not, the operator is required to realign and recalibrate the system until it passes the audit process.

2.2.4. Quarterly Audits (drive-by audits)

Three times during the course of the study, an Audit Truck was deployed from ESP's Missouri Program to audit both RSD4000 systems being used in the Virginia Study.

The audit truck is outfitted with a gas cylinder rack that holds a maximum of 6 compressed gas cylinders. Each gas cylinder is equipped with a high flow regulator, a high flow solenoid and a Tygon hose, which is adapted to a simulated tailpipe. Inside the truck cab, the audit truck operator has the ability to switch power from solenoid to solenoid to select the appropriate audit gas cylinder for drive-by audits. A traffic cone is placed 60-70 feet preceding the test site. This is used as a mark to begin the flow of gas to ensure there is an adequate plume of audit gas as the truck passes the RSD4000. The typical gas blends used in the audits are show below:

HC (ppm)	**CO**	**CO2**	**NO_X (ppm)**

Blend # 1	500	0.5%	14.70%	3000
Blend # 2	3000	1.00%	14.38%	2000
Blend #3	2000	2.75%	13.10%	500
Blend #4	6000	5.00%	11.55%	250

In addition to the equipment, the operator is also audited for following procedures: site setup, calibration, camera alignment, traffic safety and documentation.

2.3. Site Selection Criteria

Evaluation of sites used in the previous study and the selection of new sites was performed during the work plan preparation. Site selection goals included:

2.3.1.1 Developing a network of sites covering:

(1) the I/M Cities of Alexandria, Fairfax, Falls Church, Manassas and Manassas Park, and the counties of Arlington, Fairfax, Loudon, Prince William and Stafford.

(2) a non-I/M area in the greater Richmond area to serve as a suitable reference.

2.3.1.2 The sites should:

(1) Provide a representative sampling of the I/M area fleet over the 8-month collection period.

(2) Provide a representative sampling of the out-of-area fleet observed in the I/M area.

(3) Maximize valid records without compromising geographic coverage and data quality.

(4) Allow for multiple observations of vehicles when sites are repeated.

(5) Yield a measurement distribution roughly similar to the vehicle population.

2.3.1.3 Developing a site visit schedule that best supports the goals of the study.

The agreed site visit strategy was to visit each site on two successive days twice during the data collection phase for a total of four collection days per site. This provided a good balance of general fleet coverage as well as a significant number of vehicles with multiple measurements that have been used to assess the effectiveness of alternative high emitter and low emitter identification protocols.

This scheme allowed for a mid-term assessment of progress towards study goals and of area coverage after the first two-day visit to each site. Some additional sites were then added in the southern Richmond area and the visit schedule adjusted to cover these new sites during the second half of the collection phase.

The study data collection phase lasted a total of 14.5 van months or 63 van weeks. Two vans were used to accomplish the data collection effort within a nine-month window. ESP worked some 12-hour days in order to reduce travel and set-up time and maximize on-road collection time.

Vans were co-located at the same site approximately one day per month in order to be able to compare the results from each van for consistency.

2.4. Site Locations

2.4.1. Site Selection Activity

Two two-man teams canvassed the I/M and non-I/M areas. Each team was led by a member of the Georgia Institute of Technology (GIT) experienced in site selection for remote sensing studies. Mikhail Fogelson, GIT, and Vladimir Yekimov, ESP-Maryland, canvassed the I/M Area from January 14th through January 23rd. The team visited the productive sites used in the 1996 study and identified new sites in the area.

Alexander Samoylov, GIT, and Nathan Williams, ESP-Maryland, canvassed the Non-I/M Area from January 14th through January 21st. Sites were selected within the city of Richmond and in the surrounding county of Henrico. Some non-I/M area sites were selected in Fredericksburg to supplement the Richmond sites in case they are needed.

The teams logged traffic information, site locations, and site configurations using GPS units, laser rangefinders, digital cameras, and traffic counters. The information was entered into an Access database through an ESP interface utility (developed by GIT) known as Analyzer, which enables immediate electronic filing of all pertinent information.

For site selection, the following procedure was adopted: At first a jurisdiction (or part of a jurisdiction) was selected, then a route was designed that encompassed the known candidate sites from the 1996 study. The known sites were evaluated and additional sites were found as needed to complement the existing inventory. If a superior site was discovered close to the old one, then the new site was selected.

2.4.2. Site Selection Results

In total, 87 sites were used, 59 sites in northern Virginia and the Fredericksburg area, 23 sites in the Richmond area and 5 sites in Washington DC. This slightly exceeds the goal of 75 sites. Table 2-1 summarizes the number of sites used by jurisdiction vs. plan. The distribution of the identified sites closely matches the desired number in each jurisdiction. Following an interim project evaluation, greater weight was given to the southern Richmond area and two sites in Fauquier County were added. Results from the 0.5% RSD survey in the DC area conducted during the study period were also included in the study database.

Table 2-1: Number of Selected Sites in Virginia

	Sites		
Region / County	**Plan**	**Actual**	**Days**
Northern Virginia:			
ALEXANDRIA	5	2	8
ARLINGTON	6	3	4
FAIRFAX	30	27	77
FAIRFAX CITY	1	2	7
FALLS CHURCH	1	1	2
FAUQUIER		2	6
FREDERICKSBURG	7	3	9
LOUDOUN	6	7	16
MANASSAS	1	1	1
PRINCE WILLIAM	8	8	23
STAFFORD	3	3	11
Subtotal	68	59	164
Richmond Area:			
CHESTERFIELD		8	18
HANOVER		1	2
HENRICO		7	12
RICHMOND		7	17
Subtotal	15	23	49
Washington DC		5	5
Total	83	87	218

Only a limited number of productive surface street sites were found. To select additional surface street sites would require coning down lanes in addition to acquiring resources from law enforcement to ensure traffic safety.

Figures 2-2 through 2-5 display the distribution of the sites in Northern Virginia, Fredericksburg, Richmond and Washington, DC. In these Figures, sites visited three times or more are shown in green, sites visited less than three times are shown in red and two Fauquier County sites added to the study and visited three or more times are shown in purple.

Figure 2-2 Site Locations in Northern Virginia

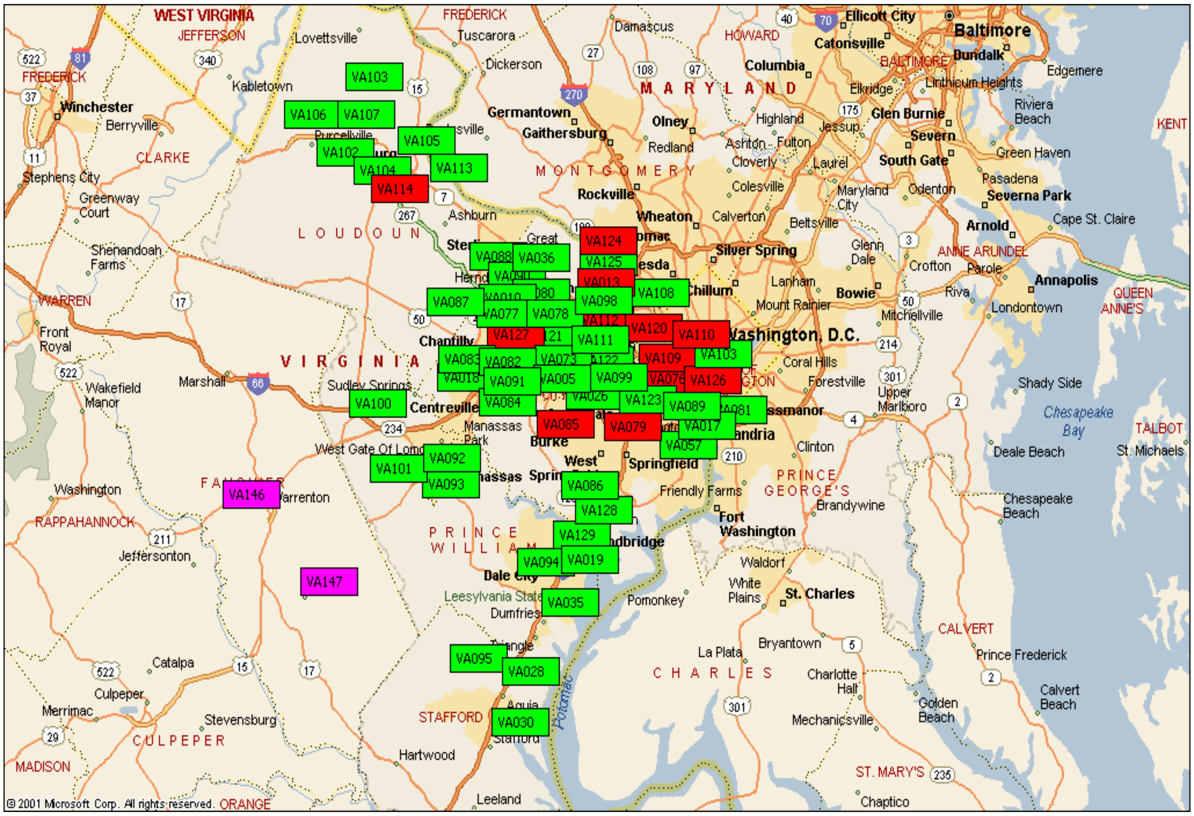


Figure 2-3 Site Locations in Fredericksburg

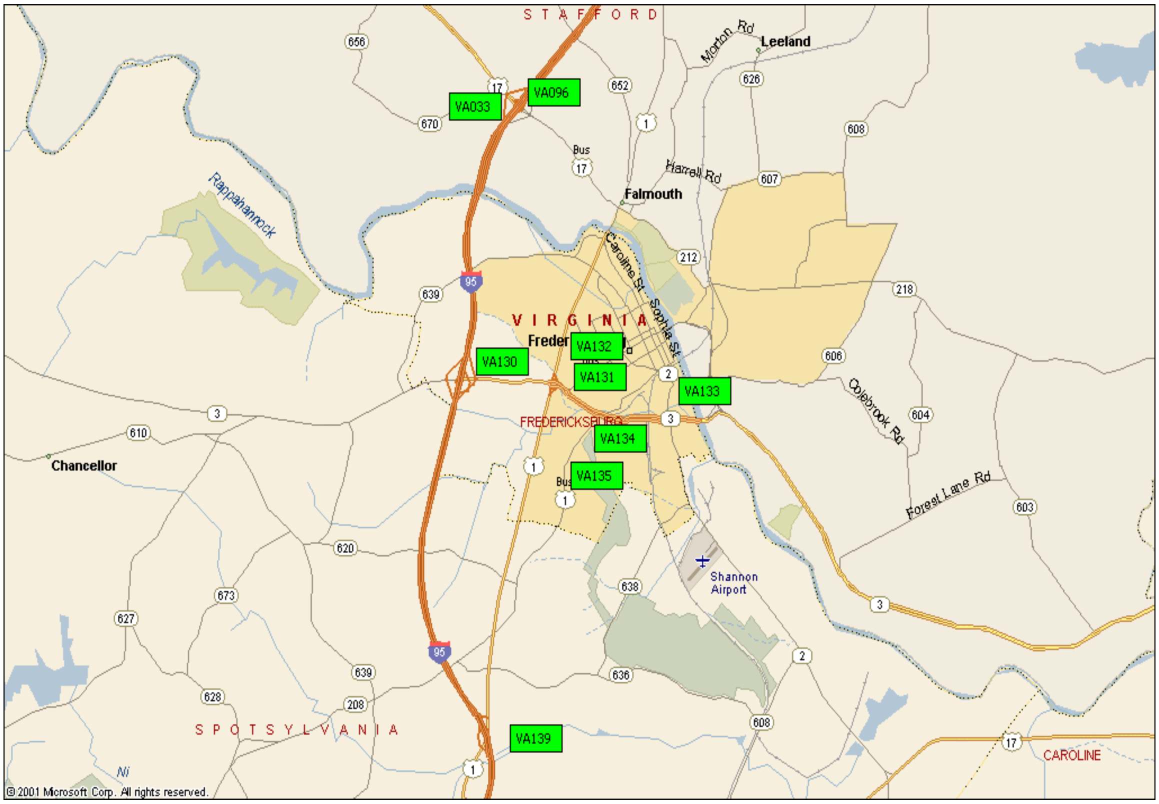


Figure 2-4 Site Locations in the Richmond Area

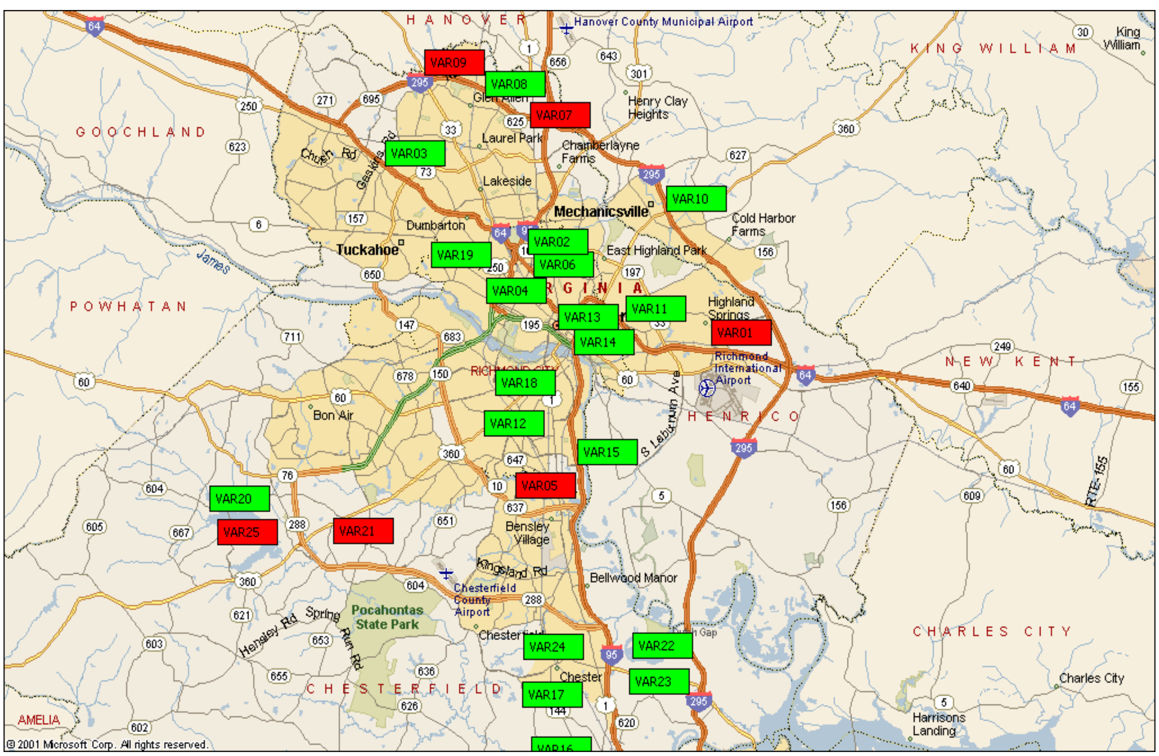


Figure 2-5 Site Locations in Washington DC

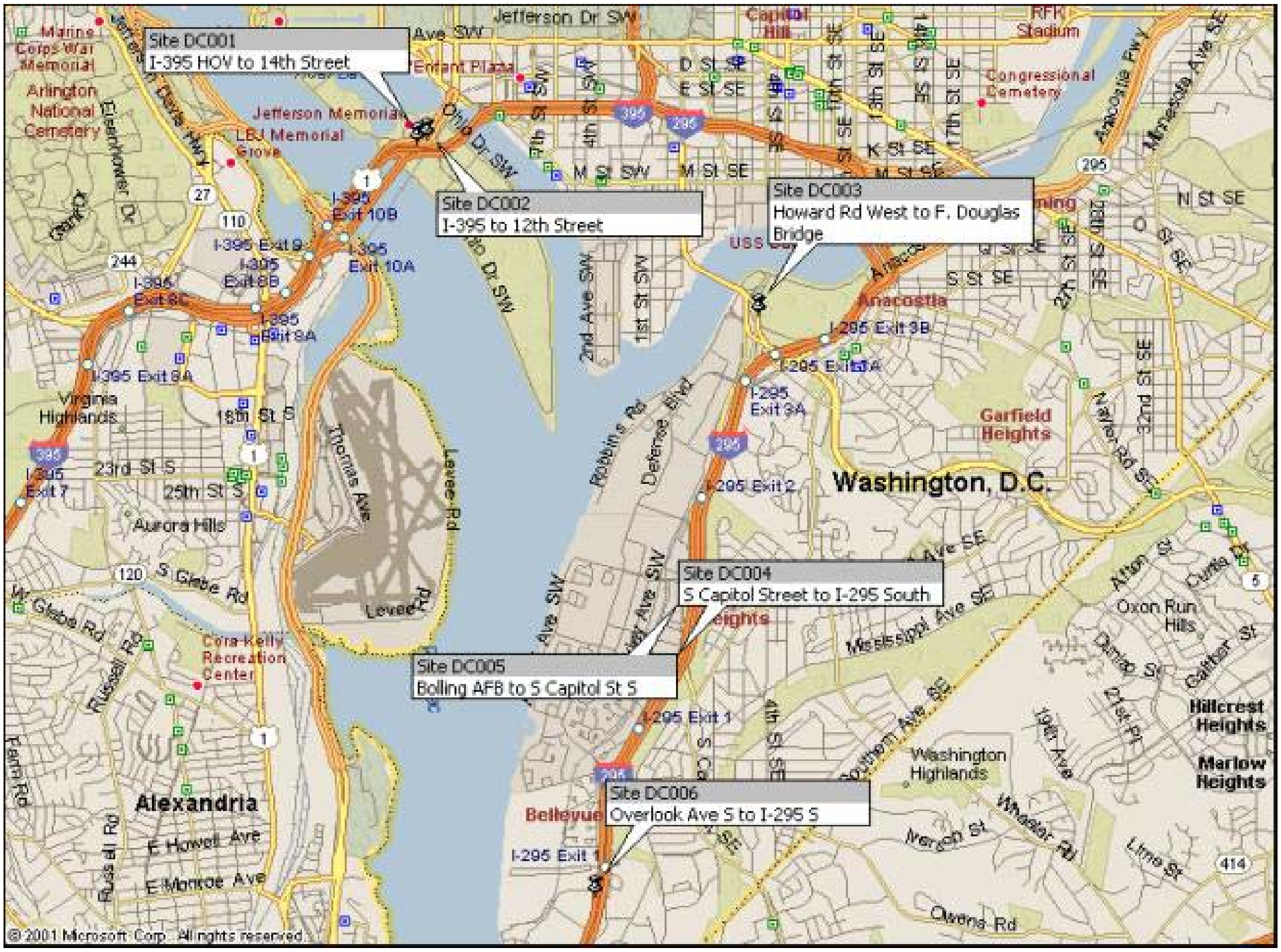


Table 2-2 lists the set of site locations visited during the study, the road grade in degrees, the number of days the site was used and the total active hours of data collection excluding any set-up and takedown time.

Table 2-2: Site Locations

Site	Location	City	County	Road Grade Degrees	Days	Active Collection Hours	In I/M Area
Northern Virginia Sites:							No
VA005	Rte 7100 North to I-66 East	Centreville	FAIRFAX	3.6	3	25.1	Yes
VA010	VA 657 S, to South from VA 608 after street light atr McLearen Rd, opposite to Texaco Station	Highlands Mews	FAIRFAX	0.0	3	22.0	Yes
VA013	VA 7 West to VA 123 North	Tysons Corner	FAIRFAX	3.5	1	12.1	Yes
VA016	US 29 South/North to I-66 East	Centreville	FAIRFAX	0.5	2	13.0	Yes
VA017	VA 611 S, to south from VA644, opposite to Browne Academy	Huntington	FAIRFAX	1.8	3	24.7	Yes
VA019	VA 638 (Neabesco Mills Road) South 400 feet after the intersection with Dale Blvd (VA 784) between I-95 and US 1. Type Surface	Dale City	PRINCE WILLIAM	6.0	3	25.3	Yes
VA026	Rte 620 East to I-495 South	Ravensworth	FAIRFAX	0.0	4	34.2	Yes
VA028	I-95 South to VA 610 West	Garrisonville	STAFFORD	4.1	4	35.5	Yes
VA033	VA 17 South to I-95 South	Falmouth	STAFFORD	4.1	4	36.4	Yes
VA035	VA 234 East and West to I-95 North	Prince William	PRINCE WILLIAM	0.5	4	32.1	Yes
VA036	VA 828 North/ South to VA 267 East, on single lane after toll gate.	Reston	FAIRFAX	0.2	4	29.8	Yes
VA057	633 N to North from VA 611 after intersection with Vantage Rd	Rose Hill	FAIRFAX	4.1	2	19.6	Yes
VA073	VA 123 South at Fairfax city limit, 1/4 mile south from I-66 overpass	Fairfax	FAIRFAX CITY	1.7	4	29.6	Yes
VA074	From I-66 East to US 50 East, exit 57 to Fairfax city.	Fairfax	FAIRFAX CITY	0.0	3	28.1	Yes
VA076	From VA 244 E/W to VA 7 E	Baily's Crossroads	FAIRFAX	3.5	1	8.1	Yes
VA077	From I-395 S (exit 4) to VA 236 East (Duke Rd)	Landmark	ALEXANDRIA	3.4	3	19.8	Yes
VA078	From VA 236 W (Duke Rd) to I-395 N (exit 4)	Landmark	ALEXANDRIA	1.7	5	45.5	Yes
VA079	From Franconia Rd (VA 644) West to I-95 North	Springfield	FAIRFAX	1.8	1	10.0	Yes
VA080	VA 674 South, East from Rte 5320 and Parkridge Bus. Park	Wayside	FAIRFAX	3.6	2	15.5	Yes
VA081	I-95/495 South (West) to US 1 South	Alexandria	ALEXANDRIA	3.1	4	34.1	Yes
VA082	I-66 West to VA 28 South	Centreville	FAIRFAX	2.4	7	52.6	Yes
VA083	Braddock Rd (VA 620) North , between I-66 and VA 657, near Cedar Break Rd	Centreville/Sully Station	FAIRFAX	0.0	3	23.3	Yes
VA084	VA 620 East/West to Rte 7100 North	Brentwood	FAIRFAX	0.0	4	32.3	Yes
VA085	Rte 7100 South to VA 123 N/S (Ox Rd)	Brentwood	FAIRFAX	2.0	2	3.8	Yes
VA086	VA 123 South (Ox Rd) after intersection with Lee Chapel/Javdee Rd	Barrington	FAIRFAX	2.9	4	20.9	Yes
VA087	VA 608 West at intersection with McLearen Rd	Franklin Farm	FAIRFAX	1.7	4	30.6	Yes
VA088	From Sunset Hills Rd East in Herndon to Rte 7100 South	Herndon	FAIRFAX	4.1	2	15.0	Yes
VA089	I-95/495 South (West) to US 1 North	Alexandria	ALEXANDRIA	2.9	2	15.9	Yes
VA090	VA 673 (Lawyers Rd) North/West west from intersection with Church St at Vienna	Vienna	FAIRFAX	5.9	4	32.6	Yes
VA091	US 29 South/West to VA 28 South, to Manassas	Centreville	FAIRFAX	1.2	3	10.9	Yes
VA092	VA 234 bus (Dumfries Rd) South in Manassas,south from VA 661 after intersection with Donner Rd	Manassas	MANASSAS	2.4	1	8.2	Yes
VA093	VA 234 bus (Dumfries Rd) North before Virginia Armory, at Texaco Gas station	Manassas	PRINCE WILLIAM	0.0	1	8.0	Yes

Table 2-2: Site Locations continued

Site	Location	City	County	Road Grade Degrees	Days	Active Collection Hours	In I/M Area
VA094	VA 234 (Dumfries Rd) North at Lake Montclair, intersection with Waterway Rd	Lake Montclair	PRINCE WILLIAM	1.1	2	16.1	Yes
VA095	VA 610 W between VA 648 and VA 643 after intersection with Ripley Rd	Garrisonville	STAFFORD	1.2	3	23.8	Yes
VA096	VA 17 bus N to I-95 S	Falmouth	STAFFORD	2.4	3	25.6	Yes
VA097	On VA 630 W 0.2 mi west from intersection with US 1	Stafford	STAFFORD	2.9	1	10.0	Yes
VA098	VA 7 West/North to I-66 West	Falls Church	FAIRFAX	2.9	3	21.7	Yes
VA099	US 50 East to VA 7 North and South, at Seven Corners Place. Map 16	Falls Church	FALLS CHURCH	2.9	2	16.1	Yes
VA100	From US 15 (James Madison Hwy) to I-66 East	Haymarket	PRINCE WILLIAM	-1.5	2	16.1	Yes
VA101	State Route 28 North Just North of State Route 619	Bristow	PRINCE WILLIAM	0.0	4	32.7	Yes
VA102	From Berlin Trke (State Route 287) to State Route 7 East	Purcellville	LOUDOUN	3.5	1	5.1	Yes
VA103	State Route 9 (Charles Town Pike) East just East of State Route 287 (Berlin Trpe)	Wheatland	LOUDOUN	8.0	4	24.5	Yes
VA104	From State Route 7 East to US15 North	Leesburg	LOUDOUN	-1.5	2	5.0	Yes
VA105	From 7 Business (W Market St) West to State Route 7 and 9 West	Leesburg	LOUDOUN	-0.5	2	7.3	Yes
VA107	From Berlin Trpk State Route 287 to State Route 7 East	Purcellville	LOUDOUN	3.5	4	31.2	Yes
VA108	From Lee Hwy (US29) to I-66 West	Cherrydale	ARLINGTON	5.5	1	5.7	Yes
VA110	From N Carlin Springs to US 50 East	Glencarlyn	ARLINGTON	2.5	1	8.2	Yes
VA111	From State Route 7 East to I-66 East	West Falls Church	FAIRFAX	0.5	4	32.3	Yes
VA112	From State Route 7 East to I-66 West	West Falls Church	FAIRFAX	4.5	2	16.1	Yes
VA113	From VA 7 West (Market St) to VA 15 Bypass South	Leesburg	LOUDOUN	3.8	2	9.3	Yes
VA114	From VA 267 to 15 Bypass/7 East (Leesburg Bypass)	Leesburg	LOUDOUN	2.9	1	8.1	Yes
VA120	From N George Mason Dr South/East to N Carlyn Springs Rd South/West	Buckingham	ARLINGTON	7.4	2	5.1	Yes
VA121	US 50 West to Rte 7100 North	Fair Lakes	FAIRFAX	0.2	6	44.1	Yes
VA122	US 50 East to I-495 North	Fair View Park	FAIRFAX	3.6	4	33.6	Yes
VA123	I-395 North (exit 2) to VA 648 West (Edsall Rd)	Shirley Industr.Park	FAIRFAX	3.6	3	25.3	Yes
VA124	VA 193 East (Georgetown Pike), east from I-495, at Saint Luke Cath. Church.	Langley	FAIRFAX	2.9	2	15.8	Yes
VA125	VA 267 East to I-495 South	Tysons Corner	FAIRFAX	4.7	6	43.7	Yes
VA126	VA 120 South (Glebe Rd) to I-395 North	Arlington	ARLINGTON	4.1	1	7.9	Yes
VA128	I-95 S to VA 123 N	Occoquan	PRINCE WILLIAM	2.9	2	15.8	Yes
VA129	From Horner Rd (VA 639) to I-95 S. Ramp from St_Hwy (city street) to I-Hwy.	Dale City	PRINCE WILLIAM	1.2	5	35.3	Yes
VA132	From VA 3 East to US 1 South.	Fredericksburg	FREDERICKSBURG	3.6	2	16.4	No
VA134	Lafayette Blvd (US 1 bus) South at St Paul Street	Fredericksburg	FREDERICKSBURG	4.7	3	16.4	No
VA135	Lafayette Blvd (US 1 bus) South at Wilderness Lane	Fredericksburg	FREDERICKSBURG	1.2	4	24.6	No
VA140	From south 7100 to east VA 644.	Burke	FAIRFAX	1.3	1	8.0	Yes
VA141	I-395 north to VA 236 (Duke St.) east	Alexandria	FAIRFAX	0.2	3	24.7	Yes

Table 2-2: Site Locations continued

Site	Location	City	County	Road Grade Degrees	Days	Active Collection Hours	In I/M Area
VA142	VA267 (Dulles Toll) east to I-495 north	McLean	FAIRFAX	2.0	4	30.7	Yes
VA143	VA 123 (Ox Rd.) north just north of Lee Chapel Rd.	Fairfax City	FAIRFAX	2.9	3	28.5	Yes
VA144	VA 123 north to I-495 south.	McLean	FAIRFAX	2.3	2	15.9	Yes
VA145	VA 7 east to I-495 south.	Vienna	FAIRFAX	0.1	3	27.6	Yes
VA146	VA 211 E to VA 29/15 Lee Hwy N	Warrenton	FAUQUIER	1.7	3	25.0	No
VA147	VA 28 N just past VA Rte 634	Eustaces Corner	FAUQUIER	-0.4	3	26.5	No
Richmond Area Sites:							
VAR01	State Highway 156 (N.Airport Dr)South to I-64 West	Henrico	HENRICO	0.5	2	15.5	N
VAR02	From State route 161 to I-64 west	Richmond	RICHMOND	0.8	2	8.0	N
VAR03	From Gaskins Rd North to I-64 East	Henrico	HENRICO	4.5	2	16.7	N
VAR04	From Cary Street(State Route 147) to I-195	Richmond	RICHMOND	1.5	2	17.4	N
VAR05	From Iron Bridge Road to State Route 150 East	Chesterfield	CHESTERFIELD	3.5	2	14.3	N
VAR06	From Robin Hood (Boulevard Road North) to I-95 Soth I-64 East	Henrico	HENRICO	1.5	1	8.7	N
VAR07	From US1 South to I-295 West	Henrico	HENRICO	-1.5	2	23.3	N
VAR08	From Nuckols Road North to I-295 East	Henrico	HENRICO	-0.8	2	19.2	N
VAR09	From Woodman Rd North to I-295 East	Henrico	HENRICO	0.5	1	15.2	N
VAR10	Cold Harbor Road (State Route 156) to US 360	Hanover	HANOVER	-2.5	2	16.2	N
VAR11	From Nine Mile Road South to I-64 West	Henrico	HENRICO	1.0	2	16.1	N
VAR12	From State Route 161 (Westover Hills) to US 60 West	Richmond	RICHMOND	8.5	1	4.9	N
VAR13	From Byrd Street to State Route 195 East	Richmond	RICHMOND	1.5	2	9.4	N
VAR14	From 4th Street to I-95	Richmond	RICHMOND	5.8	2	16.3	N
VAR15	From Walmsley Blvd and Commerce Road to I-95 South	Richmond	RICHMOND	0.5	5	39.0	N
VAR16	I-95 south to VA 144 east/west.	Col. Heights	CHESTERFIELD	2.0	3	19.9	N
VAR17	VA 144 east/west to I-95 north/south.	Col. Heights	CHESTERFIELD	0.1	2	16.8	N
VAR18	US 60 south on overpass VA 161.	Midlothian	CHESTERFIELD	2.7	4	29.4	N
VAR19	I-95 south to 195 south.	Richmond	RICHMOND	0.9	3	26.4	N
VAR20	VA 288 west to VA76 north.	Midlothian	CHESTERFIELD	0.3	2	16.4	N
VAR22	VA 10 west to I-95 north.	Chester	CHESTERFIELD	1.5	2	16.1	N
VAR23	VA 10 east to I-95 north.	Chester	CHESTERFIELD	1.3	1	8.2	N
VAR24	I-95 south to VA 288 west.	Chester	CHESTERFIELD	1.0	2	16.4	N
DC Sites:							
DC001	I-395 north in HOV lanes to 14th St.	Southwest	DC	1.2	1	8.1	Y
DC002	I-395 north in HOV lanes to 12th St.	Southwest	DC	1.4	1	8.1	Y
DC003	Howard Rd. west to F. Douglas bridge.	Anacostia	DC	0.6	1	9.7	Y
DC004	South Capital St. to I-295 north.	Congress Heights	DC	1.5	1	10.8	Y
DC005	Bolling AFB to South Capital St. south.	Congress Heights	DC	0.6	1	10.9	Y

2.5. ***Data Screening***

ESP applied the following screening checks to the RSD measurements to ensure the data used for fleet evaluation and fleet comparisons are reasonable and consistent:

Screening of exhaust plumes
Screening of hourly observations to check for cold starts;
Screening of high values
Screening of day-to-day variations in emissions values
Screening for Vehicle Specific Power (VSP) range

The first four of these screening procedures are described in the following paragraphs. The VSP screening is described in section 3.2.

2.5.1. Screening of Exhaust Plumes

The RSD4000 unit takes many measurements of each exhaust plume in the one half second after each vehicle passes the equipment.

The basic gas record validity criteria applied are:

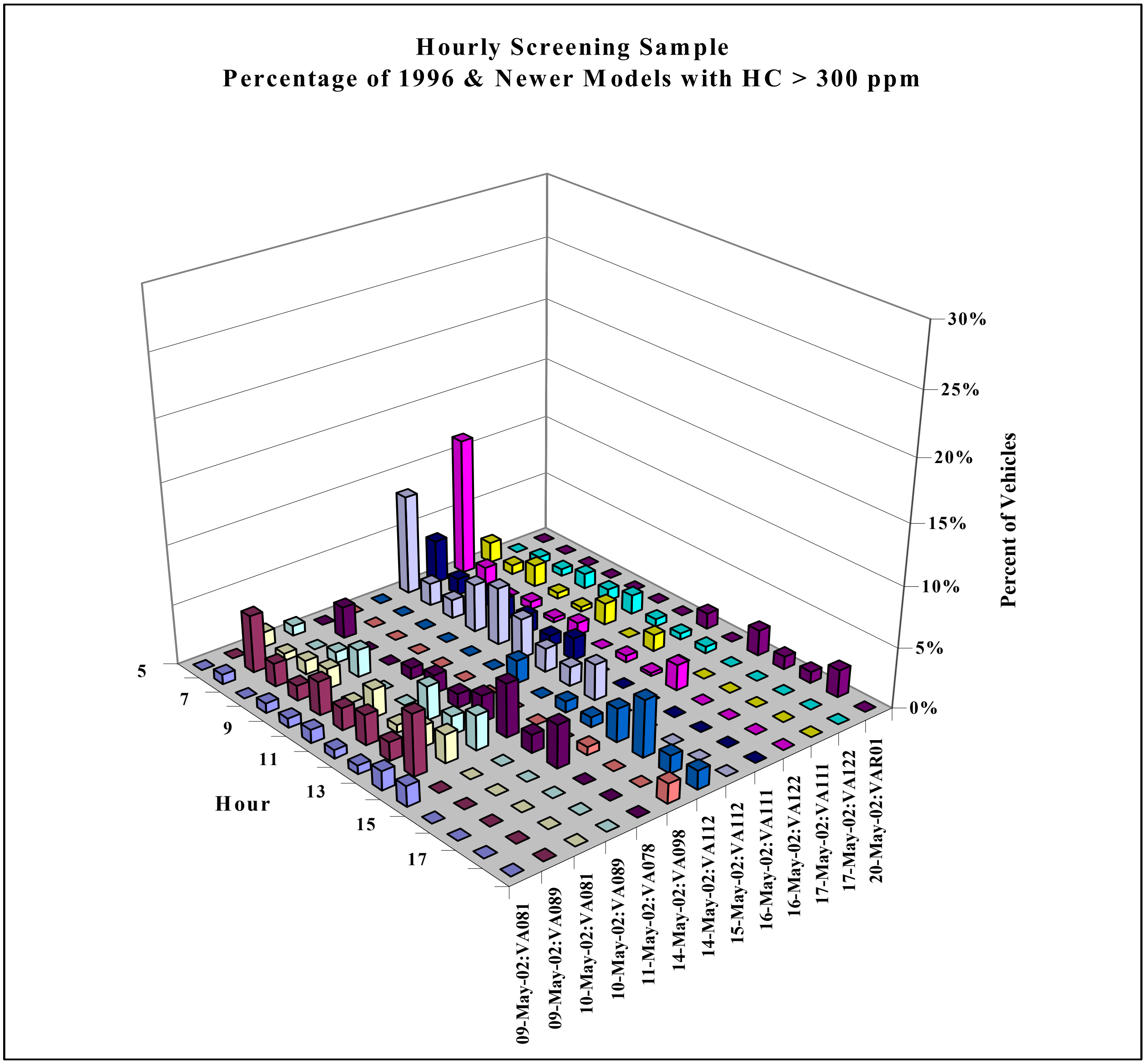
- A gas record is valid if there are at least 5 plume measurements where the sum of the amount of CO2 and CO gas exceed 10%-cm[i]; or
- A gas record is valid if there are at least 5 plume measurements where the sum of the amount of CO2 and CO gas exceed 5%-cm and the background gas values are very stable (not changing faster than a specified rate) at the time the front of the vehicle breaks the measurement beam.

2.5.2. Screening of Hourly Observations

ESP is concerned about vehicles operating in cold start mode or under conditions when exhaust plumes condense to steam. Vehicles measured under these conditions could appear to have high emissions without any emission system problems. To investigate this possibility, ESP tabulated for each site and hour the percentage of 1996 and newer vehicles that exceeded 2% CO or 300 ppm HC. The percent of 1996 and newer vehicles that exceed 300 ppm HC tend to be higher for the early morning observations, which could indicate more vehicles are operating under cold start mode. A typical sample of the hourly percentage of observations exceeding 300 ppm HC is shown in Figure 2-6. To avoid these measurements ESP removed observations made during hours when more than 5% of 1996 and newer vehicles exceeded 300 ppm HC.

[i] The unit of measurement 10%-cm is a measurement of the amount of a gas in the optical path. In this case, if all the molecules of the gas in the path were collected together into just one centimeter of the path then the concentration of the gas in the one-centimeter would be 10%.

Figure 2-6 Hourly Percent of Vehicles with HC > 300 ppm



2.5.3. Screening of High Values

Measurements were screened for the presence of unusually high values. We found some vehicle measurements with extremely high emissions values, especially for HC. We found, however, that the emissions values were not beyond the range physically possible, that in most cases the vehicles were old and that on a few vehicles similarly high values were observed on more than one occasion by different RSD units. Therefore, we concluded the high values were probably correct and none were removed. However, it is possible that some high HC readings could be caused by gasoline leakage.

2.5.4. Screening of Day-to-Day Variations in Emissions Values

Day-to-day decile values were compared for 1996 and newer vehicles. Only a small percentage of these vehicles are expected to have high emissions. For this group of vehicles, we expect the intermediate decile emission values should not vary significantly from day-to-day, from site-to-site or between RSD units. In Figure 2-7, the HC decile values for several days of measurements are plotted side-by-side as an example. A false origin of +200 ppm HC has been used to overcome a difficultly in charting stacked bars that start below zero. This comparison reveals offsets that typically range up to 50 ppm in the day-to-day decile values. Although differences of 50 ppm are within the HC specification of the RSD4000 units they are significant compared to average fleet emissions.

We looked to determine whether the day-to-day movements correlated with other variables such as site conditions and exhaust plume volumes but no obvious correlation was found. The most likely explanation is that this represents the limits of accuracy in the daily instrument set-up. For all three pollutants, HC, CO and NOx, an adjusted set of values was created by direct addition or subtraction of a daily offset that would align the daily 50^{th} percentile values with the 50^{th} percentile value for the entire dataset. The results of this correction are shown in Figure 2-8.

Many of the analyses shown later in this report were run two ways, 1) using the RSD results as measured and 2) using the adjusted values. The differences between the results were small but the adjusted values resulted in slightly lower average emissions for the newest vehicles and slightly smaller standard deviations from mean values. We believe this indicates the adjusted values are more accurate and have therefore presented the data using the adjusted values.

Figure 2-7 Daily HC Deciles

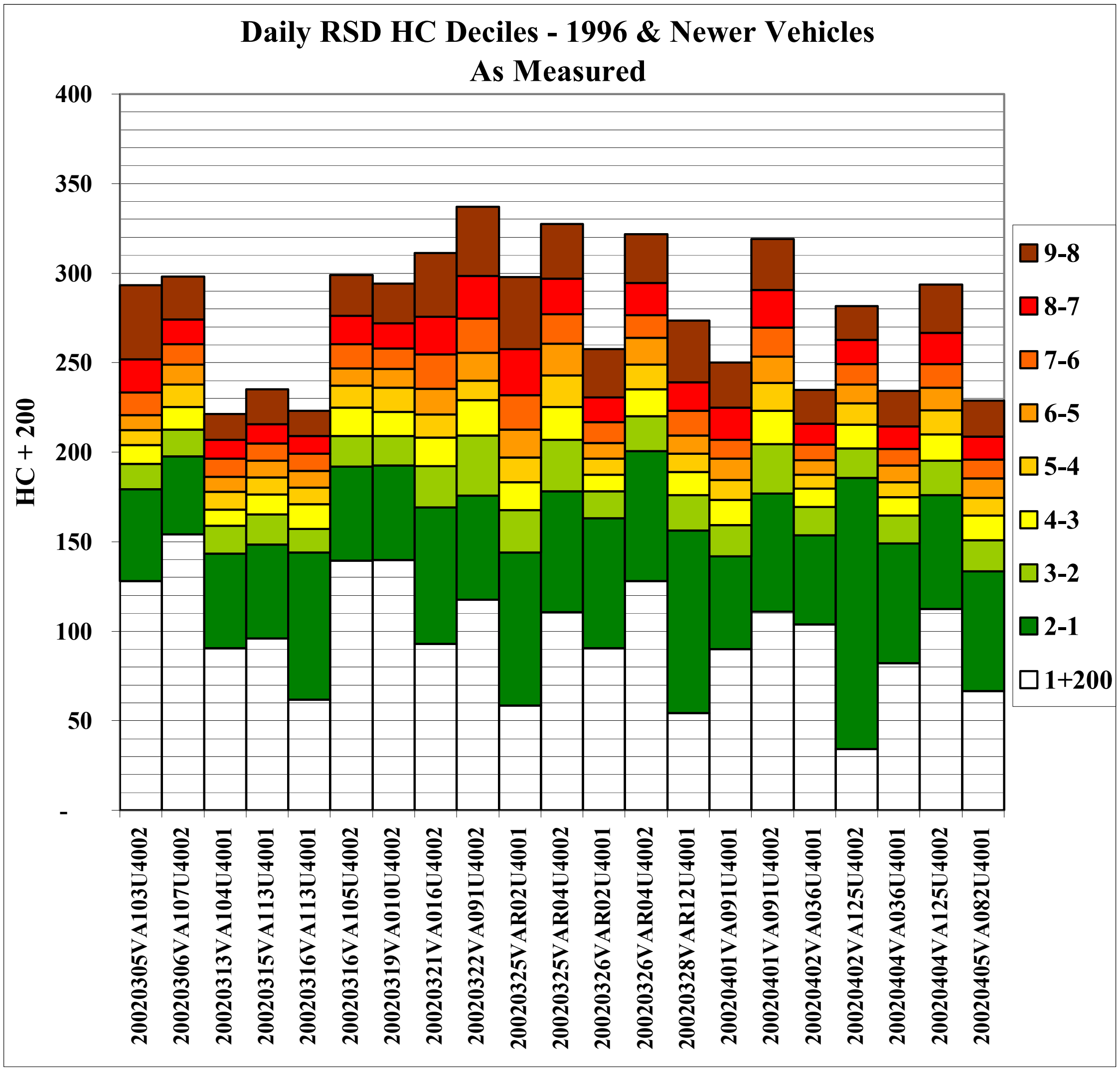
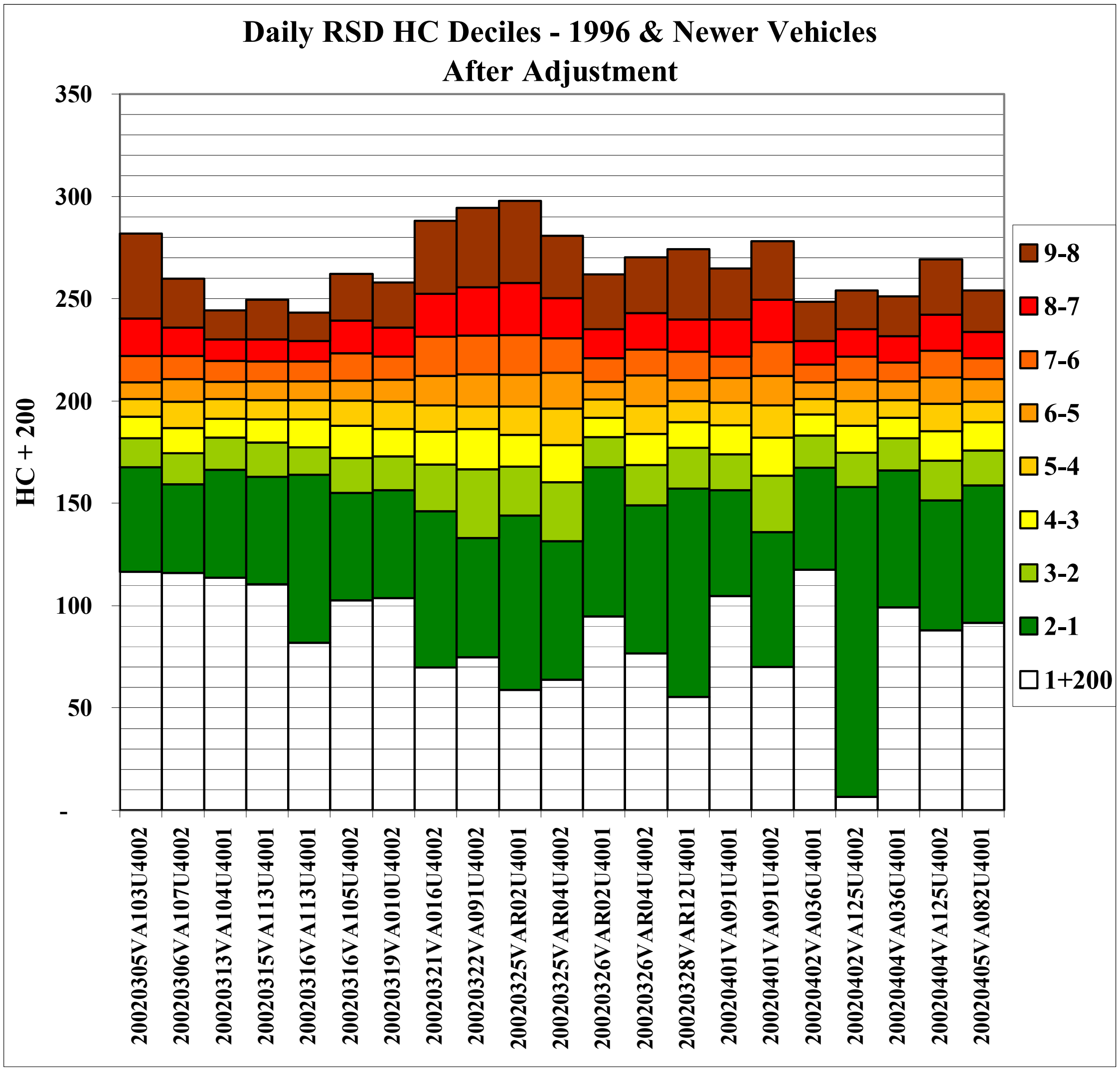


Figure 2-8: Daily HC Deciles – After Adjustment



3. ANALYSIS OF DATA COLLECTED DURING THE MARCH TO NOVEMBER 2002 TIMEFRAME

3.1. *Statistics and RSD Coverage*

3.1.1. Overall Program Statistics

Table 3-1: Number of Remote Sensing Records by License Plate

	Measured in I/M Program Area	Measured in Non-I/M Area*	Out of State	Total
Vans Utilized	2	2	N/A	4
Total Number of Sites Utilized	59	23	N/A	82
Total Number of Data Collection-Days Readings Taken	193	58	N/A	251
Total Number of Readings Taken	844,740	215,726	N/A	1,060,466
Total Number of Valid Readings Taken (Emissions, Operation, & License Plate)	466,125	140,760	73,756	680,641
Total Number of Readings With Readable License Plates	624,050	183,241	97,554	904,845
Total Number of Readings With License Plates Not-in-picture, obscured or unreadable	220,690	32,485	N/A	253,175
Total Number of Unique Vehicles Identified	393,172	128,941	75,354	597,467
Total Number of Vehicles Identified Once	252,224	90,905	58,636	401,765
Total Number of Vehicles Identified Twice	87,153	27,199	12,740	127,092
Total Number of Vehicles Identified Three Times	31,420	7,299	2,705	41,424
Total Number of Vehicles Identified Four or More Times	22,375	3,538	1,273	27,186
Total VA Registered Fleet*	1,717,437	928,477	N/A	
% of registered fleet measured	23%	14%		

* Registrations for Non-I/M Area Counties in Study

Table 3-2: Number of Remote Sensing Records by License Plate

Plate Flag	Plate Type	Records	Matched	Matched %	Model Year	Year %	Vehicle Type	Type %
M		814,366	795,368	98%	795,367	98%	783,626	96%
P		11,279	10,189	90%	10,189	90%	9,943	88%
O	DC	12,889	11,526	89%	11,410	89%	11,254	87%
O	MD	74,958	54,523	73%	54,523	73%	53,519	71%
O	WV	10,064	8,660	86%	8,660	86%	8,523	85%
Other	Other	93	30	32%	30	32%	29	31%
Total		923,649	880,296	95%	880,179	95%	866,894	94%

Plate Flag – M –Manual entry, P-Special plate (usually government), O-Out-of-State
Plate Type – Null for Virginia plates and the two letter State abbreviation for other States
Matched – Vehicles matched to a Registration Record
Model Year – Vehicles whose model year has been determined. All vehicles were matched to registration model year information except 1980 and older DC vehicles.
Vehicle Type – Vehicles whose type (LDGV / LDGT1 / LDGT2 / HDGV) has been determined

In Table 3-1, vehicles were counted regardless of their registration jurisdiction. Table 3-3 considers only vehicles registered in the jurisdictions surveyed as part of the study.

Table 3-3: Multiple Measurements

Number of Measurements of Vehicle	Unique Vehicles Matched to Study Area Jurisdiction Registrations
1	295,029
2	104,866
3	36,733
4	16,096
5+	8,903
Total Unique Vehicles	**461,627**
Unique Vehicles with 2 or more measurements	**166,598**

3.1.2 Remote Sensing Coverage by Jurisdiction

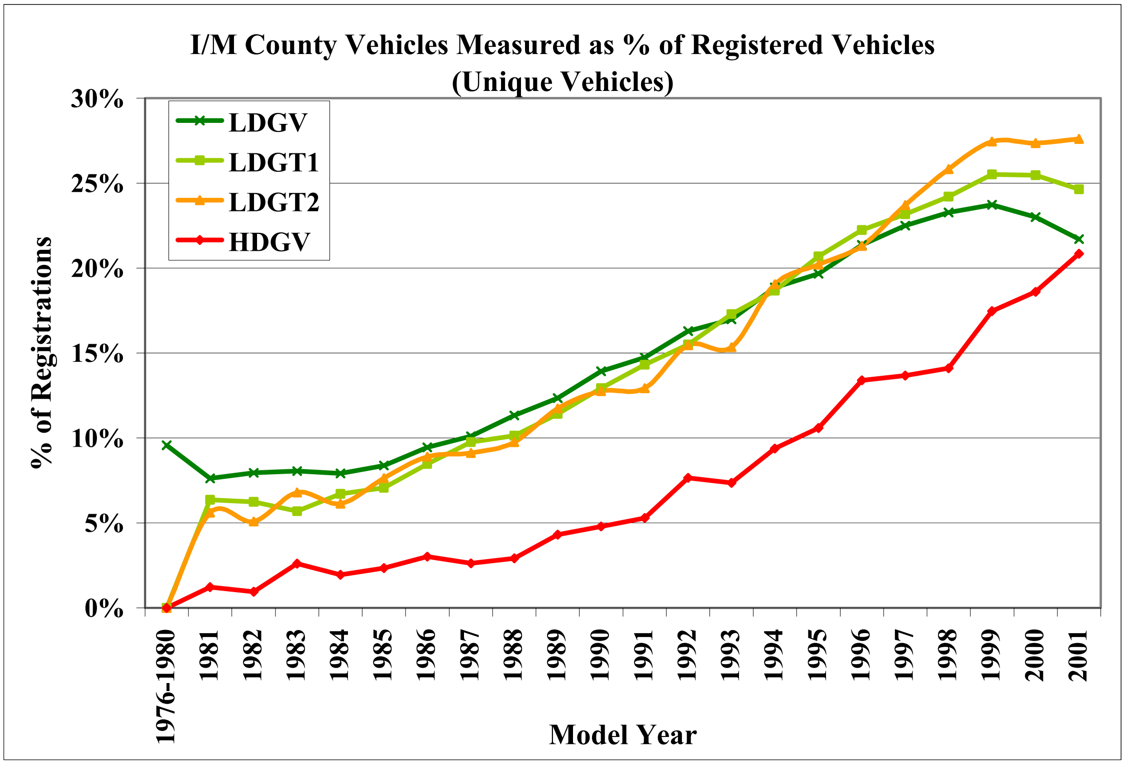
Table 3-4: Unique VINs measured as a percentage of registered vehicles:

Jurisdiction	Pre-1981	LDGV	LDGT1	LDGT2	HDGV	Total
I/M Jurisdictions:						
Alexandria	3.7%	15.8%	14.7%	15.7%	8.4%	15.3%
Arlington	2.3%	9.7%	10.4%	12.6%	6.7%	9.7%
Fairfax	3.3%	21.0%	21.7%	20.9%	11.9%	20.7%
Fairfax City	2.9%	22.0%	21.3%	23.6%	10.2%	21.2%
Falls Church	2.0%	16.5%	15.4%	15.2%	8.3%	15.9%
Loudoun	1.9%	18.9%	18.2%	19.0%	9.9%	18.0%
Manassas	4.6%	19.8%	19.3%	20.9%	12.7%	19.1%
Manassas Park	4.2%	27.3%	26.6%	24.4%	14.2%	24.7%
Prince William	4.3%	26.5%	24.5%	23.5%	12.5%	24.6%
Stafford	5.9%	33.4%	30.1%	29.5%	14.7%	30.4%
Non-I/M Counties:						
Chesterfield	2.3%	12.8%	11.7%	12.0%	6.1%	11.8%
Fauquier	4.0%	26.9%	23.9%	21.8%	10.8%	23.1%
Fredericksburg	4.5%	20.2%	20.9%	22.3%	8.2%	19.3%
Hanover	1.8%	15.1%	13.7%	12.8%	7.1%	13.2%
Henrico	2.6%	12.6%	12.3%	12.2%	6.1%	11.9%
King George	1.3%	7.8%	6.4%	6.8%	3.6%	6.8%
Richmond	2.8%	11.4%	11.5%	12.3%	3.6%	10.4%
Spotsylvania	3.3%	17.0%	15.1%	15.8%	8.3%	15.4%
Total	3.0%	18.2%	18.1%	17.7%	9.1%	17.4%

3.1.3 RSD Coverage by Type and Model Year

Figure 3-1 shows the percent of vehicles registered in I/M counties that were seen by RSD. Vehicles measured by remote sensing were compared to the number of vehicles registered in March 2002. Coverage of the 2002 vehicles has been omitted as new vehicles being put into service after March were not included in the March count of registered vehicles. Thus the fraction of current 2002 registrations observed on-road is not known.

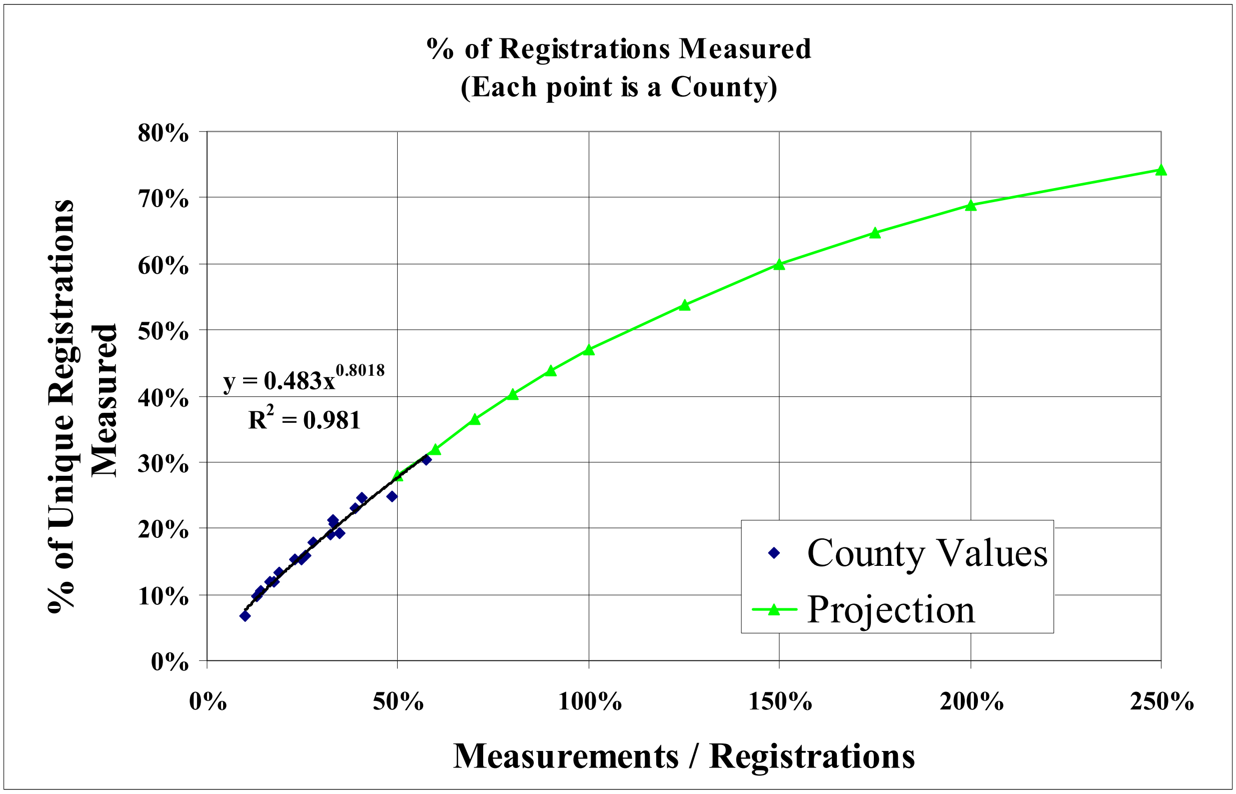
Figure 3-1 Percentage of Registered Vehicles Measured by Model Year



3.1.4 Projected RSD Coverage

Figure 3-2 shows projected coverage for an RSD program. In order to cover 70% of a fleet you need to perform about twice as many tests as the number of registered vehicles. The percent of registered vehicles covered (i.e., observed by RSD) will be lower than the percent of vehicles actually operating on the roads that are tested. This is because of "dead records" at VA DMV.

Figure 3-2 Percentage of Registrations Measured vs. Total Measurements



3.2. Effect of Engine Load on Measured Vehicle Emissions

3.2.1. Emissions vs. Speed and Acceleration

ESP plotted emissions by measured acceleration and speed (see Figures 3-3 to 3-5). CO and NOx emissions are greatest under high acceleration and speed combinations. HC emissions are greatest under high deceleration conditions.

Figure 3-3: CO% vs. Speed and Acceleration

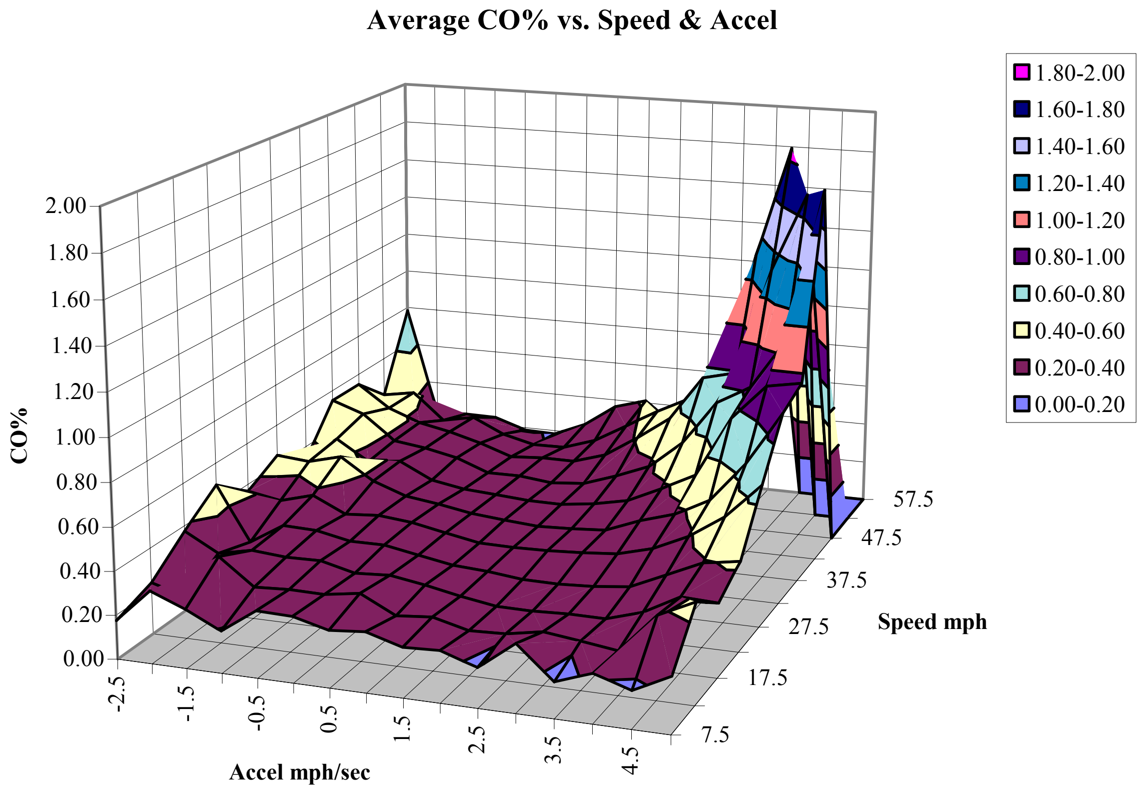


Figure 3-4 HC vs. Speed and Acceleration

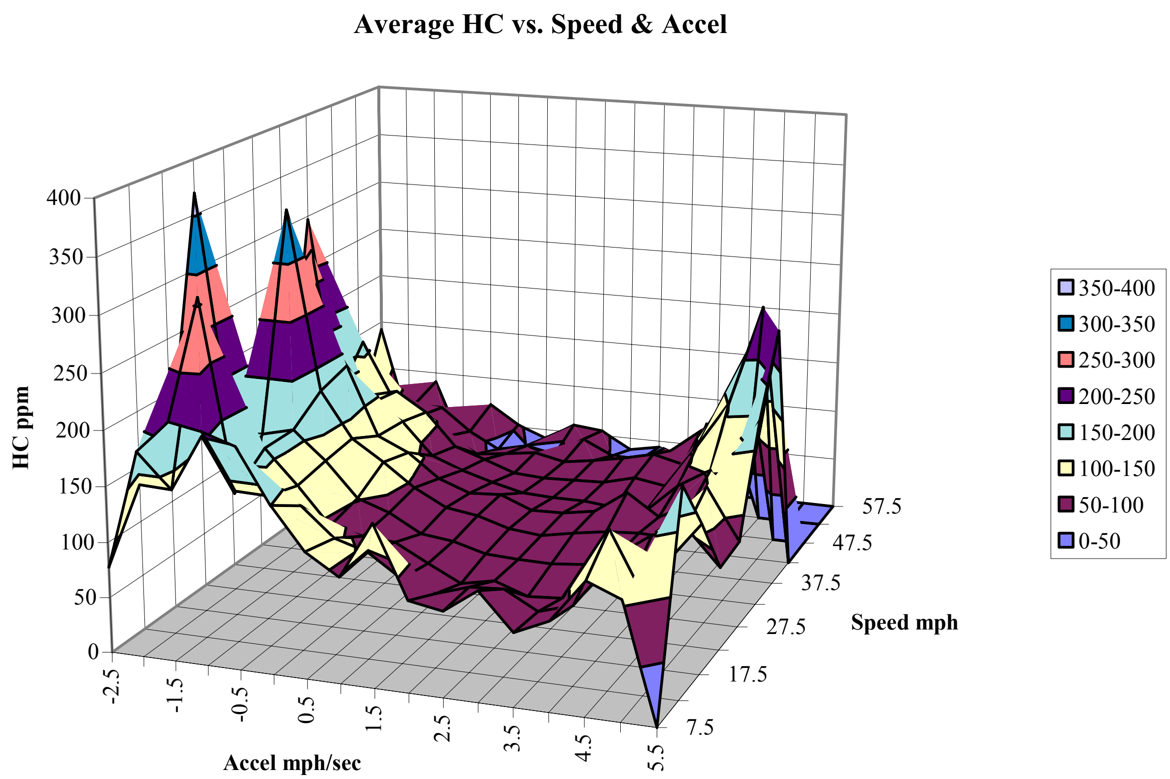
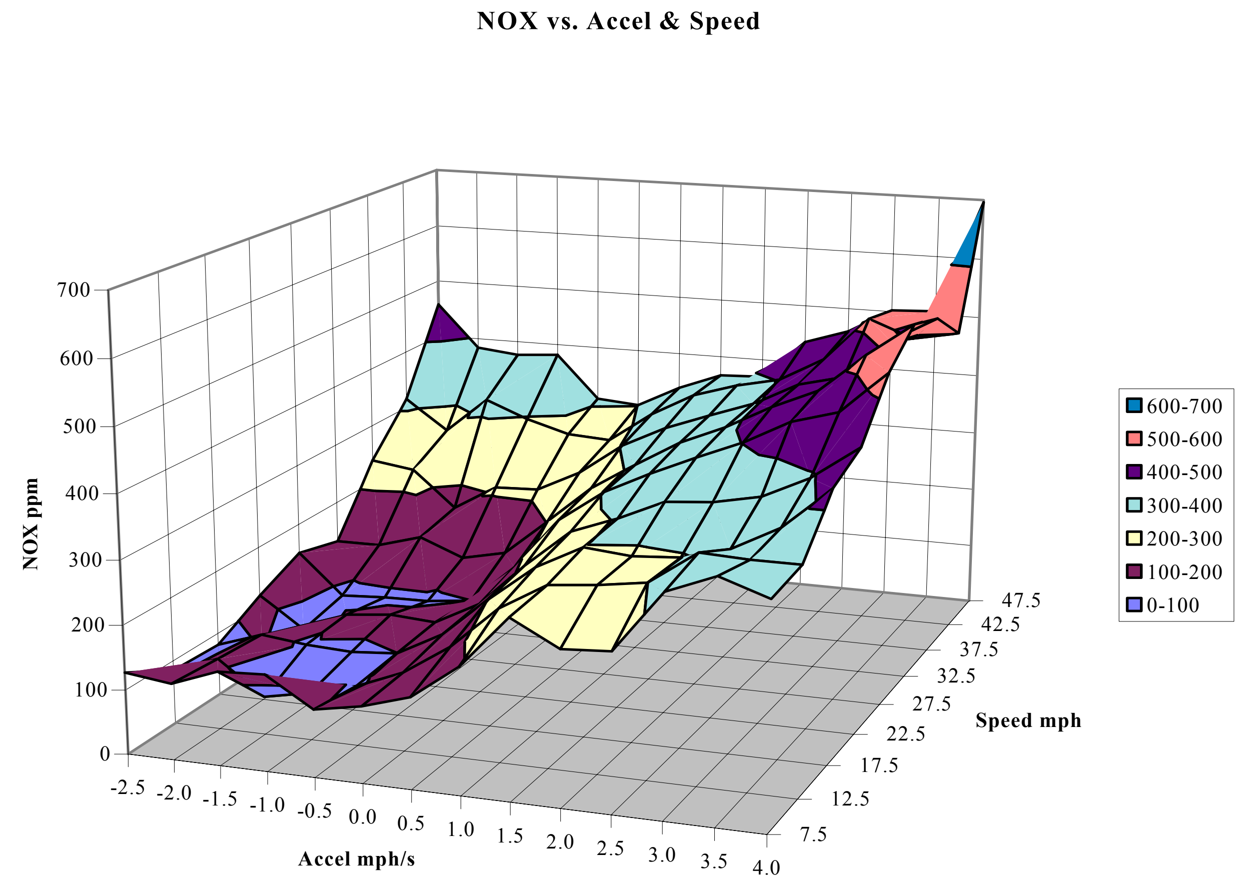


Figure 3-5 NOx vs. Speed and Acceleration



3.2.2. Emissions vs. Vehicle Specific Power (VSP)

ESP used the speed/acceleration and site grade data to determine Vehicle Specific Power (VSP). VSP attempts to normalize the power requirements of the vehicle based upon speed, acceleration and slope at the site. VSP is defined by the following equation:

VSP = 4.364*sin(Grade in Deg/57.3)*Speed + 0.22*Speed*Accel + 0.0657*Speed + 0.000027*Speed*Speed*Speed

Measurements were binned by VSP and average emissions were plotted (Figures 3-6 to 3-8). Points with less than fifty RSD measurements are omitted. CO and NOx generally are greatest during high VSP conditions. HC generally is greatest under negative VSP conditions. Similar charts for LDGV, LDGT and HDGV vehicles are provided in Appendix A.

ESP used observations where VSP is between 3 and 22 kW/t in subsequent analysis.

Figure 3-6: CO vs. VSP

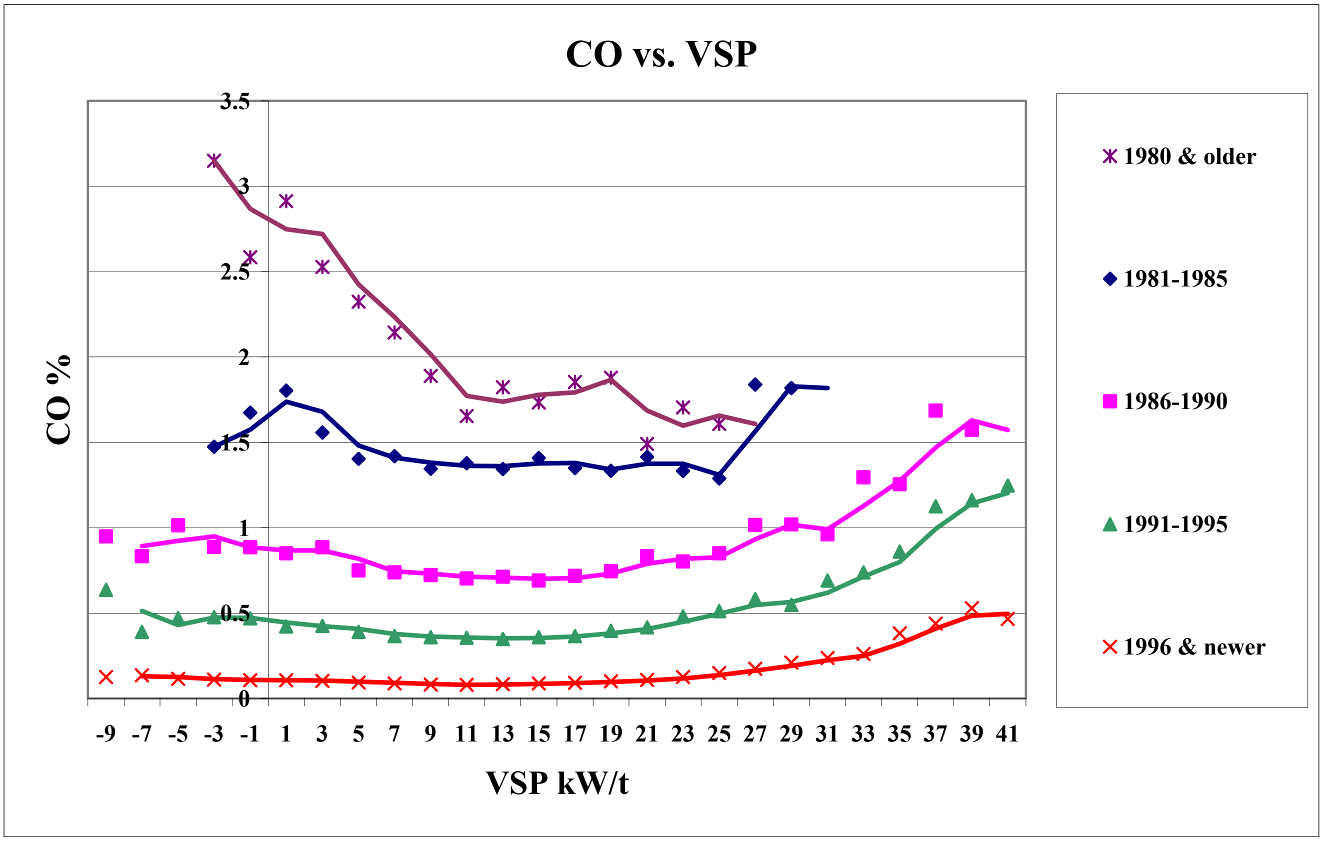


Figure 3-7: HC vs. VSP

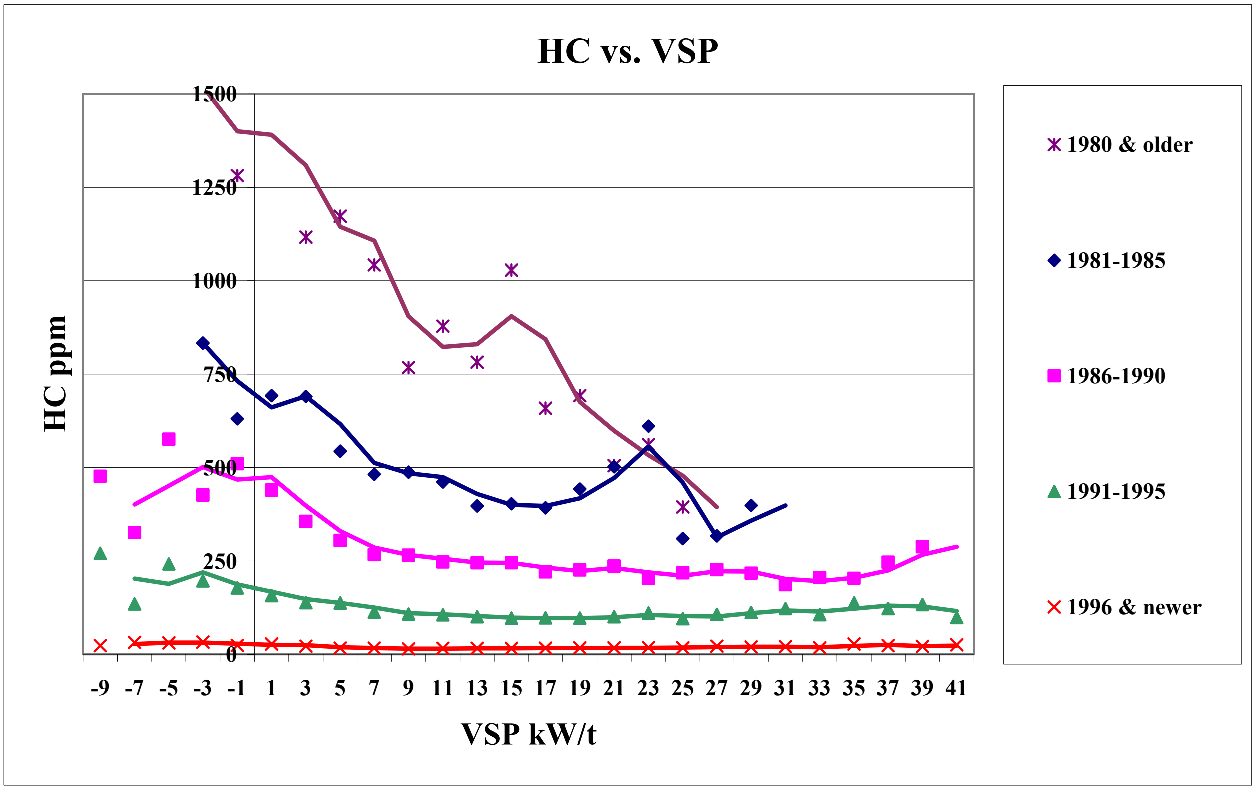
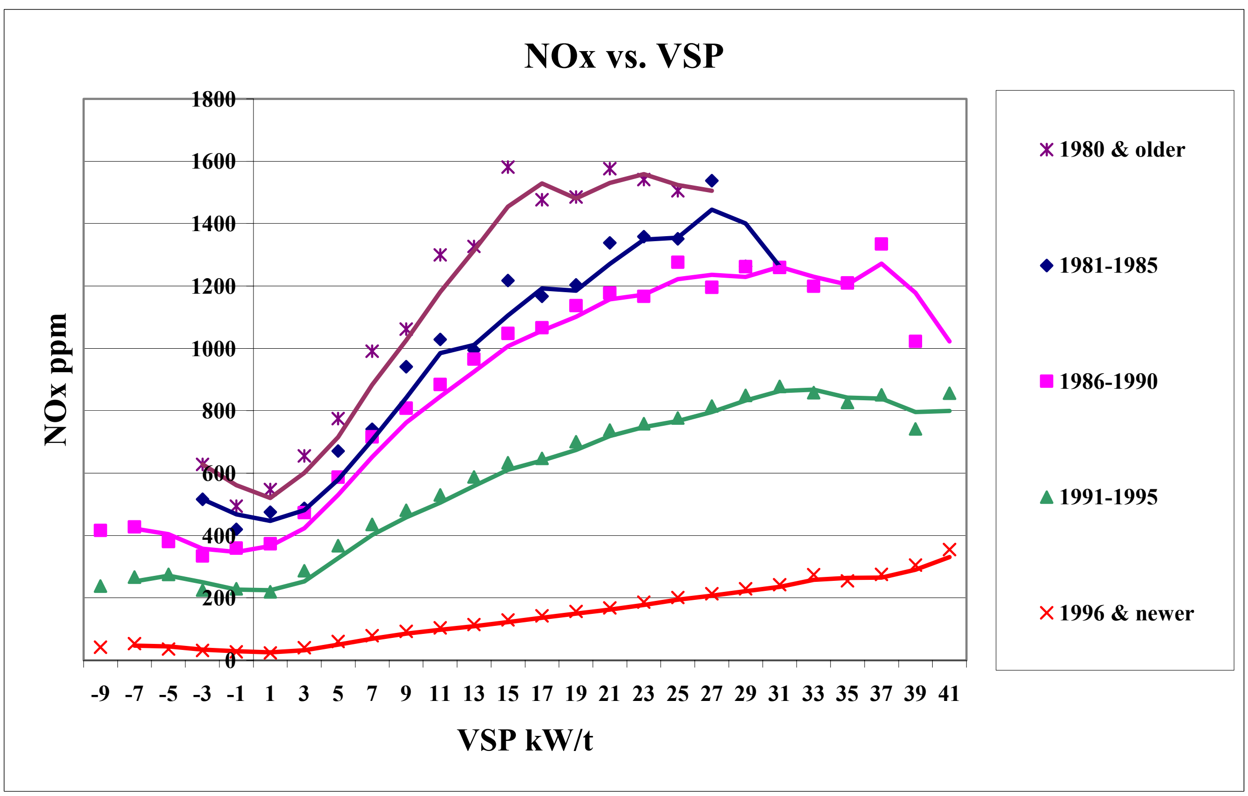


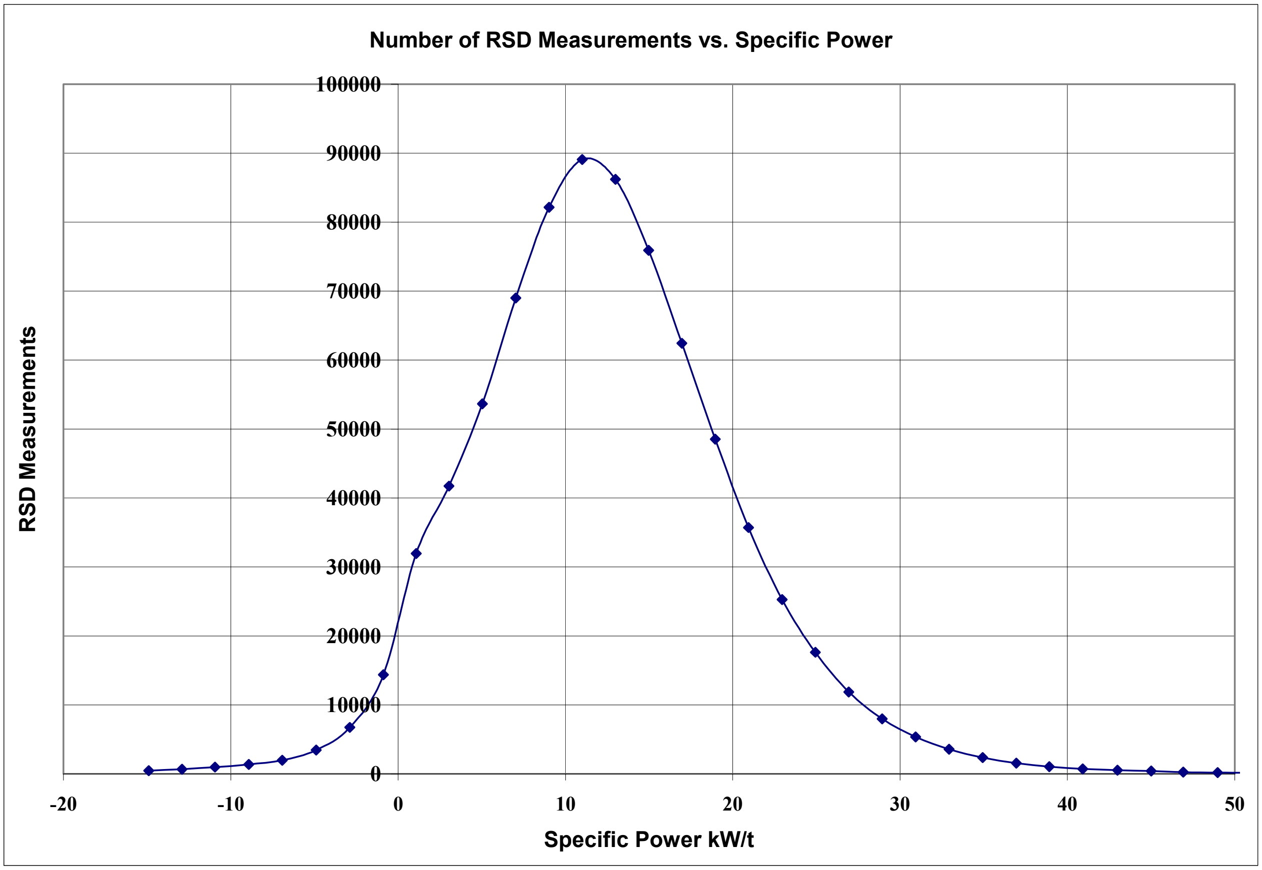
Figure 3-8: NOx vs. VSP



3.2.3. Distributions of VSP

Figure 3-9 shows the overall distribution of VSP. Most observations were made within the range of 3 to 21 kW/t, which are considered to be valid readings by ESP for program evaluation.

Figure 3-9: Distribution of VSP for All Sites



3.3. ***Distribution of Vehicles in Virginia's Fleet***

ESP generated vehicle travel fractions for different vehicle types by model year. We assumed the distributions of observations by vehicle type and model year correspond with actual travel fractions. ESP then compared these distributions with default travel fractions from MOBILE6. The MOBILE6 fractions were calculated by multiplying MOBILE6 registration fraction matrix by the MOBILE6 annual VMT matrix. Results for passenger cars (LDGVs) registered in I/M areas are shown on Figure 3-10. Virginia's I/M fleet appears to be newer than the national average. Figure 3-11 shows the observed VMT fractions for different types of vehicles.

Figure 3-10: Observed LDGV Model Year Percentages vs. MOBILE6

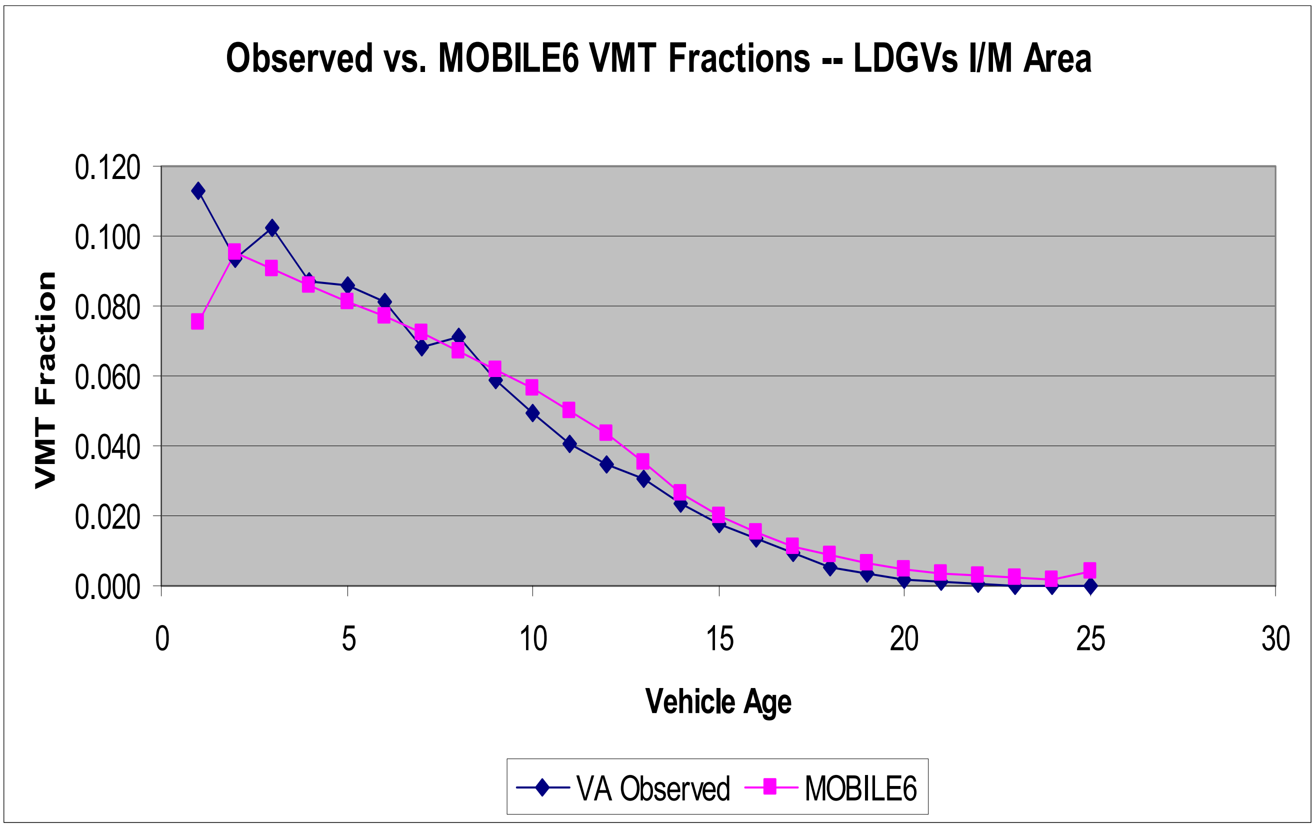
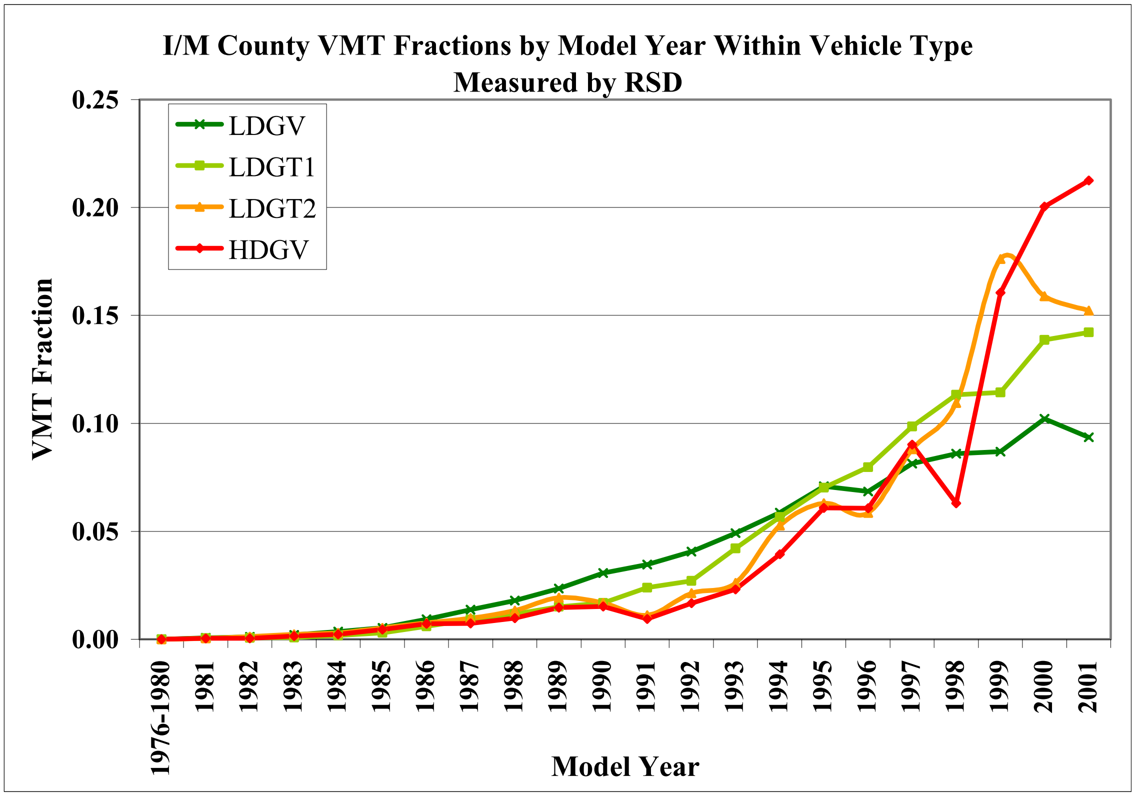


Figure 3-11: Model Year VMT Fractions Within Vehicle Type



3.4. Vehicle Fleet Emission Rates

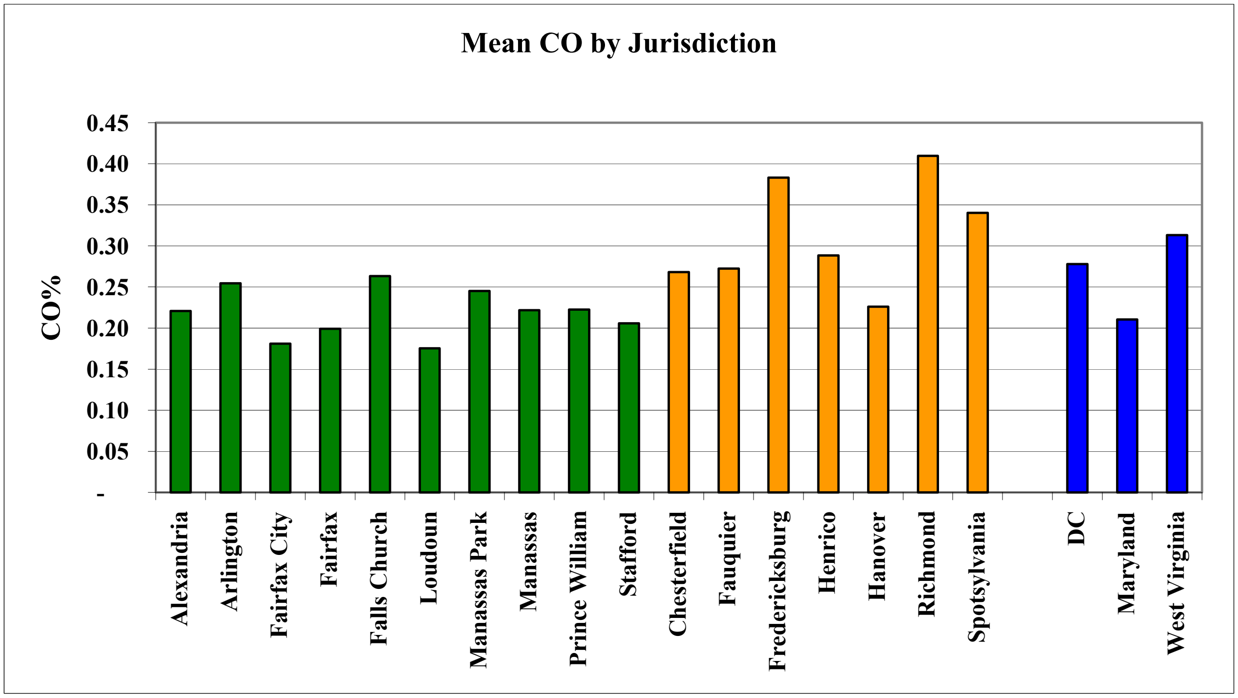
3.4.1. Emission Rates by Residence of Registration

ESP calculated average carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_X) emission rates by Resident Jurisdiction of registration (Figures 3-12 to 3-14). Results are grouped into I/M Virginia, non-I/M Virginia, Maryland, DC and West Virginia. Vehicles registered in the I/M areas of Virginia and Maryland appear to have lower emission rates than those registered in non-I/M areas in Virginia, DC or West Virginia.

Figure 3-15 shows the mean VSP by jurisdiction. Note that it's fairly uniform (with the exception of West Virginia vehicles) so the I/M effect is real.

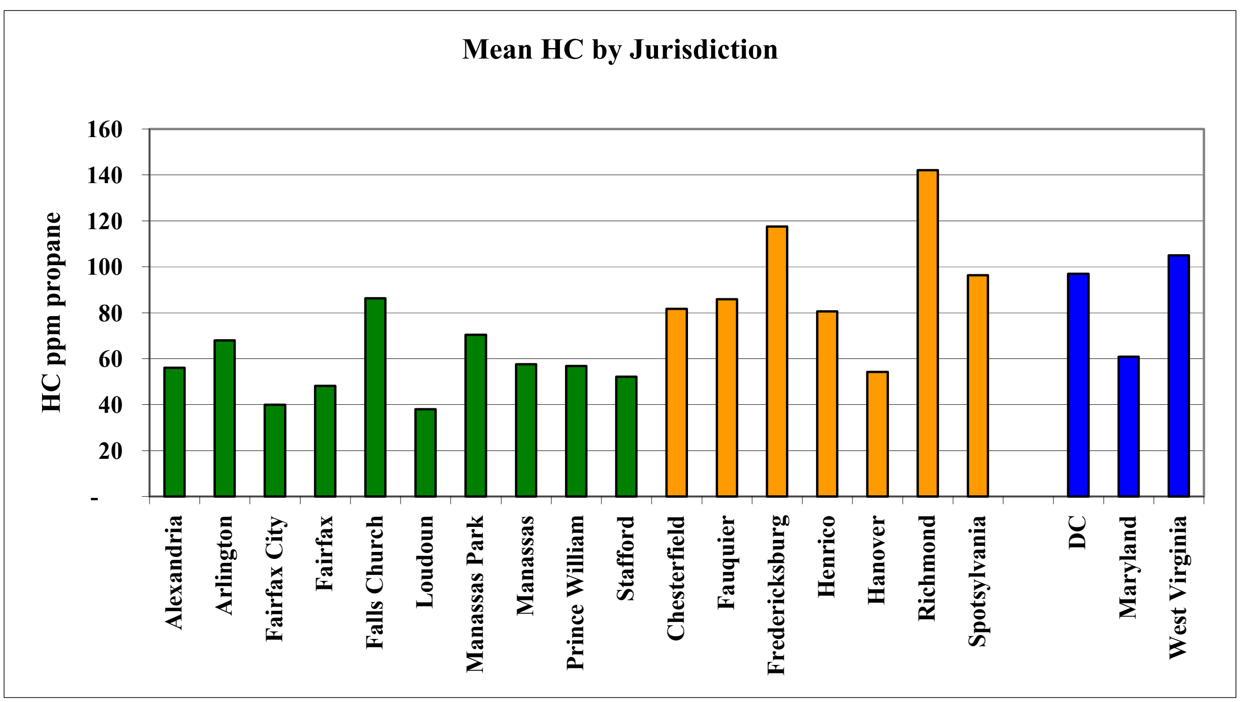
Vehicles that have commuted a longer distance before being measured are likely to have lower emissions than those typically measured in their originating jurisdiction. First, they will all be fully warmed up and, second, the best family vehicle will more often be used to drive a longer distance. This may explain the lower emissions observed for vehicles registered in Hanover County and Loudoun County, which are both on the outskirts of the sampling area.

Figure 3-12: Mean CO by Jurisdiction



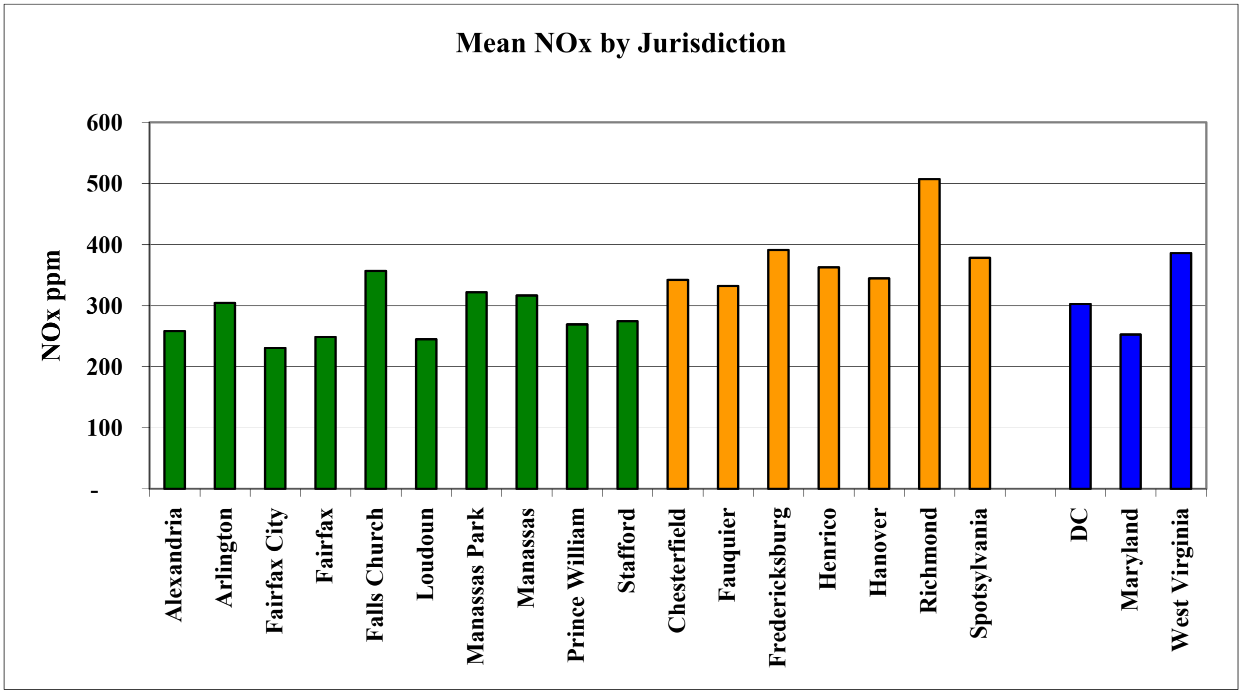
(Green - I/M, Orange - Non-I/M, Blue - Other states)

Figure 3-13: Mean HC by Jurisdiction



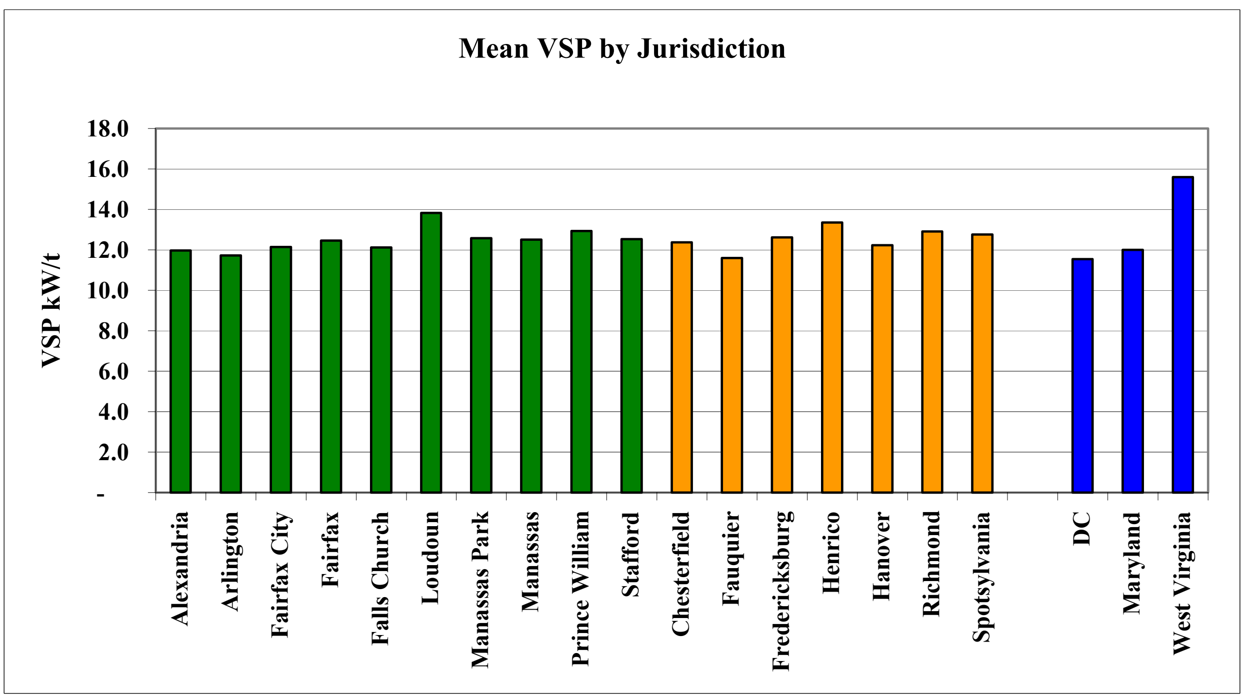
(Green - I/M, Orange - Non-I/M, Blue - Other states)

Figure 3-14: Mean NOx by Jurisdiction



(Green - I/M, Orange - Non-I/M, Blue - Other states)

Figure 3-15: VSP vs. Jurisdiction



(Green - I/M, Orange - Non-I/M, Blue - Other states)

3.4.2. Emissions Rates from In-Program vs. Out of I/M Program Vehicles

ESP compared emission rates by model year group for vehicles falling into the following categories:

(1) I/M Virginia

(2) Non-I/M Virginia,

(3) Maryland (Most are I/M)

(4) DC (I/M)

(5) West Virginia (No I/M)

The number of vehicles in each bar in the following series of charts is shown in the table below.

Table 3-5: RSD Measurement Counts

Model Years	***West Virginia***	***DC***	***Maryland***	***Virginia Non-I/M***	***Virginia I/M***
Passenger Vehicles:					
1981-1985	29	124	232	1,282	2,531
1986-1990	215	595	1,683	6,649	17,911
1991-1995	535	1,467	5,051	15,276	49,406
1996 & newer	1,147	2,840	12,343	31,130	127,036
Trucks:					
1981-1985	52	21	92	776	900
1986-1990	191	129	529	3,624	7,066
1991-1995	379	295	1,995	9,846	24,471
1996 & newer	958	1,141	8,753	26,471	85,448

Figures 3-16 to 3-21 show the results of this analysis. Vehicles registered in Maryland and the I/M areas of Virginia appear to have lower emission rates than those registered in DC, non-I/M areas in Virginia, or West Virginia.

Figure 3-16: CO by Model Year and Jurisdiction – Passenger Vehicles

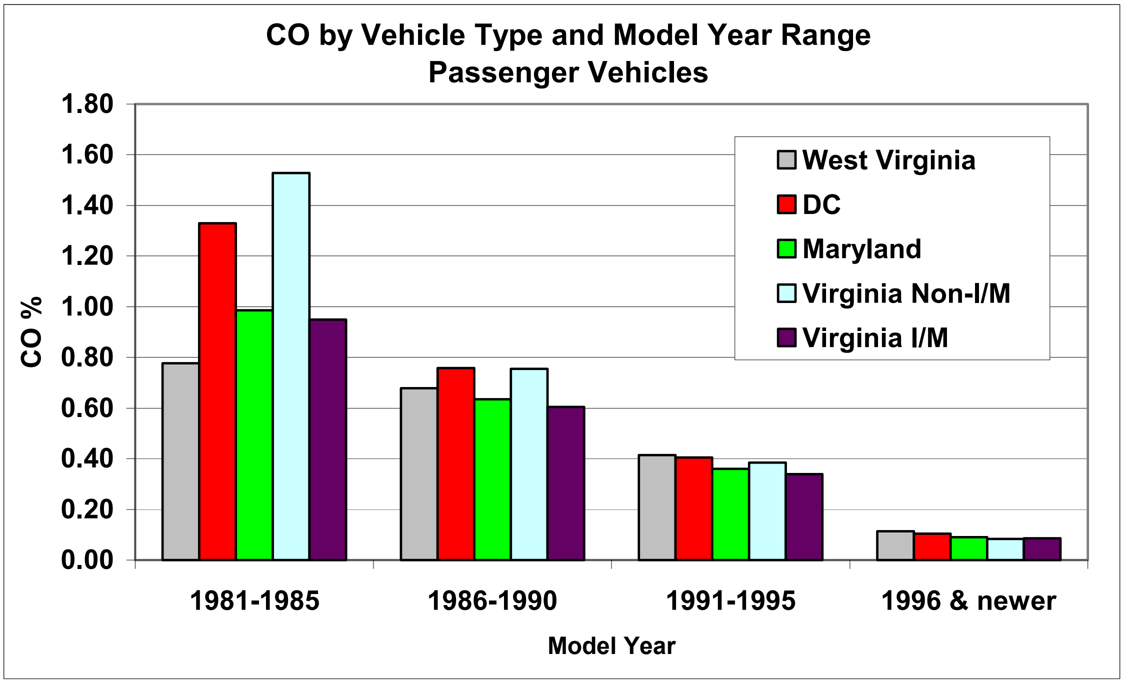


Figure 3-17: CO by Model Year and Jurisdiction - Trucks

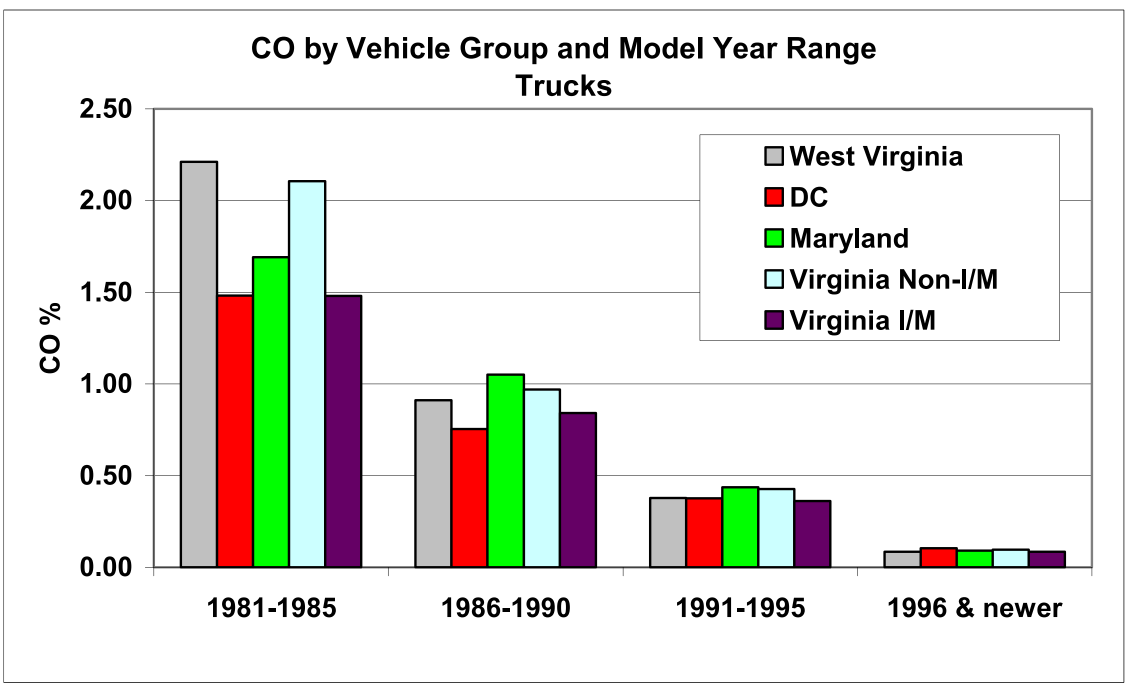


Figure 3-18: HC by Model Year and Jurisdiction – Passenger Vehicles

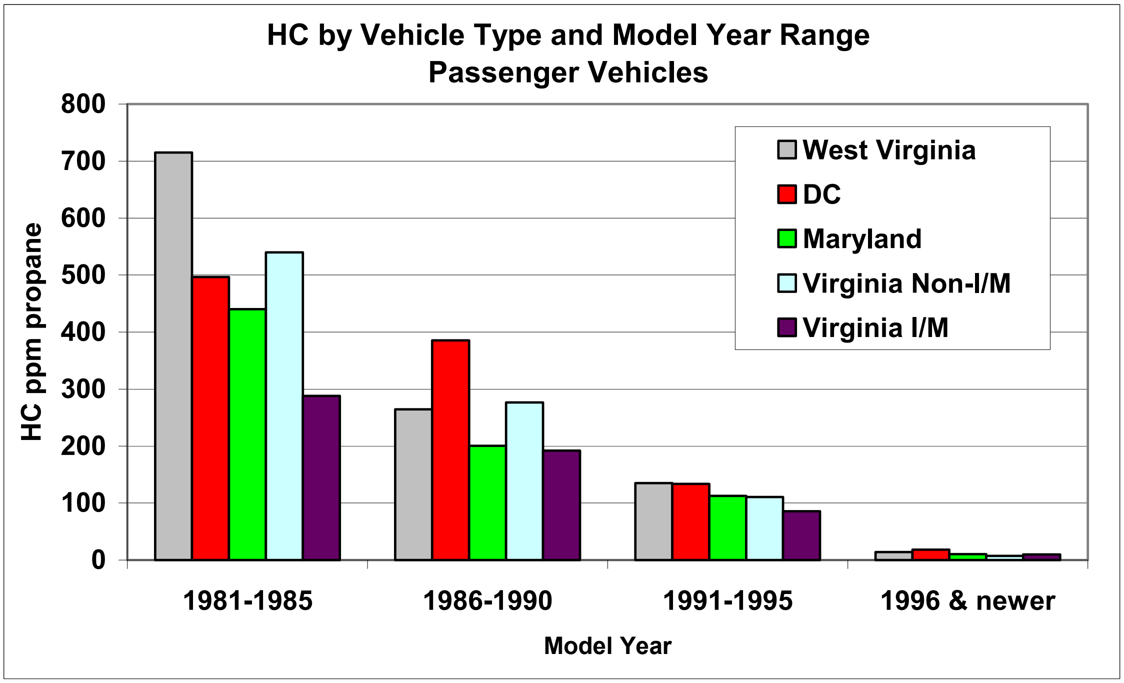


Figure 3-19: HC by Model Year and Jurisdiction - Trucks

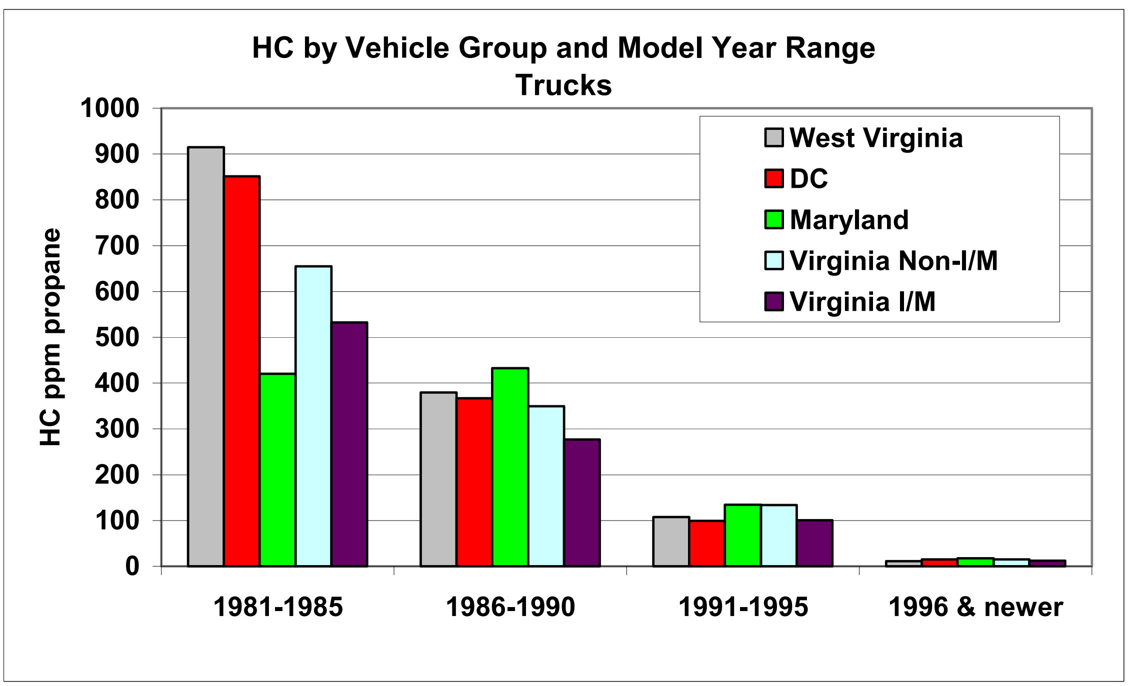


Figure 3-20: NOx by Model Year and Jurisdiction – Passenger Vehicles

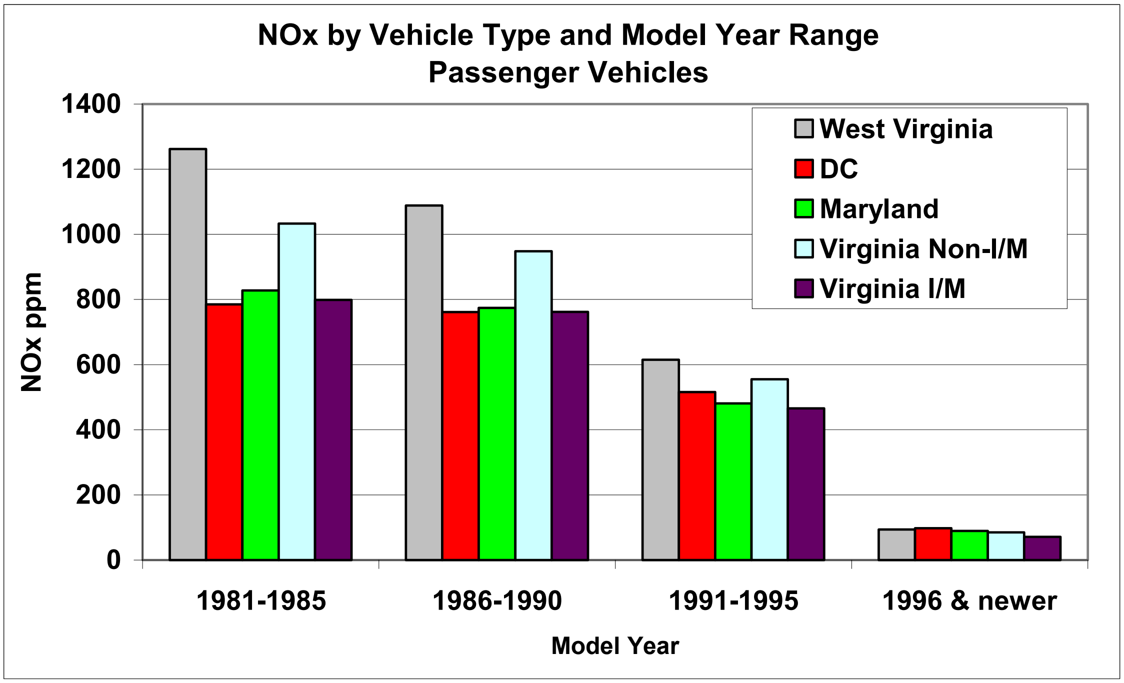
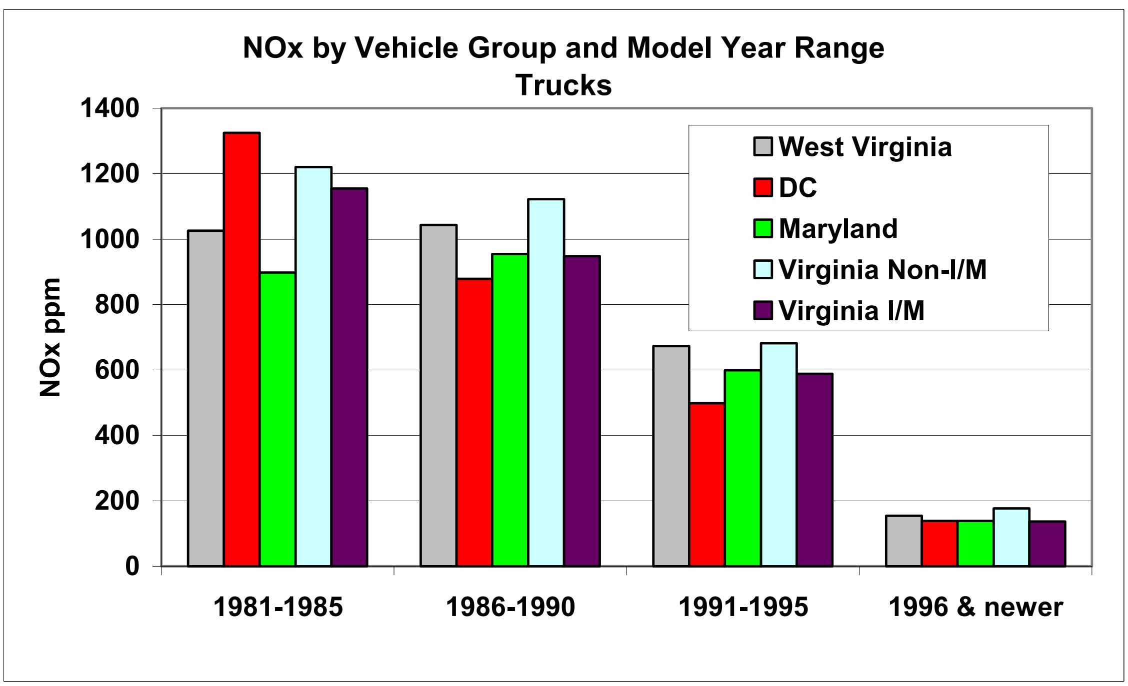


Figure 3-21: NOx by Model Year and Jurisdiction - Trucks



ESP calculated average emission rates for observations on vehicles registered in the following areas:

The Northern Virginia I/M area and
The Virginia non-I/M area.

Figures 3-22 through 3-24 show a comparison of emissions for the two groups. Two scenarios are presented:

Registered vehicles, and
Model year adjusted.

The registered fleet scenario reflects averages of observations of vehicles registered in the area. The model year adjusted scenario takes the average emissions by model year for the area and multiplies them by the combined model year fractions for both the I/M and non-I/M areas. This is intended to eliminate reductions that occur solely because one area has more new vehicles than the other area. It could be argued the mere presence of an I/M program creates a shift to newer vehicles, so the adjustment may partially hide some I/M benefits. The model year adjustment reduces the apparent difference between the I/M and non-I/M areas to roughly 12% for CO, 22% for HC and 15% for NOx.

Figure 3-22: I/M vs. Non-I/M CO

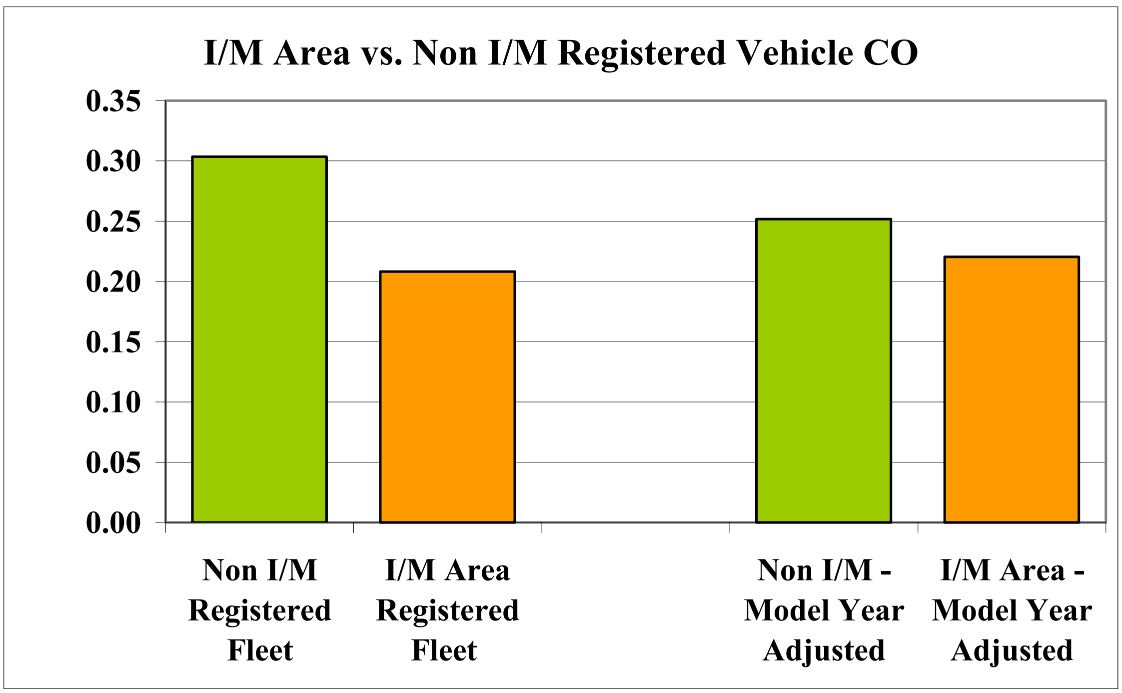


Figure 3-23: I/M vs. Non-I/M HC

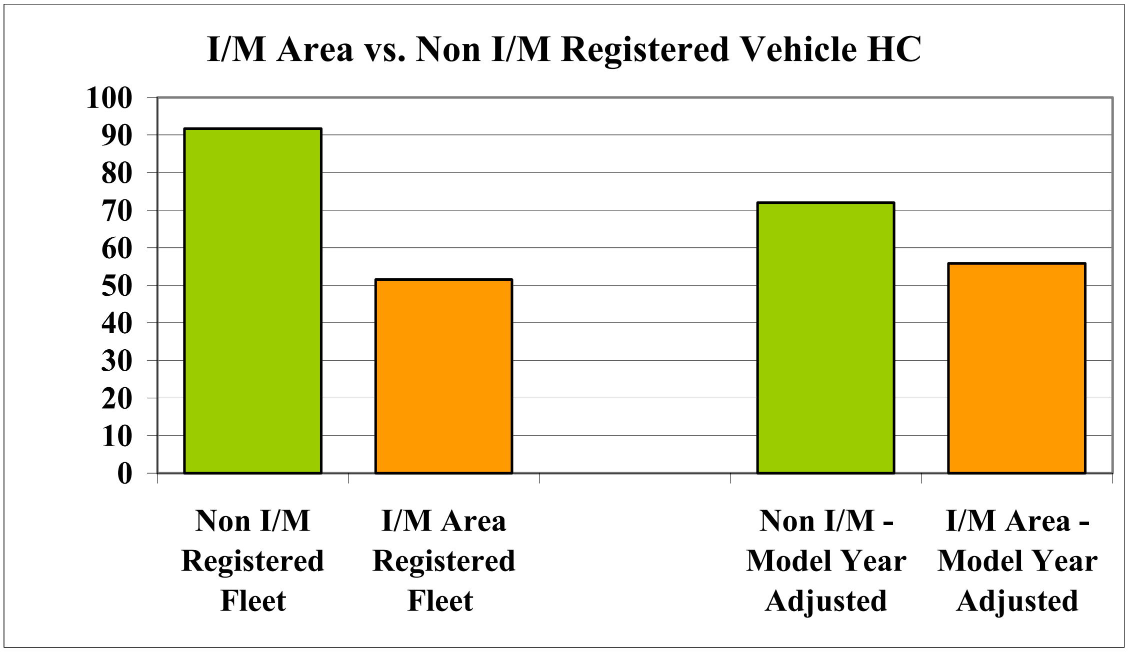
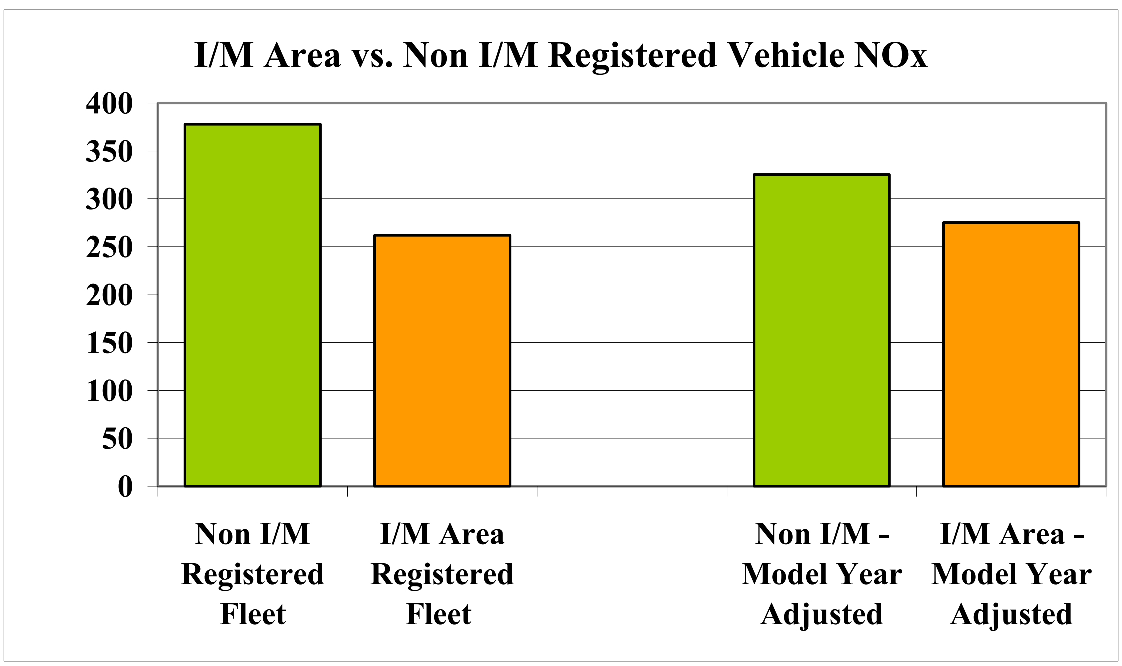


Figure 3-24: I/M vs. Non I/M NOx



3.4.3. Breakdown of Observations and Emissions in the Northern Virginia I/M Area

Figures 3-25 to 3-28 show a breakdown of observations in the Northern Virginia I/M area. As shown, vehicles that are registered outside the Northern Virginia I/M area account for 28% of the observations, 32% of the HC emissions, 29% of the CO emissions and 28% of the NOx emissions in Northern Virginia.

Figure 3-25: Source of Vehicles On-Road in the I/M Area

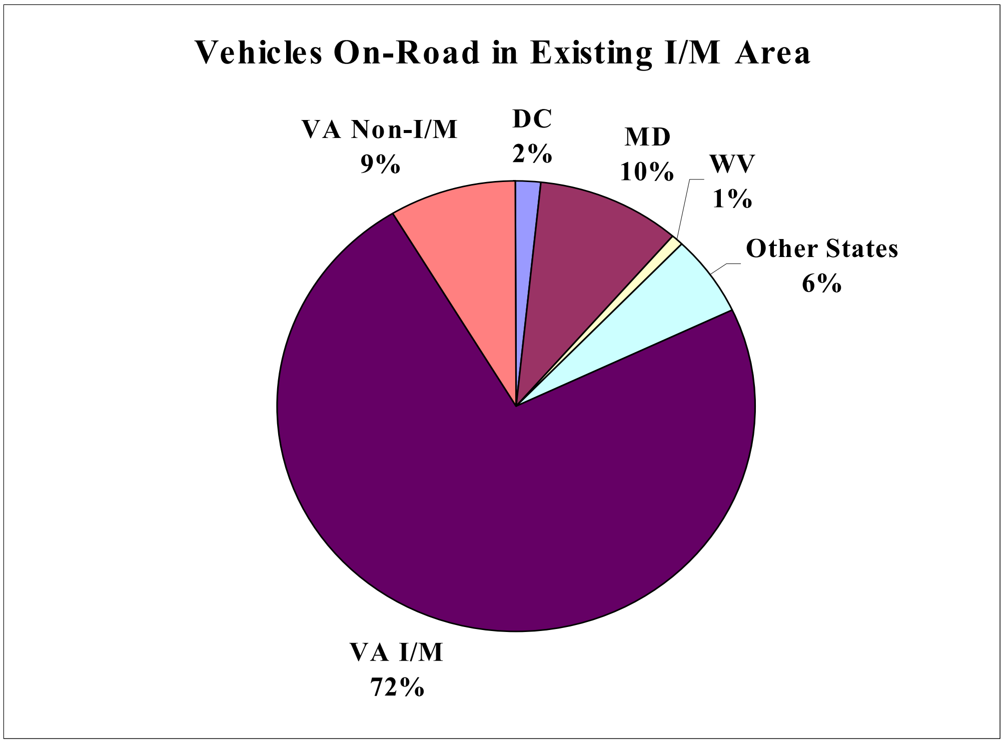


Figure 3-26: Source of CO Contributions in the I/M Area

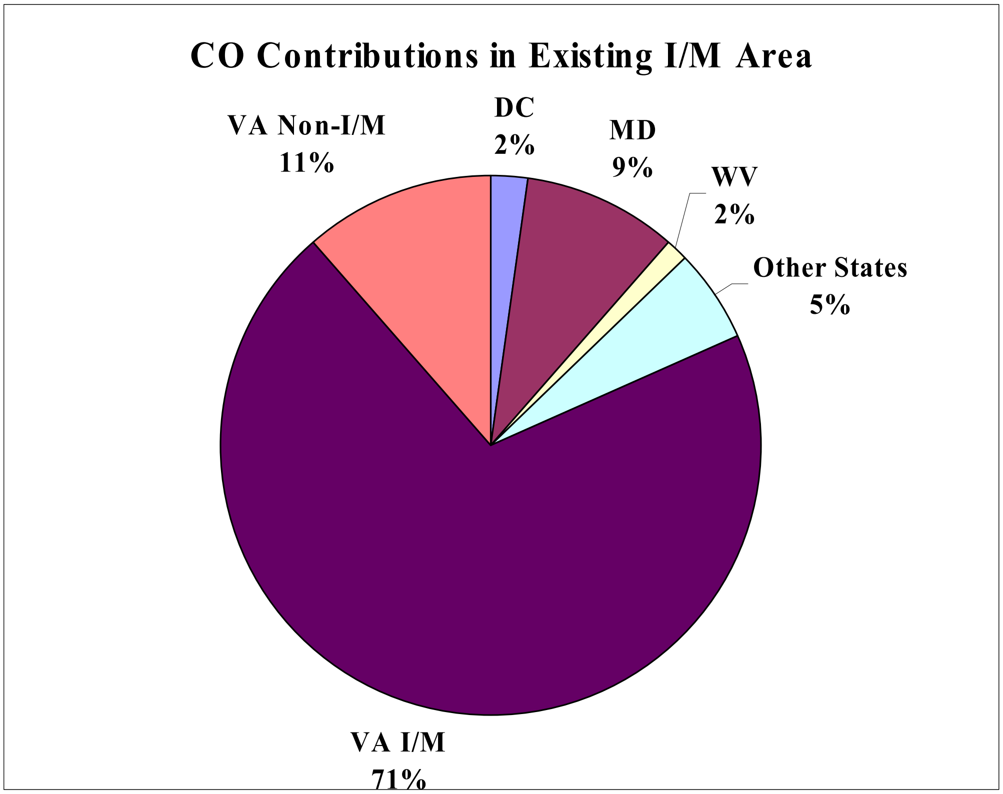


Figure 3-27: Source of HC Contributions in the I/M Area

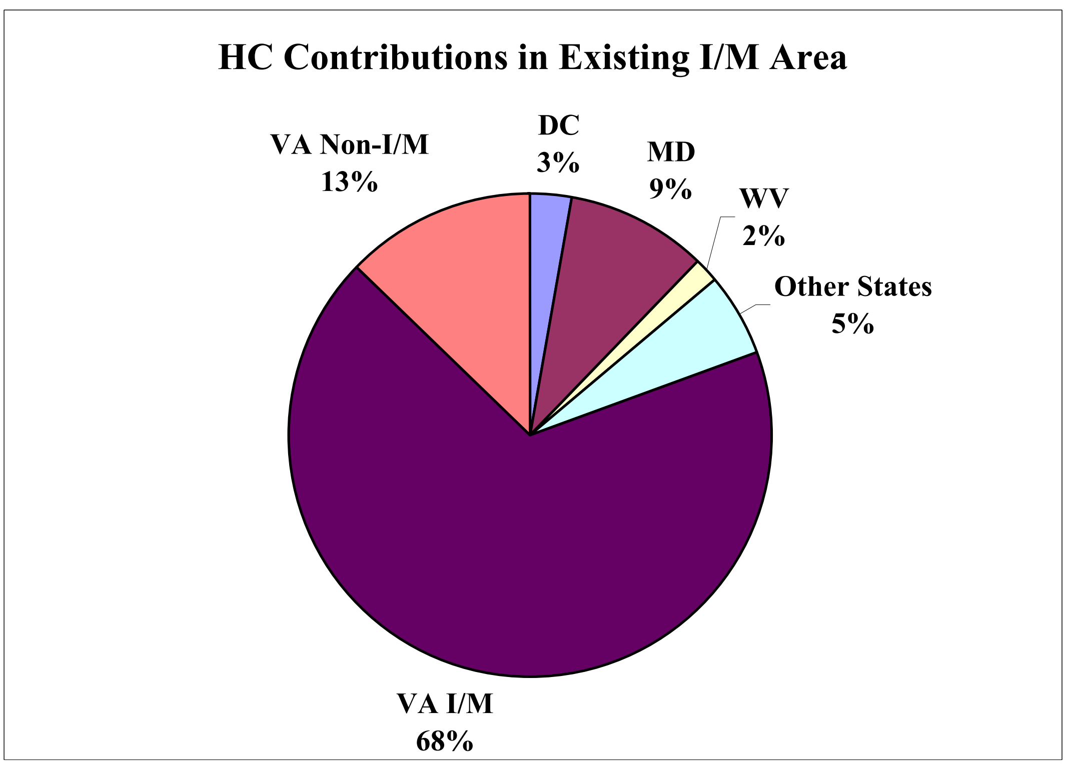
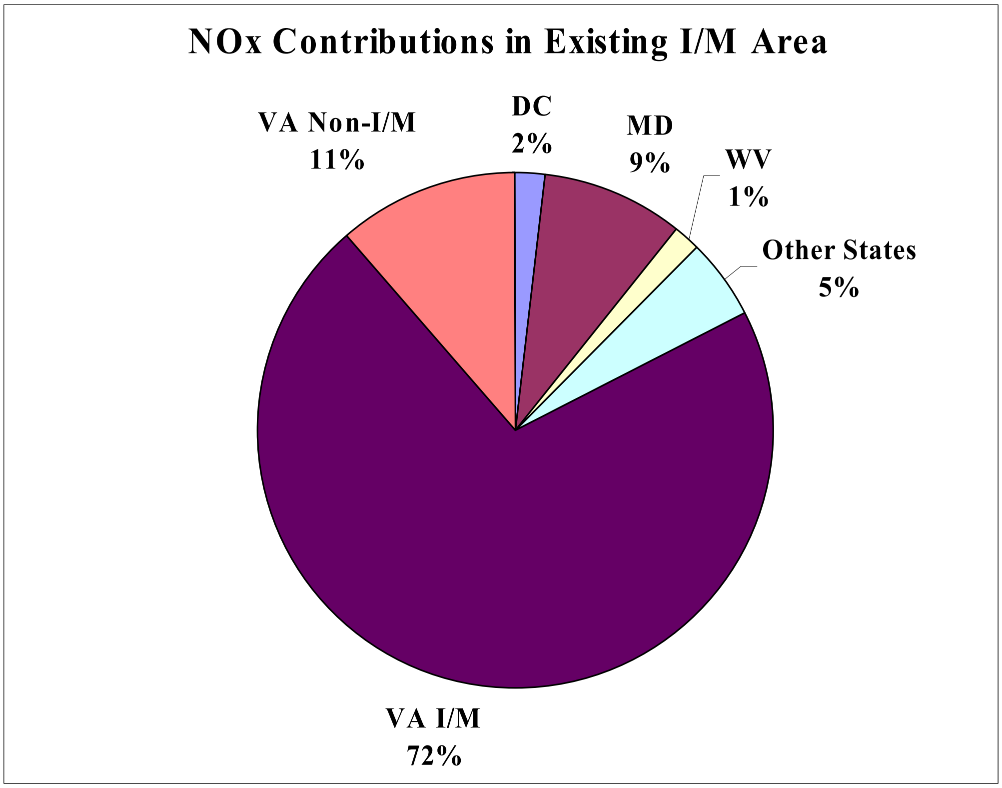


Figure 3-28:Source of NOx Contributions in the I/M Area



3.4.4. Total Emissions by Model Year

Figures 3-29 through 3-31 show total emissions by model year. These totals represent sums of RSD values by model year. Note that the totals peak in the 1993 to 1995 model years and then drop dramatically in 1996. Requirements for onboard-diagnostics (OBDII) and Tier 1 emission standards, which were both in effect in model year 1996, and National Low Emission (NLEV) vehicles, which were sold in VA, DC and MD beginning with model year 1999, could be contributing to this drop.

Figure 3-29: Model Year CO Contribution

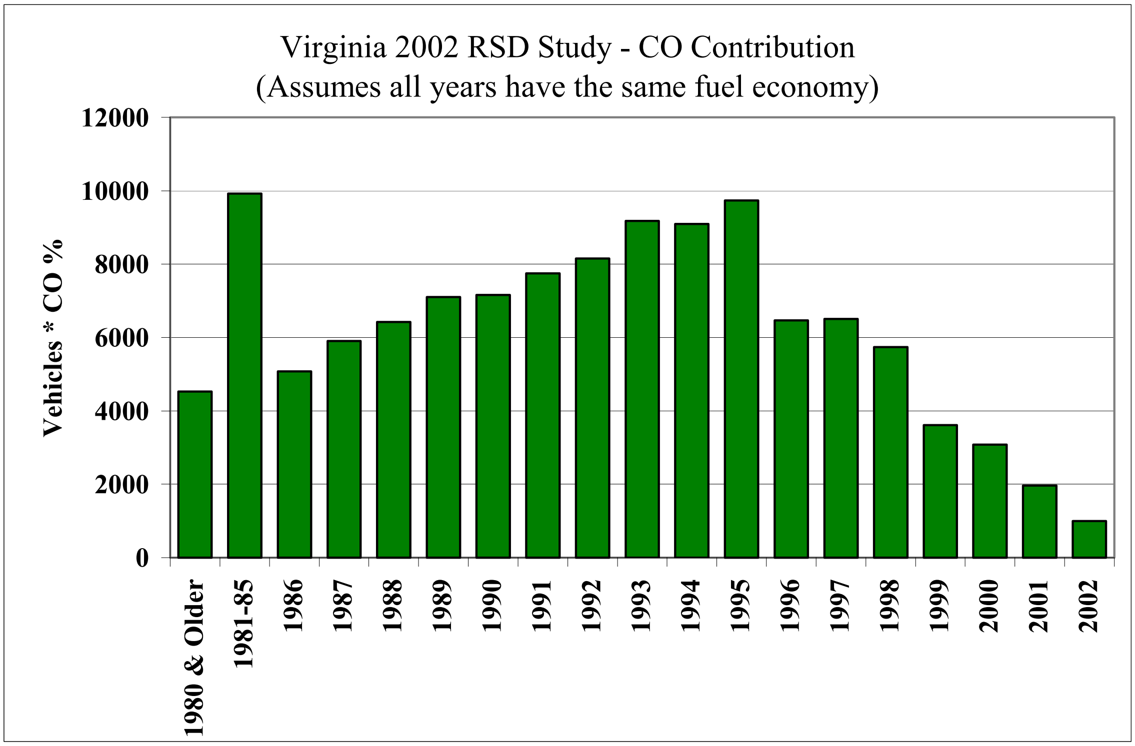


Figure 3-30: Model Year HC Contribution

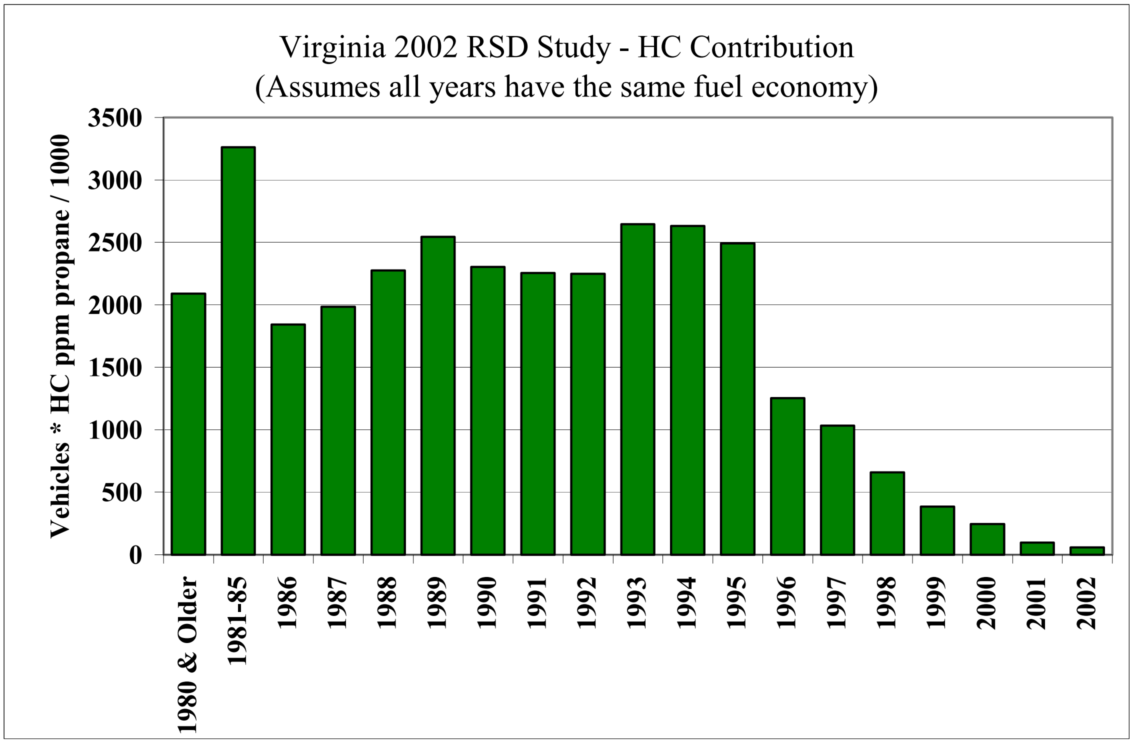
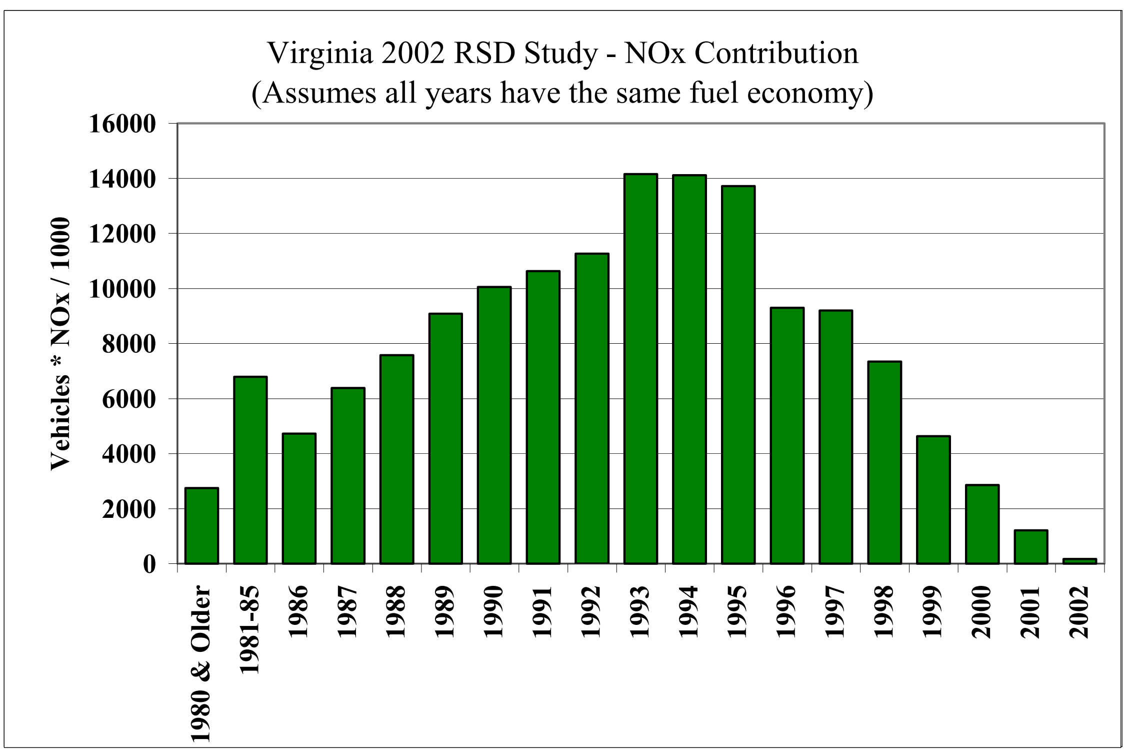


Figure 3-31: Model Year NOx Contribution



ESP created decile plots for each pollutant by model year (Figures 3-32 to 3-34). These plots showed the average emissions for the cleanest to dirtiest tenth of the group. The plots indicated that more of the 1996 and newer model year vehicles were extremely low polluting than the older model year vehicles, but that the dirtiest tenth still had excessively high emissions.

The cleanest 10% of vehicles for the newer model year have negative emissions values. This is a result of instrument noise in the remote sensing measurements. All instrument measurements include some random variation about the actual value being measured. When the value being measured is very small, the noise can result in a negative value. A clean car following a dirty car can also produce a negative measurement since the ambient background emissions, which are deducted from the exhaust measurement, may be elevated following passage of a dirty vehicle. Under this circumstance, a clean vehicle with good fuel/air control and an effective catalyst can have lower tailpipe emissions than the ambient background.

Figure 3-32: CO Deciles

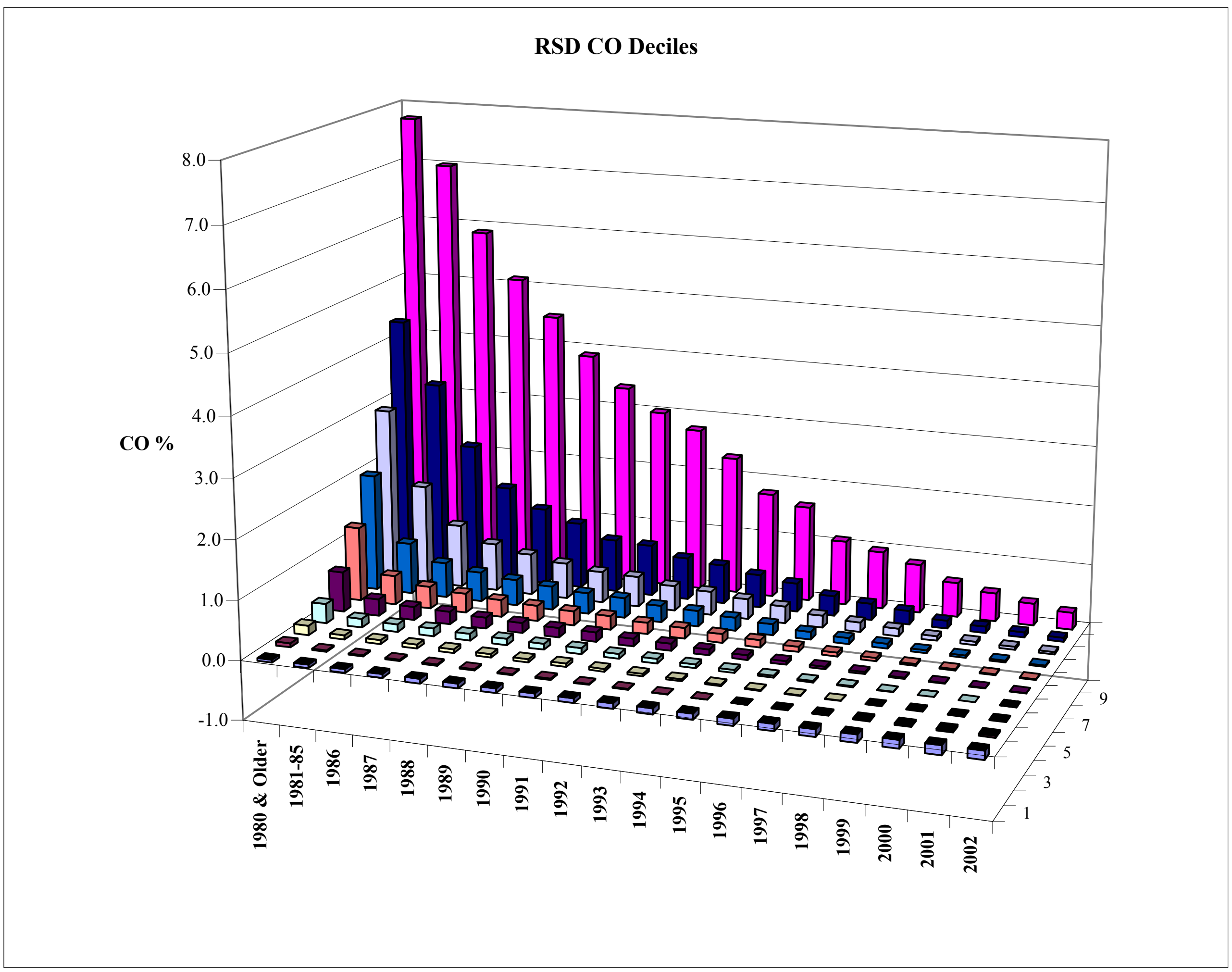
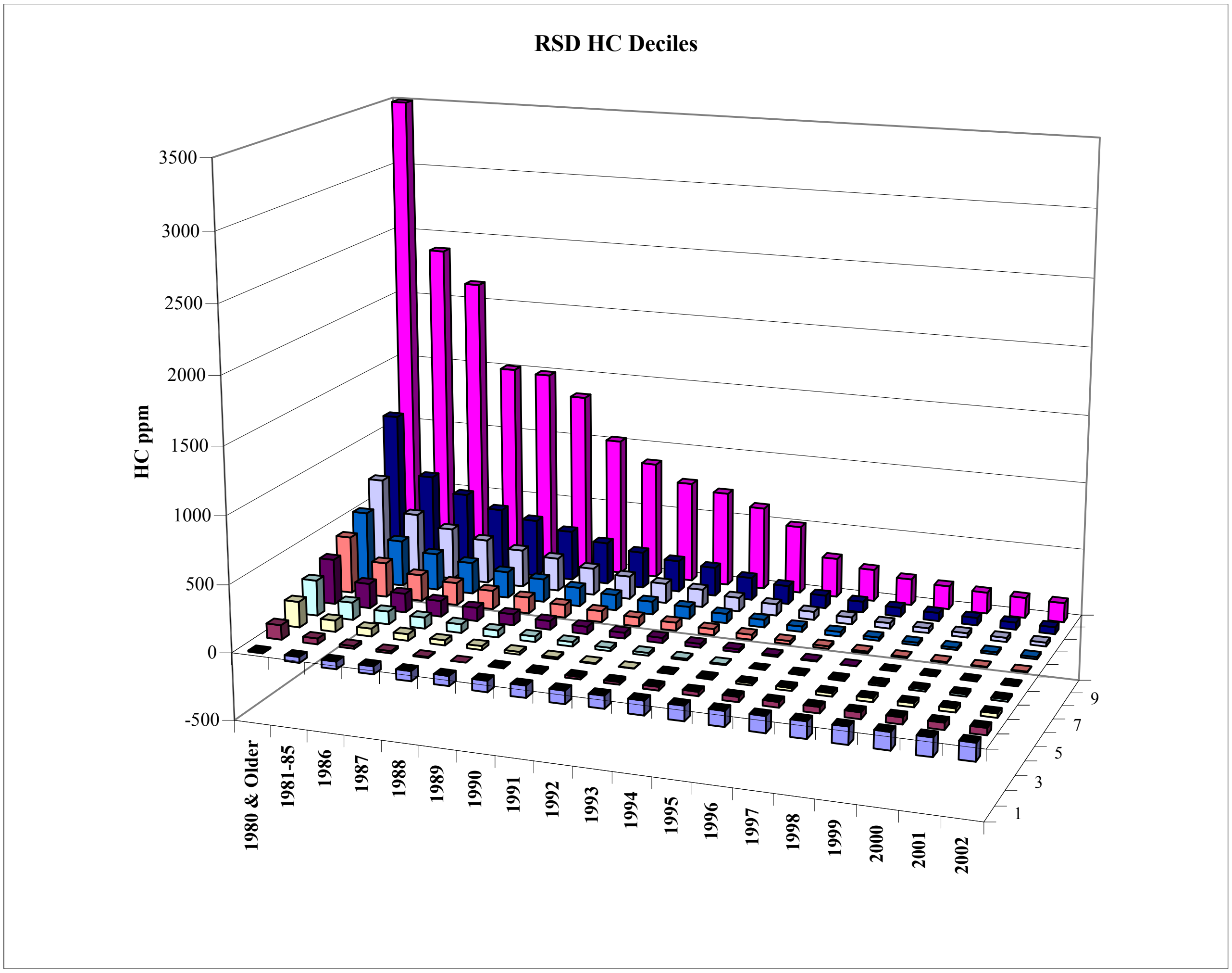
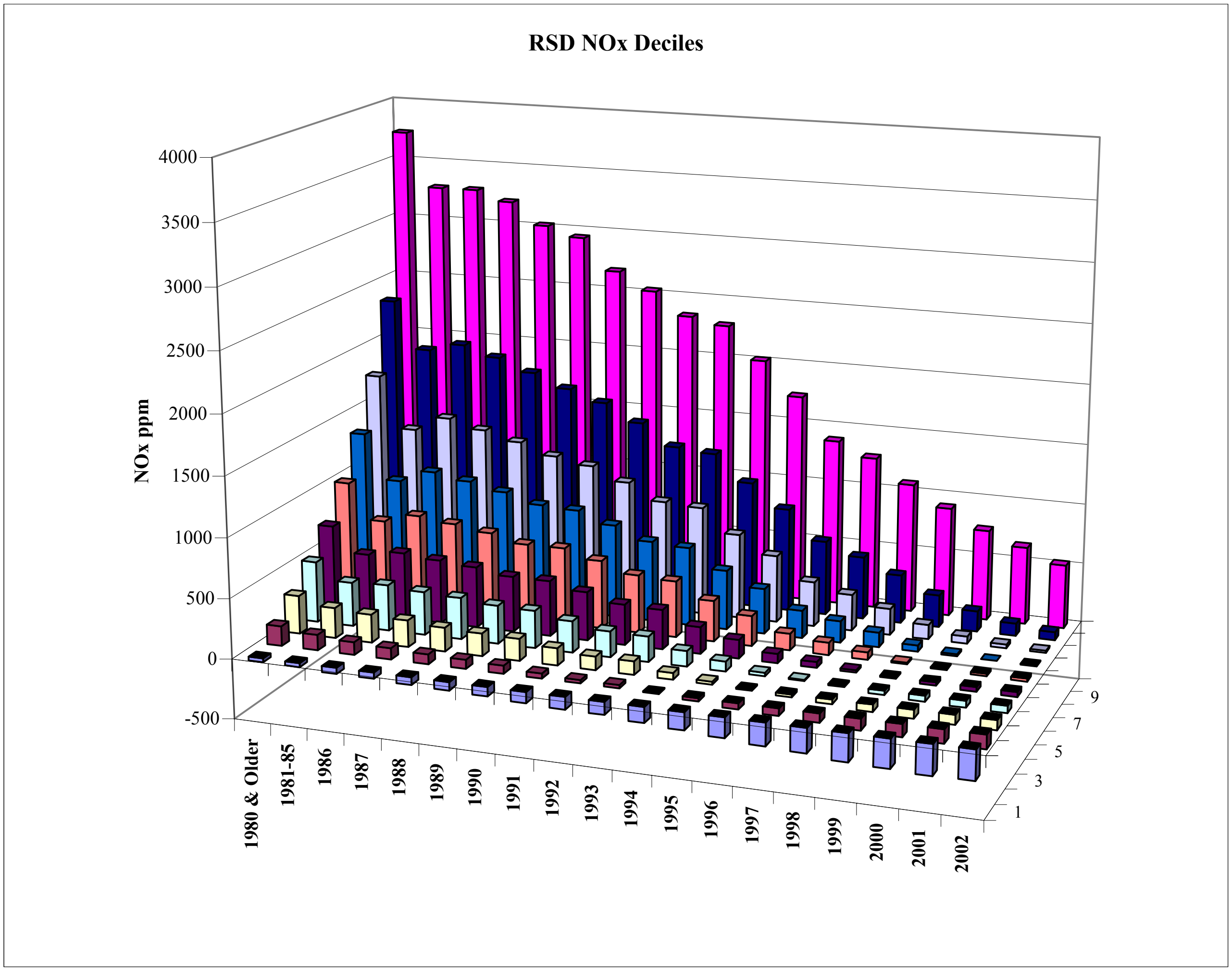


Figure 3-33: HC Deciles



Y-axis capped at 3,500 ppm. The highest decile value for 1980 & older models is 5,311.

Figure 3-34: NOx Deciles



3.5. Analysis of Data on Vehicles that Received ASM Inspections Before or After Being Observed by RSD

3.5.1. Matching RSD Results with I/M Results

RSD results were matched with the most recent I/M result before and after the RSD measurement. The "matched dataset" contains the following information:

(1) Date of most previous and/or first future I/M test

(2) First past or future I/M test result (pass, fail or waiver);

(3) First past or future test type performed (ASM-2 or TSI);

(4) First past or future test type (Initial or Retest);

(5) First past or future test emissions results;

3.5.2. Observed I/M Effects Based on Matched Data

ESP compared emissions for the following cases:

> Non-I/M registered fleet;
> I/M area registered fleet before I/M; and
> I/M area registered fleet after I/M.

These comparisons are shown in Figure 3-35 to 3-37 and Table 3-6. RSD results show that the I/M program has cumulative effects that go beyond the impact of one inspection and repair cycle. The observed emission reductions for one inspection and repair cycle are listed below:

> 5% reduction for CO;
> 4% reduction for HC; and
> 6% reduction for NOx.

However, when the after I/M results are compared to the non-I/M registered fleet, the following reductions are observed:

> 16% reduction for CO;
> 30% reduction for HC; and
> 21% reduction for NOx.

Figure 3-35: Age Adjusted I/M vs. Non-I/M CO

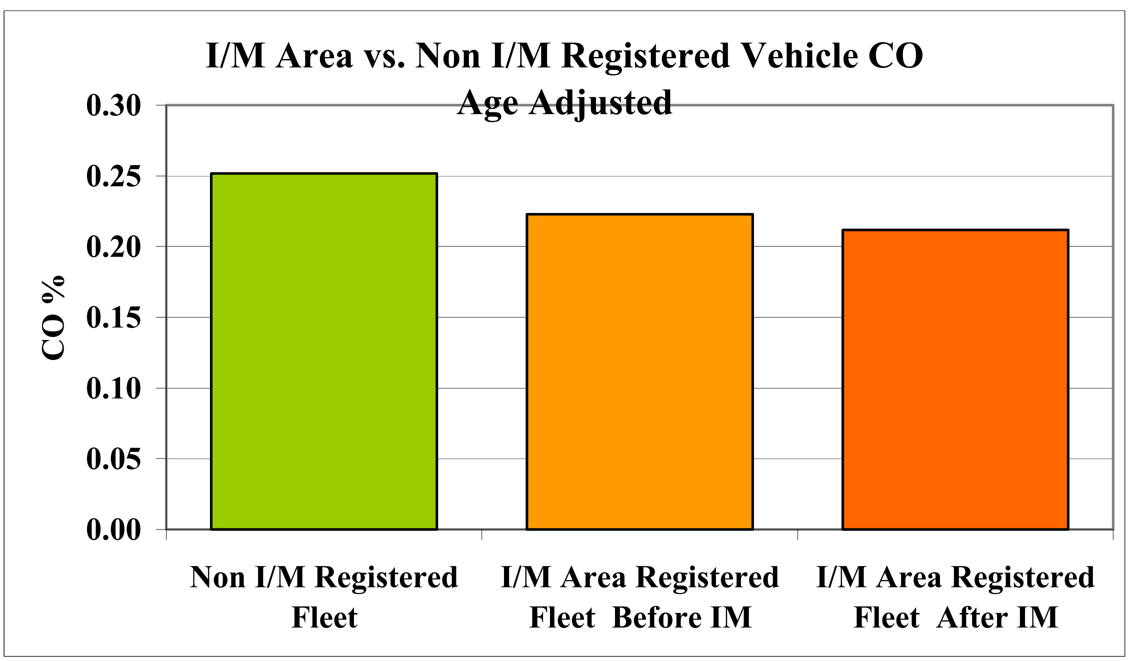


Figure 3-36: Age Adjusted I/M vs. Non-I/M HC

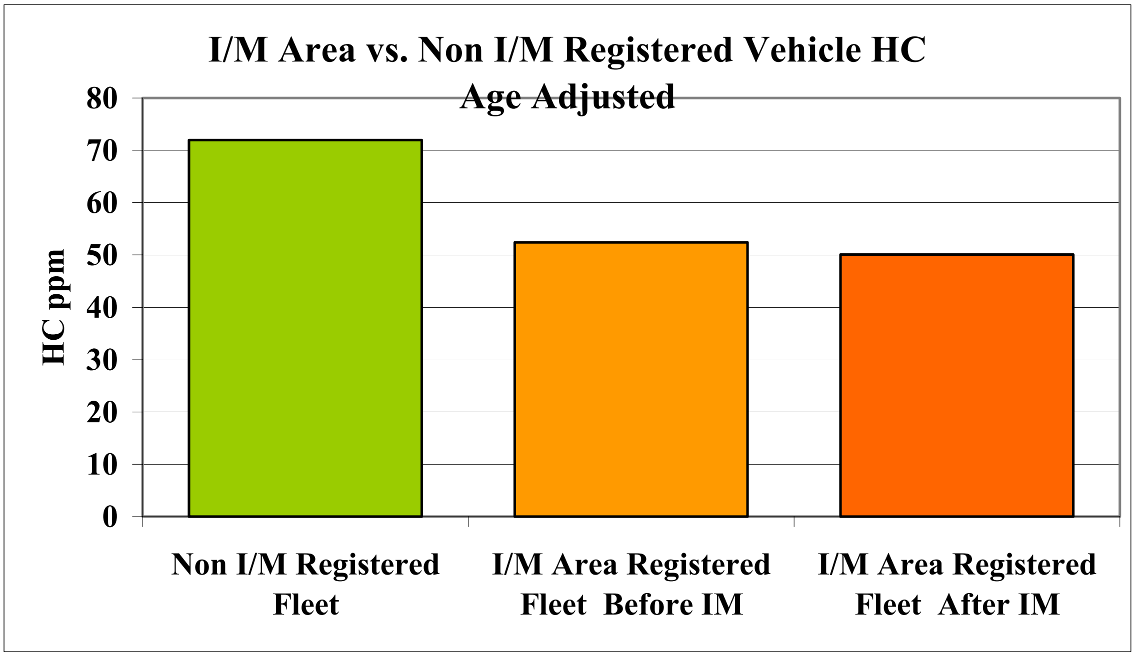


Figure 3-37: Age Adjusted I/M vs. Non-I/M NOx

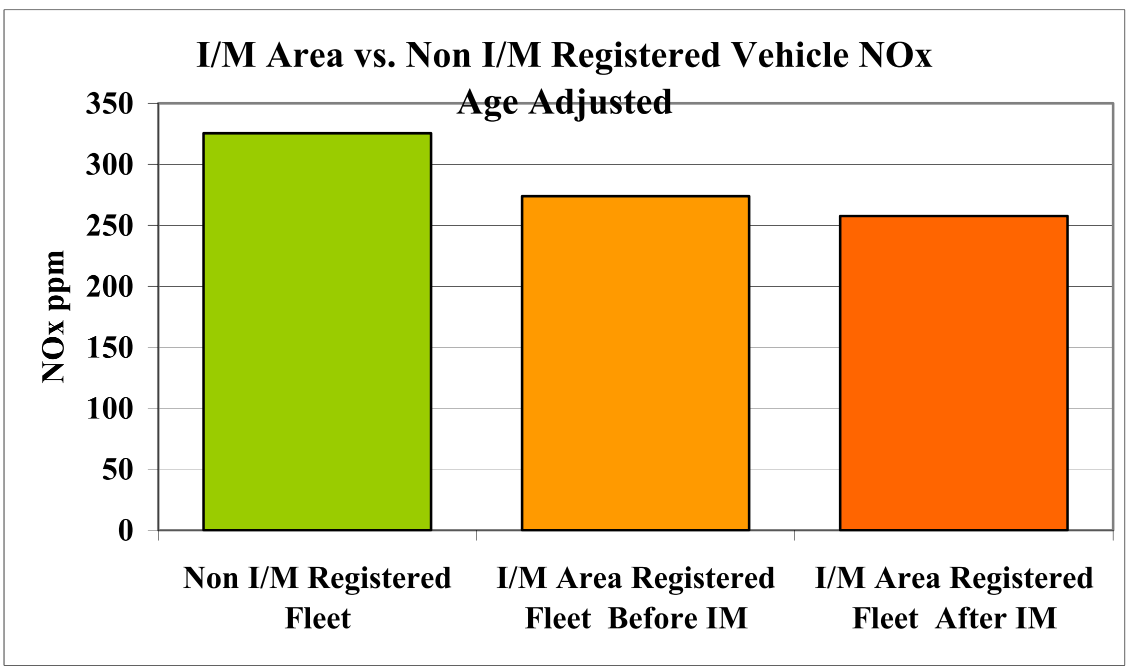


Table 3-6 Observed Emission Reductions from Virginia's I/M Program

Scenario	Pollutant		
	CO	**HC**	**NOx**
Non I/M	0.25	72	375
I/M Vehicles Before Test	0.22	52	274
I/M Vehicles After Test	0.21	50	258
% Reduction: After vs. Before	**5.0%**	**4.5%**	**5.9%**
% Reduction: After Test vs. Non I/M	**15.9%**	**30.4%**	**20.9%**

3.5.3. Emission Rates Before and After I/M Based Upon I/M Disposition

ESP compared emissions before and after I/M for the following groups of vehicles:

Vehicles that passed the initial I/M inspection;
Vehicles that failed the initial inspection but ultimately passed;
Vehicles that failed the initial inspection and never passed prior to receiving an RSD measurement.

As shown on Figure 3-38 through Figure 3-40, the lowest emission levels were observed for vehicles that passed the initial inspection. Vehicles that failed the initial inspection and were repaired to pass generally showed much greater reductions then the group that failed and never passed. The data shown on Figures 3-38 through Figure 3-40 were not adjusted for model year differences. They represent averages for 30-day periods before and after the I/M test. Vehicles in the failing groups are much older models than those in the pass initial group, which explains the discrepancy between after I/M emission levels for the initial fail/final pass group and the pass initial group.

Figure 3-38: CO Before and After I/M Inspection

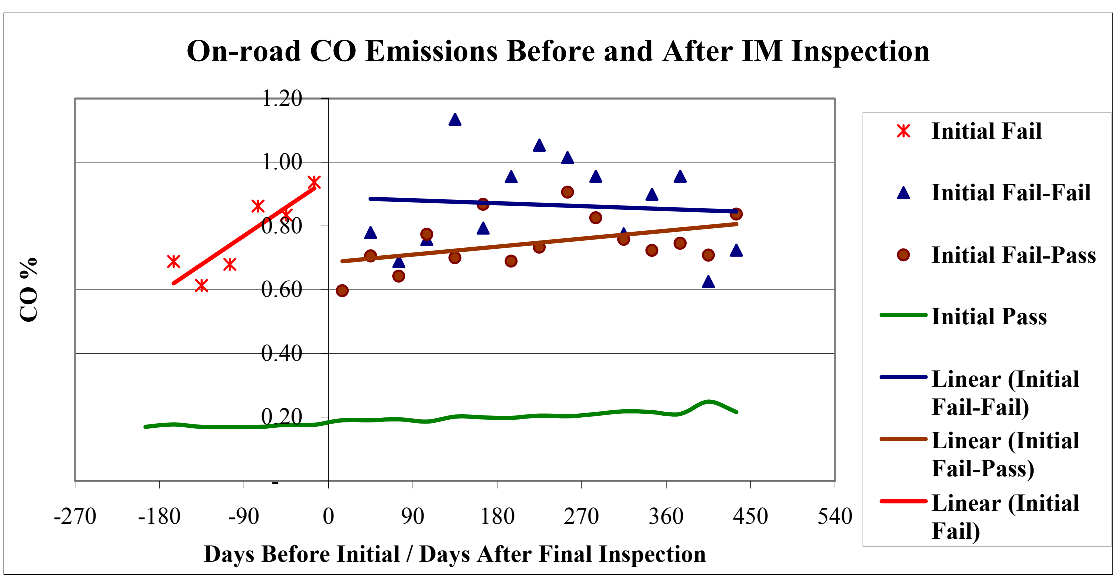


Figure 3-39: HC Before and After I/M Inspection

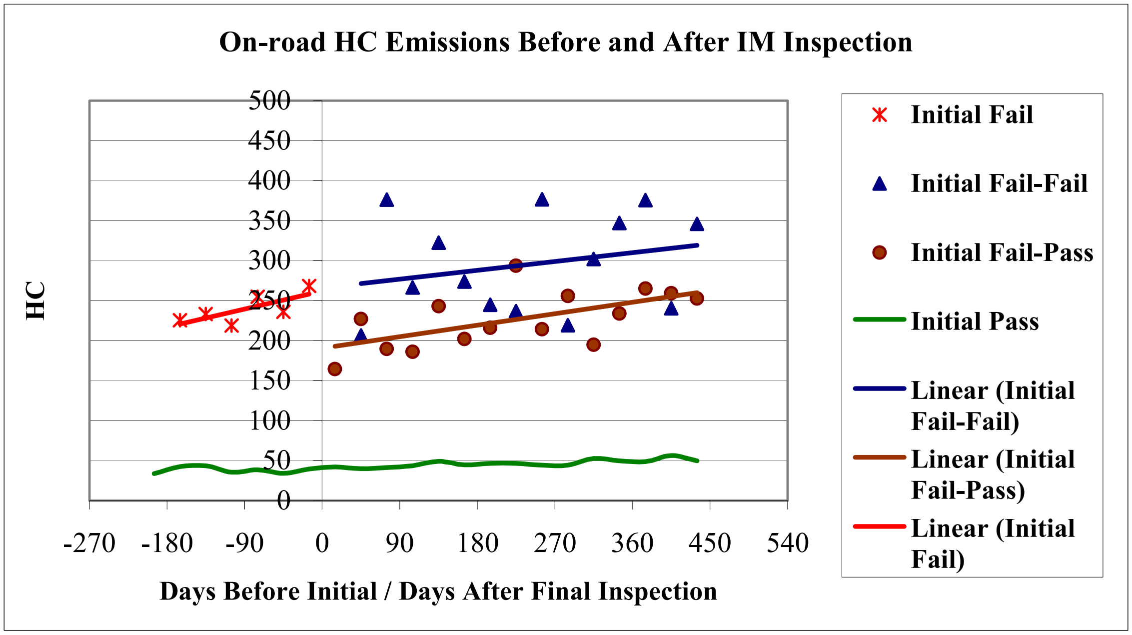
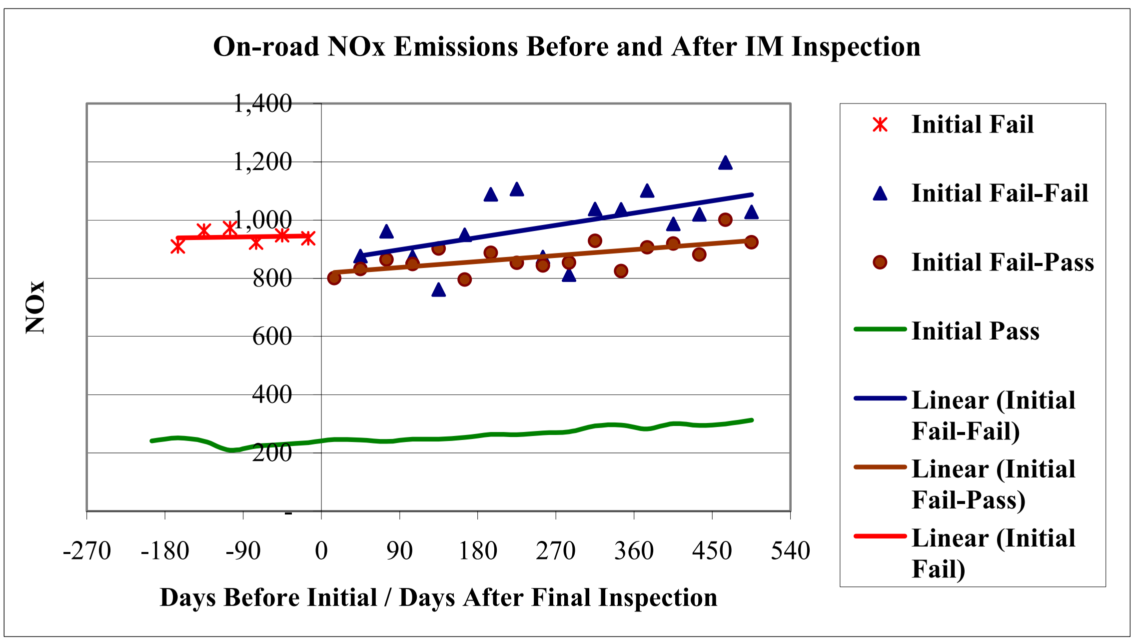


Figure 3-40: NOx Before and After I/M Inspection



3.6. MOBILE6 I/M Credits vs. RSD Observed I/M Emission Reductions

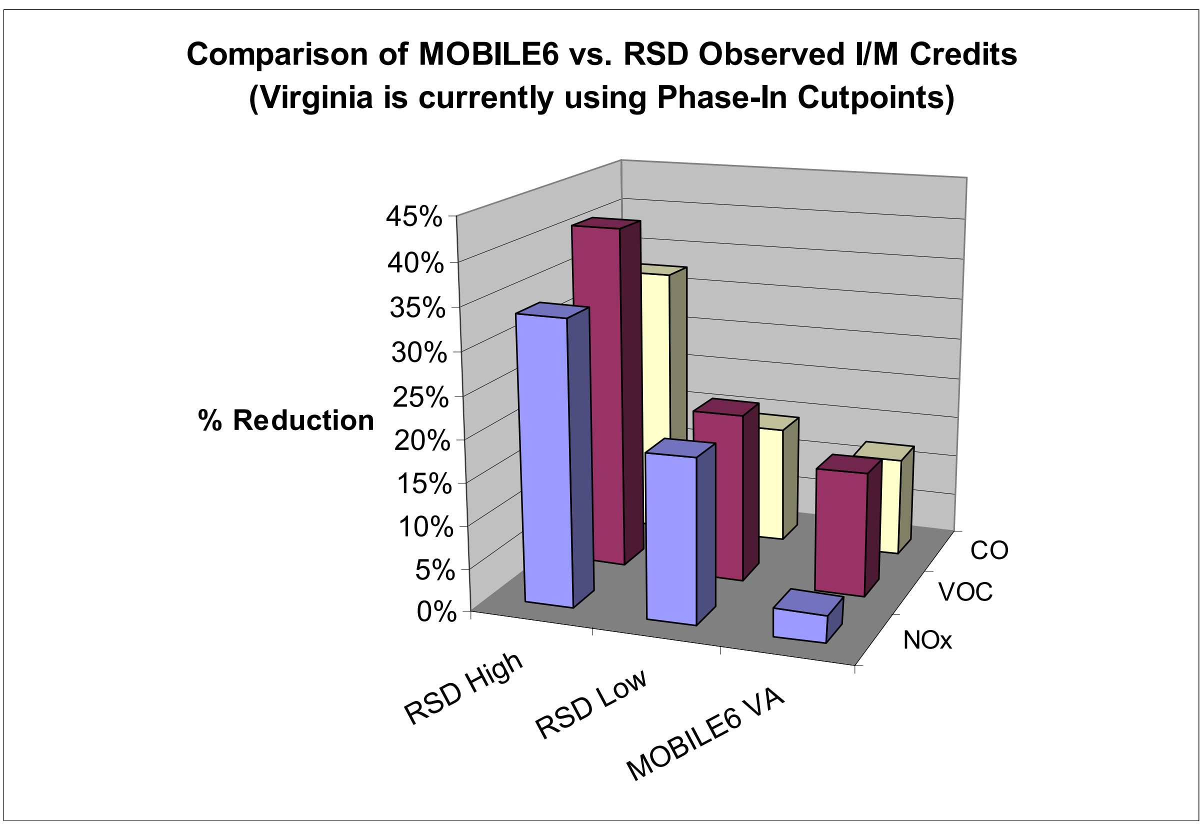
The Virginia Department of Environmental Quality ran MOBILE6 and estimated I/M credits for VA's current program in 2002. ESP then compared the MOBILE6 results with the reductions based on the Virginia RSD program. ESP calculated the percent reductions based on the difference between RSD emission rates on vehicles registered in Virginia's I/M and non-I/M areas. The RSD High estimate is based on

the unadjusted averages of RSD observations in I/M and non-I/M areas. The RSD Low estimate is based on the normalized by model year averages of RSD observations in I/M and non-I/M areas. These reductions are lower than the normalized averages for the subset of the sample that were observed after I/M (see Table 3-6 above). Results are summarized on Table 3-7 and Figure 3-41. As shown, in all cases, the RSD based I/M credits, including the low estimates, are larger than credits based on MOBILE6. The greatest difference between MOBILE6 and RSD based reductions were for NOx.

Table 3-7: MOBILE6 I/M Credits vs. RSD Observed I/M Emission Reductions

Pollutant	% Reduction Based on RSD		% Reduction Based on MOBILE6
	Registered Fleet	Model Yr Adjusted	Phase-In Cut Pts
VOC	41%	20%	15%
CO	33%	14%	12%
NOx	34%	19%	3.3%

Figure 3-41: Mobile6 vs. RSD Observed Emission Reductions



3.7. Commuters

Many of the vehicles seen in the Northern I/M Area were registered in other jurisdictions. Table 3-8 shows how many times unique vehicles were observed in the I/M area. Over 2,600 vehicles were observed four or more times each. A majority of these, 62%, were from other Virginia jurisdictions, 5% were from DC, 22% were from Maryland and 11% were from West Virginia. A higher percentage of the West Virginia vehicles were seen four or more times.

Table 3-8 Vehicles From Other Jurisdictions Operating in the I/M Area

Number of Times Vehicle Observed in the I/M Area	Number of Vehicles From Jurisdiction: VA Non-I/M Counties	DC	MD	WV
1	31,853	7,557	31,528	2,558
2	9,349	1,227	7,047	1,528
3	2,533	250	1,338	543
4	1,220	82	409	221
5	263	35	100	47
6	68	9	45	16
7	39	5	17	8
8	15	2	5	1
9	8		4	1
10	6			
11	1			
12	1	1		
31	1			
78	1			
Total unique vehicles	**45,358**	**9,168**	**40,493**	**4,923**
Vehicles observed 4 of more times	**1,623** **3.6%**	**134** **1.5%**	**580** **1.4%**	**294** **6.0%**

The Virginia vehicles seen at least four times most often came from Fauquier County and Spotsylvania County. A majority of these Maryland vehicles were from Montgomery County and Prince Georges County. All these counties border the I/M area. Jurisdiction information was not obtained for West Virginia vehicles.

Table 3-9 Source of Virginia and Maryland Vehicles Seen Four or More Times

Virginia	
Fauquier	32%
Spotsylvania	19%
Culpepper	5%
Fredericksburg	4%
Other Jurisdictions	39%
Maryland	
Montgomery	40%
Prince Georges	32%
Other Counties	28%

4. Correlation Between RSD Results and ASM Results

4.1. ASM vs. RSD After

RSD and ASM emission rates were averaged by model year and plotted. This analysis used the final ASM 2525 results and RSD measurements following within 90 days after the ASM test. Results are shown on Figures 4-1 to 4-3. RSD NOx results agree well with ASM results for all model years. However, CO and, especially, HC results for RSD do not agree well for pre-1993 vehicles. It's possible that the conditions of the ASM test tend to result in lower than typical emissions for older vehicles. It's also possible that some vehicles receive repairs that temporarily reduce HC and CO.

Figure 4-1: Last ASM Test and Subsequent RSD Within 90 Days - CO

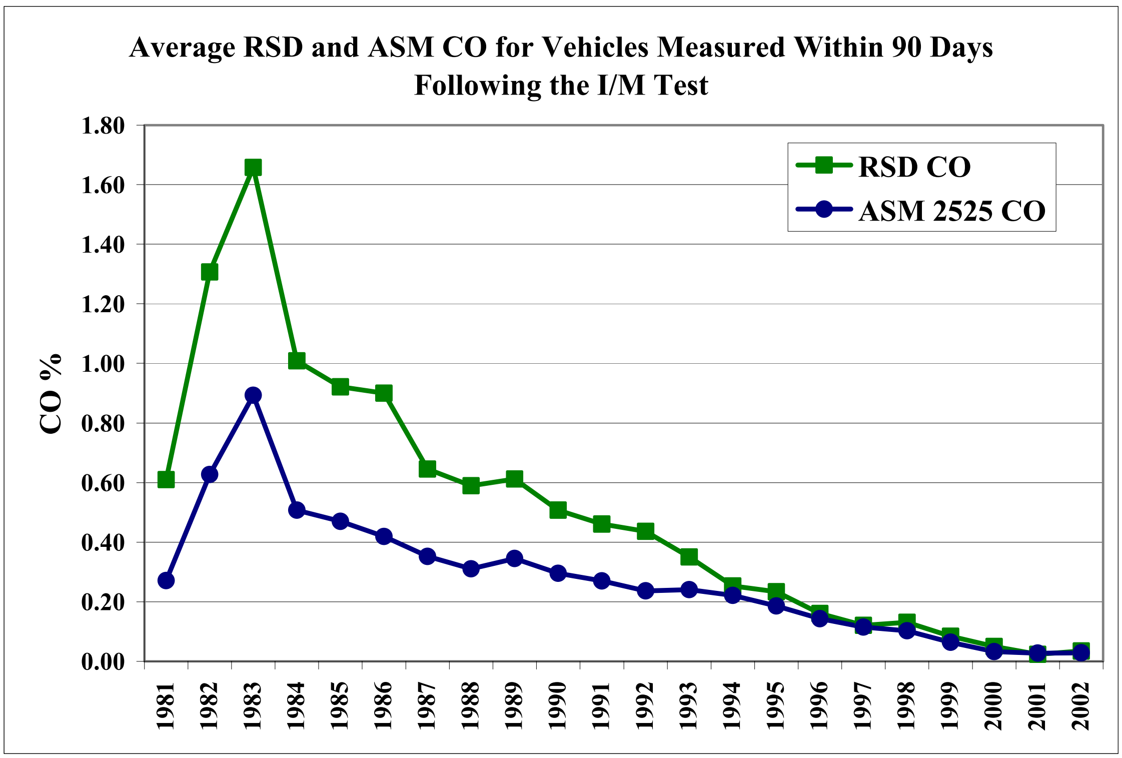


Figure 4-2: Last ASM Test and Subsequent RSD Within 90 Days - HC

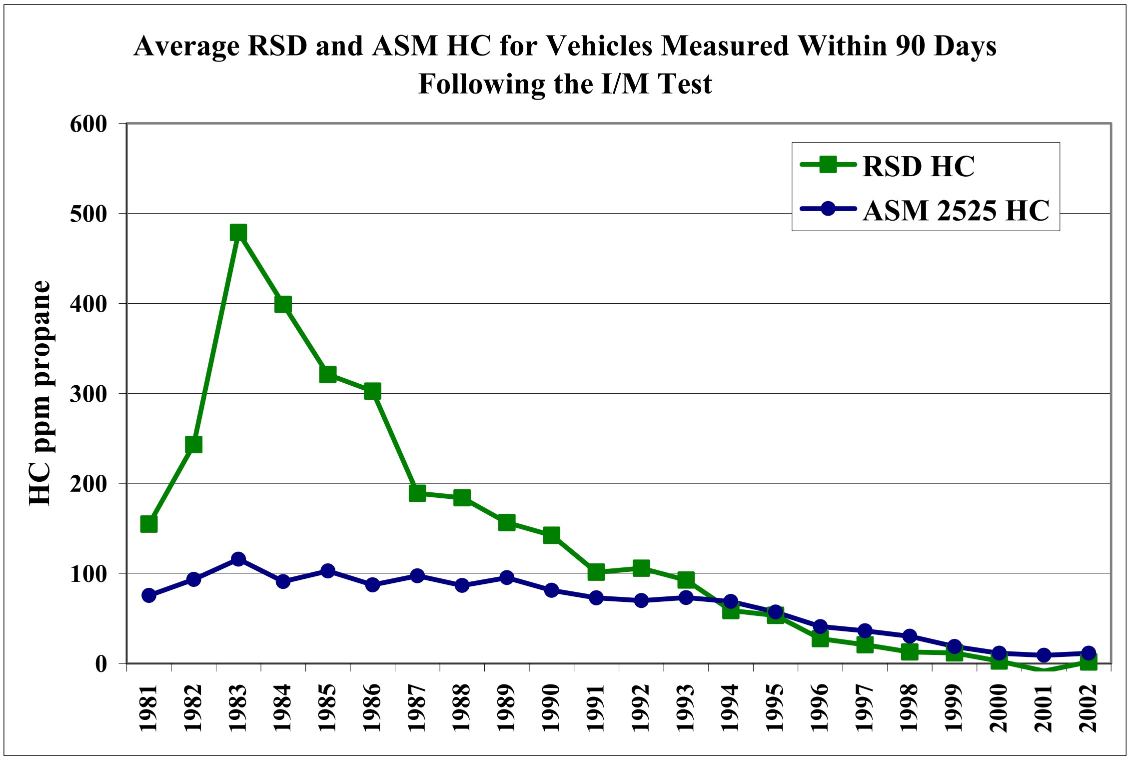
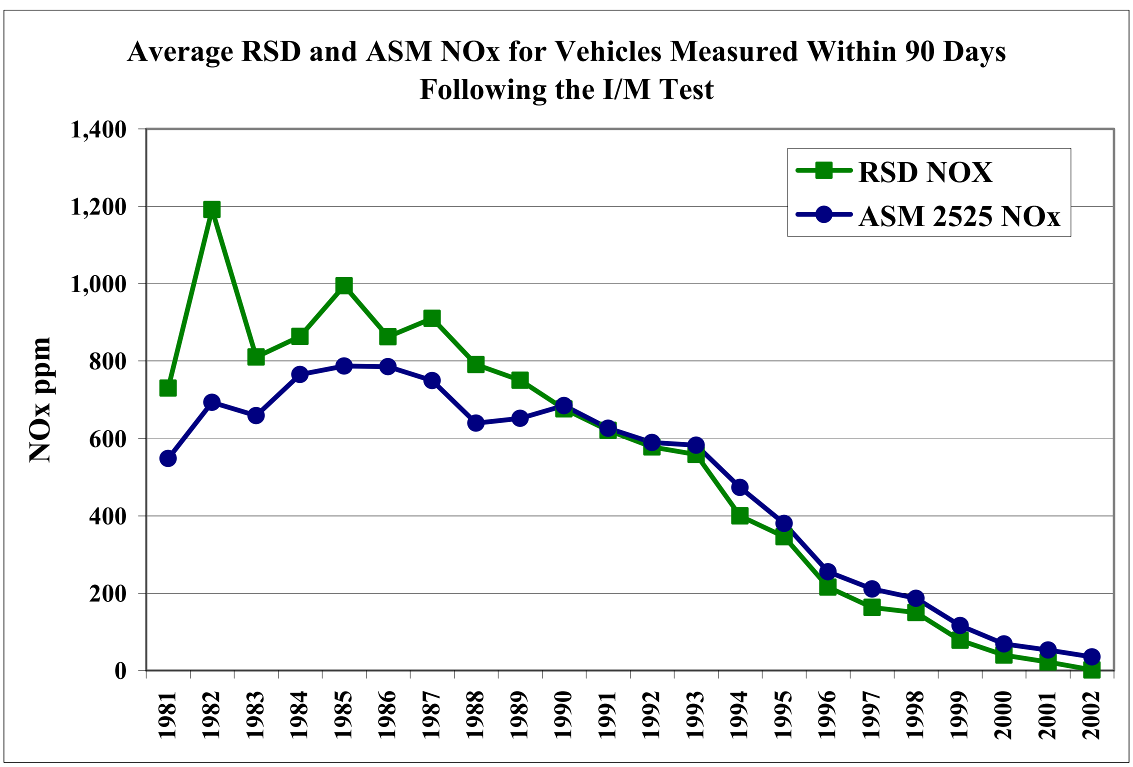


Figure 4-3: Last ASM Test and Subsequent RSD Within 90 Days - NOx



4.2. RSD vs. ASM After

A similar analysis was performed using RSD measurements that were followed by an initial ASM inspection. Results are shown on Figures 4-4 to 4-6. NOx results again agree well with ASM results for all model years. CO RSD results agree more closely with the ASM results than in the previous case. HC results for RSD continue to deviate from the ASM values for pre-1993 vehicles. It's possible that motorists routinely get their vehicles tuned-up just before they get their emission tests. Tune-ups typically affect HC emissions more than CO or NOx emissions. A survey of motorists could reveal if this practice is occurring.

Figure 4-4: RSD vs. Subsequent Initial ASM Test

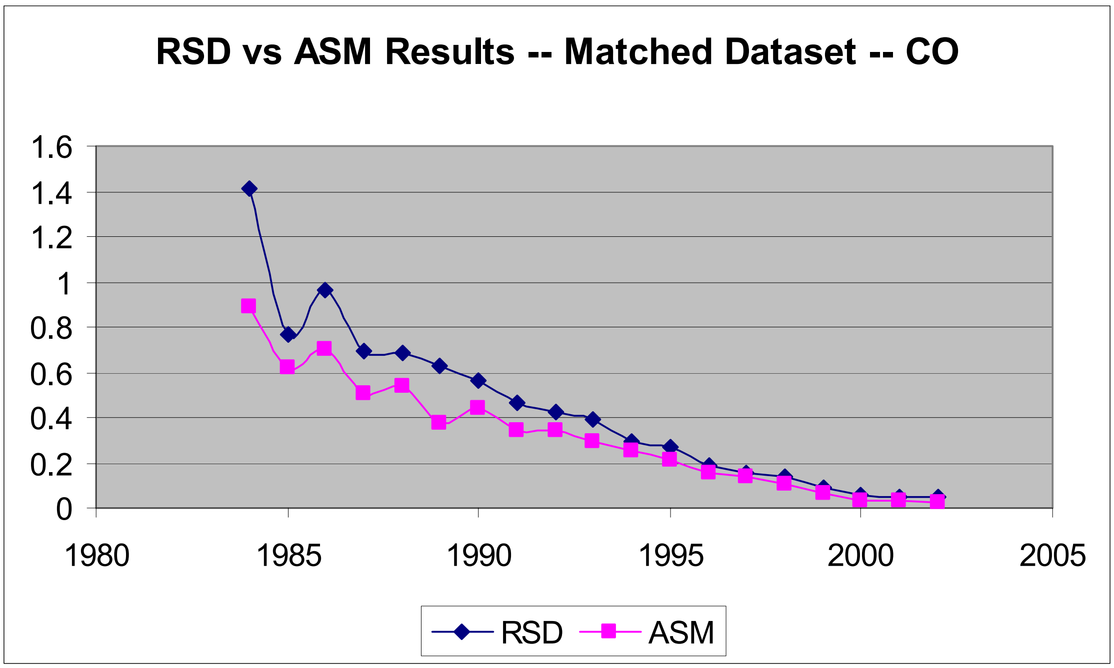


Figure 4-5: RSD vs. Subsequent Initial ASM Test

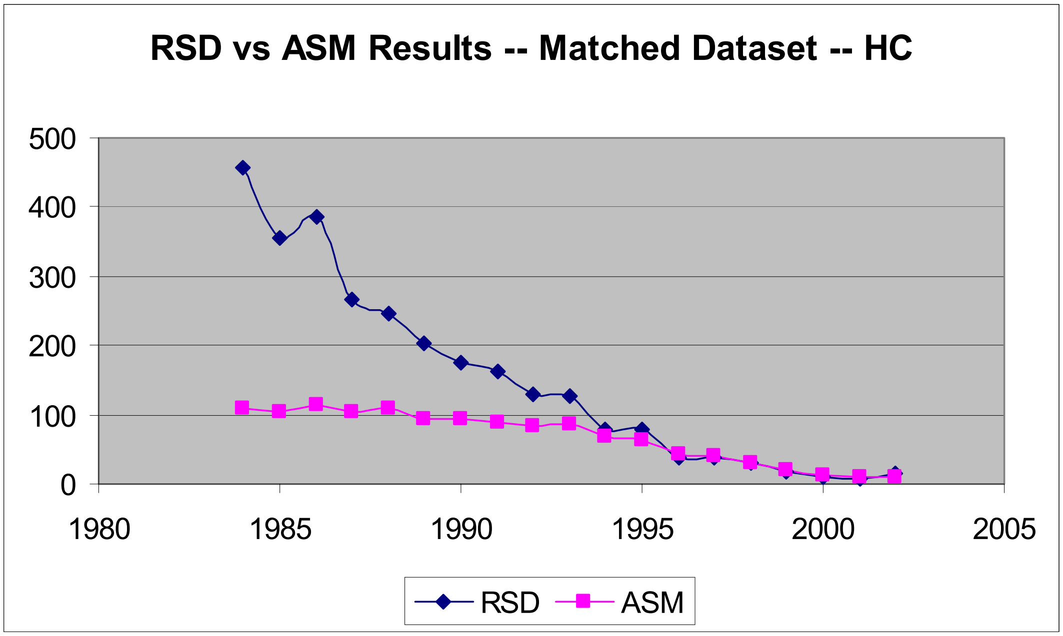
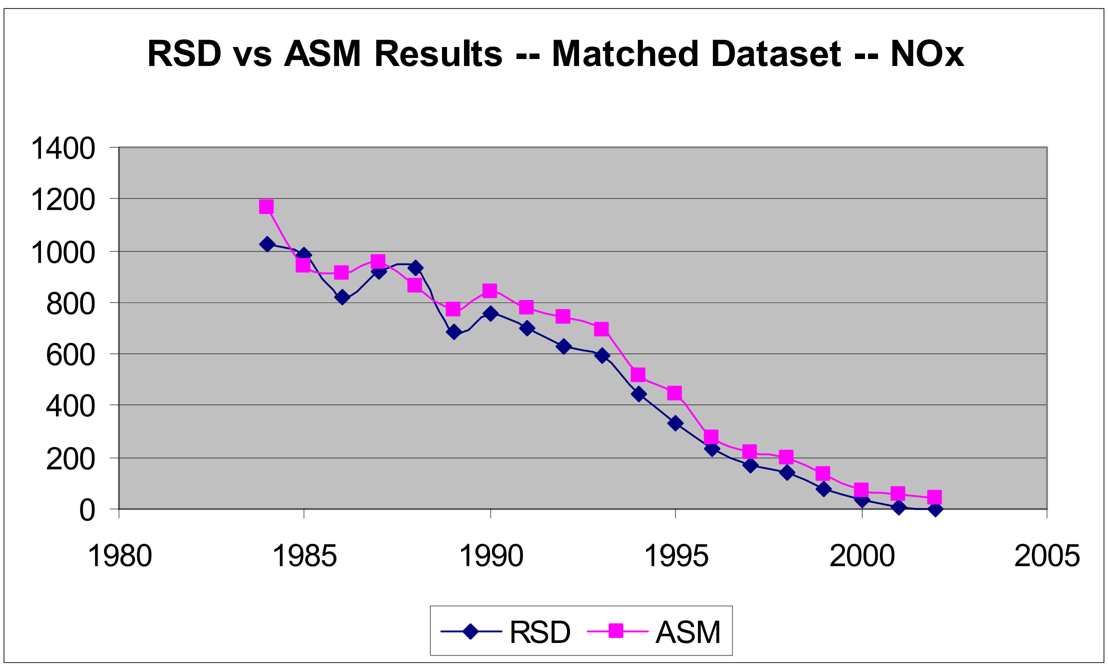


Figure 4-6: RSD vs. Subsequent Initial ASM Test - NOx



4.3. Effectiveness of RSD as a Tool to Identify High Emitting Vehicles

ESP investigated the effectiveness of RSD as a tool for identifying high emitting vehicles. This evaluation was done for two groups:

- Pre-1996 vehicles; and
- 1996 and newer vehicles (i.e., those equipped with OBDII systems).

ESP specifically investigated the effectiveness of combining high emitter indexing and RSD in identifying high emitting vehicles. High emitter indexing refers to using the historical emission characteristics for a particular group of vehicles. The high emitter index in this analysis was based upon ASM tests conducted in the northern Virginia I/M program. Vehicles falling into the high emitter index were those that had high failure rates in the northern Virginia program.

ESP found that vehicles that had a high (or dirty) emitter index and failed RSD had much higher ASM emissions than vehicles falling into other groups.

4.3.1. Results for Pre-1996 Vehicles

Vehicles that had a “Dirty” high emitter index, based on tests in Northern Virginia on similar makes and models, had much higher ASM emissions than those with a “Clean” high emitter index. Figures 4-7 to 4-9 compare different combinations of RSD pass/fail and high emitter index in terms of:

- Percent Fail ASM.
- Percent of excess HC and NOx emissions identified.
- ASM failure rate for vehicles identified.

As shown, the dirtiest group contains vehicles that are classified as high emitters by RSD and are in the dirtiest 25% of the high emitter index.

In an optimum Dirty Screen program, vehicles that are identified for I/M tests should contain most of the excess emissions. These vehicles should have high ratios for the following parameters:

- % of ASM Failures Identified to % of Vehicles Identified.
- % of Excess Emissions Identified to % of Vehicles Identified.

Ratios greater than 1:1 indicate that the selection strategy preferentially identifies high emitters. Figures 4-10 to 4-12 show the ratios for different combinations of RSD pass/fail and high emitter index. The highest ratios were for the group that failed RSD and fell into the dirtiest 75-100%. Another group that has ratios greater than 1:1 contained RSD failures that have indexes in the 50-75% group.

Figure 4-7: Percent of Selected Vehicles Failing ASM

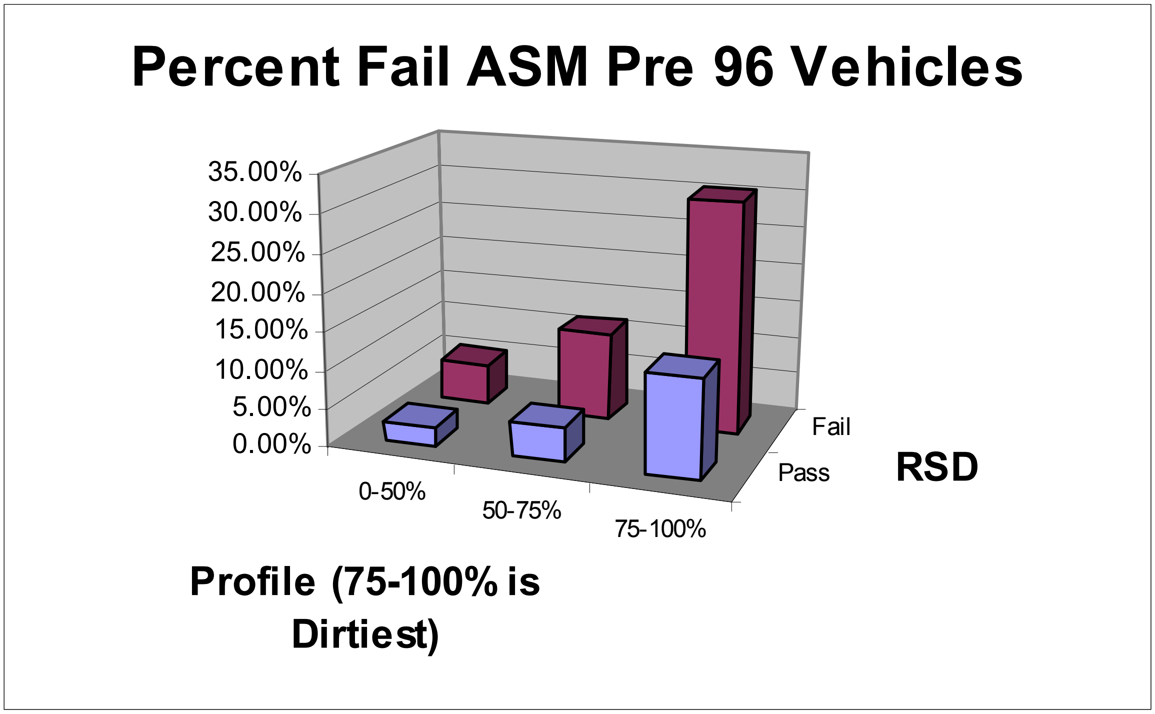


Figure 4-8: Percent of Excess HC Emissions Identified

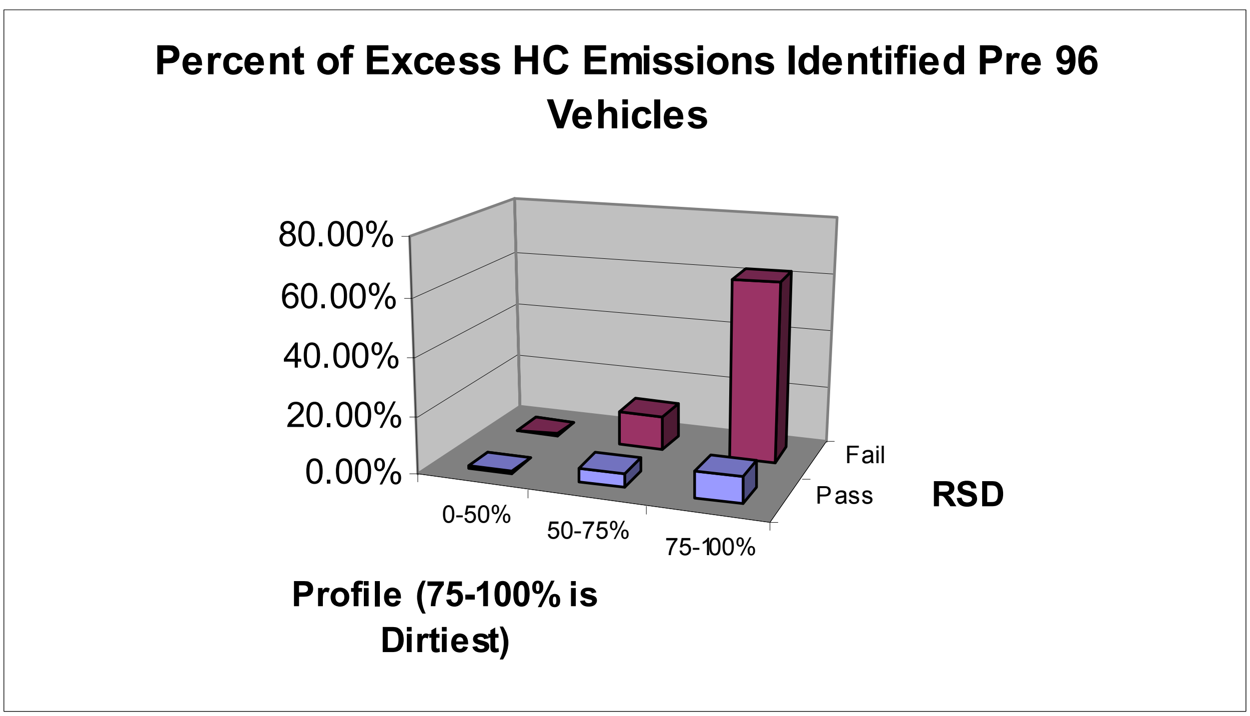


Figure 4-9: Percent of Excess NOx Emissions Identified

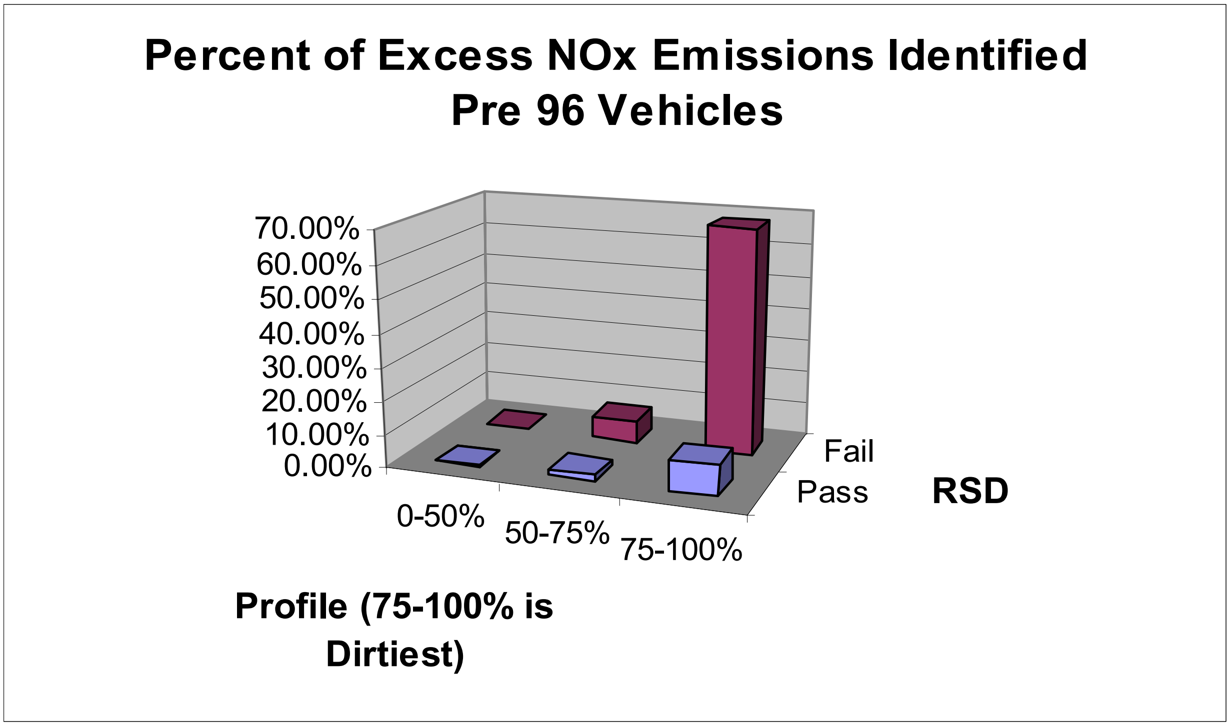


Figure 4-10: Percent of ASM Failure Ratio

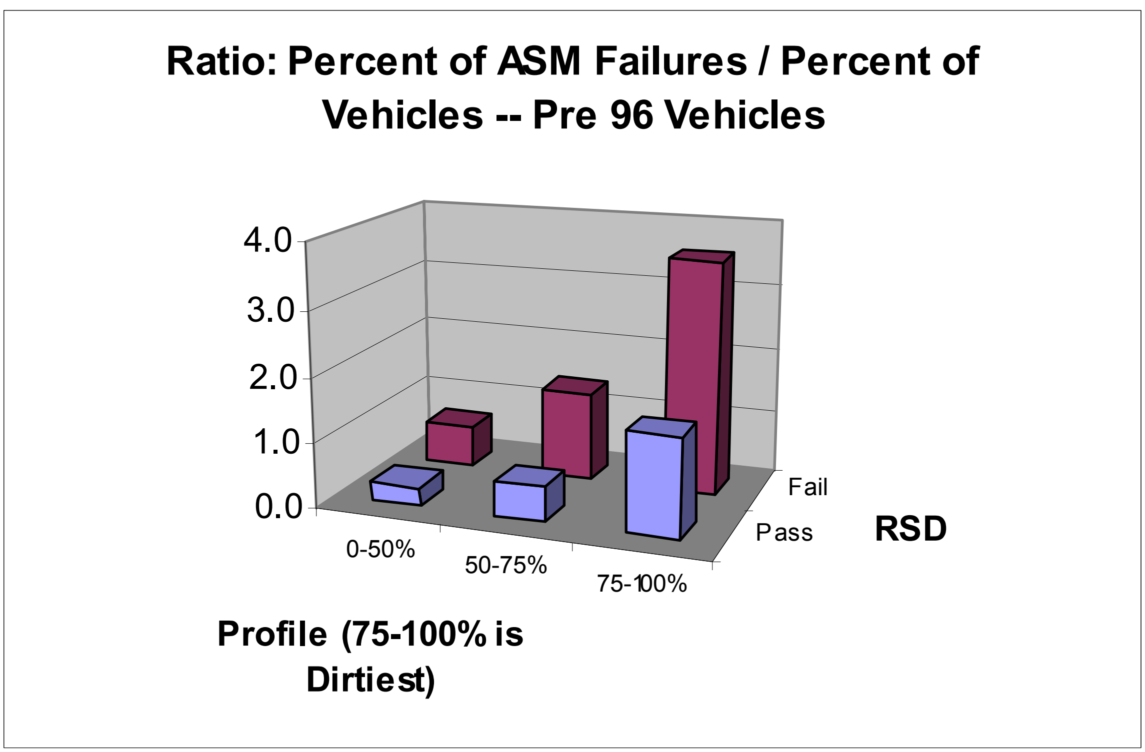


Figure 4-11: Excess HC Identification Ratio

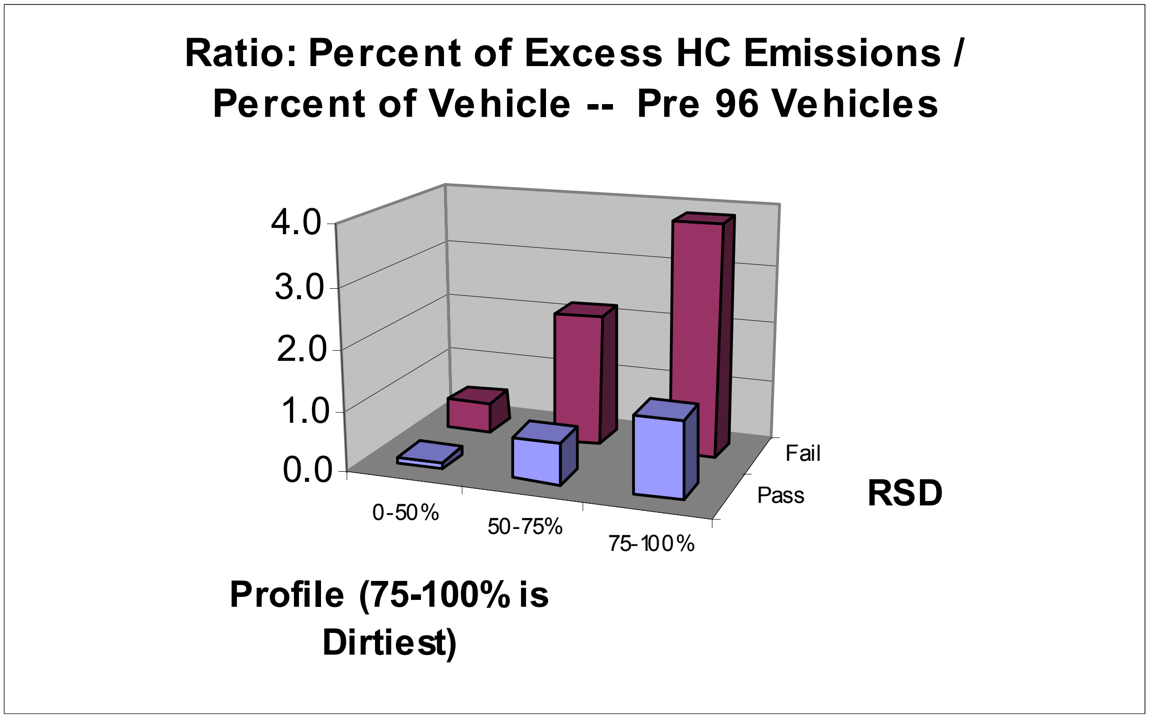
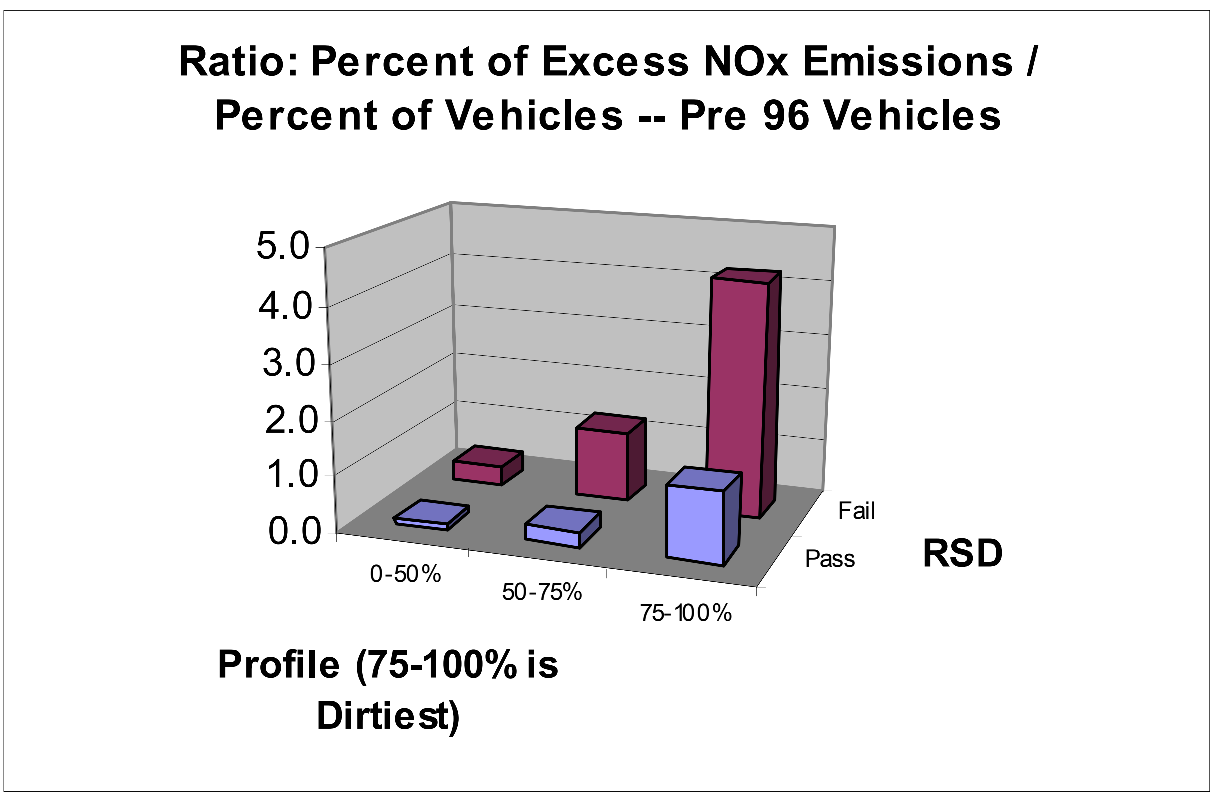


Figure 4-12: Excess NOx Identification Ratio



4.3.2. Results for 1996 and Newer Vehicles

ESP performed the same analysis that was done for pre 1996 vehicles on 1996 and newer vehicles (Figures 4-13 to 4-18). Results for 1996 and newer vehicles were similar to results for the pre-1996 vehicles; RSD combined with high emitter indexing preferentially identifies high emitting 1996 and newer vehicles. RSD appears to be equally effective on 1996 and newer vehicles as it is on pre-1996 vehicles. The group of vehicles that was in the dirtiest 25% of the high emitter index and failed RSD had much higher ASM fail rates than the other groups. In terms of percent of excess HC and NO_x emissions identified, this group of vehicles contained a much larger fraction of the excess HC and NO_x emissions than the other groups and had very high ratios of the following:

- percent of ASM failures to percent of vehicles,
- percent of excess HC emissions to percent of vehicles, and
- percent of excess NO_x emissions to percent of vehicles.

It would be interesting to correlate the results of OBDII tests with ASM emissions and RSD results. The pilot OBDII testing program that was conducted in northern Virginia did not generate enough test results to perform this comparison. Based upon data collected in California's ASM test program, OBD identifies about 30 to 40% of the excess ASM emissions, which is lower than the percent of excess ASM emissions identified by a combination of RSD and high emitter indexing.

Figure 4-13: Selected 1996 & New Models – Percentage Failing ASM

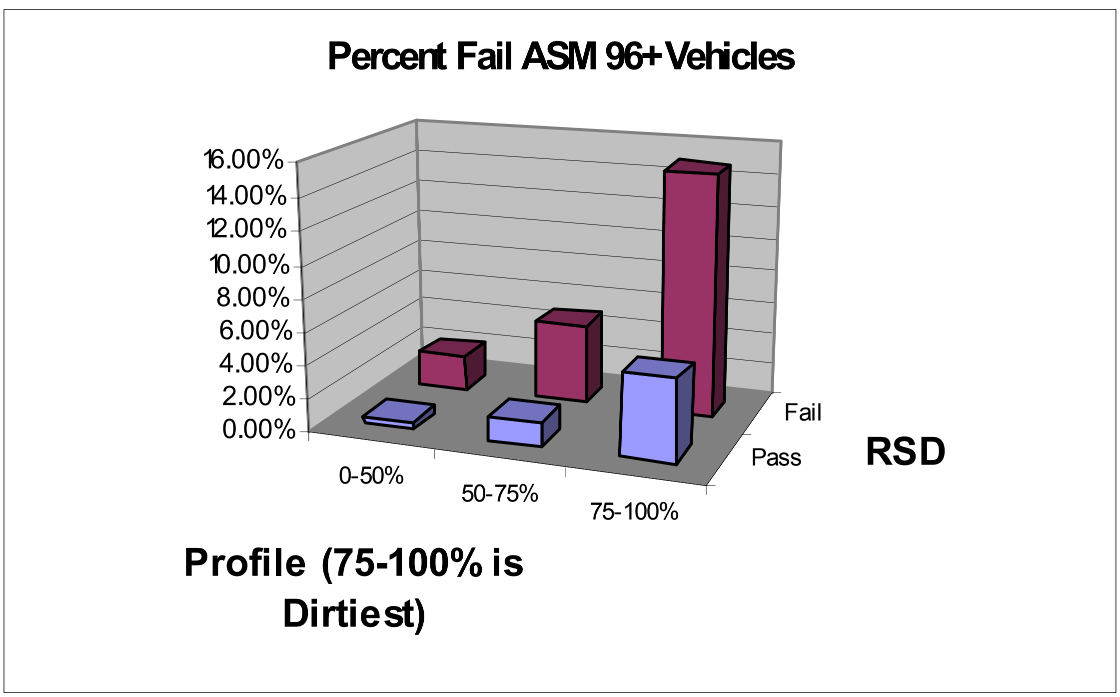


Figure 4-14: Selected 1996 & New Models – Excess HC Identified

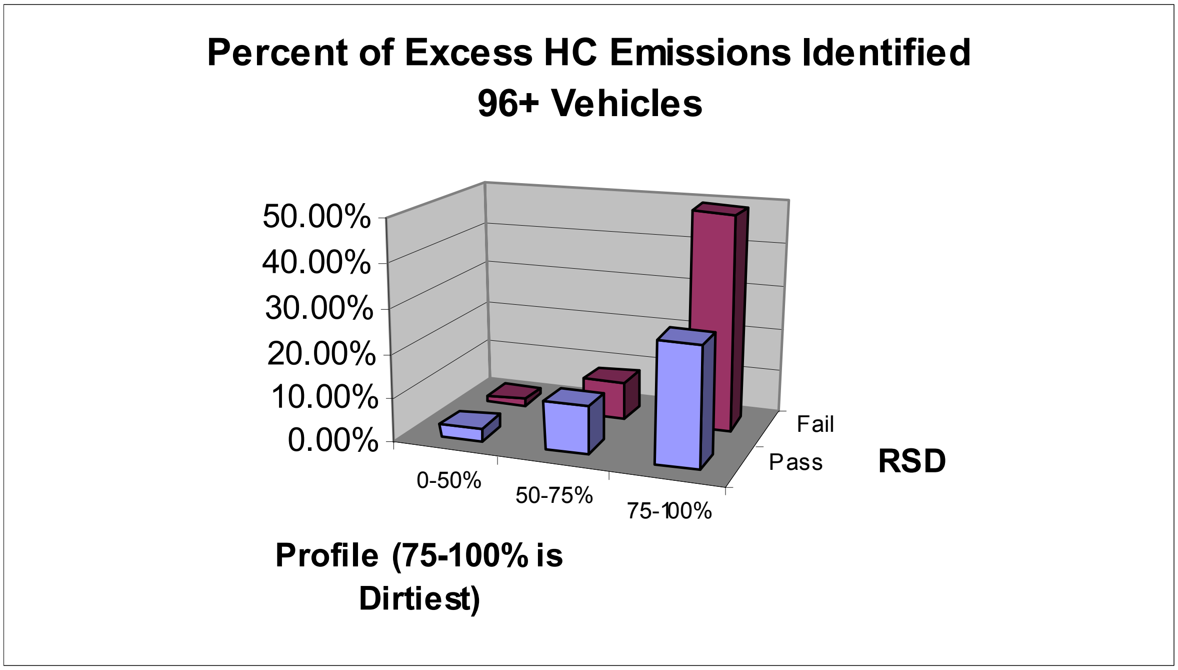


Figure 4-15: Selected 1996 & New Models –Excess NOx Identified

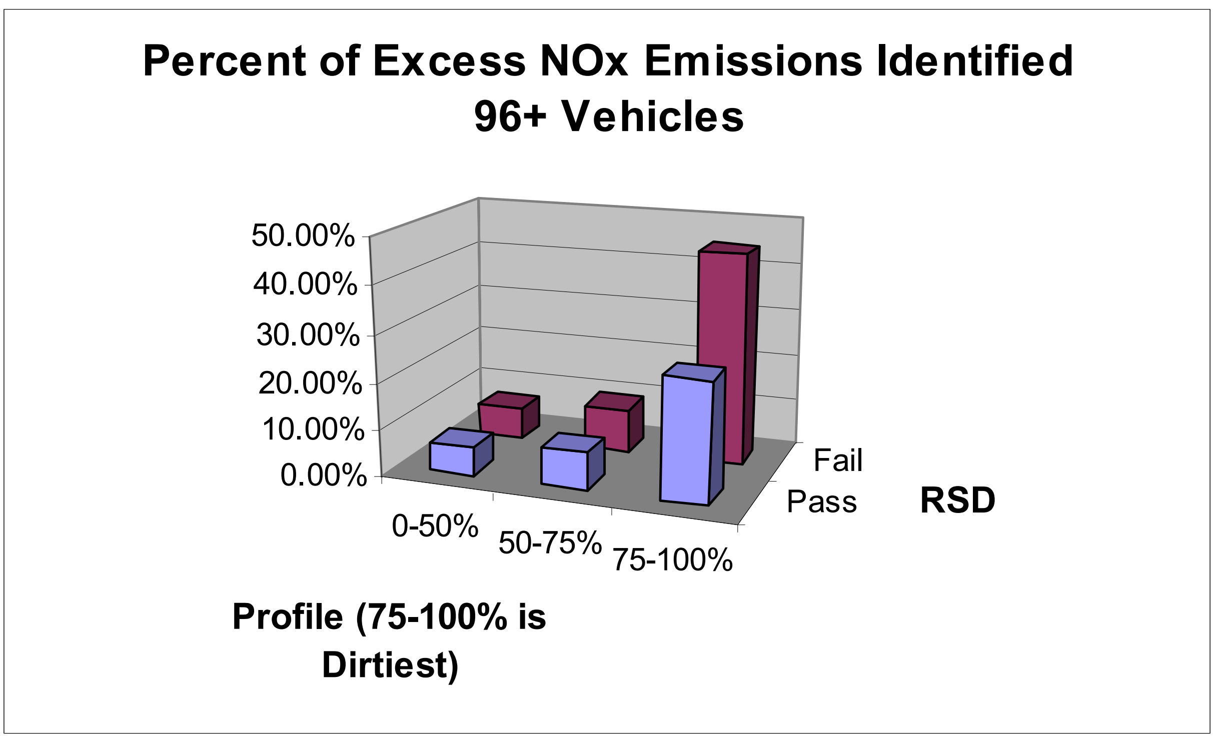


Figure 4-16: Selected 1996 & New Models – Ratio of ASM Failures

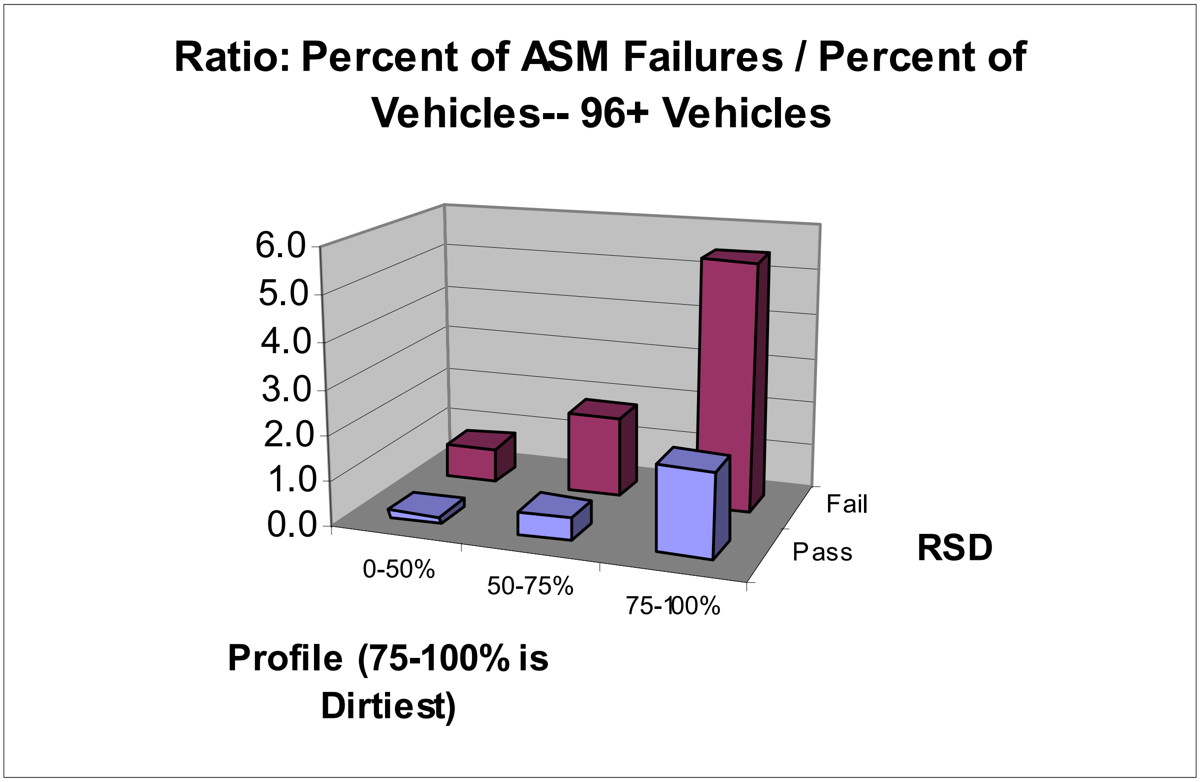


Figure 4-17: Selected 1996 & New Models – Excess HC Identification

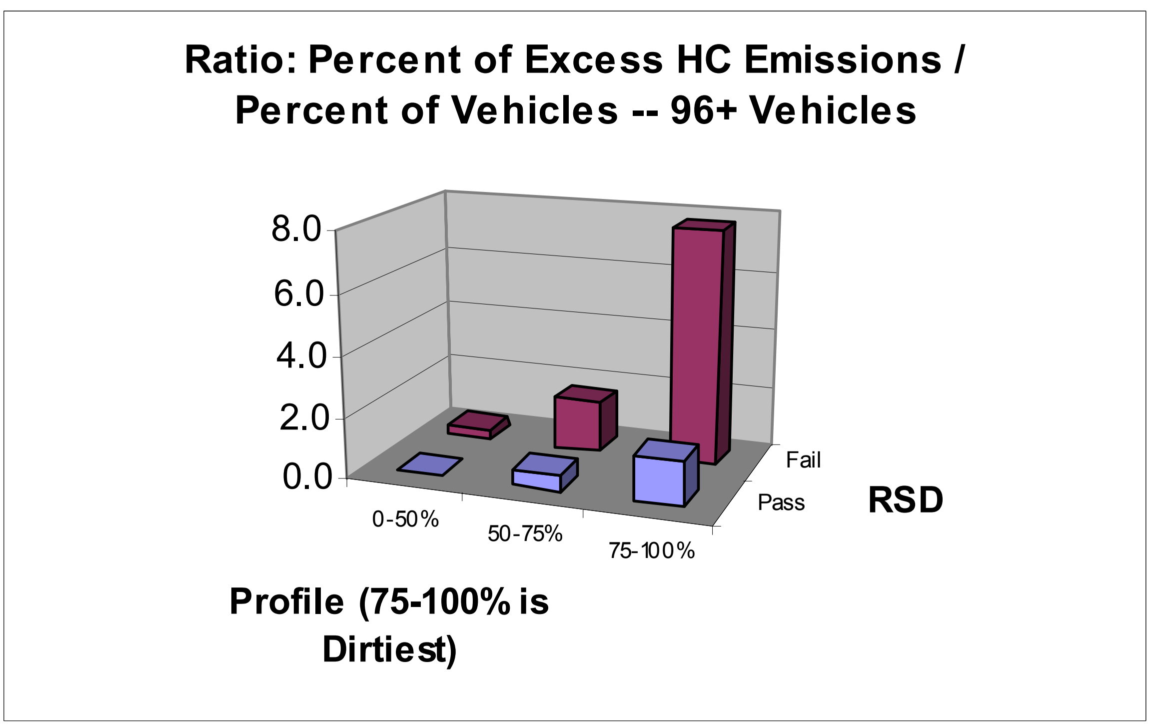
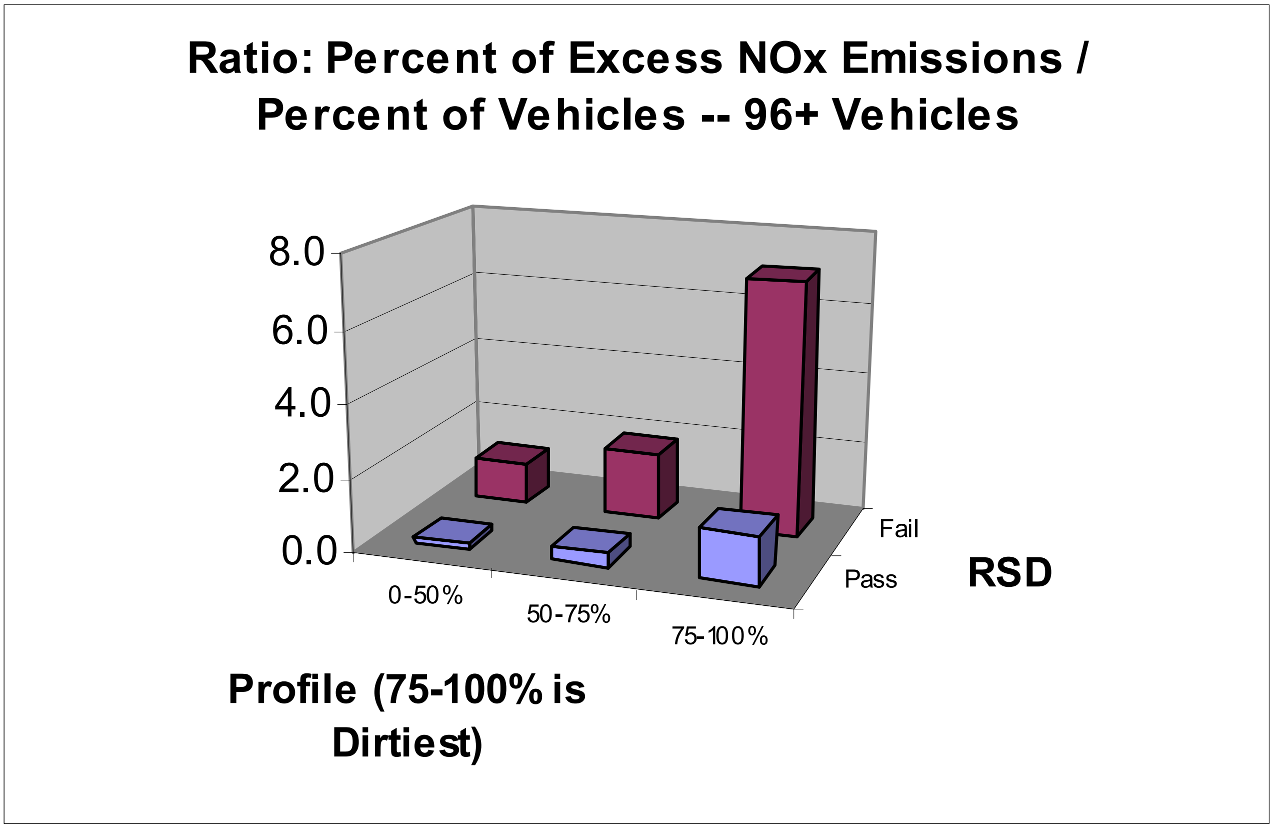


Figure 4-18: Selected 1996 & New Models – Excess NOx Identification



4.4. RSD Dirty Screen Scenarios: One-Hit Plus High Emitter Indexing vs. Two-Hits

Dirty screen refers to identifying high emitting vehicles using RSD that are then tested using conventional ASM tests. The effectiveness of RSD as a dirty screen tool was investigated. One scenario in this evaluation assumes that only pre-1996 vehicles are subjected to the Dirty Screen program and that 1996 and newer vehicles will receive OBD Inspections.

ESP evaluated the following scenarios to identify likely high emitting vehicles for I/M tests:

- One-hit plus high emitter indexing. Require the vehicles in the dirtiest 25% of the high emitter index that also exceeded RSD cutpoints to be tested (N~35,000).
- Two-hits. Use the lower of two RSD observations to identify high-emitting vehicles (N~13,500). An in-depth analysis of vehicles with multiple hits is presented in Appendix B.

Figures 4-19 to 4-22 compare the performance of these RSD scenarios in terms of:

- Percent of fleet tested.
- Percent of ASM failures identified.
- Percent of excess HC and NOx emissions identified.

- ASM failure rate for vehicles identified.

Results indicate that using one hit with high emitter indexing has similar performance to using two-hits. It's much easier to get one hit on a vehicle than 2 hits, so this scenario would be more cost-effective.

Figure 4-19: One-Hit & High Emitter Indexing vs. Two-Hit

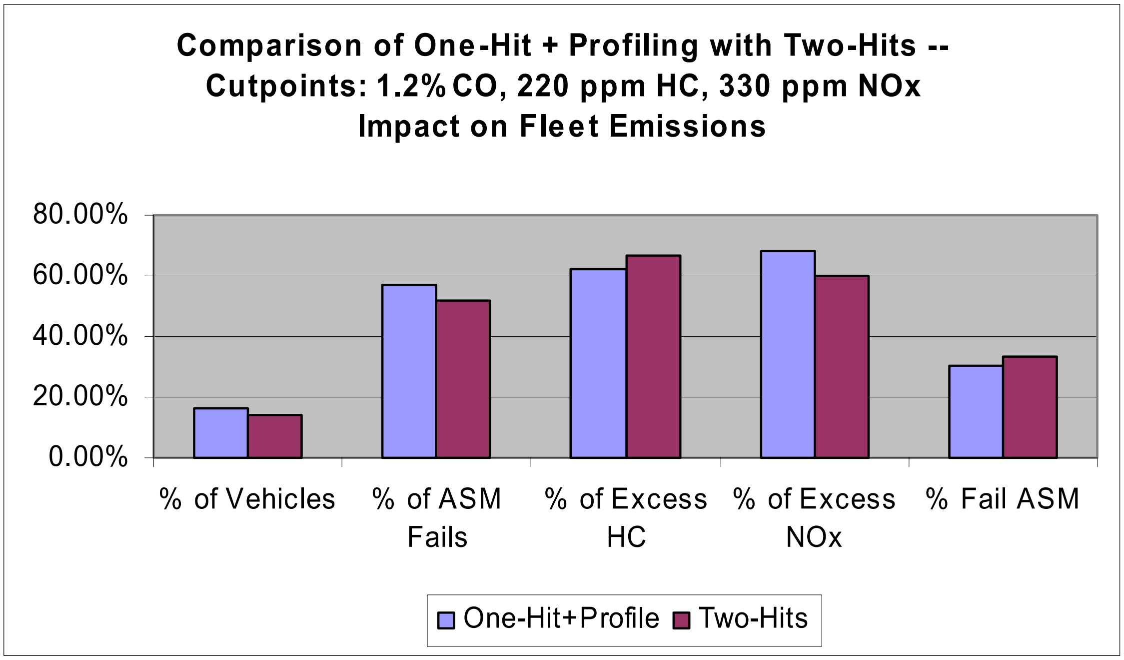


Figure 4-20: One-Hit & High Emitter Indexing vs. Two-Hit – 1995 & Older Models

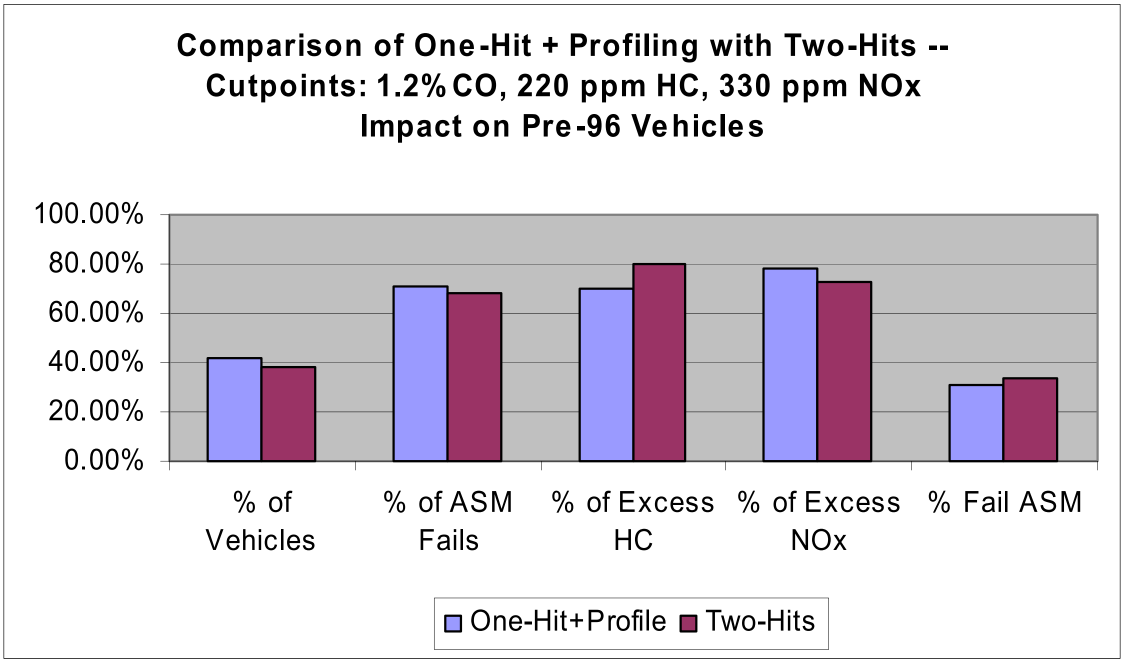


Figure 4-21: One-Hit & High Emitter Indexing vs. Two-Hit – Looser Cutpoints

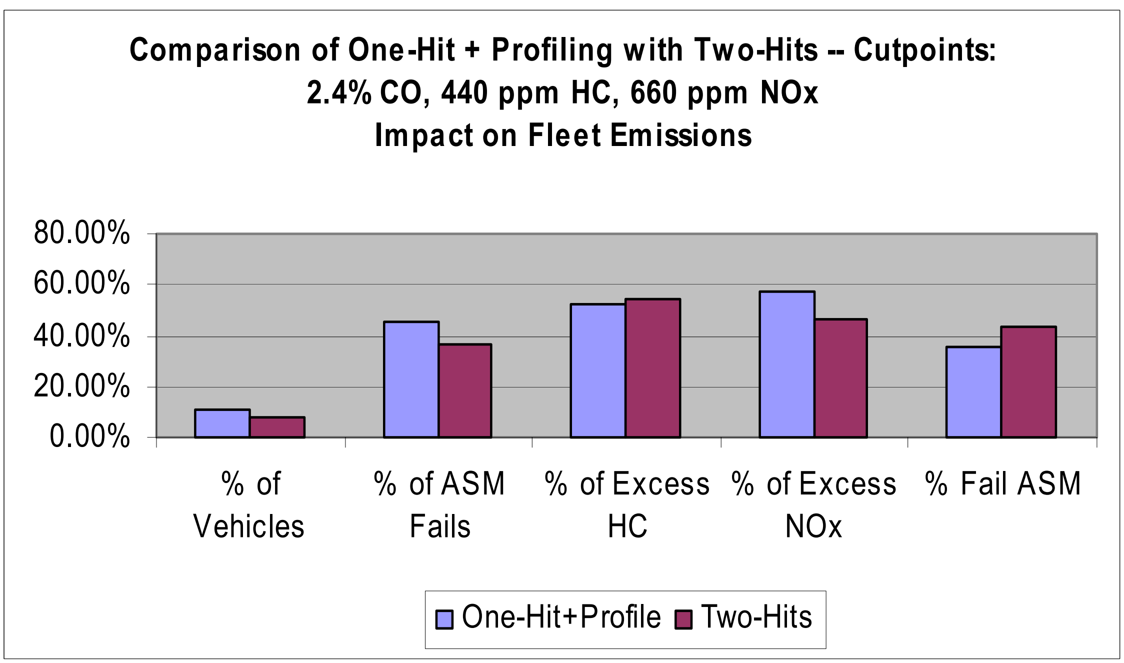
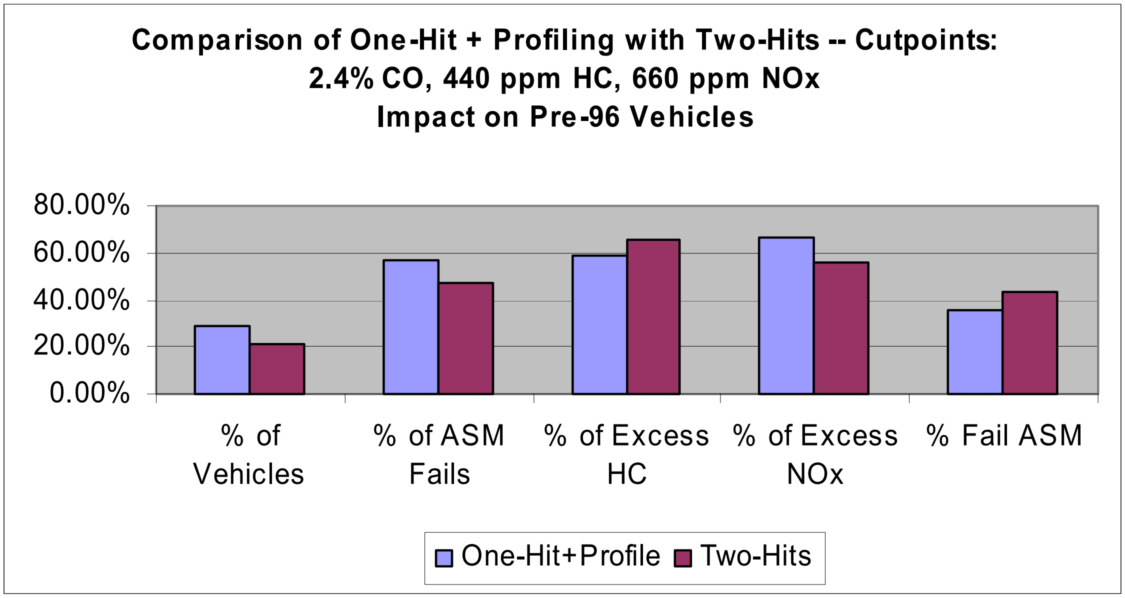


Figure 4-22: One-Hit & High Emitter Indexing vs. Two-Hit – Looser Cutpoints-1995 & Older Models



4.5. Vehicle Coverage Considerations

A dirty screen program must cover a majority of the vehicle fleet to be effective. Records indicate that 740,000 vehicles are registered in the 4-county Richmond area. Study data indicate that we need valid RSD observations totaling 2x this number to cover 70% of the registered vehicles (a higher % of driven vehicles will be covered). From the study, we determined that 30,000 valid observations could be made on vehicles registered in the Richmond area per van month[i]. From this we calculate that 50 van-months or about 4 vans per year will be needed to adequately cover the Richmond Area fleet.

In the northern Virginia about 9 to 10 vans would be needed to obtain similar coverage of the approximately 1.7 million vehicles registered in the I/M area.

4.6. A Design for Stand-Alone High Emitter Program in the Richmond Area

A remote sensing high emitter identification program could be used to identify dirty on-road vehicles and select them to come in for confirmatory emissions testing. To ensure adequate coverage, the RSD program should measure a majority of the active vehicles in the fleet each year. As shown above, about 4 vans would be required to obtain coverage of 70% of the vehicles in the Richmond area. By calling in the identified dirtiest 25% of the vehicles approximately 65% of excess tailpipe HC and 70% of excess NOx could be captured.

[i] Each van averaged 47,000 valid observations per month. Adjusting this number for the % matched (97%), % with valid VSP (90%), and the % of observations in the 4 jurisdiction area that are on vehicles registered in the 4-Jurisdiction (72%) yielded 30,000 observations per van-month.

To avoid potential public relations concerns, we suggest the program be presented in the following manner. All vehicles would be subject to the I/M program but only those selected would be required to come in for their scheduled inspection. They could be notified of the inspection requirement on their registration renewal notice. The inspection should be enforced through registration denial.

Once this program is established and accepted, the 1%-2% of the dirtiest gross emitters observed on-road by remote sensing could also be called in for 'off-cycle' testing. This would require special letters to be sent and would require follow-up. The incremental costs would be small.

The costs of this program in the Richmond area are expected to be $1.5M for RSD operations and program administration plus the costs of confirmatory ASM testing. Assuming the ASM testing is performed by licensed test and repair inspection stations, the cost of the ASM tests at $28 per test would be $5.2M (740,000 X 25% X $28) if 25% of vehicles are called in annually and half that amount if 25% of vehicles are called in biennially. The annual cost of this program is, therefore, $4.1M to $6.7M annually or $5.54 to $9.05 per vehicle – a considerable savings over a traditional ASM program.

4.7. *Add-on RSD High Emitter Program in the Northern Virginia Area*

In the northern Virginia Enhanced I/M area, it is suggested that a high emitter remote sensing program be combined with the existing inspection program. The average life of a passenger vehicle is 10-15 years. Towards the end of their life, vehicles are far more likely to be poorly or incorrectly maintained, to deteriorate more rapidly and to be high emitters. It is proposed that the dirtiest vehicles, up to 10% of the fleet, be required to obtain an annual confirmatory inspection between their normally scheduled biennial inspections. The dirtiest 10% of vehicles are estimated to account for 52% of excess HC and 57% of excess NOx.

In addition, the presence of the on-road program would:

- identify vehicles on-road that are not complying with the I/M program;
- identify commuters and government vehicles operating in the Enhanced area that have high emissions;
- facilitate the evaluation of the effectiveness of inspection stations and identify stations that could benefit from follow-up audits;
- provide ongoing program evaluation.

The costs of a ten van RSD program would be approximately $3.5M annually. Confirmatory tests in 10% of the fleet per year would be an additional $4.8M (1.7M x 10% x $28).

4.8. *Cutpoints for a High Emitter Program*

The previous sections, showed the effectiveness of a high emitter program using cutpoints and 1.2% CO, 220ppm HC and 330ppm NOx. We also showed that a single remote sensing measurement in combination with high-emitter indexing was as effective as using two remote sensing measurements for identifying high emitters.

To better understand the sensitivity of cutpoints ESP has run a series of trials with varying cutpoints on a sample of 30,000 vehicles that received an ASM test following a remote sensing emissions measurement. As shown in Figure 4-23, the percentage of excess emissions identified increases as an increasing percentage of vehicles are selected. In this analysis, vehicles were required to exceed a high emitter index value and any one of the HC, CO or NOx cutpoints. The percentage of excess emissions identified is the average of the percentage of HC and NOx measured as exceeding the I/M program cutpoints by the ASM test in initial I/M inspections. The scatter in the points shows that some combinations of cutpoints are more effective than others.

A table of trial cutpoints and results is provided in Appendix C.

Figure 4-23 High Emitter Identification Effectiveness

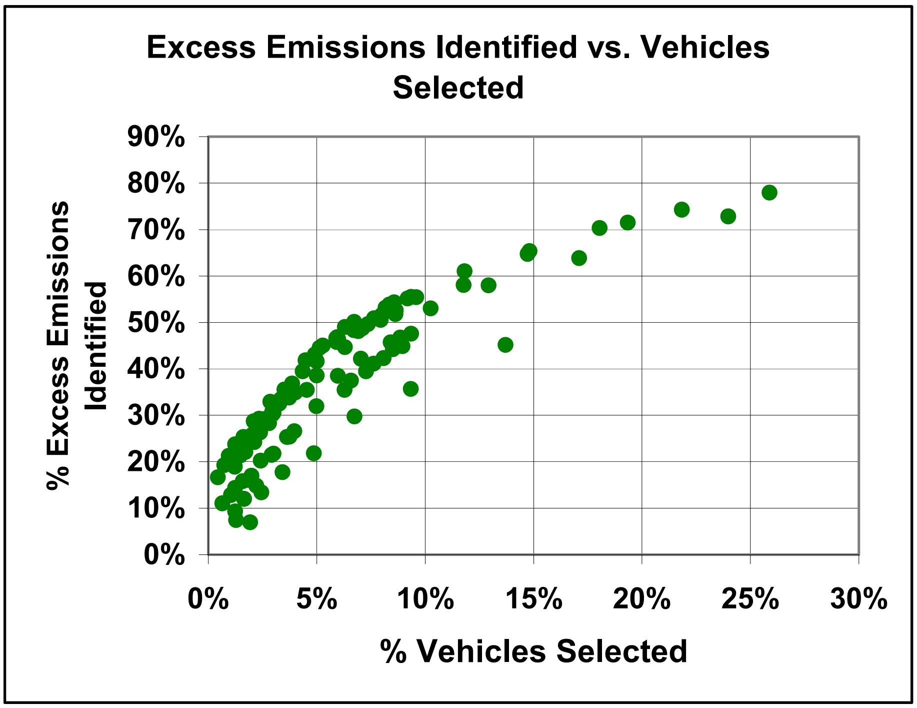
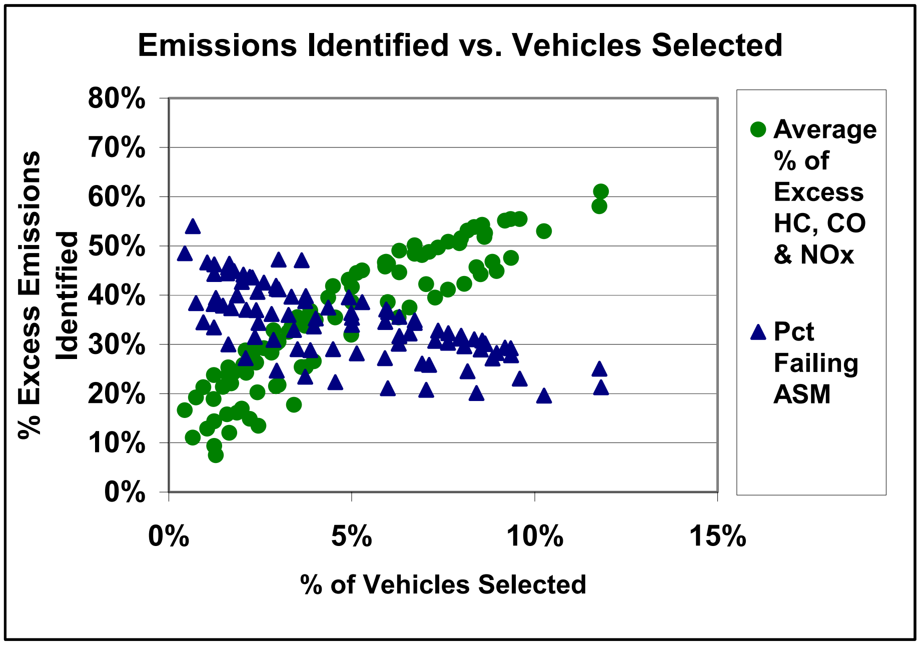


Figure 4-24 shows the percentage of selected vehicles failing their subsequent initial ASM test. The presence of pre-inspection repairs in the I/M program reduces the effectiveness of this analysis. If vehicles selected by the remote sensing high emitter screen are repaired before they receive their initial I/M inspection then the percentage of selected vehicles that fail ASM is reduced. The projected percentage of excess emissions identified may also be low. To correctly determine the percentage of selected vehicles that fail the I/M ASM test requires a pull over study in which vehicles are stopped and given an ASM test immediately following a remote sensing measurement. In a 2001 study, California Bureau of Automotive Repair found that 83-88% of vehicles pulled over with remote sensing emissions exceeding of 2% CO or 1000ppm HC or 1500ppm NOx would have failed the I/M inspection.

Figure 4-24 Emissions Identification and Vehicles Failing ASM



4.8.1. NOx Cutpoints as a Function of VSP

Figure 3-8, and the charts in Appendix A, show that NOx emission concentrations increase linearly with VSP up to maximum value and then remain roughly constant. This means that the observed NOx emissions are dependent upon the VSP level of the vehicle at the time of the measurement and suggests that high emitter cutpoints should take VSP into account.

NOx emissions in terms of VSP can be approximated by:

$NOx = NOx_{Zero} + b \times \min(VSP_{Measured}, VSP_{NOxMax})$.

Where NOx_{Zero} are the NOx emissions at a VSP of 0 kW/t, $VSP_{Measured}$ is the VSP value at which the RSD measurement was made, VSP_{NoxMax} is the VSP value at which the constant NOx concentration is first reached and 'b' is the linear increase in NOx per unit of VSP. Assuming that NOx_{Zero} and VSP_{NoxMax} are fixed for a class of vehicle (type, model year range), then, it is possible to use an RSD measurement taken at one VSP value to project the NOx emissions at a different VSP value. By projecting the NOx emissions of each vehicle at the same VSP level we should obtain more comparable NOx values.

For ease of comparison with the ASM 2525 inspection results we projected NOx values for a VSP value of 6 kW/t, which approximates the ASM 2525 VSP value, using the equation:

$NOx_6 = NOxZero + 6 \times (NOx_{Measured} - NOx_{Zero}) / \min(VSPMeasured, VSP_{NOxMax})$

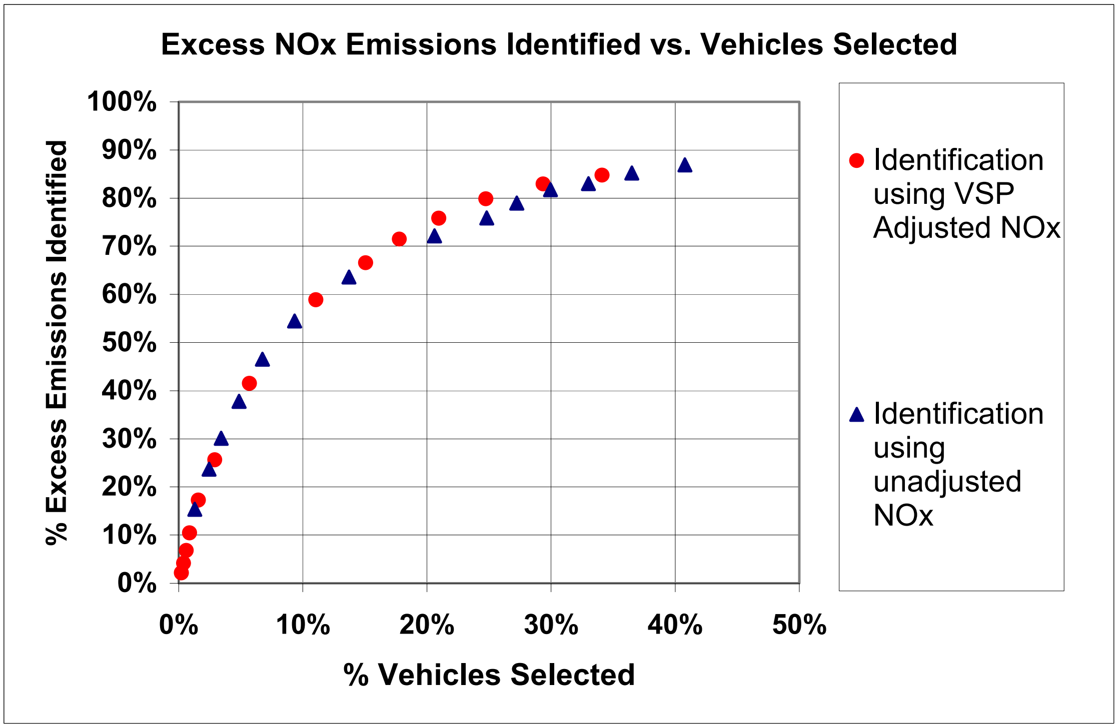
Table 4-1 shows the values of NOx_{Zero} and VSP_{NoxMax} used in the projection. Inevitably, some vehicles had measured NOx emissions lower than $NOx_{Zero.}$ For these vehicles the projection equation does not hold, so in these cases the projected emissions were set to the measured emissions.

Table 4-1 Values Used in NOx Projections

Vehicle Type	Model Years 1981-1985	1986-1990	1991-1995	1996 & newer
LDGV:				
NOx_{Zero} ppm	393	316	181	(1)
VSP_{NOxMax} kW/t	21	23	29	41
NOx_{Max} ppm	1,250	1,168	822	281
NOx_{Zero}/NOX_{Max}	31%	27%	22%	0%
LDGT:				
NOx_{Zero} ppm	318	258	177	11
VSP_{NOxMax} kW/t	17	23	29	41
NOx_{Max} ppm	1,543	1,505	875	350
NOx_{Zero}/NOX_{Max}	21%	17%	20%	3%
HDGV:				
NOx_{Zero} ppm	305	601	438	267
VSP_{NOxMax} kW/t	11	17	17	17
NOx_{Max} ppm	1,354	1,386	1,294	582
NOx_{Zero}/NOX_{Max}	22%	43%	34%	46%

Figure 4-25 shows the identification of excess NOx emissions using only the most recent remote sensing NOx measurement. As with previous charts in this section, the same cutpoint has been applied to all vehicles regardless of the type and age of the vehicle. There is a slight improvement in the identification rate vs. vehicles selected using the VSP adjusted NOx values. It is expected that further improvement will be obtained by developing separate cutpoints by vehicle type/age and by refining the projection of NOx emission values.

Figure 4-25 NOx Emissions Identification Using VSP Adjusted and Unadjusted NOx Values



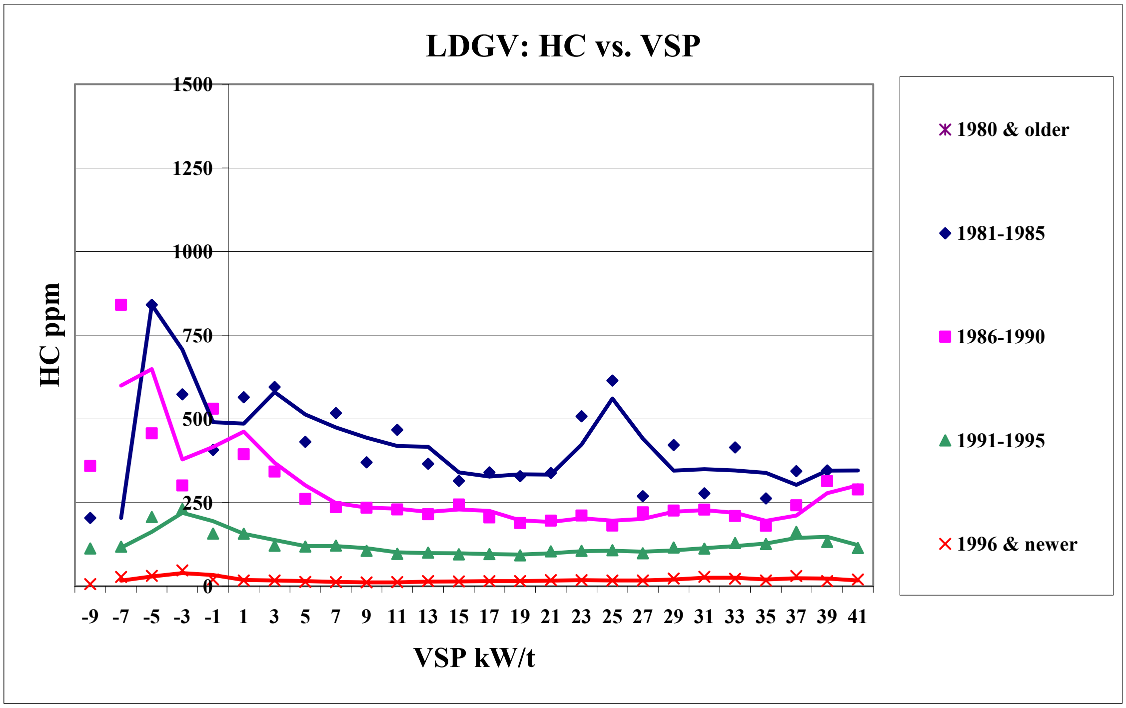
5. CONCLUSIONS

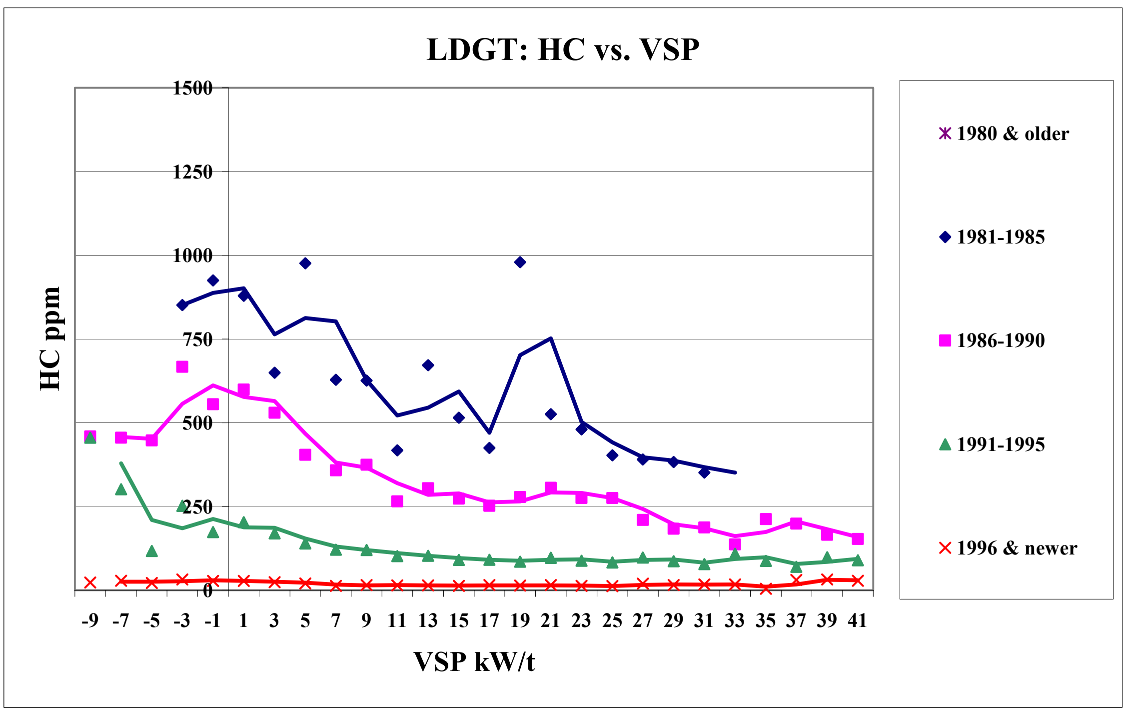
Following are the key conclusions drawn from this analysis:

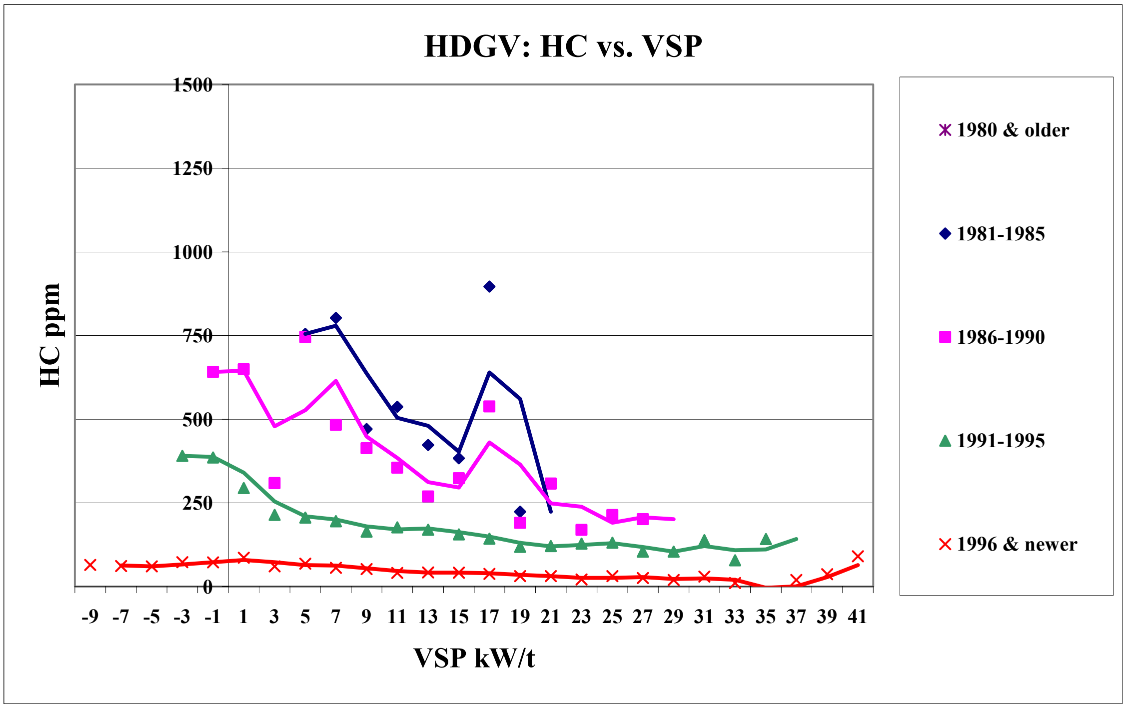
- The study met its data collection goals. Valid RSD measurements were made on 23% of the Northern Virginia I/M fleet.
- Vehicles registered in Virginia's I/M areas had significantly lower HC, CO, and NOx remote sensing levels than vehicles registered in Virginia's non-I/M areas.
- Vehicle Specific Power (VSP) is a good measure to judge the conditions that a vehicle should be operating under to generate reliable RSD emission readings. In addition, site/hour combinations with high percentages of new vehicles with high emissions (after VSP screens are applied) are likely to be seeing more vehicles in cold start mode or with condensing exhaust plumes. ESP removed observations from these sites for the periods during which the percentages were elevated.
- Estimated emission reductions for Virginia's I/M program based on RSD observations in I/M and non-I/M areas are much greater than emission reductions estimated by EPA's MOBILE6 model.
- Combining RSD results with high emitter indexing can identify most of the high emitters. Vehicles that are classified as high emitters by RSD and are in the dirtiest 25% of the high emitter index have much higher emission levels than the average vehicle.
- A dirty screen program using one hit with high emitter indexing has similar performance to one using two-hits. Initially, it's much easier to get one hit on a vehicle than 2 hits, so this scenario would be more cost-effective.

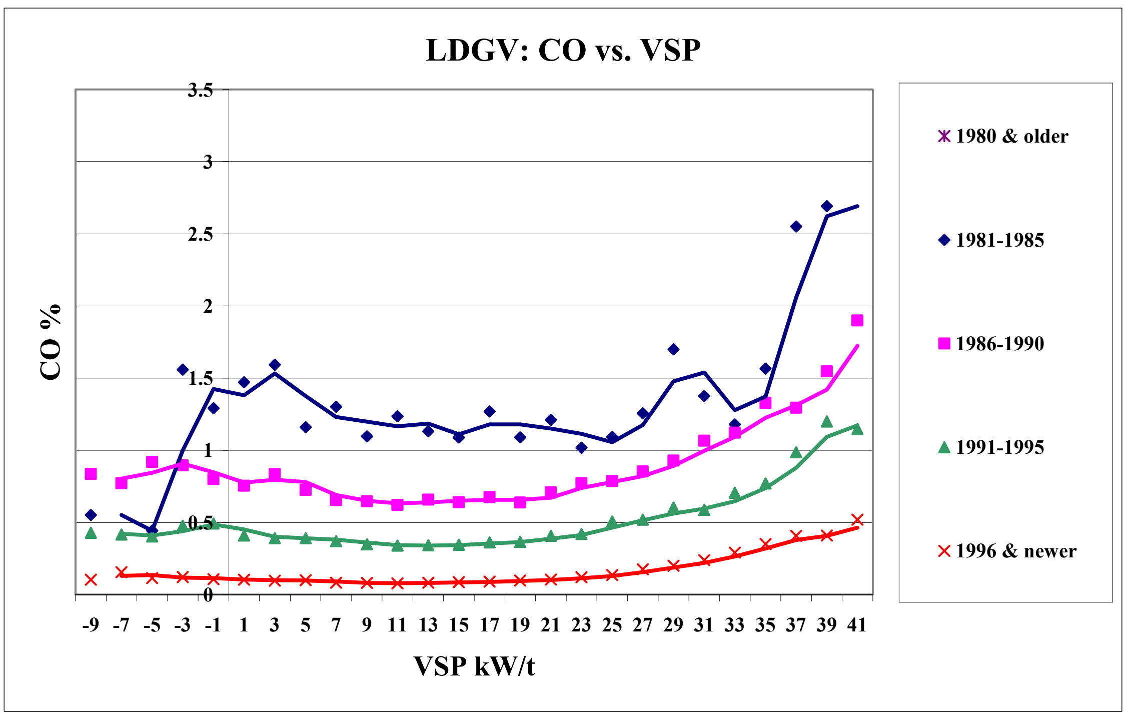
APPENDIX A

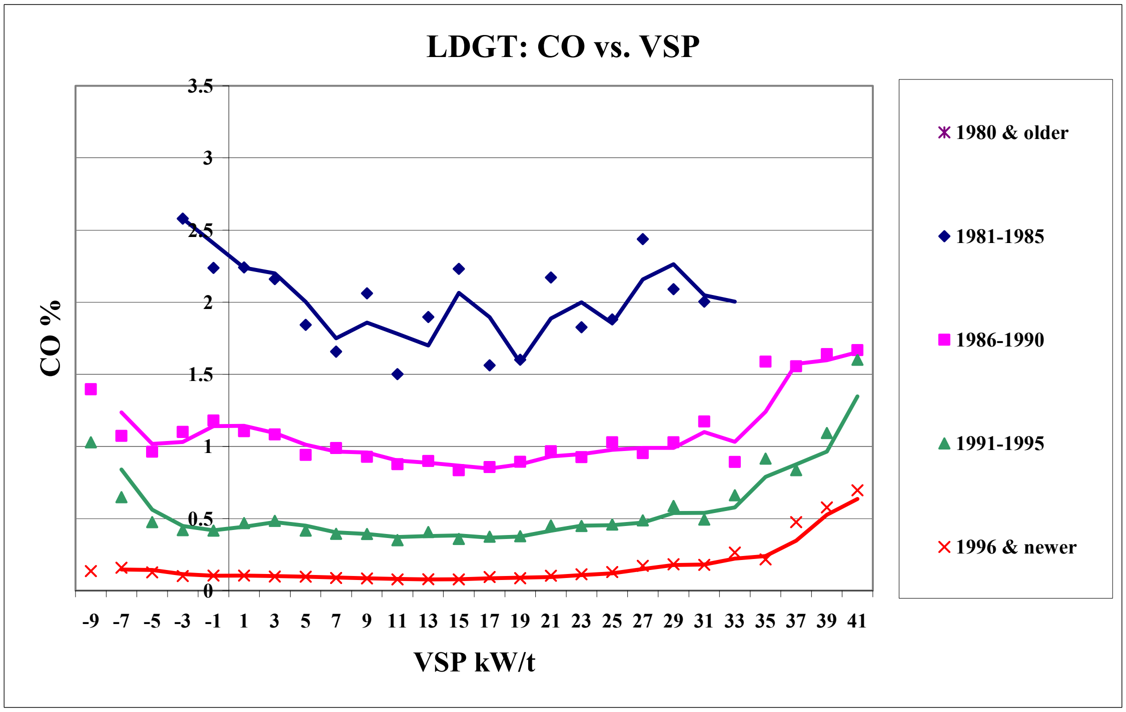
LDGV, LDGT & HDGV EMISSIONS VS. VSP

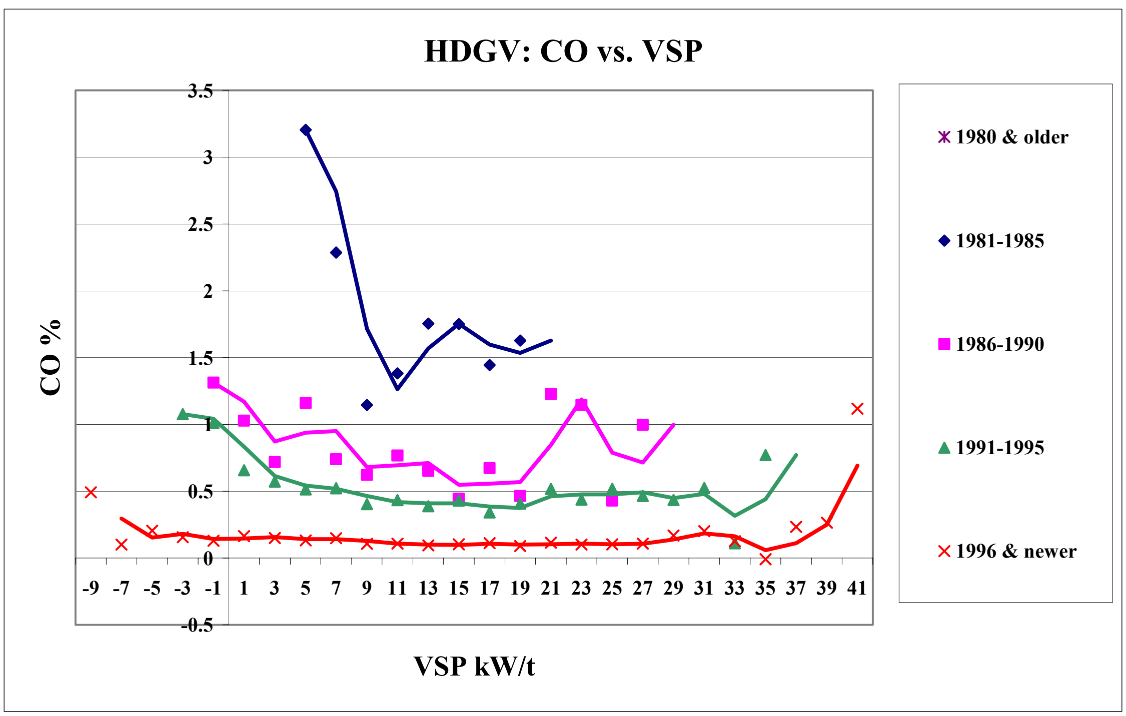


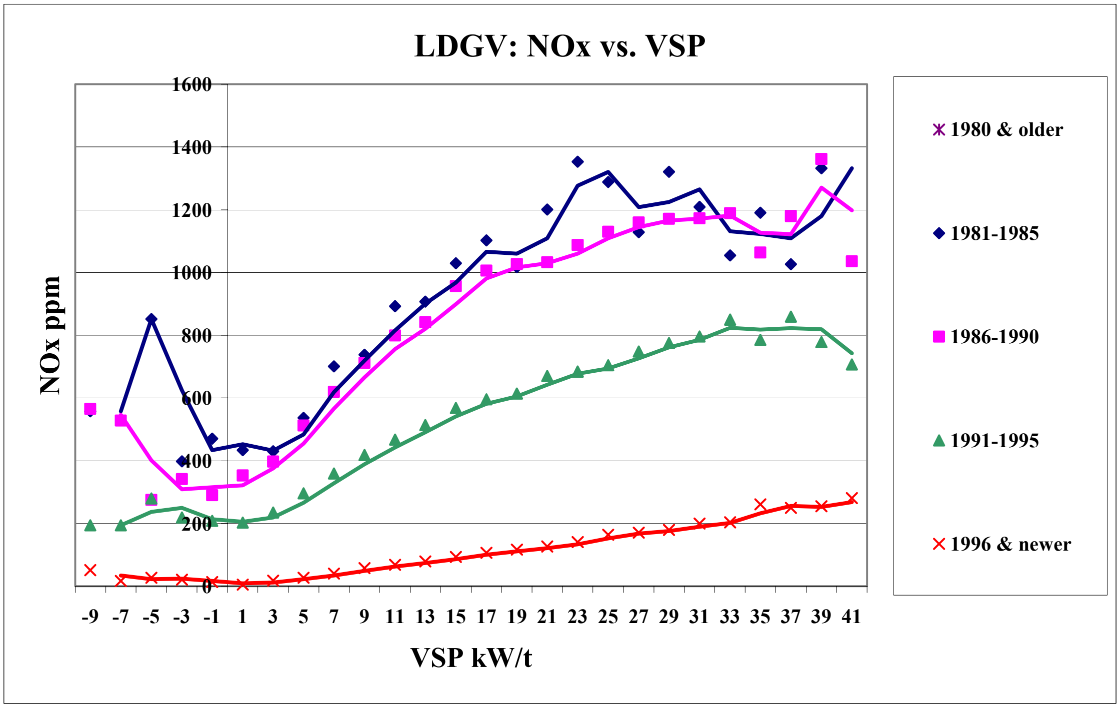


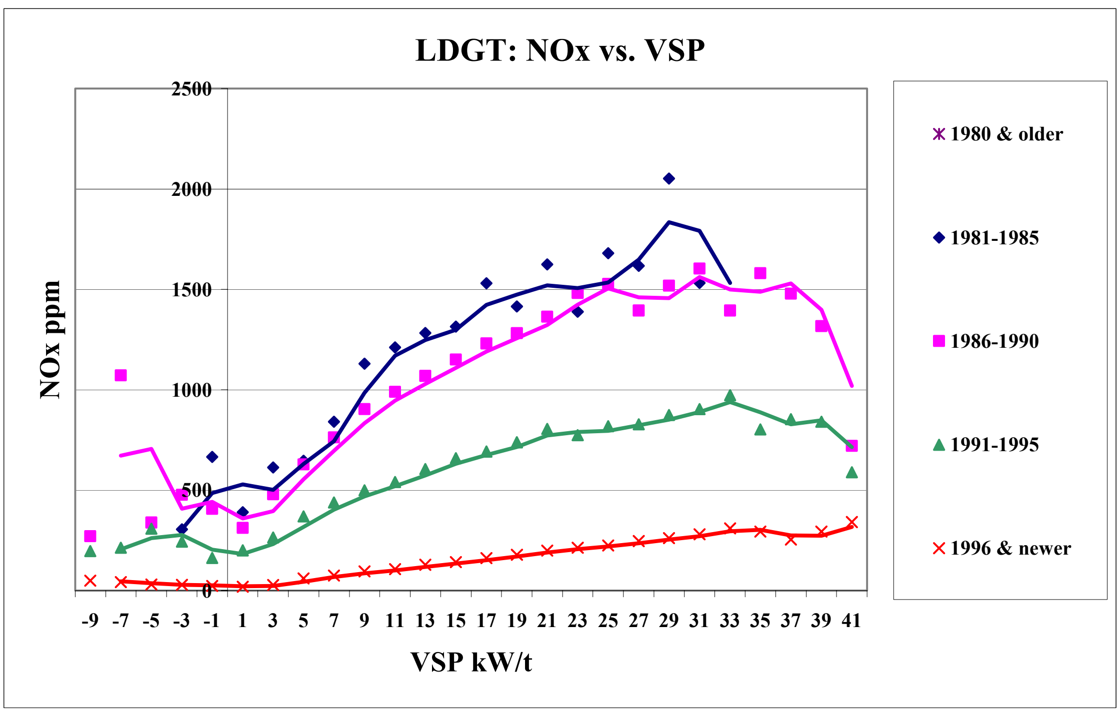

HDGV: HC vs. VSP
HC ppm
VSP kW/t
1500
1250
1000
750
500
250
0
-9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
1980 & older
1981-1985
1986-1990
1991-1995
1996 & newer

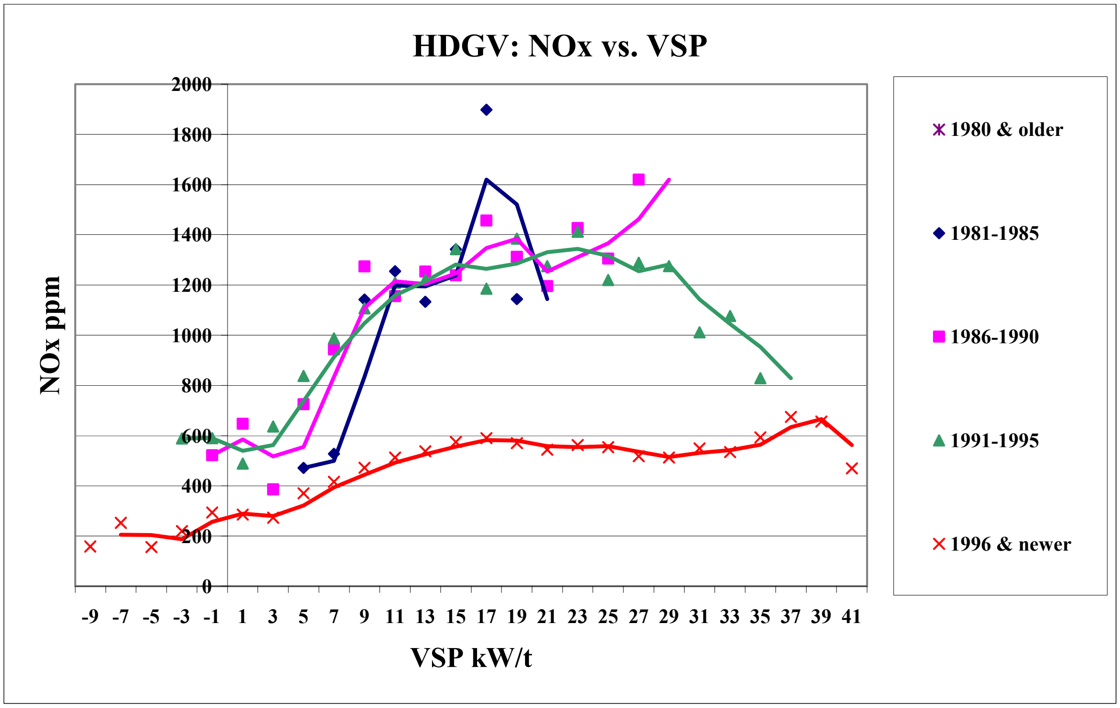

LDGV: CO vs. VSP
CO %
VSP kW/t
3.5
3
2.5
2
1.5
1
0.5
0
-9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
1980 & older
1981-1985
1986-1990
1991-1995
1996 & newer


LDGT: CO vs. VSP
CO %
VSP kW/t
3.5
3
2.5
2
1.5
1
0.5
0
-9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
1980 & older
1981-1985
1986-1990
1991-1995
1996 & newer


HDGV: CO vs. VSP
CO %
VSP kW/t
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
1980 & older
1981-1985
1986-1990
1991-1995
1996 & newer


LDGV: NOx vs. VSP
NOx ppm
1600
1400
1200
1000
800
600
400
200
0
-9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
VSP kW/t
1980 & older
1981-1985
1986-1990
1991-1995
1996 & newer


LDGT: NOx vs. VSP
NOx ppm
2500
2000
1500
1000
500
0
-9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
VSP kW/t
1980 & older
1981-1985
1986-1990
1991-1995
1996 & newer

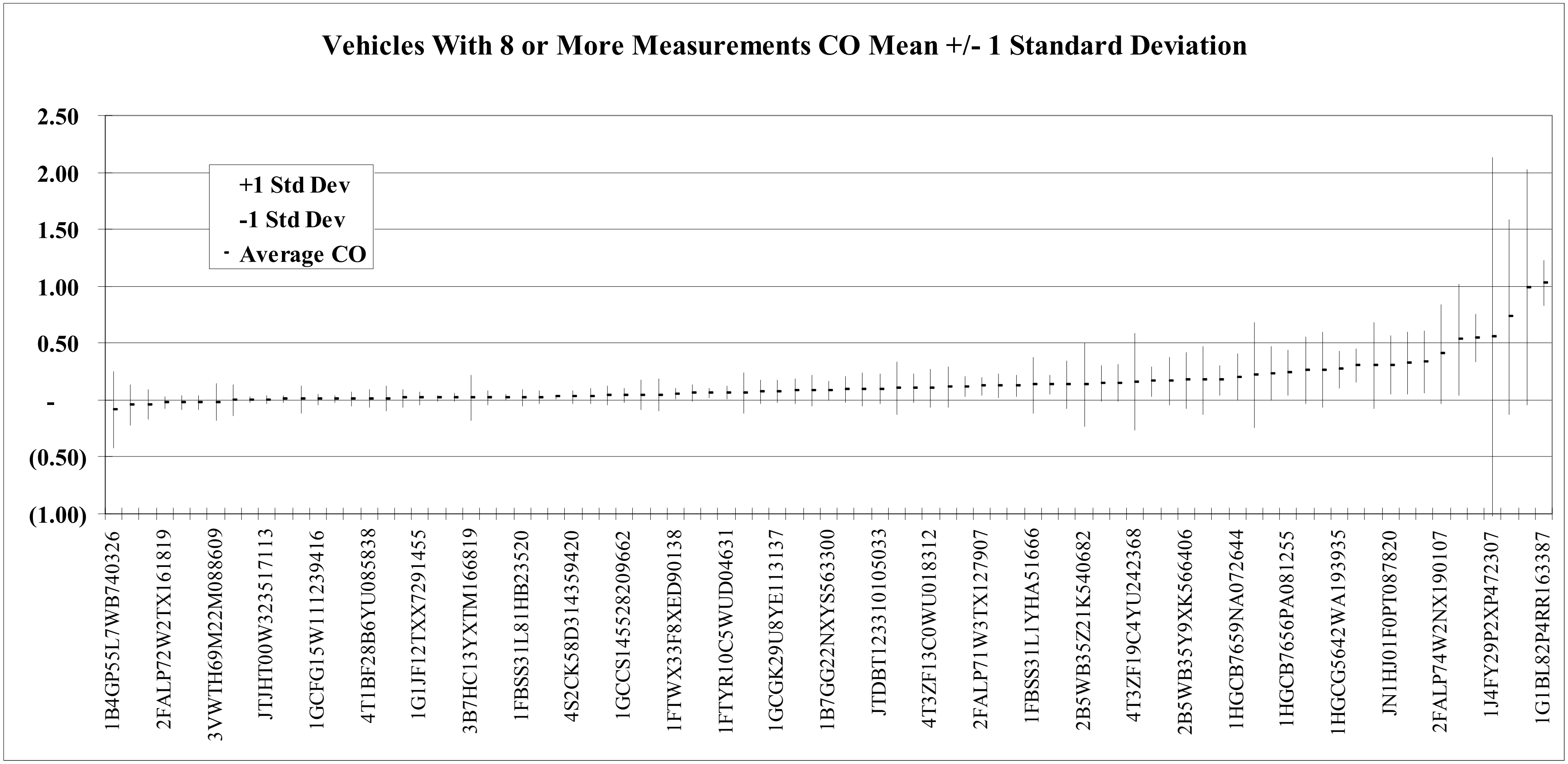


HDGV: NOx vs. VSP
NOx ppm
VSP kW/t
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
1980 & older
1981-1985
1986-1990
1991-1995
1996 & newer

APPENDIX B

ANALYSIS OF VEHICLES WITH MULTIPLE HITS

The following charts show RSD emissions for vehicles that were observed at least 7 times. The data indicate that vehicle emission rates are much more variable for high emitters than low emitters. This is why either multiple RSD hits or high emitter indexing must be used to reliably identify high emitters.


Vehicles With 8 or More Measurements CO Mean +/- 1 Standard Deviation
+1 Std Dev
-1 Std Dev
Average CO
2.50
2.00
1.50
1.00
0.50
-
(0.50)
(1.00)
1B4GP55L7WB740326
2FALP72W2TX161819
3VWTH69M22M088609
JTJHT00W323517113
1GCFG15W111239416
4T1BF28B6YU085838
1G1JF12TXX7291455
3B7HC13YXTM166819
1FBSS31L81HB23520
4S2CK58D314359420
1GCCS145528209662
1FTWX33F8XED90138
1FTYR10C5WUD04631
1GCGK29U8YE113137
1B7GG22NXYS563300
JTDBT123310105033
4T3ZF13C0WU018312
2FALP71W3TX127907
1FBSS31L1YHA51666
2B5WB35Z21K540682
4T3ZF19C4YU242368
2B5WB35Y9XK566406
1HGCB7659NA072644
1HGCB7656PA081255
1HGCG5642WA193935
JN1HJ01F0PT087820
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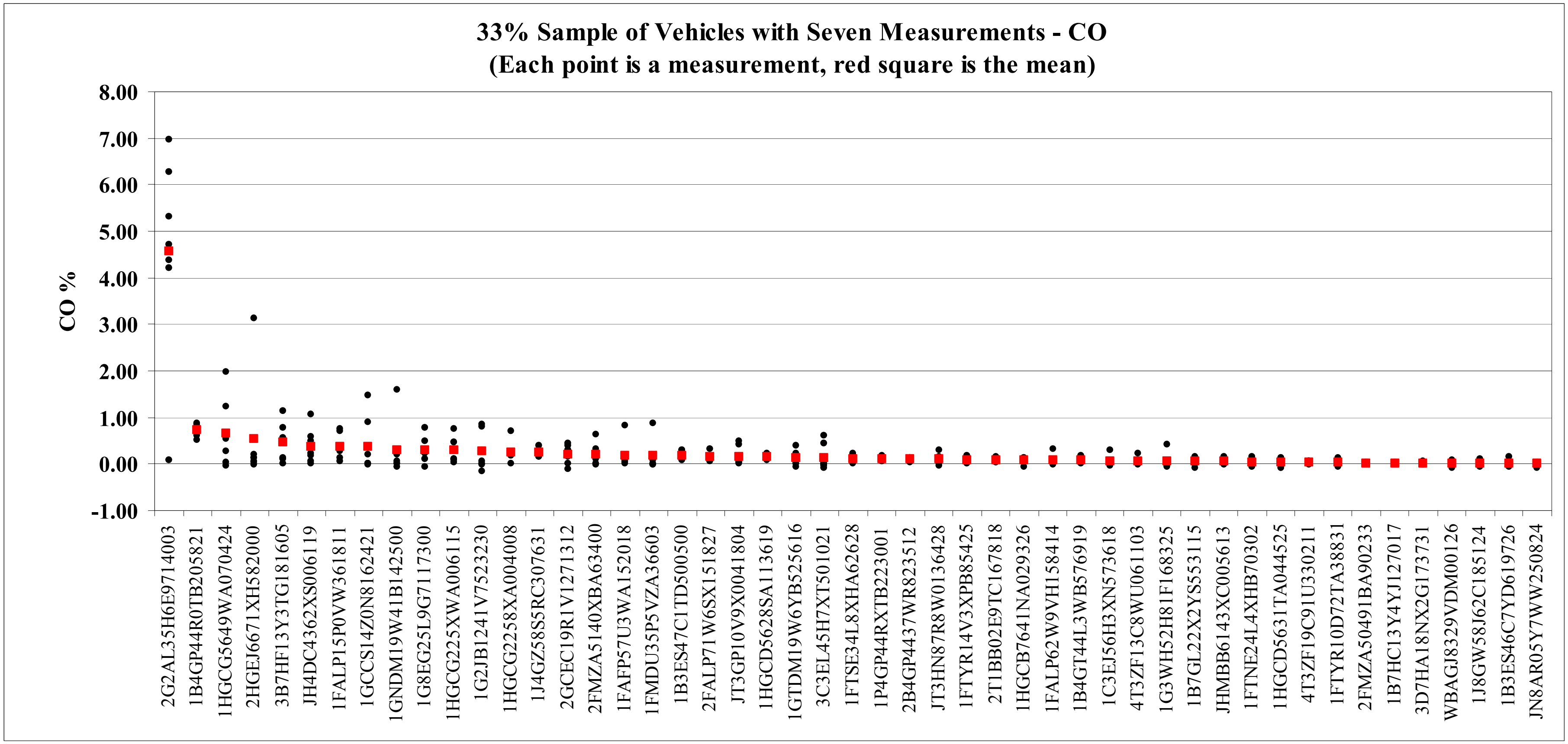
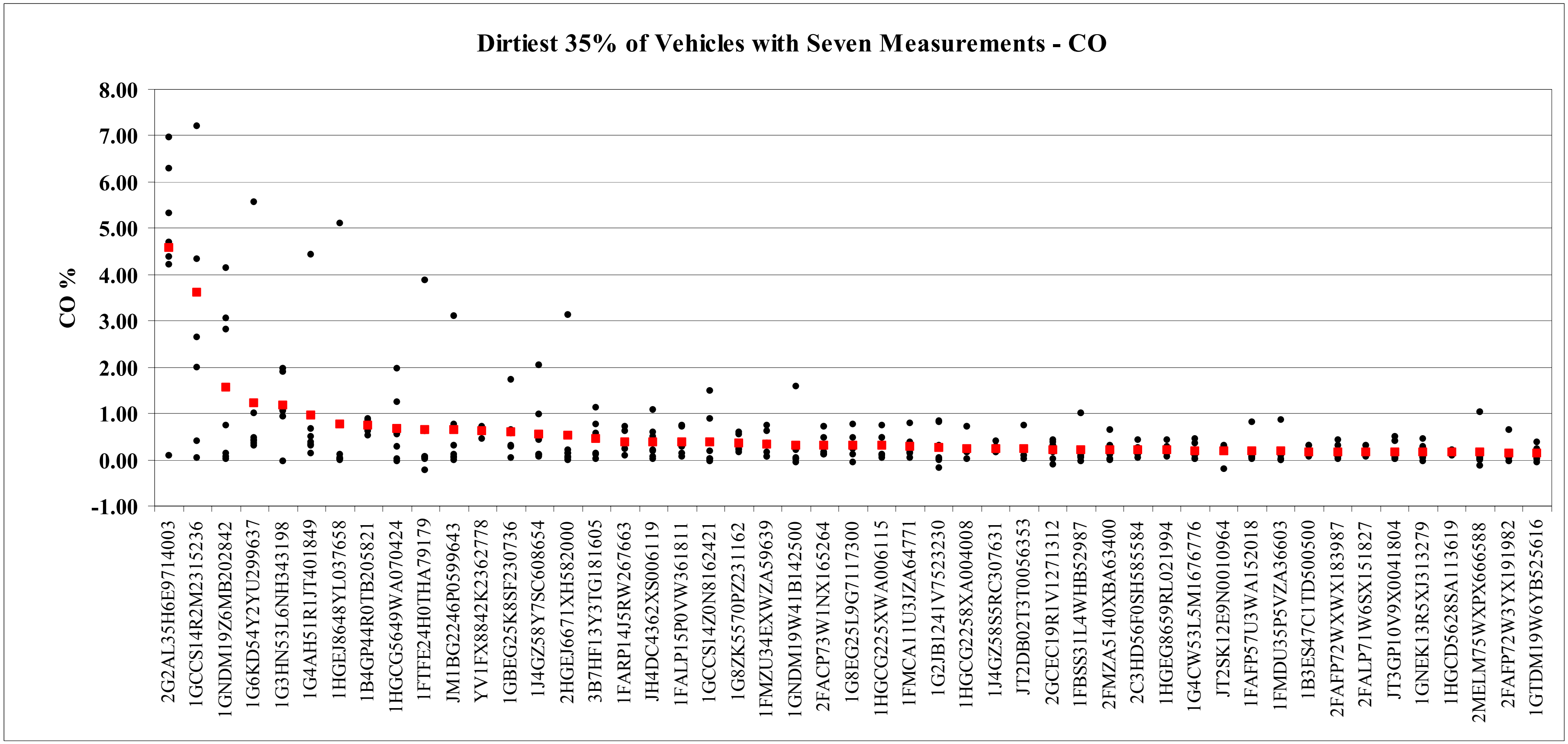
1G1BL82P4RR163387


33% Sample of Vehicles with Seven Measurements - CO
(Each point is a measurement, red square is the mean)
CO %
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
2G2AL35H6E9714003
1B4GP44R0TB205821
1HGCG5649WA070424
2HGEJ6671XH582000
3B7HF13Y3TG181605
JH4DC4362XS006119
1FALP15P0VW361811
1GCCS14Z0N8162421
1GNDM19W41B142500
1G8EG25L9G7117300
1HGCG225XWA006115
1G2JB1241V7523230
1HGCG2258XA004008
1J4GZ58S5RC307631
2GCEC19R1V1271312
2FMZA5140XBA63400
1FAFP57U3WA152018
1FMDU35P5VZA36603
1B3ES47C1TD500500
2FALP71W6SX151827
JT3GP10V9X0041804
1HGCD5628SA113619
1GTDM19W6YB525616
3C3EL45H7XT501021
1FTSE34L8XHA62628
1P4GP44RXTB223001
2B4GP4437WR823512
JT3HN87R8W0136428
1FTYR14V3XPB85425
2T1BB02E9TC167818
1HGCB7641NA029326
1FALP62W9VH158414
1B4GT44L3WB576919
1C3EJ56H3XN573618
4T3ZF13C8WU061103
1G3WH52H81F168325
1B7GL22X2YS553115
JHMBB6143XC005613
1FTNE24L4XHB70302
1HGCD5631TA044525
4T3ZF19C91U330211
1FTYR10D72TA38831
2FMZA50491BA90233
1B7HC13Y4YJ127017
3D7HA18NX2G173731
WBAGJ8329VDM00126
1J8GW58J62C185124
1B3ES46C7YD619726
JN8AR05Y7WW250824



Dirtiest 35% of Vehicles with Seven Measurements - CO
CO %
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
2G2AL35H6E9714003
1GCCS14R2M2315236
1GNDM19Z6MB202842
1G6KD54Y2YU299637
1G3HN53L6NH343198
1G4AH51R1JT401849
1HGEJ8648YL037658
1B4GP44R0TB205821
1HGCG5649WA070424
1FTFE24H0THA79179
JM1BG2246P0599643
YV1FX8842K2362778
1GBEG25K8SF230736
1J4GZ58Y7SC608654
2HGEJ6671XH582000
3B7HF13Y3TG181605
1FARP14J5RW267663
JH4DC4362XS006119
1FALP15P0VW361811
1GCCS14Z0N8162421
1G8ZK5570PZ231162
1FMZU34EXWZA59639
1GNDM19W41B142500
2FACP73W1NX165264
1G8EG25L9G7117300
1HGCG225XWA006115
1FMCA11U3JZA64771
1G2JB1241V7523230
1HGCG2258XA004008
1J4GZ58S5RC307631
JT2DB02T3T0056353
2GCEC19R1V1271312
1FBSS31L4WHB52987
2FMZA5140XBA63400
2C3HD56F0SH585584
1HGEG8659RL021994
1G4CW53L5M1676776
JT2SK12E9N0010964
1FAFP57U3WA152018
1FMDU35P5VZA36603
1B3ES47C1TD500500
2FAFP72WXWX183987
2FALP71W6SX151827
JT3GP10V9X0041804
1GNEK13R5XJ313279
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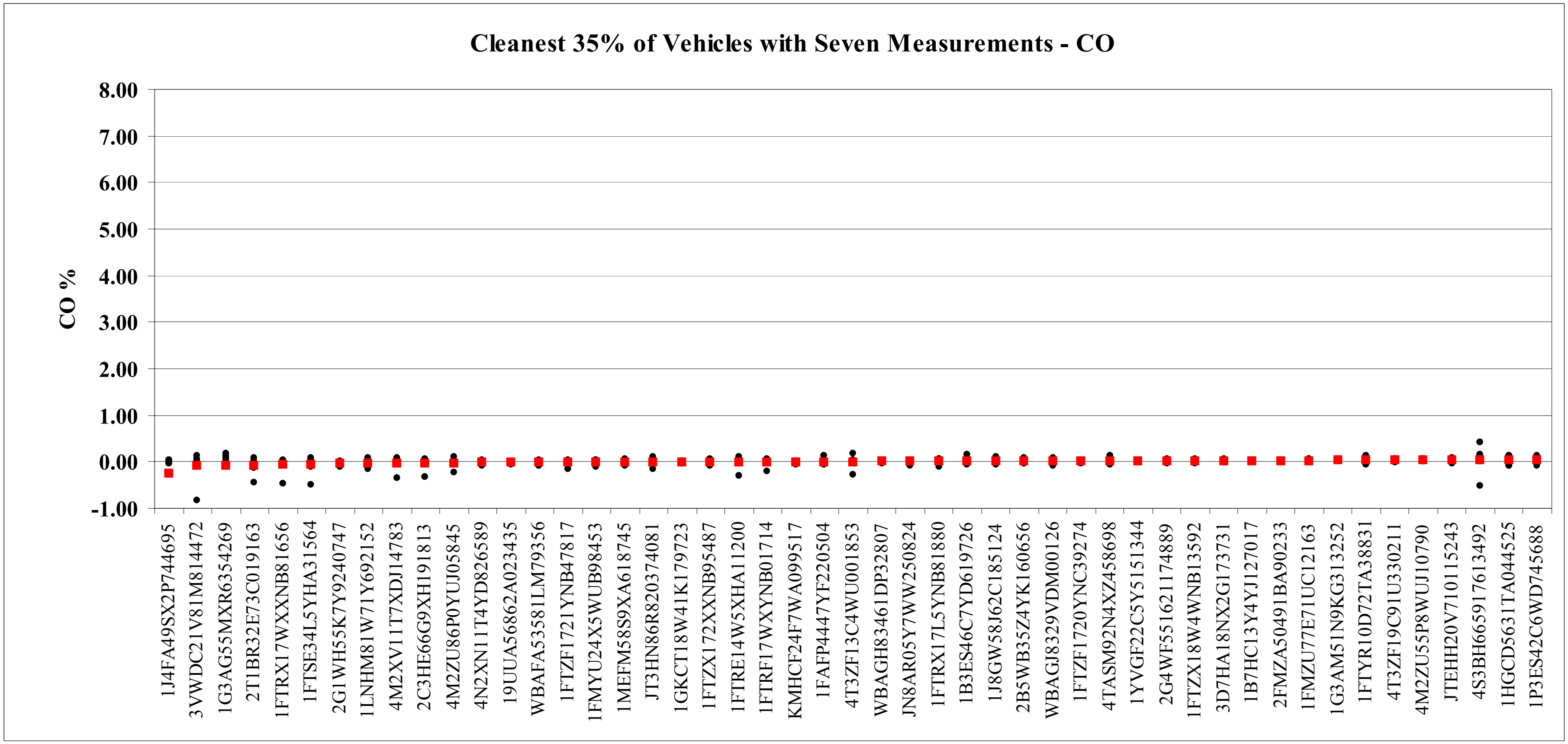
Cleanest 35% of Vehicles with Seven Measurements - CO
CO %
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
1J4FA49SX2P744695
3VWDC21V81M814472
1G3AG55MXR6354269
2T1BR32E73C019163
1FTRX17WXXNB81656
1FTSE34L5YHA31564
2G1WH55K7Y9240747
1LNHM81W71Y692152
4M2XV11T7XDJ14783
2C3HE66G9XH191813
4M2ZU86P0YUJ05845
4N2XN11T4YD826589
19UUA56862A023435
WBAFA53581LM79356
1FTZF1721YNB47817
1FMYU24X5WUB98453
1MEFM58S9XA618745
JT3HN86R820374081
1GKCT18W41K179723
1FTZX172XXNB95487
1FTRE14W5XHA11200
1FTRF17WXYNB01714
KMHCF24F7WA099517
1FAFP4447YF220504
4T3ZF13C4WU001853
WBAGH83461DP32807
JN8AR05Y7WW250824
1FTRX17L5YNB81880
1B3ES46C7YD619726
1J8GW58J62C185124
2B5WB35Z4YK160656
WBAGJ8329VDM00126
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4TASM92N4XZ458698
1YVGF22C5Y5151344
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1FTZX18W4WNB13592
3D7HA18NX2G173731
1B7HC13Y4YJ127017
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1FMZU77E71UC12163
1G3AM51N9KG313252
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4T3ZF19C91U330211
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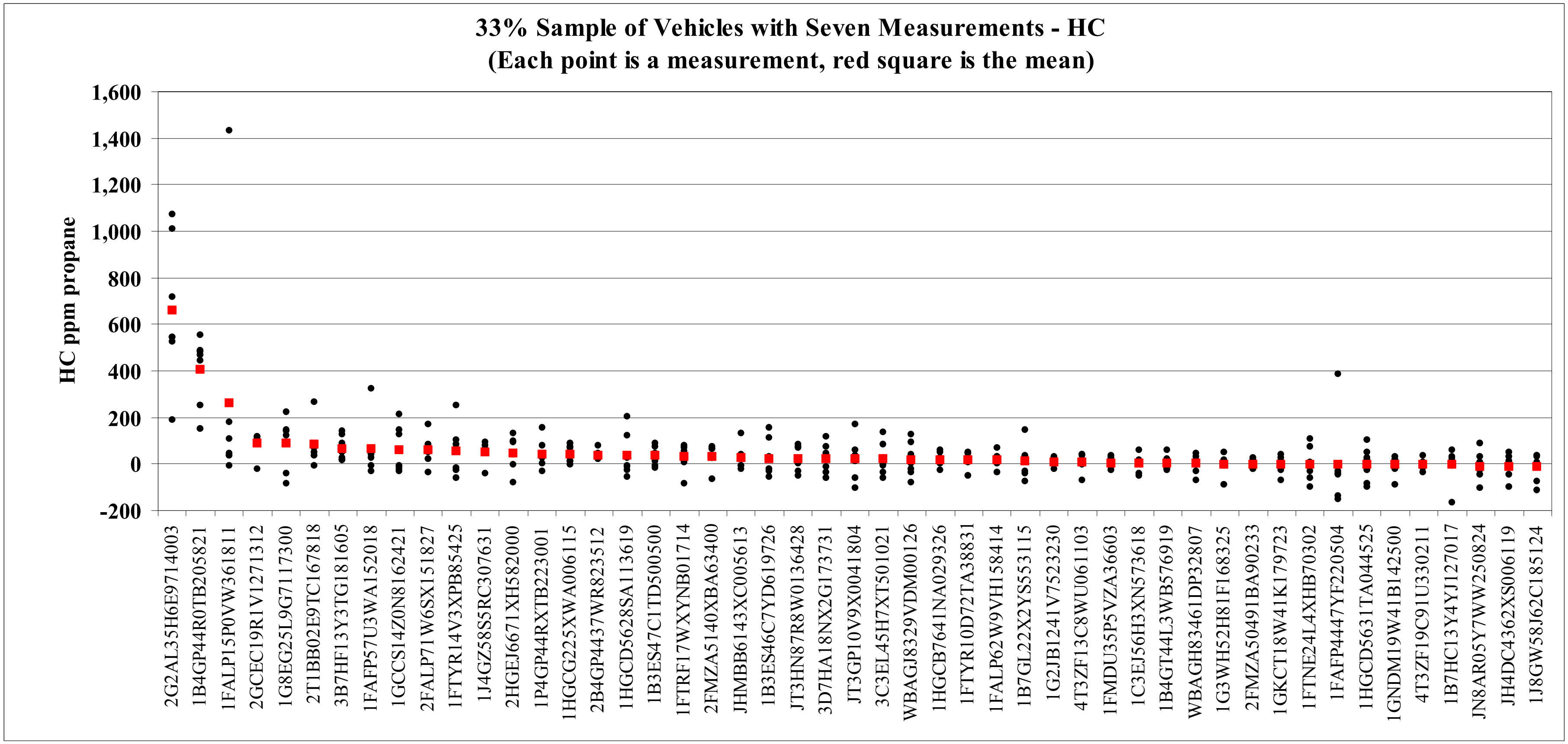
1HGCD5631TA044525
1P3ES42C6WD745688


33% Sample of Vehicles with Seven Measurements - HC
(Each point is a measurement, red square is the mean)
HC ppm propane
1,600
1,400
1,200
1,000
800
600
400
200
0
-200
2G2AL35H6E9714003
1B4GP44R0TB205821
1FALP15P0VW361811
2GCEC19R1V1271312
1G8EG25L9G7117300
2T1BB02E9TC167818
3B7HF13Y3TG181605
1FAFP57U3WA152018
1GCCS14Z0N8162421
2FALP71W6SX151827
1FTYR14V3XPB85425
1J4GZ58S5RC307631
2HGEJ6671XH582000
1P4GP44RXTB223001
1HGCG225XWA006115
2B4GP4437WR823512
1HGCD5628SA113619
1B3ES47C1TD500500
1FTRF17WXYNB01714
2FMZA5140XBA63400
JHMBB6143XC005613
1B3ES46C7YD619726
JT3HN87R8W0136428
3D7HA18NX2G173731
JT3GP10V9X0041804
3C3EL45H7XT501021
WBAGJ8329VDM00126
1HGCB7641NA029326
1FTYR10D72TA38831
1FALP62W9VH158414
1B7GL22X2YS553115
1G2JB1241V7523230
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1B4GT44L3WB576919
WBAGH83461DP32807
1G3WH52H81F168325
2FMZA50491BA90233
1GKCT18W41K179723
1FTNE24L4XHB70302
1FAFP4447YF220504
1HGCD5631TA044525
1GNDM19W41B142500
4T3ZF19C91U330211
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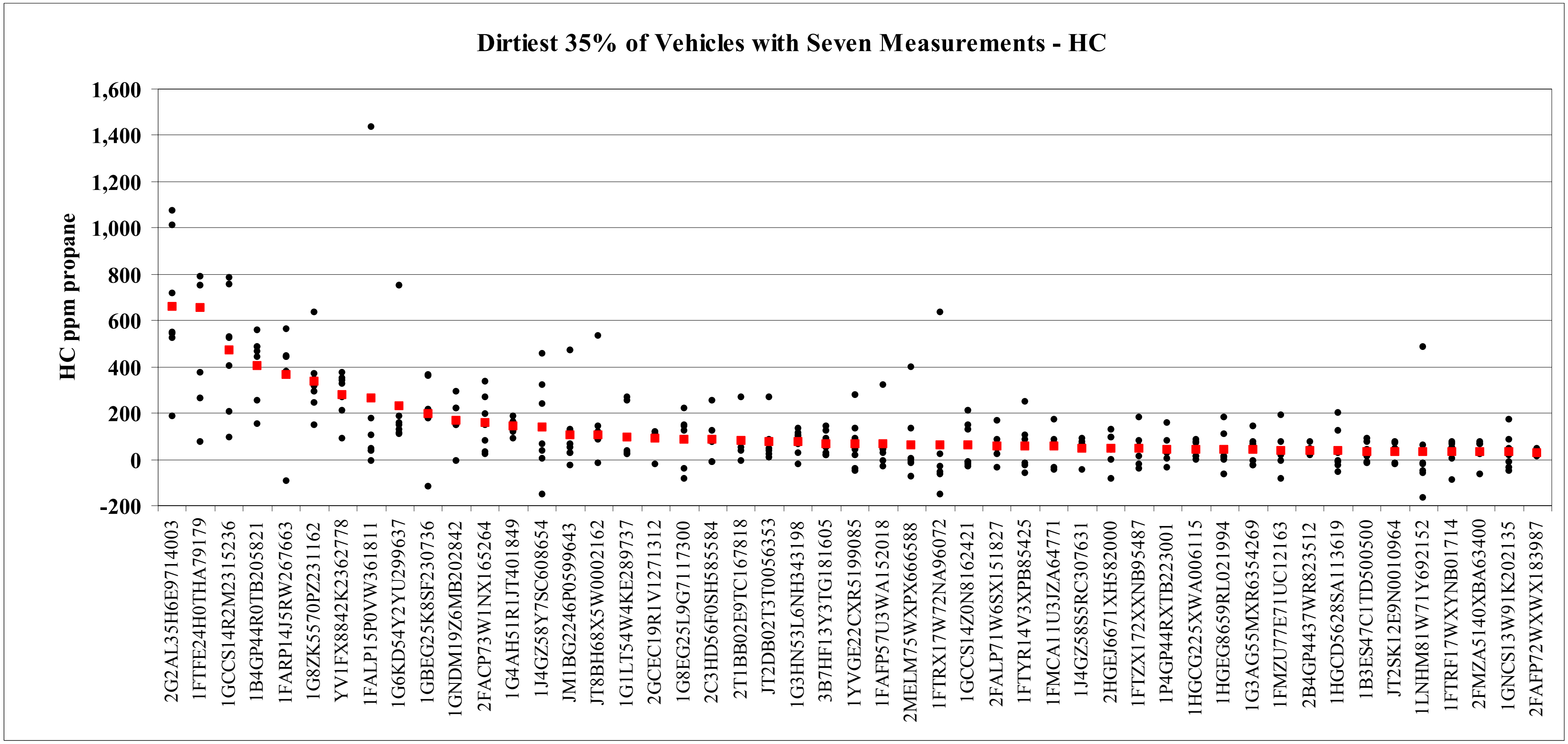
JH4DC4362XS006119
1J8GW58J62C185124


Dirtiest 35% of Vehicles with Seven Measurements - HC
HC ppm propane
1,600
1,400
1,200
1,000
800
600
400
200
0
-200
2G2AL35H6E9714003
1FTFE24H0THA79179
1GCCS14R2M2315236
1B4GP44R0TB205821
1FARP14J5RW267663
1G8ZK5570PZ231162
YV1FX8842K2362778
1FALP15P0VW361811
1G6KD54Y2YU299637
1GBEG25K8SF230736
1GNDM19Z6MB202842
2FACP73W1NX165264
1G4AH51R1JT401849
1J4GZ58Y7SC608654
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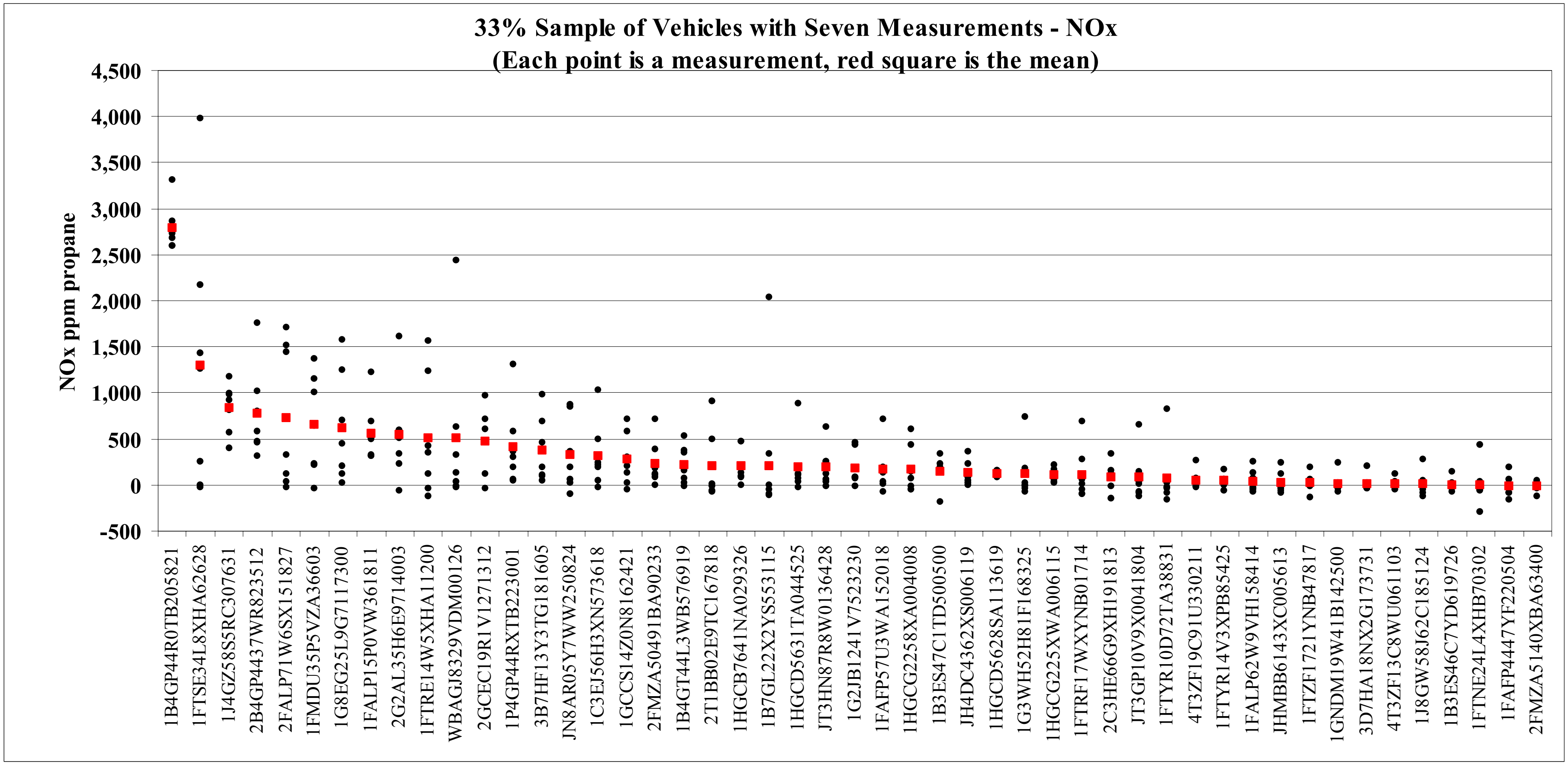
1G1LT54W4KE289737
2GCEC19R1V1271312
1G8EG25L9G7117300
2C3HD56F0SH585584
2T1BB02E9TC167818
JT2DB02T3T0056353
1G3HN53L6NH343198
3B7HF13Y3TG181605
1YVGE22CXR5199085
1FAFP57U3WA152018
2MELM75WXPX666588
1FTRX17W72NA96072
1GCCS14Z0N8162421
2FALP71W6SX151827
1FTYR14V3XPB85425
1FMCA11U3JZA64771
1J4GZ58S5RC307631
2HGEJ6671XH582000
1FTZX172XXNB95487
1P4GP44RXTB223001
1HGCG225XWA006115
1HGEG8659RL021994
1G3AG55MXR6354269
1FMZU77E71UC12163
2B4GP4437WR823512
1HGCD5628SA113619
1B3ES47C1TD500500
JT2SK12E9N0010964
1LNHM81W71Y692152
1FTRF17WXYNB01714
2FMZA5140XBA63400
1GNCS13W91K202135
2FAFP72WXWX183987


33% Sample of Vehicles with Seven Measurements - NOx
(Each point is a measurement, red square is the mean)
NOx ppm propane
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
1B4GP44R0TB205821
1FTSE34L8XHA62628
1J4GZ58S5RC307631
2B4GP4437WR823512
2FALP71W6SX151827
1FMDU35P5VZA36603
1G8EG25L9G7117300
1FALP15P0VW361811
2G2AL35H6E9714003
1FTRE14W5XHA11200
WBAGJ8329VDM00126
2GCEC19R1V1271312
1P4GP44RXTB223001
3B7HF13Y3TG181605
JN8AR05Y7WW250824
1C3EJ56H3XN573618
1GCCS14Z0N8162421
2FMZA50491BA90233
1B4GT44L3WB576919
2T1BB02E9TC167818
1HGCB7641NA029326
1B7GL22X2YS553115
1HGCD5631TA044525
JT3HN87R8W0136428
1G2JB1241V7523230
1FAFP57U3WA152018
1HGCG2258XA004008
1B3ES47C1TD500500
JH4DC4362XS006119
1HGCD5628SA113619
1G3WH52H81F168325
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JT3GP10V9X0041804
1FTYR10D72TA38831
4T3ZF19C91U330211
1FTYR14V3XPB85425
1FALP62W9VH158414
JHMBB6143XC005613
1FTZF1721YNB47817
1GNDM19W41B142500
3D7HA18NX2G173731
4T3ZF13C8WU061103
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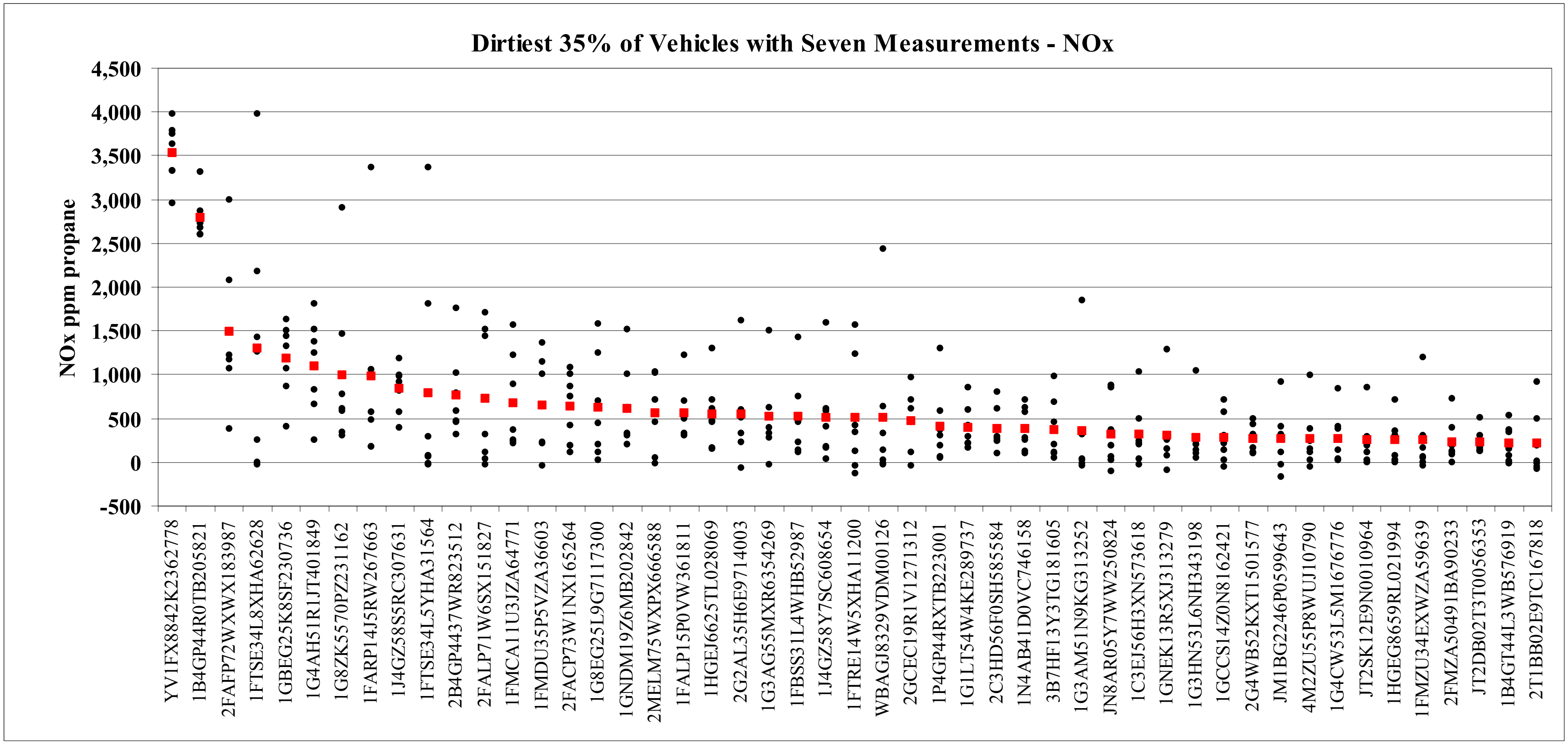
2FMZA5140XBA63400



Dirtiest 35% of Vehicles with Seven Measurements - NOx
NOx ppm propane
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
YV1FX8842K2362778
1B4GP44R0TB205821
2FAFP72WXWX183987
1FTSE34L8XHA62628
1GBEG25K8SF230736
1G4AH51R1JT401849
1G8ZK5570PZ231162
1FARP14J5RW267663
1J4GZ58S5RC307631
1FTSE34L5YHA31564
2B4GP4437WR823512
2FALP71W6SX151827
1FMCA11U3JZA64771
1FMDU35P5VZA36603
2FACP73W1NX165264
1G8EG25L9G7117300
1GNDM19Z6MB202842
2MELM75WXPX666588
1FALP15P0VW361811
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2G2AL35H6E9714003
1G3AG55MXR6354269
1FBSS31L4WHB52987
1J4GZ58Y7SC608654
1FTRE14W5XHA11200
WBAGJ8329VDM00126
2GCEC19R1V1271312
1P4GP44RXTB223001
1G1LT54W4KE289737
2C3HD56F0SH585584
1N4AB41D0VC746158
3B7HF13Y3TG181605
1G3AM51N9KG313252
JN8AR05Y7WW250824
1C3EJ56H3XN573618
1GNEK13R5XJ313279
1G3HN53L6NH343198
1GCCS14Z0N8162421
2G4WB52KXT1501577
JM1BG2246P0599643
4M2ZU55P8WUJ10790
1G4CW53L5M1676776
JT2SK12E9N0010964
1HGEG8659RL021994
1FMZU34EXWZA59639
2FMZA50491BA90233
JT2DB02T3T0056353
1B4GT44L3WB576919
2T1BB02E9TC167818

APPENDIX C

High Emitter Identification Trials

The Appendix contains results of trial high emitter identification cutpoints applied to a sample of 30,000 vehicles that subsequently received an initial ASM I/M test. The results of the ASM tests are used to compute the trial result statistics. Results are reported at three levels of detail:

- Results for the whole sample (all model years) are reported in aggregate for each trial (3 pages)
- Results for the sample are reported separately for a) 1995 & older, and b) 1996 & newer for each trial (6 pages)
- Results for the sample are reported by four model year ranges

A vehicle is required to exceed the HE Index cutpoint and any one of the HC, CO or NOx cutpoints. The HE Index cutpoint value is the percentage of ASM tested vehicles with that failure rate or lower - the lower the cutpoint the more vehicles fail the cutpoint (cutpoint of 0 will fail all vehicles). Twenty-five percent of ASM tested vehicles exceed a cutpoint of 75.

Since the vehicles observed and matched on road are generally newer than all the vehicles tested as part of the I/M program (because newer vehicles are more active), the percentage of vehicles failing the HE Index screen in the RSD sample is lower than indicated by the HE Index cutpoint value, e.g. an HE cutpoint of 50 acting alone fails 31% of the sample.

Results in the real world should be better because:

1) De-centralized ASM test results following RSD measurement are used as the yardstick and many vehicles may be obtaining pre-inspection repairs, which would create the appearance of a false failure and reduce the emissions benefits

2) The ASM test may not always represent on-road performance

3) The study sample is more biased towards newer vehicles than a comprehensive program would be and a smaller fraction of newer vehicles have high emissions.

Results in the no-I/M area should be better:

1) For the reasons given above

2) These tables are based on I/M area vehicles, which have lower emissions and fewer high emitting vehicles to select.