The Greeley Remote Sensing Pilot Program

Final Report

January 5, 1998

Prepared for:

The Colorado Department of Public Health and Environment

Prepared by :

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de la Torre Klausmeier Consulting, Inc.

Peter McClintock
Applied Analysis

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EXECUTIVE SUMMARY

The Greeley Remote Sensing Pilot Program, otherwise known as the Greeley study, has been a multi-year program whose purpose was to evaluate how remote sensing technology can be used as a supplement or alternative to an inspection/maintenance (I/M) program. The Greeley study was mandated by House Bill (93)-1340, and has operated in the Greeley area since December 1995. According to HB(93)-1340, the state's Air Quality Control Commission (AQCC) and Department of Public Health and Environment (CDPHE) were instructed to conduct... "a pilot study of the feasibility and costs of implementing remote sensing emissions detection technology as a potential supplemental maintenance strategy for areas that have attained applicable (air quality) standards." The Greeley area was chosen since it has not violated the National Ambient Air Quality Standard (NAAQS) for carbon monoxide since 1988.

Remote sensing is an emerging technology which allows measurement of instantaneous exhaust emission concentrations while vehicles are driven on the road. Remote sensing has a significant advantage over other ways to measure vehicle emissions, because it is a relatively non-intrusive method of obtaining large numbers of measurements of in-use vehicle emissions. Remote sensing has been proposed as a means to identify high emitting vehicles that should be repaired and/or low emitting vehicles that could be exempted from inspection requirements. This latter situation, identifying low emitters, is commonly termed "clean screen".

The goals of the Greeley Remote Sensing Pilot Program included:

1) Determine the technical feasibility of the use of remote sensing to either detect and fail excess emitting vehicles, or denote vehicles which are low in emissions and waive them for I/M inspection (i.e., "clean screen").

2) Determine the cost and cost-effectiveness of remote sensing.

3) Determine the administrative costs associated with an on-going remote sensing program.

During the Greeley study, Remote Sensing Technologies Inc. (RSTi) set up remote sensing sites throughout the Greeley metropolitan area with the goal of obtaining at least one valid emission measurement on a majority of the vehicle fleet. In addition, CDPHE setup an IM240 emission test facility at Aims Community College in Greeley to conduct mass emission tests on vehicles that were seen by the remote sensing devices. IM240 test results are considered to be a good indication of on-road mass emission rates in grams per mile. RSTi merged data from the remote sensing devices with data from the IM240 test facility to analyze the reliability of remote sensing in identifying high emitters that should be targeted for inspections and repairs, and conversely, identifying low emitters that could be waived from inspection requirements in Greeley's basic I/M program. RSTi also collected data and compiled a database on vehicle registration information for vehicles registered in Colorado. This allowed an analysis of vehicle coverage trends as well as analysis of emission trends by model year and vehicle type.

Following are the major findings of the Greeley study:

- In 181 days at 11 sites, remote sensing devices (RSD) used in the Greeley study generated one or more valid CO measurements on 72% of the Greeley vehicle population. Two or more observations have been generated on 45% of the vehicle population. Because the Greeley study shared its testing resources with the Denver enhanced program, vans were not used full time to monitor vehicle emissions in Greeley. It is estimated that a study focused strictly on Greeley could potentially generate one or more valid observations on 80% of the vehicle fleet in a year.

- Clean screening vehicles[1] on the basis of RSD emission measurements can reduce the number of vehicles that must undergo Greeley's basic I/M test by about half with little loss in emission benefits. Emission benefits are proportional to amount of excess emissions identified. Based upon the results of RSD and IM240 tests, vehicles seen more than once by the RSD monitors and having maximum CO levels less than 0.5% contain less than 5% of the excess CO emissions. In other words, clean screening vehicles with RSD CO less than 0.5% would reduce I/M program benefits for CO by less than 5%. Greeley data indicate that 46% of the fleet had CO emissions less than 0.5%.

- Two or more remote sensing observations (hits) are needed before a clean screen determination can be made on a vehicle. Basing clean screen determination on vehicles that were seen only once by RSD would significantly reduce emissions benefits of an I/M program. For example, vehicles that were seen only once by RSD and had CO emissions less than 0.5% contained about 30% of the excess CO emissions as determined by IM240 mass emission tests.

- Some basic I/M programs could most likely use less stringent clean screen criteria than 0.5% CO and still achieve the basic I/M performance standard. For example, clean screening vehicles with RSD CO less than 1%, causes the program to lose less than 10% of the CO benefits, if there are 2 or more hits available on the candidate vehicles. 65% of the vehicles had maximum CO values less than 1%.

- The annual cost for a clean screen program that adequately covers a city the size of Greeley has been estimated to be $172,000. The cost to inspect

[1]Clean Screen -- Exempting vehicles that are likely to have low emissions from inspection requirements.

vehicles that would be screened-out from inspection requirements is estimated to be $205,000, so there is a possibility of a net savings of $33,000. If the economic value of time were considered, the cost savings would be much greater.

- In the Greeley program, the dirtiest vehicles identified by remote sensing devices consistently failed the IM240 mass emission test for HC and CO. Data from the Greeley program indicate that RSD can identify 40% of the excess CO emissions as determined by the IM240 test by failing less than 5% of the vehicle fleet, with low errors of commission rates. Due to small numbers of high emitting vehicles that were procured for IM240 tests, there is considerable uncertainty in the results. Data from IM240 and RSD tests conducted in Denver show higher errors of commission rates and lower excess emissions identification rates, leading us to conclude that additional data are needed before a final recommendation can be made on using RSD to identify high emitting vehicles.

1.0 INTRODUCTION

Colorado has been evaluating the use of remote sensing devices (RSD) to measure emissions from vehicles being driven on the road. With RSD, vehicle emissions are measured remotely by passing an infrared light source across a highway to an infrared source detector. The source detector measures absolute concentrations of hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2) in the exhaust plume. From these measurements, concentrations of hydrocarbons (HC) and carbon monoxide (CO) in the exhaust are calculated. RSD has a significant advantage over other ways to measure vehicle emissions, because it is a relatively non-intrusive method of obtaining measurements of in-use vehicle emissions. RSD has been proposed as a means to identify high emitting vehicles that should be repaired and/or low emitting vehicles that could be exempted from inspection requirements.

House Bill (93) 1340 tasked the Air Quality Control Commission (AQCC) and the Colorado Department of Public Health and Environment (CDPHE) to conduct a pilot study on the feasibility and costs of using remote sensing technology as a maintenance strategy for areas that have attained applicable air quality standards. The Greeley, Colorado area is such a "maintenance" area having demonstrated compliance with the national ambient air quality standards (NAAQS) for CO. As part of Envirotest Systems Corporation's contract to perform enhanced I/M tests in the Denver metropolitan area, Envirotest through its subsidiary, Remote Sensing Technologies, Inc. (RSTi) has been conducting the Greeley study. RSTi, working together with state and local officials, deployed RSD monitors and collected and analyzed data from the Greeley RSD program. This report presents the final results of the Greeley study.

1.1 <u>Purpose of the Greeley Study</u>

The Greeley study was conducted to fulfill the requirements of HB (93) 1340. It specifically investigates the effectiveness of remote sensing as a tool to identify high emitting vehicles and as screening device to limit the number of vehicles undergoing the I/M test. The emphasis of the Greeley study has been on evaluating the cost-effectiveness of remote sensing devices (RSD) as a way of screening out vehicles from the periodic I/M requirement. Although considerable work has been conducted on the measurement accuracy, to date, a comprehensive evaluation of the cost-effectiveness and feasibility of using RSD as a clean screen device has not yet been performed. The Greeley study was conducted to fill in these data gaps. It addresses the uncertainties that currently exist regarding an enforceable remote sensing program by addressing the following questions:

- What is the cost-effectiveness of a remote sensing program?
- What is the effectiveness of remote sensing in detecting high emitting vehicles?
- What is the effectiveness of remote sensing in screening out low emitting vehicles?
- What would be the air quality impact of a remote sensing based clean screen program? and
- What operational requirements are associated with an RSD program, for example siting criteria, vehicle selection criteria, enforcement, and program administration?

1.2 Summary of Project Test Plan

RSTi initiated the Greeley Project in the fall of 1995. Beginning in December 1995, one RSD 2000 van (Unit R300) was deployed in the Greeley area to measure vehicle emissions. Unit R300 continued to be used throughout 1996. Beginning in September 1996, RSTi deployed an additional van, Unit R307, to perform tandem RSD measurements with R300. The two vans used identical emissions analysis equipment but different infra-red beam set ups. R300 used the double pass set up where the beam was reflected off a mirror back to the test van. R307 used a single pass set up where the light source was placed across the test lane from the van. In addition to measuring emissions of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x), RSTi also recorded speeds and accelerations as vehicles passed by the monitors. RSTi set up speed bars approximately 10 feet in front of the light source to measure speeds and accelerations.

Data collected from the RSD vans were processed daily. The van operator transcribed license plates and prepared a data tape that was then transmitted to the Envirotest host computer. On a weekly basis, lists of vehicles and their remote sensing measurements were prepared and sent to the State.

The Colorado Department of Health, working with Aims Community College in Greeley, conducted IM240 emission tests on vehicles that were seen by the remote sensing devices. Using the list of vehicles provided by RSTi, motorists were sent letters requesting that they bring their vehicles to Aims Community College to receive a free IM240 test. In addition, motorists received a $20 voucher as an incentive.

To assist with the data analysis, RSTi collected and compiled a database on vehicle registration information. This database, which is stored on the Colorado host computer operated by Envirotest, contains specific owner and vehicle information for each license plate in Colorado. RSTi merged this vehicle registration database with RSD results to analyze emissions and vehicle coverage trends. RSTi also merged the RSD data set with the results of the Greeley IM240 program to determine the relationship between IM240 and RSD test results.

1.3 Success in Meeting the Goals of the Greeley Remote Sensing Program

The primary goals of the Greeley remote sensing pilot program were to determine the air quality benefits and estimate the costs of a comprehensive remote sensing program. The Greeley Program has been successful in meeting most of its original goals.

1.3.1 Primary Goal No. 1 - Determine the Technical Feasibility of Remote Sensing.

A primary goal of the Greeley RSD pilot program is to determine the air quality benefits of RSD. In order to meet this goal, the following issues must be addressed:

- How effective is RSD in identifying high emitting vehicles?
- Can RSD be used to screen out low emitting vehicles?
- Can RSD be used to evaluate other mobile source control programs?

Identifying High Emitting Vehicles — The Greeley program collected data to determine how well a vehicle fleet could be covered using reliable RSD sites. It appears that a single remote sensing van can collect emission measurements on at least 80% of the Greeley vehicles in a year. *181 van days of operation have resulted in at least 1 valid measurement on 72% of the Greeley fleet. At least two valid measurements have been observed on 45% of the Greeley fleet.*

Data were collected to evaluate the effectiveness of RSD in identifying high emitters while minimizing false fail rates. *In the Greeley program, the dirtiest vehicles identified by remote sensing consistently failed the IM240 test for HC and CO. Data from the Greeley program indicate that RSD can identify 40% of the excess CO emissions as determined by the IM240 test by failing less than 5% of the vehicle fleet, with low errors of commission rates. Due to small numbers of high emitting vehicles that were procured for IM240 tests, there is considerable uncertainty in the results. Data from IM240 and RSD tests conducted in Denver show higher errors of commission rates and lower excess emissions identification rates, leading us to conclude that additional data are needed before a final recommendation can be made on using RSD to identify high emitting vehicles.*

Screening Out Low Emitters — The Greeley project provides a comprehensive test of the ability of remote sensing to serve as an effective clean screen tool. The project generated data on the emissions impact of screening vehicles based upon their remote sensing measurements. *IM240 data from the Greeley study indicate that RSD has potential of* *identifying low emitting vehicles. In order to accurately identify low emitting vehicles, at least two observations, each with low emission readings, must be observed. Data from single observations are not sufficient to accurately screen out a low emitting vehicle from its inspection requirements. Results from IM240 and RSD tests conducted in Denver agree with the Greeley results, adding to our confidence in RSD as a clean screen tool.*

Evaluate Other Mobile Source Control Programs — The Greeley study provides data to evaluate the effectiveness of oxygenated fuels and other vehicle emission control programs. The advantage of remote sensing is that it is relatively nonintrusive and, therefore, provides a fairly unbiased estimate of vehicle emissions. Counteracting this advantage, though, are the relatively wide range of emission levels observed at different sites. *A large number of observations from one of the sites indicate that oxygenated fuels result in significant CO emission reductions.* Using the same site, we could evaluate Greeley's basic I/M program. We have not yet attempted this evaluation.

1.3.2 Primary Goal No. 2 - Determine Cost and Cost-effectiveness of RSD

Another key goal of the Greeley program is to determine the cost and cost-effectiveness of a comprehensive RSD program. In order to meet this goal, several issues must be addressed.

- What are the true testing costs of a comprehensive RSD program?
- What are the administrative costs of a comprehensive RSD program?
- What is the cost and cost-effectiveness of an RSD based clean-screen and gross polluter identification program?

Testing Costs — The Greeley program provides data to determine true testing costs for a comprehensive RSD program. Testing costs depend upon the number of unique vehicle observations that can be made per van day, defined as one day of operation of an RSD van.

The Greeley program helps us determine the number of van days needed to cover the fleet the size of Greeley's. *It appears feasible to cover at least 80 % of the Greeley fleet with at least one observation using a single RSD van, two or more observations appear feasible on at least 70% of the fleet.* Assuming these coverage projections, we have derived overall staffing requirements for a comprehensive monitoring program.

Administrative Costs — The Greeley program helps us determine the administrative costs of a comprehensive RSD program. In addition, enforcement and quality assurance costs can be derived from the Greeley program. Due to the low numbers of high emitting vehicles that were procured for IM240 tests, we cannot determine the need for confirmatory tests, i.e. tests to confirm that high emitting vehicles identified by RSD must obtain confirmatory tests. *Depending on the RSD emission standards that are used to flag high emitters, confirmatory tests may not be needed before issuing failure notices to vehicle owners, but more data are needed before a final recommendation can be made.*

Cost -Effectiveness of RSD — Combining coverage estimates with estimated costs derived from the project allow us to project the costs and cost-effectiveness of a clean screen program. *Clean screening with RSD appears to be more cost-effective than testing all vehicles in a I/M program.*

1.4 Organization of This Report

The following section provides details on the design of the Greeley Pilot Program. The analysis of data collected in the Greeley Pilot Program is presented in Section 3. Conclusions that can be drawn from the data are then discussed in Section 4.

2.0 STUDY DESIGN

This section provides details on the test equipment, monitoring sites, and data collection procedures that were used in the Greeley Study.

2.1 <u>Test Equipment</u>

The two remote sensing devices (RSD) used in the Greeley Study were four-gas instruments that measured carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC) as propane, and oxides of nitrogen (NO_x). Each instrument was operated from its own support vehicle. The RSD instruments were arrayed in two different configurations during the study—the dual pass configuration and the single pass configuration. The position of other equipment—vans, generators, speed/acceleration bars, cameras, road cones and road work signs was essentially identical. Refer to Figures 2-1 and 2-2, which illustrate typical RSD equipment setup for single and dual pass setups respectively. At various times during the study the RSD units were used in tandem—the single pass unit always preceding the dual pass unit relative to traffic flow. The following paragraphs describe the RSD equipment used in the Greeley Study.

2.1.1 Vans

The vans used in the Greeley Remote Sensing Study were 1994 Dodge B350 one ton Maxivans. Both were fuel injected, V-8 powered, two-wheel drive units with automatic transmission. Both units had power steering, power brakes, air conditioning, and cruise control. The gross vehicle weight ratings (GVWR) were 9000 pounds.

Each van had a full length roof extension that allowed room for the operator to stand and move about. The interior were comfortably furnished with carpet, cabinets, counter top, lights, and electrical outlets. Each van contained a generator, computer, storage space for the source detector module (SDM), light source, speed bars, camera, span gas cylinder, road cones, road work sign, and other incidental equipment needed for remote sensing. The vans had Coleman roof-mounted air conditioner/heaters for interior climate control.

Figure 2-1

Figure 2-2

2.1.2 Generator

An Onan model 4.5BGDFB air-cooled, gasoline powered generator was mounted in a special enclosure in the rear of the van. The enclosure isolated the generator from the van's interior but was exposed to ambient air for cooling and ventilation. The generator weighed 204 pounds and had dimensions of 14 x 25 ¼ x 19 inches (H x L x W). The generator's output specifications were:

AC Volts: 120/240
Amps: 18.8
Phase: 1
Hertz: 60
Kilowatts: 4.5

The generator was operated through remote controls mounted inside the van near the operator's chair. Then generator had its own separate exhaust system that exited just aft of the passenger's side rear bumper. An 18-foot flexible, removable extension was used to carry generator exhaust away from the van.

2.1.3 IR and UV Sources

The infrared (IR) source used in this study was a commonly available igniter for a gas clothes dryer. It was a silicon carbide element manufactured and sold by General Electric as G.E. part number WE4X444. The IR source was mounted near the front the light source assembly, a structure with dimensions of 8 ½ x 6 ¾ x 22 inches (H x W x L). Also mounted within this enclosure was the deuterium lamp ultra violet (UV) source. A beam splitter installed ahead of the UV source allowed the collimation of UV and IR beams. The light source assembly was mounted on a horizontally and vertically adjustable tripod.

2.1.4 Span Gas

Scott Specialty Gases of San Bernardino California supplied calibration (span) gases used in this study. The calibration gas came as a blend in a 7 x 32-inch cylinder containing about 2000 psi of pressure. A cylinder this size lasted several months. An actual Certificate of Analysis form a cylinder of gas used during the study is reproduced below.

CRS Reg. Component No.	Component	Certified Analysis
124-38-9	Carbon Dioxide	12.9 PCT/M
631-08-0	Carbon Monoxide	3.01 PCT/M
10102-43-9	Nitric Oxide	2990 PPM/M
74-98-6	Propane	1490 PPM/M
7727-37-9	Nitrogen-Oxygen free	BAL
	NOX	3000 PPM
Analytical Accuracy +/_ 2%	Analysis Date 06/11/96	Project No. 01-79798 Cylinder No. BLM003296 Item No.0102C504310BL

2.1.5 Speed/Acceleration Bars

The speed and acceleration of remote sensed vehicles were measured with the aid of two speed /acceleration (S/A) bars. One bar was known as the S/A source bar, the other was the S/A detector bar. Both bars were constructed of 1¼ x 1 1/16-inch square aluminum tubing 72 inches in length. Both bars mounted two Bogen model numbers 3009 tripods 9 inches from the ends of the bar for bar support. The tripods gave both bars a height of 4¼ inches from the road's surface. The S/A source bar had two low-power lasers mounted one inch from each end of the bar. The lasers were horizontally and vertically adjustable. Power for the lasers came from three "D" cell alkaline batteries connected in series to make a supply voltage of 4.5 volts. The S/A detector bar mounted two laser detector assemblies one inch from each end of the bar. The detector assemblies were constructed of 1½ inch inside diameter aluminum tubing 5½ inches long. A lens to focus the laser on the detector was mounted 2¼ inches from one end of the tube. The detector was mounted in the other end of the tube, which was sealed with an aluminum plug. The detector assemblies were horizontally and vertically adjustable. The S/A detector bar also contained two vu meters, one mounted 2 3/8 inches from each end of the bar.

The meters were used in laser/detector alignment.

2.1.6 Camera

The camera used in the study was a Cohu solid state video camera equipped with a manually focused Fujinon TV zoom lens. The camera's shutter speed was set to 1/1000 of a second. The zoom lens' operational range was 12.5 to 75 feet. The camera was typically setup about 35 feet ahead (upstream) of the SDM. The camera, along with an RSTi circuit board to process and combine video data with speed/acceleration data before going to the computer, was contained in a sturdy 4½ x 9 x 17 inch housing (H x W x L). The housing mounted to a Bogen number 3006 tripod by way of a Bogen number 3029 camera mount. The camera was typically set at a height of about 46 inches off the road's surface.

2.1.7 Computer

The computer used to process and record data throughout the study was an IBM compatible "clone". The computer hardware was the off-the-shelf variety. Briefly the computer specifications were:

Microprocessor	486
Processor speed	66 megahertz
Operating system	DOS 6.2
RAM	8 megabytes
Cache	256 kilobytes
C: drive (hard drive)	340 megabytes
A: drive (floppy drive)	3.5 inch 1.44 megabytes
D: drive	Early: Hewlett-Packard optical disk 1.2-gigabyte capacity. Late: Iomega JAZ drive 1.0 gigabyte capacity.
Video display	640 x 480 VGA
Video card	Generic VGA
Keyboard	Typical 101 variety
Mouse	Not used

Computer software was MS-DOS based. Its function was to perform plume analysis, apply screening criteria to determine the validity of emissions data, merge emissions data with video, speed, acceleration, time, and sequence number data, and write the combined data to a file.

Additionally, the computer created files containing site and calibration data. A software upgrade late in the study improved the plume analysis function and added more data screening criteria flags, which improved data validity. At the time of the software upgrade the large optical floppy storage device was exchanged for a small removable hard drive (JAZ drive).

2.1.8 Source Detector Module (SDM)

Two SDM units housed in two separate vans were used during this study. SDM unit number 307 was used from December 1995 through January 1996. SDM unit 300 was added in September 1996 and used though the end of the study, March 1997. Both SDMs measured 8 ½ x 16 x 17 1/16 inches (H x W x L). Both units were mounted on aluminum tripods that were horizontally and vertically adjustable.

Unit 307 was a dual-pass remote sensing instrument. Its light source was mounted atop the SDM. The dual-pass unit used a lateral transfer mirror (LTM) to focus the IR and UV beams from the source back across the traffic lane into the SDM.

Unit 300 was a single-pass instrument. Its light source was placed across the traffic lane from the SDM and powered by an extension cord from one of the van's 120-volt outlets. Light sources were identical containing power supply, mirror, nondispersive IR and UV sources (NDIR and NDUV), and beam splitter.

Both SDMs were identical containing:

- optical benches,
- cooled PbSe detectors fitted with filters specific for CO2, CO, and HC,
- photomultiplier tube NOX detector,
- RSTi designed hardware/firmware.

2.2 Remote Sensing Monitoring Sites

Sites were selected for the Greeley program based upon the following general criteria:

- Provides good vehicle coverage.
- Provides valid RSD measurements.
- Provides a safe place to set up and take down equipment.
- Has absence of high accelerations and decelerations.
- Has absence of cold start conditions.

RSTi worked with local transportation authorities in Greeley and identified several sites on high volume streets. Most of the sites were located on surface streets although a majority of the observations were taken from the few freeway on-ramp sites.

The accuracy of remote sensing is extremely sensitive to vehicle operating mode. For vehicles to be in correct operating mode, engines and emission control systems should be at operating temperature, sufficient exhaust must be emitted to yield reliable data, and the vehicle should not be operating under high load conditions. Sites where vehicles are operating under cold start conditions, high acceleration conditions, or high deceleration conditions often do not produce accurate remote sensing measurements. RSTi selected freeway on-ramp sites where vehicles would be operating under mild acceleration and, therefore, would produce a relatively large plume of volume. RSTi avoided sites where vehicles were likely to be operating under cold start conditions. These sites include residential locations.

Figure 2-3 presents a map of Greeley showing the sites that were used through the end of October. Table 2-1 lists each site and describes its location. Two sites, G2 and G9, were located on on-ramps from 23rd avenue to Highway 34. One site (G1) was on an off-ramp at the same interchange and another (G6) was on an off-ramp connecting north bound Highway 85 to east bound Highway 34. The remaining sites were on surface streets. Appendix A contains more details on the different sites.

For the first six months, a majority of the observations were obtained at Site G2. Since then, a greater diversity of sites have been used, but the total number of observations is still dominated by site G2. A detailed log of the daily observations is contained in Appendix B. The log provides comments on why tests were not performed on some days.

Table 2-1 Description of Sites in Greeley

Site	Location
G1	Off-ramp of E.B. 34 to 23rd Ave.
G2	On-ramp of E.B. 34 from 23rd Ave.
G3	Intersection of W.B. 10th St. and N.B. 23rd Ave.
G4	N.B. 11th Ave. Just before the intersection of M. St.
G5	E.B. Reservoir Rd. At Glen Meadow Rd.
G6	Off-ramp from N.B. 85 to E.B. 34
G7	W.B. 16th St. at entrance to Aims Community College
G8	E.B. 10th St. just before intersection of 12th Ave (Downtown)
G9	On-ramp of W.B. 34 from 23rd Ave.
G10	W.B. 4th street between 37th and 38th avenue.
G11	E.B. 20th street 150 -200 feet east of its intersection with 59th avenue.

E.B.: East Bound; W.B.: West Bound

Figure 2-3 Location of RSD Monitoring Sites in Greeley

2.3 Data Collection

Data from a wide variety of sources were collected to meet the goals of the Greeley Pilot Remote Sensing Project. Following is a discussion of how each of the major types of data were collected.

2.3.1 Collection of Data from Remote Sensing Devices

Vehicle emissions and video image data from remote sensing devices were collected and processed by the Greeley program office. These data include the following:

- HC, CO, CO_2, and NO_x emissions;
- Speed and acceleration;
- License plate;
- Site location;
- Date and time of observation; and
- RSD unit number.

The first step in the data collection was receipt of vehicle emissions and image data from the remote sensing van. This information was written on to rewritable optical disks. Each disk can contain more than 9,000 vehicle emissions records and corresponding images.

A person employed by the Greeley program office was responsible for keying in the license plate that were recorded on the optical disks. The operator was only allowed to enter license plate numbers and was never given access to the emissions readings. The plate numbers were saved in the same record as the emissions readings; all emissions records for a specific site were saved in a single file. The Greeley operator maintained a daily log of site conditions. In addition, the operator was responsible for performing at least four calibrations per day on the remote sensing equipment.

2.3.2 Vehicle Registration Data

Using Envirotest's host computer that is maintained as part of the enhanced IM240 program, RSTi compiled a database of vehicle information including the following:

- Plate;
- Vehicle identification number (VIN);
- Model year;
- Make, fuel type; and
- Information on the registered owner.

RSTi then created a database of RSD results and vehicle registration data. The database was queried to identify vehicles that could be solicited as part of the IM240 program. In addition, the database was analyzed to evaluate vehicle coverage, characterize vehicle emissions, and evaluate sites.

2.3.3 IM240 Data

The Colorado Department of Public Health and Environment (CDPHE) established an IM240 test facility in Greeley. This facility was used to quantify emissions in grams per mile so that RSD data can be correlated to mass emissions data. RSTi provided a list of vehicles to be solicited for IM240 testing. About 800 vehicles observed by RSD were then procured for testing. The first 320 vehicles procured were selected from low and high RSD emission groups. This was done to evaluate the effectiveness of RSD identifying gross polluters and clean screen candidates. Halfway through the IM240 test program, the procurement process was changed with vehicles being randomly selected regardless of RSD emission level. This was done to assess the fleet emission impact of an RSD program.

CDPHE provided RSTi with the IM240 test results along with a vehicle identifier field, e.g., license plate. RSTi merged these data with vehicle registration and RSD data and maintained a database on IM240 and RSD test results.

2.3.4 Air Care Colorado Program Data

RSTi merged data from the Greeley program with IM240 data from the Denver enhanced program to identify IM240 and RSD emission levels for Denver vehicles that were observed in Greeley. It then developed a database of IM240 test results and RSD test results. The most recent RSD measurements before the IM240 test were matched up with the initial IM240 test results. RSD measurements after the IM240 test were matched up with the last IM240 results, for example, retest results.

3.0 ANALYSIS OF DATA COLLECTED IN THE GREELEY PILOT PROJECT

Since the inception of the Greeley Program, the following data has been collected and analyzed:

- Remote sensing observations (primarily using one van, but in some cases, using two vans operating at various sites in Greeley).
- Data on vehicles registered in Colorado -- make, model year, type, and owner address.
- Data on 720 IM240 tests that were conducted in Greeley on vehicles that had been seen by the RSD monitors.
- Data from RSD and IM240 tests conducted as part of the Enhanced program in the Denver area.
- Data from other remote sensing studies.

These data were compiled into a data base as they were received.. RSTi, with assistance from its subcontractors, dKC and Applied Analysis, analyzed these data. Results of this analysis are presented in this section. Because CO emissions are of greatest interest in this study, they are analyzed in greater detail than HC or NO_x emissions.

3.1 <u>Emission Trends Observed in Greeley Remote Sensing Project</u>

RSTi analyzed the data collected in the Greeley Pilot Program to determine general emission trends for the Greeley population. Following is a brief discussion of the trends that were observed.

3.1.1 Summary of Number of Observations

Table 3-1 summarizes the number of readings that have been taken in the December 1995 to May 1997 time period. During this period, 181 van days of operation resulted in 269,422 valid CO readings. RSTi was able to match 242,743 of these readings with license plates (and VINs) in the Colorado vehicle registration database. These matches translated into 95,719 unique vehicles; 33,770 of these vehicles were from Greeley. This equates to 72% of the Greeley fleet. We discuss projected coverage later; it appears that over 80% of the Greeley fleet can ultimately be covered.

Table 3-1 Summary of Number of Observations

Parameter	Number (As of May 27, 1997)
Valid CO	274,911
Valid HC	269,422
Valid NO_x	125,529
Valid Speed/Accel.	231,113
Matched with VIN	242,743
Observations of Greeley Regis. Vehicles	132,454
Unique VINs	95,719
Unique VINs Greeley	33,770
% of Greeley Fleet Observed[2]	72%
Number of Van Days	181

Figure 3-1 shows the number of observations broken down by model year and vehicle type. Note that the passenger car category used by the Colorado DMV includes many vehicles that EPA classifies as light-trucks, such as special-utility vehicles (SUVs) and mini-vans, so we show lower than expected percentages of light trucks.

[2]Percent of vehicles that have Greeley as their registered address.

Figure 3-1

3.1.2 Emission Trends Observed

Figures 3-2 and 3-3 present average CO and HC emissions by model year and vehicle type groups, broken down by lowest to highest emission decile (10^{th} percentile groups). For all model year groups, the dirtiest 10% are have much higher emission levels than the cleaner deciles. The results are similar to other studies of vehicle emissions, i.e., a majority of the vehicles have relatively low emissions and a small, but significant, percentage of the vehicles are gross emitters. Table 3-2 presents average RSD CO readings broken down by model year and vehicle type. Overall, vehicles with passenger plates have slightly lower RSD CO readings than light trucks. Figure 3-4 shows average CO emissions by model year for light trucks and passenger cars. The trend is expected — older vehicles have higher average emission rates than newer vehicles.

Figure 3-5 shows total CO emissions by model year and vehicle type. Vehicles in the 1981 to 1990 model year range contribute a majority of CO emissions. The greatest contribution comes from 1984 to 1986 model year vehicles. These estimates consider expected vehicles miles traveled (VMT) by model year. Figure 3-6 presents the cumulative distribution of vehicle emissions by model year. The newest five model years account for 5% of the emissions from cars and light trucks, even though they account for 25% of the observations.

3.1.3 Monthly CO Trends

The Greeley Program has collected RSD measurements since December 1995. Figure 3-7 shows average RSD levels at the most commonly used site, site G2, for weekly periods beginning in December. Note that emission levels appear to be lower during the oxygenated fuels season which corresponds with the mid-November through the end of February time period. In 1996, there was a sharp increase in average CO emissions at site G2 at the end of the oxygenated fuels period. In 1997, we did not observe a sharp increase in CO emissions after oxygenated fuels were no longer mandated. According to the State, many suppliers continued to use oxygenated fuels in the March-April time frame which could explain the lack of an observed increase in emissions.

Figure 3-2

Figure 3-3

Table 3-2 Average RSD CO by Plate Type and Model Year

Figure 3-4

Figure 3-5

Figure 3-6

Figure 3-7

3.1.4 Relationship Between Speed/Acceleration and Emissions

We attempted to identify vehicles with abnormally high or low accelerations and abnormally high or low speeds. We used the relationship shown on Figure 3-8 to define high and low accelerations. This relationship is being used by the California Bureau of Automotive Repair (BAR) to flag vehicles undergoing high accelerations or decelerations. So far we have used the 100% line to define vehicles with suspect accelerations and decelerations. We define low speed as being below 15 miles per hour and high speed as being above 50 miles per hour. Table 3-3 summarizes speeds and accelerations that have been observed. Overall, we found that less than 2% of the observations were taken during high acceleration events, while 5% of the observations were taken during low acceleration events.

Table 3-3 Frequency of Occurrence of High/Low Speeds and High/Low Accelerations

Speed Groups	Acceleration Group			Totals
	High	Low	Medium	
High	1048	1055	641	2744 (1.22%)
Low	30	19	1524	1573(0.70%)
Medium	2342	8827	209410	220579 (98.1)%
Totals	3420(1.52%)	9901 (4.40%)	211575(94.1%)	224896

RSTi's California program found similar percentages of vehicles operating under high deceleration conditions but much higher percentages of vehicles operating under high acceleration conditions. For example, approximately 5% of the valid RSD measurements from the California Program take place under acceleration conditions exceeding the criteria defined on Figure 3-8. On-ramps are used for most of the sites in California, so the greater percentages of high accelerations are expected. Table 3-4 summarizes the relationship between acceleration and CO emissions. We found that CO emissions were much higher for the high acceleration group. The high acceleration group averaged 1.61% CO while the medium acceleration group averaged 0.90% CO. Also, we found that the high acceleration group had much greater percentages of vehicles exceeding 1% and 2% CO thresholds.

Figure 3-8

Table 3-4 Effect of Acceleration on CO Emissions

Accel.Group	Count	Ave.%CO	% > 1%CO	%>2%CO	%<0.5%CO
High	3420	1.61	37%	29%	54%
Medium	211575	0.90	21%	13%	67%
Low	9901	0.95	21%	14%	68%

As expected, the high acceleration group had smaller percentages of vehicles with CO less than 0.5% than the medium acceleration group, 54% versus 68%. Vehicles in the low acceleration group had similar CO readings and percentages of vehicles exceeding CO thresholds than vehicles in the medium acceleration group. The differences were not significant. These results indicate that screening out observations taken during high accelerations may help lower the number of false failures, i.e. vehicles flagged by RSD as high emitters that actually meet State or federal emission standards.

Note, however, that less than 2% of the observations were taken under possible high acceleration conditions. The expense to accurately measure acceleration may not be justified in light of the fact that less than 2% of the observations would have been thrown out of the data set. From a clean screen perspective, the risk of including observations taken under high load conditions is low, since they will not lead to errors of omission. In the case of low acceleration (deceleration) conditions, internal quality control checks such as checking for maximum CO_2 (plume strength) probably will eliminate many of the questionable readings. Therefore, the readings that were observed under low acceleration conditions that were not thrown out because of internal quality control checks did not show a significant difference with the medium acceleration group. So, throwing out readings that were taken under high deceleration conditions may not improve the quality of the measurements significantly.

3.2 Relationship Between IM240 Emissions and Remote Sensing Measurements

As part of the Greeley program, the Colorado Department of Public Health and Environment (CDPHE) set up an IM240 lane at Aims College in Greeley. Over 700 vehicles that were observed by the remote sensing monitors were then procured for testing by the IM240 test. The IM240 test is a 240 second long mass emission test that generates emission results in grams per mile as opposed to concentration measurements generated by remote sensing devices (RSD). IM240 test results are considered to be a good indicator of the real world emissions from a vehicle. Therefore, data from the IM240 program can help us assess the effectiveness of RSD in identifying high emitting vehicles and screening out low emitting vehicles.

3.2.1 Description of the Greeley IM240 Sample

Vehicle Procurement -- Two different techniques were used to select vehicles that were then voluntarily procured for testing in the IM240 program at Aims College.

- Vehicles that had either low RSD emissions or high RSD emissions were solicited for testing. 320 vehicles were selected in this manner. These vehicles are referred to as **the non-random sample**.

- Vehicles that have been seen by the RSD monitors were randomly selected regardless of RSD emission level. 401 vehicles were selected in this manner. These vehicles are referred to as **the random sample**.

The focus of the analysis was on the random sample, since the non-random sample cannot be used to assess the fleet emissions impact of using RSD to screen out low emitters or identify high emitting vehicles. The non-random sample was used to supplement the random sample in the analysis of false failure rates, since it included more gross polluting vehicles (according to RSD).

Sample Characteristics -- Table 3-5 compares the random sample in the IM240 program with the overall RSD sample. The random sample was broken down according to the number of RSD hits that were observed on the vehicle. The following groups were used:

- Single hits only. This group includes those vehicles in the IM240 sample that were only seen once by the RSD monitors. In order to supplant the number of single hits, we also added to this sample the most recent RSD observation among the vehicles that were seen more than once. For example, if we had three RSD measurements on a vehicle in the IM240 program, we selected the RSD measurement closest to the IM240 test in order to simulate having only one hit on that vehicle.

- Vehicles that were observed two or more times by the RSD monitors. Of the 401 vehicles in the random sample, 324 were observed by the RSD monitors two or more times.

- All vehicles in the random sample.

When characterizing the IM240 samples, we used different criteria to deal with vehicles that had multiple RSD observations. In the case of potential clean screen candidates, we identified the maximum RSD level that was observed for each vehicle. Vehicles that had maximum RSD levels below given thresholds were considered clean screen candidates. For example, as shown on Table 3-5, 53% of the vehicles that were observed in the complete random sample had maximum RSD levels less than 0.5% CO. In the case of cutpoints to identify high emitting vehicles, we used the average RSD level per vehicle to determine if a vehicle exceeded the cutpoint. For example, 13% of the vehicles in the complete random sample had average RSD CO readings exceeding 1% CO.   We investigated other ways to select clean screen and high emitter candidates, but determined that the above techniques minimized false identification rates. Appendix C contains an analysis of alternative ways to select clean screen and high emitting candidates. The effectiveness of RSD in identifying high emitters and clean screen candidates is discussed later in this section.

As shown, the percentage of vehicles in the IM240 samples that were potential clean screen candidates was similar to the percentage of vehicles in the complete RSD sample of over 90,000 vehicles. On the other hand, the percentage of vehicles in the IM240 sample

Table 3-5
Characteristics of the IM240 Samples

Cutpoint Classification	Percentage in RSD Group			
	IM240 Random Sample			All Vehicles seen by RSD
	Single Hits[3]	2 or More Hits	All Vehicles	
CLEAN SCREEN CANDIDATES[4]				
< 0.5%	**83%**	**47%**	**53%**	**53%**
< 200ppm	**83%**	**34%**	**43%**	**50%**
<0.5% and <200ppm	**75%**	**26%**	**34%**	**37%**
HIGH EMITTERS[5]				
>1%	**9.8%**	**15%**	**13%**	**24%**
>2%	**6.4%**	**6.2%**	**5.2%**	**14%**
>3%	**4.8%**	**2.8%**	**2.2%**	**9%**
>4%	**2.6%**	**1.2%**	**1.0%**	**6%**
>1% and >200 ppm	**6.4%**	**14%**	**7.7%**	**18%**
>2% and >300 ppm	**4.0%**	**3.1%**	**2.5%**	**9.4%**
EXCEED IM240 FINAL STANDARDS - CO	**13%**	**14%**	**13%**	**NA**
EXCEED IM240 FINAL STANDARDS - HC/CO	**20%**	**20%**	**20%**	**NA**
SAMPLE SIZE	**401**	**324**	**401**	**95,719**

[3]Composed of vehicles seen only once plus the most recent RSD observation for multiple hits.

[4]Selection based on maximum RSD reading per vehicle.

[5]Selection based on average RSD reading per vehicle.

that were classified as likely high emitters because they exceeded a set RSD cutpoint, were much lower than the percent of vehicles in the complete RSD sample. For example, only 1% of the vehicles in the IM240 sample had average RSD emission levels exceeding 4%, while 6% of the vehicles in the complete RSD sample had average RSD emission levels exceeding 4%. Therefore, the random sample underestimates the true percentage of high emitters. Because owners who suspect their vehicles are high emitting historically have been reluctant to respond to procurement requests, this bias in the sample is expected. In fact, other studies where vehicles were voluntarily procured showed lower than average RSD levels. For example, in the California Pilot Program, vehicles that were procured for IM240 testing had average RSD emission levels that were approximately 30% lower than vehicles that were solicited but did not respond.

There are several implications of the bias in the sample.

- The random sample may underestimate the effectiveness of RSD in identifying high emitting vehicles, because there are lower than expected percentages of vehicles exceeding a given RSD cutpoint.

- The random sample may over predict the loss in I/M benefits from using RSD to clean screen vehicles, because a greater percentage of the total excess emissions could be contained in the clean screen portion of the sample (i.e., those with low RSD levels) if there are lower percentages of high polluting vehicles in the sample.

- The sample is better suited at assessing the use of RSD as a clean screen tool than as a means of identifying high emitting vehicles.

3.2.2 Observed Correlation Between IM240 and RSD Readings in Greeley

We analyzed the correlation between the IM240 results and RSD results. We correlated RSD results with surrogate CO and HC IM240 concentrations. Table 3-6 summarizes the assumptions used to calculate surrogate IM240 concentrations. Surrogate CO and HC concentrations were calculated using IM240 results for CO, CO_2, and HC. In the case of multiple hits, the average of the RSD results prior to the IM240 test was used in the analysis. We performed this analysis for different groups defined by the number of observations.

Table 3-7 summarizes the coefficient of determination (r^2) between surrogate CO concentrations and RSD CO concentrations for different subgroups of the random and complete data sets. A statistically significant, but relatively poor correlation, appears to exist between IM240 emissions and RSD emissions. The coefficient of determination (r^2) between the surrogate CO concentrations and RSD CO levels was greater for vehicles that were seen two or more times than vehicles that were seen only once. For example, note on Table 3-7 that the r^2 between RSD and IM240 concentrations for the single hit sample was 0.30, while for the sample composed of two or more hits, the r^2 was 0.53. There were a wide range of r^2 values among the different sites that had an adequate number of observations to perform the regression analysis. Also, the r^2 by site was greatest for the multiple observations than the single observations, except for site G10 where both groups showed a poor correlation.

Previous studies have correlated overall IM240 emissions with RSD concentrations. Generally, they found much poorer correlations. By converting IM240 results in grams per mile to a surrogate concentration, our methodology has improved the relationship between RSD emissions and IM240 emissions. The correlation for HC emissions was much worse than the correlation for CO. HC results are presented in Appendix D along with scatter plots showing the relationship between surrogate IM240 concentrations and average RSD concentrations.

3.2.3 Effectiveness of RSD in Screening Out Clean Vehicles

Results of Greeley Study — Using data from the Greeley IM240 program in conjunction with matched RSD measurements, we assessed the ability of RSD to screen out clean vehicles. In the case of vehicles with two or more RSD hits, we tested the maximum value against clean screen criteria. We investigated testing the average and minimum values against clean screen criteria, but found excessive errors of omissions[6] with these parameters.

[6]Clean screen candidates that fail the IM240 test.

Table 3-6 Estimation of Surrogate IM240 Concentrations

Estimation of IM240 CO%:
1. 'The assumption for a dilution factor of 1 is: 13.4% = HC% (single Carbon) + CO% + CO2%
2. Assume IM240 raw exhaust has volume of V cubic feet, then gas% = (gas grams/gas gr per cu ft at STP) / V
3. At standard temperature & pressure: HC = 16.33 gr/cu ft, CO = 32.97 gr/cu ft, CO2 = 51.81 gr/cu ft, NOX = 54.16 gr/cu ft
4. 13.4% = (HCgr / HCgpcf + COgr / CO gpcf + CO2gr / CO2 gpcf) / V
5. 1 / V = 13.4% / [(HCgr / HCgpcf + COgr / CO gpcf + CO2gr / CO2 gpcf)]
6. Estimated CO% = (COgr/CO gpcf) *13.4% / [(HCgr / HCgpcf + COgr / CO gpcf + CO2gr / CO2 gpcf)]
7. Estimated CO% = 13.4 * CO gr * 0.03033 / (HC * .061237 + CO*0.03033+CO2 *.01930)
8. Estimated HC% Hexane = 13.4 * HC gr * .061237 / (HC * .061237 + CO*0.03033+CO2 *.01930) / 6
9. Estimated NOX% = 13.4 * NOX gr * 0.018464 / (HC * .061237 + CO*0.03033+CO2 *.01930)

Table 3-7 Correlation Between RSD and IM240

Sites	**Correlation Between RSD CO and IM240 CO**[7]	
	Single Hits	**2 or More Hits**
All	**0.30**	**0.53**
G2	**0.26**	**0.49**
G5	**0.29**	**0.36**
G7	**0.53**	**0.65**
G9	**0.17**	**0.69**
G10	**0.14**	**0.08**

[7] Surrogate IM240 Concentrations

We investigated clean screen effectiveness for three cutpoint scenarios.

- Vehicles with maximum CO readings less than 0.5% CO.
- Vehicles with maximum RSD HC readings of less than 200 ppm HC.
- Vehicles with maximum CO less than 2% and HC less than 200 ppm.

We analyzed the above cutpoints for three groups of vehicles:

- All observed matches between IM240 and RSD;
- Vehicles that were observed only once by the RSD monitors; and
- Vehicles that were observed two or more times by the RSD monitors.

We evaluated the impact of clean screening on the basis of excess emissions loss. We defined excess emissions as IM240 emissions above EPA's final standards. Table 3-8 presents the results of the analysis. Figure 3-9 shows the relationship between number of hits and clean screen accuracy as determined from the data from the Greeley Program. For this chart, we are using a clean screen cutpoint of 0.5% CO.

It appears that single RSD observations do not provide a good basis for clean screen. Vehicles in the random sample that would have been exempted based upon single hits using the above clean screen cutpoints contained 25 to 32% of the excess CO emissions and 56 to 65% of the excess HC emissions. On the other hand, clean screen candidates based upon two or more hits contained only 3 to 5% of the excess CO emissions (depending on cutpoint) and 5 to 8% of the excess HC emissions. Up to 47% of the fleet that was seen two or more times would be clean screen candidates.

In the AirCare program, vehicles less than 4 years old are exempted from inspection requirements. An RSD based clean-screen program could expand the number of vehicles eligible to be exempted. To address the impact of inspecting older model year vehicles based on RSD CO and HC levels, we repeated the above analysis on 1990 and older vehicles only. Results based on two or more hits in the random sample are summarized on Table 3-9. Trends were similar to the overall random sample — a 0.5% clean screen cutpoint would exempt 35% of the 1990 and older model year vehicles with a 7% loss in excess HC identified and 4% loss in excess CO identified.

Table 3-8 Evaluation of Clean Screen with RSD

Parameter	# of Hits	Clean Screen Criteria (Max RSD Value[8])		
		<.5	<200ppm	<.5/200ppm
% of Vehicles Exempted[9]	Single	82.86%	83.33%	74.52%
	2 +	46.91%	34.26%	26.23%
	All	52.87%	43.14%	33.92%
%IM240 CO Fails Exempted	Single	60.00%	56.36%	45.45%
	2 +	13.33%	8.89%	4.44%
	All	19.23%	19.23%	11.54%
%IM240 HC/CO Fails Exempted	Single	65.12%	62.79%	51.16%
	2 +	18.75%	9.38%	4.69%
	All	27.85%	21.52%	13.92%
%Excess CO Loss	Single	32.01%	36.05%	25.57%
	2 +	4.87%	3.80%	3.27%
	All	9.00%	11.35%	7.73%
%Excess HC Loss	Single	64.79%	59.09%	55.94%
	2 +	7.76%	4.75%	4.54%
	All	11.22%	10.39%	8.49%

[8] Max value used for multiple hits.

[9] % of vehicles meeting clean screen criteria

Figure 3-9

Table 3-9 — Evaluation of Clean Screen with RSD - Random Sample
1990 and Older Vehicles Seen Two or More Times

Evaluation Parameter	Screening Criteria		
	<0.5%CO	<200ppm HC	<0.5 &<200ppm HC
% of Vehicles Exempted	35%	26%	18%
% IM240 HC/CO Fails Exempted	19%	10%	5%
% IM240 CO Fails Exempted	13%	10%	5.1%
% Excess HC Loss	7.4%	4.9%	4.6%
% Excess CO Loss	4.1%	3.9%	3.4%

IM240 fail rates: Random: 32%

We investigated less stringent cutpoints for clean screen determination. We found that a 1% CO cutpoint when applied to the maximum reading per vehicle causes a 6% loss of excess CO identified, which would be more than adequate for a maintenance area like Greeley. 65% of the vehicles (with 2 or more hits) would be eligible for clean screen under this scenario.

Trends by Site — We analyzed clean screen trends by site using the most recent remote sensing measurement by site prior to the IM240 test. We were investigating the theory that sites where vehicles are operating under load will provide more reliable remote sensing measurements for clean screen determination. We had adequate data to perform this analysis for five sites: G2, G5, G7, G9, and G10. Results of the analysis are presented on table 3-10. As will be discussed in the next section, sites G2, G7, and G9 had higher accelerations than sites G5 and G10. As shown on table 3-10, a smaller percentage of the excess emissions was screened out at sites G2, G7, and G9 than at sites G5 and G10, based on single RSD observations. Still, single hits at the high load sites were inferior to multiple hits (at all sites) in making a clean screen determination.

Table 3-10 Effectiveness of RSD as a Clean-Screen Tool ─ Results by Site

Parameter	Site	IM240 Fail Rate	Clean Screen Exemption Criteria		
			<.5	<200ppm	<.5 and 200ppm
% of Vehicles Exempted	G2	19.57%	73.19%	70.21%	59.15%
	G5 *	18.45%	84.47%	79.61%	74.27%
	G7	30.68%	80.68%	77.27%	69.32%
	G9	14.46%	78.31%	87.95%	73.49%
	G10 *	17.72%	88.61%	91.14%	83.54%
%IM240 HC/CO Fails Exempted	G2		52.17%	52.17%	39.13%
	G5 *		71.05%	60.53%	60.53%
	G7		59.26%	66.67%	44.44%
	G9		33.33%	41.67%	16.67%
	G10 *		71.43%	71.43%	57.14%
%Excess CO Loss	G2		21.46%	26.77%	18.79%
	G5 *		51.76%	50.96%	50.96%
	G7		13.62%	31.08%	11.25%
	G9		19.00%	8.24%	1.14%
	G10 *		39.91%	42.06%	19.27%
%Excess HC Loss	G2		16.57%	17.68%	13.79%
	G5 *		77.77%	76.81%	76.81%
	G7		35.04%	36.29%	24.86%
	G9		3.39%	3.88%	1.01%
	G10 *		17.81%	79.72%	6.19%

* Vehicles were operating under light loads at these sites.

Results of Denver Tests — We analyzed data from the Denver RSD program to determine if they showed the same trends concerning clean screen effectiveness as was shown in the Greeley data. RSTi, on a quarterly basis, performs remote sensing tests on vehicles in the Denver area. Data from this remote sensing program were matched by license plate and VIN with IM240 data from the Denver area to create a database of RSD and IM240 results.

Two RSD tests prior to the IM240 test were found for 847 vehicles. IM240 results were found on 5293 vehicles that were seen by RSD only once and were operating under load[10].

Table 3-11.1 presents the impact of a clean screen program as determined with Denver RSD and IM240 data. The data again show that two or more hits provides a better basis for clean screen than single hits alone. For example, With 0.5% CO and 200 ppm HC cutpoints, 48% of vehicles seen twice are clean screened while retaining 94% of the potential excess CO emissions reductions and 91% of the potential excess HC emissions reductions. This is similar to the results of the Greeley study. With 0.3% CO and 200 ppm HC cutpoints, 40% of vehicles are clean screened, while retaining 95% of the potential excess emissions reductions. A 200 ppm HC and 0.5% CO clean screen cutpoint, when applied to vehicles that were seen only once by the RSD monitors would result in an approximately 20% loss of CO emission benefits and a 30% loss of HC emission benefits according to the IM240 test.

Table 3-11.1 — Effectiveness of Clean Screen Based on Denver RSD and IM240 Data

Parameter	Number of Hits	Clean Screen Criteria	
		<0.5%CO & 200 ppm HC	<0.3%CO & 200 ppm HC
% of Vehicles Exempted	Single	74%	59%
	Double	52%	48%
False Passes (% of All Vehicles)	Single	7.8%	5.1%
	Double	4.2%	3.4%
% Excess CO Loss	Single	22%	19%
	Double	6%	5%
% Excess HC Loss	Single	30%	18%
	Double	9%	6%

[10]We used the criteria that the average of the vehicle loads must exceed 1.5 x the standard deviation of the vehicle loads.

We analyzed two additional data sets from the enhanced program to further evaluate the impact of a clean screen program

- Data from vehicles tested in the Denver enhanced IM240 program that were matched with Greeley RSD observations.

- Data on vehicles that passed by an RSD van in Boulder just after obtaining an IM240 test. In this case, RSTi set up unit 300 for four days outside the Boulder IM240 test station.

These data agreed with the Greeley results, but the sample size of failed vehicles derived from the above data sets were too low to draw any firm conclusions.

Results of Arizona Clean Screen Study -- The Arizona Department of Environmental Quality investigated the impact of a clean screen program on the emission reductions from the IM240 program that is operated in the Phoenix area. Arizona contracted with Hughes to perform tandem remote sensing measurements outside one of the state's IM240 facilities. Hughes also collected remote sensing data from six vans that were deployed at various locations throughout the Phoenix metropolitan area. Data from the measurements taken outside the IM240 lanes were used to construct a statistical model to select clean screen candidates. Data from the six vans operated throughout the Phoenix metropolitan area were used to validate the statistical model.

Radian International was contracted by Arizona Department of Environmental Quality to develop the statistical models and evaluate the effectiveness of a clean screen program. Table 3-11.2 summarizes the effectiveness of clean screen based only on RSD results. The HC and CO impacts are similar to the Greeley study using 0.5% CO and 200ppm HC screening criteria. The Arizona study found that 29% of the vehicles could be exempted with a loss of 10% of the excess HC identified and 4% of the excess CO identified. The Greeley study found that 27% of the vehicles could be exempted with a loss of 5% of the excess HC identified and 3% of the excess CO identified.

Table 3-11.2
Performance Summary of Clean Screen Model for Arizona
Model Predictor Variables: RSD CO, RSD HC

Expected Screening Percentage[a]	Percent of Total Excess Emissions Contained in Clean Screen Group		
	Exhaust HC	CO	NO_x
29%	10%	4.2%	21%
50%	21%	8.5%	40%

[a] Percentage of vehicles with eligible RSD readings included in Clean Screen.

Radian's final model predicted the probability of a vehicle being clean based upon its historical IM240 failure rate and its RSD measurements. This model was able to screen out up to 50% of the vehicle population from I/M requirements with a loss of 3.1% of the excess CO emissions, 2.4% of the excess HC exhaust emissions, and 5.6% of the excess NO_x emissions.

Summary — Data from the Greeley study indicate that remote sensing can be used to identify vehicles that could be exempted from inspection requirements. It appears that two or more RSD observations are needed before a valid clean screen determination can be made. Data from RSD and IM240 tests in Denver and Arizona also show that remote sensing can be used to accurately clean screen vehicles.

3.2.4 Effectiveness of RSD in Identifying High Emitting Vehicles

Results of Greeley Study -- We analyzed the IM240 and RSD matches in the random data set using the following cutpoint scenarios:

- Average RSD greater than 1% CO;
- Average RSD greater than 2% CO;

- Average RSD greater than 3% CO;
- Average RSD greater than 4% CO;
- Average RSD greater than 1% CO and 200 ppm HC; and
- Average RSD greater than 2% CO and 300 ppm HC.

In the case of vehicles with two or more RSD hits, we tested the average value against high emitter cutpoints. We investigated testing the maximum and minimum values against the high emitter cutpoints, but found excessive errors of commissions[11] with these parameters. Results of the analysis are summarized on Table 3-12. Figures 3-10 and 3-11 compare the effectiveness of RSD in terms of excess CO emissions identified and false fail rates. We defined excess emissions as IM240 emissions above EPA's final standards. Errors of commission (false failures) are expressed in terms of percent of vehicles exceeding RSD cutpoints that passed final IM240 cutpoints.

The data indicate that two or more RSD observations on the vehicle provide better accuracy than single observations in terms of false failures. It may be possible to use more stringent cutpoints, e.g. 4% CO instead of 3% CO, if high emitters are identified based on single hits versus multiple hits, in order to minimize false fail rates. Using a combination of HC and CO cutpoints does not provide appreciably greater accuracy over a CO cutpoint alone in terms of excess emissions identification rates or false failure rates. For example, about 3% of the vehicles will fail either a 3% CO cutpoint or the combination of the 2% CO and 300 ppm HC cutpoint. As shown on Table 3-12 , both of these cutpoint combinations identified about the same amount of excess HC and CO and had similar false failure rates.

Data from the non-random sample that was discussed in Section 3.2.1, showed higher false failure rates than the random sample for the 3% and 4% RSD cutpoints. In the non-random sample, 13% of the vehicles that exceeded an RSD cutpoint of 3% CO passed the IM240 test for HC and CO; 12% of the vehicles that exceeded an RSD cutpoint of 4% CO, passed the IM240 test for HC and CO.

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[11]High emitter candidates that pass the IM240 test.

Table 3-12 — Summary of RSD as a Gross Polluter Identification Tool --Results of Greeley Study — (Single Hits / 2 or More Hits)

Cutpoint *	% of Fleet Above Cutpt.	% of IM240 Fails Identified		% False Fails (% of failed vehicles)		% Excess HC Identified	% Excess CO Identified
		CO only	HC or CO	CO only	HC or CO		
>1% CO	9.8% / 15%	35% / 56%	27% / 47%	54% / 50%	44% / 40%	33% / 79%	62% / 84%
>2% CO	6.4% / 6.2%	27% / 29%	21% / 25%	44% / 35%	33% / 20%	26% / 65%	50% / 57%
>3% CO	4.8% / 2.8%	24% / 18%	19% / 14%	35% / 11%	20% / 0%	22% / 60%	43% / 43%
>4% CO	2.6% / 1.2%	15% / 6.7%	12% / 6.2%	27% / 25%	9.1% / 0%	15% / 14%	29% / 26%
>1% CO and 200 ppm HC	6.4% / 14%	29% / 53%	22% / 45%	41% / 48%	30% / 37%	32% / 79%	57% / 83%
>2% CO and 300 ppm HC	4.0% / 3.1%	20% / 18%	15% / 16%	35% / 20%	24% / 0%	23% / 60%	43% / 47%

* For vehicles with 2 or more hits, average RSD levels must exceed cutpoint.

Trends by Site — Table 3- 13 shows the effectiveness of remote sensing measurements at different sites in identifying high emitting vehicles. The results shown on Table 3-13 are based on matches between the most recent remote sensing observation by site and the IM240 observation. Site G2, where are over half of the observations were made in the Greeley study, showed inferior performance to most of the other sites in terms of false fail rates, but better performance in terms of % excess emissions identified. However the number of IM240 and RSD matches were limited even for site G2, so we cannot draw firm conclusions concerning the effectiveness of different sites.

Figure 3-10

Figure 3-11

Table 3-13 Effectiveness of RSD in Identifying High Emitting Vehicles — Results by Site

Parameter	Site	Gross Polluter Identification Criteria						
		>1	>2	>3	>4	>300	>1%/200	>2/300
% of Vehicles	G2	16.60%	11.49%	8.09%	4.68%	17.87%	12.34%	6.38%
	G5	9.22%	5.83%	4.37%	3.88%	13.59%	7.77%	5.34%
	G7	10.23%	5.68%	3.41%	1.14%	15.91%	6.82%	3.41%
	G9	8.43%	2.41%	2.41%	2.41%	4.82%	3.61%	0.00%
	G10	7.59%	5.06%	5.06%	5.06%	3.80%	2.53%	1.27%
%IM240 Fail HC/CO	G2	34.78%	30.43%	26.09%	17.39%	30.43%	30.43%	19.57%
	G5	26.32%	21.05%	18.42%	15.79%	31.58%	26.32%	21.05%
	G7	25.93%	14.81%	11.11%	3.70%	18.52%	18.52%	7.41%
	G9	41.67%	16.67%	16.67%	16.67%	16.67%	25.00%	0.00%
	G10	28.57%	21.43%	21.43%	21.43%	14.29%	14.29%	7.14%
%False Fail HC/CO	G2	58.97%	48.15%	36.84%	27.27%	66.67%	51.72%	40.00%
	G5	47.37%	33.33%	22.22%	25.00%	57.14%	37.50%	27.27%
	G7	22.22%	20.00%	0.00%	0.00%	64.29%	16.67%	33.33%
	G9	28.57%	0.00%	0.00%	0.00%	50.00%	0.00%	0.00%
	G10	33.33%	25.00%	25.00%	25.00%	33.33%	0.00%	0.00%
%Excess CO	G2	71.76%	57.15%	55.32%	42.20%	49.74%	70.56%	42.01%
	G5	48.24%	46.37%	44.76%	42.78%	46.61%	48.24%	46.37%
	G7	78.95%	46.15%	27.33%	12.99%	55.45%	66.55%	25.09%
	G9	77.70%	30.62%	30.62%	30.62%	50.75%	73.48%	0.00%
	G10	60.09%	37.30%	37.30%	37.30%	39.62%	37.30%	37.17%
%Excess HC	G2	79.75%	70.17%	69.03%	60.45%	73.90%	79.01%	64.44%
	G5	22.04%	19.98%	19.06%	15.92%	21.13%	22.04%	19.98%
	G7	57.71%	29.12%	15.72%	7.58%	47.91%	53.53%	19.83%
	G9	94.93%	83.32%	83.32%	83.32%	5.97%	93.39%	0.00%
	G10	82.19%	9.21%	9.21%	9.21%	8.54%	8.66%	7.91%

Results of Denver Tests -- Using data from the Denver remote sensing tests coupled with IM240 test results, we analyzed the effectiveness of remote sensing as a method to identify high emitting vehicles. Table 3-14 summarizes the effectiveness of remote sensing in identifying high emitters based upon the Denver IM240 and remote sensing data. We found that remote sensing devices showed worse performance in the Denver tests than in the Greeley tests in identifying high emitting vehicles. False failure rates (errors of commission) were much higher for a given cutpoint in the Denver data set than in the Greeley data set. In addition, excess emissions identification rates were lower for given cutpoint in the Denver data set than in the Greeley data set.

Vehicles in the Denver data set had already received at least one IM240 test, so the sample could show a different response to remote sensing than the Greeley sample where vehicles had only been tested by the basic BAR90 test. In addition, some owners may tune-up or repair their vehicles prior to their scheduled emission test, and therefore be classified as an RSD false failure, when, in fact they were correctly identified. This would explain the disagreement with the Greeley results in using RSD to identify high emitting vehicles and the agreement with the Greeley results in using RSD as a clean screen tool. Because of the small number of high emitters procured in the Greeley study and the fact that Denver results differ significantly from Greeley results, additional data are needed before a strategy for using remote sensing to identify high emitting vehicles can be finalized.

Results of Arizona Tests -- The effectiveness of RSD as a tool for identifying high emitting vehicles also was investigated as part of the Arizona Clean Screen Study. The results are somewhat similar for CO to the results of the Greeley study. The dirtiest 5% contain 48% of the excess CO emissions. However, unlike the Greeley study, the dirtiest 5% contained only 25% of the excess HC emissions. Like data from the Denver area, the discrepancy could be due to the enhanced I/M program that has been in place for several years in the Phoenix area.

Table 3-14 — Summary of RSD as a Gross Polluter Identification Tool — Results of Denver RSD and IM240 Tests — (Single Hits / Double Hits)

Cutpoint[12]	% of Fleet Above Cutpt.	% False Fail (% of Fails)	% Excess HC	% Excess CO
>1% CO	14% / 18%	66% /76%	41% /48%	51% /70%
>2% CO	8.0% / 8.6%	63% / 72%	31% / 25%	43% / 51%
>3% CO	5.2% / 2.6%	59% / 52%	25% / 13%	35% / 33%
>4% CO	3.2% / 1.0%	57% / 33%	18% / 8%	25% / 21%
>1% CO and 200 ppm HC	7.7% / 11%	60% / 79%	32% / 22%	36% / 52%
>2% CO and 300 ppm HC	3.8% / 4.7%	56% / 73%	20% / 15%	22% / 35%

Summary -- Data from the Greeley study indicate that RSD might be an effective compliment to an existing I/M program by identifying gross polluting vehicles between inspection cycles. In addition, it might serve as an effective stand alone I/M program, particularly for a maintenance area such as Greeley. When likely coverage is considered, an RSD based I/M program might achieve 30 to 40% of the benefits of a full I/M program where all vehicles are tested. This by requiring the inspection and repair of less than 3% of the vehicle fleet. These emission reductions might be sufficient for maintaining compliance with the NAAQS for CO. Data from Denver remote sensing and IM240 tests show much lower potential for RSD as a stand- alone emission reduction measure, but there are concerns over the applicability of Denver data in area that does not yet have an IM240 test program. More data are needed to resolve the discrepancies between the Greeley results and Denver results before a final recommendation can be made on the use of RSD as a tool to identify high emitting vehicles.

[12] Pass/fail based on average for multiple hits.

3.3 Site Performance Evaluation

RSTi, working with local transportation authorities in Greeley, set-up several sites on relatively high volume streets and access roads. We analyzed data for each site to assess its performance with the goal of identifying guidelines for selecting future sites. There are three main criteria that characterize a good site:

- A large number of vehicles pass by the site;
- The site results in a high percentage of valid emission measurements (i.e. the exhaust plume is easily observed); and
- Vehicles passing by the site are not experiencing high or low accelerations, high or low speeds, and are not operating in cold start conditions .

Using these criteria, we evaluated the sites that have been used in the Greeley study.

Table 3-15 provides summary statistics on the following:

- Number of valid tests;
- % of valid tests (CO, HC, NOx);
- % of readings taken under high acceleration or deceleration conditions.
- Correlation of readings with IM240

Percent of Valid Emission Tests — Readings are declared invalid if they do not meet RSTi's criteria for maximum CO_2 (the maximum absolute value for CO_2 that was observed) or there is too much scatter in CO versus CO_2 regression line. Overall, 76% of the readings had at least a valid value for CO. The percent of valid CO observations was consistently lower for sites located on off-ramps, G1 and G6. Vehicles on off-ramps often are decelerating at a fairly rapid rate. These conditions often do not produce a large exhaust plume because the engine throttle is closed, so the lower percentage of valid observations is expected. The site with the greatest percentage of high decelerations (G1) had the lowest percentage of valid NO_x measurements.

Table 3-15 Summary of Site Statistics

Site	# of Days	Valid Tests per Hour	# of Tests / % of Total	% Valid CO	% Valid HC	% Valid NO_x	% High Accel.	% Low Accel.	Average % CO	R^2 With IM240[13]
G1	5	167	4319/3.2%	63%	54%	18%	0.5%	59.3%	0.56%	NA
G2	72	297	129438 /58%	79%	72%	47%	1.9%	1.9%	1.08%	0.49
G3	5	163	4211/1.89%	78%	69%	40%	9.9%	6.7%	0.76%	NA
G4	1	180	949/0.43%	71%	70%	37%	NA	NA	0.95%	NA
G5	26	245	33018/15%	69%	57%	22%	0.7%	4.5%	0.73%	0.36
G6	2	153	1349/0.61%	62%	53%	34%	0.7%	20.3%	1.20%	NA
G7	8	72	2468/1.1%	79%	71%	39%	1.6%	3.7%	0.86%	0.65
G8	1	216	1684/0.76%	56%	33%	21%	0.9%	5.9%	1.16%	NA
G9	25	175	26778/12%	76%	72%	45%	1.7%	7.2%	0.77%	0.69
G10	13	189	15475/7.0%	75%	67%	16%	0.6%	7.8%	0.51%	0.08
G11	3	154	2990/1.3%	61%	55%	25%	0.8%	0.2%	0.53%	NA
All	161	239	222,761	76%	68%	39%	1.5%	4.4%	0.94%	0.53

NA — Insufficient number of vehicles to establish correlation

[13] Average of 2 or more hits, CO readings

Hourly Test Volume — Table 3-15 also shows the number of tests per hour broken down by site. Average hourly observations were much greater for sites G2 (the on-ramp to east bound 34) and G5 (east bound Reservoir Road At Glen Meadow Road) then for the other sites. G9, which was at another on-ramp to Highway 34, recorded much lower numbers of readings per hour.

Speed and Accelerations — We investigated speed and acceleration readings for the different sites. Sites with erratic speed vs acceleration profiles or with too many vehicles operating in high acceleration or deceleration conditions may be generating valid yet unreliable emission readings. None of the sites, including G2 and G9 which were located on on-ramps, had significant percentages of vehicles exceeding the upper acceleration limits. At site G1, which was an off-ramp, a significant fraction of the fleet was decelerating. Based upon the speed versus acceleration criteria that were shown in the quarterly report, 59% of the observations at G1 fell into the high deceleration category. Another off-ramp site, G6, also had a greater than average percentage (20.3%) of vehicles undergoing high deceleration. RSTi could not set up the speed bars at Site G4, so there is no speed or acceleration data for this site.

Figures 3-12 and 3-13 show percentile distributions of speeds and accelerations for each of the sites in the Greeley Program. Note that there is a significant difference in the speeds and the accelerations by site. As expected, the sites located on off-ramps, i.e. G1 and G6, had significant percentages of observations under deceleration conditions. For example, 98% of the observations for Site G1 were under deceleration conditions. None of the sites encountered high percentages of vehicles operating under high acceleration conditions. At site G2, which collected about 2/3 of the RSD measurements in Greeley, vehicles generally were operating at moderate speeds and under a mild acceleration condition. Figure 3-14 plots acceleration vs. speed at the different sites. Sites G2, G7, and G9 have the most uniform distributions. Accelerations were erratic at several sites.

Emission Levels by Site — Figure 3-15 shows the distribution of CO emissions by site. There is a large range in the distribution of CO levels among the nine sites that were analyzed especially above the 60th percentile level. Similarly, average CO varies significantly by

Figure 3-12

Figure 3-13

Figure 3-14

Figure 3-15

site. These data indicate that it may be necessary to establish site specific criteria for identifying high emitting vehicles or clean screen candidates based upon RSD measurements. Site G1, which observed vehicles primarily under deceleration conditions, appeared to have significantly lower CO levels than the other sites. This could indicate that deceleration conditions lead to unrealistically low CO levels, possibly due to a fuel shut off mechanism in the vehicle. Many vehicles built since 1980 have such devices to prevent excessive hydrocarbon emissions during deceleration conditions. There is not a clear trend in the speed or acceleration characteristics among the sites showing the higher emission levels.

Correlation with IM240 — The correlations between RSD and IM240 readings vary significantly among the different monitoring sites. The highest correlations were at sites where vehicles usually were accelerating while they passed by the monitor. The small number of observations for each site limits conclusions that can be drawn on the correlations.

In section 3.2, we discussed the effectiveness of remote sensing measurements at different sites in identifying high emitting vehicles and clean screen candidates as determined by the IM240 test. We found that sites where vehicles usually were operating under load provided more reliable RSD measurements from a clean-screen perspective. We did identify any significant trends in the performance of the different sites in identifying high emitting vehicles.

Summary — Following are the primary conclusions we have drawn concerning selecting sites that provide reliable emission readings:

- Sites where vehicles are accelerating moderately provide a greater percentage of valid RSD readings;

- The accuracy of RSD readings in predicting vehicles with high IM240 emission levels was greater for sites where vehicles were consistently under load over a range of speeds;

- On-ramps can be good sites to monitor large numbers of vehicles under moderate loads.

3.4 Analysis of Vehicle Coverage

3.4.1 Summary of Overall Coverage

Table 3-16 presents a break down of unique vehicle observations by legal city. Less than half (48%) of the tests were performed on vehicles registered in Greeley. In terms of unique vehicles tested, about a third of the vehicles tested were registered in Greeley. Table 3-17 breaks down observations by number of readings per vehicle. As expected, there were more multiple observations on vehicles registered in Greeley than those registered in other cities. As of May 28, 1997, 72% of the Greeley vehicle population has been observed by the remote sensing device. Of those observed, 62% were observed more than once.

RSTi tabulated the number of unique vehicles observed by registered address as indicated by census block groups, so that coverage could be analyzed within the Greeley area. Figure 3-16 shows the results of this exercise. Coverage appears to be fairly uniform.

Figure 3-17 shows a comparison of the percent of vehicles covered by one or more, two or more and three or more observations. Initially, a much greater fraction of the fleet was covered by one or more observations than two or more observations. However, as the program progressed, more vehicles are covered by two or more observations. By the end of the data collection phase, 45% of the vehicles had at least two valid readings by the remote sensing device; 30% had three or more valid readings. Also at the end of the data collection phase, the percent of vehicles covered by two or more observations appeared to be growing at about the same rate as the percent of vehicles covered by one or more tests. This indicates that, by the end of a van-year, there should be two or more observations on a majority of the vehicles. Note that the curves defining the percent of vehicles covered by one or more observations and two or more observations have straightened out. This indicates that coverage may steadily grow as the program continues, so eventually over 80% of the Greeley fleet will be covered.

Table 3-16 Breakdown of Coverage by City

Table 3-17 Number of RSD Observations

Figure 3-16 Greeley: Active Gas Vehicles and Fraction Measured

Red = Number Registered; Green = Number Seen by RSD

Figure 3-17

To date, over 91,000 unique vehicles have been observed by a single Greeley RSD monitors, 95,000 unique vehicles have been observed by both monitors. Two or more observations have been made on about 42,000 unique vehicles. As indicate below by the results of the Greeley Tag survey, it appears that many vehicles are consistently operated in Greeley but registered outside of the Greeley area. An RSD based I/M program set up in Greeley could potentially be more effective than a periodic program, if it expands the emission test requirement to all vehicles operated in Greeley and not just those registered in Greeley.

3.4.2 Coverage Trends By Site

We analyzed coverage trends by site with the goal of characterizing sites that efficiently measured unique Greeley vehicles. The large number of observations that were taken at site G2 versus the other sites limits the analysis, but conclusions can be drawn from the data. Table 3-18 shows a tabulation of the cumulative unique vehicles covered at each site. The incremental percentage of new Greeley vehicles observed at least once and twice is shown on the right-hand columns of the table. The analysis is sorted chronologically; sites change back and forth. The table highlights when the site was changed by offsetting the site and results. Changing to a new site usually resulted in an increased percentage of new Greeley vehicles being observed. However, the percent of unique Greeley vehicles observed at new sites dropped quickly for subsequent days at the site. For example, note on Table 3-18 that 39% of the observations taken at Site G5 on the first day were for new Greeley vehicles. However, by the third day at that site, the percent of new Greeley vehicles dropped to 23%. When we set-up at Site G5 in September 1996, 16% of the observations on the first day were new unique vehicles, dropping to 13% on the next day. Generally, later in the program, we did not see large jumps in coverage percentages when we set-up at new sites.

Figure 3-18 plots the percent of observations that were made on unique Greeley registered vehicles as a function of the overall number of tests. Initially, about 40% of the tests resulted in one or more observations on unique Greeley registered vehicles. This percentage quickly dropped to between 10 and 15%, but did not drop below this level, again indicating that coverage will continue to increase. If unmanned RSD units could be deployed, a 10% rate of finding new Greeley vehicles still could be acceptable. The sharp jumps in percent of new observations corresponds with changes in sites.

Table 3-18

Table 3-18 (Continued)

Figure 3-18

* % of tests that are observations of Greeley vehicles for the first time.

The trend shown in Figure 3-18 for the percent of new vehicles with two or more observations is different than the trend for one or more observations. Starting at close to 0%, the percent of new vehicles with two or more observations quickly rises to about 10%, and remains roughly at this level through the rest of the period. Usually changing to a new site did not cause a sharp increase in the percent of unique vehicles with two or more observations.

There were similarities and differences in coverage trends at each site. Sites G2 and G5 consistently resulted in the greatest number of new unique observations, because of the relatively high throughput at these sites. At a given site, the incremental percentage of new Greeley vehicles observed at least once tends to drop consistently and then levels off at about 10%. This trend is most apparent in site G2, but also occurs consistently in other sites that were used for several days. Some of the sites appear to result in a greater percentage of vehicles with two or more observations. For example, close to 15% of the measurements at sites G5 and G7 resulted in two or more readings on a vehicle.

3.4.3 Projected Van Days Required for 80 % Coverage

Using data from the Greeley Program, we can project the number of observations that must be made to cover 80% of the vehicle fleet. Based upon the last four months of data, it appears that the percent of new vehicles is stabilizing at roughly 10% of the RSD observations. This means that for every 100 observations there are 10 observations on Greeley vehicles that have been seen for the first time. Similarly, the percent of new Greeley vehicles that are being seen two or more times has stabilized to approximately 10%. If we assume that the 10% rate continues, the following number of observations must be made to cover 80% of the Greeley registered fleet.

- 263,000 observations must be made to cover 80% of the vehicles with at least one observation; and

- 393,000 observations must be made to cover 80% of the Greeley fleet with two or more observations.

In the Greeley Program, each van day, on the average, produced 1,400 valid observations (at least valid CO readings). Assuming that observations would continue at this rate, the following number of van days are needed to observe 80% of the vehicle fleet:

- 208 van days are needed to provide at least one valid reading on 80% of the vehicles.

- 301 van days are needed to provide two or more valid readings on at least 80% of the vehicles.

The number of van days needed to obtain at least one valid reading on 80% of the Greeley registered vehicles could conceivably be achieved in one year of operation.

3.4.4 Greeley Plate Survey

The coverage estimates presented so far are based upon Colorado motor vehicle data on vehicles registered in Greeley. The Department of Health conducted a license plate survey in Greeley at a variety of locations. Using the results of the survey, we calculated coverage of the Greeley RSD Program. Results are summarized on Table 3-19. Based on the survey, RSD measurements were made on 64% of the Greeley registered vehicles that were observed in the Greeley area; based on vehicle registrations we covered 72% of the Greeley registered vehicles. We expected to see a higher percentage, since many registered vehicles are not frequently used. However, the Greeley tag survey was performed in the fall of 1996 and, therefore, may not be truly representative of vehicles currently operated in the Greeley area. This may account for the fact that the survey saw slightly lower coverage percentages (64%) than observed based upon vehicle registration (72%).

Note that there was fairly uniform coverage by city among the plates that were observed in the Greeley tag survey. This indicates that vehicles from other municipalities are being consistently operated in Greeley. It also indicates that RSD effectively covers vehicles that are registered consistently outside the Greeley area but are being consistently driven in Greeley.

Table 3-19 Results of Greeley Tag Survey

3.5 Analysis of Multiple Observations

We investigated RSD emission trends for vehicles that were seen more than once. We specifically analyzed the following data:

- Data from tandem RSD measurements;
- Data from two or more RSD measurements with a single RSD van; and
- Observed variation in RSD measurements for vehicles that were tested in the IM240 program.

During the months of September and October, two RSD vans were used at some of the sites to collect measurements. We analyzed data from tandem emissions measurements to determine if RSD measurements collected in this manner have better agreement than multiple RSD observations.

Figure 3-19 shows a scatter plot of tandem observations along with the calculation of the coefficient of determination (r^2). Figure 3-20 shows a comparison of multiple observations at site G2. As shown, a better correlation exists among the tandem observations than among the multiple observations. The IM240 database is not adequate to determine if tandem observations correlate better with IM240 levels than multiple observations. Tandem observations may be a more efficient means to obtain at least 2 observations on a vehicle; as mentioned earlier, two or more observations may be needed to accurately identify clean screen candidates. On the other hand, two or more observations at different points in time may be a more accurate indicator of clean screen potential. This issue is unresolved.

We have included in Appendix E plots showing RSD measurements among the most frequently observed vehicles in the IM240 data set. Most vehicles show a wide range of RSD levels.

Figure 3-19 Correlation Between Tandem RSD Measurements

Figure 3-20 Correlation Between Multiple RSD Measurements at Site G2

3.6 Analysis of Costs

CDPHE estimated the cost estimate for a remote sensing clean screening program in the Greeley area. This cost analysis attempted to quantify operational, staffing, and equipment costs. Many of the assumptions used to determine costs were derived from the pilot Greeley remote sensing program. Others are best estimates based on CDPHE's experience with similar mobile source programs. Program costs have been split into the following six areas:

- cost of collecting data
- data-processing
- registration/compliance costs
- state oversight costs
- confirmatory testing costs and
- program effectiveness evaluation costs

Table 3-20 summarizes the estimated costs for a clean screen program in the Greeley Colorado area..

The first year costs are driven by capital equipment expenses, which are not incurred during the subsequent years of the program. The first three years of the proposed Greeley clean screen program is influenced by state oversight and the confirmatory testing costs, which would not be incurred on ongoing basis. These costs are necessary to further refine the air quality impact of a clean screen program for areas with more serious air quality concerns, such as the Denver metropolitan area. While the Greeley remote sensing pilot program was adequate to identify the benefits of a remote sensing clean screen program in air quality attainment areas such as Greeley, the expansion of this type of program to the rest of the front range, including the Denver metropolitan area, will require additional research. As such, the major expenses in terms of state oversight calls, confirmatory testing costs, and program effectiveness evaluation costs should not be apportioned to the Greeley area fleet, but to the entire I/M program fleet.

Costs should be apportioned among all vehicles benefitting from the program. In this manner, the ongoing operational costs of $172,000 per year would be recovered through a $3.60

vehicle registration fee on all vehicles registered in the Greeley/Weld County area.

In terms of cost effectiveness, presently based on 48,000 vehicles, the Greeley I/M program collects an estimated $341,000 in initial inspection fees. If we had 2 or more observations on 70% of the Greeley fleet and 65% of these vehicles were clean screened (assuming a 1% CO clean screen limit), then approximately 22,000 vehicles would avoid inspection during each inspection cycle. A savings of $205,000 in inspection fees would be achieved by not inspecting the clean screen candidates. The cost to clean screen these vehicles is estimated to be $172,000, so a net savings of $33,000 would occur over the current I/M program alone. More importantly increased convenience to the motorist would result from 22,000 vehicles avoiding routine inspection. A similar number of high emitting vehicles would continue to fail their initial I/M inspection, and require repair, even though 45% of the vehicles would avoid inspection. Therefore air quality benefits would be similar to an I/M program without clean screen.

Table 3-20 -- Cost Estimates for a Greeley Remote Sensing "CLEAN SCREENING" Program

1) COST OF COLLECTING DATA

New remote sensing van .... $140,000 first year cost

- R.S. source
- R.S. detector
  - HC, CO, NOx, PM
- Computer/software
- Speedbars
- Video camera
- License plate reader

Capitol improvement for van / operating cost .... $25,000 per year

- Van/RS unit maintenance/upgrades
  - (Annualized cost equal to 20% of value)
- Van operation

Contractor cost .... $90,000 per year

Table 3-20 Continued

Operate RS van
Provide engineering support
Program administration

Maintain present van as backup van to assist Greeley R.S. .... $10,000 per year
van when it is down for repairs/maintenance, or when additional van is needed for fleet coverage or double measurements, for audit activities, etc. (NOTE: present van has early production R.S. equipment which has degraded performance compared to current equipment and limited NOx and no PM capabilities)

SUBTOTAL — COST OF COLLECTING DATA

First Year $265,000
Second Year $125,000
Third Year $125,000
On-going $125,000

2) DATA PROCESSING COSTS

Contractor costs ....$35,000 per year
Data system operator
Programming support
Equipment:
Process 393,000 valid matched readings per year
(80% of fleet monitored at least twice per year)
Quality assure R.S. measurements
Match R.S. readings with license plate
Automated license plate reader (80%+ read)
Quality assure license / R.S. match

Vehicle ownership matching with Dept. Of Revenue ....$12,000 per year
$0.25/Greeley registered vehicle

SUBTOTAL — DATA PROCESSING COSTS

First Year $47,000
Second Year $47,000
Third Year $47,000
On-going $47,000

Table 3-20 Continued

3) REGISTRATION/COMPLIANCE COSTS

Modify computer programs and registration .... $45,000 per year
renewal procedures to permit "clean screened"
vehicles to forego scheduled inspection
Dept of Revenue supply VIN matches flagged
for "clean screening" to county clerks
County clerk mail vehicle owners clean-screen
Letter, vehicles remain part of I/M fleet

SUBTOTAL — REGISTRATION/COMPLIANCE COSTS
First Year $45,000
Second Year $0
Third Year $0
On-going $0

4) STATE OVERSIGHT COSTS

1.5 FTE first year .... $80,000 first year

1.0 FTE 2nd-3rd years .... $55,000 2nd-3rd years

0 FTE On-going .... $0 On-going

Travel expenses 3 days a week ($0.35/mile................ $5,000 per year, 1st three years

Audit computer and software .... $10,000 first year

SUBTOTAL — STATE OVERSIGHT COSTS
First Year $95,000
Second Year $60,000
Third Year $60,000
On-going $0

5) CONFIRMATORY TESTING COSTS

Portable IM240 .... $140,000 first year
IM240 dynamometer, analytical equipment,
support equipment
trailer

Table 3-20 Continued

Building rent .... $18,500 per year for first three years

Personnel costs .... $90,000 per year, first three years
2 FTE to man and operate IM240 lane first three years
(3500 IM240s per year, 3 per hr, 15 cars per day)
no incentives - require they come in

Purchase/modify one-ton van to house air conditioned .... $55,000 first year
instruments and pull IM240 trailer

SUBTOTAL --- CONFIRMATORY TESTING COSTS

First Year $303,500
Second Year $108,500
Third Year $108,500
On-going $0

6) PROGRAM EFFECTIVENESS EVALUATION COSTS

Operational Evaluation and Reporting ....$25,000 per year, first three years

Program Effectiveness Determination .... $25,000 third year

SUBTOTAL — PROGRAM EFFECTIVENESS EVALUATION COSTS

First Year $25,000
Second Year $25,000
Third Year $50,000
On-going $0

TOTAL PROGRAM COST

First Year $780,500
Second Year $365,500
Third Year $390,500
On-going $172,000

4.0 DISCUSSION OF STUDY RESULTS

4.1 Technical Feasibility of Remote Sensing

Data from the Greeley remote sensing project can help us evaluate the technical feasibility of remote sensing. In particular, these data can help us address the following issues:

- Effectiveness of remote sensing in identifying high emitting vehicles;
- Remote sensing as a clean screen tool;
- Use of remote sensing in estimating mobile source emissions inventories; and
- Use of remote sensing in evaluating mobile source control programs.

4.1.1 Effectiveness of Remote Sensing in Identifying High Emitting Vehicles

The following specific results from the Greeley program lead to the conclusion that remote sensing might be effective at identifying high emitting vehicles:

- Data from the Greeley study indicate that RSD can identify about 40% of the excess HC and CO emissions as determined by the IM240 test by failing less than 5% of the vehicle fleet. For example, a 3% CO cutpoint identifies 43% of the excess CO and 60% of the excess HC emissions by failing only 2.8% of the vehicles. (See Section 3.2.4)
- Errors of commission (false failures) are relatively low when a relatively high cutpoint is used to identify potential high emitting vehicles. The 3% CO cutpoint that was previously discussed resulted in no errors of commission. (See Section 3.2.4)
- To use remote sensing to identify gross polluters, it may not be necessary to have two or more RSD observations before making a pass/fail decision. Higher cut points may be needed if pass/fail decisions are made on the basis of single hits

- In 181 days at 11 sites, the Greeley study generated one or more valid CO measurements on 72% of the Greeley vehicle population. Two or more observations have been generated on 45% of the vehicle population. Because the Greeley study shared its testing resources with the Denver enhanced program, vans were not used full time to monitor vehicle emissions in Greeley. It is estimated that a study focused strictly on Greeley could potentially generate one or more valid observations on 80% of the vehicle fleet in a year. (See Section 3.4.1)

- When likely vehicle coverage is considered, a RSD based I/M program could identify vehicles accounting for about 30 to 40% of the excess HC and CO emissions. This level of performance may be acceptable for a basic I/M program. It would fall far short of the performance needed for an enhanced I/M program. On the other hand, identifying 30 to 40% of the excess emissions during an off-cycle period i.e., between inspections, could be a significant enhancement to an enhanced I/M program.

- Data from IM240 and RSD tests conducted in Denver show higher errors of commission rates and lower excess emissions identification rates for RSD than indicated by the Greeley data. The presence of the IM240 program in Denver since 1995 might account for the higher errors of commission rates and lower excess emissions identification rates. More data are needed before a final conclusion can be made about the effectiveness of RSD in identifying gross polluting vehicles.

4.1.2 Remote Sensing as a Clean Screen Tool

Remote sensing appears to be promising as a clean screen tool as indicated by the following results:

- Based upon the results of IM240 tests, vehicles seen more than once by the RSD monitors and having CO levels less than 0.5% contain less than 6% of the excess HC emissions and less than 5% of the excess CO emissions. When both CO and HC screening criteria were used (<0.5% CO and <200 ppm HC) vehicles qualifying for clean screen contain less than 5% of the excess HC and 3% of the excess CO emissions. (See Section 3.2.3)

- Two or more hits are needed before a clean screen determination can be made on a vehicle. Basing clean screen determination on vehicles that were seen only once by RSD would have significant emissions impacts. For example, vehicles that were seen only once by RSD and had CO emissions less than 0.5% contained about 60% of the excess HC and 30% of the excess CO IM240 emissions. (See Section 3.2.3)

- A basic I/M program could use less stringent clean screen criteria than 0.5% CO and still achieve the basic I/M performance standard. For example, a CO cutpoint of 1% CO, based on the maximum observed value, still identifies over 90% of the excess emissions if there are 2 or more hits available. Greeley data indicate that 46% of the fleet had CO emissions less than 0.5%; 65% of the vehicles had maximum CO values less than 1%.

- An enhanced program, particularly one that was concerned about HC as well as CO emissions impacts may need more stringent clean screen criteria, e.g. cutpoints of 0.5% CO and 200 ppm HC as the limit for clean screen consideration. According to the Greeley program, 26% of the vehicles meet this criteria.

- We analyzed data IM240 and RSD tests conducted in Denver to assess the effectiveness of RSD as a clean screen tool. Unlike the analysis of RSD as a tool to identify high emitters, results of the clean screen analysis agree with the Greeley results, adding to our confidence in RSD as a clean screen tool.

4.1.3 Use of Remote Sensing in Estimating Mobile Source Emissions Inventories

The Greeley study provided over 200,000 emission tests on vehicles operating in the Greeley area. CO emission test results from the high volume sites, i.e. G2, G5, and G9, correlate fairly well with IM240 measurements, when the IM240 measurements are expressed in terms of average concentration over the 240 second cycle (See Section 3.2.2). This leads to the conclusion that RSD measurements could be useful in estimating mobile source CO emissions.

In order to use RSD measurements to estimate mobile source emissions, screening criteria must be developed to select sites for this purpose. The three sites mentioned above, G2, G5, and G9, showed fairly uniform distributions of CO emissions. These sites saw vehicles that were traveling between 30 and 40 mph under mild acceleration conditions, (See Figures 3-12 and 3-13) Many of the other sites, as shown on Figure 3-14 in Section 3.3, saw a wide range in CO emissions. These sites also saw a wide range of speeds and accelerations.

Emissions in grams per mile for the fleet average vehicle can be estimated by correcting the CO concentrations using the expected fuel consumption for the vehicle being monitored. Fuel consumption could be based on the EPA rating for that particular make, model, and engine size. If fuel consumption is not available, then inertia weight could be used as a surrogate, but this assumption would likely introduce more error into the estimates.

The above methodology should be validated using data from the 0.5% RSD sampling program in Denver. RSD observations could be converted to grams per mile using correlations derived from the Greeley study. These grams per mile values could then be compared with grams per mile values generated in the Denver IM240 program.

4.1.4 Use of Remote Sensing in Evaluating Mobile Source Control Programs

As presented in Section 3.1.3, RSD measurements from a high volume site, G2, appeared to be much lower during the oxygenated fuel season than during other periods of the year. This indicates that RSD might be a useful tool to evaluate other mobile source control programs. However, as noted in Section 3.3, there were a wide range of RSD CO readings among the different sites. In many cases, site-to-site differences were greater than the expected impact of the control program. Care must, therefore, be taken when selecting sites for purposes of evaluating mobile source control programs. Sites that show similar distributions of emissions across a range of time should be selected.

The state of California has been successful in using RSD to evaluate its decentralized basic I/M program by focusing on vehicles that passed and failed the I/M test. A similar analysis could be performed using data from Greeley’s basic I/M program. The same concerns that were expressed above from using RSD to evaluate the oxygenated fuels program also apply to using it for evaluating the I/M program, since we are looking for the same approximate change in emission levels.

4.2 Cost and Cost-Effectiveness of Remote Sensing

Based upon the cost analysis presented in Section 3.6, the annual cost for a clean screen program that adequately covers a city the size of Greeley is $172,000. The cost to inspect vehicles that would be screened-out from inspection requirements is estimated to be $205,000, so there would be a net savings of $33,000. When the economic value of time is considered, the cost savings are greater. This cost assumes that 65% of the vehicles are eligible for clean screen and that one year of van operation should be able to provide two or more hits on 70% of the Greeley fleet. This scenario would achieve 95% of the CO benefits of a basic I/M program without clean screen, so the cost effectiveness would be improved. These assumptions were derived from the coverage analysis and the analysis of RSD as a clean screen tool.

APPENDIX A

ADDITIONAL DETAILS ON RSD MONITORING SITES

APPENDIX B

SUMMARY OF DAILY ACTIVITIES

APPENDIX C

COMPARISON OF DIFFERENT PARAMETERS IN IDENTIFYING LOW AND HIGH EMITTING VEHICLES

APPENDIX D

SCATTER PLOTS OF SURROGATE IM240 AND RSD CONCENTRATIONS

APPENDIX E

RSD LEVELS FOR SELECTED VEHICLES MULTIPLE HITS