Alternative Technologies for Evaluating Paved-Road Dust Emission Potential – Mobile Sampling Methodology as an Alternative to Traditional AP-42 Silt Measurements

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ABSTRACT

Clark County Department of Air Quality and Environmental Management (DAQEM) is investigating alternative methods to estimate paved road dust (PM_{10}) emissions. DAQEM, in 2004, began a comprehensive research program to demonstrate that vehicle-based mobile sampling systems can be used as an alternative to traditional paved road silt sampling (AP-42). To gain U.S. Environmental Protection Agency (EPA) acceptance of the data collected, DAQEM has completed three phases of this study. Vehicle-based mobile sampling systems allow for measurements of actual PM_{10} emissions over a complete range of paved roadway classifications (local, collectors, arterials, and freeways) and can sample hundreds of lane miles within a few days.

The ability to measure PM_{10} emissions from paved roads on a Valley-wide basis in a matter of days provides a realistic assessment of paved road emissions for emission inventory purposes and assessment of control measure effectiveness. Unlike traditional paved road silt sampling, which is labor-intensive and time-consuming, vehicle-based mobile sampling systems provide a cost-effective, scientifically defensible method to compile data to improve emission inventories.

The College of Engineering, Center for Environmental Research and Technology (CE-CERT), University of California, Riverside and the Nevada System of Higher Education's Desert Research Institute (DRI) have developed vehicle-based mobile sampling systems for sampling PM_{10} emissions of re-entrained paved road dust.

Results show that both mobile systems produce data at higher spatial and temporal resolutions than is possible with AP-42 silt sampling. DRI's and CE-CERT's systems were in general agreement regarding location and timing of high and low paved road emissions. CE-CERT's system generally recorded lower emission factors than DRI's system. CE-CERT's SCAMPER system measured emissions factors one-third the magnitude of AP-42 emissions factor estimates generated from silt sampling.

INTRODUCTION

The Las Vegas Valley in Clark County, Nevada, is classified as serious nonattainment for federal fine particulate matter (PM_{10}) National Ambient Air Quality Standards (NAAQS). Clark County submitted a PM_{10} State Implementation Plan (SIP) for this nonattainment area in June of 2001. As part of the SIP development, Clark County contracted with a consultant to collect 24 silt samples representative of Clark County roadways for estimating PM_{10} paved road emissions. The silt measurements were significantly higher than EPA default values, and public works officials from four agencies and other stakeholders asserted that the Clark County SIP overestimated PM_{10} emissions from paved roadways. Clark County committed to conducting quarterly silt sampling through the end of 2006 as part of the now federally approved PM_{10} SIP. Sampling is ongoing and the current data set includes sampling from the spring of 2000 through the fall of 2005. The PM_{10} SIP also contained a research commitment to explore the feasibility of vehicle-based mobile sampling systems for development of improved paved road emissions inventories.

During this timeframe, Clark County has seen substantially improved air quality for the PM_{10} pollutant, particularly from the year 2004 forward. Visually, it also appears that Las Vegas Valley roads have become cleaner, in part due to tightened controls on construction site track-out and an increased emphasis on enforcement, implemented in early 2003. However, statistical analysis performed by UNLV under contract has generally not shown statistically significant declines in paved road emission factors during this timeframe using silt sample data and AP-42 emission estimation methods. These results have reinforced Clark County's belief that the paved road emissions inventory developed using AP-42 methods for the PM_{10} SIP overestimates actual emissions. In addition, silt measurements are time consuming, expensive, and frequently require the alteration of roadway traffic patterns while samples are being procured.

Initial work utilizing vehicle-based mobile sampling systems in Clark County occurred in 1999 as part of PM_{10} SIP development. The test results showed even higher emission rates than corresponding AP-42 calculations and were not considered realistic. In addition, the need to complete an approvable PM_{10} SIP was urgent and EPA approval of this new method was very unlikely based on work completed at that time. Phase I of the current research effort was initiated in 2004 and Phase II was completed in early 2005. Fieldwork for Phase III occurred in late 2005 with augmentation work occurring in early 2006. Phase IV of the study is currently in the design phase with fieldwork tentatively scheduled for late June of 2006.

METHODOLOGY

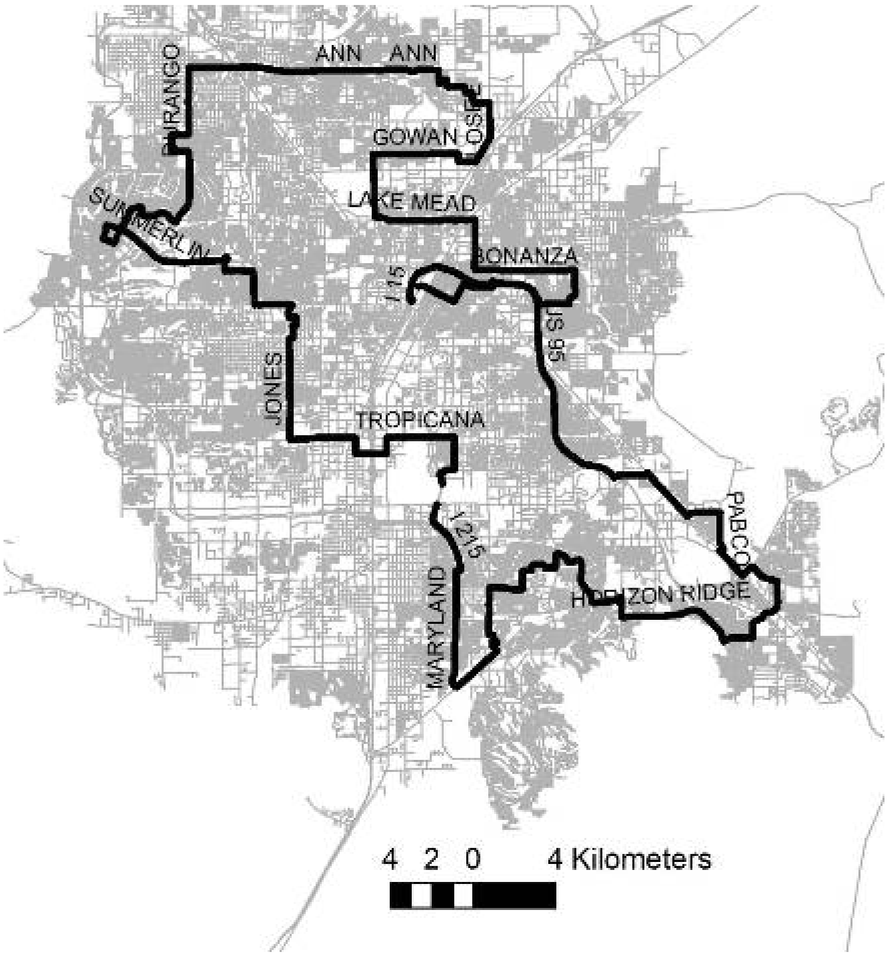
Clark County's vehicle-based mobile sampling system work is based on the System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways (SCAMPER) developed by the CE-CERT and Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER) system developed by the DRI.

The Phase I study entailed a two-day field study utilizing a 107-mile sampling route. The purpose of the study was to determine the feasibility of vehicle-based mobile sampling system for use in Clark County to better characterize paved-road emissions and to develop real-time emissions of PM_{10} for emissions inventory use. The sampling route was designed to include worst-case silt-impacted roads and best-case clean roads in order to evaluate the detection limits of the two systems. The route was further designed to include all political jurisdictions in the Las Vegas Valley. Several deviations from the original sampling route were required due to road closures resulting from road construction. An effort was made to note road infrastructure conditions and deposition sources during sampling using notepads and "wrist watch time." A total of sixteen AP-42 silt samples were also collected on the sampling route. Phase I demonstrated the feasibility of using vehicle-based mobile sampling systems as an alternative to conventional AP-42 paved-road emissions estimating methods.

The Phase II study entailed four days of sampling on a 103-mile sampling route. The Phase II sampling route was designed to include a number of parameters. The route included the five classes of roadways (local, collector, minor arterial, major arterial, and freeway) and four political jurisdictions in the Las Vegas Valley. Consideration was given to development patterns in the Las Vegas Valley and the final sampling route included developing areas, older established neighborhoods, and newer planned communities that were completely built out. The developing areas included a cross section of incomplete road infrastructure (e.g. unpaved road shoulders) and deposition sources such as vacant lots and construction activities. The built-out areas included completed road infrastructure, few vacant lots, and little construction activity. The final route also included a cross section of soil classifications based on Clark County's Particulate Emission Potential (PEP) soil classification system[1]. The sampling route included ten historical AP-42 sampling sites and eleven new sites that had not previously been sampled using AP-42 methodology. Relative humidity was measured during sampling at each AP-42 site. Specific road conditions and sources were not mapped or recorded during the study. The study was delayed for two weeks due to rain. The sampling route is shown in Figure 1. Staff from Maricopa County, U.S. EPA Region IX and U.S. EPA observed the field study. Limited notes on road infrastructure and silt deposition sources were made during development of the sampling route.

[1] Geotechnical and Environmental Services, Inc., *Presentation of Final Versions of Deliverables for Re-Evaluating and Updating the Particulate Emission Potential Map and Soil Classification for Dust Mitigation Best Management Practices Manual for Clark County,* dated September 26, 2003.

Figure 1. Map of Clark County 2/14/05 – 2/17/05 sampling route



The Phase III study utilized only the SCAMPER and focused on development of specific emission factors for specific conditions and to assess measurement variability. A comparison of SCAMPER data to AP-42 emissions estimates was a second component of this study. To accomplish these objectives, the study occurred over seven consecutive days and utilized three sampling routes. Road infrastructure, adjacent land use (e.g. vacant land, residential, etc) and sources of deposition were comprehensively mapped prior to the study. In order to better evaluate site conditions during the study, a video camera was mounted externally on the drivers side of the vehicle. The video camera was linked to the SCAMPER GPS clock and camera sound was wired to a microphone located inside the vehicle to permit the operators to record comments and observations while operating the system.

The first sampling route (industrial route) was dominated by industrial haul roads with heavy silt loadings and was used to calibrate the precision of the SCAMPER unit. This route included local, collector and arterial roads. This route was sampled for most of day one of the study. The second route (transitional route) was a 7.3-mile track in a transitional area in the Las Vegas Valley. Development in the area is a mix of commercial, residential, rural residential, and vacant land. Paved roads range from fully improved with sidewalks, curbs and gutters to unimproved with unpaved shoulders on both sides. Sources of deposition included road construction, residential construction, vacant land used for storing fill soil, and vacant land with no active use. The area also has some of the highest PEP (Particulate Emission Potential[2]) soils in the Las Vegas Valley. The transitional sampling area route was sampled for four consecutive days, including the weekend. This allowed a comparison of weekday and weekend paved road emission rates. The third route (developed community route) consisted of a 12.6-mile track traversing a newly developed planned community and contained local, collector and arterial roads. This route contained fully developed road infrastructure that was not impacted by any sources of silt deposition. The route included local, collector, and arterial streets, all of which contained very light silt loadings. In addition to providing baseline measurements for fully developed roadways with minimal silt deposition sources, this route was used to evaluate the sensitivity of the SCAMPER unit. Measurements were taken on this route for two full days. Relative humidity was measured during sampling at each AP-42 site and at a nearby DAQEM monitoring site. The study was coordinated with the cities of Las Vegas and North Las Vegas to insure that none of the streets were swept within three days prior to sampling.

The Phase IV Study, also known as the empirical study, is currently in the design phase with fieldwork tentatively scheduled for 2006. This study will entail upwind/downwind source emissions sampling, measurements using SCAMPER and TRAKER, AP-42 sampling, and deposition of known quantities of road silt material. Study objectives include a comparison of upwind/downwind source emissions measurements to SCAMPER/TRAKER measurements, a comparison of SCAMPER to TRAKER measurements, and AP-42 silt measurements/emission estimates under controlled conditions. It is anticipated that the controlled traffic conditions will enhance the quality of upwind/downwind source emissions measurements for paved roads compared to some previous studies. A second objective is to determine the rate at which known amounts of silt material is entrained. This will provide important information as to the effectiveness of street sweeping for reducing PM_{10} emissions from typical urban streets.

RESULTS

The Phase I Field Study

The Phase I field study established that the two vehicle-based mobile sampling systems were effective in measuring paved road emissions. Both systems measured high emission rates on roads with high silt loadings and low emission rates on roads with low silt loadings. Measurements completed with two systems during this study are directly comparable. However, due to difficulty experienced by the CE-CERT team with data logging, it is only possible to compare TRAKER and SCAMPER data for a few hours during the first day of sampling. Overall, analysis showed that emission factors were generally higher for low speed roads such as residential streets than high-speed roads such as freeways. The DAQEM staff and participating consultants also learned that the wristwatch and notepad approach to recording data was not an effective way to compare measured emissions from either system to a specific road condition or deposition source.

The Phase II Field Study

The Phase II field study provided a number of additional findings. During the first two days, measurements were significantly higher for both systems than the following two days (CE-CERT 2005, Etyemezian et al, 2005). This can be attributed to enforcement action against construction sites in the developing areas on the sampling route. Both systems lost GPS signals at various locations on the sampling route, particularly when traveling under the McCarran Airport tunnel. Data from both systems recorded variability in point-to-point data. It is hypothesized that this reflects actual variations in road surface roughness and point-to-point silt loadings. Keeping both mobile sampling system vehicles in the same lane throughout the sampling course under uncontrolled conditions was not possible. Descriptive fields provided by Clark County delineated the road class (arterial, collector, freeway, local), presence/absence of construction, presence/absence of vacant lands, curbing/shouldering, and the number of travel lanes per direction. Using these descriptive fields, it was possible to segregate road characteristics and calculate emission factors for a specific set of conditions. However, the averages may be misleading because these attributes are not associated with a quantity. For example, it is likely that a larger number of construction sites, or a larger acreage under construction along a road segment would have a greater influence on emission factors than fewer sites or fewer construction acres. The data provided by Clark County DAQEM does not specify the extent of construction or the prevalence of vacant land along a specific segment.

SCAMPER data is summarized in Table 1. All data points measured at a vehicle speed of less than ten miles per hour were excluded when calculating the averaged emission rate. This matches the protocol used by the TRAKER system and allows for a comparison of the respective data sets.

Table 1. Summary of average emission rate data for SCAMPER system

Date	Average PM10 Emission Rate (>10 mph) mg/meter?
2/14/2005	0.086
2/15/2006	0.105
2/16/2006	0.040
2/16/2006	0.012

TRAKER data is summarized in Table 2. DRI calculated emissions rates by road characteristics, noting the limitations of the Clark County descriptive fields. The majority of road segments (~90%) have associated emission factors that fall between 0.1 and 0.3 g/vkt. Roads that fall in the northeast and southernmost portions of the test loop exhibit the highest emission factors. These coincided with areas that were undergoing road and home construction and in areas with high PEP soils.

Table 2. TRAKER emissions factors classified by road segment attributes on 820 road segments

Class	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
Arterial	0.153	0.093	469	0.004
Collector	0.199	0.121	203	0.008
Freeway	0.166	0.054	107	0.005
Local	0.327	0.241	41	0.038
Lanes/direc	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
1	0.287	0.179	141	0.015
2	0.153	0.079	374	0.004
3	0.143	0.076	257	0.005
4	0.154	0.028	6	0.012
5	0.241	0.047	8	0.016
Constr	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No	0.169	0.113	648	0.004
Yes	0.197	0.122	172	0.009
Vac lands	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No	0.154	0.103	563	0.004
Yes	0.220	0.129	257	0.008
Curbs/shoulders	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No/No	0.572		1	
No/Yes	0.208	0.139	115	0.013
Yes/No	0.158	0.109	533	0.005
Yes/Yes	0.204	0.105	171	0.008

DRI also compared the emissions measurements from the TRAKER system to the SCAMPER. They note that a side-by-side comparison of segment averaged emission factors using the TRAKER and SCAMPER shows that qualitatively, the two measurement methods give similar spatial distributions for road dust emission factors. In general, portions of the loop where SCAMPER measures high emission factors correspond to portions where TRAKER measures high emission factors. There are however some important differences between the two methods. A scatter plot of road segment-averaged emission factors shows that the two measurement methods are correlated (R^2 = 0.46 and R^2 = 0.30 for a linear fit with and without an intercept, respectively). The SCAMPER however gives slightly lower emission factors. When segregated by day, the ratio of SCAMPER to TRAKER emission factors is quite variable ranging from 0.05 on 2/17/05 to 0.45 on 2/15/05 (See Table 3).

Table 3. Emission factors for TRAKER and SCAMPER averaged over all road segments by sample day and associated ratios of emission factors using the two methods

Day_	TRAKER Emission Factor Avergaed over all segments(g/vkt)	SCAMPER Emission Factor Averaged over all segments(g/vkt)	Ratio SCAMPER EF/ TRAKER EF
2/14/2005	0.185	0.062	0.34
2/15/2005	0.180	0.081	0.45
2/16/2005	0.176	0.029	0.17
2/17/2005	0.168	0.008	0.05
All Days Average	0.177	0.045	0.25
Standard deviation	0.007	0.033	0.18

Table 3 also shows that the standard deviation of the TRAKER measurement among the 4 sampling days (4.1% of average) is comparatively lower than that of the SCAMPER (72% of average). This may be a consequence of the differences between the two measurement configurations. Owing perhaps to the larger signal range behind the front tires than in the wake of the vehicle, the TRAKER measurement has a higher degree of precision on the spatial scale of a road segment than the SCAMPER, especially under light silt loading conditions.

The DAQEM notes the following general characteristics of the two vehicle-mounted sampling systems. The major difference between the SCAMPER and TRAKER systems is that the SCAMPER measures the amount of road dust entrained by the test vehicle in the wake of the vehicle while the TRAKER measures the road dust entrained behind the two front tires. Thus, the SCAMPER uses first principles and some simplifying assumptions to estimate road dust emission factors while the TRAKER requires that the signal measured behind the tire be calibrated against a known standard such as the upwind/downwind tower flux method. These design characteristics result in SCAMPER measuring diluted emission concentrations behind the vehicle and producing smaller differentials between the ambient background concentrations and vehicle emissions. As a result, many of the raw SCAMPER measurements are negative (~33%), reflecting greater sensitivity to crosswinds compared to the TRAKER system, which recorded far fewer negative values (~3%). The SCAMPER design is relatively modular and can be fitted to different types and sizes of vehicles with relative ease.

A one-time calibration of the TRAKER system is required for any specific version of the vehicle in order to accurately measure emissions factors under varying conditions. Early measurements with TRAKER on paved roads using calibration factors from unpaved roads resulted in overestimates of paved road emissions. It was later determined that the paved road emission factor is lower than the unpaved road trend line by approximately a factor of 25.

The Phase III Field Study

The Phase III field study provided additional noteworthy results (CE-CERT 2006). A total of 103 test route passes were completed over the seven test days. Table 4 shows the breakdown of the tests conducted.

Table 4. Summary of number of SCAMPER PM_{10} test loops conducted November 2-8, 2005

Date	Sample Route 1 (Industrial Area)	Sample Route 2 (Transitional Area)	Sample Route 3 (Developed Community)
11/02/05	20	1	1
11/03/05			9
11/04/05		15	
11/05/05		16	
11/06/05		17	
11/07/05		18	
11/08/05			6
Sum	20	67	16

The results showed that PM_{10} emission rates met the loop expectations and were generally low except when “hot spots” were encountered, which is consistent with previous measurements. CE-CERT concluded that the SCAMPER system is useful for both identifying “hot spots” and generally characterizing PM_{10} emission rates from paved roads with a precision of approximately 25%. The PM_{10} emission rates did not change significantly during the course of the day, but on the high emission longer loop the rates dropped by a factor of two over the weekend. The comparison with AP-42 silt sampling showed good correlation (R^2 = 0.86) with the SCAMPER segment results, which were about one third the silt sampling values. Since SCAMPER directly measures PM emission rates, it is likely to be a more direct and accurate measure of PM emissions from roads.

Sample Route 1 (Industrial Area). Table 5 summarizes the average values for each loop performed. The average speed was very consistent at 14.7 meter/second (53 km/hr, 32.9 mph). The mean PM_{10} emission rate was 0.52 mg/meter with a standard deviation of 0.19 mg/meter. The overall Coefficient of Variation (measurement and environmental) was therefore 100% x (0.19 / 0.52) = 37%. Given the variability of traffic and dust production observed, a set of measurements with this amount of variability was considered very good.

Table 5. Summary of Sample Route 1 (Industrial Area) runs

Start Time PDT	Period Ave EF mg/m	Period Ave Speed MPH
10:29:15	0.639	32.0
10:34:44	0.325	33.1
10:45:53	0.740	33.0
10:50:39	0.730	34.3
10:54:45	0.370	32.2
10:58:43	0.839	33.2
11:02:52	0.412	34.3
11:07:31	0.943	33.6
11:12:14	0.611	30.5
11:22:03	0.487	34.1
11:26:19	0.533	32.1
11:30:38	0.346	32.8
11:35:28	0.334	33.2
11:39:55	0.505	32.8
11:44:48	0.432	31.8
11:49:17	0.438	34.4
11:53:46	0.352	29.2
11:58:45	0.545	33.0
12:03:32	0.515	35.4
12:07:43	0.234	32.8
Mean	**0.516**	**32.9**
Std Dev	**0.186**	**1.4**

The PM_{10} emission rate was also calculated for specific segments where silt sampling was conducted. The segment was defined as the block in which the sampled area was located. If the sampled area was near the end of a block, the next block was included. For test loop A the entire section of Gowan Road was defined the segment. The mean PM_{10} emission rate for all traverses was 0.94 mg/m with a standard deviation of 0.46 mg/meter.

Sample Route 2 (Transitional Area). Table 6 summarizes the average values for each loop performed and verifies the consistency with daily mean PM_{10} emission factors ranging from 0.35 to 1.07 mg/meter. The daily overall Coefficient of Variation (COV) ranged from 23-30%. As in the Route 1 testing, this was considered to be better-than-expected precision given the multiple and changing sources. Both of the weekend days were significantly lower than weekdays, by almost a factor of two. The jump in emission rate from Sunday to Monday was particularly striking. The average speed was consistent at 13.0 $\pm$ 0.4 m/sec (46.7 $\pm$ 1.6 km/hr, 29 $\pm$ 1) mph for all four days.

Table 6. Summary of Sample Route 2 (Transitional Area) runs

Date	Period Start Time	Period Ave EF	Period Ave Speed
	PDT	mg/m	MPH
11/02/05	13:31:09	0.601	27.1
11/02/06	13:48:13	0.826	28.1
11/04/06	8:56:01	0.758	27.2
11/04/06	9:14:33	0.813	28.4
11/04/06	9:38:56	0.658	28.3
11/04/06	9:56:01	0.702	29.5
11/04/06	10:11:50	0.982	28.3
11/04/06	10:30:44	0.860	29.8
11/04/06	10:46:14	0.911	29.3
11/04/06	11:01:55	0.708	29.5
11/04/06	11:23:08	0.641	29.0
11/04/06	12:43:22	0.634	28.8
11/04/06	13:00:09	0.695	29.5
11/04/06	13:19:30	0.810	29.0
11/04/06	13:40:31	0.507	28.6
11/04/06	13:56:40	0.368	29.5
11/04/06	14:13:59	0.145	28.7
11/04/06	**Mean**	**0.684**	**28.7**
11/04/06	**Std Dev**	**0.204**	**0.8**
11/05/05	8:30:42	0.50	30.5
11/05/05	8:45:37	0.435	29.9
11/05/05	9:01:35	0.364	28.9
11/05/05	9:21:53	0.421	29.6
11/05/05	9:38:25	0.403	29.9
11/05/05	9:54:31	0.410	29.3
11/05/05	10:12:47	0.473	29.9
11/05/05	10:59:48	0.373	30.9
11/05/05	12:18:15	0.387	29.2
11/05/05	12:34:03	0.213	29.7
11/05/05	12:49:48	0.213	29.0
11/05/05	13:08:29	0.276	29.7
11/05/05	13:23:43	0.273	29.6
11/05/05	13:40:02	0.320	29.7
11/05/05	13:58:35	0.332	30.1
11/05/05	14:43:52	0.270	30.5
11/05/05	**Mean**	**0.354**	**29.8**
11/05/05	**Std Dev**	**0.087**	**0.5**
11/06/05	8:27:07	0.371	29.4
11/06/05	8:42:24	0.317	28.9
11/06/05	9:05:09	0.355	29.1
11/06/05	9:27:03	0.276	28.6
11/06/05	9:43:17	0.306	29.5
11/06/05	10:26:20	0.210	29.1
11/06/05	11:09:48	0.617	31.0
11/06/05	11:24:30	0.586	30.4
11/06/05	12:37:37	0.535	19.8
11/06/05	12:53:18	0.501	28.8
11/06/05	13:10:11	0.478	28.3
11/06/05	13:29:20	0.528	28.2
11/06/05	13:46:00	0.502	28.9
11/06/05	14:30:31	0.598	28.7
11/06/05	14:46:10	0.487	29.9
11/06/05	15:01:51	0.505	28.4
11/06/05	**Mean**	**0.448**	**28.6**
11/06/05	**Std Dev**	**0.125**	**2.5**
11/07/05	8:32:56	0.990	27.9
11/07/05	8:50:32	1.783	29.3
11/07/05	9:11:50	1.086	28.6
11/07/05	9:32:17	0.960	28.2
11/07/05	9:49:55	0.876	28.1
11/07/05	10:06:17	1.327	30.6
11/07/05	10:24:49	1.124	29.5
11/07/05	10:46:26	1.386	29.3
11/07/05	11:01:58	1.278	30.0
11/07/05	12:16:13	0.985	29.8
11/07/05	12:33:33	0.944	29.7
11/07/05	12:50:24	0.952	29.6
11/07/05	13:09:49	1.107	30.3
11/07/05	13:25:28	0.907	29.1
11/07/05	13:43:17	0.868	29.4
11/07/05	14:02:55	0.852	29.7
11/07/05	14:18:03	0.963	28.5
11/07/05	14:34:59	0.831	29.2
	Mean	**1.068**	**29.3**
	Std Dev	**0.242**	**0.8**

The mean PM_{10} emission rates were calculated for each of the three segments for which silt sampling was conducted. The following overall average (all days) emission rate results were obtained:

Emerald Stone and Sapphire Light: average: 2.20 mg/meter; standard deviation: 1.18 mg/meter,
Lone Mountain and Losee: average: 0.43 mg/meter; standard deviation: 0.68 mg/meter,
Goldfield and Washburn: average: 0.78 mg/m; standard deviation: 1.27 mg/m

As expected, the variability for a single segment is higher than that of the entire route.

Sample Route 3 (Developed Community). Table 7 shows the average PM_{10} emission rate for each of the Route 3 test runs.

Table 7. Summary of Sample Route 3 (Developed Community) runs

Date	Period Start Time	Period Ave EF	Period Ave Speed
	PDT	mg/m	MPH
11/02/05	14:56:00	0.015	30.5
11/03/05	8:46:11	0.019	31.0
11/03/05	9:13:35	0.022	30.8
11/03/05	9:45:34	0.030	31.6
11/03/05	10:17:47	0.039	32.6
11/03/05	10:45:25	0.021	31.2
11/03/05	11:19:48	0.039	31.0
11/03/05	13:33:18	0.032	29.4
11/03/05	14:04:49	0.032	30.8
11/03/05	14:40:26	0.022	30.2
	Mean	**0.027**	**30.9**
	Std Dev	**0.008**	**0.8**
11/08/05	9:30:58	0.011	30.3
11/08/05	9:58:32	0.009	31.8
11/08/05	10:27:33	-0.006	31.2
11/08/05	12:50:27	0.061	30.5
11/08/05	13:22:40	0.077	29.8
11/08/05	13:54:02	0.054	30.5
11/08/05	**Mean**	**0.034**	**30.7**
11/08/05	**Std Dev**	**0.034**	**0.7**

On November 3rd, when the DustTraks were operating properly, the average PM_{10} emission rate was 0.027 mg/m, about a factor of twenty less than the other loops that were chosen for high potential PM_{10} emission rates. Despite these much lower rates, the relative variability was 30%, consistent with values obtained from the other loops. Although the PM_{10} emission rates on November 8th were erratic, the mean rate was 0.034 mg/meter, consistent with data collected on the 2nd and 3rd of November, but the relative variability was 100%. All the mean loop speeds were 31 $\pm$ 1 mph.

The mean PM_{10} emission rates were calculated for each of the three segments for which silt sampling was conducted. The following average (all days) PM_{10} emission rates were obtained:

Crestdale and Hillpointe: mean = 0.04 mg/m; standard deviation = 0.07 mg/m
Banbury Cross and Crestdale: mean = 0.02 mg/m; standard deviation = 0.02 mg/m
Aspen Glow and Warm Walnut: mean = 0.17 mg/m; standard deviation = 0.0.10 mg/m

The standard deviation of the measurements was elevated due in part to the erratic response of the front DustTrak on November 8th, which produced some negative values, although negative values were also obtained on November 3rd. It is likely that some of these negative values were a result of measurements very near the detection limit of the instruments and the noise in the emission factor may be due to slight zero drift, which cannot be completely eliminated. An emission factor of 0.02 represents a net concentration difference of only 0.005 mg/m^3, which is well within expected daily drift. The conclusion is that comparison of emission rates with silt sampling on "clean" portions of roads will generally be near the SCAMPER detection limit and therefore will produce data with low confidence limits.

Comparison of SCAMPER and AP-42 silt sampling emission rates. Figure 2 is a plot of the emission factors calculated from AP-42 silt sampling (X-axis) compared to ± average values obtained from the SCAMPER for the seven segments of roads where the silt sampling was conducted. All sampling days were included for the SCAMPER data. The R^2 value from the least squares regression is 0.86 and the slope is 0.29, indicating that the SCAMPER emission rates are approximately one third the values derived from silt sampling. The correlation, however, is steered by the single high emission location (Emerald Stone and Sapphire Light). The primary conclusion is that SCAMPER and AP-42 emission rates are generally correlated. This result has been consistently observed from previous phases of this study and reported upwind-downwind emission rate determinations from paved roads. Correlations are not necessarily expected to be high since silt loading is merely a surrogate for the direct PM emission measurement.

Source-specific Analysis. A list of segments was supplied by DAQEM personnel that were typical of roads with unpaved shoulders, near construction activities, and next to vacant land. Table 8 shows these segments along with the coordinates of the endpoints that were obtained from a Google™ Earth interactive map. For the vacant land comparison intersection endpoints were not supplied so we chose the endpoints from a Google™ Earth aerial photographs. All of these segments were from sample route 2 (transitional area).

Figure 2. Comparison of PM_{10} emission rates determined by AP-42 silt sampling and the average segment values obtained with the SCAMPER.

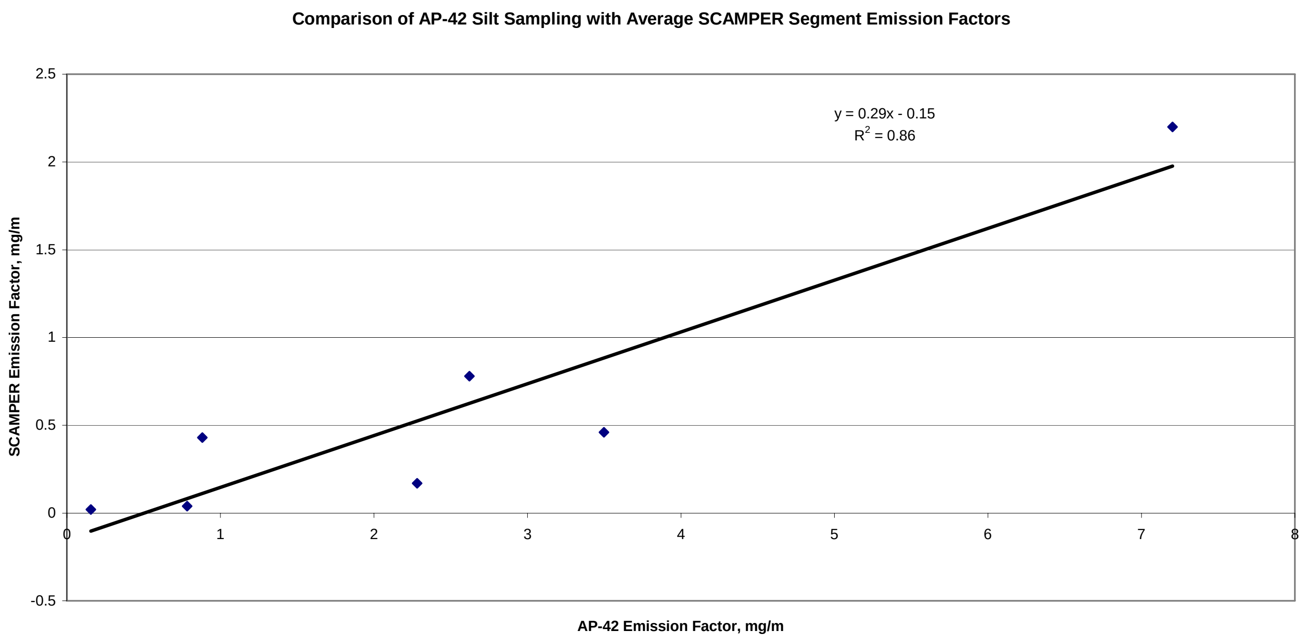


Table 8. Road segments typical of roads with unpaved shoulders or near construction activities or vacant land

Segment Description	Intersection 1	Intersection 2	Latitude 1	Latitude 2	Longitude 1	Longitude 2
Unpaved shoulders						
Arterial: Losee	Washburn	Lone Mountain	36.254267	36.247053	-115.116938	-115.117080
Curbed Comparison Arterial: Losee	Lone Mountain	Craig	36.246774	36.239811	-115.116561	-115.117049
Arterial: Craig	Losee	5th St.	36.239912	36.23962	-115.116811	-115.134213
Arterial Assessment: Craig	Bruce	Donna	36.239869	36.23965	-115.125515	-115.129825
Arterial Assessment: Lone Mountain	Bruce	Donna	36.247064	36.246845	-115.125946	-115.130191
Collector: Washburn	Donna	Bruce	36.254364	36.254105	-115.125907	-115.130205
Collector: Washburn	Lawrence	Bruce	36.25433	36.254184	-115.12137	-115.12574
Collector: Bruce	Washburn	Lone Mountain	36.254063	36.247114	-115.125761	-115.125944
Construction Activities						
Arterial: Losee	Washburn	Lone Mountain	36.254267	36.247053	-115.116938	-115.117080
Collector: Washburn	Lawrence	Losee	36.254319	36.254201	-115.116971	-115.121302
Collector: Washburn	5th St.	Donna	36.254334	36.254096	-115.130289	-115.134673
Collector: 5th Street	Washburn	La Madre	36.254163	36.250555	-115.134579	-115.134878
Local: Donna	Washburn	Emerald Stone	36.25414	36.25153	-115.13025	-115.13044
Local: Emerald Stone	Sappire Light	Drifting Pebble	36.2517	36.251444	-115.126623	-115.129667
Local: Graphite Ash	Sappire Light	Drifting Pebble	36.247553	36.247401	-115.126581	-115.129506
Vacant Lands						
Arterial: Nevada Power Equipment on Losee	Lone Mountain	Parking Lot	36.246830	36.254364	-115.116561	-115.117049
Arterial: Losee north of Mendenhall	Parking Lot	Mendenhall	36.254178	36.241858	-115.116561	-115.117049

Table 9 shows the mean PM_{10} emission rate averaged over all of the test runs along with the standard deviation. The PM_{10} emissions on Losee Road were a factor of two higher on the segment with unpaved shoulders. Craig was over a factor three higher than Lone Mountain between Bruce and Donna. For the collector roads the PM_{10} emission rates on Washburn with curbs and gutters was between that of segments of Washburn and Bruce that had only partial shoulder improvement. Except for 5th St, all of the construction segments were higher than typical improved roads without construction activities. The two roads with vacant land along side were only somewhat higher than 5th St.

Table 9. PM_{10} emission rates of segments typical of roads with unpaved shoulders or near contraction activities or vacant land.

UNPAVED SHOULDERS	PM10 EF mg/m Ave	PM10 EF mg/m Std Dev
Arterial		
Losee: Washburn to Lone Mountain - Two-lane road, gravel shoulders	1.85	0.85
Losee: Lone Mountain to Craig - Both road directions are paved, full curb and gutter	0.79	1.03
Craig: Losee to 5th Street - Full curb and gutter	0.12	0.14
Craig: Bruce to Donna - Full curb and gutter, vacant land on travel side	0.40	3.45
Lone Mountain: Bruce to Donna - Full curb and gutter	0.12	0.02
Collector		
Washburn: Donna to Bruce - Fully improved curb and gutter	0.43	0.26
Washburn: Lawrence to Bruce - No curb and gutter on travel side. Full improvements on opposite side	0.62	0.47
Bruce: Washburn to Lone Mountain - Curb and gutter on travel side. No curb and gutter, though stabilized on opposite side	0.32	0.15

CONSTRUCTION ACTIVITIES	PM10 EF mg/m Ave	PM10 EF mg/m Std Dev
Arterial		
Losee: Washburn to Lone Mountain - Roadway is a two lane road with gravel shoulders, limited construction	1.85	0.85
Collector		
Washburn: Lawrence to Losee - Narrow road, unpaved sholders	2.06	1.77
Washburn: 5th Street to Donna - no curb and gutter on travel side, opposite side has full improvements and limited landscaping	0.70	0.35
5th Street: La Madre to Washburn - New road construction with curb and gutter, travel side has partial construction activity	0.10	0.09
Local		
Emerald Stone: Drifting Pebble to Sapphire Light - Fully Improved. Track-out/on from construction activities.	1.87	0.81
Granite Ash: Sapphire Light to Drifting Pebble-- Fully improved. Limited track-out/on from construction activities.	0.87	0.21

VACANT LANDS	PM10 EF mg/m Ave	PM10 EF mg/m Std Dev
Arterial		
Nevada Power Equipment: Losee - Unpaved	0.29	0.32
Industrial Lots North of Mendenhall: Losee - Paved industrial lots	0.29	0.19

Phase III conclusions. CE-CERT concluded that the overall relative variability of PM_{10} emission measurements using the SCAMPER was consistently 25-30%. Since these values include environmental uncertainty, the precision of the SCAMPER measurement method is most likely considerably less than this. The data summarized in the previous section show that PM_{10} emission rates were generally near the detection limit except when occasional "hot spots" were encountered, which show up as spikes and peaks. This is consistent with all of the previous SCAMPER data we have collected.

The test loops chosen for high PM_{10} emission potential gave rates about a factor of twenty higher than the loop chosen for minimal PM_{10} potential. No significant change of PM_{10} emission rates was observed during the course of the day. The emissions on the high potential test route (Loop 2) dropped by a factor of two on weekend days.

The comparison of averaged SCAMPER segment data with AP-42 silt sampling at seven test sites resulted in an R^2 of 0.86 with the SCAMPER results lower by about a factor of three.

The results show that SCAMPER measurement system is useful for both quantitatively identifying PM_{10} "hot spots" and determining the overall emission rate from roadways with a known and acceptable precision. Since SCAMPER is a more direct measure of PM emission rates, we suggest that it is a more accurate measurement of rates than silt sampling.

DISCUSSION

Peer Review

A two-day workshop was held with all contractors and DAQEM staff participating in the Phase II field study to discuss study findings. It was noted that preparing consolidated report fell outside of the existing contracts. Individual researchers have just begun to publish individual papers from this work in peer review forums and the primary authors of this paper do not have an updated status list at this time.

The Phase III field study was developed by DAQEM staff on consultation with the participating consultants based in part findings presented in the Phase II workshop. The findings were reviewed by Region IX staff, who requested additional documentation and analysis before a vehicle-based mobile sampling system data set could be accepted as a local paved road PM_{10} emission factor. Specifically, Region IX staff requested additional documentation on the systems and methods used; additional data analysis; additional data (including meteorological data); and additional field work to document the uncertainty of the AP-42 statistical estimating method for comparison with the vehicle-based mobile sampling system. The Clark County DAQEM has earmarked funding for additional consulting services and staff resources to develop a more comprehensive report on the Phase III field study that will address these issues.

Ongoing and Additional Work

Maricopa County has contracted with CE-CERT to conduct a study modeled roughly on Clark County's Phase II field study. Maricopa County staff used a similar approach to developing the sampling route and the study will entail sampling during multiple seasons. The study will include a meteorological analysis, but will employ only one vehicle-based sampling system and will not include an AP-42 silt sampling component. Clark and Maricopa counties are committed to working collaboratively on obtaining EPA approval for an alternative emissions measurement method.

As detailed in the methodology section of this paper, Clark County is planning a Phase IV empirical study, which will utilize upwind/downwind sampling, SCAMPER/TRAKER vehicle-based mobile sampling systems, and AP-42 silt sampling under controlled conditions. This study was originally planned for May-June 2006, but funding issues have now delayed the study for several months.

The EPA Region IX staff and EPA OAQPS staff have been very supportive of Clark and Maricopa County's efforts to date. Members of the Western States Air Partnership (WRAP) have recently indicated an interest to assisting with this effort.

CONCLUSIONS

Vehicle-based mobile sampling system measurements correlate with real world conditions, as expected. Both systems measure very low emissions on clean streets in developed communities and much higher emissions on silt-impacted roads in developing areas. Each of the tested state-of-the-art systems have strengths and weaknesses related to each system's design and configuration. Work is ongoing to better refine performance factors for each system. Both systems have demonstrated the ability to reliably take measurements on many miles of roadway in a relatively short period of time. This ability is critical to the development of a paved road emission factor that representative of the paved road network to which it is applied.

IMPLICATIONS

In calendar year 2000, Clark County DAQEM developed the PM_{10} paved road emissions inventory that was incorporated into the now federally-approved Clark County PM_{10} SIP. During the public comment period, this inventory was widely criticized by both members of the public and public works agencies, even though Clark County had developed emissions factors based on local data in accordance with AP-42 protocols. In the ensuing five years, Clark County has invested tremendous resources in improving local emissions factors using the AP-42 approach. The emissions factors computed using the AP-42 statistical equation quite simply cannot be reconciled with real world conditions. Comparison of SCAMPER EF data to AP-42 EF data indicates that AP-42 EF data are significantly higher than EF's measured with vehicle-based technologies. Although Clark County believes that both the accuracy and precision of the basic AP-42 statistical equation and the representativeness of using a few point samples to characterize an entire road network are highly suspect, we have not yet completed an analysis that demonstrates these assertions.

SCAMPER and TRAKER data show variations in paved road PM_{10} emissions at much higher spatial resolution than the AP-42 method. Additionally, repeated SCAMPER measurements in Phase III show significant variations in paved road emissions over time scales of several days, and indicate a relationship between paved road emissions and local activity patterns. This high degree of spatial and temporal resolution could only be achieved by AP-42 sampling at a much greater cost. It is now well documented that use of vehicle-based mobile sampling systems can provide planning agencies with PM_{10} emissions information at much higher spatial and temporal resolutions that would facilitate creation of more accurate emissions inventories.

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