Reference # 6

MRI REPORT

Unpaved Road Emission Impact

Final Report

For Arizona Department of Environmental Quality

MRI Project No. 9525-L

March 18, 1991

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March 18, 1991

Ms. Kathryn D. Stevens
Air Quality Assessment Section
Arizona Department of Environmental Quality
2005 North Central Avenue
Phoenix, AZ 85004

Subject: Submission of Final Report Entitled "Unpaved Road Emission Impact"
MRI Project No. 9525-L

Dear Ms. Stevens:

Enclosed please find five (5) copies of the final report prepared in response to your December 3 and February 26 letters, as well as our January 2 telephone conversation. With regard to six specific items outlined in your letter, please note that:

1. As we agreed over the phone, I sent a copy of a Southern Research Institute report to the USEPA. We believe that this report meets the DEQ's stated needs of an overall objective description of the exposure profiling method (i.e., not prepared by MRI). The material starting on page 58 of the SoRI report indicates that exposure profiling test results are largely insensitive to numerical scheme used.

   The same relative insensitivity was found during our internal, redundant quality assurance program for this study. MRI employs up to two independent numerical integration schemes to cross-check the primary method. We consider this validation technique and associated software to be proprietary and we further believe that greater elaboration is outside the scope of work.

2. As I mentioned during our phone conversation, arithmetic averages have been routinely employed in applications of the AP-42 models because of the very small errors involved. For example, the error associated solely with the use of arithmetic average speeds in Equations (4-1), (4-2), (4-6), and (4/7) is less than 5% over the range of 35 of 55 mph. As I also mentioned, any error associated with the use of arithmetic averages in log-linear models could be eliminated by calculating an emission factor for each vehicle pass and then summing individual emission factors to form a total factor.

3. Material has been added discussing the different models listed.

4. Table 4-7 has been added to the report as an example and an additional recommendation has been made in Section 5. However, as I mentioned over the phone, the DEQ would need to specify any "trigger" concentration value, the associated averaging time, and the applicable background concentration. These points are reiterated in the new recommendation.

5. As we discussed over the phone, the DEQ during the summer of 1989 requested TSP field measurements because of the interest in possibly keeping a secondary state standard based on TSP. A statement has been added to the Introduction. Figure 4-3 now presents both TSP and PM_{10} concentrations.

6. Additional recommendations are presented in Section 5.

Furthermore, as you mentioned over the phone, the DEQ received the filter log sheets (and other information requested on page 2 of your December 3 letter) after the letter was sent.

Please call if you have any questions or comments.

Sincerely,

MIDWEST RESEARCH INSTITUTE

Gregory E. Muleski
Principal Environmental Engineer

GEM/gls

Enclosures

MRI REPORT

Unpaved Road Emission Impact

Final Report

For Arizona Department of Environmental Quality
2005 North Central Avenue
Phoenix, Arizona 85004

Attn: Kathryn Stevens

MRI Project No. 9525-L

March 18, 1991

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PREFACE

This report describes the program conducted under Arizona Department of Environmental Quality (DEQ) Grant No. 2283-000000-4-6-GP-0016. All work was performed in Midwest Research Institute (MRI's) Air Quality Assessment Section. The report was prepared by Dr. Gregory E. Muleski.

Approved:

Charles F. Holt, Ph.D., Director
Engineering and Environmental
Technology Department

March 18, 1991

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SECTION 1

INTRODUCTION

The Arizona Department of Environmental Quality (DEQ) requires a means to accurately assess particulate matter emissions from vehicles traveling on rural unpaved roads. However, some previous investigations have questioned the applicability of the U.S. Environmental Protection Agency's (EPA's) current unpaved road emission model to roads in arid and semiarid climates.

This report describes the results from a research program conducted by Midwest Research Institute (MRI) with two primary objectives:

1. Recommend a mathematical model for DEQ use in estimating emissions from unpaved rural roads in Arizona, based on a review of historical data as well as of Arizona-specific field sampling results.

2. Examine the feasibility of using an ambient concentration standard to regulate public unpaved roads in Arizona, based on analysis of field measurements.

Two size ranges of particulate matter (PM) are of concern in this study:

PM_{10} Particulate matter no greater than 10 μm in aerodynamic diameter. PM_{10} is the current basis for the EPA particulate matter National Ambient Air Quality Standards (NAAQSs).

TSP Total suspended particulate which served as the basis for the previous EPA NAAQSs. TSP is defined as the concentration measured by the standard high volume (hi-vol) air sampler.

TSP measurements were requested because the DEQ believed the TSP size range may prove useful in establishing a near-source concentration standard.

The remaining sections of this report present (a) a review of available information; (b) a description of the field sampling methodology; (c) a discussion of the results from the field sampling program; and, (d) recommendations for DEQ's consideration.

SECTION 2

REVIEW OF AVAILABLE INFORMATION

ESTIMATION OF EMISSIONS FROM UNPAVED ROADS

Several investigators have questioned the applicability of the EPA unpaved road emission factor model to roads in arid and semiarid climates. This model--referred to as the "AP-42 model" because of its inclusion in an EPA document with that number[1]--uses road surface and vehicle parameters to estimate the amount of particulate matter emitted from vehicle travel. Questions raised involve the perceived systematic underprediction of emissions from roads in the western United States.

As part of the process to recommend models to the DEQ, MRI performed a review of historical unpaved road data. (Table A-1 in Appendix A lists the test data base considered.) These tests represent "independent" data--that is, none of the tests were used to develop the AP-42 emission factor model.

Each test location was classified as "eastern" or "western" on the basis of a common soil classification scheme. For "pedalfer" soils, precipitation exceeds evaporation; these are the soils common in the eastern United States. Conversely, evaporation is greater than precipitation in the West and the common soils are termed "pedocals." The 97th meridian is approximately coincident with the dividing line between pedalfer and pedocal soils.

Most of the available data are from industrial roads (such as those at coal mines and steel plants) rather than from the rural public roads of interest in this study. Consequently, the data base reviewed is generally characterized by heavier vehicles and slower travel speeds than would be expected for rural public unpaved roads. (That is also the case for the data used in developing the AP-42 model.)

Associated with each test is a ratio related to emission factor performance. This ratio is found by dividing the emission factor reported for the test into the value obtained from the AP-42 emission factor equation.

The equation uses road surface and vehicle parameters to estimate emissions under dry conditions:

$$e = k\,(5.9)\,(s/12)\,(S/30)\,(W/3)^{0.7}\,(w/4)^{0.5} \qquad (2\text{-}1)$$

where:

e	=	size-specific emission factor in units of pounds per vehicle mile traveled (lb/vmt)
k	=	dimensionless particle size range multiplier (equals 0.36 for PM_{10})
s	=	silt content (%) of the road surface material
S	=	mean vehicle speed (mph)
W	=	mean vehicle weight (tons)
w	=	mean number of wheels per vehicle

Thus the performance of the equation is measured by the ratio

$$R = e/q \qquad (2\text{-}2)$$

where

e	=	emission factor obtained from Equation (2-1)
q	=	emission factor measured during the field test

Values of R less than one indicate underprediction.

To examine the model's applicability to unpaved roads in arid and semiarid climates, the data were subjected to several analyses. First, summary statistics were calculated for the variables related to the road surface material in Table A-1:

	Moisture (%)		Silt (%)	
	West	East	West	East
Number of cases	54	29	59	51
Mean	3.0	1.2	13	10
Standard deviation	2.7	1.2	7.8	4.9

Both material properties differ at the 5% significance level between the east and west. Note, however, that the moisture data would not support an a priori alternative hypothesis that road surfaces are "drier" in the west.

Because of the primary interest in rural roads, tests with light-duty traffic (i.e., vehicle weight less than 4 tons) were separated from the other data. Summary statistics for this "reduced" data set follow:

	Moisture (%)		Silt (%)	
	West	East	West	East
Number of cases	16	10	17	14
Mean	0.84	1.6	8.9	12
Standard deviation	0.60	0.56	1.4	2.0

Note that in the reduced data set, the moisture values differ significantly and in the manner of the a priori alternative hypothesis (i.e., drier in the west).

The following are geometric summary statistics for the ratio R in the reduced data set:

	Geometric mean	Standard geometric deviation	No. cases
West	0.94	2.69	17
East	0.52	1.95	14

For this data set, then, the AP-42 model only slightly underpredicts (on average) emissions from light-duty traffic on roads in the western portion of the country. On the other hand, the underprediction is much more severe for roads in the eastern United States. Note that these findings conflict with the notion that unpaved road emissions are systematically underpredicted in arid and semiarid climates.

A series of Mann-Whitney U tests[2] were conducted on the ratio R. Neither the entire nor the reduced data sets exhibited a significant difference in R between east and west. Although the differences were not significant, the eastern roads tended to be have lower predicted-to-observed ratios than did the western roads. Again, this contrasts with the notion of systematic underprediction for western roads.

Finally, the entire data set indicated that moisture content is significantly linearly correlated with R. However, no significant relationship was found when the data were divided into eastern/western and light-/heavy-duty categories.

In summary, although some findings suggest that the moisture content of the road surface material may influence model performance, the available data do not provide evidence of systematic underestimation of emissions from western roads.

EXAMINATION OF APPLICABLE REGULATORY FORMATS

To determine current practice in regulating dust emissions, MRI contacted the PM_{10} topic coordinators at EPA Regions VI, VIII, IX, and X during April 1990. Each coordinator was asked to describe any current attempts to regulate emissions from public unpaved roads in the arid and semiarid portions of his/her jurisdiction. Only one such attempt was identified-- namely, Regulation VIII drafted for the San Joaquin Valley Air Basin Non-Attainment Area Plan.

MRI reviewed two drafts of the regulation (dated April 11, 1990, and May 3, 1990). Because the regulation is in draft form at this writing, it is impossible to say how provisions will be implemented in practice. Nevertheless, the draft San Joaquin regulation is substantially different from most previous regulations. A wide variety of mostly unregulated open dust sources--such as public paved roads, landfills, and construction/demolition activities--are covered by rules contained in the draft regulation. Furthermore, a written PM_{10} Dust Prevention and Control Plan must be approved by the Air Pollution Control Officer (APCO) before any dust-emitting activities take place.

Specific to unpaved roads, Rule 806 of the draft regulation requires a permit for any road over one-half mile in length with more than 20 vehicle trips per day be permitted. The control plan must demonstrate a minimum of 25% overall average control; the regulation requires that this minimum increase by 25% every three years to a maximum of 75%. Finally, with the exception of emergency vehicles, the rule prohibits the operation of any vehicle on an unpaved road at a speed of more than 25 mph unless "suitable APCO approved reasonable dust control measures are applied"; no specific exemptions to this prohibition are noted.

Again, because of the draft nature of the regulation, it is not clear how provisions will be implemented in practice. At the very least, considerably greater labor will be required on the part of the air regulatory agency to review and approve dust control plans and to permit and monitor previously unregulated open dust sources. In addition, it is possible that some provisions--such as the 25 mph speed limit or demonstration that a minimally acceptable overall average control efficiency has been met--will require additional interpretation and may be challenged in the court system.

In summary, it is not believed that any agency currently regulates emissions from public unpaved roads in the arid or semiarid environments of the United States. Although one draft regulation addressing public unpaved roads was found, the lack of practical experience precludes further discussion of its applicability to roads in Arizona. It is recommended, however, that the DEQ monitor the progress of draft Regulation VIII by maintaining contact with the EPA Regional office.

SECTION 3

FIELD TEST METHODOLOGY

A major portion of this program was devoted to collection of Arizona-specific field data. Prior to the field activities, MRI submitted a test plan which described sampling methods and associated quality assurance procedures. The approved plan is presented as Appendix B. The remainder of this section summarizes the major features of the testing program to allow the reader to interpret the results presented in Section 4.

Exposure profiling, which formed the basis of the measurement technique, relies on simultaneous multipoint sampling over the effective cross-section of the dust plume. This method employs a direct mass-balance calculation similar to standard EPA Method 5 stack testing rather than appealing to indirect calculations requiring the use of generalized and uncalibrated dispersion models (as in the so-called "upwind/downwind" method).

As shown in Figure 3-1, sampling equipment was deployed in two downwind vertical arrays, "D1" and "D2," and a one upwind vertical array, "U." In addition, DEQ TSP and PM_{10} samplers were operated both at the upwind location and at a station farther downwind from the road. Note that the distances shown in the figure represent nominal distances from the road; actual distances depended upon terrain, vegetation and logistical considerations. Section 4 presents detailed information on the spacing of the samplers from the roadway.

Arrays D1 and U were fitted with cyclone preseparators to sample PM_{10} emissions. During half of the sampling periods, array D2 was equipped with cyclones; during the other periods, samplers were fitted with standard hi-vol roofs to collect TSP samples. The DEQ supplied a standard hi-vol and a dichotomous sampler ("dichot") to monitor background TSP and PM_{10} concentrations, respectively, at the upwind station. In addition, one pair each of DEQ hi-vols and dichots monitored near-field concentrations at a nominal 100 foot distance from the road.

In addition to particulate samplers, a variety of meteorological equipment was deployed at each test site. That equipment, as well as additional details related to sampling equipment and testing procedures, are presented in Appendix B.

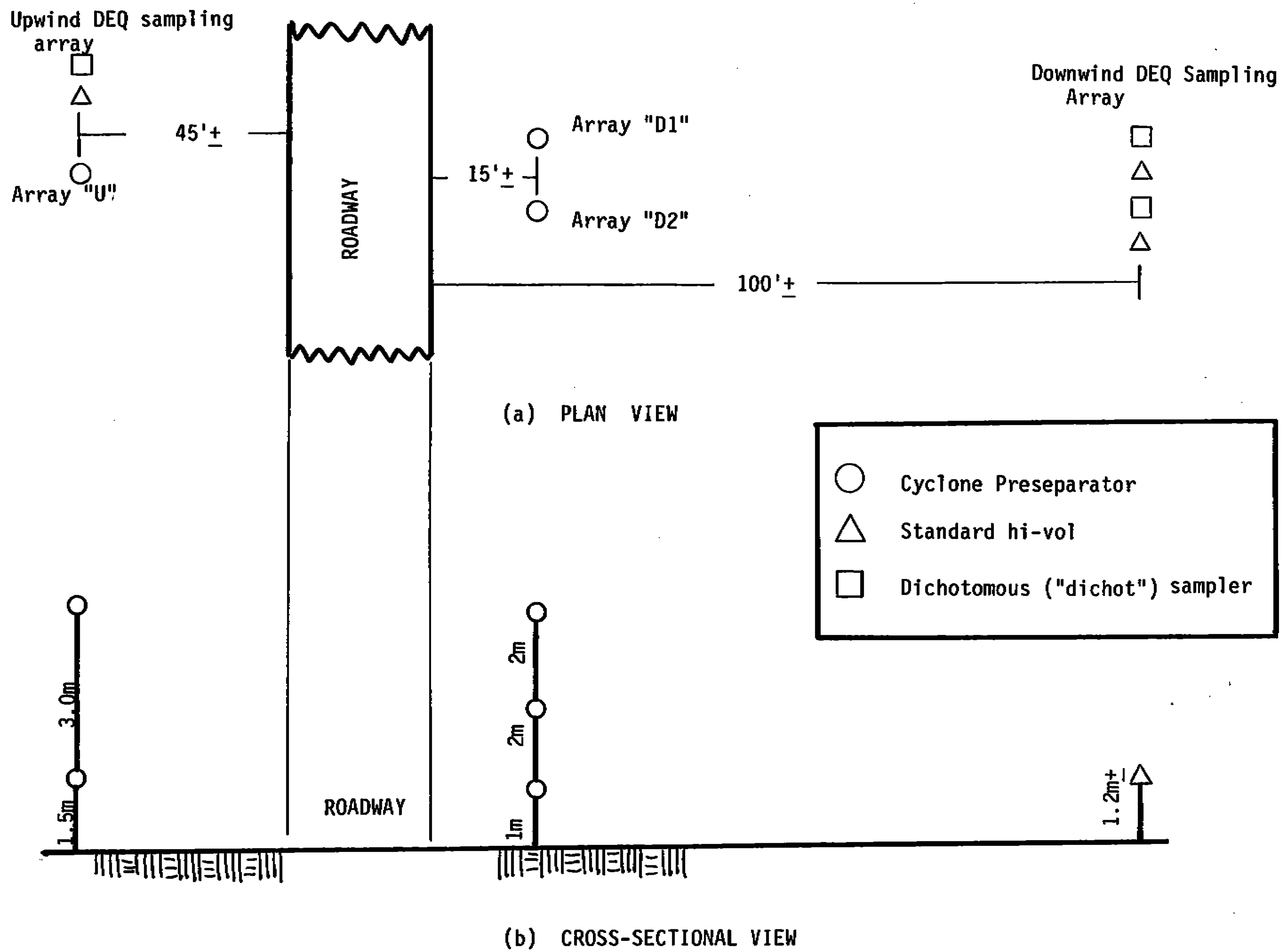


Figure 3-1. Sampling locations.

SECTION 4

RESULTS AND DISCUSSION

This section describes the results of the field testing program and interprets the results in light of the two major program objectives:

- Recommendation of a mathematical emission factor model for use with rural unpaved roads in Arizona

- Examination of near-field concentrations and the implications for development of a concentration-based standard

FIELD TEST RESULTS

Three test roads were considered during the field sampling program. Each site was a publicly accessible unpaved road in a rural area of southern Arizona. Figure 4-1 indicates the general test area; Figure 4-2 provides a schematic of the sampling locations at each site.

A total of 27 PM_{10} and 9 TSP emission tests were conducted during the period of May 22 to June 5, 1990. This test matrix represents triplicate PM_{10} and single TSP emission tests for each of three vehicle speeds on each of the three test roads. Because two downwind sampling arrays were used, the 36 tests correspond to 18 sampling periods during which both source emissions and the resulting near-field concentrations were measured.

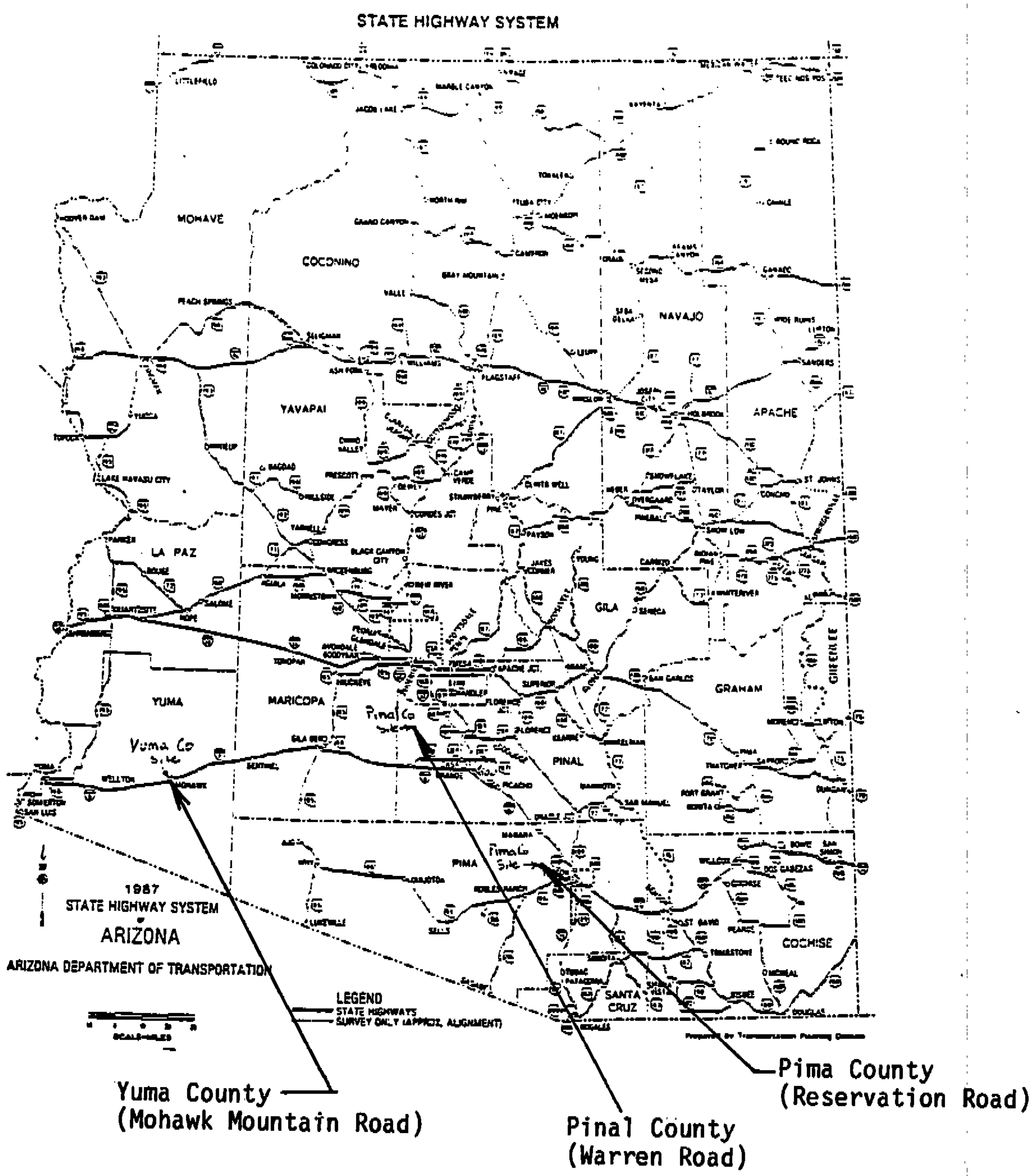


Figure 4-1. General location of test sites.

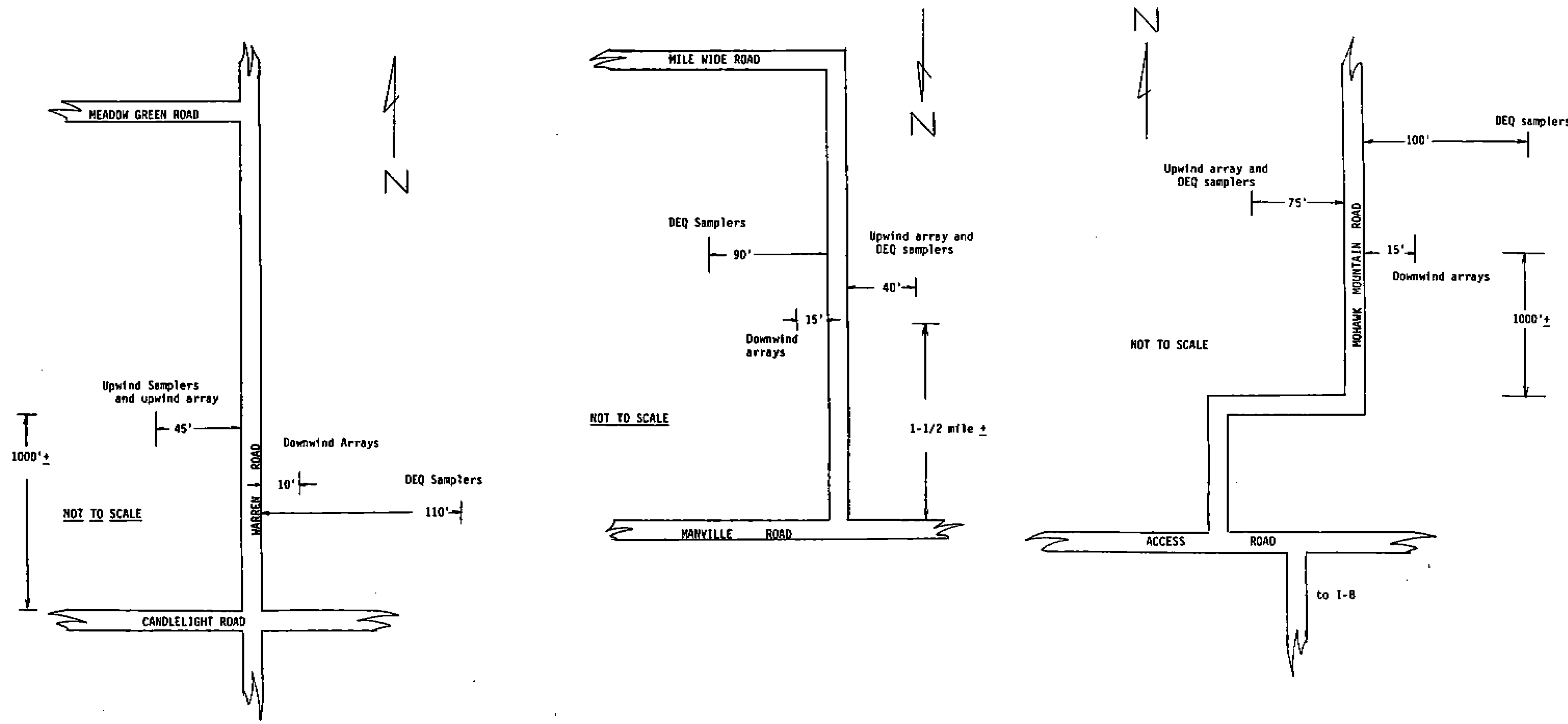


Figure 4-2. Sampling locations at the Pinal, Pima, and Yuma County sites.

Table 4-1 presents site-specific test parameters for each of the 36 tests. Test runs are identified by a two-digit suffix to the "AZ" test code prefix:

- Runs AZ-01 through AZ-12 were conducted at the Pinal County test site, Warren Road.

- Runs AZ-21 through AZ-33 were performed on Reservation Road in Pima County. (Note that MRI conducted a replacement test, AZ-33, when an improper filter seal was found on run AZ-30.)

- Runs AZ-41 through AZ-52 were conducted at the Yuma County test site, Mohawk Mountain Road.

Note that "captive" vehicle passes were used to control traffic parameters during testing periods. The vehicle speeds tested (35, 45 and 55 mph) were chosen to represent the range of common, legal speeds found on rural unpaved roads in Arizona.

Representative concentration values at various locations are shown in Table 4-2. When more than one concentration measurement was available, the table entry reflects the mean of the measured values. With few exceptions, the downwind concentrations are more than an order of magnitude greater than the upwind values. Exceptions are almost exclusively restricted to the third test site (Yuma County) where unfavorable wind conditions resulted in prolonged breaks during testing. Nevertheless, each downwind concentration in Table 4-2 is substantially (factor of 2 or more) higher than the corresponding upwind value.

On average, samplers at the 100-ft downwind stations recorded TSP and PM_{10} values roughly one-fifth of the corresponding value at the 15-ft location. Thus, the dust plume at the 100-ft location was (on average) five times more dilute than in the immediate vicinity of the road. The mean ratio of PM_{10} to TSP concentrations was approximately one-fourth at each downwind location.

Table 4-1. TEST SITE PARAMETERS

Run	Date	Wind speed[a] (mph)	Duration (min)	Vehicle passes[b]	Mean vehicle[c] Weight (ton)	Speed (mph)	Wheels
AZ-01,02[d]	5-22-90	4.9	21	51 + 2	1.9	45	4.0
AZ-03,04	5-22-90	6.0	22	53 + 2	1.9	45	4.0
AZ-05,06	5-22-90	4.2	71	53 + 9	1.9	55	4.1
AZ-07,08[d]	5-22-90	4.8	31	50 + 4	1.9	55	4.0
AZ-09,10[d]	5-23-90	5.9	97	161 + 11	1.9	35	4.0
AZ-11,12	5-24-90	3.9	96	159 + 19	1.9	35	4.0
AZ-21,22	5-26-90	8.2	42	95 + 3	1.6	45	4.0
AZ-23,24[d]	5-27-90	5.0	47	48 + 2	1.6	45	4.0
AZ-25,26[d]	5-27-90	5.4	27	50 + 1	1.6	55	4.0
AZ-27,28	5-27-90	7.4	39	75 + 2	1.6	55	4.0
AZ-29,30	5-27-90	7.0	50	150 + 3	1.6	35	4.0
AZ-31,32[d]	5-29-90	4.0	82	101 + 4	1.6	35	4.1
AZ-33	5-30-90	6.4	46	130 + 4	1.8	35	4.0
AZ-41,42	6-1-90	3.8	96	150 + 5	1.6	35	4.1
AZ-43,44[d]	6-1-90	3.7	76	104 + 3	1.6	35	4.0
AZ-45,46[d]	6-3-90	3.9	48	72 + 0	1.6	55	4.0
AZ-47,48	6-4-90	3.0	97	35 + 0	1.6	55	4.0
AZ-49,50	6-5-90	5.2	72	34 + 2	1.6	45	4.3
AZ-51,52[d]	6-5-90	5.0	115	42 + 3	1.6	45	4.0

[a] At 1.5 m height.
[b] First number represents captive traffic; second, noncaptive.
[c] Means for weight and speed based on captive passes.
[d] TSP test, array D2 fitted with standard hi-vols.

Table 4-2. REPRESENTATIVE CONCENTRATIONS ($\mu g/m^3$)[a]

	TSP			PM_{10}			
		Downwind		Upwind		Downwind	
Run	Upwind	15 ft[b]	100 ft	Cyclone[c]	Dichot	15 ft[b]	100 ft
AZ-01,02	19	9,780	2,050	16	13	1,510	329
AZ-03,04	19	--	1,150	16	13	1,640	299
AZ-05,06	19	--	973	16	13	1,200	336
AZ-07,08	19	9,390	1,530	16	13	1,480	476
AZ-09,10	46	4,600	785	6	18	550	238
AZ-11,12	23	--	716	25	22	988	194
AZ-21,22	15	--	2,850	8	29	1,020	582
AZ-23,24	29	4,360	2,420	9	13	912	419
AZ-25,26	29	11,900	3,640	9	13	2,300	849
AZ-27,28	29	--	4,040	9	13	2,120	1,020
AZ-29,30	29	--	3,340	9	13	1,060	864
AZ-31,32	179	3,110	1,840	65	88	953	332
AZ-33	42	--	--	27	35	343	--
AZ-41,42	69	--	647	37	37	1,120	156
AZ-43,44	69	2,990	447	37	37	1,480	106
AZ-45,46	40	7,030	1,580	17	20	1,820	425
AZ-47,48	43	--	416	23[d]	27	968	194 157
AZ-49,50	70	--	302	56	51	754	98
AZ-51,52	70	890	272	56	51	591	98

[a] At a nominal 1.2-m height.
[b] Interpolated from 1- and 3-m values from D1 and D2 arrays.
[c] Average of 1.5- and 4.5-m values.
[d] 1.5-m value; 4.5-m sampler blown over.

Table 4-3 summarizes both the emission factors and the road surface material properties measured during the field program. The material property entries represent the arithmetic means from a minimum of three surface samples taken from each road.

In general, Table 4-3 shows that there is relatively little variation between the three PM_{10} emission factors measured for an individual travel speed on a particular road. The largest relative standard deviation found for tests in Pima and Pinal Counties is 20%. The results for Yuma County show greater variation (presumably due to the less favorable wind conditions), but the relative standard deviations are still less than 40%. Furthermore, the simultaneous (collocated) PM_{10} source measurements show little variation:

Simultaneous PM_{10} tests	Percent difference in emission factors
AZ-03,04	3.5
AZ-05,06	7.8
AZ-11,12	5.3
AZ-21,22	12
AZ-27,28	0.3
AZ-41,42	41
AZ-47,48	9.4
AZ-49,50	14

In summary, then, the field testing appears to have resulted in very reproducible emission factor measurements.

Table 4-3. SURFACE MATERIAL PROPERTIES AND MEASURED EMISSION FACTORS

Run	Road surface material: Silt content (%)	Road surface material: Silt loading (g/m²)	Road surface material: Moisture content (%)	Emission factor (lb/vmt)
PM_{10} tests:				
AZ-01	11	110	0.20	0.777
AZ-03	11	110	0.20	0.916
AZ-04	11	110	0.20	0.884
AZ-05	11	110	0.20	1.350
AZ-06	11	110	0.20	1.460
AZ-07	11	110	0.20	0.969
AZ-09	11	110	0.20	0.497
AZ-11	11	110	0.20	0.667
AZ-12	11	110	0.20	0.632
AZ-21	7.4	32	0.22	0.812
AZ-22	7.4	32	0.22	0.920
AZ-23	7.4	32	0.22	1.160
AZ-25	7.4	32	0.22	1.550
AZ-27	7.4	32	0.22	2.010
AZ-28	7.4	32	0.22	2.010
AZ-29	7.4	32	0.22	0.728
AZ-31	7.4	32	0.22	0.633
AZ-33	7.4	32	0.22	0.652
AZ-41	4.3	11	0.17	1.030
AZ-42	4.3	11	0.17	0.677
AZ-43	4.3	11	0.17	1.430
AZ-45	4.3	11	0.17	1.280
AZ-47	4.3	11	0.17	2.880
AZ-48	4.3	11	0.17	2.620
AZ-49	4.3	11	0.17	2.970
AZ-50	4.3	11	0.17	2.570
AZ-51	4.3	11	0.17	1.910
TSP tests:				
AZ-02	11	110	0.20	4.560
AZ-08	11	110	0.20	6.160
AZ-10	11	110	0.20	3.860
AZ-24	7.4	32	0.22	5.940
AZ-26	7.4	32	0.22	9.240
AZ-32	7.4	32	0.22	3.190
AZ-44	4.3	11	0.17	3.190
AZ-46	4.3	11	0.17	5.350
AZ-52	4.3	11	0.17	3.560

RECOMMENDATION OF MATHEMATICAL MODELS

Models for Emission Factor Estimation

The following table presents summary statistics for the performance of the AP-42 emission factor model (as given in Equations [2-1] and [2-2]) when applied to the AZ test series,

	TSP	PM_{10}
Number of cases	9	27
Geometric mean ($\bar{x}_g$) of R	0.765	1.13
Standard geometric deviation (s_g) of R	1.52	2.23
Minimum value of R	0.477	0.262
Maximum value of R	1.34	3.58

The data do not suggest that the AP-42 equation severely underestimates emissions from unpaved roads in Arizona. The variability in R (s_g) is not particularly surprising, given that two-thirds of the AZ tests were conducted with vehicle speeds outside the range of the AP-42 emission factor model.[1]

Although the performance of the AP-42 appears reasonably good when applied to the field tests conducted in this study, another emission factor model is recommended below. As noted in the last paragraph, common travel speeds on rural unpaved roads in Arizona generally fall outside the range of values in the AP-42 model's underlying data base. Fully 90% of tests in the data base were conducted with vehicle speeds slower than 35 mph. The data base also consists mostly of roads in industrial settings; roughly 80% of the tests were conducted on industrial rather than public roads. As a result of the numerous industrial road tests, the data base generally reflects heavier vehicles than are common on rural roads. Given the interest in rural unpaved road emissions in Arizona, it was decided that development of an empirical relationship specific to that situation was warranted.

Because of the many replicate PM_{10} tests during identical source conditions (road, travel speed, wind speed, duration), it was first necessary to average the emission factors for runs AZ-03 and -04; for AZ-05 and -06; etc. Stepwise linear regression (with a 15% significance level for variables to enter or leave) was used to develop the forms for multiplicative models for TSP and PM_{10}. The (log-transformed) emission factor was regressed against the following (log-transformed) potential "predictors":

- Vehicle travel speed
- Surface material silt content
- Surface silt loading
- Surface material moisture content
- Duration of test
- Wind speed

Mean vehicle weight and number of wheels were not considered because those parameters spanned very small ranges during testing.

Because only vehicle speed and the road surface properties were found to enter the regression analysis, a "final" data set was constructed from the 27 PM_{10} emission tests. This data set is comprised of the geometric mean emission factor for each of the nine road/speed combinations tested:

Table 4-4. "FINAL" PM_{10} AND TSP DATA SETS

Road surface material					
Silt content (%)	Silt loading (g/m^2)	Moisture content (%)	Mean vehicle speed (mph)	Geometric mean PM_{10} emission factor (lb/vmt)	TSP emission factor (lb/vmt)
11	110	0.20	45	0.857	4.56
11	110	0.20	55	1.24	6.16
11	110	0.20	35	0.586	3.86
7.4	32	0.22	45	0.953	5.94
7.4	32	0.22	55	1.84	9.24
7.4	32	0.22	35	0.670	3.19
4.3	11	0.17	35	0.999	3.19
4.3	11	0.17	55	2.13	5.35
4.3	11	0.17	45	2.44	3.56

For both TSP and PM_{10}, vehicle travel speed entered on the first step. On the second step, silt content and moisture content entered in the case of PM_{10} and TSP, respectively. However, multiple regression analyses for both size ranges resulted in expressions in which the power for the surface material property was opposite to what one would expect:

0.0043 (vehicle speed)^1.86 / (silt content)^0.73

with an r^2 of 0.89 for the PM_{10} emission factor and

0.15 (vehicle speed)^1.50 (moisture content)^1.35

with an r^2 of 0.85 for the TSP emission factor.

While the r^2 values are high, the expressions nevertheless show (a) a direct relationship between TSP emissions and moisture content and (b) an inverse relationship between PM_{10} emissions and silt content. Neither relationship appears physically meaningful. Because the objective of this program is to recommend general expressions for roads in Arizona rather than to develop very accurate expressions for specific data sets, the following emission factor models based solely on vehicle travel speed (which enters both regressions first) are recommended for use:

$$ePM_{10} = 1.22\ (S/45)^{1.86} \quad (4\text{-}1)$$

$$eTSP = 4.83\ (S/45)^{1.50} \quad (4\text{-}2)$$

where

e	=	emission factor (lb/vmt) for the size range indicated
S	=	vehicle travel speed (mph)

The r^2 values are 0.52 and 0.67 for the PM_{10} and TSP expressions, respectively.

These expressions are intended for use in estimating emissions from light-duty (i.e., nominally 4 wheel and 2 ton vehicles) traffic during dry conditions on western public unpaved roads. The following defines the range of applicability for Equations (4-1) and (4-2):

- Vehicle travel speeds of 35 to 55 mph
- Surface silt contents in the range of 4.3% to 11%

When applied to pertinent western U.S. data in Appendix A, Equations (4-1) and (4-2) result in the following ratios of predicted to observed emission factors:

Table 4-5. APPLICATION OF EQUATIONS (4-1) AND (4-2) TO PERTINENT TESTS IN THE HISTORICAL DATA BASE

Run	Moisture (%)	Silt (%)	Mean vehicle Weight (tons)	Speed (mph)	No. of wheels	Emission factor (lb/vmt)	Predicted/ observed ratio
K-3	1.6	4.9	2.65	35	4	1.1(T)	3.01
K-4	1.7	5.3	2.65	35	4	3.3(T)	1.00
K-5	1.7	5.3	2.65	35	4	2.7(T)	1.23
P-11	0.9	5.5	2.2	42	4	4.5(T)	0.97
P-12	0.9	5.5	2.2	43	4	4.1(T)	1.10
P-13	0.9	5.5	2.2	43	4	7.1(T)	0.64
AE-1	.26	5	2.3	40	4	0.713(P)	1.37
AE-2	.26	5	2.0	35	4	0.957(P)	0.80

(T) = TSP value, (P) = PM_{10} value.

As can be seen, the performance of the recommended emission factor models when applied to independent data sets is reasonably good. Over the 8 tests, the geometric mean ratio is 1.14, and the geometric standard deviation equals 1.58.

Models for Estimation of Ambient Near-Field Concentrations

In addition to recommending mathematical models to estimate source emissions, a second objective of this research program was to examine the transport of emissions away from the road and the resulting near-field (nominally 100 ft distant) particulate concentrations. The most commonly employed air pollution dispersion algorithm (the so-called "Gaussian" model) is not generally considered applicable closer than ~ 100 m or 300 ft from the emitting source. In addition, during the field program, MRI noted that near-field concentrations appeared greater under higher winds; a Gaussian model would predict exactly the opposite condition. For these reasons, an empirical dilution factor approach was taken.

Because of different sampling durations, it was necessary to first calculate an intermediate quantity "C":

$$C = (Xd - Xu)\ T \qquad (4\text{-}3)$$

where

C	=	net PM_{10} or TSP "catch" (µg-min/m^3)
Xd	=	downwind PM_{10} or TSP concentration (µg/m^3) at a nominal 100 ft distance
Xu	=	upwind PM_{10} or TSP concentration (µg/m^3)
T	=	sampling duration (min)

In effect, C "normalizes" the data and thus facilitates comparisons between tests. Under the assumption that sampler flow rates (m^3/min) are essentially constant between tests and between units of the same design, then the quantity C is proportional to the net (i.e., due to emissions from the road) mass caught in the sampler.

A "dilution factor" D was in turn derived by dividing the mass "caught" by the mass emitted from the road:

$$D = C / (N \times e^*) \qquad (4\text{-}4)$$

where

D	=	PM_{10} or TSP "dilution factor" (µg-mile-min/lb-m^3)
C	=	net PM_{10} or TSP catch (µg-min/m^3), as defined above
N	=	number of vehicle passes during testing
e*	=	PM_{10} or TSP emission factor (lb/vmt)

Two sets of dilution factors were considered; one corresponding to the mean measured emission factor, the other to emission factors estimated from Equations (4-1) and (4-2).

Neither D data set nor the C data set exhibited significant correlation with any of the independent variables--such as wind speed or vehicle travel speed--recorded during testing. Furthermore, no substantial difference in dilution was found between the two particle size ranges. Because no meaningful relationships were identified, it was determined that adequate estimates of near-field concentration could be obtained from the expression

$$X^* = 170\ e\ N / T \qquad (4\text{-}5)$$

where

X*	=	estimated net PM_{10} or TSP concentration ($\mu g/m^3$) at a nominal 100-ft distance from the road
e	=	estimated PM_{10} or TSP emission factor (lb/vmt) from Equation (4-1) or (4-2), respectively
N	=	number of vehicle passes during the averaging time period T (min) of interest

The leading term in Equation (4-5) is the geometric mean dilution factor calculated over all the tests. Note that Equation (4-5) is similar in form to so-called "box" models

$$X^* = M / (U \times h)$$

where

X*	=	estimated concentration (mass/volume)
M	=	mass emission rate per unit length (mass/length-time)
U	=	transverse wind speed (length/time)
h	=	"box" height (length)

In this program, the product of U and h was found to remain essentially constant. Note that this is consistent with the field observation of higher ground-level concentrations for higher winds. In those situations, the emitted mass is more highly concentrated in a "shorter" box.

Combining Equation (4-5) with Equations (4-1) and (4-2) results in

$$XPM_{10} = 210\ (S/45)\hat{}\ 1.86\ N / T \qquad (4\text{-}6)$$

$$XTSP = 820\ (S/45)\hat{}\ 1.50\ N / T \qquad (4\text{-}7)$$

where XPM_{10} and XTSP represent the estimated net PM_{10} and TSP concentrations ($\mu g/m^3$), respectively, and all other quantities are as defined earlier. As before, these expressions are intended for use in <u>estimating net concentrations at a nominal 100-ft distance resulting from light-duty (i.e., nominally 4-wheel and 2-ton vehicles) traffic during dry conditions</u> under the additional assumption of prevailing winds approximately perpendicular to the road during period of traffic on western public unpaved roads. Also, Equations (4-6) and (4-7) share the same range of applicability as Equations (4-1) and (4-2):

- Vehicle travel speeds of 35 to 55 mph
- Surface silt contents in the range of 4.3% to 11%

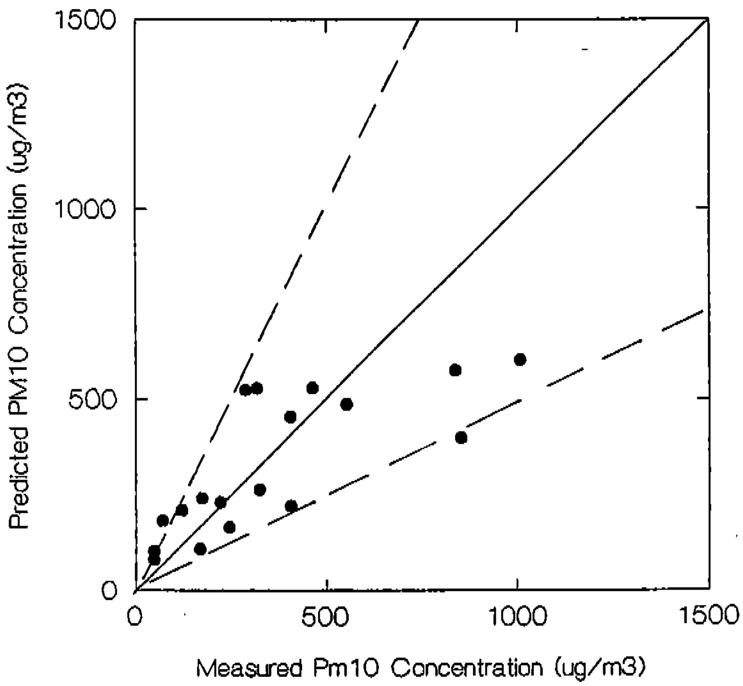
Figure 4-3 shows net concentrations estimated for and measured during the 18 sampling periods during the field program. Agreement between estimated and observed concentrations is generally good for both TSP and PM_{10}. Table 4-6 presents summary statistics for "Q," the ratio of estimated to measured concentrations.

Equations (4-6) and (4-7) allow the DEQ to assess the likelihood that travel on a public unpaved road would result in violations of any near-field concentration-based standards established by the state. In addition, the models also provide means to estimate--subject to the applicability restraints--the effectiveness of speed and vehicle reduction measures.

To illustrate the use of the near-field concentration estimation methods, consider a road with an average of 100 daily light-duty vehicle passes at an average speed of 50 mph. Assuming that the silt content of the road falls in the range of applicability, then Equation (4-7) results in an estimated net TSP concentration of

$$820\ (50/45)\,^\wedge\,1.50\ (100)/\ (24 \times 60)$$

or, 67 $\mu g/m^3$. When added to an appropriate background concentration value, the resulting TSP concentration estimate could easily exceed the former EPA annual primary standard of 75 $\mu g/m^3$.



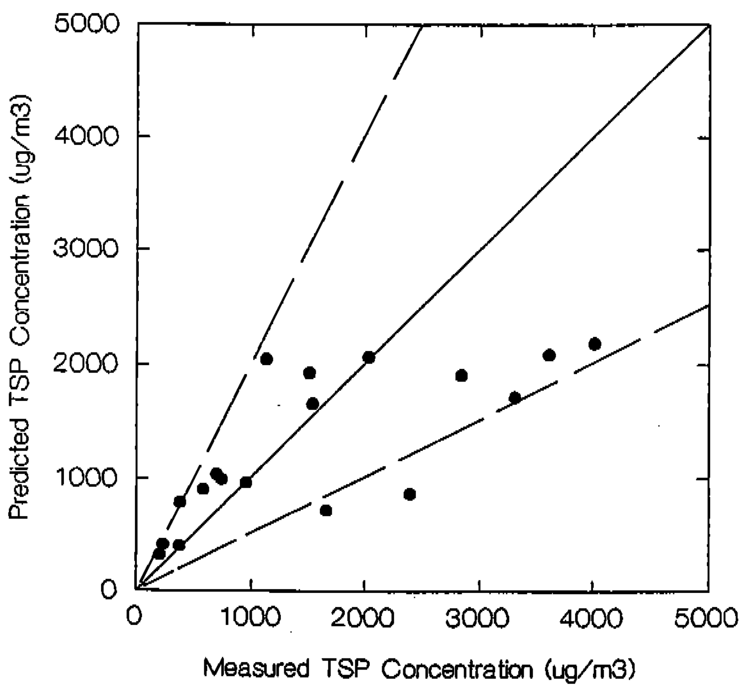


Figure 4-3. Predicted versus observed concentrations. Solid line indicates perfect agreement, dashed lines, factor of 2.

Table 4-6. SUMMARY STATISTICS FOR RATIO OF ESTIMATED TO MEASURED CONCENTRATIONS

	PM_{10}	TSP
Geometric mean ($\bar{x}_g$)	1.04	1.00
Geometric standard deviation (s_g)	1.68	1.71
Minimum value of Q	0.46	0.36
Maximum value of Q	2.58	2.10

To continue the example, suppose that it has been found necessary to reduce the estimated net TSP concentration by 10% (i.e., from 67 to 60). Because Equation (4-7) is linear in the number of vehicle passes, a 10% reduction in vehicle trips would achieve the desired goal. In addition, by solving the following equation for S

$$60 = 820\ (S/45)\hat{}1.50\ (100)\ /\ (24 \times 60)$$

one sees that reducing the average travel speed to approximately 46 mph achieves the goal. Finally, combined vehicle and travel speed reductions would also result in the desired effect.

The DEQ can also use Equations (4-6) and (4-7) to estimate the minimum traffic level that might result in a violation of a given PM standard. As an example, Table 4-7 presents the minimum average daily number of vehicle passes that result in a calculated violation of the federal annual PM-10 standard of 50 µg/m³:

Table 4-7. "CALCULATED" PM-10 VIOLATIONS[a]

Mean speed (mph)	Background PM-10 concentration (µg/m³)				
	0	10	20	30	40
35	547	438	328	219	109
45	343	274	206	137	68
55	236	189	142	94	47

a Entries represent the minimum value of N in Equation (4-6) such that the concentration estimate exceeds the federal primary annual standard for PM-10.

SECTION 5

SUMMARY AND RECOMMENDATIONS

The following summarizes the major results of this program and presents several recommendations for the DEQ's consideration:

1. Contrary to previous suggestions, available historical data do not indicate systematic underestimation of emissions from unpaved roads in the western United States. Nevertheless, common vehicle weights and travel speeds for rural unpaved roads are usually outside the general range of applicability for the AP-42 model.

2. At present, no air pollution control agency was found to actively regulate the emissions from rural public unpaved roads in the arid or semiarid portions of the United States. Although one draft regulation was found, the lack of practical experience precludes further discussion of its applicability to Arizona. It is recommended, however, that the DEQ monitor the progress of the draft regulation through contact with the EPA Regional office.

3. The Arizona-specific field testing resulted in very reproducible emission factor measurements. As was the case for the historical review, the field data did not show severe systematic underestimation by the AP-42 model.

4. Although the AP-42 model performed reasonably well when it was applied to the field tests, alternative emission factor models were recommended. When the recommended emission factor models were applied to independent historical data sets, they appeared to perform quite well. It is recommended, however, that additional Arizona-specific data be collected to better assess the accuracy of the models.

5. The field program also resulted in mathematical models to estimate particulate concentrations near rural unpaved roads. These models allow the DEQ to assess (a) the likelihood that travel on the road would result in violations of any concentration standards established by the State and (b) the effectiveness of speed and vehicle reduction measures. Although agreement between observed and measured values was found to be generally good, it is again recommended

that more Arizona-specific data be collected to better define the accuracy of these models.

6. It is recommended that the DEQ construct tables similar to Table 4-7 for a variety of conditions, such as different background concentration levels and averaging times (e.g., 1 hr vs. 24 hr). Equations (4-6) and (4-7) allow DEQ to examine different "trigger" concentration values that could be used as a guideline for response to public complaints.

7. Although agreement between measured and estimated values is generally good for both the emission factor and the near-field concentration models, additional data are needed to support the DEQ's development of effective, regulatory programs. In particular,

   a. It is recommended that similar field tests be undertaken in other areas of Arizona.

   b. The effectiveness of the unpaved road dust controls should be quantified over time in another series of field tests.

Taken together, these recommendations would allow the DEQ (1) to estimate the impact of unpaved road emissions throughout Arizona with greater confidence and (2) to better design effective control programs to reduce the impact.

SECTION 6

REFERENCES

1. Environmental Protection Agency. Compilation of Air Pollution Emission Factors (AP-42). Research Triangle Park, North Carolina, September 1985.

2. Hollander, W., and J. Wolfe. *Nonparametric Statistical Methods*. J. Wiley and Sons, New York, 1973.

APPENDIX A

HISTORICAL UNPAVED ROAD EMISSIONS DATA

Table A-1 lists the data considered in the historical review of unpaved road emission tests. In general, the ratio "R"--as defined in Equation (2-2) in the body of this report--is based on estimated and measured emission factors for PM_{10}. Note that, for some tests PM_{10} values were unavailable, and the ratio is based on a different size category (e.g., particulate matter less than 15 µm in aerodynamic diameter [PM_{15}] or, total suspended particulate [TSP]).

Table A-1. HISTORICAL UNPAVED ROAD EMISSIONS DATA BASE

Test	E/W	Moisture content (%)	Silt content (%)	Mean vehicle Weight (tons)	Mean vehicle Speed (mph)	Mean vehicle No. of wheels	Ratio[a] "R"
			Provo, UT				
A-7	W	N/A	4.8	3	30	4	0.482
A-14	W	N/A	4.8	70	30	4	0.793
A-14	W	N/A	4.8	70	30	4	0.738
			Colstrip, MT				
J-1	W	5.7	8.9	55	19	4.1	2.61
J-2	W	2.3	23.4	58	19	4	34.9
J-3	W	4.1	15.8	50	24	4.1	3.23
J-4	W	1.5	14.6	40	20	4	30.6
J-5	W	0.9	10.6	77	18	4	1.73
J-9	W	3.4	9.4	71.7	19	7.9	2.97
J-10	W	2.2	9.4	66.2	19	7.3	1.76
J-11	W	4.2	8.2	66.2	20	9.7	2.46
J-12	W	6.8	14.2	109	15	8.6	45.1
J-13	W	1.0	10.1	2.4	25	4	0.738
J-18	W	1.1	8.8	2.87	25	4	0.222
J-19	W	0.9	8.2	2.54	25	4	0.648
J-20	W	8.5	11.6	138	17	9.3	7.18
			Stanton, ND				
K-1	W	2.2	7.7	69.5	33	6.1	6.82
K-2	W	1.6	4.9	2.54	35	4	3.13
K-3	W	1.6	4.9	2.65	35	4	3.23
K-4	W	1.7	5.3	2.65	35	4	5.24
K-7	W	0.9	2.8	26.5	34	5	5.81
K-9	W	1.5	4.7	81.6	29	6.7	6.35
K-10	W	2.0	7.7	76.1	36	6.7	18.9
K-11	W	2.0	8.9	80.5	30	6.4	14.6
K-12	W	2.3	11.8	105	36	7.2	18.1
K-16	W	6.0	25.2	71	30	4	4.17
K-17	W	6.0	25.2	73	25	4	3.54
K-18	W	6.0	25.2	73	25	4	3.54
K-19	W	9.1	23.1	15	5	6	2.38
K-20	W	8.8	29	15	6	6	11.7
K-21	W	7.2	27.8	15	6	6	2.06
K-22	W	5.4	21.6	50	32	4	15.6
K-23	W	7.8	24.6	60	28	4	4.78
K-24	W	4.0	17.6	14	6	6	2.83
K-25	W	5.4	24.5	15	6	6	0.843

Table A-1 (continued)

Test	E/W	Moisture content (%)	Silt content (%)	Mean vehicle Weight (tons)	Mean vehicle Speed (mph)	Mean vehicle No. of wheels	Ratio[a] "R"
			Colstrip, MT				
L-1	W	7.7	13	105	26	8.7	234
L-3	W	4.9	13.8	118	20	9.3	1.13
L-4	W	5.1	18	94.8	20	8.3	1.20
L-5	W	N/A	21	58	21	4	0.478
L-6	W	N/A	21	55	20	4	0.440
			Farmington, NM				
P-1	W	0.4	4.7	87.1	27	8.5	2.96
P-2	W	0.4	4.7	46.3	26	7.6	11.1
P-3	W	0.3	4.1	104	31	9.7	1.58
P-5	W	0.0	3.1	51.8	30	7.1	1.66
P-11	W	0.9	5.5	2.2	42	4	0.477
P-12	W	0.9	5.5	2.2	43	4	0.355
P-13	W	0.9	5.5	2.2	43	4	0.363
P-16	W	5.4	24.5	15	12	6	1.44
P-17	W	5.4	24.5	15	10	6	4.21
P-18	W	1.0	7.2	71	10	4	2.45
			Middletown, OH				
F-28	E	N/A	10	3	15	4	1.17
F-29	E	N/A	10	3	15	4	0.289
F-30	E	N/A	10	3	15	4	0.411
F-31	E	N/A	10	3	15	4	0.315
F-68	E	N/A	14	22	20	5.9	0.334
F-69	E	N/A	15	53	20	10	1.12
F-70	E	N/A	16	53	20	10	0.942
			Miami County, KS				
U-1	E	0.25	9.5	2.1	35	4	0.168
U-2	E	0.30	9.1	2.1	35	4	0.472
U-3	E	0.27	7.7	2.1	35	4	0.709
U-4	E	0.40	8.6	2.1	25	4	0.528
U-5	E	0.37	9.2	2.5	25	4	0.604
U-6	E	0.20	3.7	2.1	30	4	0.288

Table A-1 (continued)

Test	E/W	Moisture content (%)	Silt content (%)	Mean vehicle Weight (tons)	Mean vehicle Speed (mph)	Mean vehicle No. of wheels	Ratio[a] "R"
			Stanley, KS				
AA-1	E	0.40	13.7	12	15	5	1.67
AA-2	E	0.34	15.3	14	15	4.4	4.42
AA-3	E	0.84	10.5	11	10	4	1.71
AA-4	E	2.1	15.6	15	10	5.6	0.743
AA-5	E	2.1	15.6	14	10	5	0.520
			Clay County, MO				
AB-1	E	3.9	35.1	2.5	25	4	0.377
AB-2	E	4.5	16.7	2.5	25	4	2.28
AB-3	E	3.2	16.8	2.5	25	4	1.10
AB-4	E	3.1	5.8	2.5	25	4	0.405
			Kearny, AZ				
AC-1	W	0.07	19.1	2.4	10	4.8	0.650
AC-2	W	0.07	15.9	2.3	10	4	0.534
AC-3	W	0.03	16	2.6	10	4.3	0.463
AC-4[b]	W	0.43	19.8	6.3	10	7.4	0.692
AC-5[b]	W	0.43	15.4	7.7	15	6.2	1.15
AC-6[b]	W	0.53	21.7	3.4	20	4.2	2.12
			Boulder, CO				
AE-1	W	0.26	5	2.3	40	4	1.37
AE-2	W	0.26	5	2.0	35	4	0.812
			East Chicago, IN				
AG-1	E	0.59	7.5	27	15	9.8	3.61
AG-2	E	0.33	5.8	25	17	7.3	0.625
AG-3	E	0.27	7.2	28	16	6.6	1.09
			Kansas City, KS				
AF-1	E	0.23	4.2	32	5	14.5	0.477
AF-2	E	0.17	6	30	5	16.6	0.774
AF-3	E	0.15	4.1	30	5	12.5	0.328
			Kansas City, MO				
AJ-1	E	N/A	6.3	54	15	6	1.24
AJ-2	E	N/A	7.4	52	15	6	2.26
AJ-3	E	N/A	7.7	50	15	7.1	3.04

Table A-1 (continued)

Test	E/W	Moisture content (%)	Silt content (%)	Mean vehicle Weight (tons)	Mean vehicle Speed (mph)	Mean vehicle No. of wheels	Ratio[a] "R"
			Gary, IN				
AL-1[c]	E	N/A	11.1	22	19	12	1.21
AL-2[c]	E	N/A	11.1	7.7	20	5.2	0.948
AL-3[c]	E	N/A	10.6	28	19	14	1.34
AL-4[c]	E	N/A	10.6	27	20	13	0.789
AL-6[c]	E	N/A	10.6	7.1	20	4.7	0.614
AL-7[c]	E	N/A	11	28	17	14	1.05
AL-8[c]	E	N/A	11	33	18	16	1.54
AL-9[c]	E	N/A	6.9	31	25	15	2.77
AL-10[c]	E	N/A	6.9	9.0	20	5.6	0.636
AL-11[c]	E	N/A	6.9	11	20	6.3	0.454
AL-12[c]	E	N/A	10.3	32	16	15	1.27
			East Chicago, IN				
AP-2U	E	0.64	8.1	33	16	7	0.984
AP-3U	E	1.1	8.3	37	16	5.2	1.45
AP-7U	E	N/A	6	25	16	13.4	8.18
			Detroit, MI				
AN-24U	E	1.7	7.7	49	18	4	0.214
AN-24Y	E	1.7	7.7	49	18	4	0.263
AN-25U	E	1.7	7.7	49	20	4	0.195
AN-25Y	E	1.7	7.7	49	20	4	0.214
			Kansas City, MO				
AQ-1U	E	1.5	7	10	15	6	2.07
AQ-2U	E	1.5	7	9.8	15	5.9	1.5

[a] See Equation (2-2) and following discussion in text.

[b] The road surface for these tests was technically paved; however, the surface dust loading was heavy enough that the field crew mistook it for an unpaved road. Following general EPA guidance, the road is better characterized as "unpaved" in terms of particulate emissions.

[c] The source in the AL series was a simulated unpaved road, which was used for a series of collaborative exposure profiling tests.

APPENDIX B

TEST PLAN

PREFACE

This study plan describes the field testing program to be conducted as part of Arizona Department of Environmental Quality (DEQ) Grant No. 2283-000000-4-6-GP-0016. All work is being performed in Midwest Research Institute's (MRI's) Air Quality Assessment Section (Dr. Gregory E. Muleski, Acting Section Head). The plan was prepared by Dr. Muleski and Mr. Gary Garman.

Approved:

Charles F. Holt, Ph.D., Director
Engineering, Environmental, and
Management Systems

March 22, 1990

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SECTION 1

INTRODUCTION

This report describes the Test Plan to be followed during a field sampling exercise in the state of Arizona. These field characterizations will support the recommendation of a mathematical emission factor model to estimate dust emissions from unpaved roads in arid and semiarid environments.

The study plan describes the sampling methodology, data analysis, and quality assurance procedures to be followed in the field study. For each road selected for testing, triplicate tests will be conducted to quantify the mass emissions under three different average vehicle speeds (spanning the range of common travel speeds on the road). Note that:

- MRI will provide "captive" traffic in order to maintain constant average vehicle characteristics during the testing periods.
- The roads will be tested in the "uncontrolled" condition.
- The primary pollutant of concern during the field exercise is particulate matter no greater than 10 µm in aerodynamic diameter (PM_{10}). However, at each test site, at least one set of total suspended particulate (TSP) emission measurements (using standard high volume [hi-vol] air samplers) will be taken.

The basic field sampling methodology will use the concept of "exposure profiling" developed by MRI during the early 1970s. The exposure profiling method calculates emission rates using a conservation of mass approach. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by the spatial integration of exposure (mass/area) measurements distributed over the effective cross-section of the plume. Note that for a line or "moving point" source such as an unpaved road, only a vertically distributed sampling array is required to characterize the plume's effective cross-section.[1,2]

Throughout this Test Plan, emphasis has been placed upon the collection of field data in a prompt and cost-effective manner. A close working relationship among all interested parties will be required for the completion of the field program. In order to meet the goals of the program, the Test Plan identifies certain responsibilities on the part of Arizona Department of Environmental Quality (DEQ), Arizona State University (ASU), and Midwest Research Institute (MRI) personnel. Specific responsibilities will be discussed in conjunction with the activities to which they apply.

SECTION 2

DESCRIPTION OF THE TEST SITES

The test roads selected during a February 1990 visit to Arizona are:

1. Reservation Road, in Pima County

2. Warren Road in Pinal County

3. Mohawk Mountain Road in Yuma County

The general location of each road is shown in Figure 1. All three roads run north-south and have gravel surfaces.

As of the date of this Test Plan, verbal approval to use Mohawk Mountain Road had been received by ASU. Approval for the other sites is expected.

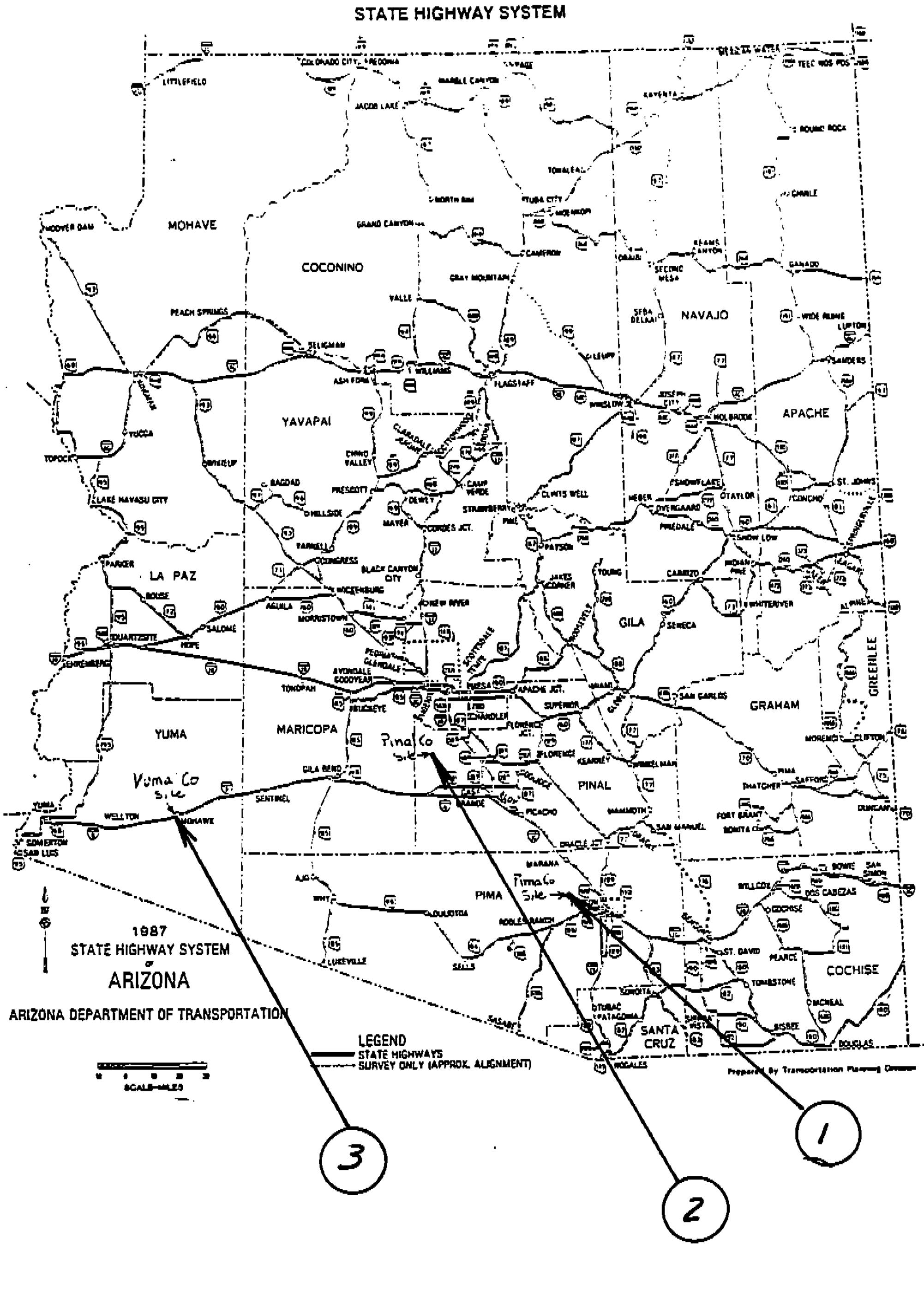

Figure 1. General location of test sites 1, 2, and 3.

SECTION 3

QUALITY ASSURANCE

The sampling and analysis procedures to be followed in this field testing program are subject to certain quality control (QC) guidelines. These guidelines will be discussed in conjunction with the activities to which they apply. These procedures meet or exceed the requirements specified in the reports entitled "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II--Ambient Air Specific Methods" (EPA 600/4-77-027a) and "Ambient Monitoring Guidelines for Prevention of Significant Deterioration" (EPA 450/2-78-019).

As part of the QC program for this study, routine audits of sampling and analysis procedures will be performed. The purpose of the audits is to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items to be audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially designed reporting forms for sampling and analysis of data obtained in the field and laboratory aids in the auditing procedure. Further details on specific sampling and analysis procedures are provided in the following section.

SECTION 4

SAMPLING AND ANALYSIS PROCEDURES

This section describes the general methodology MRI will use to characterize particulate emissions from the test roads. Note that additional DEQ samplers will be deployed to examine the near-source dispersion of emissions from the road. The location and operation of those samplers are discussed in Section 5.

GENERAL AIR SAMPLING EQUIPMENT AND TECHNIQUE

Exposure profiling, which will be the primary air sampling technique in this study, is based on simultaneous multipoint sampling (Table 1) over the effective cross section of the open dust source plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model (as in the so-called "upwind/downwind" method).

Table 1. AIR SAMPLING EQUIPMENT DEPLOYMENT

Device	Location[a]	Height (m)
Cyclone preseparator	Array U	1.5 4.5
Cyclone preseparator	Array D1	1 3 5
Standard High-Volume sampler or cyclone preseparator[b]	Array D2	1 3 5

[a] Sampling arrays are shown in Figure 2. "U" refers to upwind locations and "D" to downwind locations.
[b] Samplers will be switched between every other test period. See the discussion in the text.

As shown in Figure 2, the planned equipment deployment scheme makes use of two downwind vertical sampling arrays, D1 and D2. Both downwind arrays (as well as the upwind array U) make use of high-volume (hi-vol) air samplers with electronic flow controllers.

The primary air sampling device in this program will be a standard high-volume air sampler fitted with a Sierra Model 230CP cyclone preseparator (Figure 3). The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 microns (µm) in aerodynamic diameter when operated at a flow rate of 40 cfm (68 m^3/hr).

Samplers in arrays D1 and U are fitted with the cyclone preseparator to sample PM_{10} emissions. During half the test periods, samplers in array D2 will be fitted with cyclone preseparators; during the other test periods, standard hi-vol roofs will be used to sample TSP emissions. In this way, three PM_{10} tests will be conducted for every TSP test.

Throughout each test, wind speed will be monitored by warm-wire anemometers (Kurz Model 465) at two heights and the vertical wind speed profile determined by assuming a logarithmic distribution. An integrating Biram's vane anemometer will be used as a backup system. Horizontal wind direction will be monitored by a wind vane at a single height, with 5- to 15-min averages determined electronically prior to and during the test. The sampling intakes will be adjusted for proper directional orientation based on the monitored average wind direction.

In addition, a recording wind station will be deployed at the regional test site during the field exercise.

EMISSION TESTING PROCEDURE

Preparation of Sample Collection Media

Particulate samples will be collected on Type AE grade glass fiber filters. Prior to the initial weighing, the filters will be equilibrated for 24 hr at constant temperature and humidity in a special weighing room. During weighing, the balance is to be checked at frequent intervals with standard (Class S) weights to ensure accuracy. The filters will remain in the same controlled environment for another 24 hr, after which a second analyst will reweigh them as a precision check. If a filter cannot pass audit limits, the entire lot is to be reweighed. Ten percent of the filters taken to the field will be used as blanks. The quality assurance guidelines pertaining to preparation of sample collection media are presented in Table 2.

Note that an additional set of field blanks will be collected during the field exercise. These blanks will be transferred to the DEQ at the end of the field activities for gravimetric analysis. Following DEQ's analysis, the blanks will be shipped to MRI for a comparative weighing.

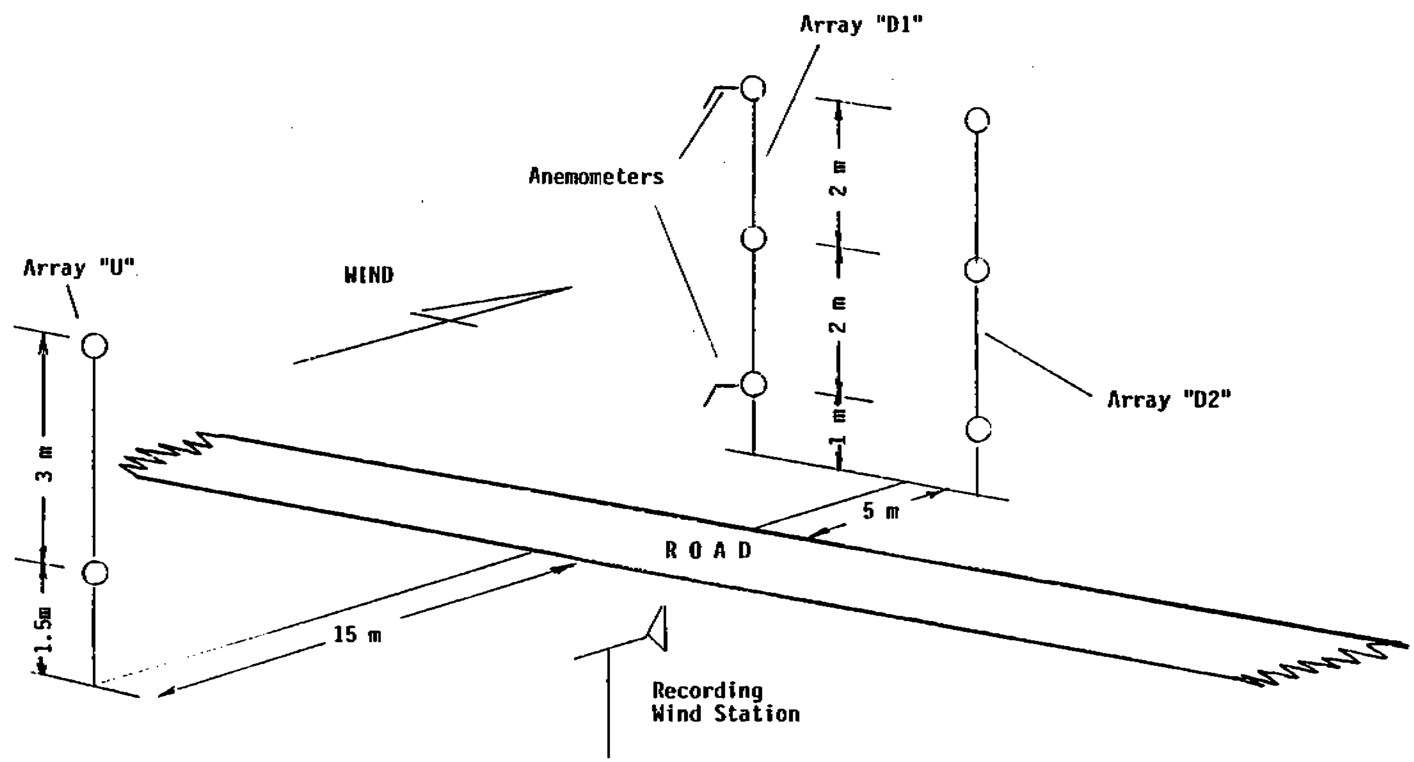

Figure 2. Sampling arrays U, D1, and D2. (DEQ sampling equipment described in Section 5.)

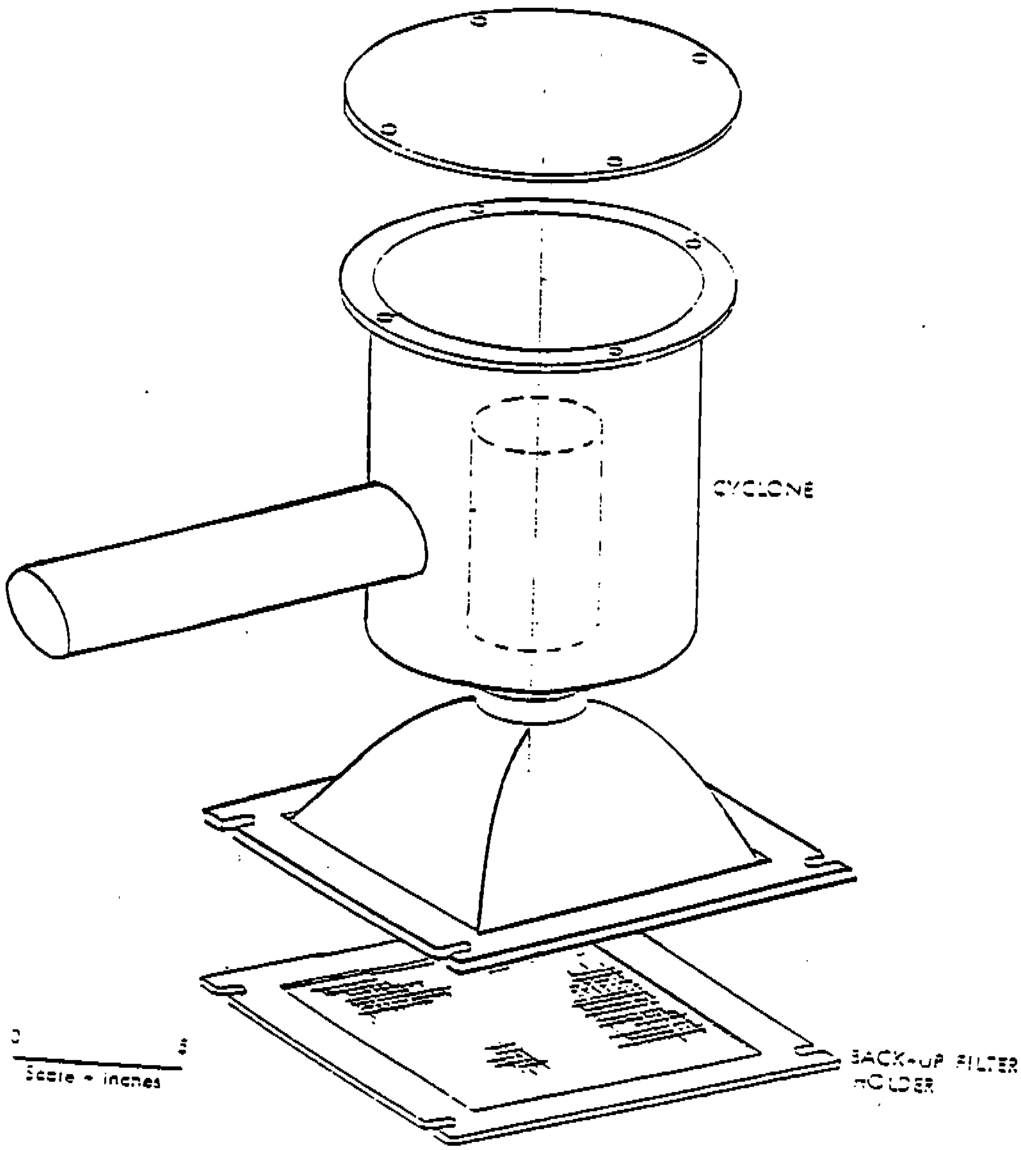

Figure 3. Cyclone preseparator.

Table 2. QUALITY ASSURANCE PROCEDURES FOR SAMPLING MEDIA

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 hr in clean controlled room with relative humidity of less than 50% (variation of less than ±5%) and with temperature between 20° and 25°C (variation of less than ±3%).
Weighing	Weigh hi-vol filters to nearest 0.1 mg.
Auditing of weights	Independently verify final weights of 10% of filters (at least four from each batch). Reweigh batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit. Reweigh tare weight of any filters that deviate by more than ±1.0 mg.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type for each test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

Pretest Procedures/Evaluation of Sampling Conditions

Prior to equipment deployment, a number of decisions will be made as to the potential for acceptable source testing conditions. These decisions shall be based on forecast information obtained from the local U.S. Weather Service office. If conditions are considered acceptable, the sampling equipment deployment will be initiated. At this time the sampling flow rates will be set for the various air sampling instruments. The quality control guidelines governing this activity are found in Table 3.

Table 3. **QUALITY ASSURANCE PROCEDURES FOR SAMPLING FLOW RATES**

Activity	QA check/requirement
• High volume air samplers	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter at each regional site prior to testing.
• Orifice and electronic calibrator	Calibrate against displaced volume test meter annually.

Once the source testing equipment is set up and the filters inserted, air sampling will commence. Information is recorded on specially designed reporting forms and includes:

a. Air samples--Start/stop times, wind speed profiles, flow rates, and wind direction relative to the roadway perpendicular (5- to 15-min average). See Table 4 for QA procedures.

b. Traffic count by vehicle type and speed.

c. General meteorology--Wind speed, wind direction, and temperature.

Sampling time will be long enough to provide sufficient particulate mass and to average over several cycles of the fluctuation in the emission rate (i.e., vehicle passes on the road). Occasionally sampling may be interrupted because of the occurrence of unacceptable meteorological conditions and then restarted when suitable conditions return. Table 5 presents the criteria used for suspending or terminating a source test.

Sample Handling and Analysis

To prevent particulate losses, the exposed media will be carefully transferred at the end of each run to protective containers for transportation. In the field laboratory, exposed filters will be placed in individual glassine envelopes and then into numbered file folders. When exposed filters and the associated blanks are returned to the MRI laboratory, they will be equilibrated under the same conditions as the initial weighing. After reweighing, 10% will be audited to check weighing accuracy.

Table 4. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA check/requirement[a]
Maintenance	
• All samplers	Check motors, gaskets, timers, and flow measuring devices at each plant prior to testing.
Operation	
• Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates.
	Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. This technique allocates no nozzle for wind speeds ranging from 0 to 10 mph, and unique nozzles for four wind speed ranges above 10 mph.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

[a] All means refer to 5- to 15-min averages.

Table 5. CRITERIA FOR SUSPENDING OR TERMINATING A TEST

A test may be suspended or terminated if:[a]

1. Rainfall ensues during equipment setup or when sampling is in progress.

2. Mean wind speed during sampling moves outside the 1.3- to 8.9-m/sec (2- to 20-mph) acceptable range for more than 20% of the sampling time.

3. The angle between mean wind direction and the perpendicular to the path of the moving point source during sampling exceeds 45 degrees for two consecutive averaging periods.

4. Daylight is insufficient for safe equipment operation.

5. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill or accidental water splashing prior to uncontrolled testing).

[a] "Mean" denotes a 5- to 15-min average.

EMISSION FACTOR CALCULATION PROCEDURE

To calculate emission rates, a conservation of mass approach is used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure are described below.

Particulate Concentrations

The concentration of particulate matter measured by a sampler is given by:

$$C = 10^3 \frac{m}{Qt}$$

where: C = particulate concentration (μg/m³)

m = particulate sample weight (mg)

Q = sampler flow rate (m^3/min)

t = duration of sampling (min)

To be consistent with the National Ambient Air Quality Standards, all concentrations and flow rates are expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 inHg).

The isokinetic flow ratio (IFR) is the ratio of a directional sampler's intake air speed to the mean wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q}{aU}$$

where: Q = sampler flow rate (m^3/min)

a = intake area of sampler (m^2)

U = mean wind speed at height of sampler (m/min)

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. Note, however, that because the primary interest in this program is directed to PM_{10} emissions, sampling under moderately nonisokinetic conditions poses no difficulty. It is readily agreed that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.[3]

Exposure represents the net passage of mass through a unit area normal to the direction of plume transport (wind direction) and is calculated by:

$$E = 10^{-7} \times CUt$$

where: E = particulate exposure (mg/cm^2)

C = net concentration ($\mu g/m^3$)

U = approaching wind speed (m/sec)

t = duration of sampling (sec)

Exposure values vary over the height of the plume. If exposure is integrated over the height of the plume, then the quantity obtained represents the total passage of airborne particulate matter due to the source per unit length of the line source. This quantity is called the Integrated Exposure and is found by:

$$A = \int_0^H E \, dh$$

where: A = integrated exposure ($m\text{-}mg/cm_2$)

E = particulate exposure (mg/cm^2)

h = vertical distance coordinate (m)

H = effective extent of plume above ground (m)

Particulate Emission Factors

The emission factor for particulate generated by vehicular traffic on a straight road segment expressed in grams of emissions per vehicle-kilometer traveled (VKT) is given by:

$$e = 10^4 \frac{A}{N}$$

where: e = total particulate emission factor (g/VKT)

A = integrated exposure ($m\text{-}mg/cm^2$)

N = number of vehicle passes (dimensionless)

SECTION 5

ANCILLARY SAMPLES AND ANALYSIS

In addition to the air samples described in Section 4, the successful completion of this field program and application of its results will require additional samples. This section describes those samples.

SURFACE MATERIAL SAMPLES

Associated with each unpaved road test site will be a series of at least three samples of the roadway surface material. The collection and analysis of these samples are important because the available emission factor and control performance models make use of road surface parameters. Samples of the road surface will be analyzed for silt (particles passing a 200-mesh screen) and moisture contents and to determine road surface loading values. Detailed steps for collection and analysis of samples for silt and moisture are given elsewhere.[1,2,4] An abbreviated discussion is presented below.

Unpaved roadway dust samples are to be collected by sweeping the loose layer of soil or crushed rock from the hardpan road base with a broom and dust pan. Sweeping is performed so that the road base is not abraded by the broom, and so that only the naturally occurring loose dust is collected. The sweeping will be performed slowly so that dust is not entrained into the atmosphere.

Once the field sample is obtained, it will be prepared for analysis. If necessary, the field sample will be split with a riffle to a sample size amenable to laboratory analysis.

The basic procedure for moisture analysis is determination of weight loss on oven drying. Silt analysis procedures follow the ASTM-C-136 method.

AMBIENT CONCENTRATION MEASUREMENTS

In addition to the sampling arrays described in Section 4, DEQ samplers will be deployed during the field exercise. Specifically, the collection of TSP and PM_{10} concentrations at locations further downwind than arrays D1 and D2 provides a basis for developing a near-source, ambient-concentration-based standard for unpaved roads in Arizona. This standard could act as a "trigger" to require treatment of unpaved roads to control nuisance dust at nearby homes. The additional PM_{10} and TSP samplers will be placed at an approximate height of 5 ft above grade, and 75 ± 25 ft downwind of arrays D1 and D2. The exact location of these samplers as well as sampling times required will depend upon certain site conditions (e.g., type of vegetation, etc.) found at the time of the field exercise. An additional DEQ sampler of each type will be placed in the general location of array "U" in Figure 2 to collect background PM_{10} and TSP concentrations.

The study plan assumes that the DEQ will deliver the ambient samplers and sampling media (all filters and two filter cartridges per sampler) required to each test site. MRI personnel will deploy and recover the sampling media, which will be returned to the ADEQ for gravimetric analysis. The resultant concentration values will be reported to MRI.

NEAR ROADWAY OPACITY MEASUREMENTS

It is recommended that ASU furnish at each test site a device to record near-surface opacity readings. During testing periods, this device will be attached to an ASU vehicle providing captive traffic. The collection and analysis of these opacity measurements will be the responsibility of ASU. Results will be provided to MRI.

SECTION 6

TESTING SCHEDULE

It is expected that field tests will be conducted at three different unpaved road sites within Arizona. The following describes the expected schedule of field activities upon arrival of the two-person crew at each site:

1. Unpack the transport truck and arrange field laboratory facilities. Provide at least 1 hr of captive traffic prior to the start of air testing.

2. Erect the upwind and downwind sampling arrays (i.e., U, D1 and D2 in Figure 1) and deploy the recording wind station.

3. Calibrate each hi-vol sampler to the volumetric flow rate of 40 cfm.

4. Providing captive traffic at a constant vehicle speed S1, conduct air sampling following the procedures described in Section 4. At the end of this test period:

   - Discontinue the captive traffic.

   - Remove and store the sampling media from the downwind samplers as specified in Section 4.

   - Visually evaluate loadings on the DEQ TSP and PM_{10} samplers located downwind of arrays D1 and D2. If loadings appear adequate, replace the sampling media.

   - Switch cyclones and standard hi-vol roofs on array D2 and reinstall new sampling media in the downwind arrays.

   - Conduct air sampling again with captive traffic at the speed S1, thus completing the three PM_{10} tests and one TSP test at that vehicle speed.

- Again evaluate loadings on the DEQ TSP and PM_{10} samplers located downwind of arrays D1 and D2. If loadings appear adequate, replace the sampling media. If loadings appear inadequate, restart the captive traffic until approximately 4 hr of total sampling time has been accumulated.

- Collect a road surface material sample following the procedures given in Section 4.

5. Repeat step 4 until all three vehicle speeds of interest have been considered.

6. Pack equipment for transport to the next regional test site or for return to the main MRI laboratories.

Note that the contract has limited the field testing activities to a total of 320 person labor hours in Arizona.

SECTION 7

REFERENCES

1. Muleski, G. E., T. Cuscino, Jr., and C. Cowherd, Jr., "Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry," EPA-600/2-84-027, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina (February 1984).

2. Cuscino, T., Jr., G. E. Muleski, and C. Cowherd, Jr., "Iron and Steel Plant Open Source Fugitive Emission Control Evaluation," EPA-600/2-83-110, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina (October 1983).

3. Davies, C. N., "The Entry of Aerosols in Sampling Heads and Tubes," *British Journal of Applied Physics*, 2:921 (1968).

4. Muleski, G. E. Critical Review of Open Source Particulate Emissions Measurements: Field Comparison. MRI Final Report Prepared for Southern Research Institute, MRI Project No. 7993-L(2) (August 1984).

Arizona DEQ Data from 5/90 (Rural Unpaved Roads)

		TSP ($\mu g/m^3$)			PM10 ($\mu g/m^3$)									
					Upwind					Downwind				
		Upwind	Downwind		Cyclone[1]	Dichot			Fine	@15 ft	Dichlot @ 100 ft			Fine
Site	Run #		15ft	100ft		Fine	Coarse	Total	Fraction		Fine	Coarse	Total	Fraction
Pinal Co.	AZ-01,02	19	9780	2050	16	6.4	6.4	13	0.50	1510	91	239	330	0.28
Pinal Co.	AZ-03,04	19		1150	16	6.4	6.4	13	0.50	1640	78	221	299	0.26
Pinal Co.	AZ-05,06	19		973	16	6.4	6.4	13	0.50	1200	77	259	336	0.23
Pinal Co.	AZ-07,08	19	9390	1530	16	6.4	6.4	13	0.50	1480	132	344	476	0.28
Pinal Co.	AZ-09,10	46	4600	785	6	8.3	9.8	18	0.46	550	52	186	238	0.22
Pinal Co.	AZ-11,12	23		716	25	8.7	13.7	22	0.39	988	56	138	194	0.29
Pima Co.	AZ-21,22	15		2850	8	9.6	19.1	29	0.33	1020	157	426	583	0.27
Pima Co.	AZ-23,24	29	4360	2420	9	7.2	6.2	13	0.54	912	112	307	419	0.27
Pima Co.	AZ-25,26	29	11900	3640	9	7.2	6.2	13	0.54	2300	246	603	849	0.29
Pima Co.	AZ-27,28	29		4040	9	7.2	6.2	13	0.54	2120	237	780	1020	0.23
Pima Co.	AZ-29,30	29		3340	9	7.2	6.2	13	0.54	1060	173	691	864	0.20
Pima Co.	AZ-31,32	179	3110	1840	65	17.3	71.2	89	0.20	953	83	249	332	0.25
Pima Co.	AZ-33	42			27	11.5	23.5	35	0.33	343				
Yuma Co.	AZ-41,42	69		647	37	14.5	22.9	37	0.39	1120	41	115	156	0.26
Yuma Co.	AZ-43,44	69	2990	447	37	14.5	22.9	37	0.39	1480	37	69	106	0.35
Yuma Co.	AZ-45,46	40	7030	1580	17	9.1	10.7	20	0.46	1820	132	293	425	0.31
Yuma Co.	AZ-47,48	43		416	23	13.3	13.9	27	0.49	968	50	106	156	0.32
Yuma Co.	AZ-49,50	70		302	56	12.5	38.3	51	0.25	754	29	70	98	0.29
Yuma Co.	AZ-51,52	70	890	272	56	12.5	38.3	51	0.25	591	35	63	98	0.36

[1] "Cyclone" refers to a Hi-Vol sampler with a cyclone precollector.