AP42 Section: Section 13.2.2 Unpaved Roads

Title: Correspondance and communications for September 1998 supplement

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INTEROFFICE COMMUNICATION

MIDWEST RESEARCH INSTITUTE

January 3, 1997

~~February 11, 1997~~

To: Ron Myers, EPA

From: Greg Muleski

Subject: Regression results for unpaved road PM10 emission tests

This memo summarizes the results of the stepwise regressions that you and I have talked about over the past few months. As we discussed, I assembled the unpaved road PM10 emission factor data base without regard to the type of vehicle (e.g., haul trucks) as long as the vehicle is moving along an unpaved surface. Thus, test results for public rural roads with light-duty traffic would be included with tests of haul trucks at steel plants, quarries and surface mines. Furthermore, scrapers in the "travel" mode (i.e., fully loaded or unloaded and moving) would be included. The ranges of vehicle weights/speeds are shown below:

Type of Road	Vehicle Weight (tons)		Vehicle Speed (mph)	
	Geometric Mean	Range	Geometric Mean	Range
Industrial	40	2 - 280	20	5 - 43
Public	1.8	1.5 - 2.5	36	15 - 55

The assembled data set is shown in Attachment A. Note that only tests of uncontrolled and watered roads were considered. The assembled data sets comprises 203 individual test results. This includes the 6 "total" PM10 tests I developed from the report to the National Stone Association and presented in the set of comments that I sent you last month. It also includes the Reno, NV unpaved road tests conducted as part of Bill Kuykendal's PM2.5/PM10 study. On the other hand, the tests from Raleigh, NC and the first tests that Chat conducted at our Field Station in Grandview, MO are not included because those tests (BJ-1 through BJ-4 in Raleigh and BG-1 through BG-5 at the Field Station) have not yet been formally reported. However, I did reserve the 9 tests for validation purposes. This is discussed later in the memo.

<u>Emission Factor Development</u>

Stepwise multiple linear regression was used with the data set. The potential correction factors include:

- surface silt content, s
- surface moisture content, M

- mean vehicle weight, W
- mean vehicle speed, S
- mean number of wheels, w

All variables were log-transformed in order to obtain a multiplicative model as in the past.

The data base was then sorted by whether the test represented uncontrolled or watered conditions. The first analysis involved the stepwise regression of the uncontrolled tests using the potential correction parameters of s, W, S, and w (silt, weight, speed and number of wheels). Note that moisture content was not considered. In this case, W entered the regression first, and silt on the second step. The resulting model is of the following form:

$$e \alpha \ s^{0.81} W^{0.36} \qquad (2)$$

(This first regression is roughly analogous to repeating how the unpaved road emission factor was derived. As before, only uncontrolled tests were included in the data set. In this case, however, the effort focused on the PM10 size fraction of emissions. The resulting emission factor is roughly comparable to the current AP-42 unpaved road emission factor equation. The silt content has almost a linear ("power of 1") relationship with the emission factor. In addition, emissions follow a "less-than-linear" relationship with vehicle weight. In Equation (1), however, the exponent for W is roughly half that in the current AP-42 equation.

Next, uncontrolled and watered tests were considered separately, but this time with moisture content included as a potential correction parameter. For the 137 uncontrolled tests, weight and silt were again the first two variables to enter the regression. Moisture entered on the third step and speed on the fourth, with the resulting model of the form:

$$e \alpha \ s^{0.85} W^{0.49} S^{0.29} / M^{0.25} \qquad (2)$$

Inclusion of speed is somewhat tentative, in that its level of significance is just slightly greater than 10%. Had the requirement for a variable to enter been tightened, speed would not have entered.

For the 43 watered tests, only two correction parameters entered the regression, silt and weight. The resulting model is of the form

$$e \alpha \ s^{0.72} W^{0.57} \qquad (3)$$

Finally, both uncontrolled and watered tests were considered as one data set, again with M included as a potential correction parameter. In this instance, weight and silt again entered first and second, with moisture entering on the third step. As before, speed S entered on the fourth iteration. The resulting model is of the form

$$e \alpha \ s^{0.85} W^{0.50} S^{0.32} / M^{0.29} \qquad (4)$$

Again, inclusion of the variable S may be viewed as somewhat contingent. As opposed to Equation (2), S enters at the 10% level of significance in this regression. Still, its inclusion is definitely the product of the data set being used. For example, the exclusion of only one or two certain low-speed tests from the data set would probably result in S not entering the regression at all. On the other hand, dropping those tests would essentially have not effect on the rest of the model.

Unlike vehicle weight (which spans two orders of magnitude), most speeds in the data set lie in a fairly tight band between 15 and 35 mph. In addition, the emission factor is found to have a reasonably weak (0.3 power) dependence on speed. Had the requirement for a variable to enter the regression been tightened from 10% to 5% level of significance, speed would not enter the equation, and the resulting model would have the form:

$$e \propto s^{0.82} W^{0.46} / M^{0.28} \qquad (5)$$

Fairly strong cases could be argued for selecting either Equation (4) or Equation (5). I first thought that (4) is preferrable for the following reasons:

1. For the majority of cases when the average speed is roughly between 15 and 35 mph, the two equations have roughly, the same predictive accuracy.

2. Equation (4) would allow an AP-42 user to account for instances with either low- or high-speed traffic. Equation (4) is likely to have greater accuracy in those cases.

However, in performing some of the validation studies, I found that, when part of the data base was held back for validation purposes, the number of wheels rather than speed would enter on the last step. It appears to me that the fourth variable is just a little too much on the "ragged" edge. Equation (5) somewhat sidesteps the issue, but it is still based on good science and allows one to perform more straightforward validation analyses.

The unpaved road emission model I recommend incorporating into AP-42 is based on Equation (5) and thus has the general form,

$$e = 1.6\ (s/12)^{0.8}\ (W/3)^{0.5} / (M/1)^{0.3} \qquad (6)$$

where

e = PM10 emission factor (lb/vmt)
s = surface material silt content (%)
W = mean vehicle weight (tons)
M = surface material moisture content (%)

Note that the "normalizing factors" of 12% silt and 3 tons are the same as for the current AP-42 model. This allows one to compare the leading term of 1.6 lb/vmt in Equation (6) to the factor of 2.1 lb/vmt inherent in the current version of the unpaved road predictive model. This is consistent with my earlier finding that "re-centering" the current factor to PM10 data would require reducing the leading term by about 30%.

Validation Studies

The first validation study made use of a cross-validation analysis. In this approach, each data point is eliminated one at a time. The regression obtained from the "reduced" data base is used to estimate the missing data value. In this way, a set of "n" quasi-independent observations is obtained from the data set of "n" tests.

The cross-validation (CV) shows that the model is fairly accurate for a very broad range of source conditions. Table 1 indicates that, although the model may slightly under- or overpredict emission for some specific subset of the data base, the general agreement is quite good. The CV analysis further found that, for the quasi-independent estimates of the measured emission factors,

- 52% are within a factor of 2
- 73% are within a factor of 3
- 90% are within a factor of 5
- 98% are within a factor of 10

In examining the residuals (i.e., the error between the predicted and observed emission factors), I found that Equation (6) tends to overpredict the lowest and underpredict the highest observed factors. In other words, the model appears to have a systematic bias at the extremes of the parent data base. This is not believed to be overly restrictive, given AP-42's goal to represent "average" conditions. No other significant relationship was found for the residuals.

A limited second validation study involved reserving approximately 20 to 25% of the data base for validation purposes. Test data were randomly selected for inclusion in either the "development" or the "validation" data set. Two separate random selections were performed. The development data set is used to develop the relationship which is used to estimate tests in the validation set. The first development set led to the following predictive model

$$e = 1.55\ (s/12)^{0.78}\ (W/3)^{0.44}\ /\ (M/1)^{0.35}$$

and Development Set 2 led to the following model

$$e = 1.72\ (s/12)^{0.80}\ (W/3)^{0.43}\ /\ (M/1)^{0.26}$$

Note that both development sets led to models very similar to that in Equation (6). When the two models were used to predict data in the validation sets, the following summary statistics result:

	No. of	Ratio of Predicted to Observed			
Validation Set	Cases	Minimum	Maximum	Geo. Mean	Geo. Std. Dev.
1	n = 41	0.123	29.3	0.926	2.92
2	n = 40	0.125	6.58	1.27	2.63

A final validation study involved the 9 emission tests that have not yet been formally reported. Table 2 shows the results of the comparisons of predicted to observed PM10 emission factors. Predictions based on both Equation (6) and the current AP-42 model are considered. In general, agreement is quite good for the new unpaved road model.

Summary

A revised unpaved road emission factor of the type presented in Equation (6) satisfactorily predicts emissions from a broad range of vehicles traveling over unpaved surfaces. It appears that this model could replace not only the "generic" unpaved factor in Section 13.2 but also the haul truck factor in the surface coal mine section.

Table 2. Application of new model to Raleigh and Grandview data

Run	Silt (%)	Moisture (%)	Weight (tons)	Speed (mph)	No. of Whls	Measured PM10 EF (lb/vmt)	Ratio of Predicted to Observed: Equ. (6)	Ratio of Predicted to Observed: Current AP-42
BJ-1	4.01	0.1	2	30	4	1.23	0.88	0.43
BJ-2	2.9	0.1	2	30	4	1.29	0.65	0.30
BJ-3	4.26	0.07	2	30	4	0.84	1.51	0.67
BJ-4	3.7	0.09	2	30	4	1.32	0.80	0.37
BG-1	7.2	7.2	2	30	4	0.503	0.95	1.89
BG-2	6.22	0.65	2	30	4	0.925	0.95	0.89
BG-3	6.07	0.54	2	30	4	1.12	0.81	0.71
BG-4	7.56	1.38	2	30	4	0.118	6.95	8.44
BG-5	7.97	1.12	2	30	4	0.0884	10.30	11.88

NOTE: BG-4 and -5 conducted under mist and rainy conditions.

Table 1. Results of Cross-validation

Type of Vehicle/Road	Uncontrolled/ Watered/	No. of Cases	Ratio of quasi-independent estimate to measured emission factor	
			Geo. Mean	Geo. Std. Dev.
Haul trucks	U	39	0.98	2.44
	W	34	1.10	2.49
	Overall	**73**	**1.03**	**2.45**
Light-medium duty traffic on industrial roads	U	29	1.09	2.85
Light-medium duty traffic on public roads	U	43	0.97	2.36
	Overall	**72**	**1.02**	**2.54**
Heavy duty traffic on industrial roads	U	3	1.28	1.39
Scrapers in travel mode	U	23	0.82	3.62
	W	9	1.00	5.13
	Overall	**32**	**0.87**	**3.93**

Ron Myers Comments
Received 5/97

Emission Factor Documentation for AP-42
Section 13.2.2

Unpaved Roads

Draft Report

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Factor and Inventory Group
Research Triangle Park, NC 27711

Attn: Mr. Ron Myers (MD-14)
Emission Factor and Inventory Group

EPA Contract 68-D2-0159
Work Assignment No. IV-02

MRI Project No. 4604-02

April 1997

for PM-10. Also, a reapplication of the petroleum resin had an estimated lifetime of 23,000 vehicle passes for PM-10.

A cost effectiveness was calculated for each of the three controls as follows: the Petro Tac initial application was $0.06/lb of PM-10 reduced; the Coherex® initial application was $0.64/ lb of PM-10 reduced; the Coherex® reapplication was $0.16/lb of PM-10 reduced; and the water application was $1.30/lb of PM-10 reduced.

4.2.14 Reference 14

Midwest Research Institute, "Improved Emission Factors for Fugitive Dust From Western Surface Coal Mining Sources" for U. S. Environmental Protection Agency, Cincinnati, OH, July 1981.

This study was conducted to develop emission factors for major surface coal mining activities occurring in the western United States. Results are reported of testing conducted in 1979 and 1980 at three surface coal mines located in Wyoming, North Dakota, and New Mexico. Sampling was conducted on the following mining operations: drilling, blasting, coal loading, bulldozing, dragline operations, haul trucks, light- and medium-duty trucks, scrapers, graders, and wind erosion of exposed areas. Particulate sizes measured include, TSP, IP, and PM-2.5.

Exposure profiling was used to measure emissions from line source activities such as vehicle traffic on unpaved roads and from scraping and grading. Comparisons of data from profiling and upwind-downwind methods were made for scrapers and haul roads. A modified exposure profiling methodology was utilized for blasting emission measurements, and a wind tunnel was used to measure wind erosion emissions. Area source emissions such as coal loading were tested with an upwind/downwind methodology.

The exposure profiling method used a downwind profiler with four sampling heads located at heights of 1.5 to 6.0 m. A standard hi-vol sampler (2.5 m), a hi-vol sampler fitted with a cascade impactor (2.5 m), and two dichotomous samplers (1.5 and 4.5 m) were located downwind. Dust fall buckets were placed upwind and downwind at a height of 0.75 m to measure the particle deposition. Upwind concentrations were measured with one dichotomous sampler and one standard hi-vol sampler, both located at a height of 2.5 m. Wind speed was measured with warm wire anemometers downwind at heights of 1.5 and 4.5 m.

PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Work Assignment No. 4-02. Mr. Ron Myers was the requester of the work.

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1. INTRODUCTION

The document *Compilation of Air Pollutant Emission Factors* (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State and local air pollution control programs, and industry.

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Emission factors usually are expressed as the weight of pollutant divided by the unit weight, volume, distance, or duration of the activity that emits the pollutant. The emission factors presented in AP-42 may be appropriate to use in a number of situations, such as making source-specific emission estimates for area wide inventories for dispersion modeling, developing control strategies, screening sources for compliance purposes, establishing operating permit fees, and making permit applicability determinations. The purpose of this report is to provide background information from test reports and other information to support revisions to AP-42 Section 13.2.2, Unpaved Roads.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a characterization of unpaved road emission sources and a description of the technology used to control emissions resulting from unpaved roads. Section 3 is a review of emission data collection and emission measurement procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission equations and methods of emission factor determination. Section 4 details how the revised AP-42 section was developed. It includes the review of specific data sets, a description of how candidate the emission equation was developed, and a summary of changes to the AP-42 section. Section 5 presents the AP-42 Section 13.2.2, Unpaved Roads.

Throughout this report, the principal pollutant of interest is PM-10—particulate matter (PM) no greater than 10 μmA (microns in aerodynamic diameter). PM-10 forms the basis for the current National Ambient Air Quality Standards (NAAQS) for particulate matter. PM-10 thus represents the particle size range that is of the greatest regulatory interest. Because formal establishment of PM-10 as the standard basis for the NAAQS occurred in 1987, many earlier emission tests (and in fact the current version of the unpaved road emission factor) have been referenced to other particle size ranges, such as,

TSP Total Suspended Particulate, as measured by the standard high-volume (hi-vol) air sampler. Total suspended particulate, which encompasses a relatively coarse size range, was the basis for the previous NAAQS for PM. Wind tunnel studies have shown that the particle mass capture efficiency curve for the hi-vol sampler is very broad, extending from 100 percent capture of particles smaller than 10 micrometers to a few percent capture of particles as large as 100 micrometers. Also, the capture efficiency curve varies with wind speed and wind direction, relative to roof ridge orientation. Thus, the hi-vol sampler does not provide definitive particle size information for emission factors. However, an effective cutpoint of 30 μm aerodynamic diameter is frequently assigned to the standard hi-vol sampler.

SP Suspended Particulate, which is often used as a surrogate for TSP, is defined as PM with an aerodynamic diameter no greater than 30 μmA. SP may also be denoted as "PM-30."

IP Inhalable Particulate is defined as PM with an aerodynamic diameter no greater than 15 μmA. IP may also be denoted as "PM-15."

FP Fine Particulate is defined as PM with an aerodynamic diameter no greater than 2.5 μmA. FP may also be denoted as "PM-2.5."

As of this writing, the EPA plans to promulgate new PM NAAQS based on PM-2.5.

2. SOURCE DESCRIPTION

2.1 SOURCE CHARACTERIZATION[1]

Particulate emissions occur whenever vehicles travel on unpaved roads. Dust plumes trailing behind vehicles on unpaved roads are a familiar sight in rural areas of the United States. Many industrial areas also have active unpaved roads. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

2.2 EMISSIONS[1,2]

and PM less than 2.5 microns in aerodynamic diameter (PM-2.5)

The emission of concern from unpaved roads is particulate matter (PM) including PM less than 10 microns in aerodynamic diameter (PM-10). The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on correction parameters that characterize (a) the condition of a particular road and (b) the associated vehicle traffic. Parameters of interest in addition to the source activity (number of vehicle passes) should include the vehicle characteristics (e.g., vehicle weight), the properties of the road surface material being disturbed (e.g. silt content, moisture content), and the climatic conditions (e.g., frequency and amounts of precipitation).

Dust emissions from unpaved roads have been found to vary directly with the fraction of silt in the road surface material. Silt consists of particles less than 75 μm in diameter, and silt content can be determined by measuring the proportion of loose dry surface dust that passes through a 200-mesh screen, using the ASTM-C-136 method.

2.3 HISTORY OF THE UNPAVED ROAD EMISSION FACTOR EQUATION IN AP-42

The current version of the AP-42 unpaved road emission factor equation for dry conditions has the following form:[1]

$$E = k\ 5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5} \quad (2\text{-}1)$$

where:

E = Emission factor, pounds per vehicle-mile-traveled, (lb/VMT)

k = Particle size multiplier (dimensionless)

s = Silt content of road surface material (%)

S = mean vehicle speed, kilometers per hour (km/hr) (miles per hour [mph])

W = mean vehicle weight, megagrams (Mg) (ton)

w = mean number of wheels (dimensionless)

AP-42 discusses how Equation 2-1 can be extrapolated to annual conditions through the simplifying assumption that emissions are present at the "dry" level on days without measurable precipitation and conversely, are absent on days with more than 0.1 in. (0.254 mm) of precipitation. Thus, the emission factor for annual conditions is:

$$E = k\ 5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad (2\text{-}1a)$$

where all quantities are as before and:

p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year

The particle size multiplier "k" for different particulate size ranges is shown below.

Aerodynamic Particle Size Multiplier (k) for Equation 2-1					
≤30μm[a]	≤30μm	≤15μm	≤10μm	≤5μm	≤2.5μm
1.0	0.80	0.50	0.36	0.20	0.095

[a]Stoke's diameter

The earliest emission factor equation for unpaved roads first appeared in AP-42 in 1975. The current version of the emission factor equation appeared in 1983 as part of Supplement 14 to the third edition of AP-42.

The earliest version of the unpaved road emission factor equation included the first two correction terms shown in Equation 2-1 (i.e., silt content and mean vehicle speed). However, the data base for that version was limited to tests of publicly accessible unpaved roads travelled by light-duty vehicles and had a small range of average travel speeds (30 to 40 mph).[3] Subsequent emission testing (especially roads at iron and steel plants) expanded the ranges for both vehicle weight and vehicle speed. In 1978, a modified equation that included silt, speed, and weight was published in an EPA report.[4] In 1979, the current version (Equation 2-1) was first published;[5] it incorporated a slight reduction in the exponent for vehicle weight and added the wheel correction term.

Although the emission factor equation for unpaved roads has been modified over the past 20 years, all versions have important common features. All were developed using multiple linear regression of the suspended particulate emission factor against correction parameters that describe source conditions. The silt content has consistently been found to be of critical importance in the predictive equation. The first version of the predictive equation (and each subsequent refinement) included a roughly linear (power of 1) relationship between the emission factor and the road surface silt content.[a]

In addition to the unpaved road emission factor equation discussed above, other studies have been undertaken to model emissions from unpaved road vehicular traffic. For example, the 1983 background document for this section of AP-42 lists three other candidate emission factor equations.[6] Equation 2-1 was recommended over the other candidates on the basis of its wider applicability.

Additional studies addressed emissions from restricted classes of unpaved roads. In particular, a 1981 report included separate emission factors for (a) light-to medium-duty traffic, and (b) haul trucks on unpaved roads for use at western surface coal mines.[7] Neither equation bore resemblance to the generic unpaved road emission factor (Equation 2-1). A 1991 study (described in Section 4 of this report) addressed emissions due to relatively high-speed traffic on publicly accessible roads in Arizona.[2]

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[a]Note that during the 1970's, the exponent for the silt content was rounded to unity because of the greater computational ease. Recall that this equation predated inexpensive calculators with "x to the y" capability.

Furthermore, in response to Section 234 of the Clean Air Act Amendments, the western surface coal mining emission factors were reexamined.[8,9] Results from that study are also described in Section 4.

2.4 EMISSION CONTROL TECHNOLOGY[1,10,11]

Controls to reduce particulate emissions from unpaved roads fall into three general categories as follows: source extent reductions, surface improvements, and surface treatment. Each of the categories is discussed below.

Source extent reductions limit the amount of traffic to reduce particulate emissions. The emissions directly correlate to the vehicle miles traveled on the road. An example of limiting traffic is restricting road use to certain vehicle types. The iron and steel industry, for example, has instituted some employee busing programs to eliminate a large number of vehicle passes during shift changes.

Surface improvements offer a long term control technique. Paving is a surface improvement that is a highly effective control, but can be cost prohibitive especially on low volume roads. From past experience, paving has an estimated 99 percent control efficiency for PM-10. Control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions. The predictive emission factor equation for paved roads, given in AP-42 Section 13.2.1, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on (a) the intensities of deposition processes that add silt to the surface, and (b) whether the pavement is periodically cleaned.

Other surface improvements include covering the road surface with a new material of lower silt content. For example a dirt road could be covered with gravel or slag. Also, regular maintenance practices, such as grading, of gravel roads help to retain larger aggregate sizes on the traveled portion of the road and thus help reduce emissions. The amount of emissions reduction is directly tied to the reduction in surface silt content.

Surface treatments include control techniques that require reapplication such as watering and chemical stabilization. Watering increases the road surface moisture content, which conglomerates the silt particles and reduces their likelihood to become suspended when a vehicle passes over the road surface. The control efficiency of watering depends upon (a) the application rate of the water, (b) the time between applications, (c) traffic volume during the period, and (d) the meteorological conditions during the period.

Chemical stabilization attempts to change the physical characteristics of the road and its surface to suppress emissions. Common chemical dust suppressants form a hardened cement-like road surface. The control effectiveness of chemical dust suppressants depends on the dilution rate, application rate, time between applications, and traffic volume between applications. Other factors that effect the performance of dust suppressants include the vehicle characteristics (e.g. average vehicle weight) and road characteristics (e.g. bearing strength). The variabilities in the above factors and in individual products make the control efficiencies of chemical dust suppressants difficult to calculate. Past experience has shown that chemical dust suppressants provide a PM-10 control efficiency of about 80 percent when applied at regular intervals. Figure 2-1 presents control efficiency relationships averaged over two common application intervals, 2 weeks and 1 month.

How was the control efficiency of the chemical dust suppressants determined? If the method was by re-evaluating the silt content of the road material then it would be worthwhile including that into the section,

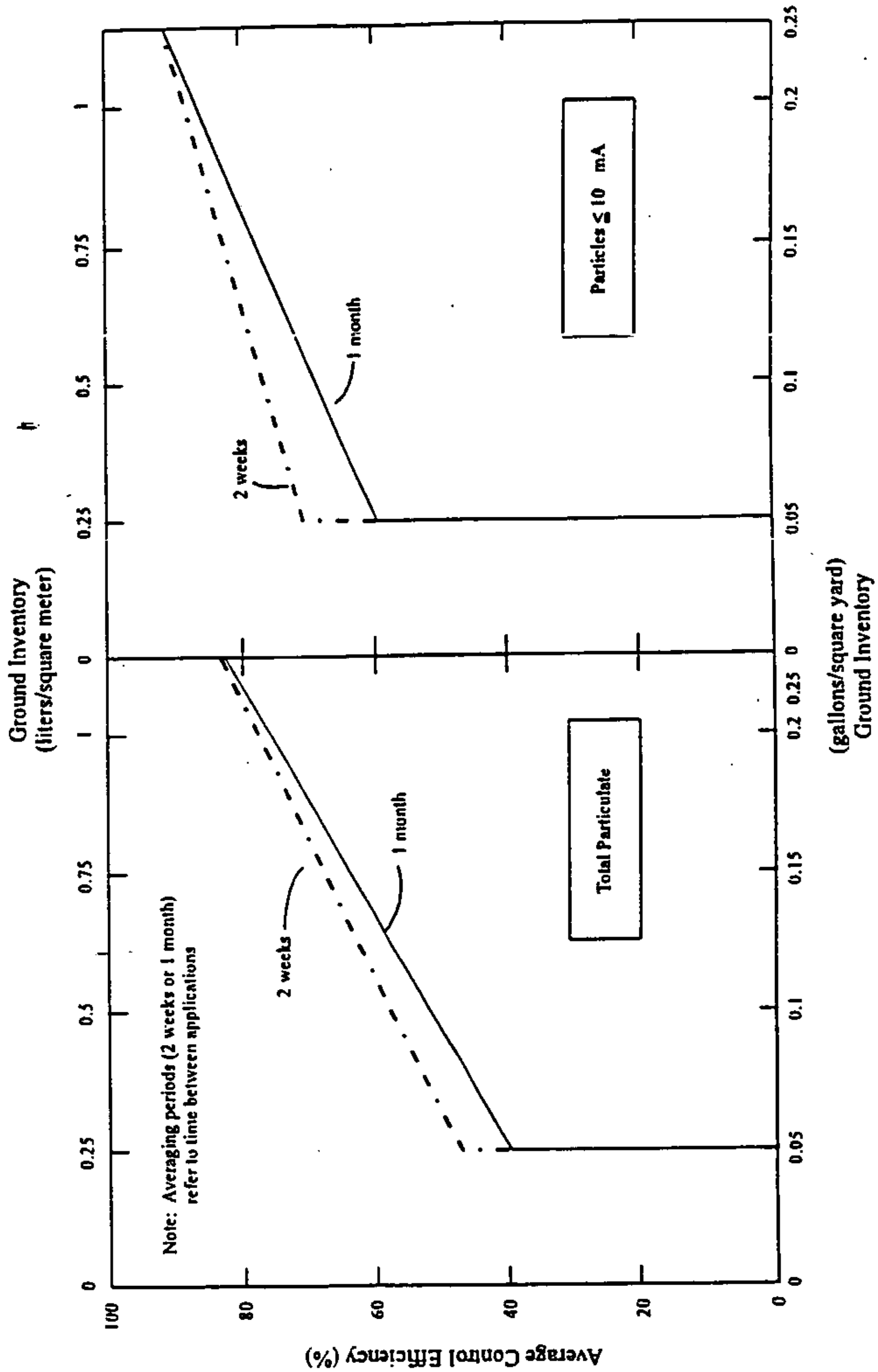

Figure 2-1. Average control efficiencies over common application intervals for chemical dust suppressants.

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2. *Unpaved Road Emission Impact, Final Report*, Arizona Department of Environmental Quality, Phoenix, AZ, March 1991.

3. *Development of Emission Factors for Fugitive Dust Sources*, EPA-450/3-74-037, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency , Research Triangle Park, NC, June 1974.

4. *Fugitive Emissions from Integrated Iron and Steel Plants*, EPA-600/2-78-050, Office of Research and Development, U. S. Environmental Protection Agency , Research Triangle Park, NC, March 1978.

5. *Iron and Steel Plant Open Source Fugitive Emission Evaluation*, EPA-600/2-79-103, Office of Energy, Minerals, and Industry, U. S. Environmental Protection Agency , Research Triangle Park, NC, May 1979.

6. *Fugitive Dust Emission Factor Update for AP-42*, EPA Contract No. 68-02-3177, Assignment 25, Industrial Environmental Research Laboratory, U. S. Environmental Protection Agency , Research Triangle Park, NC, September 1983.

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8. *Review of Surface Coal Mining Emission Factors*, EPA-454/R-95-007, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1991.

9. *Surface Coal Mine Emission Factor Study*, U. S. Environmental Protection Agency, EPA Contract No. 68-D2-0165, Assignment I-06, Research Triangle Park, NC, January 1994.

10. *Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures*, EPA-450/2-92-004, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1992.

11. *Control of Open Fugitive Dust Sources*, EPA-68-02-4395, Assignment 14, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1988.

3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

To reduce the amount of literature collected to a final group of references from which emission factors could be developed, the following general criteria were used.

1. Emissions data must be from a primary reference.

a. Source testing must be from a referenced study that does not reiterate information from previous studies.

b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.

2. The referenced study must contain test results based on more than one test run.

3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions.

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

3.2 DATA QUALITY RATING SYSTEM[1]

As part of the analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The following data are to be excluded from consideration:

1. Test series averages reported in units cannot be converted to the selected reporting units.

2. Test series representing incompatible test methods.

3. Test series of controlled emissions for which the control method is not specified.

4. Test series in which the source process is not clearly identified and described.

Test data sets that were not excluded were assigned a quality rating. The rating system used was that specified by EPA for preparing AP-42 sections.[9] The data were rated as follows:

A   Multiple tests that were performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform to the methodology specified in EPA reference test methods, although these methods were used as a guide for the methodology actually used.

B   Tests that were performed by a generally sound methodology, but lack enough detail for adequate validation.

C   Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

D   Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report, and any variations in the sampling and process operation are noted. If a large spread between test results

cannot be explained by information contained in the test report, the data are suspect and were given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations were dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

3.3 EMISSION FACTOR QUALITY RATING SYSTEM[1]

The quality of the emission factors developed from analysis of the test data was rated using the following general criteria:

A—Excellent: Developed from A- and B-rated source test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B—Above average: Developed only from A- or B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. The source category is specific enough so that variability within the source category population may be minimized.

C—Average: Developed only from A-, B- and/or C-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. In addition, the source category is specific enough so that variability within the source category population may be minimized.

D—Below average: The emission factor was developed only from A-, B-, and/or C-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E—Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are footnoted.

The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer. Details of the rating of each candidate emission factor are provided in Section 4.

3.4 METHODS OF EMISSION FACTOR DETERMINATION[2]

Fugitive dust emission rates and particle size distributions are difficult to quantify because of the diffuse and variable nature of such sources and the wide range of particle size involved including particles which deposit immediately adjacent to the source. Standard source testing methods, which are designed for application to confined flows under steady state, forced-flow conditions, are not suitable for measurement of fugitive emissions unless the plume can be drawn into a forced-flow system. The following presents a brief overview of applicable measurement techniques.

3.4.1 Mass Emission Measurements

Because it is usually impractical to enclose open dust sources or to capture the entire emissions plume, only the upwind-downwind and exposure profiling methods are suitable for measurement of particulate emissions from most open dust sources.[3] These two methods are discussed separately below.

The basic procedure of the upwind-downwind method involves the measurement of particulate concentrations both upwind and downwind of the pollutant source. The number of upwind sampling instruments depends on the degree of isolation of the source operation of concern (i.e., the absence of interference from other sources upwind). Increasing the number of downwind instruments improves the reliability in determining the emission rate by providing better plume definition. In order to reasonably define the plume emanating from a point source, instruments need to be located at two downwind distances and three crosswind distances, at a minimum. The same sampling requirements pertain to line sources except that measurement need not be made at multiple crosswind distances.

Net downwind (i.e., downwind minus upwind) concentrations are used as input to dispersion equations (normally of the Gaussian type) to backcalculate the particulate emission rate (i.e., source strength) required to generate the pollutant concentration measured. Emission factors are obtained by dividing the calculated emission rate by a source activity rate (e.g., number of vehicles, or weight of material transferred per unit time). A number of meteorological parameters must be concurrently reported for input to this dispersion equation. At a minimum, the wind direction and speed must be recorded on-site.

more info on criteria for the best possible sampling and analysis criteria for performing an acceptable upwind/downwind emission factor determination, - eg. winds within ±45° during almost all of the sampling time, proper selection of surface roughness parameters, initial dispersion, mixing height (σ_{z_0}) and, Measurement of all of the critical parameters such as surface silt percent, moisture, vehicle weight, vehicle speed, etc.

While the upwind-downwind method is applicable to virtually all types of sources, it has significant limitations with regard to development of source-specific emission factors. The major limitations are as follows:

1. In attempting to quantify a large area source, overlapping of plumes from upwind (background) sources may preclude the determination of the specific contribution of the area source.

2. Because of the impracticality of adjusting the locations of the sampling array for shifts in wind direction during sampling, it cannot be assumed that plume position is fixed in the application of the dispersion model.

3. The usual assumption that an area source is uniformly emitting does not allow for realistic representation of spatial variation in source activity.

4. The typical use of uncalibrated atmospheric dispersion models introduces the possibility of substantial error (a factor of three according to Reference 4) in the calculated emission rate, even if the stringent requirement of unobstructed dispersion from a simplified (e.g., constant emission rate from a single point) source configuration is met.

More details is needed on appropriate & acceptable sampling criteria and required for profiling. The objective is to educate the reviewers of this report, the users of this report, future researchers that may want to reproduce or check that factors or tests.

The other measurement technique, exposure profiling, offers distinct advantages for source-specific quantification of fugitive emissions from open dust sources. The method uses the isokinetic profiling concept that is the basis for conventional (ducted) source testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the effective cross section of the fugitive emissions 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.

For measurement of nonbuoyant fugitive emissions, profiling sampling heads are distributed over a vertical network positioned just downwind (usually 5 m) from the source. If total particulate emissions are to be measured, sampling intakes are pointed into the wind and sampling velocity is adjusted to match the local mean wind speed, as monitored by anemometers distributed over heights above ground level.

present the equation(s) for calculating the initial dispersion (σ_{z1}) for a line source

The size of the sampling grid needed for exposure profiling of a particular source may be estimated by observation of the visible size of the plume or by calculation of plume dispersion. Grid size adjustments may be required based on the results of preliminary testing. Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing about 90 percent of the total mass flux (exposure). For example, assuming that the exposure from a point source is normally distributed, the exposure values measured by the samplers at the edge of the grid should be about 25 percent of the centerline exposure.

To calculate emission rates using the exposure profiling technique, 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. The exposure is the point value of the flux (mass/area/time) of airborne particulate integrated over the time of measurement.

3.4.2 Emission Factor Derivation

emission factors are more typically arethmetic means. Only in unusual instances would a geometric mean be used. Emission factors are for developing average values that are good predictor of an areas emissions.

Usually the final emission factor for a given source operation, as presented in a test report, is derived simply as the geometric mean of the individual emission factors calculated from each test of that source. ~~Frequently~~ In rare instances the range of individual emission factor values is also presented.

As an alternative to the presentation of a final emission factor as a single-valued ~~geometric~~ arethmetic mean, an emission factor may be presented in the form of a predictive equation derived by regression analysis of test data. Such an equation mathematically relates emissions to parameters ~~when characterizing source~~ which are those physical parameters having the most affect on the emissions and are easily measured for the aplication of the final equation. conditions. These parameters may be grouped into three categories:

1. Measures of source activity or energy expended (e.g., the speed, number of wheels and weight of ~~a~~ vehicles traveling on an unpaved road).

2. Properties of the material being disturbed (e.g., the content of suspendable fines in the surface material on an unpaved road, moisture content of the surface material).

The general method employed in regression analysis is to first examine the physical forces that affect the dependent variable, to construct an empirical model reflective of those forces then to use regression to provide a best fit

Use the Air Control Technique document for the Crushed Stone Haul Roads (pg 11-22) as a guide in the description of the physical forces and probable effects. Also identify some parameters that may be important but that would be difficult to quantify either retrospectively or prospectively (e.g. aerodynamics, tire tread design)

3. Climatic parameters (e.g., number of precipitation-free days per year on which emissions tend to be at a maximum).

An emission factor equation is useful if it is successful in "explaining" much of the observed variance in emission factor values on the basis of corresponding variances in specific source parameters. This enables more reliable estimates of source emissions on a site-specific basis. In general, an equation's success in explaining variance is gauged by the R-squared value. If an equation has an R-squared value of 0.47, then it is said to "explain" 47 percent of the variance in the set of emission factors. Note, however, that a high value of R^2 may sometimes prove misleading in developing an emission factor equation for a particular data set.

For example, an equation may be "fine tuned" to the developmental data set by including an additional correction parameter, but in a manner that is contrary to the physical phenomena of the dust generation process. This was illustrated in a field study conducted for the Arizona Department of Environmental Quality (as described in Section 4) that found that inclusion of moisture and silt content as correction parameters would require that they enter into the equation in a manner opposite to common sense. That is to say, emissions would increase with increasing moisture content and would decrease with increasing silt content. In that instance, it is important to recognize that the goal of an emission factor equation is not to provide a near-perfect fit to the emission measurements in the developmental data base, but rather to provide reasonably reliable estimates of emissions for situations where no test data are available.

A generic emission factor equation is one that is developed for a source operation defined on the basis of a single dust generation mechanism that crosses industry lines. An example would be vehicular traffic on unpaved roads. To establish its applicability, a generic equation should be developed from test data obtained in different industries. As will be discussed in Section 4, the approach taken to develop a new unpaved road equation has been to combine (to the extent possible) all emission tests of vehicles traveling over an unpaved surface. The combination is made without regard to previous groupings in AP-42. In particular, tests at surface coal mines are combined with tests of unpaved roads within other industries and tests of publicly accessible unpaved roads.

3.5 EMISSION FACTOR QUALITY RATING SCHEME USED IN THIS STUDY[2]

The uncontrolled emission factor quality rating scheme used in this study represents a refinement of the rating system developed by EPA for AP-42 emission factors, as described in Section 3.3. The scheme entails the rating of test data quality followed by the rating of the emission factor(s) developed from the test data, as described below.

Test data that were developed from well documented, sound methodologies are assigned an A rating. Data generated by a methodology that was generally sound but either did not meet minimum test system requirements or lacked enough detail for adequate validation receives a B rating.

In evaluating whether an upwind-downwind sampling strategy qualifies as a sound methodology, the following minimum test requirements are used. At least five particulate measuring devices must be operated during a test, with one device located upwind and the others located at two downwind and three crosswind distances. The requirement of measurements at crosswind distances is waived for the case of line sources. Also wind direction and speed must be monitored concurrently on-site.

The minimum requirements for a sound exposure profiling program are the following. A one-dimensional, vertical grid of at least three samplers is sufficient for measurement of emissions from line or moving point sources while a two-dimensional array of at least five samplers is required for quantification of fixed virtual point source emissions. At least one upwind sampler must be operated to measure background concentration, and wind speed must be measured on-site. what about wind direction, speed, mass increase, height of samplers, upwind downwind distances

Neither the upwind-downwind nor the exposure profiling method can be expected to produce A-rated emissions data when applied to large, poorly defined area sources, or under very light and variable wind flow conditions. In these situations, data ratings based on degree of compliance with minimum test system requirements were reduced one letter.

After the test data supporting a particular single-valued emission factor are evaluated, the criteria presented in Table 3-1 are used to assign a quality rating to the resulting emission factor. These criteria were developed to provide objective definition for (a) industry representativeness; and (b) levels of variability within the data set for the source category. The rating system obviously does not include estimates of statistical confidence, nor does it reflect the expected accuracy of fugitive dust emission factors relative to conventional stack emission factors. It does, however, serve as a useful tool for evaluation of the

Other criteria for rating the data would be the collection of the activity and process info for each test (eg. silt %, moisture, ave wt, speed, wheels)

The test data rating scheme does not seem appropriate. A profile test should have a precision of ±20-30% and even under ideal conditions an upwind/downwind evaluation would have a precision of ±200-300% (factor of 2-3). I would say that the best rating achievable by upwind/downwind analysis and receptor analysis is a C without many samples, then maybe B.

quality of a given set of emission factors relative to the entire available fugitive dust emission factor data base.

Minimum industry representativeness is defined in terms of number of test sites and number of tests per site. These criteria were derived from two principles:

1. Traditionally, three tests of a source represent the minimum requirement for reliable quantification.

2. More than two plant sites are needed to provide minimum industry representativeness.

The level of variability within an emission factor data set is defined in terms of the spread of the original emission factor data values about the mean or median single-valued factor for the source category. The fairly rigorous criterion that all data points must lie within a factor of two of the central value was adopted. It is recognized that this criterion is not insensitive to sample size in that for a sufficiently large test series, at least one value may be expected to fall outside the factor-of-two limits. However, this is not considered to be a problem because most of the current single-valued factors for fugitive dust sources are based on relatively small sample sizes.

Development of quality ratings for emission factor equations also requires consideration of data representativeness and variability, as in the case of single-value emission factors. However, the criteria used to assign ratings (Table 3-2) are different, reflecting the more sophisticated model being used to represent the test data. As a general principle, the quality rating for a given equation should lie between the test data rating and the rating that would be assigned to a single-valued factor based on the test data. The following criteria are used to determine whether an emission factor equation has the same rating as the supporting test data:

1. At least three test sites and three tests per site, plus an additional three tests for each independent parameter (P) in the equation.

2. Quantitative indication that a significant portion of the emission factor variation is attributable to the independent parameter(s) in the equation.

Loss of quality rating in the translation of these data to an emission factor equation occurs when these criteria are not met. In practice, the first criterion is far more influential than the second in rating an emission factor equation, because development of an equation implies that a substantial portion of the emission factor variation is attributable to the independent parameter(s). As indicated in Table 3-2, the rating is reduced by one level below the test data rating if the number of tests does not meet the first criterion, but is at least three times greater than the number of independent parameters in the equation. The rating is reduced two levels if this supplementary criterion is not met.

The rationale for the supplementary criterion follows from the fact that the likelihood of including false relationships between the dependent variable (emissions) and the independent parameters in the equation increases as the ratio of the number of independent parameters to sample size increases. For example, a four parameter equation based on five tests would exhibit perfect explanation ($R^2 = 1.0$) of the emission factor data, but the relationships expressed by such an equation cannot be expected to hold true in independent applications.

The evaluation criteria should be based to some extent on the same criteria for single value factors. However, the eveness of test data across the range of the data for each parameter should be considered. The following criteria for the single valued factors are important:

1) Three runs comprise a test
2) The estimate of uncertainty of the population mean is:

$$\bar{X} \pm \frac{6}{\sqrt{n}}$$

3) An evaluation is made to attempt to subcategorize the population.

This could be expanded to allow a test series that makes a significant change in one or more of the variables to be considered as more than one test. For example Ref 1 would be one test while Ref 2 would be 4 tests due to moisture and weight; Ref 3 would be one or 2½ tests due to slight variation in H2O and since two facilities were involved.

Figures which present the ratio of predicted vs actual by the value of the parameter should be developed (X is the value of the parameter and Y is the ratio of pred/actual). So figures for silt content, moisture, avg weight, speed and even wheels. A statistical calculation can present an estimate of population uncertainty for the range of these values

TABLE 3-1. QUALITY RATING SCHEME FOR SINGLE-VALUED EMISSION FACTORS

Code	No. of test sites	No. of tests per site	Total No. of tests	Test data variability[a]	Adjustment for EF rating[b]
1	≥3	≥3	-	< F2	0
2	≥3	≥3	-	> F2	-1
3	2	≥2	≥5	< F2	-1
4	2	≥2	≥5	> F2	-2
5	-	-	≥3	< F2	-2
6	-	-	≥3	> F2	-3
7	1	2	2	> F2	-3
8	1	2	2	> F2	-4
9	1	1	1	-	-4

[a]Data spread in relation to central value. F2 denotes factor of two.
[b]Difference between emission factor rating and test data rating.

TABLE 3-2. QUALITY RATING SCHEME FOR EMISSION FACTORS EQUATIONS

Code	No. of test sites	No. of tests per site	Total No. of tests[a]	Adjustment for EF rating[b]
1	≥3	≥3	≥(9 + 3P)	0
2	≥2	≥3	≥3P	-1
3	≥1	-	<3P	-1

[a]P denotes the number of correction parameters in the emission factor equation.
[b]Difference between emission factor rating and test data rating.

REFERENCES FOR SECTION 3

1. *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections*, EPA-454/B-93-050, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1993.

2. *Emission Factor Documentation for AP-42, Section 11.2.5 and 11.2.6, Paved Roads*, EPA-68-D0-0123, Assignment 44, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1993.

3. *Fugitive Dust Emissions Factor Update for AP-42*, EPA 68-02-3177, Assignment 25, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1970.

4. *Workbook of Atmospheric Dispersion Estimates*, *AP-26*, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1970.

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4. REVIEW OF SPECIFIC TEST REPORTS

4.1 INTRODUCTION

A total of 12 field test reports were identified as being either potentially directly useful data on PM-10 emissions from unpaved roads or data that could be used to interpolate the necessary PM-10 information. These reports are described in Section 4.2 of this report.

4.2 REVIEW OF SPECIFIC DATA SETS

4.2.1 Reference 1

Midwest Research Institute, "Letter Report of Field Tests, Road Sampling," for Washoe County District Health Department, Reno, NV, August 1996.

This letter report presents results of sampling of an unpaved road and a paved road in Washoe County, Nevada, in May and June of 1996. The study was undertaken to provide site-specific test data to supplement a yearlong road surface sampling program. Also, the study supported ongoing EPA reviews of the PM-2.5 fraction of PM-10 emissions from paved and unpaved roads.

Exposure profiling was employed downwind to measure particulate emissions. For the unpaved road tests, three hi-vol samplers each fitted with a cyclone preseparator were located downwind of the test road at heights of 1, 3, and 5 m. Reference method PM-10 samplers were located upwind and downwind of the roadway as well. Wind speed was also recorded at heights of 1, 3, and 5 m.

What was the width of the road? What were the height of disturbances upwind and downwind of the road and what would the angles be. How does the height of the highest sampler compare to the initial dispersion (σz0)

Four unpaved road tests and three paved road tests were completed. The unpaved road tests used only lightweight captive vehicles at low vehicle speeds. The test data were assigned an "A" rating. Table 4-1 presents summary test data and Table 4-2 presents detailed test information.

A comment about the lack of measured moisture content should be added, this may be reason for downgrading the test rating to B. Also was wind direction within ±30° or ±45° during all of the testing. The table needs the results of the PM-2.5 tests. What other data were collected

4.2.2 Reference 2

Midwest Research Institute, "Improvement of Specific Emission Factors (BACM Project No. 1)" for South Coast AQMD, California, March 1996.

This study developed improved particulate emission factors for construction activities and paved roads in western States. Sampling results are reported from testing in June and July, 1995, at three construction sites located in Nevada and California. Also, surface silt loading measurements were taken from paved roads in four separate areas in Nevada and California.

Exposure profiling was employed for the emission measurements. The downwind profiling arrays contained three high volume air samplers fitted with cyclone preseparators at heights of 1, 3, and 5 m. One high volume air sampler with a cyclone preseparator measured upwind concentrations at a 2 m height. Warm wire anemometers, located at heights of 1 and 5 m, measured wind speed.
what was the width of the road? what was the initial dispersion height (σ_{zo})? Were the upwind and downwind disturbances within acceptability criteria?

The unpaved road testing focused on particulate emissions from scraper travel and light-duty vehicles. Six uncontrolled scraper tests and three uncontrolled light duty vehicle tests were completed. In addition, watering was utilized as a control for two controlled scraper tests. The test data were assigned an "A" rating. Table 4-3 presents summary test data and Table 4-4 presents detailed test information.
were PM-2.5 data collected? what about wind direction
were any other data collected. A comment should be made that because of the variations in moisture and vehicle weights this report is considered to be 4 tests

4.2.3 Reference 3

Air Control Techniques, "PM10, PM2.5, and PM1 Emission Factors for Haul Roads at Two Stone Crushing Plants," for National Stone Association, Washington, D.C., November 1995.

This test program presents the results of sampling at two stone crushing plant quarries in August 1995. This study was undertaken to accurately measure PM-10, PM-2.5, and PM-1 emissions from a controlled haul road at a stone quarry. Testing occurred at Martin Marietta's Garner and Lemon Springs quarries in North Carolina.

The study used an upwind-downwind profiling technique that varied from the more commonly used exposure profiling method. Downwind samples were drawn into 10 sample nozzles 8 to 10 inches in diameter that joined a single downcomer connected to an 18 in. horizontal duct. Sampling occurred along the 18 in. horizontal duct using EPA Method 201A for in-stack measurements of PM-10. Particle
what was the road width. what was the initial dispersion height (σ_{zo}).
what was the height of the vehicle

distribution for downwind measurements were collected with a cascade impactor and a nephelometer. Upwind measurements were made using a hi-vol sampler at a height of 15 ft, a cascade impactor, and a nephelometer. Analysis included polarizing light microscopy (PLM) that measured particles of combustion products.

Three emission tests were completed at both Garner and Lemon Springs. All samples were considered controlled through water application during the test periods. Specific water application rates were not reported, although the watering is said to have occurred approximately every 2.5 to 3 hours. Table 4-5 presents summary test data and Table 4-6 presents detailed test information. Noncombustible particulate emissions are presented in Table 4-5 as reported in the study, however, the emissions calculation in the study did not adjust for noncombustible particles in the upwind measurements. For the development of the AP-42 emission equation, combustible material was factored into the emissions.

At the Garner test location, a large rock wall that stood immediately behind the downwind sampling site may have interrupted natural wind flows and/or created a local recirculation event. The potential wind obstruction and the variation in methodology from common exposure profiling methods accounted for a "B" rating of the test data at the Garner quarry, the Lemon Springs test was assigned an "A" rating.

4.2.4 Reference 4

Midwest Research Institute, "Surface Coal Mine Emission Factor Study," for U. S. EPA, January 1994.

This test report presents results of sampling during September and October 1992 at a surface coal mine near Gillette, Wyoming. This study was undertaken to address issues identified in the Clean Air Act Amendments of 1990 regarding the potential overestimation of the air quality impacts of western surface coal mining. The principal objective was to compare field measurements against available emission factors for surface coal mines and revise the factors as necessary.

The study focused on characterizing particulate emissions from line sources such as haul roads and scrapers at a surface mining site. Four haul road sites (No. 1, 1B, 2, and 4) and one scraper site (No. 5) were characterized using downwind exposure profilers for PM-10 fitted with cyclone preseparators, a Wedding PM-10 sampler, and two hi-vol samplers for TSP. The exposure profiling arrays consisted of four samplers located from 1 m to 7 m in height. Upwind concentrations were monitored with a Wedding

PM-10 sampler and one cyclone preseparator. Wind direction at one height (3 m) and wind speed at three heights (1 m, 3 m, and 5 m) were recorded at the downwind sites. Additional sampling studies included measuring the near-source particle size distributions using a combination cyclone preseparator and a cascade impactor. What was the road width? What was the height of the trucks? Give some indication of how valid of data a sampling array with a maximum height 7 meters is when trucks are 20 ft high. What would be the initial dispersion height (σ_{z0}) for these tests?

At the five sites a total of 36 PM-10 emission tests were completed. A majority of the tests (34 PM-10 tests) were performed on haul roads. The haul road tests spanned a large range of wind speeds from 4.5 mph to 22 mph. Approximately half of these tests were controlled by use of water/surfactant. The water/surfactant provided a control efficiency from 40 to 70 percent for PM-10 and from 30 to 60 percent for TSP. A summary of emissions data are presented in Table 4-7 and detailed test information is presented in Table 4-8.

put data & section here

The study evaluated the independent haul road test data against the AP-42 Western Surface Coal Mine, the AP-42 Unpaved Road, and the Wyoming Department of Environmental Quality emission factor models and found none to adequately estimate independent emissions. With the exception of the generic AP-42 unpaved road emission factor (i.e., Equation 2-1) for PM-30, each model considered exhibited a systematic bias toward over- or under-prediction. It is important to note that the AP-42 Section 8.24 (now Section 11.9) haul road emission factor equation generally performed no better in predicting the independent haul road emission factor results than did the "generic" unpaved road equation in AP-42 Section 11.2 (now Section 13.2).

Present the equation in this doc so people don't have to look it up. Also indicate the data for this section.

The 1992 field study also provided new independent test data against which the performance of the Section 8.24 (now Section 11.9) factor for light- to medium-duty traffic could be assessed. That same model was found to be capable of providing unacceptable estimates in some cases. This is believed to be the result of the model's dependence on the fourth power of moisture content. Again, the generic AP-42 unpaved road emission factor equation (Equation 2-1) performed at least as well as the equation in the surface coal mining section. As noted in Section 4.3 of this report, these findings prompted thinking to combine all unpaved travel emission tests into one large data set for emission factor development.

The test data were assigned a rating of A. The report included adequate detail and the methodology meets the requirements for a sound exposure profiling system.

The PM-2.5 data should be presented in the table as should TSP if avail. What about wind direction (±30° or ±45°). This Reference is probably equivalent to only two or three tests due to variations in vehicle weight and moisture.

4.2.5 Reference 5

Entropy, "PM10 Emission Factors for a Haul Road at a Granite Stone Crushing Plant," for National Stone Association, Washington, D.C., December 1994.

This test report presents test data from measurements at a granite quarry in Knightdale, North Carolina. The testing program occurred in October 1994 and focused on PM-10 emissions from an unpaved haul road.

The testing protocols followed what the report termed a "push-pull method." Four 36-inch diameter circulating fans were utilized on the upwind side of the road and large hoods were located downwind to capture particulate emissions. Two sets of two hoods stacked vertically were collocated. A set of hoods consisted of two hoods each four ft high by seven ft wide with one located 2 ft and the other seven ft above the ground. Emissions captured in a set of hoods were drawn through a common 12 inch duct and sampled for PM-10 using EPA Method 201A. One hi-vol PM-10 ambient sampler was located upwind of the circulating fans. Wind speed and wind direction were also monitored.

Three controlled tests and four uncontrolled tests were performed. All seven tests utilized both sets of hoods and the results from both sets were averaged for the emission factor calculations. Testing was discontinued when wind speeds exceeded 3 mph. Controlled tests utilized water as the dust suppressant. For the controlled tests, watering occurred on average every 3.6 hr, however, the water application rate was not reported. Table 4-9 presents summary test data and Table 4-10 presents detailed test information.
What was the road width, what was the initial dispersion height (σ_{z0}). Any indication of vehicle height ($\approx$10 ft)

The "push-pull method" used for this study is not considered an accepted methodology for measuring open source particulate emissions. Strong evidence of recirculation of emissions to the upwind sampler is provided by the fact that the upwind concentrations increased by roughly an order of magnitude from the controlled to the uncontrolled tests. The low sampling height at relatively low wind conditions used for this test program potentially allows the particulate plume to pass over the sampling device without capture. The test data were assigned a "D" rating and were not used in the development of the AP-42 emission factor equation. Also mention the difference in paired mass results for the concurrent tests. Also note the estimated face velocity of the hood systems

4.2.6 Reference 6

Midwest Research Institute. "Unpaved Road Emission Impact," for Arizona Department of Environmental Quality. March 1991.

This study performed field sampling on Arizona rural roads in Pima, Pinal, and Yuma counties. The study also recommended a mathematical model to estimate emissions from unpaved rural roads for arid and semiarid regions, based on a review of historical data as well as Arizona-specific field sampling results. Particle emission sizes of interest in this study were TSP and PM-10. Contrary to expectation, the examination of the historical data base did not find a systematic underprediction of emissions from unpaved roads in the arid portions of the Western United States.

Exposure profiling formed the basis of the measurement technique used at the Arizona sampling sites. For this study, two downwind arrays were deployed 5 m from the road. Each array had three sampling heads located at heights of 1, 3, and 5 m. One downwind unit was fitted with cyclone preseparators. The other downwind unit was equipped with cyclones for half the sampling periods and with standard high volume roofs for the other sampling periods. In addition, one pair each of high volume and dichotomous samplers were operated at a 100 ft downwind distance. Upwind measurements were obtained with a vertical array containing two sampling heads, a standard hi-vol sampler, and a dichotomous sampler. Wind speed was measured with warm wire anemometers at two heights (1 and 5 m), and wind direction was measured at a single height. What was the road width? What is the estimated initial dispersion (σzo) and how does it compare to sampling heights? Were there any obstruction in the upwind or downwind critical areas

A total of 27 PM-10 and 9 TSP emission tests were conducted during May and June 1990. Vehicle passes were controlled during testing periods and three vehicle speeds were tested (35, 45, and 55 mph). The test data were assigned an "A" rating. Table 4-11 presents summary test data and Table 4-12 presents detailed test information. The report examined how well the data developed in the field tests agreed with the current version of the AP-42 emission factor.

Although the AP-42 equation provided reasonably accurate results when applied to the field tests conducted in this study, another emission factor model was developed. 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. As a result of the numerous industrial road tests, the data base generally reflected heavier vehicles than are common on rural roads. Given the interest in rural unpaved road emissions in Arizona, development of an empirical relationship specific to that situation was warranted.

It should be noted that this reference contains the equivalent of about 7 or 8 test series (three speeds and three silt contents) the TSP and PM-2.5 data should be put in the tables. What about wind direction

4.2.7 Reference 7

Midwest Research Institute, "Roadway Emissions Field Tests at US Steels Fairless Works," for U.S. Steel Corporation, May 1990.

This testing program focused on paved and unpaved road particulate emissions at an integrated iron and steel plant near Philadelphia, Pennsylvania, in November 1989. Exposure profiling was used to characterize one unpaved road (Site "X") located near the center of the facility and used principally as a "shortcut" by light-duty vehicles.

was this data included in the regression?

Two tests were conducted using a profiling array, with sample heights from 1.5 m to 6.0 m, that measures downwind mass flux. A high-volume, parallel-slot cascade impactor was employed to measure the downwind particle distribution and a hi-vol sampler was utilized to determine the downwind TSP mass fraction. The upwind particle size distribution was determined with a standard high-volume/impactor combination. *what was the road width? what was the initial dispersion heights (σ_{z0}) and how does it compare to the maximum sample height. Were there any disturbances within the upwind or downwind critical areas what were the heights of the vehicles?*

The unpaved road was treated with chemical suppressants prior to and throughout the testing period. Therefore, the results of this test program were not included in the development of an uncontrolled unpaved road emission equation. The data may be used to estimate the degree of dust control provided by the chemical suppressants. The control efficiencies for PM-10 were estimated to be 80 to 90 percent. Control efficiencies for TSP were estimated at 70 percent to 80 percent for the unpaved road chemical suppressants. Table 4-13 presents summary information and Table 4-14 presents detailed test information.

the TSP and the PM-2.5 emissions should be presented in the table. Put info on wind directions in the summary

4.2.8 Reference 8

Midwest Research Institute, "Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads," for U. S. EPA, EPA-600/2-87-102, November 1987.

This study obtained data on the control effectiveness of common dust suppressants used in the iron and steel industry. Tests were conducted from May through November, 1985, at LTV's Indiana Harbor Works in East Chicago, Indiana, and at Armco's Kansas City Works in Missouri. The testing program measured control performance for five chemical dust suppressants including two petroleum resin products (Coherex® and Generic 2), a emulsified asphalt (Petro Tac), an acrylic cement (Soil Sement), and a calcium chloride solution.

The exposure profiling methodology was utilized for all testing. The downwind exposure profiler contained sampling heads at 1.5, 3.0, 4.5, and 6.0 m. Particle size distribution was determined both upwind and downwind with high volume cascade impactors. Wind speed was monitored at two heights and wind direction was monitored at a single height. What was the road width? What was the initial dispersion height ($6\sigma_z$) compared to the height of the sampling array? Were there any disturbances within the upwind or downwind critical areas. What was the heights of the vehicles?

A total of 64 tests were completed with seven uncontrolled tests and 57 controlled tests. Suppressants tested at Indiana Harbor Works were initially applied as follows: Petro Tac at 0.44 gal/yd^2, Coherex® at 0.56 gal/yd^2, and calcium chloride at 0.25 gal/yd^2. All five suppressants were tested at the Kansas City Works facility and were initially applied at the following rates: Petro Tac at 0.21 gal/yd^2, Coherex® at 0.21 gal/yd^2, Soil Sement at 0.16 gal/yd^2, Generic at 0.14 gal/yd^2, and calcium chloride at 0.24 gal/yd^2. A rating of "A" was assigned to the data. Testing followed an acceptable methodology and the test report was well documented.

Total particulate, IP, PM-10, and PM-2.5 were measured during this study. A control efficiency of 50 percent or greater was measured for all chemicals tested. Reapplication of the suppressant resulted in a notably higher level of control. A cost-effectiveness comparison found little variation between suppressants under the test conditions with the exception of a nonfavorable comparison of calcium chloride. Table 4-15 presents summary test data and Table 4-16 presents detailed test information.

It would be informative to know if the opacity performed well at predicting the emissions from the tests. This would allow the use of silt & moisture as an indicator of controlled emissions.

The results of the IP, PM-2.5 should be presented in the tables. Were all tests used in the regression? Identify the tests that were used and those that were not.

4.2.9 Reference 9

Midwest Research Institute, "Fugitive Emission Measurement of Coal Yard Traffic at a Power Plant," for Confidential Client, December 1985.

This study included seven tests of controlled, unpaved surfaces and four tests of uncontrolled, unpaved surfaces at a power plant. Data were given an "A" rating. Airborne particle size fractions of interest in this study are total particulate, TSP, IP, PM-10, and PM-2.5. A section of road within the facility's coal yard was tested in August 1985. The road was a permanent ramp up the main stockpile and is used by scrapers for both stockpiling and reclaiming operations.

Particulate emissions were characterized using three downwind exposure profilers, each consisting of four profiling heads at heights of 1.5, 3.0, 4.5 and 6.0 m. (The use of three profiling systems allowed continuous testing after water application by staggering the operation of the samplers.) Three high-volume, parallel-slot cascade impactors equipped with cyclone preseparators were used to characterize the

What was the road width? What was the initial dispersion height ($6\sigma_z$) compared to the maximum sampling height? Were there any disturbances in the upwind or downwind critical areas? What were the heights of the vehicles.

downwind particle size distribution at a height of 2.2 m. One cyclone/impactor combination was used to characterize the upwind particle size distribution and total particulate concentration. Wind speed was measured with warm-wire anemometers at two heights (3 and 6 m) and wind direction was measured at a single height (4.5 m). Also, incoming solar radiation was measured with a mechanical pyranograph.

The TSP, IP and PM2.5 data should be presented in the Table

For the controlled tests, the road and surrounding areas were watered for approximately 30 minutes before the start of air sampling. Water was applied to the surface at a mean rate of 0.46 gal/yd^2 and found to provide effective control for 3 to 4 hours with 35 vehicle passes/hr. The control efficiency for TSP averaged 74 percent over the 3 hours and the PM-10 control efficiency averaged 72 percent over 3 hours. The control efficiency closely correlated to the surface moisture content, with a higher moisture content increasing the control efficiency. Summary of emissions data are presented in Table 4-17 and detailed test information is presented in Table 4-18. A mention of the method used for drying the samples should be included. It should also be mentioned that due to testing two different moisture levels this would be equivalent to two tests. What variations in wind direction were measured relative to perpendicular to the road.

4.2.10 Reference 10

Midwest Research Institute, "Critical Review of Open Source Particulate Emission Measurements - Part II - Field Comparison," for Southern Research Institute, August 1984.

I don't see how the surface conditions at this site is much different than many unpaved roads. Check the fit of this data with the equations. Include the data if the data is consistent with the other data

This report presents test results from a June, 1984, test at U.S. Steel's Gary Works in Gary, Indiana. The study was conducted to compare exposure profiling methodologies as used by five independent testing organizations to characterize fugitive emissions originating from vehicular traffic. The source tested was a paved road simulated as an unpaved road through the addition of exceptionally high road surface loading (600,000 lb/mile).

An exposure profiler with 5 sampling heads (located at heights of 1.5, 3.0, 4.5, 6.0, and 7.5 m) was used to characterize downwind emissions. Particle sizing was determined using cyclone/impactors located alongside the exposure profiler. Particle sizes of interest in this study included total particulate (TP), $<30\ \mu m$, $<15\ \mu m$, $<10\ \mu m$, and $<2.5\mu m$ in aerodynamic diameter. One cyclone/impactor and one cyclone were deployed upwind for background measurements. Warm wire anemometers measured wind speed at two heights (1.5 and 4.5 m). What was the road width. What were the height of the vehicles. What was the initial dispersion height (σ_{z0}). Were there any disturbances in the upwind or downwind critical zones.

This test program was not included in the development of the unpaved road emission factor equation because the source was a "simulated" unpaved road that was formed by artificially loading a paved road. The particle size information from this study was included in the data set to develop the mean

Present the results of TSP, IP and PM-2.5 in the Table. If used it should be mentioned that this report is equivalent to two tests. Comment on the direction of the wind during the tests.

PM-2.5/PM-10 ratios discussed in Section 4.3. Table 4-19 presents summary test data and Table 4-20 presents detailed test information.

4.2.11 Reference 11

Midwest Research Institute "Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads" for U. S. EPA, January 1983.

This study reports the results of testing conducted in 1981 and 1982 at industrial unpaved and paved roads and at rural unpaved roads. Unpaved industrial roads were tested at a stone crushing facility in Kansas, a sand and gravel processing facility in Kansas, and a copper smelting facility in Arizona. The rural unpaved road testing occurred in Colorado, Kansas, and Missouri. The study was conducted to increase the existing data base for size-specific particulate emissions. The following particle sizes were of specific interest for the study: IP, PM-10, and PM-2.5.

Exposure profiling was utilized to characterize particulate emissions. Five sampling heads, located at heights of up to 5 m, were deployed on the downwind profiler. A standard hi-vol sampler and a hi-vol sampler with a 15 μm size selective inlet (ssi) were also deployed downwind. In addition, two cyclone impactors were operated to measure particle size distribution. A hi-vol sampler, a hi-vol sampler with an ssi, and a cyclone impactor were utilized to characterize the upwind particulate concentrations. Wind speed was monitored with warm wire anemometers. What were the road widths? What were the vehicle heights? What was the initial dispersion height (σ_{z0}) compared to the maximum sampler heights? Were there any disturbances in the upwind or downwind critical zones?

A total of 18 paved road tests and 21 unpaved road tests were completed. The test data were assigned an "A" rating. Eleven industrial unpaved road tests were conducted as follows: five unpaved road tests at the stone crushing plant, three unpaved road tests at the sand and gravel processing plant, and three unpaved road tests at the copper smelting plant. For rural unpaved roads, six tests were conducted on roads with a crushed limestone surface in Kansas, four tests were conducted on dirt roads in Missouri, and two tests were conducted on gravel roads in Colorado. Rural road tests only measured emissions from light duty vehicles at speeds from 25 to 40 mph. The industrial road tests were conducted with medium duty vehicles at the stone crushing and copper smelting plants and heavy duty vehicles at the sand and gravel processing facility. Table 4-21 presents summary test data and Table 4-22 presents detailed test information. The data for IP and PM-2.5 should be put in the table. Comments should be made on the wind direction. It should be mentioned that this study is equivalent to seven tests due to variations in vehicle weight, moisture and silt.

J:\dms\460402\unpvbkgd
4/1/97

4.2.12 Reference 12

Midwest Research Institute, "Iron and Steel Plant Open Source Fugitive Emission Control Evaluation," for U. S. EPA, August 1983.

This test report centered on the measurement of the effectiveness of different control techniques for particulate emissions from open dust sources in the iron and steel industry. The test program was performed at two integrated iron and steel plants, one located in Houston, Texas, and the other in Middletown, Ohio. Water and petroleum resin were used to reduce emissions from traffic on unpaved roads. Control techniques to reduce emissions from paved roads and coal storage piles were also evaluated. Particle emission sizes of interest in this study were total particulate (TP), IP, and PM-2.5.

Is this Coherex?

The exposure profiling method was used to measure unpaved road emissions at Armco's Middletown Iron and Steel plant. For this study, one downwind profiler with four or five heads located at heights of 1 to 5 m was deployed. Two high volume parallel slot cascade impactors samplers, one at 1m and the other at 3m, measured the downwind particle size distribution. A standard hi-vol sampler and an additional hi-vol sampler fitted with a size selective inlet (SSI) were located downwind at a height 2 m. One standard hi-vol sampler and two hi-vol samplers with SSIs were located upwind for background collections.

What were the road widths? What were the vehicle heights? What were the initial dispersion heights (σ_{z0}) compared to the highest sample height? Were there any disturbances in the upwind or downwind critical areas?

Nineteen unpaved road tests for controlled and uncontrolled emissions were performed. Testing included 10 runs of heavy-duty traffic (>30 tons) and 9 runs of light-duty traffic (<3 tons). Six heavy duty traffic tests were controlled and four were uncontrolled, whereas, the light-duty traffic had five controlled tests and four uncontrolled tests. The test data were assigned an "A" rating. Table 4-23 presents summary test data and Table 4-24 presents detailed test information. The data for TP, IP, and PM-2.5 should be included in the Table. The moisture content for at least the uncontrolled and the watered test should be added too.

For heavy-duty traffic, a 17 percent solution of Coherex® in water applied at a rate of 0.19 gal/yd^2, provided an average control efficiency of 95.7 percent for TP, 94.5 percent for IP, and 94.1 percent for PM-2.5 over a 48 hr period. Water was applied at a rate of 0.13 gal/yd^2 and, ½ hour after application, was found to decrease emissions by 95 percent for all particles. Control efficiencies 4.4 hours after the water applications were 55.0 percent for TP, 49.6 percent for IP, and 61.1 percent for PM-2.5.

What data were used in the analysis and what data were not used?

A 17 percent solution of Coherex® in water was the only control applied during testing for the light-duty traffic. The Coherex® solution was applied at a rate of 0.19 gal/yd^2 and, 51 hr after application, provided a control efficiency of 93.7 percent for TP, 91.4 percent for IP, and 93.7 percent for PM-2.5.

A evaluation of whether silt analysis and moisture analysis are good measures of control effectiveness for these chemical additive.

4.2.13 Reference 13

Midwest Research Institute. "Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry."for U. S. EPA. October 1983.

This study centered on the reduction of particulate emissions for various dust suppressants used on unpaved roads in the iron and steel industry. Long-term control effectiveness of the dust suppressants was determined through testing at iron and steel plants located in East Chicago, Indiana and Kansas City, Missouri. Water, an emulsified asphalt, and a petroleum resin were the dust suppressants used. Particle emission sizes of interest in this study were TSP, IP, PM-10, and PM-2.5.

The exposure profiling method was used to measure unpaved road emissions at the Jones and Laughlin's (J&L's) Indiana Harbor Works and Armco's Kansas City Works. For this study, one downwind profilier, with four sampling heads at heights of 1.5 to 6 m, was deployed during all testing. High volume cascade impactors located at heights of 1.5 and 4.5m measured particle sizes. A high volume cascade impactor was also used to characterize the upwind particle distribution. Warm-wire anemometers at two heights monitored wind speed and a wind vane monitored horizontal wind direction. Info on the wind direction should be added. What was the road width. What were the vehicle heights? What was the initial dispersion height compared to highest sampler.

Twenty-nine controlled and uncontrolled unpaved road tests were performed in this study. Three uncontrolled tests and eight controlled tests were conducted at J&L's Indiana Harbor Works; and three uncontrolled tests and 15 controlled tests were completed at Armco's Kansas City Works. All tests have been assigned an "A" rating. Table 4-25 presents summary test data and Table 4-26 presents detailed test information. The data for TSP, IP and PM-2.5 should be included in the table. The data for the moisture content should be included or an explanation on why it wasn't should be included in the summary.

Were there any disturbances in the upwind or downwind critical zones?

A comment that this test is considered to approximately [illegible] tests should be made.

The three controlled conditions in this study included a 20 percent solution of emulsified asphalt (Petro Tac) applied at 0.7 gal/yd^2, water applied at 0.43 gal/yd^2, and a 20 percent solution of petroleum resin (Coherex®) applied at 0.83 gal/yd^2 followed by a repeat application of 12 percent solution 44 days later. Information on what data was used in the analysis and what was not should be included

The control effectiveness was reported as the number of vehicle passes that occurred as the control efficiency decayed to zero. The initial asphalt emulsion application had an estimated lifetime of 91,000 vehicle passes for PM-10, the initial petroleum resin application had an estimated lifetime of 7,700 vehicle passes for PM-10, and the water application had an estimated lifetime of 560 vehicle passes for PM-10. Also, a reapplication of the petroleum resin had an estimated lifetime of 23,000 vehicle passes for PM-10.

A cost effectiveness was calculated for each of the three controls as follows: the Petro Tac initial application was \$0.06/lb of PM-10 reduced; the Coherex® initial application was \$0.64/ lb of PM-10 reduced; the Coherex® reapplication was \$0.16/lb of PM-10 reduced; and the water application was \$1.30/lb of PM-10 reduced.

4.2.14 Reference 14

Midwest Research Institute, "Improved Emission Factors for Fugitive Dust From Western Surface Coal Mining Sources" for U. S. Environmental Protection Agency, Cincinnati, OH, July 1981.

This study was conducted to develop emission factors for major surface coal mining activities occurring in the western United States. Results are reported of testing conducted in 1979 and 1980 at three surface coal mines located in Wyoming, North Dakota, and New Mexico. Sampling was conducted on the following mining operations: drilling, blasting, coal loading, bulldozing, dragline operations, haul trucks, light- and medium-duty trucks, scrapers, graders, and wind erosion of exposed areas. Particulate sizes measured include, TSP, IP, and PM-2.5.

Exposure profiling was used to measure emissions from line source activities such as vehicle traffic on unpaved roads and from scraping and grading. Comparisons of data from profiling and upwind-downwind methods were made for scrapers and haul roads. A modified exposure profiling methodology was utilized for blasting emission measurements, and a wind tunnel was used to measure wind erosion emissions. Area source emissions such as coal loading were tested with an upwind/downwind methodology.

The exposure profiling method used a downwind profiler with four sampling heads located at heights of 1.5 to 6.0 m. A standard hi-vol sampler (2.5 m), a hi-vol sampler fitted with a cascade impactor (2.5 m), and two dichotomous samplers (1.5 and 4.5 m) were located downwind. Dust fall buckets were placed upwind and downwind at a height of 0.75 m to measure the particle deposition. Upwind concentrations were measured with one dichotomous sampler and one standard hi-vol sampler, both located at a height of 2.5 m. Wind speed was measured with warm wire anemometers downwind at heights of 1.5 and 4.5 m. present information on wind direction compliance with a named specification. what were the road widths. what were the vehicle heights? what was the initial dispersion height (σ_{z0}) compared to the highest sampler? was there any disturbance within the upwind or downwind critical zones

A comment about the approximate number of equivalent test series that this represents should be made

A total of 256 tests were performed in the study. Fifty-six of the tests were used in the development of the AP-42 emission factor equation. The source activity distribution for unpaved road tests was as follows: 20 uncontrolled haul road tests, 8 controlled haul road tests, 10 uncontrolled light- and medium-duty vehicle tests, 2 uncontrolled light- and medium-duty vehicle tests, and 15 uncontrolled scraper tests. Table 4-27 presents summary test data and Table 4-28 presents detailed test information.

Present data on TSP, PM and PM-2.5 in Table, Information on what controlled data ($CaCl_2$) was used in the analysis should be made.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTOR EQUATION

For unpaved roads, an emission factor equation is much more successful than a single-valued average in predicting particulate emissions at different sites with varying source parameters. This section describes the development of the emission factor equation that will be proposed for the updated AP-42 Unpaved Road section.

Put an explanation of the physical forces that produce the emissions, a general relationship that may be expected in the absense of measured data, some of the inter-relationships that may exist. See Air Control Tech presentation for specific issues to address.

The development of a revised unpaved road emission factor equation was built upon findings from the reviewed data sets. First, the decision was made to include all tests of vehicles traveling over unpaved surfaces. For example, tests of scrapers in the "travel mode" between cut and fill areas were included. Also, tests of very large off-road haul trucks used in the mining industry were also included in the developmental data set. On the other hand, graders blading an unpaved road were not included because of the low speed involved. This decision had the effect of greatly expanding the historical data base. Not only is far more data available, but a wider range of vehicle weights and travel speeds is available. The decision was based on findings from Reference 4, which dealt with the western surface coal mining industry. It was found that the general unpaved road emission factor equation (Equation 2-1) performed as well in estimating emissions from haul truck and light- to medium-duty vehicles as did factors developed specifically for those sources within western surface coal mines.

Explain that some of the parameters are difficult to measure and more difficult to document the effect on emission and that a limited set of information was available to use in an empirical model the unknowns of which can be determined through statistical methods.

The low speed should not be the reason the reason should be the extra physical disturbance of the road surface.

Next, the decision was made to add tests of watered roads to tests of uncontrolled roads. (Note that chemically controlled unpaved roads were not considered because those treatments cause lasting physical changes to the road surface.) This decision also was based on findings in the Reference 4 study. That study and a later review included moisture as a potential correction parameter in developing a predictive equation for unpaved roads. It was found that both the old (Reference 14, circa 1980) and new (Reference 4, 1992) haul truck data could be successfully fitted with one equation that applied to both watered and uncontrolled surfaces. The decision was also supported by a similar approach taken in developing the current AP-42 paved road equation. In that case, controlled and uncontrolled tests were combined.

Just because the changes are lasting and produce physical changes is not as important as whether the physical parameters change can be measured by either a change in surface moisture content or the silt content.

It would be educational to see if measurement moisture or silt is a good predictor of control efficiency and emissions

Inclusion of watered surfaces in the data base recongizes a fundamental difference in how the addition of water controls emissions (as opposed to the addition of other types of suppressants). First, the addition of water is a short-term control measure. In addition, it causes no permanent change in the road surface characteristics. To an extent, one could argue that a road subject to frequent rain is no different than a road which is routinely watered.

Finally, the decision was made to focus on PM-10 emission tests. Because Equation 2-1 was developed earlier than the 1987 promulgation the PM-10 NAAQSs, this represents a major departure from the way in which the current AP-42 factor was developed. The focus on PM-10 was also the approach taken in developing the newest AP-42 emission factor for paved roads. The approach requires that the models developed for different particle size ranges be "consistent," in the sense discussed below.

As a first step, the "developmental" data base was prepared from the test reports discussed in the previous section, with the following exceptions:

1. No test data were included from Reference 5. As noted earlier, these data were rated "D."

2. No data were included from Reference 7, because the unpaved road considered had been previously treated with a chemical dust suppressant.

3. No emission data were included from Reference 10 because the source tested was a "simulated" unpaved road formed by artificially loading a paved road. Note, however, that ratios of different particulate size ranges were included for the purpose of developing PM-15 and PM-2.5 emission factors.

Finally, some additional preparation of the data base was required. For example, References 12 and 14 did not present PM-10 emission factors; values were developed by log-normal interpolation of the PM-15 and PM-2.5 ratios to total particulate emissions. In addition, References 1, 12, and 13 did not report individual surface moisture contents. However, because silt content is determined after oven drying, the necessary information was readily available for Reference 1, which was being prepared at the same time that the current work was being undertaken. In Reference 12, some individual tests had moisture contents reported and a few additional tests were associated with moisture contents as well. Furthermore, the data from Reference 3 had been corrected for "combustible" content (although upwind concentrations had not). Using information contained in the report, "total" (i.e., without regard to chemical composition) PM-10 emission factors were calculated for inclusion in the developmental data set.

Model development relied on the stepwise linear regression routine contained in the SYSTAT, Version 4 set of statistical routines. The default level of significance used by SYSTAT for a variable to "enter" the stepwise linear regression is 0.15 (15 percent). In this context, "level of significance" refers to the probability of making a so-called Type I error. The possibility of making this kind of error arises because we are dealing with samples drawn from a parent population. That is to say, under the default setting, samples drawn from two completely independent populations would be found to have a significant relation purely due to chance 15 times out of 100. The 15 percent level of significance was used for exploratory data analysis; refined analysis relied on specifying a 5 or 10 percent significance level.

Is a 5 or 10 percent significance level appropriate for an equation that needs less precision. For example if I only expect the emission to be within 20% on average can a less stringent significance level be used?

Stepwise multiple linear regression was used to develop a predictive emission factor equation from the data set. Five potential correction parameters were included:

1. Surface silt content, s;
2. Surface moisture contents, M;
3. Mean vehicle weight, W;
4. Mean vehicle speed, S; and
5. Mean number of wheels, w.

A justification on why a log transform is appropriate based upon the expected effects of the physical forces creating the emissions (the empirical relationships)

All variables were log-transformed in order to obtain a multiplicative model as in the past. The dependent variable of interest was the log-transformed PM-10 emission factor.

The past is not the important item. The important items are the expected effects of the physical forces that cause emissions. However, an overly complex model may be too difficult to use

In addition to the emission factor and correction parameter values, the data base also contained codes indicating

1. Whether the test was of an uncontrolled or a watered surface;
2. The type of road;
   a. publicly accessible unpaved road
   b. unpaved travel surface at an industrial facility
   c. "simulated" unpaved road
3. The predominant type of vehicle traveling the road;
4. Light or medium-duty vehicles;
5. Haul trucks;
6. Scrapers in the travel mode; and
7. Heavy-duty, over-the-road trucks.

shouldn't these be a, b, c, d?

For the initial analyses, the data base was sorted by whether the test represented uncontrolled or watered conditions and by the type of road (industrial vs. public unpaved road). There were two main objectives in this step. The first objective was to determine simply whether the different portions of the data base could be successfully combined. The second objective was to determine whether an emission factor model resulting from the large combined data would be consistent. The term "consistent" refers to (a) whether or not the same basic set of correction parameters could be used to estimate emission levels and (b) whether or not the relationships were similar between different subsets in the data base.

For example, suppose that stepwise regression of one portion (*I*) of the data base (e.g., uncontrolled industrial roads) showed that emissions were highly dependent on variable X but independent of variable Y. If stepwise regression of another portion (*II*) of the data base, on the other hand, indicated that emissions were very dependent upon Y but not on X, then the results for the two portions would not be viewed as consistent. The consistency in the relationships between independent and dependent variables is also important. To continue the example, suppose that regression of portions *I* and *II* both showed that the emission levels depend on variable X. If, however, for portion *I*, emissions depended on the 0.5 power of X while in portion *II*, emissions varied with the second power of X, then the relationships would again be viewed as "inconsistent."

Another consistency check that should be identified is the general agreement with the empirical relationships. eg emission increase with increasing speed (by some range of power) or decrease in surface moisture.

Given that the individual sets within the data base do not necessarily contain many test results, evaluation of consistency cannot always follow hard and fast rules. For example, one would reasonably expect that the emissions from watered tests would depend on the surface material moisture content. The lack of a discernible relationship between moisture and emissions from the uncontrolled tests in the data base would not necessarily indicate inconsistency. Furthermore, determining how "close" two relationships are, requires considerable judgment as well. For example, both a power of 0.86 and power of 1.1 indicate a roughly linear relationship.

The analysis began by stepwise regression of only uncontrolled tests in the data base, using the potential correction parameters of silt, weight, speed and number of wheels. Note that moisture content was not included. In this case, mean vehicle weight entered the regression first, and surface silt content on the second step. This first regression was roughly equivalent to repeating how the current AP-42 unpaved road emission factor was derived. Unlike the past, however, the effort focused on PM-10. The resulting emission factor for PM-10 exhibited an almost linear (power of 1) relationship with silt content. Furthermore, emissions were shown to follow a "less-than-linear" relationship with vehicle weight, although the exponent was roughly half of that contained in the current AP-42 equation.

present the small equation and some amount of goodness of fit information.

Next, uncontrolled and watered tests were considered separately, but this time with moisture content included as a potential correction parameter. For the 137 uncontrolled tests, weight and silt were again the first two variables to enter the regression. The exponents for both these variables were consistent with the values obtained for only the uncontrolled tests. However, two additional variables entered the stepwise regression in this case. Surface moisture content entered on the third step and mean vehicle speed on the fourth. Present the equations and some goodness of fit info

Inclusion of speed was somewhat tentative, in that its level of significance was just slightly greater than 10 percent. The default significance level for a variable to enter the regression was 15 percent. If the requirement for a variable to enter had been tightened to the 10 percent level of significance, speed would not have entered the relationship.

For the 43 watered tests, only two correction parameters entered the regression--silt and weight. The powers for silt and weight were reasonably consistent with the results obtained when the uncontrolled tests were considered separately. The reasonably consistent relationships for both silt and weight suggested that the two uncontrolled and watered portions of the data base could be successfully combined.[b]

When both uncontrolled and watered tests were considered as one data set, weight and silt again entered first and second, with moisture entering on the third step. Speed entered on the fourth iteration. The resulting emission factor equation has the form

$$e = k\, s^{0.85}\, W^{0.50}\, S^{0.32} / M^{0.29} \qquad (4\text{-}1)$$

where k is a constant of proportionality.[c]

Would the number of wheels enter the equation if the significance level were relaxed to 20%?

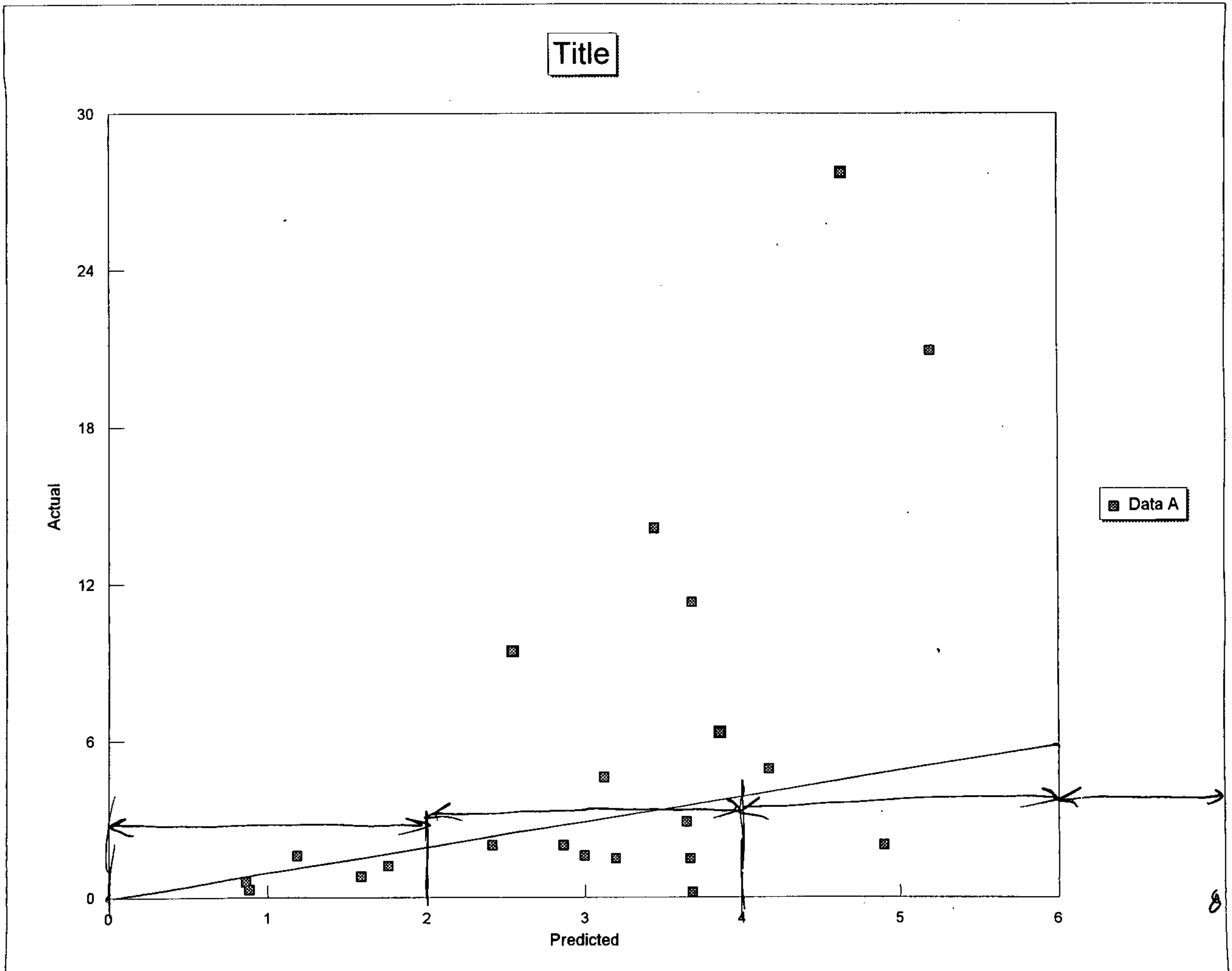
The constant should be presented. Also information on the diagnostics of the regression should be available and presented (such as R², examination of some of these (such as predicted vs actual) a discussion of the goodness of fit etc, predicted vs actual would be worthwhile. The graphs of the goodness of fit ... Four graphs would be one of the parameters verses the ratio of predicted vs actual

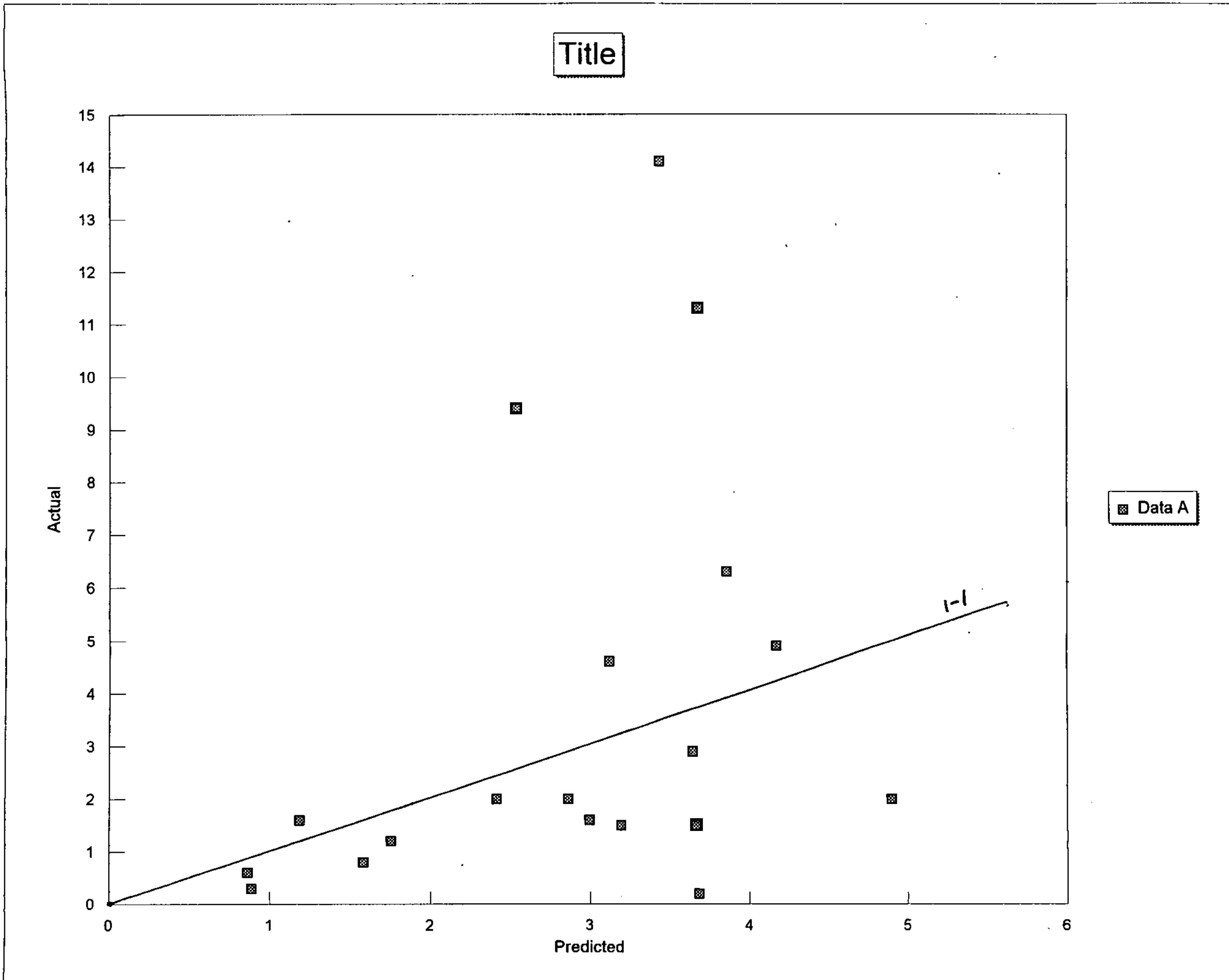
---

[b]The relationships for both of these variables are also reasonably consistent with the relationships in the current AP-42 model (Equation 2-1).

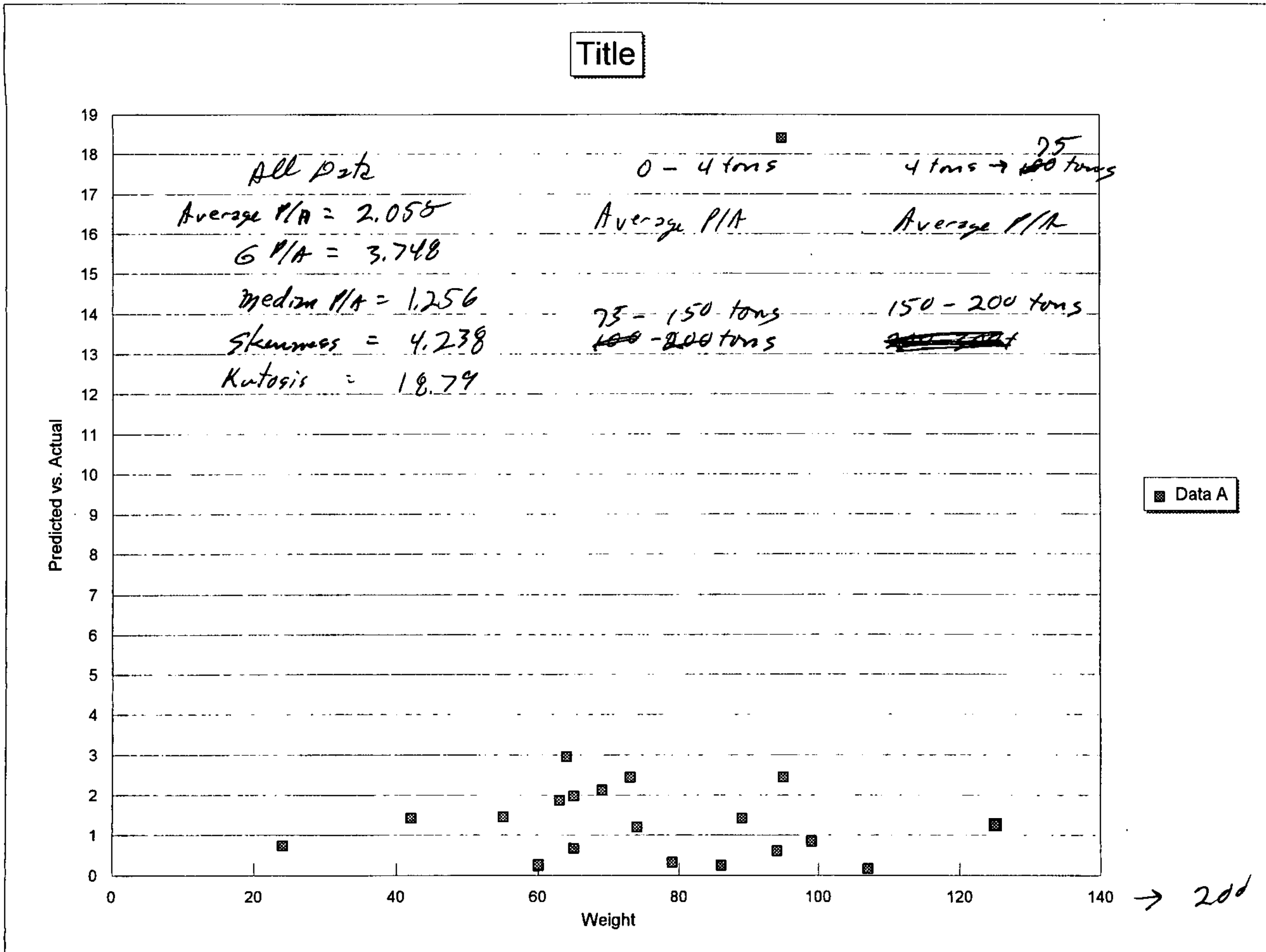
[c]Working versions of the emission factor equation are presented. In this context, the term "working" refers to factors that require that weight be expressed in tons, speed in mph, and silt and moisture contents in percent. Furthermore, the emission factor must be expressed in lb/VMT. In this case, the constant of proportionality has a complicated set of dimensions. The model recommended later in Equation 4-3 has been "normalized" by dividing, for example, weight by a default vehicle weight of 3 tons. In that case, the constant of proportionality has the same dimensions as the emission factor itself and can be readily converted from one set of units to another.

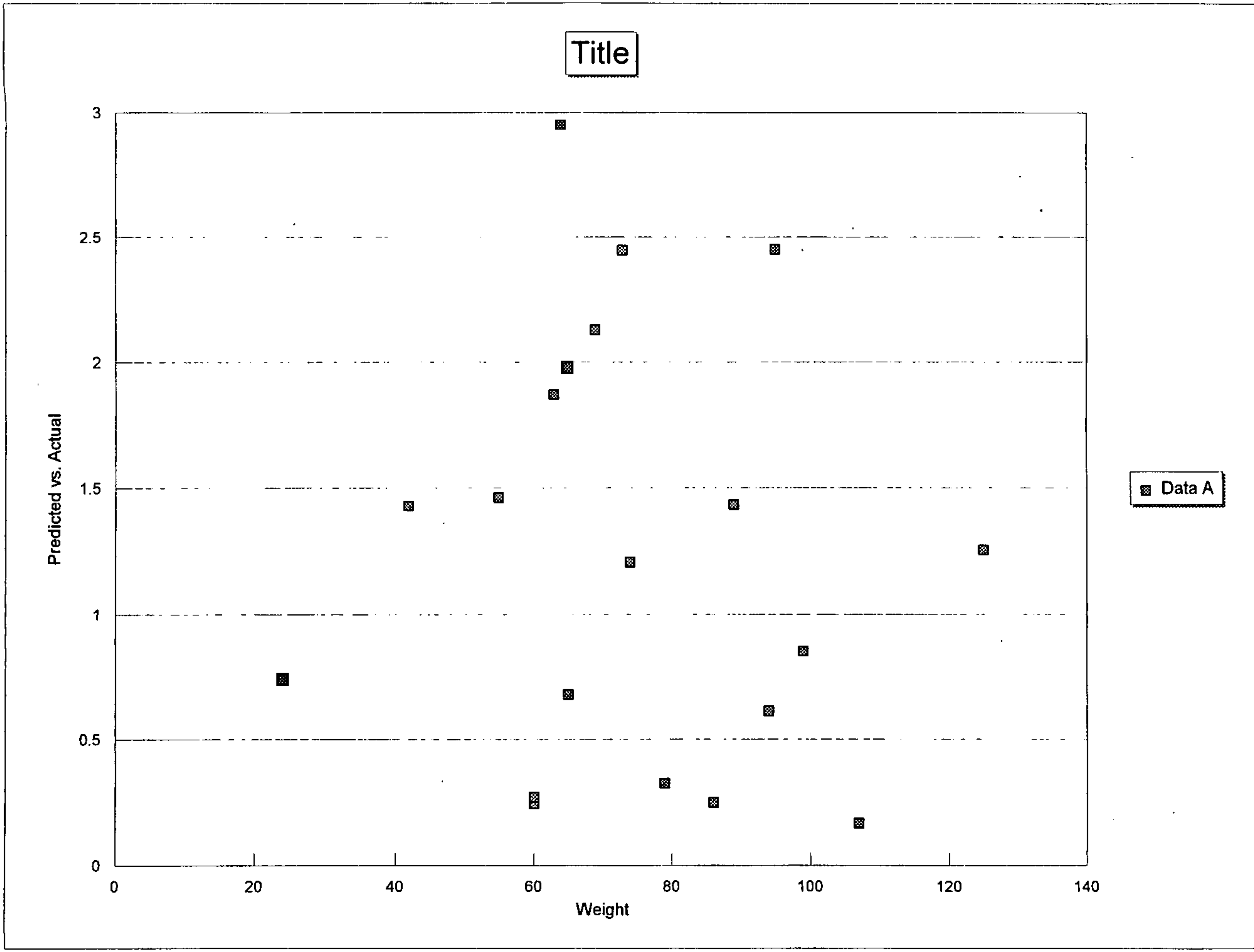
Run	Weight	wheels	Speed	silt	Moisture	PM-10 Measured	Predic PM-10 Eq w/o speed	Pred/Act	Predic PM-10 Eq w/ speed	Pred/Act
J-6										
J-9	65	8	19.3	9.4	3.4	4.6	3.1200	0.6783	3.6817	0.8004
J-10	60	7.7	19.3	9.4	2.2	14.1	3.4432	0.2442	4.0133	0.2846
J-11	60	9.9	20	8.2	4.2	9.4	2.5425	0.2705	2.9964	0.3188
J-12	99	9.5	15	14.2	6.8	4.9	4.1712	0.8513	4.8682	0.9935
J-20	125	10	16.8	11.6	8.5	2.9	3.6428	1.2561	4.4771	1.5438
J-21	110	9.3	15			3.1				
K-1	63	6.1	32.9	7.7	2.2	1.6	2.9931	1.8707	4.1169	2.5731
K-6	89	7.4	34.8	2.2	7.9	0.6	0.8597	1.4328	1.1856	1.9760
K-7	24	4.9	34.2	2.8	0.9	1.6	1.1843	0.7402	1.4110	0.8819
K-8	65	6.3	36	3.1	1.7	0.8	1.5814	1.9768	2.1404	2.6755
K-9	74	6.7	29.2	4.7	1.5	2	2.4125	1.2063	3.1546	1.5773
K-10	69	6.6	36	7.7	2	1.5	3.1941	2.1294	4.5588	3.0392
K-11	73	6.5	30	8.9	2	1.5	3.6682	2.4455	5.0028	3.3352
K-12	95	7.3	36	11.8	2.3	2	4.8978	2.4489	7.3835	3.6918
K-13	64	6.6	31.7	1.8	2.7	0.3	0.8855	2.9518	1.1233	3.7444
L-1	95	8.8	26.1	13	7.7	0.2	3.6832	18.4159	5.0950	25.4750
L-3	107	9.3	20	13.8	4.9	27.7	4.6401	0.1675	5.9559	0.2150
L-4	86	8.3	20	18	5.1	20.9	5.1960	0.2486	6.6154	0.3165
P-1	79	8.5	26.7	4.7	0.4	11.3	3.6816	0.3258	4.6470	0.4112
P-2	42	7.2	26.1	4.7	0.4	2	2.8595	1.4297	3.3637	1.6819
P-3	94	9.7	31.1	4.1	0.3	6.3	3.8572	0.6122	5.1515	0.8177
P-4	55	7.6	31.7	2	0.3	1.2	1.7529	1.4608	2.1539	1.7949
							Average	2.055393		2.768934
							Std. Dev	3.746496		5.201445
							Median	1.256126		1.577295
							Skewness	4.23816		4.233945
							Kutosis	18.79144		18.75907

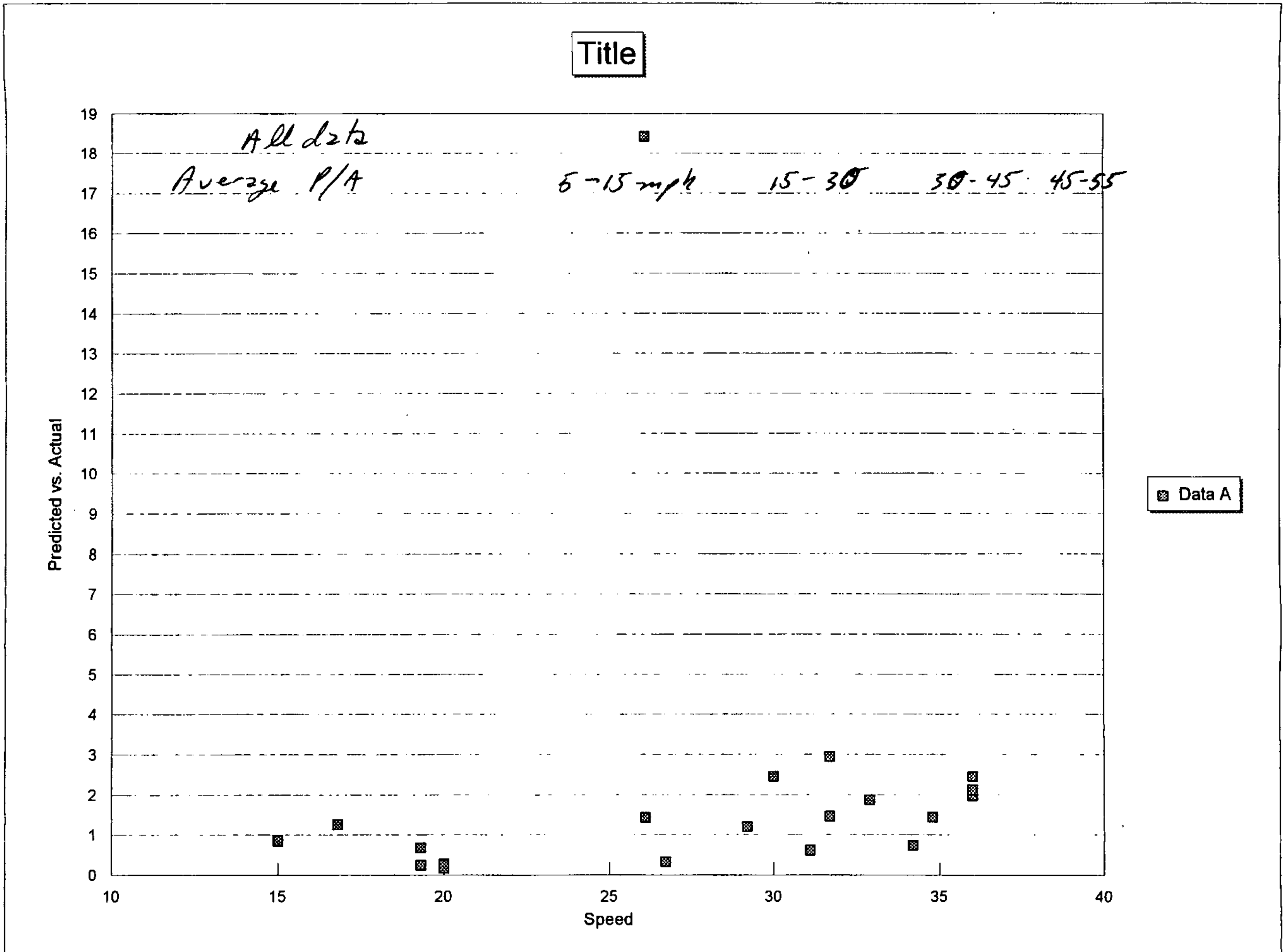

Title
30
24
18
12
6
0
Actual
0
1
2
3
4
5
6
Predicted
Data A



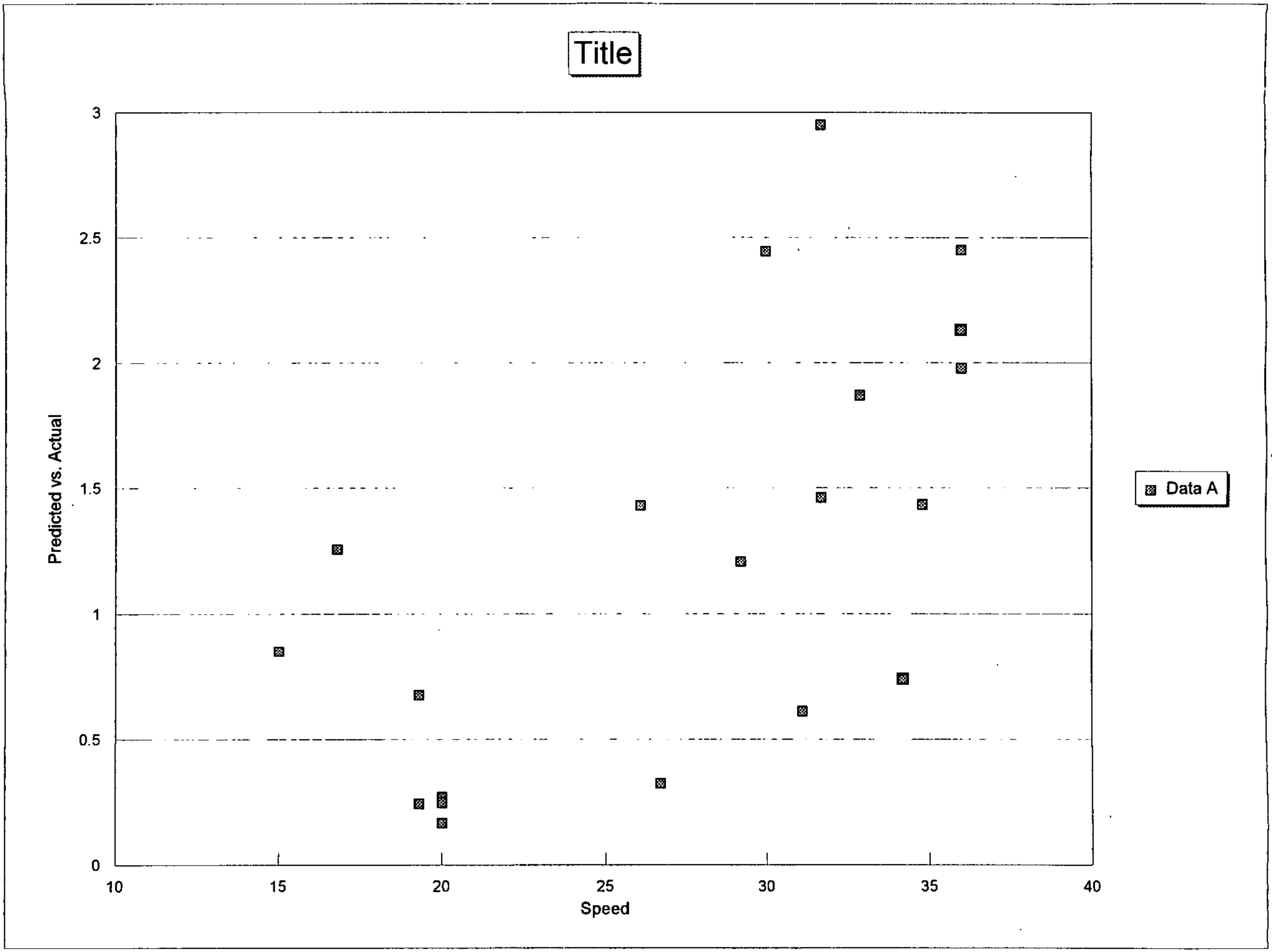
Title
Actual
Predicted
Data A
1-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

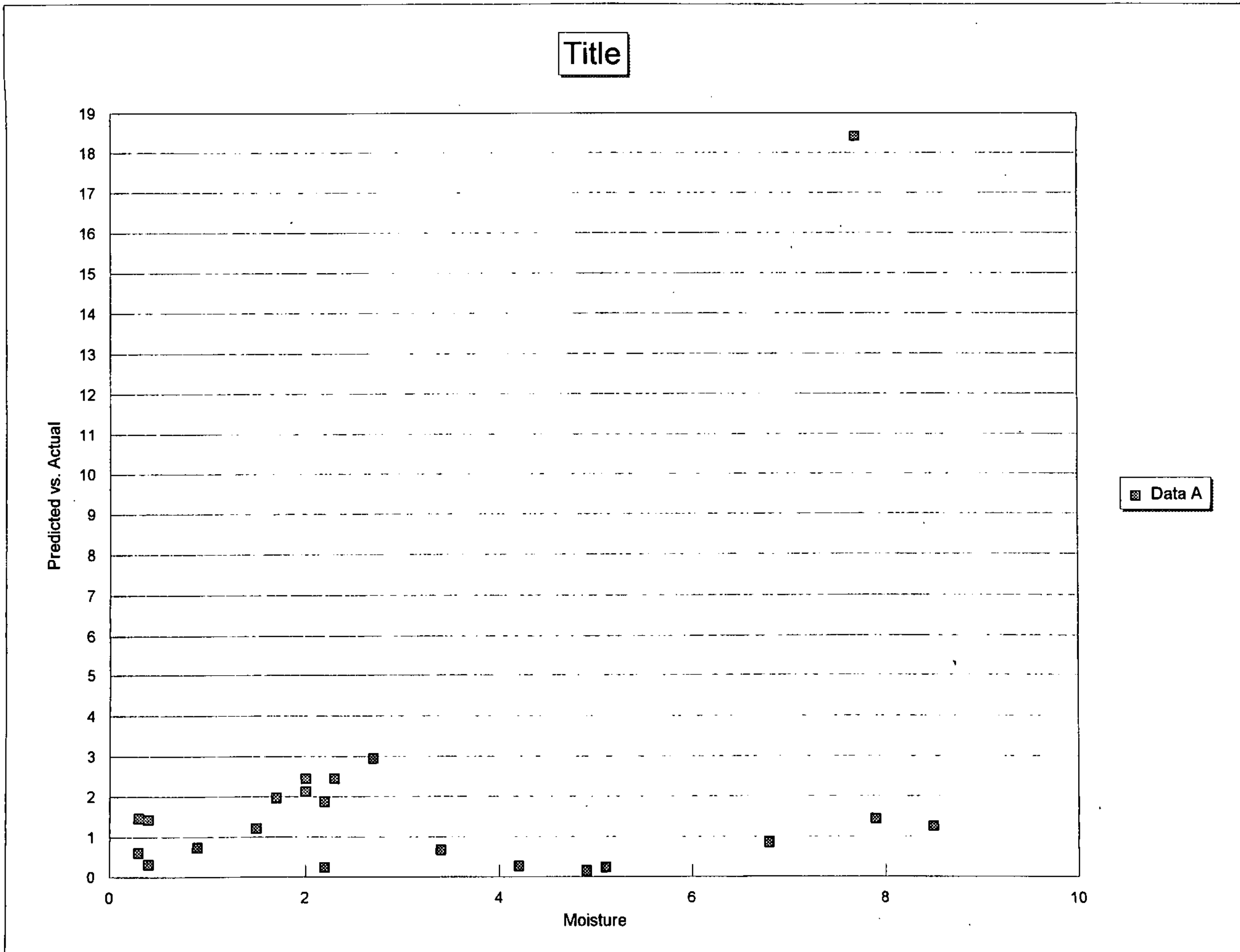

Title
All Data
Average P/A = 2.058
G P/A = 3.748
Median P/A = 1.256
Skewness = 4.238
Kurtosis = 18.79
0 – 4 tons
Average P/A
75 – 150 tons
-200 tons
4 tons → 75 tons
Average P/A
150 – 200 tons
Data A
Predicted vs. Actual
Weight
0
20
40
60
80
100
120
140
→ 200
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Title
Predicted vs. Actual
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
Weight
Data A

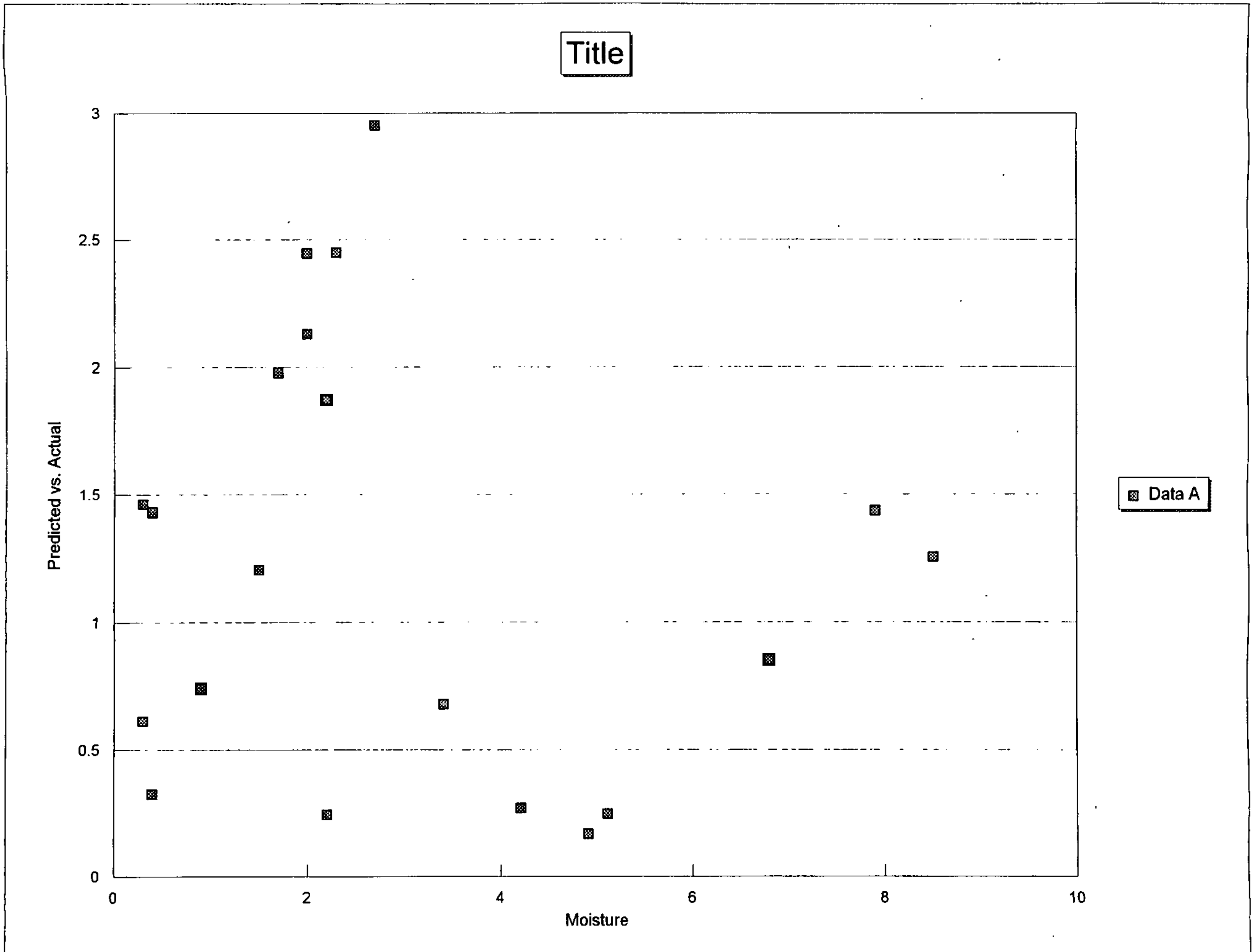


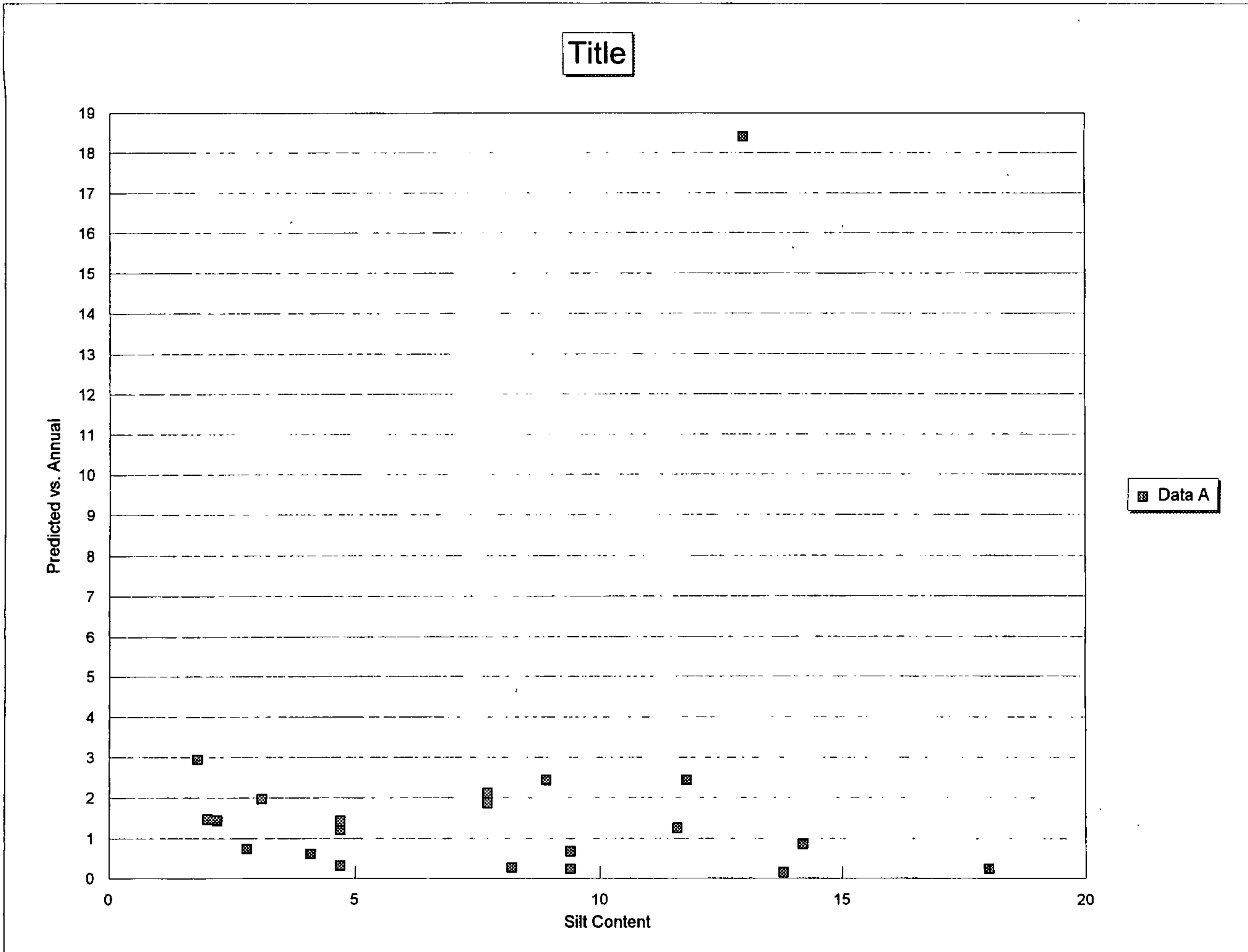
Title
All data
Average P/A
5-15 mph
15-30
30-45
45-55
Predicted vs. Actual
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
10
15
20
25
30
35
40
Speed
Data A

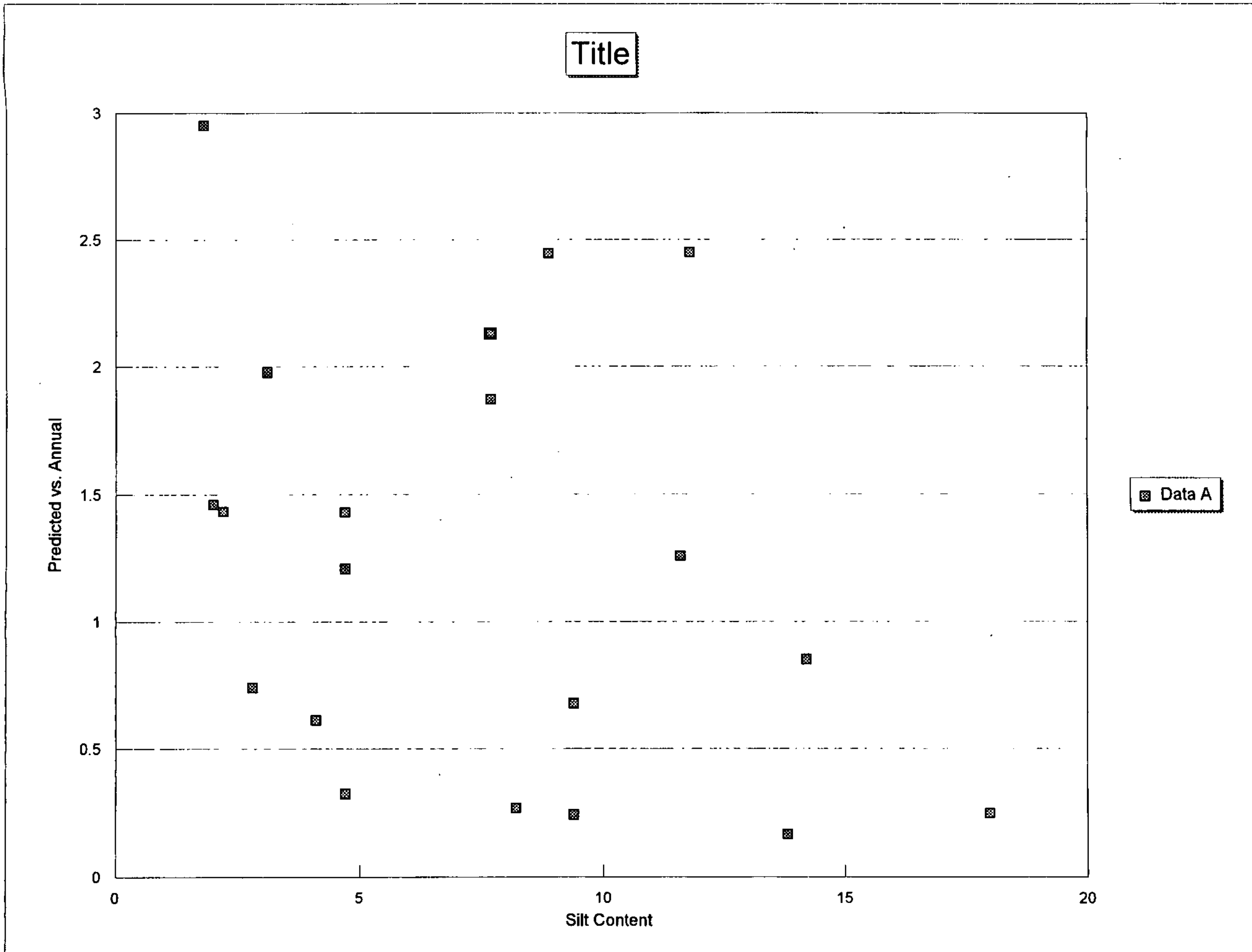

Title
3
2.5
2
1.5
1
0.5
0
Predicted vs. Actual
10
15
20
25
30
35
40
Speed
Data A



Title
Predicted vs. Actual
Moisture
Data A
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
0
2
4
6
8
10


Title
Predicted vs. Actual
Moisture
Data A
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10


Title
Predicted vs. Annual
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
5
10
15
20
Silt Content
Data A


Title
Predicted vs. Annual
Silt Content
Data A
0
0.5
1
1.5
2
2.5
3
5
10
15
20

An alternative to Equation 4-1 results from tightening the significance requirement, from 10 percent to 5 percent, for a variable to enter the regression. In this case, speed does not enter the equation, and the equation has the form:

$$e = k\, s^{0.82}\, W^{0.46} / M^{0.28} \qquad (4\text{-}2)$$

see commentation previous equation and example figures

Equations 4-1 and 4-2 represent the two candidate emission factor equations considered in this study. Initially, preference was given to Equation 4-1 because the inclusion of speed was viewed as providing additional predictive accuracy for instances involving very slow or very fast traffic. Furthermore, the resulting equation would (like the current AP-42 model) allow one to gauge the effect of speed reduction as a control technique. Equation 4-1 was initially chosen and validation of that model proceeded.

However, in performing the next step, it was found that speed did not always enter the regression when part of the data set was held back for validation purposes. When roughly 25 percent of the data set was reserved for validation purposes (as described in the next section), weight, silt and moisture entered first, but at times the number of wheels, rather than speed, entered on the fourth step. It was judged that, with a 15 percent level of significance set as the criterion for a variable entering the regression, the resulting model could be too close to being unstable. Although vehicle speed entered at the 10 percent level of significance in Equation 4-1, the inclusion of speed was highly dependent on the data set being used. For example, exclusion of only one or two low-speed tests from the data resulted in speed not entering the regression at even the 15 percent level of significance. On the other hand, dropping those tests had no effect on the other terms in the model. Thus, the four-parameter model (Equation 4-1) appeared to be relatively unstable.

Our statisticians indicate that it is preferable to keep all of the data in for developing the equation and that this process only validates the regression technique, they indicate that the diagnostics of the regression are better indicators of the predictive accuracy of the equation. They specifically mentioned the predicted vs actuals. I would like to see the graphs relating each of the variables to the ratio of predicted to actual (perfect agreement would be a horizontal line at 1.0.

Further justification in selecting the "no-speed" model expressed as Equation 4-2 was based on a comparison of the power of 0.32 to exponents developed in other test programs designed to directly consider the effect of vehicle speed. For example, Reference 6 test data support a relationship between emissions and speed raised to the 1.86 power. Other studies have developed models with powers of speed ranging from roughly 1 to 2. The inconsistency between the result found here and that found in other studies appears to be a result of "fine tuning" the other models to the specific data sets.

Justification should be based on the predicted vs actuals and the other diagnostics of the model. Also an examination of the figures of the ratio of predicted to actual verses the parameters. Additionally, a criteria should be how stupid we look by saying that a parameter is not important given "common" knowledge. For example it is intuitive to people that follow vehicles on unpaved roads, that speed is important in the generation of dust, it is also supported by the physical forces in the system. There fore even though it does not always enter the regression equation it should be added. We can put some restrictions on it though.

In summary, the following emission factor equation is recommended for estimating PM-10 emissions from vehicles traveling over unpaved surfaces:

$$e_{10} = 1.6\,(s/12)^{0.8}\,(W/3)^{0.4}/M^{0.3} \qquad (4\text{-}3)$$

where:

e_{10} = PM-10 emission factor (lb/VMT)
s = surface material silt content (%)
W = mean vehicle weight (tons)
M = surface material moisture content (%)

Note that the "normalizing factors" of 12 percent silt and 3 tons are the same as for the current AP-42 model. This allows one to compare the leading term of 1.6 lb/VMT in Equation 4-3 to the factor of 2.1 lb/VMT inherent in the current version of the unpaved road predictive model.[d] This agrees with an earlier finding that "re-centering" the current factor to available PM-10 data would require reducing the leading term by about 30 percent.

The development of emission factor equations for other PM size ranges depended upon the how many tests were available for the purpose. The preferred approach relied on the same type of stepwise regression used to obtain the PM-10 model. For TSP (considered as PM-30), stepwise regression of the 92 available tests led to the following model

$$e_{TSP} = 5.3\,(s/12)^{0.8}\,(W/3)^{0.5}/\,(M/1)^{0.4} \qquad (4\text{-}4)$$

where all the variables are the same as before and

PM-15 is not that critical

e_{TSP} = TSP emission factor (lb/vmt)

The form of the TSP emission factor equation is clearly consistent with the form of PM-10 model. On the other hand, stepwise regression of the emission tests for PM-2.5 and PM-15 did not lead to models of the same form as for PM-10. For PM-15, silt entered on the first step and weight on the second; powers

[d] *That is, the leading value of 5.9 (in Equation 2-1) times the aerodynamic particle size multiplier of 0.36 for PM-10.*

for both variables were comparable to those in the PM-10 model. The differences between the results for PM-10 and PM-15 were due mainly to difference in the size of the available data base for PM-15. Not all tests were associated with moisture content, and the dependence of PM-15 emissions on moisture content could not be discerned.

For PM-2.5, however, stepwise regression of the emission tests led to a result different from that for PM-10, PM-15 and PM-30. Silt, weight, number of wheels, moisture content, and average speed entered the regression (in that order). The powers for silt, weight and moisture were fairly comparable to the corresponding powers in the PM-10 model. Nevertheless, despite the five parameters, the resulting model has a low R-squared value and thus would be expected to have limited predictive accuracy .

present it here along with the diagnostics with figures and like with PM-10

Emission factors for PM-2.5 and PM-15 were developed by multiplying the PM-10 model by the mean measured ratio of that size range to PM-10 in the available data base:

why use the ratio of geometric means and not the average the ratio the PM 2.5/PM-10

	Geometric mean ratio	
	PM-2.5 / PM-10	PM-15 / PM-10
Uncontrolled (n = 108)	0.140	1.53
Watered (n=20)	0.196	1.46
Overall (n=128)	0.148	1.52

No significant difference was found between the ratios for watered versus uncontrolled conditions, so the overall mean was applied. (how about weight of vehicle, the silt level or the speed or with the final emissions.)

In summary, the following emission factor equation is recommended for inclusion in AP-42:

$$e = k\,(s/12)^{a}\,(W/3)^{b}\,(M/1)^{c} \quad (4\text{-}5)$$

the ambient data that sent to Bill Kuykendal showed that at high PM-10 concentrations the ratio between PM-10 and PM-2.5 was different than at low PM-10 concentrations

where: k, a, b and c are empirical constants given below and

e = size-specific emission factor (lb/vmt)

s = surface material silt content (%)

W = mean vehicle weight (tons)

M = surface material moisture content (%)

The parameters for size-specific emission factors in Equation 4-5 are given below:

Empirical constant	PM-2.5	PM-10	PM-15	PM-30
k	0.24	1.6	2.4	5.3
a	0.8	0.8	0.8	0.8
b	0.4	0.4	0.4	0.5
c	-0.3	-0.3	-0.3	-0.4

Based on the rating system given in Section 3.5, both the PM-10 and PM-30 emission factors are rated "A." The remaining factors are downgraded one letter because they were developed by scaling an A-rated model.

4.3.1 Validation Studies

A series of validation studies were undertaken to examine the predictive accuracy of the various emission factors recommended in the preceding section. Validation focused on the PM-10 model.

The first two PM-10 validations used the data base assembled for developing the model. The first made use of a cross-validation analysis of the PM-10 data set. In this approach, each data point is eliminated one at a time. The regression obtained from the "reduced" data base is used to estimate the missing data value. In this way, a set of "n" quasi-independent observations is obtained from the data set of "n" tests.

The PM-10 cross-validation (CV) shows that the model is fairly accurate for a very broad range of source conditions. Table 1 indicates that, although the model may slightly under- or overpredict emission for some specific subset of the data base, the general agreement is quite good. The CV analysis further found that, for the quasi-independent estimates of the measured emission factors,

1. 52 percent are within a factor of 2;
2. 73 percent are within a factor of 3;
3. 90 percent are within a factor of 5; and
4. 98 percent are within a factor of 10.

All this is is a complicated methodology to get to an evaluation of the predicted vs actual values. I think a better method is to present not only this info but also what is the average, std dev, median, log mean, skewness and kurtosis for the whole population. Also it would be worthwhile to constrain this analysis to the various quartiles of the parameters (speed, weight, silt, moisture, wheels & emissions)

Or rather than quartiles, that portion of the data that is various portions of the data. 25% of the range 5-25 e.g. if range is 5-25 the portions would be 5-10, 10-15, 15-20, 20-25

In examining the PM-10 residuals (i.e., the error between the predicted and observed emission factors), it was found that Equation 4-5 tends to overpredict the lowest and underpredict the highest observed factors. In other words, the model appears to have a systematic bias at the extremes of the parent data base. This tendency is expected of most models developed from regression techniques and is not believed to be overly restrictive, given that AP-42's goal is to represent "average" conditions.

→ This is partially true. I would want an equation to predict the average of the emissions through a broad range of the parameters that affect emissions.

The only other significant relationship found for the residuals in the PM-10 cross-validation involved the tendency of the equation to overpredict emissions for very slow speeds. The equation does not exhibit this bias for mean vehicle speeds 15 mph and higher. Because roughly 90 percent of the tests in the PM-10 data base have speeds at least 15 mph, the tendency should not be overly restrictive. Nevertheless, AP-42 Section 13.2.2 contains an advisory to the reader. By only putting an advisory in the section, we encourage (or at least it results in) questions on what to do. I would like to present our best guess on how to address the situation.

A limited second validation of the PM-10 factor reserved approximately 20 to 25 percent of the data base for validation purposes. Test data were randomly selected for inclusion in either the "development" or the "validation" data set. Two separate random selections were performed. The development data set is used to develop the relationship which is used to estimate tests in the validation set. The first development set led to the following predictive equation for PM-10:

$$e = 1.55\,(s/12)^{0.78}\,(W/3)^{0.44}\,/\,M^{0.35} \qquad (4\text{-}6)$$

and Development Set 2 led to the following equation for PM-10:

$$e = 1.72\,(s/12)^{0.80}\,(W/3)^{0.43}\,/\,M^{0.26} \qquad (4\text{-}7)$$

Note that both development sets led to equations very similar to that in Equation 4-3. When the two models were used to predict data in the validation sets, the following summary statistics resulted:

use arithmetic means and std dev in addition to this info

Validation set	No. of cases	Ratio of predicted to observed			
		Minimum	Maximum	Geo. mean	Geo. std.dev.
1	n = 41	0.123	29.3	0.926	2.92
2	n = 40	0.125	6.58	1.27	2.63

Unlike the quasi-independent estimates obtained in the cross-validation, the above truly represent independent applications of an emission factor model developed through stepwise regression technique.

For that reason, this limited validation leads to a slight bias in the resulting estimates, underpredicting in the first set by 7 percent and overestimating by roughly 30 percent in the second. Nevertheless, the spread (variation) in the estimates is quite comparable to that found in the cross-validation and the estimates generally agree well with the measured values in the validation data set.

A final PM-10 validation study involved the nine emission tests that had not been formally reported when the study began (Reference 15). Table 4-29 shows the results of the comparisons of predicted to observed PM-10 emission factors. Predictions based on both Equation 4-5 and the current AP-42 equation are considered. In general, agreement is quite good for the new unpaved road equation.

Limited validation of the PM-30 and other emission factors was undertaken. For the PM-30, a cross-validation led to results very comparable to those in the PM-10 cross-validation. Interestingly, however, there was no significant relationship between the residuals and speed for the PM-30 equation. In other words, unlike the PM-10 equation, the PM-30 equation does not appear to systematically overpredict/underpredict at very fast/slow travel speeds.

For the emission factors scaled against the PM-10 model, application of Equation 4-5 to the available PM-2.5 and PM-15 data sets lead to the following results:

<u>For PM-2.5</u>

45 of 94 (48 percent) are within a factor of 2
57 of 94 (61 percent) are within a factor of 3
73 of 94 (78 percent) are within a factor of 5

<u>For PM-15</u>

42 of 94 (45 percent) are within a factor of 2
62 of 94 (66 percent) are within a factor of 3
82 of 94 (87 percent) are within a factor of 5

Because these are essentially independent applications of the predictive equation (i.e., the individual test results were not directly used in the development of the equation), a broader spread of the predicted-to-observed is to be expected. Nevertheless, both the PM-2.5 and PM-15 factors in Equation 4-5 provide very acceptable estimates of measured emission factors.

4.4 DEVELOPMENT OF DEFAULT VALUES FOR ROAD SURFACE MATERIAL PROPERTIES

As noted earlier, all previous versions of the AP-42 unpaved road emission factor have included the road surface silt content as an input variable. The predictive equations recommended in the last section are no exception. AP-42 Section 13.2 has always stressed the importance of using site-specific input parameters to develop emission estimates. Recognizing that not all users will have access to site-specific information, AP-42 has included methods to allow readers to determine default values appropriate to their situation.[e]

Table 13.2.2-1 currently in AP-42 contains default silt information for various applications. As part of this update, the table was modified to (a) include updated inforamtion on construction sites and log yards and (b) reformat the information for publicly accessible roads. Item (a) was a relatively straightforward process. On the other hand, item (b) required a thorough reexamination, as described below.

Furthermore, it was necessary to develop default information for moisture content. Because mosture content is raised to such a low power (exponent of 0.3 in Equation 4-3), the use of default values should not result in unacceptable levels of uncertainty in the resulting emission estimates. For example, when the recommended default value of 1 percent moisture is used for uncontrolled industrial roads, then

- 96 percent of the resulting emisison factor estimates are within a factor of 2
- 72 percent of the resulting emission factor estimates are within a factor of 1.5
- 52 percent of the resulting emission factor estimates are within a factor of 1.25

of the emission factor estimate based on the site-specific moisture content. Similarly, when a default value of 0.5 percent is used for publicly accessible roads in the developmental data set, all 43 of the resulting emission factor estimates are within a factor of 2 of the value based on site-specific moisute content.

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[e]The inclusion of the surface moisture content as an input variable is not considered to represent an undue burden on the users of AP-42. In particular, the methods presented in AP-42 Appendix C.2 require oven drying before sieving. In other words, determination of the silt content of a road surface sample requires that the moisture content of the sample also be determined. Thus, users of AP-42 who have already determined site-specific values for road surface silt content should have corresponding moisture content information available as well.

In order to develop default information for publicly accessible unpaved roads, a data set of available silt and moisture contents was assembled. The 78 data points were collected either as part of a field emission testing program or as input necessary to prepare emission inventories. Note that several of the inventory-type samples were aggregated from subsamples collected from different road segments within some portion of the study area.

Data are classified as being from either an "eastern" or a "western" location, based on the common disticntion between "pedalfer" and "pedocal" soils. For pedalfer soils common in the eastern U.S., precipication exceeds evaporation. Conversely, evaporation is greater than precipitation in the West and the soils are termed "pedocal." The 97th meridian is roughly coincident with the dividing line between pedalfer and pedocal soils. Also, to the extent practical, data were classified as being from a "gravel" or "dirt" type of unpaved road surface.

Statistical analysis of the data set was undertaken to examine whether significant differences exist between the characteristics of eastern vs. western and gravel vs. dirt roads. Because the available data set had not been developed for this use, i.e., specifically to explore how unpaved road surface characteristics vary because of different road surface materials or different locations in the country, the data set contains unequal subsets of data. The 78 data points are distributed as shown below:

	Location	
Surface Type	East	West
Dirt	10	14
Gravel	15	31
Unknown	0	8

The unequal sample sizes make it difficult to efficiently examine differences. First, the choice of statistical tests becomes limited. Generally, the most powerful methods to examine treatment and interation effects rely on having equal number of observations per cell. On an even more fundamental basis, there is a question whether the available data represent a reasonably representative, random sample from publicly accessible unpaved roads. That assumption would underlie any statistical test undertaken.

Because of the data limitations, a series of pairwise comparisons such as,

- eastern gravel vs. eastern dirt roads
- eastern vs. western roads
- gravel vs. dirt roads

were undertaken to determine if there existed significant differences in either moisture or silt content. The small-sample comparison of means test was used with the level of significance set at 10 percent. When appropriate, a one-sided alternative hypothesis was used. For example, one could reasonably expect, on an a priori basis, that on average

- gravel roads have lower silt contents than dirt roads
- moisture contents are lower in the western U.S. than in the East

When there was no a priori reason available, a two-sided alternative hypothesis was selected. For example, there was no reason to suspect that one set of gravel roads would have higher silt contents than the other. In that case, the alternative hypothesis selected was that the mean silt contents for eastern vs. western gravel roads are not equal.

Given the limitations on the available data set, it is not particularly surprising that the pairwise comparisons led to somewhat contradictory findings. For example, although the data set indicated that eastern dirt roads had a higher average moisture content than eastern gravel roads, that result was not found for western roads or-for roads overall. Similarly, gravel surfaces were found to have a lower mean silt content than dirt when (a) only eastern roads and (b) all roads were compared. That is, no significant difference was found for silt contents between western gravel and dirt roads.

Results from the pairwise comparisons are summarized below. In the table, "S" and "M" indicate that a significant different (10 percent level of significance) in the mean value of the silt and moisture content, respectively, was found in the comparison.

	Comparison of Gravel vs. Dirt	
East	S	M
West	S	-
Overall	S	-

	Comparison of East vs. West	
Gravel	-	-
Dirt	-	M
Overall	-	-

In keeping with the findings summarized above, it was decided to provide separate default silt values for gravel and dirt roads, for use throughout the United States (i.e., no distinction between east and west). Furthermore, only one default moisture content would be provided for use on any type of publicly accessible unpaved road in the country. The default values for silt content are based on the corresponding mean values in the assembled data set:

	Mean Silt Content
Gravel Roads	6.4 percent
Dirt Roads	11 percent

The mean overall moisture content for the data set is 1.1 percent. However, this value substantially differs from the mean moisture content of 0.6 percent for tests of emissions from public unpaved roads. It is recommended that this not serve as the basis for a default value in AP-42. Instead, a default value of 0.5 percent is recommended for publicly accessible unpaved roads.

4.5 SUMMARY OF CHANGES TO AP-42 SECTION

4.5.1 Section Narrative

Changes to the text in Section 13.2.2 had several blocks within the section updated to describe the new unpaved road equation. Many of the changes are the result of the addition of moisture as an equation parameter and the removal of speed, mean number of wheels, and precipitation as parameters. Also, Table 13.2.2-1 was modified and updated to provide default silt content and moisture contents from various locations within the continental United States. Section 13.2.2 follows with text removed from the old AP-42 version striked out. New wording added since the last version is in bold between brackets [ ]. The figures are not presented here, but are included in Section 5 of this report.

13.2.2 Unpaved Roads

13.2.2.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

13.2.2.2 Emissions Calculation And Correction Parameters[1-6]

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture, and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.[1-4]

Dust emissions from unpaved roads have been found to vary in direct proportion to **[directly with]** silt (particles smaller than 75 micrometers [μm] in diameter) in the road surface materials.[+] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen, using the ASTM-C-136 method. Table 13.2.2-1 summarizes measured silt values for industrial and rural **[public]** unpaved roads.

Since the silt content of a rural dirt road will vary with **[geographic]** location, it should be measured for use in projecting emissions. As a conservative approximation, the silt content of the parent soil in the area can be used. Tests, however, show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions caused by precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeters [mm] [0.01 inches (in.)] of precipitation).

~~7) $\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)$ (kilograms [kg~~

~~(1)~~

~~9) $\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)$ (pounds [lb]~~

[Draft] Table 13.2.2-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road Use Or Surface Material	Plant Sites	No. Of Samples	Silt Content (%)	
				Range	Mean
Copper smelting	Plant road	1	3	16 - 19	17
Iron and steel production	Plant road	19	135	0.2 - 19	6.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
	[Yard area	1	1	-	7.1]
Stone quarrying and processing	Plant road	2	10	2.4 - 16	10
	~~Haul road~~	~~1~~	~~10~~	~~5.0 - 15~~	~~9.6~~
	[Haul road	**4**	**20**	**5.0-15**	**8.3]**
Taconite mining and processing	Service road	1	8	2.4 - 7.1	4.3
	Haul road	1	12	3.9 - 9.7	5.8
Western surface coal mining	Haul road	3	21	2.8 - 18	8.4
	Access road	2	2	4.9 - 5.3	5.1
	Scraper route	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
[Construction sites	**Scraper routes**	**7**	**20**	**0.56-23**	**8.5]**
[Lumber sawmills	**Log yards**	**2**	**2**	**4.8-12**	**8.4]**
~~Rural roads~~	~~Gravel/crushed limestone~~	~~3~~	~~9~~	~~5.0 - 13~~	~~8.9~~
	~~Dirt~~	~~7~~	~~32~~	~~1.6 - 68~~	~~12~~
~~Municipal roads~~	~~Unspecified~~	~~3~~	~~26~~	~~0.4 - 13~~	~~5.7~~
Municipal solid waste landfills	Disposal routes	4	20	2.2 - 21	6.4

Industry	Road Use Or Surface Material	Plant Sites	No. Of Samples	Silt Content (%)	
				Range	Mean
[Publicly accessible roads	**Gravel/crushed limestone**	**9**	**46**	**0.10-15**	**6.4**
	Dirt	**8**	**24**	**0.83-68**	**11]**

[a] References 1,5-16.

~~where:~~

~~E = emission factor~~
~~k = particle size multiplier (dimensionless)~~
~~s = silt content of road surface material (%)~~
~~S = mean vehicle speed, kilometers per hour (km/hr) (miles per hour [mph])~~
~~W = mean vehicle weight, megagrams (Mg) (ton)~~
~~w = mean number of wheels~~
~~p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year (see discussion below about the effect of precipitation.)~~

~~The particle size multiplier in the equation, k, varies with aerodynamic particle size range as follows:~~

~~Aerodynamic Particle Size Multiplier (k) For Equation 1~~					
~~≤30 µm[a]~~	~~≤30 µm~~	~~≤15 µm~~	~~≤10 µm~~	~~≤5 µm~~	~~≤2.5 µm~~
~~1.0~~	~~0.80~~	~~0.50~~	~~0.36~~	~~0.20~~	~~0.095~~

[a] ~~Stokes diameter.~~

[The following empirical expression may be used to estimate the quantity of size-specific particulate emissions from an unpaved road, per vehicle mile traveled (VMT):

$$e = k\,(s/12)^{a}\,(W/3)^{b}\,M^{c} \qquad (1)$$

where k, a, b and c are empirical constants (REF 6) given below and

e = size-specific emission factor (lb/vmt)
s = surface material silt content (%)
W = mean vehicle weight (tons)
M = surface material moisture content (%)

The constants for Equation 1 based on the stated aerodynamic particle size are as follows:

Constant	PM-2.5	PM-10	PM-15	PM-30
k (lb/VMT)	0.24	1.6	2.4	5.3
a	0.8	0.8	0.8	0.8
b	0.4	0.4	0.4	0.5
c	-0.3	-0.3	-0.3	-0.4
Quality rating	B	A	B	A

The above table also contains the quality ratings for the various size-specific versions of *Equation* (1). The equation retains the assigned quality rating, if applied with the ranges of source conditions that were tested in developing the equation:

Range of source conditions for Equation 1						
Road silt content, %	Mean, Mg	Mean vehicle weight, ton	Mean, km/hr	Mean vehicle speed, mph	Mean No. of wheels	Road moisture content, %
1.2-35	1.4-260	1.5-290	8-88	5-55[a]	4-7[a]	0.03-20

[a]See discussion in text.

Even though mean vehicle speed and the mean number of wheels do not explicitly appear in the predictive equation, these variables should be considered when determining quality ratings. During the validation of Equation 1, it was found that the predictive equation tends to overpredict emissions for very low mean vehicle speed. The equation does not exhibit this bias for mean vehicle speeds of at least 15 mph. The equation's predictive behavior should be remembered if the emission factor is used for an instance with mean vehicle speed less than 15 mph. Although the mean number of wheels was not found to exhibit a systematic bias, the reader is similarly advised of the equation's predictive behavior outside the range of mean number of wheels given above.

Equation 1 was developed by the stepwise regression of the results from field measurements of PM-10 emissions and TSP emissions (or its surrogate - PM-30 emissions) from vehicles traveling over unpaved surfaces. Both uncontrolled and watered roads were included in the data base of 180 PM-10 and 92 TSP tests. The values given for the remaining particle size ranges were developed from mean measured PM-2.5 to PM-10 ratios and PM-15 to PM-10 ratios.

It is important to note that Equation 1 calls for the average characteristics of all vehicles traveling the road. For example, if 98 percent of traffic on the road are 2-ton cars and trucks while the remaining 2 percent consists of 20-ton trucks, then the mean weight is 2.36 tons. More specifically, Equation 1 is *not* intended to be used to calculate a separate emission factor for each vehicle class. Instead, only one emission factor should be calculated that represents the "fleet" average of all vehicles traveling the road.]

~~The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 13.2.2-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.[17] The equation is rated "A" for dry conditions (p = 0) and "B" for annual or seasonal conditions (p > 0). The lower rating is applied because extrapolation to seasonal or annual conditions assumes that emissions occur at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable precipitation. Clearly, natural mitigation depends not only on how much precipitation falls, but also on other factors affecting the evaporation rate, such as ambient air temperature, wind speed, and humidity. Persons in dry, arid portions of the country may wish to base p (the number of wet days) on a greater amount of precipitation than 0.254 mm (0.01 in.). In addition, Reference 18 contains procedures to estimate the emission reduction achieved by the application of water to an unpaved road surface.~~

~~The equation retains the assigned quality rating, if applied within the ranges of source conditions that were tested in developing the equation, as follows:~~

~~Ranges Of Source Conditions For Equation~~					
~~Road Silt Content (wt %)~~	~~Mean Vehicle Weight~~		~~Mean Vehicle Speed~~		~~Mean No. Of Wheels~~
	~~Mg~~	~~ton~~	~~km/hr~~	~~mph~~	
~~4.3 - 20~~	~~2.7 - 142~~	~~3 - 157~~	~~21 - 64~~	~~13 - 40~~	~~4 - 13~~

Moreover, to retain the quality rating of the equation when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt content are given in AP-42 Appendices C.1 and C.2. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 13.2.2-1 may be used, but the quality rating of the equation is reduced by 1 letter.

[As noted earlier, Equation 1 was developed from tests of traffic on unpaved surfaces, either uncontrolled or watered. Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall or watering. The quality ratings given above pertain to uncontrolled (dry) conditions. To estimate annual or seasonal conditions, one should determine an appropriate value for the average surface moisture content, taking into account natural precipitation and any anthropogenic watering. Recognizing that this may not always be practical, Equation 1 can be extrapolated to annual or seasonal conditions under the simplifying assumption that emissions occur at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable (more than 0.254 mm [0.01 inch]) precipitation. In other words, when the simplifying assumption is made, the emission factor for uncontrolled (dry) conditions should be multiplied by the ratio

$$\frac{365 - p}{365}$$

where p = number of days with at least 0.254 mm (0.01 inch) of precipitation per year. Figure 13.2.2-1 gives the geographical distribution for the mean annual number of "wet" days for the United States.

Clearly, the effect of water/natural mitigation depend on not only how much precipitation falls, but also on factors afffecting the evaporation rate, such as ambient air temperature, wind speed, humidity, and traffic rates. When the simplifying assumption is applied to annual/seasonal estimates, the quality rating should be downgraded by 1 letter.]

For calculating annual average emissions, the equation is to be multiplied by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted for the equation. Worst-case emissions, corresponding to dry road conditions, may be calculated by setting p = 0[.] ~~in the equation (equivalent to dropping the last term from the equation).~~ A separate set of ~~nonclimatic~~ correction parameters and a higher than normal VDT value may also be justified for the worst-case average period (usually 24 hours). Similarly, in using the equation to calculate emissions for a 91-day season of the year, replace the term

(365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91-day period. Use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

13.2.2.3 Controls~~[18-21]~~[17-21]

Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working stabilization chemicals into the roadbed, watering, and traffic control regulations. **[The effect that moisture addition has on emissions can be evaluated by use of Equation 1 if the cycle of moisture content is known.]** Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, is often not economically practical. Surface chemical treatment and watering can be accomplished at moderate to low costs, but frequent treatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions, but may be difficult to enforce. ~~The control efficiency obtained by speed reduction can be calculated using the predictive emission factor equation given above.~~

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 13.2.4, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating **[the]** control efficiency **[of paving]**.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters that determine control efficiency include dilution ratio, application intensity, mass of diluted chemical per road area, and application frequency. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (e. g., traffic volume, average weight) and road characteristics (e. g., bearing strength).

Besides water, petroleum resin products historically have been the dust suppressants most widely used on industrial unpaved roads. Figure 13.2.2-2 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads.[19] Several items should be noted:

1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (*not solution*) applied since the start of the dust control season.

2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 13.2.2-2 presents control efficiency values averaged over 2 common application intervals, 2 weeks and 1 month. Other application intervals will require interpolation.

3. Note that zero efficiency is assigned until the ground inventory reaches ~~0.2 liter per square meter (L/m²) (~~0.05 gallon per square yard ~~(gal/yd²)).~~[(gal/yd²)].

As an example of the application of Figure 13.2.2-2, suppose that the equation was used to estimate an emission factor of ~~2.0 kg/VKT (~~[7.1 lb/VMT] for PM-10 from a particular road. Also, suppose that, starting on May 1, the road is treated with ~~1 L/m²~~ [0.221 gal/yd2] of a solution (1 part petroleum resin to 5 parts water) on the first of each month through September. Then, the following average controlled emission factors are found:

Period	Ground inventory, ~~L/m²~~[gal/yd²]	Average control efficiency, %[a]	Average controlled emission factor, ~~kg/VKT~~[lb/VMT]
May	~~0.17~~[0.037]	0	~~2.0~~[7.1]
June	~~0.33~~[0.073]	62	~~0.76~~[2.7]
July	~~0.50~~[0.11]	68	~~0.64~~[2.3]
August	~~0.67~~[0.15]	74	~~0.52~~[1.8]
September	~~0.83~~[0.18]	80	~~0.40~~[1.4]

[a]From Figure 13.2.2-2, $\leq 10\ \mu m$. Zero efficiency assigned if ground inventory is less than ~~0.2 L/m² (0.05 gal/yd²).~~[0.05 gal/yd². 1 lb/VMT = 281.9 kg/VKT. 1 gal/yd² = 4.531 L/m².]

Newer dust suppressants are successful in controlling emissions from unpaved roads. Specific test results for those chemicals, as well as for petroleum resins and watering, are provided in References ~~18 through 21~~ [17 through 20].

4.5.2 Emission Factors

Analysis of the test data exhibited an emission factor equation appropriate for average conditions. The equation no longer contains speed and mean number of wheels as parameters. The current data base shows a correlation of emissions to the surface moisture content, which was added as a parameter. The addition of surface moisture content to the new equation nullifies the need to account for annual precipitation, which was removed from the equation. As with the old equation, the new equation allows for the emission calculations of different particle sizes (PM-2.5, PM-10, PM-15, and PM-30) with the use of appropriate constants. The old Section 13.2.2 Equation (1) is presented below (striked out) followed by the new Section 13.2.2 Equation (1).

Old Equation (1) ~~$e = k(5.9)\,(s/12)(S/30)(W/3)^{0.7}\,(w/4)^{0.5}(365\text{-}p/365)$~~

~~where:~~

~~e = emission factor (lb/vmt)~~

k = particle size multiplier (dimensionless)

~~s = silt content of road surface material (%)~~

~~S = mean vehicle speed, (miles per hour [mph])~~

~~W = mean vehicle weight, megagrams (Mg) (ton)~~

~~w = mean number of wheels~~

~~p = number of days with at least 0.01 in. of precipitation per year~~

~~Aerodynamic particle size multiplier~~

~~Constant~~	~~PM-2.5~~	~~PM-10~~	~~PM-15~~	~~PM-30~~
~~k (lb/VMT)~~	~~0.095~~	~~0.36~~	~~0.50~~	~~0.80~~

New Equation (1)

$$e = k\,(s/12)^{a}\,(W/3)^{b}\,M^{c}$$

where k, a, b and c are empirical constants given below

e = size-specific emission factor (lb/vmt)

s = surface material silt content (%)

W = mean vehicle weight (tons)

M = surface material moisture content (%)

Constants for Equation 1 based on the stated aerodynamic particle size

Constant	PM-2.5	PM-10	PM-15	PM-30
k (lb/VMT)	0.24	1.6	2.4	5.3
a	0.8	0.8	0.8	0.8
b	0.4	0.4	0.4	0.5
c	-0.3	-0.3	-0.3	-0.4

TABLE 4-1. SUMMARY INFORMATION - REFERENCE 1

Operation	Control method	Test run	State	Test date	No. of tests	PM-10 emission factor, lb/VMT	
						Geom. mean	Range
Unpaved road	None	BK1-BK4	Nevada	5/96	4	0.820	0.309-2.65
Paved road	None	—	Nevada	5/96	3	0.0025	0.0022-0.0028

1 lb/VMT = 281.9 g/VKT

TABLE 4-2. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 1

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min.	Meteorology		Vehicle information			Mean vehicle speed, mph	Silt, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels		
BK-1	0.375	59	72	6.0	138	1.5	4	15	7.2
BK-2	0.309	29	70	6.5	150	1.5	4	15	5.2
BK-3	1.48	47	70	6.6	100	2.0	4	15	5.9
BK-4	2.65	27	71	6.6	80	2.0	4	15	6.6

The PM-2.5 data should be presented

TABLE 4-3. SUMMARY INFORMATION - REFERENCE 2

Operation	Control method	Unpaved road test runs	State	Test date	No. of tests	PM-10 emission factor, lb/VMT	
						Geom. mean	Range
Scraper	None	BA1-BA2	Nevada	6/95	2	8.19	6.05 -11.1
Scraper	None	BA3-BA6	California	6/95	4	0.838	0.550-1.32
Scraper	Watering	BA8-BA9	California	6/95	2	0.174	0.090-0.340
Light duty	None	BA10-BA12	California	7/95	3	7.24	3.33-12.5

TABLE 4-4. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 2

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min	Temp., °F	Vehicle information				Silt, %	Moisture, %
				No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Mean vehicle speed, mph		
BA-1	6.05	43	91	19	54.8	4.2	8.8	7.69	1.16
BA-2	11.1	22	91	12	58.5	4.0	9.5	7.69	1.16
BA-3	1.32	40	74	17	86.5	4.0	14	6.04	7.41
BA-4	0.580	40	74	17	86.5	4.0	14	6.04	7.41
BA-5	1.17	56	74	14	77.0	4.0	14	6.04	7.41
BA-6	0.550	56	74	16	77.0	4.0	14	6.04	7.41
BA-8	0.340	13	70	42	86.7	4.1	16	4.11	4.14
BA-9	0.090	16	70	74	79.6	4.1	16	3.35	5.69
BA-10	3.33	29	105	32	2.8	4.3	25	15.5	0.27
BA-11	9.10	35	105	29	2.0	4.0	25	15.5	0.27
BA-12	12.5	28	105	31	2.0	4.1	25	15.5	0.27

TABLE 4-5. SUMMARY INFORMATION - REFERENCE 3[a]

Operation	Control method	Tests	State	Test date	No. of tests	PM-10 emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT		PM-1 emission factor, lb/VMT	
						Geom. mean	Range	Geom. mean[b]	Range[b]	Geom. mean[b]	Range[b]
Stone quarry Haul truck	Watering	G-DW[b]	North Carolina	8/95	3	0.195	0.006-1.60	0.109	0.027-0.441	0.092	0.063 - 0.136
Stone quarry Haul truck	Watering	S-DW	North Carolina	8/95	3	1.37	0.490-2.99	0.353	0.137-1.32	0.059	0.015 - 0.360

1 lb/VMT = 281.9 g/VKT

[a]Emissions reported are said to include noncombustible particles only. Upwind measurements were not adjusted for noncombustible particles in report calculations.

[b]Negative emissions reported at Garner location are not included in range or geometric mean calculation.

TABLE 4-6. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 3

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Average vehicle speed, mph		
G-DW-M201A-2	0.0061	356	88	4.66	204	NA[a]	NA[b]	18.55	7.22	5.96
G-DW-M201A-3	1.60	360	85	6.21	245	NA[a]	NA[b]	18.55	6.73	3.65
G-DW-M201A-4	0.76	360	86	6.35	200	NA[a]	NA[b]	18.55	8.23	9.68
S-DW-M201A-1	2.99	240	91	4.99	128	NA[a]	NA[b]	16.87	6.65	3.97
S-DW-M201A-2	0.49	300	90	3.69	250	NA[a]	NA[b]	16.87	9.81	6.44
S-DW-M201A-3	1.74	360	79	6.53	168	NA[a]	NA[b]	16.87	6.48	4.59

[a]Mean vehicle weight not available - Estimated = 52 tons for AP-42 development.

[b]Mean number of wheels not available - Estimated = 6 wheels for AP-42 development.

TABLE 4-7 SUMMARY INFORMATION FOR REFERENCE 4

Operation	Location	State	Uncontrolled test runs	Test date	No. of tests	Uncontrolled TSP emission factor, lb/VMT		Uncontrolled PM-10 emission factor, lb/VMT		Controlled TSP emission factor, lb/VMT		Controlled PM-10 emission factor, lb/VMT	
						Geom. mean	Range	Geom. mean	Range	Geom. mean	Range	Geom. mean	Range
Haul road Summary	1, 1B, 2 and 4	Wyoming	BB2-16, BB29-34, BB36, BB44-48	9/92-10/92	42	31	0.49-95.1	5.5	0.08-15.6	15	4.64-84.2	2.6	0.83 - 13.0
Coal Haul Road	Site 1	Wyoming	BB2,3,10,11	9/52-10/92	6	42	20.2-95.1	6.1	2.86 -13.6	--	--	--	--
Coal Haul Road	Site 1B	Wyoming	BB6-8, BB12-16, BB45,BB48,	10/92	24	14	0.40 - 20.2	3.6	0.08-6.52	10	4.64-18.0	2.2	0.93 - 4.25
Coal Haul Road	Site 2	Wyoming	BB33,34	10/92	4	46	44.4-47.9	7.3	5.70-9.48	17	10.2-27.3	2.4	0.83 - 6.66
Overburden Haul Road	Site 4	Wyoming	BB29,31,36,44	10/92	8	72	1.27-84.2	13	0.25-15.6	57	38.4-84.2	5.8	2.61 - 13.0
Scrapper	Site 5	Wyoming	BB46,47	10/92	2	--	--	9.5	8.17-11.0	--	--	--	--

1 lb/VMT = 281.9 g/VKT

TABLE 4-8. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 4

Site	Run	PM-10 emission factor, lb/VMT	Control measure	Duration, min.	Meteorology		Vehicle				Silt, %	Moisture, %
					Temp., °F	Avg. wind, mph	No of vehicle passes	Mean vehicle weight, ton	Avg. No. of wheels	Mean vehicle speed, mph		
1	BB-2	10.8	None	30	35	61	14.43	131	5.54	36.4	10.7	1.08
1	BB-3	13.6	None	25	35	61	14.43	131	5.54	36.4	10.7	1.08
1B	BB-6	4.67	None	55[1]	40	74	9.68	200	5.80	22.7	3.57	1.19
1B	BB-7	6.51	None	66	45	74	9.60	200	5.73	22.4	3.57	1.19
1B	BB-8	5.20	None	29	18	79	8.68	220	5.56	21.2	3.78	1.01
1	BB-10	3.26	None	88	57	80	18.06	160	5.47	27.5	3.08	1.17
1	BB-11	1.79	None	89	57	80	18.02	160	5.47	27.5	3.08	1.17
1B	BB-12	1.49	None	58	50	73	14.29	155	5.80	22.6	2.24	1.09
1B	BB-13	1.49	None	60	50	73	14.26	155	5.80	22.6	2.24	1.09
1B	BB-14	2.62	None	80	44	59	9.88	92.0	5.18	22.9	3.32	1.77
1B	BB-15	4.37	None	64	41	62	11.39	183	5.66	21.3	2.05	1.39
1B	BB-16	5.18	None	63	51	62	10.01	178	5.57	22.1	2.05	1.39
1B	BB-17	1.63	Watering	79	50	65	12.73	169	5.48	24.6	2.08	1.80
1B	BB-18	4.25	Watering	93	71	65	9.92	184	5.97	23.0	1.34	1.29
1B	BB-19	3.13	Watering	67	47	65	8.15	192	5.74	22.8	1.25	1.45
1B	BB-20	2.69	Watering	53	41	68	7.98	175	5.66	24.3	3.89	1.40
1B	BB-21	1.81	Watering	82	32	78	8.11	218	5.75	22.8	1.76	2.00
1B	BB-22	1.38	Watering	36	32	82	4.54	161	5.50	24.3	1.70	2.50
1B	BB-23	0.940	Watering	52	33	87	7.55	181	5.70	22.6	1.90	4.10
1B	BB-25	1.24	Watering	62	40	60	18.17	207	5.70	19.2	3.82	4.00
1B	BB-26	2.97	Watering	79	63	66	13.51	183	5.65	21.8	2.45	4.40
1B	BB-27	3.86	Watering	72	42	69	12.05	244	5.81	19.5	2.72	1.89
4	BB-29	15.6	None	37	21	65	5.86	283	5.90	18.8	19.2	3.78

were these tests done during a hurricane?

TABLE 4-8. (continued)

Site	Run	PM-10 emission factor, lb/VMT	Control measure	Duration, min.	Meteorology		Vehicle				Silt, %	Moisture, %
					Temp., °F	Avg. wind, mph	No of vehicle passes	Mean vehicle weight, ton	Avg. No. of wheels	Mean vehicle speed, mph		
4	BB-31	9.34	None	37	22	65	5.18	271	6.09	20.8	19.2	3.78
2	BB-33	5.70	None	92	32	61	13.72	153	5.44	29.2	3.02	1.50
2	BB-34	9.45	None	72	36	63	12.24	170	6.06	28.6	4.88	0.91
2	BB-35	6.65	Watering	87	32	60	8.27	173	5.44	28.0	3.71	2.53
4	BB-36	14.2	None	44	21	69	4.63	286	6.00	19.3	12.9	5.00
1B	BB-38	3.22	Watering	50	43	53	22.71	141	5.26	22.0	1.57	10.3
1B	BB-39	1.70	Watering	45	40	53	22.52	137	5.25	21.8	1.44	12.3
4	BB-40	2.62	Watering	78	40	45	12.24	271	6.05	21.2	4.79	5.70
4	BB-41	5.66	Watering	97	51	45	11.88	267	5.92	22.3	6.48	5.03
4	BB-42	13.0	Watering	70	36	44	11.63	275	5.94	22.0	9.48	4.35
2	BB-43	0.810	Watering	48	25	62	14.11	164	5.52	30.4	1.78	4.65
4	BB-44	0.25	None	105	200	69	9.01	2.00	4.00	30.0	1.82	0.68
5	BB-46	8.14	None	89	32	80	10.13	63.0	4.06	15.5	12.7	4.88
5	BB-47	78.2	None	44	14	80	5.31	65.0	4.00	18.0	14.0	5.11
1B	BB-45	11.0	None	75	322	53	9.93	2.00	4.00	30.0	1.95	2.10
1B	BB-48	0.120	None	50	381	53	7.71	2.00	4.00	30.0	1.95	2.10

TABLE 4-9. SUMMARY INFORMATION - REFERENCE 5

Operation	Control method	Tests	State	Test date	No. of tests	PM-10 emission factor, lb/VMT	
						Geom. mean	Range
Stone quarry haul truck	Watering	W-201A-1 to W-201A-3	North Carolina	8/95	3	0.112	0.0553-0.217
Stone quarry haul truck	None	D-201A-1 to D-201A-4	North Carolina	8/95	4	1.74	0.528-4.70

1 lb/VMT = 281.9 g/VKT

TABLE 4-10. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 5

Unpaved road test runs	PM-10 emission factor, lb/VMT[a]	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton[b]	Mean No. of wheels[c]	Average vehicle speed, mph[b]		
W-201A-1	0.116	330	69	2.7	190	52.5	NA	16.94	5.86	5.59
W-201A-2	0.055	360	63	1.1	192	52.5	NA	16.94	7.35	6.31
W-201A-3	0.217	180	57	1.0	95	52.5	NA	16.94	7.19	5.87
D-201A-1	0.528	70	62	2.3	33	52.5	NA	16.94	8.54	2.22
D-201A-2	1.57	120	72	1.6	72	52.5	NA	16.94	7.34	1.19
D-201A-3	2.34	90	73	1.3	57	52.5	NA	16.94	9.25	1.31
D-201A-4	4.70	120	62	2.1	78	52.5	NA	16.94	11.03	0.83

[a]Emission Factors are average of left hood and right hood concentrations.

[b]Mean vehicle weight and average vehicle speed were a representative sample applied to entire testing period.

[c]Mean number of wheels not reported, estimated mean from truck description = 6.

TABLE 4-11. SUMMARY OF EMISSIONS FOR REFERENCE 6

Operation	Control method	Test run	State	Test date	TSP emission factor, lb/VMT			PM-10 emission factor, lb/VMT		
					No. of tests	Geom. mean	Range	No. of tests	Geom. mean	Range
35 mph rural road	None	AZ	Arizona	5/90	3	3.40	3.19 - 3.86	9	0.735	0.497 - 1.43
45 mph rural road	None	AZ	Arizona	5/90	3	4.59	3.56 - 5.94	9	1.26	0.777 - 2.97
55 mph rural road	None	AZ	Arizona	5/90	3	6.73	5.35 - 9.24	9	1.70	0.969 - 2.88

1 lb/VMT = 281.9 g/VKT

TABLE 4-12. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 6

Unpaved road test runs[a]	PM-10 emission factor, lb/VMT	Duration, min.	Avg. wind, mph	Vehicle information				Silt, %	Moisture, %
				No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Mean vehicle speed, mph		
AZ-01	0.780	21	4.9	53	1.9	4.0	45	11	0.2
AZ-02	_[b]	21	4.9	53	1.9	4.0	45	11	0.2
AZ-03	0.920	22	6.0	55	1.9	4.0	45	11	0.2
AZ-04	0.880	22	6.0	55	1.9	4.0	45	11	0.2
AZ-05	1.35	71	4.2	62	1.9	4.1	55	11	0.2
AZ-06	1.46	71	4.2	62	1.9	4.1	55	11	0.2
AZ-07	0.970	31	4.8	54	1.9	4.0	55	11	0.2
AZ-08	_[b]	31	4.8	54	1.9	4.0	55	11	0.2
AZ-09	0.500	97	5.9	172	1.9	4.0	35	11	0.2
AZ-10	_[b]	97	5.9	172	1.9	4.0	35	11	0.2
AZ-11	0.670	96	3.9	178	1.9	4.0	35	11	0.2
AZ-12	0.630	96	3.9	178	1.9	4.0	35	11	0.2
AZ-21	0.810	42	8.2	98	1.6	4.0	45	7.4	0.22
AZ-22	0.920	42	8.2	98	1.6	4.0	45	7.4	0.22

TABLE 4-12. (continued)

Unpaved road test runs[a]	PM-10 emission factor, lb/VMT	Duration, min.	Avg. wind, mph	Vehicle information				Silt, %	Moisture, %
				No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Mean vehicle speed, mph		
AZ-23	1.16	47	5.0	50	1.6	4.0	45	7.4	0.22
AZ-24	–[b]	47	5.0	50	1.6	4.0	45	7.4	0.22
AZ-25	1.55	27	5.4	51	1.6	4.0	55	7.4	0.22
AZ-26	–[b]	27	5.4	51	1.6	4.0	55	7.4	0.22
AZ-27	2.01	39	7.4	77	1.6	4.0	55	7.4	0.22
AZ-28	2.01	39	7.4	77	1.6	4.0	55	7.4	0.22
AZ-29	0.730	50	7.0	153	1.6	4.0	35	7.4	0.22
AZ-31	0.630	82	4.0	105	1.6	4.1	35	7.4	0.22
AZ-32	–[b]	82	4.0	105	1.6	4.1	35	7.4	0.22
AZ-33	0.650	46	6.4	134	1.8	4.0	35	7.4	0.22
AZ-41	1.03	96	3.8	155	1.6	4.1	35	4.3	0.17
AZ-42	0.680	96	3.8	155	1.6	4.1	35	4.3	0.17
AZ-43	1.43	76	3.7	107	1.6	4.0	35	4.3	0.17
AZ-44	–[b]	76	3.7	107	1.6	4.0	35	4.3	0.17
AZ-45	1.28	48	3.9	72	1.6	4.0	55	4.3	0.17
AZ-46	–[b]	48	3.9	72	1.6	4.0	55	4.3	0.17
AZ-47	2.88	97	3.0	35	1.6	4.0	55	4.3	0.17
AZ-48	2.62	97	3.0	35	1.6	4.0	55	4.3	0.17
AZ-49	2.97	72	5.2	36	1.6	4.3	45	4.3	0.17

TABLE 4-12. (continued)

Unpaved road test runs[a]	PM-10 emission factor, lb/VMT	Duration, min.	Avg. wind, mph	Vehicle information				Silt, %	Moisture, %
				No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Mean vehicle speed, mph		
AZ-50	2.57	72	5.2	36	1.6	4.3	45	4.3	0.17
AZ-51	1.91	115	5.0	45	1.6	4.0	45	4.3	0.17
AZ-52	–[b]	115	5.0	45	1.6	4.0	45	4.3	0.17

[a]Test runs include simultaneously collected samples (ex. AZ-01 and AZ-02). Tests AZ-1 through 12, AZ-21 through -33, and AZ-41 through -52 conducted in Pinal, Pima, and Yuma Counties, respectively.
[b]TSP emission factor.

TABLE 4-13. SUMMARY INFORMATION FOR REFERENCE 7

Operation	Location	State	Test dates	No. of tests	Controlled TSP emission factor, lb/VMT		Controlled PM-10 emission factor, lb/VMT	
					Geom. mean	Range	Geom. mean	Range
Vehicle traffic	AU-X (Unpaved road)	PA	11/89	2	0.61	0.39-0.96	0.16	0.14-0.18
Vehicle traffic	Paved road	PA	11/89	6	0.033	0.012-0.12	0.0095	0.0009-0.036
Vehicle traffic	Paved road	PA	11/89	4	0.078	0.033-0.30	0.022	0.0071-0.036

1 lb/VMT = 281.9 g/VKT.

TABLE 4-14. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 7

Unpaved road - test runs	PM-10 emission factor, lb/VMT	Control method	Duration, min.	Meteorology		Vehicle information			Silt content, %
				Temp., °F	Wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean vehicle speed, mph	
AU-X-1	0.14	Chemical Suppressant	168	62	8.7	110	3.9	25	3.3
AU-X-2	0.18	Chemical Suppressant	71	60	6.5	101	2.1	26	4.1

TABLE 4.15. SUMMARY INFORMATION FOR REFERENCE 8

Operation	Control method	Test runs	State	Test date	No. of tests	TSP emission factor, lb/VMT		IP emission factor, lb/VMT		PM-10 emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
						Geom. mean	Range	Geom. mean	Range	Geom. mean	Range	Geom. mean	Range
Heavy-duty traffic	None (U)	AP	Indiana	5/85 & 8/85	4	10.3	2.20 - 37.6	1.21	0.064 - 7.91	2.55	0.575 - 6.42	0.408	0.156 - 0.791
Heavy-duty traffic	Calcium chloride (C)	AP	Indiana	5/85 & 8/85	1	1.26	1.26	–	–	–	–	–	–
Heavy-duty traffic	Petro Tac (P)	AP	Indiana	5/85 & 8/85	5	2.59	0.645-7.70	0.305	0.076-1.46	0.193	0.048-1.08	0.066	0.019-0.369
Heavy-duty traffic	Coherex (X)	AP	Indiana	5/85 & 8/85	5	4.68	0.653-21.3	0.776	0.108-4.26	0.564	0.078-3.20	0.079	0.011-0.766
Heavy-duty traffic	None (U)	AQ	Missouri	9/85, 10/85, & 11/86	2	6.67	5.68-7.84	1.47	1.25-1.72	1.00	0.851-1.18	0.180	0.153-0.212
Heavy-duty traffic	Calcium chloride (C)	AQ	Missouri	9/85, 10/85, & 11/86	6	2.09	0.211-17.5	0.279	0.032-3.87	0.144	0.008-2.98	0.418	0.102-0.922
Heavy-duty traffic	Generic (G)	AQ	Missouri	9/85, 10/85, & 11/86	11	3.05	1.27-14.5	0.728	0.397-2.46	0.546	0.279-2.03	0.118	0.029-0.724
Heavy-duty traffic	Petro Tac (P)	AQ	Missouri	9/85, 10/85, & 11/86	5	4.84	2.57-11.9	0.781	0.387-2.26	0.572	0.283-1.78	0.134	0.064-0.582
Heavy-duty traffic	Soil Sement (S)	AQ	Missouri	9/85, 10/85, & 11/86	11	1.63	0.200-6.78	0.265	0.050-1.08	0.176	0.014-0.816	0.053	0.009-0.148
Heavy-duty traffic	Coherex (X)	AQ	Missouri	9/85, 10/85, & 11/86	9	2.14	0.208-10.5	0.282	0.034-1.42	0.182	0.017-1.11	0.104	0.013-0.334

1 lb/VMT = 281.9 g/VKT.

TABLE 4-16. DETAILED INFORMATION FOR UNPAVED ROAD TESTS - REFERENCE 8

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Avg. vehicle speed, mph[a]		
AP2-P	0.0479	128	70	11	68	27	12.3	15	1.9	0.46
AP2-X	–	128	70	7.6	68	27	12.3	15	<0.05	0.50
AP2-C	–	128	70	4.2	65	28	11.8	15	2.7	1.2
AP2-U	6.42	127	70	4.2	8	33	7.0	15	8.1	0.64
AP3-P	0.124	119	70	11	50	29	7.08	15	2.6	0.36
AP3-X	0.0780	119	70	8.5	50	29	7.08	15	<0.05	1.4
AP3-C	–	119	70	8.5	50	29	7.08	15	4.3	1.4
AP3-U	4.47	119	70	6.2	10	37	5.2	15	8.3	1.1
AP5-P	1.08	84	73	2.6	34	28	13.9	15	6.1	0.12
AP5-X	3.20	82	73	3.9	34	28	13.9	15	11	0.14
AP6-P	0.178	59	75	2.0	51	26	17.4	15	6.8	0.13
AP6-X	1.38	56	75	3.7	51	26	17.4	15	10	0.08
AP6-U	–	46	75	3.7	51	26	17.4	15	7.3	0.10
AP7-P	0.231	104	72	0.92	87	26	13.5	15	11	–
AP7-X	0.293	109	72	1.6	90	26	13.4	15	12	–
AP7-U	0.575	87	72	1.6	85	25	13.4	15	6.0	–
AQ1-U	0.851	64	82	8.4	50	10	6.0	15	7.0	1.5
AQ1-G	0.887	66	82	8.4	50	10	6.0	15	7.6	1.5
AQ1-S	0.201	75	82	8.4	50	10	6.0	15	0.6	0.94
AQ1-X	0.809	75	82	8.4	50	10	6.0	15	15	1.2
AQ2-U	1.18	69	82	8.7	68	9.8	5.9	15	7.0	1.5
AQ2-G	1.04	82	82	8.7	68	9.8	5.9	15	7.6	1.5
AQ2-S	0.158	85	82	8.7	68	9.8	5.9	15	0.6	0.94

TABLE 4-16. (continued)

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Avg. vehicle speed, mph[a]		
AQ2-X	0.504	82	82	8.7	68	9.8	5.9	15	15	1.2
AQ3-P	0.401	105	75	11	76	9.7	5.9	15	3.1	1.8
AQ3-G	0.329	52	75	9.0	19	9.3	5.8	15	6.8	1.5
AQ3-S	0.135	50	75	9.0	19	9.6	5.9	15	1.5	1.1
AQ3-X	0.103	47	75	9.0	19	9.6	5.9	15	12	1.6
AQ4-G	2.03	22	75	11	50	24	6.0	15	6.8	1.5
AQ4-S	0.440	28	75	10	50	24	6.0	15	1.5	1.1
AQ4-X	0.585	22	75	12	50	24	6.0	15	12	1.6
AQ4-C	0.451	33	75	13	50	24	6.0	15	--	--
AQ5-P	1.78	21	63	5.9	34	24	5.9	15	5.0	1.1
AQ5-G	0.497	20	63	5.9	34	24	5.9	15	10	1.3
AQ5-S	0.816	29	63	5.9	34	24	5.9	15	4.4	0.99
AQ5-C	2.98	20	63	5.9	34	24	5.9	15	12	1.4
AQ6-P	0.568	18	75	5.0	44	24	6.0	15	5.0	1.1
AQ6-G	0.812	28	75	5.0	36	24	6.0	15	10	1.3
AQ6-S	0.646	23	75	5.0	36	24	6.0	15	4.4	0.99
AQ6-C	2.43	23	75	5.0	36	24	6.0	15	12	1.4
AQ7-P	0.283	30	64	6.5	50	24	6.0	15	3.6	1.2
AQ7-G	0.390	25	64	6.5	48	24	6.0	15	7.0	1.2
AQ7-S	0.284	28	64	6.5	50	24	6.0	15	2.9	0.95
AQ7-X	0.929	28	64	6.5	50	24	6.0	15	6.7	--

TABLE 4-16. (continued)

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Avg. vehicle speed, mph[a]		
AQ8-P	0.536	22	70	5.0	36	24	6.0	15	3.6	1.2
AQ8-G	0.401	16	70	5.0	34	24	6.0	15	7.0	1.2
AQ8-S	0.422	17	70	5.0	34	24	6.0	15	2.9	0.95
AQ8-X	1.11	17	70	5.0	34	24	6.0	15	6.7	--
AQ9-G	0.282	110	64	6.5	125	10	6.0	15	.76	0.95
AQ9-S	0.0145	110	64	6.5	125	10	6.0	15	1.2	0.77
AQ9-X	0.0200	62	64	6.5	79	10	6.0	15	1.1	0.78
AQ9-C	0.0084	267	64	6.5	125	10	6.0	15	1.6	2.1
AQ10-G	0.279	138	61	6.6	200	7.6	5.3	15	2.9	1.3
AQ10-S	0.0340	134	61	6.6	200	7.6	5.3	15	--	--
AQ10-X	0.0168	129	61	6.6	200	7.6	5.3	15	--	--
AQ10-C	0.0204	133	61	6.6	200	7.6	5.3	15	--	--
AQ11-G	0.422	127	55	8.7	250	6.5	5.0	15	2.9	1.3
AQ11-S	0.0848	127	55	8.7	250	6.5	5.0	15	--	--
AQ11-X	0.0255	130	55	8.7	250	6.5	5.0	15	--	--
AQ11-C	0.0161	130	55	8.7	250	6.5	5.0	15	--	--

[a]Test at AQ were conducted with captive traffic and vehicles were operated at 15 mph. For test runs, the following codes were used: C = calcium chloride, G = Generic, P = Petro Tac, U = uncontrolled, S = Soil Sement, X = Coherex.

TABLE 4-17. SUMMARY OF EMISSIONS FOR REFERENCE 9

Operation	Test runs	State	Test date	No. of tests	TSP emission factor, lb/VMT		IP emission factor, lb/VMT		PM-10 emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
					Geom. mean	Range	Geom. mean	Range	Geom. mean	Range	Geom. mean	Range
Uncontrolled tests - Scraper Travel	AN24-AN25	Michigan	8/85	4	51	41 - 64	34	28 - 43	26	22 - 33	7.7	6.3 - 10
Controlled Tests - Scraper Travel	AN21-AN23	Michigan	8/85	7	10	2.1 - 37	9.2	1.5 - 27	5.3	1.2 - 21	1.6	.47 - 7.2

1 lb/VMT = 281.9 g/VKT

TABLE 4-18. DETAILED INFORMATION FOR UNPAVED ROAD TESTS FOR REFERENCE 9

Unpaved road test runs	PM-10 emission factor, lb/VMT	Control method	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
				Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Avg. No. of wheels	Mean vehicle speed, mph		
AN21U	1.90	Watering	46	84	3.8	75	49	4	13	8.9	7.3
AN21X	1.20	Watering	57	84	3.7	59	49	4	15	8.9	8.7
AN21Y	6.70	Watering	81	84	3.9	99	49	4	16	8.9	3.5
AN22U	21.0	Watering	56	81	4.1	49	49	4	17	5.9	2.3
AN22Y	11.0	Watering	61	79	3.7	45	49	4	17	5.9	3.1
AN23U	7.30	Watering	35	77	3.1	40	49	4	16	8.4	3.6
AN23Y	4.80	Watering	15	72	2.1	20	49	4	16	8.4	3.4
AN24U	27.0	None	23	82	7.1	20	49	4	18	7.7	1.7
AN24Y	22.0	None	23	82	7.1	20	49	4	18	7.7	1.7
AN25U	33.0	None	12	83	6.8	10	49	4	20	7.7	1.7
AN25Y	30.0	None	12	83	6.8	10	49	4	20	7.7	1.7

AN21U = Site "AN" test no. 21 at station "U."

TABLE 4-19. SUMMARY INFORMATION FOR REFERENCE 10

Operation	Control method	Test run	State	Test date	No. of tests	TP emission factor, lb/VMT		TSP emission factor, lb/VMT		IP emission factor, lb/VMT		PM-10 emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
						Geom. Mean	Range	Geom. Mean	Range	Geom. Mean	Range	Geom. Mean	Range	Geom. Mean	Range
Heavy-duty traffic	None	AL 1, 3, 4, 7, 8, 9, 12	Indiana	6/84	6	10.4	7.16 - 15.9	4.66	3.69 - 7.13	3.20	2.65 - 4.82	2.46	2.02 - 3.75	0.781	0.618 - 1.23
Light/ Medium duty traffic	None	AL 2, 6, 10, 11	Indiana	6/84	4	4.61	2.54 - 6.88	2.13	1.75 - 2.88	1.39	1.12 - 2.02	1.09	0.860 - 1.58	0.377	0.274 - 0.524

1 lb/VMT = 281.9 g/VKT

TABLE 4-20. DETAILED INFORMATION FOR UNPAVED ROAD TESTS FOR REFERENCE 10

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min	Meteorology		Vehicle information				Silt, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Mean vehicle speed, mph	
AL-1	7.16	40	64	6.2	40	22	12	19	11.1
AL-2	3.05	55	64	6.3	31	7.7	5.2	20	11.1
AL-3	7.90	24	80	7.6	41	28	14	19	10.6
AL-4	13.3	24	80	9.2	41	27	13	20	10.6
AL-6	4.04	20	80	9.0	42	7.1	4.7	20	10.6
AL-7	9.36	29	73	5.4	42	28	14	17	11
AL-8	8.12	31	73	4.8	40	33	16	18	11
AL-9	3.65	44	59	11	67	31	15	25	6.9
AL-10	3.27	37	59	12	50	9.0	5.6	20	6.9
AL-11	5.60	30	59	14	50	11	6.3	20	6.9
AL-12	7.80	25	60	6.0	39	32	15	16	10.3

TABLE 4-21. SUMMARY OF UNPAVED ROAD EMISSIONS FOR REFERENCE 11

Operation	Type	Control method	TP emission factor, lb/VMT		IP emission factor, lb/VMT		PM-10 emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
			Geom. mean	Range	Geom. mean	Range	Geom. mean	Range	Geom. mean	Range
Rural roads	Crushed Limestone - Light duty	None	21.9	17.9-27.0	3.84	3.17-4.99	2.17	1.75-3.09	0.334	0.300-0.407
Rural roads	Dirt - Light duty	None	28.6	11.1-42.1	3.42	2.83-4.18	1.60	0.551-1.99	0.293	0.090-0.507
Rural roads	Gravel - Light duty	None	6.70	5.43-7.96	1.25	1.10-1.39	0.835	0.713-0.957	0.366	0.251-0.481
Copper smelter	Medium duty vehicle	None	8.99	7.62-10.0	2.57	2.21-2.97	1.67	1.46-1.91	0.317	0.283-0.370
Stone crushing	Medium duty vehicle	None	25.0	9.36-35.2	7.1	3.20-9.67	--	2.15-5.83	4.17	2.15-5.83
Sand and gravel	Heavy duty vehicle	None	11.1	8.28-15.3	3.92	3.35-4.44	2.73	2.34-3.26	0.742	0.620-0.982

1 lb/VMT = 281.9 g/VKT

TABLE 4-22. DETAILED INFORMATION FOR UNPAVED ROAD TESTS FOR REFERENCE 11

Run No.	PM-10 emission factor, lb/VMT	Industrial category	Type of traffic	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. wheels	Mean vehicle speed, mph	Moisture content, %	Silt content, %
U-1	9.13	Rural roads crushed limestone	Light duty	8.28	125	1.9	4.0	35	0.25	9.5
U-2	3.09	Rural roads crushed limestone	Light duty	7.61	105	1.9	4.0	35	0.3	9.1
U-3	1.75	Rural roads crushed limestone	Light duty	2.46	101	1.9	4.0	35	0.27	7.7
U-4	1.87	Rural roads crushed limestone	Light duty	7.16	102	1.9	4.0	25	0.4	8.6
U-5	1.97	Rural roads crushed limestone	Light duty	11.6	107	2.3	4.0	25	0.37	9.2
U-6	–	Rural roads crushed limestone	Light duty	13.2	51	1.9	4.0	30	--	--
AB-1	12.1	Rural roads dirt	Light duty	13.2	94	2.3	4.0	25	3.9	35.1
AB-2	0.950	Rural roads dirt	Light duty	6.49	50	2.3	4.0	25	4.5	16.7
AB-3	1.99	Rural roads dirt	Light duty	8.50	50	2.3	4.0	25	3.2	16.8
AB-4	1.86	Rural roads dirt	Light duty	11.2	50	2.3	4.0	25	3.1	5.8
AE-1	0.710	Rural roads gravel	Light duty	9.62	46	2.1	4.0	40	0.26	5.0
AE-2	0.960	Rural roads gravel	Light duty	11.2	22	1.8	4.0	35	0.26	5.0
AA-1	2.15	Stone crushing	Med. duty	4.70	55	11	5.0	15	0.4	13.7
AA-2	0.940	Stone crushing	Med. duty	2.46	24	13	4.4	15	0.34	15.3
AA-3	0.090	Stone crushing	Med. duty	4.92	34	10	4.0	10	0.84	10.5
AA-4	4.52	Stone crushing	Med. duty	8.05	56	14	5.6	10	2.1	15.6
AA-5	5.83	Stone crushing	Med. duty	9.40	56	13	5.0	10	2.1	15.6
AC-1	1.63	Copper smelting	Light duty	4.25	51	2.2	4.8	10	0.07	19.1
AC-2	1.46	Copper smelting	Light duty	5.37	49	2.1	4.0	10	0.07	15.9
AC-3	1.91	Copper smelting	Light duty	6.93	51	2.4	4.3	10	0.03	16

TABLE 4-23. SUMMARY OF UNPAVED ROAD EMISSION TEST RESULTS

Operation	Control method	Location	State	Test date	No. of tests	TP emission factor, lb/VMT		IP emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
						Geom. mean	Range	Geom. mean	Range	Geom. mean	Range
Heavy-duty traffic	None	E	Ohio	11/80	3	132	129 - 133	30.5	25.9 - 33.5	8.35	7.74 - 8.84
Heavy-duty traffic	Coherex	C	Ohio	11/80	4	5.04	3.35 - 8.17	1.48	1.18 - 2.04	0.439	0.274 - 0.594
Heavy-duty traffic	Watering	E	Ohio	11/80	3	28.9	8.27 - 99.3	4.94	0.992 - 25.8	1.07	0.219 - 5.46
Light-duty traffic	None	B	Ohio	7/80	4	11.7	9.98 - 14.2	2.69	1.05 - 4.25	0.731	0.245 - 1.27
Light-duty traffic	Coherex	B	Ohio	10/80	5	0.636	0.089 - 1.23	0.226	0.061 - 0.384	0.0628	0.0318 - 0.0945

1 lb/VMT = 281.9 g/VKT

TABLE 4-24. DETAILED INFORMATION FOR UNPAVED ROAD TESTS FOR REFERENCE 12

Site	Unpaved road test runs	PM-10 emission factor, lb/VMT[a]	Type	Control	Duration, min.	Meteorology		Vehicle information				Silt, %
						Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Avg. No. of wheels	Mean vehicle speed, mph	
E	F-68	25.1	Heavy-duty	None	17	50	7.4	21	22	5.9	20	14
E	F-69	20.6	Heavy-duty	None	13	50	7.9	14	53	10	20	--
E	F-70	25.3	Heavy-duty	None	13	50	8.2	10	53	10	20	16
E	F-65	0.70	Heavy-duty	Watering	57	60	6.4	64	53	10	20	4.5
E	F-66	3.53	Heavy-duty	Watering	20	60	5.5	41	54	9.0	25	--
E	F-67	19.4	Heavy-duty	Watering	17	55	9.5	30	54	9.8	25	5.1
C	F-59	--	Heavy-duty	Coherex	125	50	9.3	61	19	9.3	16	5.4
C	F-60	--	Heavy-duty	Coherex	123	50	8.2	84	46	9.2	22	5.4
C	F-63	--	Heavy-duty	Coherex	107	50	5.2	118	54	7.7	18	2.5
C	F-64	--	Heavy-duty	Coherex	121	50	6.5	136	54	7.8	15	--
B	F-28	0.750	Light-duty	None	45	78	1.6	101	3	4	15	--
B	F-29	3.34	Light-duty	None	34	79	6.2	50	3	4	15	--
B	F-30	2.40	Light-duty	None	17	79	6.2	50	3	4	15	--
B	F-31	3.10	Light-duty	None	40	80	3.5	33	3	4	15	--
B	F-40	--	Light-duty	Coherex	133	50	4.0	300	3	4	25	0.015
B	F-41	--	Light-duty	Coherex	100	50	5.1	255	3	4	25	0.075
B	F-42	--	Light-duty	Coherex	128	50	7.0	294	3	4	25	0.99
B	F-43	--	Light-duty	Coherex	120	50	8.5	300	3	4	25	--
B	F-44	--	Light-duty	Coherex	55	50	9.1	200	3	4	25	1.8

[a]PM-10 emission factor calculated from logarithmic interpolation of PM-15 and PM-2.5 data.

TABLE 4-25. SUMMARY OF EMISSIONS FOR REFERENCE 13

Operation	Control method	Test run	State	Test date	No. of tests	TSP emission factor, lb/VMT		IP emission factor, lb/VMT		PM-10 emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
						Geom. Mean	Range	Geom. Mean	Range	Geom. Mean	Range	Geom. Mean	Range
Heavy-duty traffic	None	AG1-3	Indiana	6/82	3	18.1	12.0-23.4	3.80	1.38 - 7.47	3.05	1.34 - 5.55	0.384	0.117-0.994
Heavy-duty traffic	Petro Tac	AG4-11	Indiana	6/82	8	3.39	0.963-8.88	0.366	0.015-2.24	0.282	0.035-1.54	0.080[a]	0.0154 to 0.259
Heavy-duty traffic	None	AJ1-3	Missouri	9/82	3	16.4	13.8 - 21.4	3.79	2.94 - 5.15	2.86	2.14 - 4.17	0.694	0.498 - 0.915
Heavy-duty traffic	Watering	AJ4-6	Missouri	9/82	3	1.77	0.255-5.81	0.340	0.086-0.781	0.242	0.051-0.563	0.191	0.122-0.272
Heavy-duty traffic	Coherex	AJ7-18	Missouri	9/82	12	2.79	0.384-16.6	0.42	0.047-3.57	0.233	0.006-2.23	0.076[a]	0.0049 to 0.449

1 lb/VMT = 281.9 g/VKT

[a]Only included test runs with reported measurements.

TABLE 4-26. DETAILED INFORMATION FOR UNPAVED ROAD TESTS FOR REFERENCE 13

Unpaved road test runs	PM-10 emission factor, lb/VMT	Duration, min.	Meteorology		Vehicle information				Silt, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean No. of wheels	Mean vehicle speed, mph	
AG-1	1.34	31	71	4.2	27	27	9.8	15	7.5
AG-2	5.55	106	69	7.4	30	25	7.3	17	5.8
AG-3	3.82	99	70	5.8	22	28	6.6	16	7.2
AG-4	0.097	107	52	2.7	79	23	9.2	15	0.28
AG-5	0.248	128	69	4.8	120	32	10	14	0.29
AG-6	0.035	166	87	6.6	160	30	13	15	5.0
AG-7	0.136	202	71	2.2	84	34	10	16	4.9
AG-8	0.610	100	70	3.2	93	31	9.1	14	5.3
AG-9	1.54	75	69	6.3	31	28	6.1	13	8.2
AG-10	1.11	76	65	3.4	49	31	8.1	13	8.5
AG-11	0.335	62	74	2.6	62	26	5.8	14	13
AJ-1	4.17	48	77	3.3	45	54	6.0	15	6.3
AJ-2	2.62	46	76	2.0	47	52	6.0	15	7.4
AJ-3	2.14	50	80	4.2	50	50	7.1	15	7.7
AJ-4	0.060	79	90	6.1	86	48	6.1	15	4.9
AJ-5	0.560	67	85	5.6	71	50	6.0	15	5.3
AJ-6	0.493	46	78	4.4	49	48	5.9	15	–
AJ-7	0.490	90	66	3.6	68	49	5.9	15	1.9
AJ-8	0.022	89	70	5.8	120	34	7.2	15	5.5
AJ-9	1.05	126	69	5.3	120	50	6.4	15	7.1
AJ-10	1.49	50	62	2.8	44	29	6.0	20	6.1
AJ-11	0.904	65	65	3.1	61	27	6.0	19	4.3
AJ-12	2.23	68	61	7.7	60	44	6.0	21	5.7
AJ-13	0.006	190	57	8.2	150	38	6.0	18	ND
AJ-14	0.183	240	42	12	250	56	6.0	22	0.034
AJ-15	0.313	131	49	8.8	107	54	6.0	17	1.6
AJ-16	0.098	140	55	4.9	140	32	6.0	23	2.1
AJ-17	0.066	125	65	7.9	120	34	6.0	20	1.5
AJ-18	0.373	119	43	5.0	115	31	6.0	22	1.7

TABLE 4-27. SUMMARY INFORMATION FOR REFERENCE 14

Operation	Control method	Test Run	State	Test date	No. of tests	TSP emission factor, lb/VMT		IP emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
						Geom. mean	Range	Geom. mean	Range	Geom. mean	Range
Haul Truck	None	J9-J12,J20,J21, K1,K7,K9-K12, K26,L1,L3,L4, P1-3, P5	North Dakota, Wyoming, New Mexico	1979-80	20[a]	10.8	0.70 - 73	5.54	0.32 - 42	0.23	0.02 - 2.88
Haul Truck	Watering	K6,K8,K13,P4,P 6-P9	Wyoming, New Mexico	1979-80	8[a]	2.97	0.60 - 8.4	1.51	0.40 - 4.1	0.09	0.05 - 0.16
Light/Medium Duty Truck	None	J13,J18,J19,K2, K3,K4,K5,P11,P 12,P13	North Dakota, Wyoming, New Mexico	1979-80	10	2.94	0.60 - 9.0	1.79	0.33 - 6.6	0.119	0.03 - 1.5
Light/Medium Duty Truck	CaCl2	J7,J8	North Dakota	1979-80	2[b]	0.35	ND-0.35	0.34	ND-0.34	0.09	ND-0.09

1 lb/VMT = 281.9 g/VKT

[a]Haul Truck uncontrolled tests listed in report text = 19 and watered tests = 9, however data tables list 20 uncontrolled and 8 watered tests.

[b]Test Run J7 was reported as a nondetect (ND). Geometric Mean was calculated using only the detected test.

TABLE 4-28. DETAILED INFORMATION FOR UNPAVED ROAD TESTS FOR REFERENCE 14

Unpaved road test run	PM-10 emission factor lb/VMT[a]	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, tons	Mean No. of wheels	Mean vehicle speed, mph		
J-6	--	67	76.1	0.9	39	–	–	–	7.9	5.4
J-9	4.6	51	82.94	4.8	41	65	8	19.3	9.4	3.4
J-10	14.1	52	87.8	4.4	45	60	7.7	19.3	9.4	2.2
J-11	9.4	48	86.9	4.2	40	60	9.9	20	8.2	4.2
J-12	4.9	49	80.06	0.8	19	99	9.5	15	14.2	6.8
J-20	2.9	49	73.4	2.5	23	125	10	16.8	11.6	8.5
J-21	3.1	26	77	1.6	14	110	9.3	15	–	–
K-1	1.6	86	58.28	6.2	65	63	6.1	32.9	7.7	2.2
K-6	0.6	177	64.04	3.4	84	89	7.4	34.8	2.2	7.9
K-7	1.6	53	74.3	2.6	57	24	4.9	34.2	2.8	0.9
K-8	0.8	105	50.54	5.7	43	65	6.3	36	3.1	1.7
K-9	2	89	53.6	5	63	74	6.7	29.2	4.7	1.5
K-10	1.5	65	51.08	5	40	69	6.6	36	7.7	2
K-11	1.5	64	54.5	5.2	50	73	6.5	30	8.9	2
K-12	2	58	59.9	5.4	43	95	7.3	36	11.8	2.3
K-13	0.3	73	39.2	3.7	78	64	6.6	31.7	1.8	2.7
L-1	0.2	92	33.26	1.9	57	95	8.8	26.1	13	7.7
L-3	27.7	47	55.76	6.5	26	107	9.3	20	13.8	4.9
L-4	20.9	48	56.48	6.1	32	86	8.3	20	18	5.1
P-1	11.3	57	95	3.8	15	79	8.5	26.7	4.7	0.4
P-2	2	95	80.6	1.8	10	42	7.2	26.1	4.7	0.4
P-3	6.3	89	80.6	3.8	18	94	9.7	31.1	4.1	0.3
P-4	1.2	135	80.6	3.7	48	55	7.6	31.7	2	0.3

TABLE 4-28. (continued)

Unpaved road test run	PM-10 emission factor lb/VMT[a]	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, tons	Mean No. of wheels	Mean vehicle speed, mph		
P-5	3.4	108	89.6	2.8	38	47	7.1	31.1	3.1	0
P-6	0.7	112	84.2	2.2	48	25	5.6	31.7	2.8	2.9
P-7	2.3	95	84.2	2.5	35	61	7.6	31.1	2.4	1.5
P-8	1.2	103	84.2	3	49	47	7.5	29.2	7.7	15.3
P-9	1.4	142	80.6	3.7	48	58	8.7	31.1	1.6	20.1
J-1	2.48	87	73.94	2.8	63	50	4.1	19.3	8.9	5.7
J-2	2.09	34	77	1.4	33	53	4	19.3	23.4	2.3
J-3	16.3	51	84.92	1.3	35	54	4.1	24.2	15.8	4.1
J-4	0.963	52	68	1.1	30	36	4	20	14.6	1.5
J-5	5.8	60	85.1	1.4	14	70	4	18	10.6	0.9
K-15	4.54	13	41	3.9	6	46	4	28		
K-16	10.3	41	47.84	2.6	10	64	4	30	25.2	6
K-17	20.9	18	53.6	4	31	57	4.1	23	25.2	6
K-18	10.7	37	55.58	2.6	30	66	4	25	25.2	6
K-22	2.92	110	41	3	20	45	4	31.7	21.6	5.4
K-23	6.61	43	42.98	4.6	20	54	4	28	24.6	7.8
L-5	115	14	38.3	8.6	20	53	4	21.1	21	
L-6	51.3	22	39.56	9.4	15	50	4	20	21	
P-15	--	43	89.6	1.6	4	42	4	16.2	7.2	1
P-18	0.714	33	80.6	3.9	18	64	4	10	7.2	1
J-7	–	59	82.94	1.1	104	7	4.2	25	3	3.6

TABLE 4-28. (continued)

Unpaved road test run	PM-10 emission factor lb/VMT[a]	Duration, min.	Meteorology		Vehicle information				Silt, %	Moisture, %
			Temp., °F	Avg. wind, mph	No. of vehicle passes	Mean vehicle weight, tons	Mean No. of wheels	Mean vehicle speed, mph		
J-8	0.27	68	86	1.6	160	3	4	25	3	3.6
J-13	3.22	26	77.9	2.9	59	2.2	4	25	10.1	1
J-18	5.32	21	79.7	3.7	34	2.6	4	25	8.8	1.1
J-19	3.69	31	80.24	3.6	70	2.3	4.1	25	8.2	0.9
K-2	0.195	55	46.94	5.5	150	2.3	4	35	4.9	1.6
K-3	0.242	58	53.78	4.8	150	2.4	4	35	4.9	1.6
K-4	0.225	67	61.16	3.1	150	2.4	4	35	5.3	1.7
K-5	0.351	68	68.72	4.3	150	2.4	4	35.9	5.3	1.7
P-11	2.56	73	95	5.8	100	2	4	42.5	5.5	0.9
P-12	2.94	60	95	5.2	125	2	4	43.1	5.5	0.9
P-13	2.52	55	84.2	4.2	100	2	4	43.1	5.5	0.9

[a]PM-10 emission factors were calculated from the PM-15 and PM-2.5 data using logarithmic interpolation.

The TSP and PM-2.5 data should be presented also

TABLE 4-29. PREDICTED VS. OBSERVED RATIOS FOR NEW UNPAVED ROAD EQUATION USING REFERENCE 15 TEST DATA

Run	Silt, %	Moisture, %	Weight, tons	Speed, mph	No. of wheels	Measured PM-10 emission factor, lb/VMT	Predicted vs. observed	
							Equation 4-5	Current AP-42
BJ-1	4.01	0.10	2	30	4	1.23	0.88	0.43
BJ-2	2.90	0.10	2	30	4	1.29	0.65	0.30
BJ-3	4.26	0.07	2	30	4	0.840	1.51	0.67
BJ-4	3.70	0.09	2	30	4	1.32	0.80	0.37
BG-1	7.20	7.2	2	30	4	0.503	0.95	1.89
BG-2	6.22[a]	0.65	2	30	4	0.925	0.95	0.89
BG-3	6.07	0.54	2	30	4	1.12	0.81	0.71
BG-4	7.56	1.4	2	30	4	0.118	6.95	8.44
BG-5	7.97	1.1	2	30	4	0.088	10.3	11.9

[a]These tests were conducted during misty conditions.

were all the data collected during misty conditions or only some

Also the study needs to be included in the descriptions portion of the report.

J:\dms\460402\unpvbkgd
4/2/97

TABLE 4-30. RESULTS OF CROSS-VALIDATION

Type of vehicle/road	Uncontrolled/ watered	No. of cases	Ratio of Quasi-Independent estimate to measured emission factor	
			Geo. mean	Geo. std. dev.
Haul trucks	U	39	0.98	2.44
	W	34	1.10	2.49
	Overall	73	1.03	2.45
Light-medium duty/traffic on industrial roads	U	29	1.09	2.85
Light-medium duty/traffic on public roads	U	43	0.97	2.36
	Overall	72	1.02	2.54
Heavy duty/traffic on industrial roads	U	3	1.28	1.39
Scrapers in travel mode	U	23	0.82	3.62
	W	9	1.00	5.13
	Overall	32	0.87	3.93

This needs to be described in validation area of this report, Also, if it would not confuse the figures, This information could be used to code the individual points on the various predicted vs actual figures

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6. *Unpaved Road Emission Impact*, Arizona Department of Environmental Quality, Phoenix, AZ, March 1991.

7. *Roadway Emissions Field Tests at US Steel's Fairless Works*, U.S. Steel Corporation, Fairless Hills, PA, USX Purchase Order No. 146-0001191-068, May 1990.

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10. *Critical Review of Open Source Particulate Emission Measurements - Part II - Field Comparison*, Southern Research Institute, Birmingham, AL, August, 1984.

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14. *Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources*, U. S. Environmental Protection Agency, Research Triangle Park, NC, EPA Contract No. 68-03-2924, Assignment 1, July 1981.

15. *Draft Report, Fugitive Particulate Matter Emissions*, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1997.

5. PROPOSED AP-42 SECTION

The proposed AP-42, Section 13.2.2 Unpaved Roads, is presented on the following pages as it would appear in the document.

DRAFT

This is preliminary material, in draft form, for purposes of review. This material must not be quoted, cited, or in any other way considered or used as final work.

13.2.2 Unpaved Roads

13.2.2.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

13.2.2.2 Emissions Calculation And Correction Parameters[1-6]

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on correction parameters that characterize the condition of a particular road and the associated vehicle traffic.

Dust emissions from unpaved roads have been found to vary directly with the fraction of silt (particles smaller than 75 micrometers [μm] in diameter) in the road surface materials.[1] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen, using the ASTM-C-136 method. Table 13.2.2-1 summarizes measured silt values for industrial and public unpaved roads.

Since the silt content of a rural dirt road will vary with geographic location, it should be measured for use in projecting emissions. As a conservative approximation, the silt content of the parent soil in the area can be used. Tests, however, show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

DRAFT

Draft Table 13.2.2-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road Use Or Surface Material	Plant Sites	No. Of Samples	Silt Content (%)	
				Range	Mean
Copper smelting	Plant road	1	3	16 - 19	17
Iron and steel production	Plant road	19	135	0.2 - 19	6.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
	Yard area	1	1	-	7.1
Stone quarrying and processing	Plant road	2	10	2.4 - 16	10
	Haul road	4	20	5.0-15	8.3
Taconite mining and processing	Service road	1	8	2.4 - 7.1	4.3
	Haul road	1	12	3.9 - 9.7	5.8
Western surface coal mining	Haul road	3	21	2.8 - 18	8.4
	Access road	2	2	4.9 - 5.3	5.1
	Scraper route	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Construction sites	Scraper routes	7	20	0.56-23	8.5
Lumber sawmills	Log yards	2	2	4.8-12	8.4
Municipal solid waste landfills	Disposal routes	4	20	2.2 - 21	6.4
Publicly accessible roads	Gravel/crushed limestone	9	46	0.1-15	6.4
	Dirt	8	24	0.83-68	11

[a]References 1,5-16.

DRAFT

The following empirical expression may be used to estimate the quantity in pounds (lb) of size-specific particulate emissions from an unpaved road, per vehicle mile traveled (VMT):

$$e = k\,(s/12)^a\,(W/3)^b\,M^c \qquad (1)$$

where k, a, b and c are empirical constants (Reference 6) given below and

- e = size-specific emission factor (lb/VMT)
- s = surface material silt content (%)
- W = mean vehicle weight (tons)
- M = surface material moisture content (%)

The metric conversion from lb/VMT to grams (g) per vehicle kilometer traveled (VMT) is as follows:

1 lb/VMT = 281.9 g/VKT

The constants for Equation 1 based on the stated aerodynamic particle size are as follows:

Constant	PM-2.5	PM-10	PM-15	PM-30
k (lb/VMT)	0.24	1.6	2.4	5.3
a	0.8	0.8	0.8	0.8
b	0.4	0.4	0.4	0.5
c	-0.3	-0.3	-0.3	-0.4
Quality rating	B	A	B	A

The above table also contains the quality ratings for the various *size-specific versions of Equation* 1. The equation retains the assigned quality rating, if applied within the following ranges of source conditions that were tested in developing the equation:

Range of Source Conditions for Equation 1						
Road Silt Content, %	Mean, Mg	Mean Vehicle Weight, ton	Mean, km/hr	Mean Vehicle Speed, mph	Mean No. of Wheels	Road Moisture Content, %
1.2-35	1.4-260	1.5-290	8-88	5-55[a]	4-7[a]	0.03-20

[a] See discussion in text.

Although mean vehicle speed and the mean number of wheels do not explicitly appear in the predictive equation, these variables should be considered when determining quality ratings. During the validation of Equation 1, it was found that the predictive equation tends to overpredict emissions for very low mean vehicle speeds. The equation does not exhibit this bias for mean vehicle speeds of at least 15 mph. The equation's predictive behavior should be remembered if the emission factor is used for an instance with mean vehicle speed less than 15 mph. Although the mean number of wheels was not found to exhibit a systematic bias, the reader is similarly advised of the equation's accuracy outside the range of mean number of wheels given above.

Equation 1 was developed by the stepwise regression of the results from field measurements of PM-10 emissions and TSP emissions (or its surrogate - PM-30 emissions) from vehicles traveling over unpaved surfaces. Both uncontrolled and watered roads were included in the data base of 180 PM-10 and 92 TSP tests. The values given for the remaining particle size ranges were developed from mean measured PM-2.5 to PM-10 ratios and PM-15 to PM-10 ratios.

It is important to note that Equation 1 calls for the average speed, weight, and number of wheels of all vehicles traveling the road. For example, if 98 percent of traffic on the road are 2-ton cars and trucks while the remaining 2 percent consists of 20-ton trucks, then the mean weight is 2.36 tons. More specifically, Equation 1 is *not* intended to be used to calculate a separate emission factor for each vehicle class. Instead, only one emission factor should be calculated that represents the "fleet" average of all vehicles traveling the road.

Moreover, to retain the quality rating of the equation when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt content are given in AP-42 Appendices C.1 and C.2. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 13.2.2-1 may be used, but the quality rating of the equation is reduced by 1 letter.

As noted earlier, Equation 1 was developed from tests of traffic on unpaved surfaces, either uncontrolled or watered. Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall or watering. The quality ratings given above pertain to uncontrolled (dry) conditions. To estimate annual or seasonal conditions, one should determine an appropriate value for the average surface moisture content, taking into account natural precipitation and any anthropogenic watering. Recognizing that this may not always be practical, Equation 1 can be extrapolated to annual or seasonal conditions under the simplifying assumption that emissions occur at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable (more than 0.254 mm [0.01 inch]) precipitation. In other words, when the simplifying assumption is made, the emission factor for uncontrolled (dry) conditions should be multiplied by the ratio

$$\frac{(365 - p)}{365}$$

where p = number of days with at least 0.254 mm (0.01 inch) of precipitation per year. Figure 13.2.2-1 gives the geographical distribution for the mean annual number of "wet" days for the United States.

Clearly, the effect of water/natural mitigation depend on not only how much precipitation falls, but also on factors affecting the evaporation rate, such as ambient air temperature, wind speed, humidity, and traffic rates. When the simplifying assumption is applied to annual/seasonal estimates, the quality rating should be downgraded by 1 letter.

For calculating annual average emissions, the equation is to be multiplied by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted for the equation. Worst-case emissions, corresponding to dry road conditions, may be calculated by setting p = 0. A separate set of correction parameters and a higher than normal VDT value may also be justified for the worst-case average period (usually 24 hours). Similarly, in using the equation to calculate emissions for a 91-day season of the year, replace the term (365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91-day period. Use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

13.2.2.3 Controls[17-21]

Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working stabilization chemicals into the roadbed, watering, and traffic control regulations. The effect that moisture addition has on emissions can be evaluated by use of Equation 1 if the cycle of moisture content is known. Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, is often not economically practical. Surface chemical treatment and watering can be accomplished at moderate to low costs, but frequent treatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions, but may be difficult to enforce.

The equation for estimating the control level that may be achievable by periodic watering should be placed in this part of the section. Both of the control efficiencies should be framed at only prospective analysis and not for use in determining the emissions from an existing road way. Also, a paragraph should be spent identifying the relevant physical characteristics at work.

Since it appears that we have included some of the roads controlled by chemical stabilizers in the data base for EF development can't we indicate that the measurement of silt and moisture is a viable method to estimate control efficiency

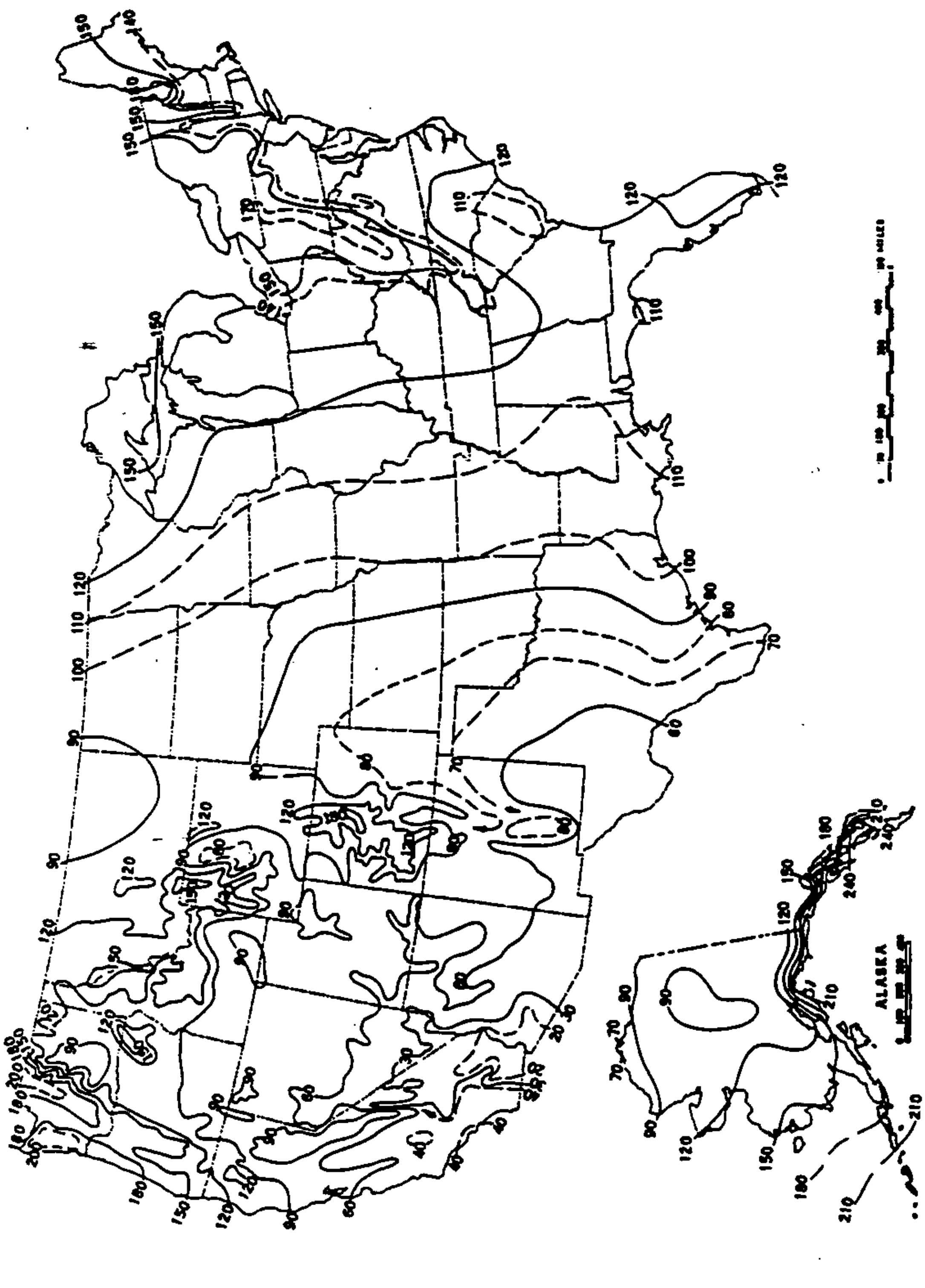

Figure 13.2.2-1. Mean number of days with 0.01 inch or more of precipitation in United States.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 13.2.4, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating the control efficiency of paving.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters that determine control efficiency include dilution ratio, application intensity, mass of diluted chemical per road area, and application frequency. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (e. g., traffic volume, average weight) and road characteristics (e. g., bearing strength).

Besides water, petroleum resin products historically have been the dust suppressants most widely used on industrial unpaved roads. Figure 13.2.2-2 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads.[19] Several items should be noted:

1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (*not solution*) applied since the start of the dust control season.

2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 13.2.2-2 presents control efficiency values averaged over 2 common application intervals, 2 weeks and 1 month. Other application intervals will require interpolation.

3. Note that zero efficiency is assigned until the ground inventory reaches 0.05 gallon per square yard (gal/yd^2).

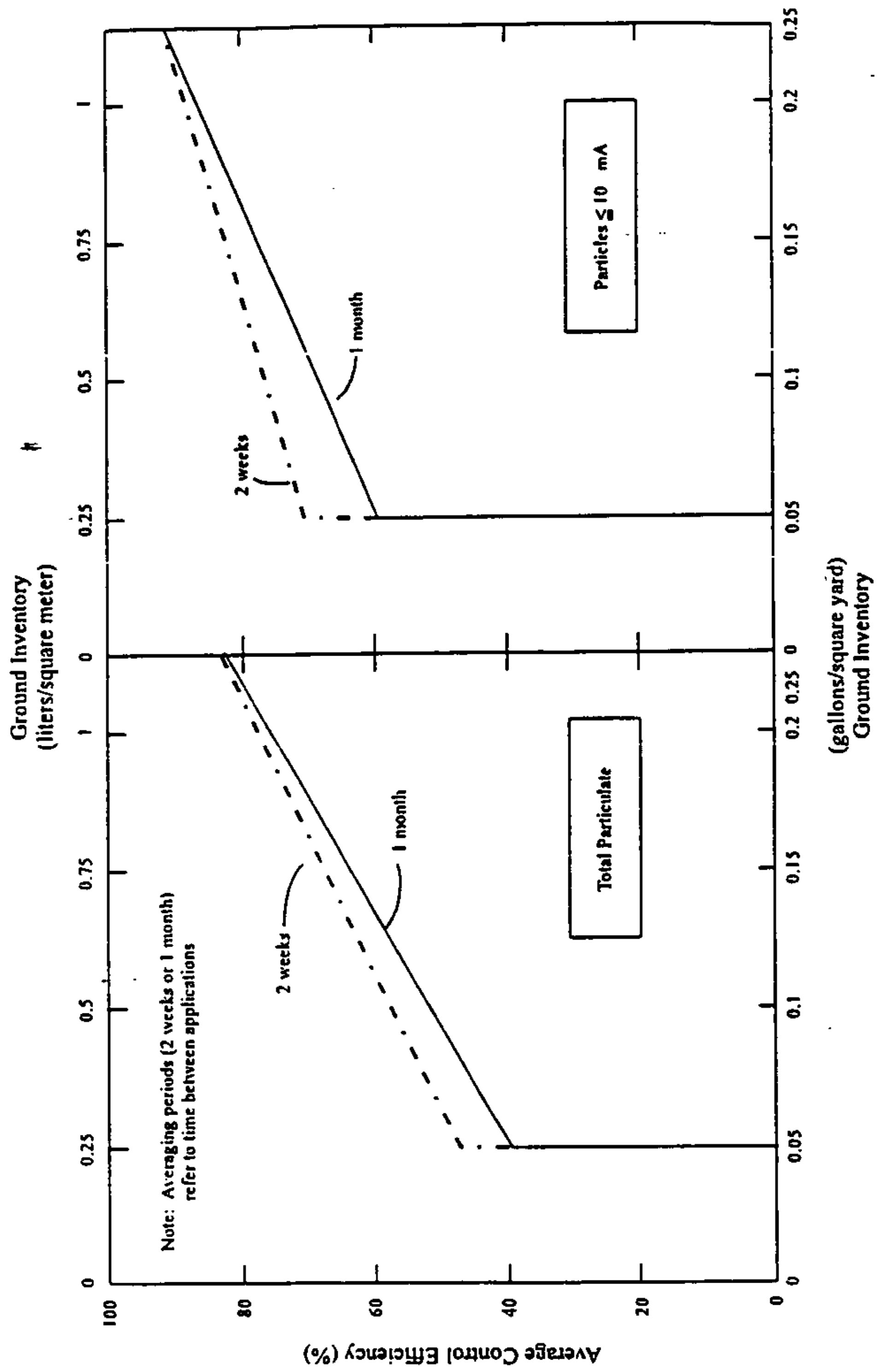

Figure 13.2.2-2. Average control efficiencies over common application intervals.

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As an example of the application of Figure 13.2.2-2, suppose that the equation was used to estimate an emission factor of 7.1 lb/VMT for PM-10 from a particular road. Also, suppose that, starting on May 1, the road is treated with 0.221 gal/yd^2 of a solution (1 part petroleum resin to 5 parts water) on the first of each month through September. Then, the following average controlled emission factors are found:

Period	Ground Inventory, gal/yd^2	Average Control Efficiency, %[a]	Average Controlled Emission Factor, lb/VMT
May	0.037	0	7.1
June	0.073	62	2.7
July	0.11	68	2.3
August	0.15	74	1.8
September	0.18	80	1.4

[a]From Figure 13.2.2-2, ≤10 μm. Zero efficiency assigned if ground inventory is less than 0.05 gal/yd^2.
1 lb/VMT = 281.9 g/VMT. 1 gal/yd^2 = 4.531 L/m^2.

Newer dust suppressants are successful in controlling emissions from unpaved roads. Specific test results for those chemicals, as well as for petroleum resins and watering, are provided in References 17 through 20.

References For Section 13.2.2

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19. C. Cowherd, Jr., and J. S. Kinsey, *Identification, Assessment And Control Of Fugitive Particulate Emissions*, EPA-600/8-86-023, U. S. Environmental Protection Agency, Cincinnati, OH, August 1986.

20. G. E. Muleski and C. Cowherd, Jr., *Evaluation Of The Effectiveness Of Chemical Dust Suppressants On Unpaved Roads*, EPA-600/2-87-102, U. S. Environmental Protection Agency, Cincinnati, OH, November 1986.

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Minnesota Pollution Control Agency

October 29,1997

Mr. Ronald E. Myers
U.S. Environmental Protection Agency (MD-14)
Research Triangle Park, North Carolina 27711

RE: Comments on Draft AP-42 Section 13.2.2, Unpaved Roads, and the Associated Draft Report

Dear Mr. Myers:

The Minnesota Pollution Control Agency (MPCA), Air Quality Division would like to comment on the draft AP-42 Section 13.2.2, Unpaved Roads, and Emission Factor Documentation for AP-42 Section 13.2.2 (Draft Report).

We appreciate the efforts of the U.S. Environmental Protection Agency (EPA) on revising fugitive emission factors from unpaved roads. We realize the importance of these emission factors to our air quality programs in Minnesota. Table 1 summarizes the findings of the MPCA staff in a thorough review on statistical analysis of the emission data provided by the EPA.

Table 1. Empirical Constants from Statistical Analysis of Uncontrolled Particulate Emission Factors[1]

	PM2.5		PM10		PM15		PM30	
Constant[2]	Draft AP42	MPCA[3]	Draft AP42	MPCA	Draft AP42	MPCA	Draft AP42	MPCA
k, lb/VMT	0.24	3.57	1.6	1.72	2.4	3.41	5.3	6.08
a	0.8	0.67	0.8	0.77	0.8	0.72	0.8	0.97
b	0.4	0.24	0.4	0.43	0.4	0.29	0.5	0.52
c	-0.3	-0.55	-0.3	-0.24	-0.3	-0.06	-0.4	-0.45
Cases, n	?	77	180	141	?	77	92	65
R-squared	?	0.125	0.345	0.384	?	0.255	?	0.512
Adj. R-sq	?	0.089	?	0.371	?	0.224	?	0.488
Q. Rating[4]	B	?	A	?	B	?	A	?
Regression	?	Forced	Stepwise	Stepwise	?	Forced	Stepwise	Stepwise

Notes: 1. Unpaved.dat (July 31,1997) posted on TTN web site was used by the MPCA staff for statistical analysis. Accordin to Greg Muleski of Midwest Research Institute, some tests results were missing from this posted file. However, our comments do not rely significantly on the completeness of the test results in this data file.

2. Constants k, a, b, and c are obtained from fitting the emission data (item 1 above) with the following equation:

$$E = k\,(s/12)^a\,(W/3)^b\,(M/1)^c$$

where E is the size-specific emission factor in lb/VMT; s is the road surface material silt content in percent; W is the mean vehicle weight in tons; and M is the road surface material moisture content in percent.

3. SPSS for MS Windows Release 6.1 was used in the MPCA's statistical analysis. Draft AP-42 data resulted from statistical analysis completed with SYSTAT Version 4. Little difference in the results is expected due to software.

4. Section 3.3 of the Draft Report provides the basis for the letter rating, which is not related to the goodness of fit that may be judged with statistics such as R-squared, adjusted R-squared, and so on.

The fitting constants' quality ratings, the potential dual role of road surface material moisture content, the annual adjustment for precipitation, and the disappearance of vehicle speed are the major concerns to the MPCA. We believe, however, that the PM_{10} emission factor equation (lb/VMT) with the fitting constants is acceptable from the statistical analysis standpoint.

Quality Rating Scheme

Emission Factor Documentation for AP-42 Section 13.2.2 (Draft Report) describes in section 3.3 emission data and emission factor quality rating scheme used for unpaved roads source category. It states, "(t)he uncontrolled emission factor quality rating scheme used for this source category represents a refinement of the rating system developed by EPA for AP-42 emission factor. The scheme entails the rating of test data quality followed by the rating of the emission factor(s) developed from the test data...."

The quality control and quality assurance efforts in the development of emission factors for this source category are important. However, we believe that the final quality rating, as seen in Table 1 for PM_{10}, should also be more related to the goodness of fit of the regression model. In plain words, we think the ratings of A and B in Table 1 should be lower, e.g., C and D.

To further explain our concern with factor ratings, let's look at another rating and the assumptions we make about it. An emission factor rating of A is given to the SO_2 emission factor for No. 6 oil fired, normal firing utility boilers in the current AP-42 Table 1.3-1. People in the regulatory and regulated communities are very confident in using such an emission factor. Now, when an emission factor rating of A is given to the uncontrolled PM_{10} emission fitting constants, it has some profound implications. First, it implies that the predicted uncontrolled PM_{10} emission for unpaved roads from the regression model is the best (true), however it also implies it is directly comparable to that of the SO_2 emission factor for No. 6 oil fired, normal firing utility boilers in the current AP-42 Table 1.3-1 (not true). People using these factors, who tend to take a number out of a table without carefully reading the context, will assume these factors are of equally high quality. Second, when people realize that less than 40 percent of the total variance in the emission data is explained by the regression model (see PM_{10} column in Table 1) and rating A still is given to the regression model, they are going to seriously doubt the reliability of all the emission factors from AP-42 -- stack emissions and fugitive emissions.

We believe that people can be satisfied with the notion that, because of inherent variability, fugitive emission factors can never achieve the same level of quality rating. Therefore, we would urge you to lower the factor ratings associated with the proposed AP-42 for unpaved roads.

Road Surface Material Moisture Content

The efficiency of water application to control particulate emissions is not analyzed statistically in this study, although equation (3) is presented in the Draft AP-42 for estimating control efficiency for water applications. Input parameters for this equation include water application parameters and pan evaporation rate, all of which to a great extent determine road surface material moisture content.

There is a potential for double-counting the road surface material moisture content and watering control efficiency. If road surface material moisture content resulted from a control technology application, the road surface material moisture content before the application should be used to establish the regression equation with fitting constants shown in Table 1. We would like confirmation from the EPA that this was done correctly.

The inclusion of road surface material moisture content makes sense in reflecting the reality, if data collection to establish the equation in Table 1 was done correctly. However, users of the equation still may double count the moisture contribution by using post-application moisture value in the equation to predict uncontrolled emissions and adding control efficiency due to water application to get the "controlled" fugitive emissions. Of course, we realize that each regulatory agency just needs to guard against dual use of moisture.

Table 2 presents moisture content data associated with PM_{10} emissions, uncontrolled, watered, and the combined data set. There is a significant overlap between the uncontrolled data and the watered data, suggesting the difficulty in preventing dual usage of moisture from happening.

Table 2. Road Surface Material Moisture Content for PM10 Emission Data

Description	Uncontrolled	Watered	Combined Data Set
Number of valid observations	145	37	182
Missing observations	27	4	31
Mean	1.611	4.751	2.249
Standard deviation	2.049	4.099	2.879
Skewness	1.786	2.170	2.621
Range	8.5	19.8	20.1
Minimum	0	0.3	0
Maximum	8.5	20.1	20.1

Annual Adjustment for Precipitation

Section 2.4 of the Draft Report (page 2-4) indicates the control efficiency of watering depends upon (a) the application rate of the water, (b) the time between applications, (c) traffic volume during the period, and (d) the meteorological conditions during the period. This suggests the annual simplifying assumption of (365-p)/365, which reflects only first term, is an over simplification on the effects of natural precipitation, which is equation (2) in the draft AP-42 Section 13.2.2.

In our experience with mining operations, 0.01 inches of precipitation in a 24-hour period cannot achieve 100 percent control of particulate emissions from unpaved roads. A multi-tier approach would be better such as minimal control for 0.01 inches, moderate control for 0.10 inches, near-maximum control for 0.50 inches, and maximum control for 1.00 inches or more. This could be done by developing four maps similar to Figure 13.2.2-1 using current monthly climatological data such as that in the enclosed Climatological Data, Minnesota, February 1997.

Vehicle Speed

Section 4.3 of the Draft Report (page 4-27) states, "it is obvious to any one who has driven on an unpaved road that vehicle speed affects emissions, with faster vehicles generating more dust than slower ones. For this reason, it was decided to incorporate the findings of the captive traffic studies into the AP-42, independent of the emission factor equation." Unfortunately, the corresponding section of the draft AP-42 Section 13.2.2 (page 13.2.2-8) is unclear on how this should be calculated.

The MPCA staff did confirm the apparent difficulty with vehicle speed in our statistical analysis of the data file, unpaved.dat (July 31, 1997). We are unable at this point of time to propose any better way of dealing with this variable in a statistically acceptable manner. As for the emission factor adjustment for vehicle speed reduction in the draft AP-42 Section 13.2.2, we strongly suggest that some examples be provided to clarify how this adjustment should be calculated for regulatory purposes. The text on page 13.2.2-8 alludes to a 30 percent reduction in emissions for a vehicle speed reduction from 50 mph to 35 mph; however, it is unclear why 50 mph is the appropriate reference vehicle speed when (1) the proposed emission factor equation lacks any reference vehicle speed, and (2) the SYSTAT regressions indicate vehicle speed adds little to the R^2-values.

In closing this letter, the MPCA would like to be informed of future changes to the draft AP-42 Section 13.2.2. We also are willing to assist the EPA in any additional statistical analysis, if needed. Please contact Hongming Jiang, of my staff, for the detail of our review.

Sincerely,

Michael J. Sandusky
Acting Division Manager
Air Quality Division

MJS:yma

Enclosure

cc: Todd Biewen, Air Quality Division
Dennis Becker, Air Quality Division
Paul Kim, Air Quality Division
Hongming Jiang, Air Quality Division

CLIMATOLOGICAL DATA

MINNESOTA

FEBRUARY 1997

VOLUME 103 NUMBER 02

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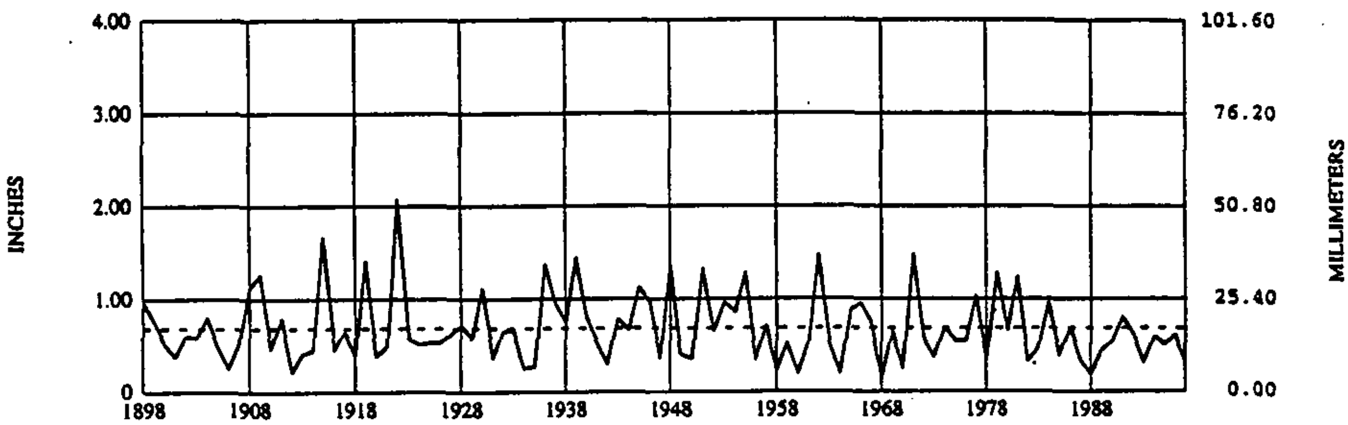

- - - - - - - - - - - Long–Term Average 0.68 inches

MINNESOTA PRECIPITATION FEBRUARY, 1898–1997

TEMPERATURE AND PRECIPITATION EXTREMES

HIGHEST TEMPERATURE	55	FEBRUARY 19	RUSHFORD
LOWEST TEMPERATURE	-42	FEBRUARY 16	EMBARRASS
GREATEST TOTAL PRECIPITATION	1.33M		LUVERNE
LEAST TOTAL PRECIPITATION	.00		3 STATIONS
GREATEST 1 DAY PRECIPITATION	.98	FEBRUARY 4	LUVERNE
GREATEST TOTAL SNOWFALL	16.5		2 STATIONS
GREATEST DEPTH OF SNOW OR ICE	64	FEBRUARY 8	FERGUS FALLS

"I certify that this is an official publication of the National Oceanic and Atmospheric Administration (NOAA). It is compiled using information from weather observing sites supervised by NOAA/National Weather Service and received at the National Climatic Data Center (NCDC), Asheville, North Carolina 28801."

ACTING DIRECTOR
NATIONAL CLIMATIC DATA CENTER

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National
Oceanic and
Atmospheric Administration

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Environmental Satellite, Data
and Information Service

National
Climatic Data Center
Asheville, North Carolina

MINNESOTA
FEBRUARY 1997

MONTHLY STATION AND DIVISION SUMMARY

STATION	TEMPERATURE (°F) AVERAGE MAXIMUM	AVERAGE MINIMUM	AVERAGE	DEPARTURE FROM NORMAL	HIGHEST	DATE	LOWEST	DATE	HEATING DEGREE DAYS	COOLING DEGREE DAYS	NO. OF DAYS MAX 90 OR ABOVE	MAX 32 OR BELOW	MIN 32 OR BELOW	MIN 0 OR BELOW
MINNESOTA														
NORTHWEST 01														
ADA	22.0	-2.1	10.0	-2.3	39	21	-26	12	1537	0	0	24	28	17
AGASSIZ REFUGE	19.5	-2.7	8.4	-.8	37	20	-27	24	1581	0	0	23	28	15
ARGYLE 4 E	21.2	-5.3	8.0	1.3	38	26	-29	13+	1596	0	0	25	28	19
CROOKSTON NW EXP STN	21.9	-2.6	9.7	1.8	38	21	-29	12	1544	0	0	25	28	16
DETROIT LAKES 1 NNE	M	M	M											
FOSSTON 1 E	21.1	-5.2	8.0	-.9	40	21+	-39	12	1594	0	0	25	28	14
GEORGETOWN 1 E	22.0	1.0	11.5	-1.3	38	20	-23	12	1492	0	0	24	28	14
ITASCA UNIV OF MINNESO	24.9	-2.0	11.5	2.0	44	21	-25	13	1495	0	0	22	28	15
MAHNOMEN 1 W	24.4	2.5M	13.5M	2.9	40	20	-25	12	1445	0	0	23	27	13
MOORHEAD	23.1	3.6	13.4		40	20	-18	12	1441	0	0	23	28	13
OKLEE	M	M	M											
RED LAKE FALLS	20.9	.4	10.7	.5	37	20+	-31	12	1516	0	0	25	28	12
ROSEAU 1 E	M	M	M											
TAMARAC WILDLIFE REF	24.8M	M	M		42	18	-24	13+			0	15	17	7
THIEF RIVER FALLS 2	21.5	.9	11.2		36	20	-24	12	1503	0	0	24	28	14
WARROAD	22.2	-4.6	8.8	3.3	40	21	-28	16	1566	0	0	25	28	15
--DIVISIONAL DATA------->			10.4	.9										
NORTH CENTRAL 02														
BAUDETTE	25.4	.5	13.0	4.1	42	25	-35	16	1452	0	0	22	28	12
BIG FALLS	26.6	M	M		45	25+	-31	16			0	23	18	10
CASS LAKE	23.9	-4.2	9.9	1.5	43	26	-29	16	1540	0	0	26	28	18
DEEP PORTAGE	22.8	-.8	11.0		48	21	-26	16	1507	0	0	24	28	15
GRAND RAPIDS FORESTRY	27.6	2.5	15.1	4.4	49	20	-25	16	1393	0	0	22	28	12
GULL LAKE DAM	24.2	2.4	13.3	1.2	43	21	-15	16+	1442	0	0	23	28	12
INT FALLS WSO AP //R	22.4	-2.1	10.2	2.5	39	20	-34	16	1533	0	0	25	28	16
KELLIHER	M	M	M											
LEECH LAKE DAM	25.6	-.3	12.7	-1.1	46	21	-23	16	1461	0	0	24	28	15
LITTLEFORK 10 SW	24.1	-5.3	9.4		43	21	-36	16	1552	0	0	25	28	19
MARCELL 5 NE	23.5	-3.2	10.2	3.7	43	21	-28	17+	1534	0	0	24	28	14
PARK RAPIDS 2 S	24.5	2.6	13.6	1.1	42	20	-26	12	1434	0	0	23	28	11
POKEGAMA DAM	M	M	M		45	21	-18	12			0	12	15	7
RED LAKE INDIAN AGENCY	22.4	-1.2	10.6	2.3	44	18	-25	16+	1518	0	0	24	28	13
REMER NO 2	M	M	M		47	21	-21	13			0	15	16	7
THORHULT 1 S	23.6	.6	12.1	2.9	43	17	-31	12	1476	0	0	24	28	14
WALKER AH GWAH CHING	25.1	3.6	14.4	1.1	47	20	-17	12	1415	0	0	23	28	9
WASKISH 4 NE	23.6	-5.3	9.2	-.2	44	18	-35	16	1559	0	0	25	28	17
--DIVISIONAL DATA------->			11.8	1.1										
NORTHEAST 03														
BRIMSON 1 E	26.4	-1.5	12.5		47	19	-30	16	1466	0	0	22	28	14
COTTON	27.4	-3.5	12.0	1.5	49	19	-34	16	1481	0	0	22	28	14
DULUTH HARBOR STA	25.5	4.6	15.1	-1.1	43	19	-13	13	1394	0	0	23	28	12
DULUTH WSO AP	24.5	4.5	14.5	2.2	46	18	-13	24+	1409	0	0	23	28	10
EMBARRASS	20.3	-8.0M	6.2M		40	21	-42	16	1659	0	0	25	26	17
EVELETH WASTE WATER PL	24.0	1.4	12.7		44	21+	-31	16	1456	0	0	24	28	11
FLOODWOOD 3 NE	24.9	-1.9	11.5		46	21+	-30	17+	1493	0	0	24	28	13
GRAND MARAIS	28.4	8.9	18.7	2.2	40	26+	-10	24	1294	0	0	22	28	9
GRAND PORTAGE RNG STN	26.0	1.5	13.8		43	20	-18	15	1432	0	0	24	28	18
HIBBING FAA AIRPORT	24.8	1.4	13.1	2.8	44	20	-28	16	1445	0	0	25	28	12
ISABELLA 1 W	M	M	M		44	19	-20	17			0	8	12	6
LUTSEN 3 NNE	22.4	-3.0M	9.7M		44	26	-26	17+	1549	0	0	24	27	15
TOWER DNR	M	M	M		45	21	-24	24+			0	13	14	10
TOWER 3 S	26.6	-5.8	10.4	2.6	47	21	-41	16	1525	0	0	24	28	17
TWO HARBORS	28.8	10.2	19.5	2.6	47	19	-13	13	1266	0	0	20	28	7
WOLF RIDGE E L C	24.8	1.5	13.2		49	26	-20	25+	1447	0	0	25	28	10
--DIVISIONAL DATA------->			13.1	1.3										
WEST CENTRAL 04														
ALEXANDRIA FAA AIRPORT	M	M	M											
ARTICHOKE LAKE	24.9	6.0M	15.5M	.1	42	20	-17	12	1389	0	0	21	27	10
BENSON	25.9	8.4	17.2	.8	41	20+	-14	12	1334	0	0	22	28	9
BROWNS VALLEY	27.4	5.8	16.6		43	21	-23	12	1350	0	0	21	28	9
CANBY	29.4	11.1	20.3	3.1	47	19	-9	12	1245	0	0	18	27	7
FERGUS FALLS	23.1	5.4	14.3	2.7	38	21+	-16	13+	1418	0	0	22	28	11
GLENWOOD 2 WNW	27.6	10.3	19.0	4.1	42	17	-18	12	1283	0	0	20	28	8
MADISON SEWAGE PLANT	29.9	11.6	20.8	2.6	43	17	-12	12	1233	0	0	16	27	7
MILAN 1 NW	28.0	6.9	17.5	1.5	43	20+	-18	12	1325	0	0	19	28	11
MONTEVIDEO 1 SW	25.4	8.0	16.7	-.8	42	18	-14	12	1347	0	0	22	28	9
MORRIS WC EXP STN //	24.0	4.3	14.2	1.3	38	21	-15	13	1414	0	0	21	28	12
ORWELL DAM	M	M	M		39	3	-26	12			0	13	17	7

MINNESOTA
FEBRUARY 1997

MONTHLY STATION AND DIVISION SUMMARY

STATION	PRECIPITATION (IN) TOTAL	DEPARTURE FROM NORMAL	GREATEST DAY	DATE	SLEET, SNOW TOTAL	MAX. DEPTH ON GROUND	DATE	NO. OF DAYS .10 OR MORE	.50 OR MORE	1.00 OR MORE
MINNESOTA										
NORTHWEST 01										
ADA	.36	-.19	.15	15	7.4	29	12	2	0	0
AGASSIZ REFUGE	.19	-.20	.08	4	3.4	24	17+	0	0	0
ARGYLE 4 E	.19	-.37	.12	16	5.9	31	16	1	0	0
CROOKSTON NW EXP STN	M .14		.07	4	M 4.1	36	1	0	0	0
DETROIT LAKES 1 NNE					M	M				
FOSSTON 1 E	M .08		.08	11	5.5	32	17+	0	0	0
GEORGETOWN 1 E	.62	.23	.20	12	5.8	51	5	3	0	0
ITASCA UNIV OF MINNESO	.21	-.39	.12	16	5.0	29	16	1	0	0
MAHNOMEN 1 W	.67	.08	.17	28	10.0	44	20+	2	0	0
MOORHEAD	.59		.17	28	8.0	22	15+	3	0	0
OKLEE					M	M				
RED LAKE FALLS	.42	-.02	.14	15	8.3	33	2+	2	0	0
ROSEAU 1 E					M	M				
TAMARAC WILDLIFE REF	.07		.05	4	1.0	M		0	0	0
THIEF RIVER FALLS 2	M .00		.00	28+	6.5	51	18+	0	0	0
WARROAD	.10	-.39	.10	16	M 1.0	26	2	1	0	0
--DIVISIONAL DATA------->	.34	-.14			6.1					
NORTH CENTRAL 02										
BAUDETTE	.03	-.32	.02	15	M 3.0	26	1	0	0	0
BIG FALLS	.21	-.39	.09	15	M 3.8	M		0	0	0
CASS LAKE	M .18				M 3.0	M		0	0	0
DEEP PORTAGE	M .00		.00	28+	7.0	28	17+	0	0	0
GRAND RAPIDS FORESTRY	.47	-.07	.32	28	7.0	31	1	1	0	0
GULL LAKE DAM	.05	-.54	.02	16+	1.7	27	2+	0	0	0
INT FALLS WSO AP //R	.19	-.44	.06	15+	5.4	22	2	0	0	0
KELLIHER	.17	-.35	.08	19	4.0	22	19+	0	0	0
LEECH LAKE DAM	.17	-.26	.12	16	2.6	26	18+	1	0	0
LITTLEFORK 10 SW	.16		.05	16	4.0	22	3+	0	0	0
MARCELL 5 NE	.18	-.35	.09	16	4.1	29	1	0	0	0
PARK RAPIDS 2 S	.21	-.29	.13	15	4.7	35	16+	1	0	0
POKEGAMA DAM	.12	-.42	.06	16	M 2.5	24	1	0	0	0
RED LAKE INDIAN AGENCY	M .34		.25	1	M 3.7	17	14+	1	0	0
REMER NO 2	.14	-.39			M 2.5	25	12+	0	0	0
THORHULT 1 S	M .00		.00	28+	3.0	38	16+	0	0	0
WALKER AH GWAH CHING	M .49		.30	28	M 4.1	29	16+	2	0	0
WASKISH 4 NE	M .11		.06	17	3.5	23	11	0	0	0
--DIVISIONAL DATA------->	.18	-.34			4.3					
NORTHEAST 03										
BRIMSON 1 E	.16	-.54	.05	16+	3.1	36	12+	0	0	0
COTTON			.09	16	M 2.5	26	17+	0	0	0
DULUTH HARBOR STA					M	M				
DULUTH WSO AP	.23	-.57	.18	28	8.9	31	1	1	0	0
EMBARRASS	.25		.08	11	5.5	26	1	0	0	0
EVELETH WASTE WATER PL	.13		.05	11	M .0	57	6+	0	0	0
FLOODWOOD 3 NE	.15		.10	16	2.5	28	1	1	0	0
GRAND MARAIS	.20	-.45	.07	19+	M 5.0	40	2	0	0	0
GRAND PORTAGE RNG STN	.24		.24	17	2.0	23	17	1	0	0
HIBBING FAA AIRPORT	.54	.05	.37	28	8.0	40	1	1	0	0
ISABELLA 1 W	M .72				M 9.0	32	11	0	0	0
LUTSEN 3 NNE	.18		.11	11	2.8	36	1	1	0	0
TOWER DNR	M .26		.12	11	M 5.5	26	12	1	0	0
TOWER 3 S	.11	-.67	.06	11	5.0	35	5+	0	0	0
TWO HARBORS	.24	-.38	.08	10	5.6	M		0	0	0
WOLF RIDGE E L C	.20		.05	16+	4.9	40	17	0	0	0
--DIVISIONAL DATA------->	.22	-.44			4.8					
WEST CENTRAL 04										
ALEXANDRIA FAA AIRPORT					M	M				
ARTICHOKE LAKE	.53	-.13	.19	4	9.8	27	5+	2	0	0
BENSON	.06	-.79	.06	23	1.5	16	1	0	0	0
BROWNS VALLEY	.63		.54	4	6.5	M		1	1	0
CANBY	.53	-.30	.41	4	5.9	21	13+	1	0	0
FERGUS FALLS	.80	.26	.60	4	M 4.0	64	8+	2	1	0
GLENWOOD 2 WNW	M .18		.10	28	3.5	30	1	1	0	0
MADISON SEWAGE PLANT	.69	.02	.56	3	12.6	M		1	1	0
MILAN 1 NW	M .53		.16	22	M10.5	38	16+	3	0	0
MONTEVIDEO 1 SW	M .20		.15	23	5.0	28	1	1	0	0
MORRIS WC EXP STN //	.31	-.39	.17	4	5.1	30	16+	1	0	0
ORWELL DAM	.28		.18	4	M 5.0	M		1	0	0

IDAHO DEPARTMENT
OF HEALTH AND WELFARE
DIVISION OF
ENVIRONMENTAL QUALITY

1410 North Hilton, Boise, ID 83706-1255, (208) 373-0502

Philip E. Batt, Governor

December 31, 1997

MEMORANDUM

TO: U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Factor and Inventory Group
Research Triangle Park, NC 27711
Attention: Mr. Ron Myers (MD-14)
E-mail: myers.ron@epamail.epa.gov
FAX: (919) 541-0684

FROM: Val Bohdan
Idaho Division of Environmental Quality
Technical Services Bureau
1410 N. Hilton
Boise, Idaho 83706
FAX: (208) 373-0417

SUBJECT: Comments on AP-42 Draft, Section 13.2.2 (Unpaved Roads)

Summary

The Idaho Division of Environmental Quality (DEQ) appreciates the opportunity to provide comment on changes to Section 13.2.2 (Unpaved Roads). We respectfully request these comments be incorporated in the document.

General Comments:

1) We would like to compliment EPA for the undertaking to update the unpaved road emission-factor section of AP-42. This section is particularly useful for Idaho's many rural and farming area roads.

2) It is very commendable that EPA is proposing in the draf factor formulas but also to simplify them. Both of these r enlisting better partnerships and cooperation among indu environmental groups to improve the environmental conc

3) The backup studies cited in this draft appear to have no r cement/concrete industry-- a significant number of which contrast, much data backup originated as studies of the c existing in Idaho. This raises the question of eventual ap emissions formulas in terms of country regional fit.

4) The issue of control efficiency factoring which can be aff reduction is very confusing and needs to be resolved mor reduction, especially on the lower range, needs to be inco emissions reduction.

5) We would like to suggest the use of clear statements in tl 13.2.2. Instead of "should be, " the direction needs to be give some assurance to the eventual user of this section.

6) Notwithstanding the derivation process for the formulas, should be mathematically simplified for the eventual user can intimidate those not acquainted with higher math and by placing the exponent as a positive number in the deno numerical constants should be carried out as far as possib ease for the user.

7) Concerning the default moisture content value of 0.5%: I which is considered "high desert" area, the 0.5% default glean this value from the 1996-1997 "Pocatello Road Dust which was performed, however, on an unpaved MgCl treate of this study indicated the moisture content value of 0.6%.

<u>**Specific Comments:**</u>

Comments pertaining to the Section 13.2.2 Draft

(a) Page 13.2.2-3; The first equation should be simplified to b

$$E = (k/7.03)\,(s)^{0.8}\,(W/3)^{b}\,(1/M^{c})$$

Notice that "a" factor has been replaced by 0.8. This is proper si for all the particulate sizes considered in the equation. Also notic is <u>positive.</u> Thus, Table 13.2.2-2 supporting Equation 1 needs a "a" (since the constant remains the same for all particulate sizes) for "c" factor to a plus sign (or better yet, <u>no sign in front of it a</u>

(b) Page 13.2.2-4; At the bottom of this page, the formula should be changed to read S/15 not (15-S/15) if you intend the factor to drop linearly from 15 to zero vehicular speed "S". It needs to be stated more clearly that the emissions factor remains constant at speeds above 15 mph.

In Table 13.2.2-3, (Range of Source Conditions for Equation 1) on this page, we recommend that column headings also contain the appropriate letter symbols (s, W, S, and M-- in that order) from Equation 1. This will aid all users, especially the infrequent users.

(c) Page 13.2.2-5; The equation on this page should also be simplified to become

$$E = (k/7.03)\,(s)^{0.8}\,(W/3)^{b}\,(1/M_{dry}{}^{c})\,[(365-p)/365] \qquad (2)$$

The issues identified in Paragraph "a" (just above) also apply to this equation. Moreover, your use of the term M/1 appears overly simplistic and should be shortened to just M.

Page 13.2.2-6; Insert the word "directly" at the sign of * in the third sentence from the bottom, which reads: "Although vehicle speed does not appear * as a parameter, it is obvious..."

(d) Page 13.2.2-8; The second paragraph (control efficiency afforded by speed reduction) is very confusing and should be either clarified or deleted. The use of a power factor for vehicular speed "S" is very misleading and counters earlier statements. However, the power factor $S^{3/2}$ may best represent the emissions factor relationship for speeds below 15 MPH. If that is the case, then it should be so stated. A simple graph may be the best way to explain and clarify this point.

The above comments represent a summary response by DEQ about the proposed changes to Section 13.2.2 (Unpaved Roads). We appreciate the opportunity to comment. As always, the public review process will result in improved guidance documents. We thank EPA for its efforts regarding this important issue and look forward to continuing to work with you on the revision of this guidance document.

DEQ is pleased to offer comments on the Emission Factor Documentation for AP-42, Section 13.2.2 (the front portion which details the documentation and reasoning for the proposed changes; pages 1-1 to 4-90) to EPA in the **Attachment** which follows these pages. We hope you accept this detailed constructive criticism as a reasoned contribution toward the creation of an improved eventual document.

Sincerely,

Val A. Bohdan, PE
Senior Engineer
Technical Services Bureau

VB/ibb (g:\ahw\rsiegel\data\wp61\val.2)

Attachment
cc: Matt Stoll
Robert Wilcosz
COF

ATTACHMENT

Attachment to Review and Comments on the Draft AP-42 Section 13.2.2, Unpaved Roads from the Idaho Division of Environmental Quality (IDEQ)

The following are the comments/suggestions compiled by the Technical Services Bureau, Air and Hazardous Waste Section, Idaho DEQ, in response to the invitation to comment on the Draft AP-42 Section 13.2.2. The cover letter addresses the AP-42 draft section whereas the following comments are more broad-based and address the background document and the overall methodology for the study.

General comments:

In making such sweeping changes to a set of equations which govern the emission estimation process from a major source category for the next decade(s), more testing and studies are warranted. The much touted ease of use is achieved by sacrificing the fine dependencies afforded by specific governing parameters, such as number of wheels and speed. The moisture term is a definite improvement but can be already enhanced in its application and by reference from other studies already performed. It is strongly recommended that this equation be implemented in a test-mode for one or two years before finalizing it. This would allow more time to analyze and study the effects of these proposed changes.

1) What were the basic guidelines used to select studies used in the background document? The IDEQ is aware of two other studies, performed in Idaho with guidance from the Midwest Research Institute (MRI) that meets established screening criteria, which could have been used as background information for developing this emission factor. As those studies were conducted in Idaho, they would have provided some regional representation, a more extensive database, and made the factors more robust and applicable to regions like Idaho.

2) The studies chosen have no representation from the cement/concrete industry. Are the differences accounted by the silt content adequate to characterize emission factor dependence on significant parameters? The cement/concrete industry constitutes a significant number of sources in Idaho.

3) The document seems to primarily focus on PM_{10}. Is there a similar study planned for $PM_{2.5}$ to decipher the relationships between significant parameters that contribute to fine particle emissions? This is especially relevant in light of the fact that geologically derived material and agricultural impacts contribute to regional contributions of fine particles from studies in the west. This is also an issue of focus since the promulgation of the new $PM_{2.5}$ standards in mid-1997.

4) There appears to be a preference to test unpaved roads in iron and steel industries in the east and coal industry in the west. Are these thought to be major contributors of emissions form this source category? Is there any test that was reviewed from unpaved roads in agricultural rural areas? IDEQ feels that such information is key to have in the database as most western states have agriculturally-dependant areas from which emissions have to be quantified, as accurately as possible, if any sort of control scenario is desired to be achieved.

5) The IDEQ is aware of several studies to characterize emissions from paved and unpaved roads by the Washington State University in Pullman from 1994 to 1997 using tracers (The Measurement of Roadway PM_{10} Emission Rates using Tracer Techniques, Washington State Department of Transportation, Technical Report # WAR 397.1). This study had important findings related to road emissions compared to relative humidity. There seems to be no mention of the same.

6) The Columbia Plateau PM_{10} study reports a number of wind erosion studies, and techniques to address them. Specifically, the soil erosion factor, and the surface roughness factor, are mentioned as key parameters for wind erosion. Would this also not be a major factor in emissions from unpaved roads? (See related comment beginning of next section).

7) As there seem to be key omissions in the literature search conducted, to compile the database for the study, IDEQ is skeptical as to the comprehensiveness and soundness of the proposed equation to adequately provide an accurate emission factor for every region in the country.

8) IDEQ is also concerned that the use of this forum to review and provide comment is instituted at a stage later than at which key directional changes to the study can be implemented. What procedures are followed at each phase of the study to ensure participation and encourage input from state and local agencies, to make the study more robust and applicable to all regions? This process would also foster confidence in the final product.

Specific comments:

<u>Chapter 2, Background Document:</u>

- Is it not intuitive that over time, over a given surface area, that the suspendable particulate loading would decrease (by advection, carry-out, etc.), provided new material is not significantly added to the road surface (relates to erosion factors)? Is there, then, any decay factor, or parameter (added or planned) to be added to the equation as a correction for this effect? The effect of not having this correction would be an assumption that constant surface loading is available for re-suspension over an infinite amount of time resultingin gross overestimates - as compared to realistic measurements.

- How is the effect of relative humidity in the friction layer of the planetary boundary layer on characteristics of suspended particles accounted for? Although there may be no measurable precipitation on the ground surface, high relative humidity associated with high pressure events and associated inversions may result in decreased circulation events in the surface friction layer closest to the ground and cause suppression of dust, as in a fog with some precipitable water content.

Chapter 3, background document:

- In the last paragraph of page 3-7 the comments suggest, that tests from various sources have been combined to derive the new equation. This approach suggests that a large amount of testing was conducted to come up with gross average. As explained elsewhere in the document, a mathematical fit needs not always imply a reality fit. A log-normal distribution conveniently encompasses a wide range. This approach is good as screening criteria but not for further refined purposes as is applied from the AP-42 for permitting, PSD, and SIP purposes. For refined purposes, an industry-by-industry equation should be considered. Although the final equation may or may not differ much, the approach makes the study more robust and increases user confidence as the database would be broad. At the very least, a comparative study should be undertaken to establish the applicability and usefulness of industry specific equations.

Chapter 4, background document:

- It is interesting to note that tests continue to be accepted as approved even as the emission factor values spread over 2-3 orders of magnitude without further investigation as to this extensive spread. The final calculations of emissions and the discretion, as to which order of magnitude to choose, is left to the field operator or engineer in the absence of any further supporting documentation on application of such ranges of values. In a practical regulatory sense this scenario leaves emissions from certain categories in "grey areas."

- Please correct table columns on Table 4-8.

- The comment on page 4-20 that Equation 2-1 performed as well in estimating emissions as did factors for specific sources in the coal industry could also mean that the specific industry factors were somehow biased. It does not necessarily mean the general Equation 2-1 is adequate and correct. It seems a fundamentally gross over-generalization to then lump all the tests, in all studies reviewed, to come up with one large data set for the emission factor development. Is this the only specific industry factor test that provided the impetus to lump all the test data?

- It is not clear whether reference 12 was used in the final equation development as it did not have moisture content or PM_{10} factors listed. What is the exact meaning of "data was used in the expanded data analysis, they were not included in equation development"?

- If as mentioned in page 4-26 the effect of speed could not be isolated due to unavailability of speed segregated data. Such data should probably be obtained to study the effects of speed on emission factors. This leads to the conclusion that if a model does not simulate reality to some extent then, perhaps, the fundamental assumptions that went into creating the model are flawed, and are unable to be verified. It could lead to serious errors if the equation is used in this manner. The speed correction factor seems like an extreme ad hoc measure to solve this problem.

- Different size fractions may have different influences and effects, as related to the determined significant parameters, in that multiplication of PM_{10} emission factors by appropriate size fraction would only be applicable as a rule-of-thumb calculation.

- It is interesting to note that a high measure of reliability is established using equation 4-5, as established by Table 4-32 without inclusion of speed in the equation! It is also particularly worrisome that the emissions increase with decreasing speed. This table also demonstrates the effect of high humidity (misty conditions) on the suppression of emissions.

  The attached graph demonstrates the effect that speed multiplier will have on the emission factor. The emission increases linearly with decreasing speed from 15 mph to 0 mph, and also causes an anomaly of having emissions from a stationary vehicle with a 'B' rating! The text implies the need for an inverse effect. So, the multiplier has to be inversed, as mentioned in the cover letter.

- What is the rationale for using 12, 3, and 1 as the norms' for silt content, mean vehicle weight, and moisture content, respectively?

Chapter 5, Proposed AP-42 section:

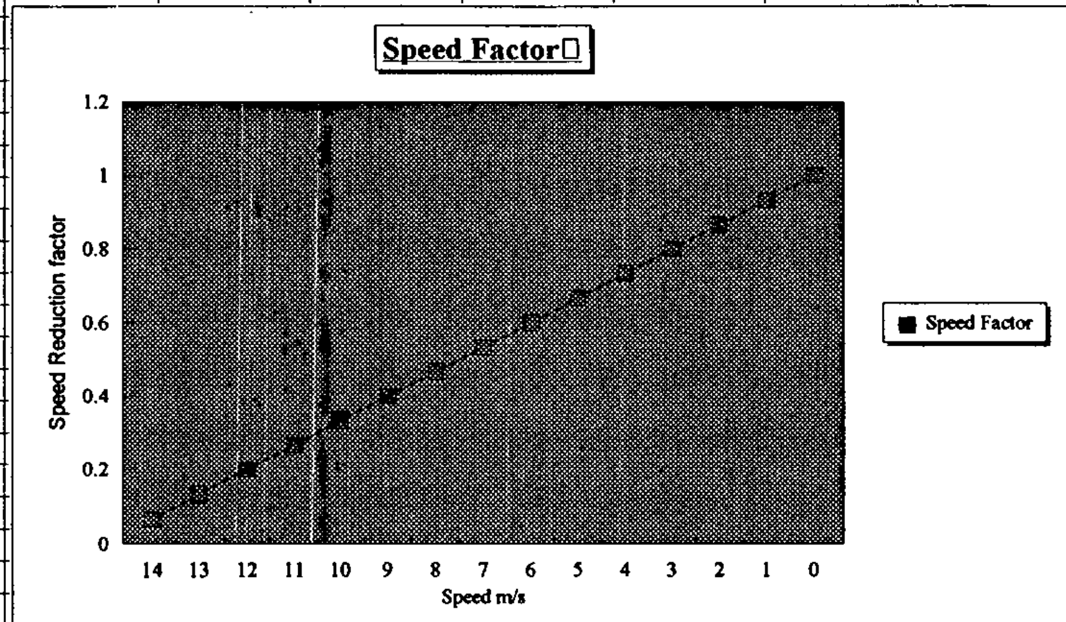
- It is possible for the end-user of the equation to obtain daily precipitation totals and relative humidity readings from the National Weather Service (NWS), Local Climatological Data (LCD's). It should be made feasible to incorporate short term relative humidity and precipitation data into daily or hourly estimates of emissions. Annual data can then be very accurately totaled from this equation. This approach is preferred to the national precipitation data map provided.

- The number of samples in determining silt content values in the Table should be at least 10 or more to provide an adequate level of confidence in the data.

These comments are complementary to the comments that are provided in the cover letter to this attachment. IDEQ would greatly appreciate your consideration of the comments/suggestions, and hopes that these will further the quality of the new equation.

SPEED

S (mph)	Speed Factor
14	0.07
13	0.13
12	0.20
11	0.27
10	0.33
9	0.40
8	0.47
7	0.53
6	0.60
5	0.67
4	0.73
3	0.80
2	0.87
1	0.93
0	1.00



x

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November 14, 1997

Mr. Ronald E. Myers
Emission, Monitoring, and Analysis Division
Emission Factor and Inventory Group
United States Environmental Protection Agency
Mail Drop 14
Research Triangle, NC 27711

Comments on the Draft Unpaved Road Emission Factor Document

Dear Mr. Myers:

The Portland Cement Association (PCA) has the following comments on the September 1997 draft version of the following U.S. Environmental Protection Agency (EPA) report:

> *Emission Factor Documentation for AP-42, Section 13.2.2 Unpaved Roads*, (the "*AP-42 Unpaved Road Document*"),

PCA appreciates the opportunity to review this document.

All portland cement manufacturing facilities require large amounts of limestone and other naturally occurring materials such as slate, shale, etc. Because of this fact, each cement plant operates quarries and crushing operations to provide these materials to the manufacturing facility, and therefore, constructs and maintains unpaved haul roads for the transportation of these materials.

The quarries are developed so that the most efficient transportation as possible of raw materials from the source to the cement plant can be accomplished. To move the volume of limestone and other materials required by the manufacturing facility, only large dump trucks or similar vehicles are used, and the trucks are operated at fairly consistent speeds from the quarry operation to the crushing and screening machinery. Smaller vehicles, such as pickup trucks or cars, are a limited percentage of the vehicles traveling the unpaved roads within the facility.

Due to the availability of limestone and similar materials, the unpaved roads at the quarry and manufacturing facility are constantly constructed and maintained with the raw materials being extracted. Overall, cement plants are very similar to limestone quarries that provide crushed stone to the road-building and construction industries.

Although several studies of unpaved roads related to the stone industry are included in the *AP-42 Unpaved Road Document*, some very dissimilar industries are also included in the development of the emission factor equations. Industries such as coal mining, copper smelting, and the iron and steel industry may require different types of vehicles, have variations in the traffic patterns, and use other materials in the construction of the their unpaved haul roads. For example, multiple types of aggregate may be used at the above industries due to the lack of the availability of road-building materials.

The emission factor equations in the *AP-42 Unpaved Road Document* are also dependent on data collected from unpaved roads used by pickup trucks and cars. The use of these vehicles results in great variations in possible dust generation due to the differences in tires, vehicle speeds, and vehicle aerodynamic effects.

Therefore, PCA requests that the EPA consider including the emission factor equations developed by the National Stone Association (NSA) in the *AP-42 Unpaved Road Document*. PCA believes that the NSA equations are more representative of the unpaved roads found at a cement facility. The inclusion of the NSA equations will allow a cement manufacturing facility to select the equation that best represents the possible emissions from the haul roads related to its operations. For your reference, a copy of the cover page of the report summarizing the NSA findings is attached.

If you have questions or comments regarding this matter, please contact me by telephone at (847) 966-6200, ext. 319 or by electronic mail at garth_hawkins@portcement.org.

Sincerely,

Garth Hawkins

Garth J. Hawkins, P.E.
Environmental Engineer
Environmental/Process Technology

Enclosure

Copy to: A. Dougherty, A.T. O'Hare

REVIEW OF THE EPA UNPAVED ROAD EQUATION AND ITS APPLICABILITY TO HAUL ROADS AT STONE CRUSHING PLANTS

Prepared for:

Robert G. Bartlett, P.E.
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Prepared by:

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May 1996

Air Control Techniques, P.C.
AIR POLLUTION CONTROL SYSTEMS ENGINEERING

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Fax Transmittal Sheet

TO:	Ronald E. Myers	U.S. Environmental Protection Agency	(919) 541-0684
CC:	Andrew T. O'Hare Ann Dougherty	American Portland Cement Alliance PCA	(202) 408-0877

FROM: Garth J. Hawkins

DATE: November 17, 1997

PAGES: 4 (Including this cover)

Comments on the AP-42 Unpaved Road Emissions Document

Attached please find comments on the USPEA's *Section 13.2.2 Unpaved Roads, Emission Factor Documentation for AP-42.*

Sincerely,

Garth Hawkins

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November 14, 1997

Mr. Ronald E. Myers
Emission, Monitoring, and Analysis Division
Emission Factor and Inventory Group
United States Environmental Protection Agency
Mail Drop 14
Research Triangle, NC 27711

Comments on the Draft Unpaved Road Emission Factor Document

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Due to the availability of limestone and similar materials, the unpaved roads at the quarry and manufacturing facility are constantly constructed and maintained with the raw materials being extracted. Overall, cement plants are very similar to limestone quarries that provide crushed stone to the road-building and construction industries.

Although several studies of unpaved roads related to the stone industry are included in the *AP-42 Unpaved Road Document*, some very dissimilar industries are also included in the development of the emission factor equations. Industries such as coal mining, copper smelting, and the iron and steel industry may require different types of vehicles, have variations in the traffic patterns, and use other materials in the construction of the their unpaved haul roads. For example, multiple types of aggregate may be used at the above industries due to the lack of the availability of road-building materials.

The emission factor equations in the *AP-42 Unpaved Road Document* are also dependent on data collected from unpaved roads used by pickup trucks and cars. The use of these vehicles results in great variations in possible dust generation due to the differences in tires, vehicle speeds, and vehicle aerodynamic effects.

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If you have questions or comments regarding this matter, please contact me by telephone at (847) 966-6200, ext. 319 or by electronic mail at garth_hawkins@portcement.org.

Sincerely,

Garth Hawkins

Garth J. Hawkins, P.E.
Environmental Engineer
Environmental/Process Technology

Enclosure

Copy to: A. Dougherty, A.T. O'Hare

nsa National Stone Association

1415 Elliot Place, N.W. • Washington, D.C. 20007-2599 • 202/342-1100

November 24, 1997

Mr. Ron Myers
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Re: Comments Concerning the Proposed Revisions to AP-42, Section 13.2 Unpaved Roads

Dear Mr. Myers:

Thank you for the opportunity to submit constructive technical comments concerning the proposed revisions to AP-42, Section 13.2.2, "Unpaved Roads". These comments concern Sections 4.2.3 and 4.2.5 of the report titled, "Emission Factor Documentation for AP-42 , Section 13.2.2, Unpaved Roads (Draft)". This report was prepared by Midwest Research Institute in accordance with EPA Contract 68-D2-0159, Work Assignment No. 4-02. Sections 4.2.3 and 4.2.5 concern stone crushing plant haul road emission factor tests sponsored by the National Stone Association (NSA). Recommendations for changes in the Emission Factor Documentation report are provided as part of this submittal.

NSA is also working with Air Control Techniques, P.C. concerning comments on Draft Section 13.2.2. These comments are being provided in a letter from Air Control Techniques, P.C.

NSA will be glad to meet with you to discuss these comments and those provided in the letter from Air Control Techniques, P.C. We look forward to continuing to work with EPA in a cooperative manner to develop accurate and representative PM_{10} and $PM_{2.5}$ emission factors for the aggregates industry.

Sincerely,

Jennifer Joy Wilson
President

TECHNICAL COMMENTS CONCERNING SECTIONS 4.2.3 AND 4.2.5 OF THE REPORT TITLED, "EMISSION FACTOR DOCUMENTATION FOR AP-42, SECTION 13.2.2 UNPAVED ROADS (DRAFT)"

1. BACKGROUND INFORMATION

1.1 Scope of Comments

This document presents technical comments concerning Sections 4.2.3 and 4.2.5 of the report titled, "Emission Factor Documentation for AP-42, Unpaved Roads, (Draft Report)." This report, dated September 1997, was prepared by the Midwest Research Institute (MRI) for the U.S. EPA, Emission Factor and Inventory Group under Contract 68-D2-0159, Work Assignment No. 4-02. The comments and recommendations prepared by the National Stone Association (NSA) and Air Control Techniques, P.C. primarily concern the following two sections of the MRI report.

- Section 4.2.3: Reference 3 titled, "Air Control Techniques; PM_{10}, $PM_{2.5}$, and PM_1 Emission Factors for Haul Roads at Two Stone Crushing Plants."
- Section 4.2.5: Reference 5 titled, "Entropy; PM_{10} Emission Factors for a Haul Road at a Granite Stone Crushing Plant."

Recommendations for changes in the MRI report are provided in Section 2. The basis for these recommendations is provided in Sections 3 and 4.

2. RECOMMENDATIONS

The National Stone Association requests the following changes concerning the material presented in Sections 4.2.3 and 4.2.5 of the draft MRI report.

2.1 Recommendations Concerning Section 4.2.3

- The "B" rating assigned to the Garner test should be changed to "A."
- MRI should remove the sentence that states, "*Specific water application rates were not reported, although the watering is said to have occurred approximately every 2.5 to 3 hours.*

2.2 Recommendations Concerning Section 4.2.5

- MRI should remove the sentence stating that, "*Two sets of hoods stacked vertically were collocated.*"
- MRI should remove the sentence stating that, "*Testing was discontinued when wind speeds exceeded 3 mph.*"

- MRI should remove the sentence stating that, "*The colocated hoods showed an order of magnitude difference between the left and right hoods in the concentrations sampled in three out of the seven tests.*
- MRI should remove the sentence stating, "*For the controlled tests, watering occurred on average every 3.6 hr, however, the water application rate was not reported.*

3. COMMENTS CONCERNING SECTION 4.2.3

3.1 Adequacy of the Testing Methodology

The first sentence of paragraph 2 of Section 4.2.3 makes an implied statement that the methodology was not adequate.

> *"The study used an upwind-downwind profiling technique that varied from the more commonly used exposure profiling method."*

A similar statement was included in the fourth paragraph of Section 4.2.3. This statement goes on to declare that a large rock wall created unrepresentative testing conditions.

> *"At the Garner test location, a large rock wall that stood immediately behind the downwind sampling site may have interrupted natural wind flows and/or created a local recirculation event. The potential wind obstruction and the variation in methodology from common exposure profiling methods accounted for a "B" rating of the test data at the Garner quarry. The Lemon Springs test was assigned an "A" rating."*

It is apparent that MRI has assigned a "B" rating to this test report due to the presence of the "large rock wall" and due to the testing methodology. NSA objects to these statements and to the "B" rating.

The clearly expressed intent of the NSA sponsored studies was to evaluate fugitive particulate emissions from quarry haul roads. A major fraction of a quarry haul road at stone crushing plants is in the quarry pit that varies in depth from 50 feet to more than 300 feet.

One of the testing locations selected for this test program was a portion of the haul road at the Garner NC quarry of Martin Marietta. As shown in the photographs included with the test report, this location was approximately 100 feet below the top of the quarry and next to a "large rock wall." The Garner site is highly representative of quarry haul roads in the stone crushing industry. The other test location selected for this test program was at the top of the Lemon Springs NC quarry of Martin Marietta. This site is representative of the portion of the quarry haul road outside of the quarry pit. NSA believes that the selection of these two sites was technically correct and justifiable.

There is, in fact, air recirculation due to the close proximity of the face of the quarry wall to the downwind side of the quarry haul road. This is the natural wind flow condition that exists in a deep quarry pit, and it must be taken into account during emission factor testing. This recirculation condition makes the emission profiling technique referred to by MRI difficult to apply for the following reasons.

- The haul road and its "shoulder" are not sufficiently wide for the fifteen meter upwind and five meter downwind spacing of the monitoring instruments

- The downwind particulate matter concentration does not necessarily approach ambient levels at the 21 foot elevation. Accordingly, there is no clear limit to the concentration profile integration.

Due to the proper selection of the test sites at the Garner and Lemon Springs quarries, the emission factor data are highly representative of stone crushing plant haul roads. The "B" rating is entirely inappropriate for the Garner tests. Exclusive use of the "*commonly used emission profiling technique*" outside of the quarry where there was sufficient room for the monitoring towers would have clearly been non-representative of quarry pit haul roads.

3.2 Adherence to the Test Program Protocol

NSA and its contactor, Air Control Techniques, P.C., fully adhered to the test protocol. The first version of this protocol was submitted by NSA to EPA on May 8, 1995. Based on EPA comments, the protocol was revised and re-submitted by NSA on July 20, 1995. Both of these versions included the following statement.

> "Due to the short distances between the downwind side of the haul road and the edge of the quarry cliff, the ambient PM_{10} monitors may be influenced by PM_{10} emissions from the quarry itself or PM_{10} particles formed due to the turbulent eddies that exist at the edge of the cliff."

This comment was included in a section of the protocol explaining why the "*commonly used emission profiling technique*" was not applicable. NSA believes that this statement also clearly indicates our intent to test in the quarry pit itself, not just on the upper portion of the quarry haul road. During an extended negotiation in the three month period prior to the beginning of these tests in late August 1995, EPA personnel, at no time, indicated that the proposed test location in the quarry pit or the testing methodology described in the July 20, 1995 version of the protocol was inadequate. The tests were conducted under the belief that EPA personnel had every opportunity to review the testing approach and that all EPA concerns had been fully satisfied. Accordingly, NSA is surprised that MRI has taken the position on behalf of EPA that the Garner tests should be rated "B" due to the test location and the test methodology. NSA have done everything in our power to work in a fully cooperative manner with EPA. Furthermore, we have conducted these tests in complete adherence to the test protocols. The rating of "B" for the Garner test is completely inappropriate.

3.3 Water Application Rates

The second sentence of paragraph 3 of Section 4.3.2 of the MRI report states the following.

> *"Specific water application rates were not reported, although the watering is said to have occurred approximately every 2.5 to 3 hours."*

Appendix D of the emission test report for Garner and Lemon Springs (pages 100 through 124) specifically lists the exact time that every haul truck, water truck, pickup truck, tractor, car, and van passed the sampling assembly. This MRI comment seems to imply that Air Control Techniques omitted an important variable and was careless in test documentation. This is not correct.

NSA and Air Control Techniques, P.C have fully reviewed the May 8, 1995 and July 20, 1995 test protocols submitted to EPA prior to the tests. It is clear in these protocols that we did not intend to record the water application rates. Furthermore, it was not our intent to analyze the data in any manner that might involve EPA's wet suppression efficiency equation. To our knowledge, this is the only equation that uses the water application rates as an independent variable. Accordingly, we are surprised that MRI has taken the position that we failed to include these data. This MRI criticism is even more surprising considering that MRI and EPA have not included water application rate data in the revised haul road equations. If the water application rate data had been present, it is clear that it would have been ignored by MRI and EPA. This MRI criticism is clearly unnecessary.

NSA would like to emphasis that we adhered fully to the revised test protocol that we submitted to EPA more than a month before the tests began. At no time during the pretest negotiations did EPA personnel request these data. NSA requests that MRI's criticism regarding the water application rate data be removed from their document.

4. COMMENTS CONCERNING SECTION 4.2.5

4.1. The Use of Colocated Push-Pull Hoods

Paragraph five of Section 4.2.5 states the following.

> "The 'push-pull' method used for this study is not considered an accepted methodology for measuring open source particulate emissions."

Paragraph 4 of Section 4.2.5 states the following.

> "The low sampling height at relatively low wind conditions used for this test program potentially allows the particulate plume to pass over the sampling device without capture."

After reviewing the Entropy emission test report (Reference 5), NSA and Air Control Techniques, P.C. believe that the emission factor calculation procedures have not been clearly described, and we understand how MRI could have misinterpreted these results. Actually, the "push-pull" method described in the Entropy emission test report is a straight-forward adaptation of the of upwind-downwind concentration monitoring often used for measurement of fugitive dust emissions. Entropy did not calculate the emissions based solely on the quantity of air captured by the hoods. It was also not necessary for the hoods to capture 100% of the haul road emissions in order to facilitate an accurate measurement of the downwind concentration. It is clear from the sample emission factor calculation shown on page 12 of the Entropy report that the average wind velocity (not the hood capture velocity) through the entire testing zone was used to calculate the emission factor. Accordingly, this test used a conventional upwind-downwind concentration measurement technique.

Entropy used the hoods simply to gather a sufficient gas stream sample to measure the downwind concentration. As shown in Figure 2-3 of the Entropy report, the hoods were located approximately 1 meter from the side of the haul road. This is considerably closer than the 5 meter position used in MRI tests. Accordingly, there is considerably less vertical dispersion from the point of dust release next to the haul road surface to the monitoring site in the Entropy tests as compared to MRI tests. Due to the extremely close position of the Entropy hoods, a representative sample of the downwind concentration was obtained

NSA and Air Control Techniques, P.C. do not believe that significant quantities of dust escaped over the top of the hoods. Almost all of the particulate matter is emitted close to the road surface. This belief is consistent with the particulate matter emission mechanism described in draft Section 13.2.2.1 of AP-42, "*Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface.*" The hoods used at Knightdale extended up to ten feet above the road surface, and smoke tracer tests confirmed that during truck passage, the large majority of the emissions remained at less than the 10 foot elevation and were sampled by the hoods. It should also be noted that hoods were located immediately adjacent to a 60 foot cliff that was part of the quarry pit wall. The 60 foot cliff less than 4 meters from the edge of the haul road also precluded the use of an emission profiling tower located 5 meters from the haul road.

It should also be noted that the fans on the upwind side of the haul road were used to enhance particle capture and reduce vertical dispersion of the plumes from the wakes of the haul road trucks. These fans increased the average wind speed across the road surface and drove the particulate toward the hoods.

4.2 Adherence to the Emission Test Protocol

The "push-pull" upwind-downwind concentration test procedure used at the Knightdale quarry was first proposed in a series of meetings attended by EPA personnel and NSA personnel in the fall of 1993. It was described in an emission testing protocol dated December 3, 1993 and submitted to the Emission Measurement Branch by NSA. EPA personnel did not raise any objections to this test procedure over the ten month period proceeding the test program. The only comments received was a telephone call from Dr. Chatten Cowherd of MRI on the first day of testing. NSA and Air Control Techniques believe that more than an adequate opportunity was provided to EPA and MRI to review the test procedure and raise any issues necessary. It was clearly unreasonable to delay the comments for over ten months and then raise issues after the equipment was set-up and testing was underway. It is also unreasonable to declare that the testing procedure is not an accepted methodology.

4.3. Co-located Hoods

Paragraph 4 of Section 4.2.5 states the following.

> *"The co-located hoods showed an order of magnitude difference between the left and right hoods in the concentrations sampled in three out of seven tests."*

It is important to note that the side-by-side hoods were not used in a co-located manner. The emissions data from the two sets of hoods were combined. This is entirely different than the procedures used for co-located ambient monitors. The term "co-located" was <u>not</u> used in the Entropy report.

The term "order of magnitude" means a factor of 10. A review of the left and right hood concentrations at Knightdale indicates that MRI is exaggerating with respect to these differences. The data shown in the Table below have been taken from Entropy Table 3-3. One of the tests (Uncontrolled Run 4) was a factor of seven different, and two of the tests (Controlled Runs 1 and 2) were approximately a factor of five different.

NSA and Air Control Techniques, P.C. have reviewed the Entropy data and believe that the difference is caused primarily by the location of the left hood relative to an intersection of two haul roads and the quarry pit haul road near the test site. It was sometimes necessary for haul road trucks to stop and idle while another vehicle passed through the intersection. The stopping point for vehicles exiting the pit and approaching the primary crushers was close to the left hood. Air Control Techniques, P.C. believes that the high concentrations observed in the left hoods during the first two runs were due to the capture of these idling emissions.

Comparison of Left and Right Hoods, Knightdale Quarry Pit Tests			
Test	Left Hood Concentration grains/DSCF	Right Hood Concentration grains/DSCF	Difference Left/Right
Controlled Run 1	1.05×10^{-4}	2.06 c 10^{-5}	5.1
Controlled Run 2	1.35×10^{-4}	2.83×10^{-5}	4.8
Controlled Run 3	2.99×10^{-4}	1.85×10^{-4}	1.6
Uncontrolled Run 1	5.94×10^{-4}	2.83×10^{-4}	2.1
Uncontrolled Run 2	1.29×10^{-3}	1.37×10^{-3}	0.94
Uncontrolled Run 3	2.18×10^{-3}	2.53×10^{-3}	0.86
Uncontrolled Run 4	7.38×10^{-4}	5.18×10^{-3}	0.14

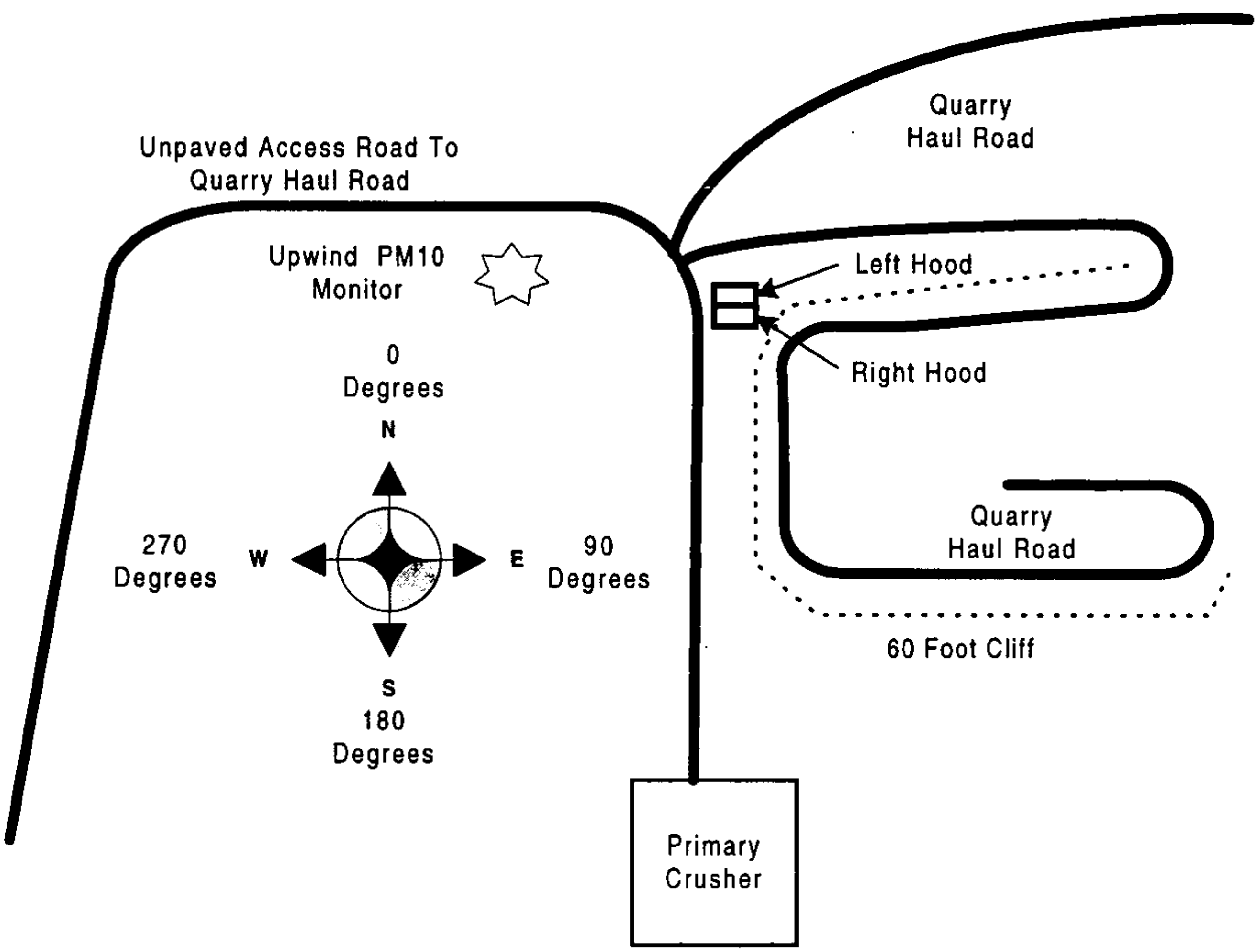

Figure 1. Arrangement of Test Equipment at the Knightdale Quarry

NSA and Air Control Techniques can not find any indications of the possible cause for the difference in the Left and Right Hood during Uncontrolled Run 4. However, we do not believe that Uncontrolled Run 4 should be treated as an outlier and discarded. Also, it should be noted that more than a factor of seven variability was described in many of the references used by MRI in developing the proposed unpaved road equation. The following examples illustrate the extent of differences in these other tests.

Variability of Particulate Emission Factor Data
(MRI Conducted Emission Factor Tests)

MRI Reference	Run #	Lbs./VMT	Difference	Silt, %	Moisture, %
2	BA-9	0.090	14.6	3.35	5.69
	BA-3	1.32		6.04	7.41
4	BB-47	78.2	9.6	14.0	5.11
	BB-46	8.14		12.7	4.88
8	AQ7-G	0.390	6.23	7	1.2
	AQ6-C	2.43		12	1.4

All three studies were conducted by MRI, and all three sets of runs were conducted at similar moisture and silt levels as indicated in the table above. MRI chose not to discuss the factor of 6 to 14 variability in their tests runs but was highly critical of the factor of five to seven variability in the Entropy data. In fact, variability is a common problem in the large majority of fugitive emission testing projects.

4.4. Recirculation Air Flow

The fourth paragraph of Section 4.3.5 states the following.

> *"Strong evidence of recirculation of emissions to the upwind sampler is provided by the fact that the upwind concentrations increased by roughly an order of magnitude from the controlled to the uncontrolled tests."*

There is no technical basis for the criticism. The upwind concentrations increased "*...roughly an order of magnitude...*" because the upwind ambient air sampler had to be located close to a portion of the unpaved quarry haul road (see Figure 1). During the uncontrolled tests, this section of the road was not watered.

Air Control Techniques has recalculated the uncontrolled emission factors by ignoring the contribution of the upwind dust concentrations to the measured downwind concentrations. By taking this approach, the data are biased to higher-than-true levels. It is apparent that the revised emission factors (ignoring upwind dust concentrations) are only slightly higher than the emission factors reported in the test report. <u>The order of magnitude increase in the ambient air concentrations upwind of the test location did not have a significant impact on the reported uncontrolled emission factors as indicated in the table below.</u> Except for one of the four runs, ignoring the contribution of the upwind air concentration entirely results in an increase of only 7% to 20% in the calculated emission factor.

It is important to note that a quarry haul road has an entirely different configuration than a public unpaved road and haul roads at iron and steel plants. The quarry haul road inherently has a swirl pattern necessary to allow heavy duty trucks to descend several hundred feet into the pit. Furthermore, there must be one or more approach roads to allow the heavy duty trucks, graders, and water trucks to reach the swirling quarry pit road. In most quarries, an ideal upwind ambient air monitoring site is hard to find due to the complex road pattern in a compact industrial site. Air Control Techniques believes that Entropy properly selected a monitoring site and accurately measured the actual upwind dust concentration approaching the portion of the haul road tested. There is no basis for the "...*recirculation* " criticism expressed by MRI.

Re-calculated Emissions Factors Based on Zero Upwind Dust Concentrations				
Test	Upwind Ambient Dust Concentration	Original PM_{10} Emission Factor (Taking Into Account the Upwind Concentration)	Revised PM_{10} Emission Factor (Subtracting out the Upwind Concentration)	% Difference in Emission Factors, Revised/Original
Uncontrolled 1	2.28×10^{-4}	0.528	1.10	2.08
Uncontrolled 2	2.28×10^{-4}	1.57	1.89	1.20
Uncontrolled 3	2.28×10^{-4}	2.34	2.59	1.11
Uncontrolled 4	1.75×10^{-4}	4.70	5.01	1.07

4.5 Testing Was Discontinued During Certain Wind Conditions.

The third sentence of the third paragraph of MRI Section 4.2.5 states the following.

> *"Testing was discontinued when speeds exceeded 3 miles per hour."*

This statement is a misinterpretation of the comments and data provided in the Entropy report. As stated in the Entropy report: *"Furthermore, the test was delayed if winds in excess of 3 miles per hour shifted and came from the North or East.* As indicated in Figure 1, the hoods were located directly west of the portion of quarry pit haul road tested. The testing was conducted whenever the winds were from the west or northwest. Furthermore, testing was conducted during all low wind speed conditions (< 3 mph) because the upwind side fans generated a west-to-east air flow of approximately 3 mph. Accordingly, the testing continued during all conditions when the air was flowing in the proper direction.

The testing was interrupted whenever there were strong winds that were not in the proper direction. The testing was restarted when the winds shifted back to the acceptable direction. Winds from the north or east that exceeded 3 mph would have caused a bias to lower-than-true emissions because the hoods were not in a proper downwind orientation during these time periods. The procedures used by Entropy were correct. Furthermore, these procedures are entirely consistent with those used by MRI in tests of unpaved roads.

Air Control Techniques, P.C.

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November 24, 1997

Mr. Ron Myers
U.S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

Re: Draft AP-42 Section 13.2.2, Unpaved Roads

Dear Ron,

Thank you for the opportunity to comment on Draft AP-42 Section 13.2.2 concerning unpaved roads. Air Control Techniques, P.C. is providing comments in two separate submittals. This letter provides constructive comments on the following two aspects of this material included specifically in the Draft AP-42 Section 13.2.2.

- Applicability of the equation to stone crushing plant haul roads
- General comments concerning the use of the equation

A separate submittal prepared by the National Stone Association and Air Control Techniques, P.C. provides comments concerning Sections 4.2.3 and 4.2.5 Emission Factor Documentation Report prepared by Midwest Research Institute for EPA. These sections concern the emission factor tests conducted by Air Control Techniques, P.C. and Entropy, Inc. for the National Stone Association.

1. Applicability of the Draft Unpaved Road Equation to Stone Crushing Plants

We believe that the predictive equation developed based strictly on emission factor tests at stone crushing plants is a better predictor of PM_{10} and $PM_{2.5}$ emissions than the general emission factor equation for all types of unpaved roads. This position is consistent with the following statement included on page 3 of the Fifth Edition of AP-42.

> "If representative source-specific data cannot be obtained, emissions information from ... actual test data from similar equipment, is a better source of information for permitting decisions than an AP-42 emission factor. When such information is not available, use of emissions factors may be necessary as a last resort."

The predictive equations developed based on NSA sponsored tests at stone crushing plants located at Knightdale, Garner, and Lemon Springs, N.C. are shown below as Equation 1 and 2..

$$E_{PM10} = (s/3)^{0.8}(M/2)^{-0.9} \quad \text{Equation 1}$$

$$E_{PM2.5} = 0.25(s/3)^{0.8}(M/2)^{-0.9} \quad \text{Equation 2}$$

Where:

E_{PM10}	= PM_{10} Emissions, Lbs./VMT
$E_{PM2.5}$	= $PM_{2.5}$ Emissions in Lbs./VMT
s	= Silt content, %
M	= Moisture content, %

The use of the precipitation factor from Section 13.2.2 can be used to adapt this equation for predicting annual emissions. This results in Equations 3 and 4.

$$E_{PM10} = (s/3)^{0.8}(M/2)^{-0.9}\left[\frac{(365-p)}{p}\right] \qquad \text{Equation 3}$$

$$E_{PM2.5} = 0.25(s/3)^{0.8}(M/2)^{-0.9}\left[\frac{(365-p)}{p}\right] \qquad \text{Equation 4}$$

We believe that these equations are more representative of the PM_{10} and $PM_{2.5}$ emissions from stone crushing plant haul roads for the following reasons.

- All tests were conducted on quarry haul roads representative of the stone crushing industry.
- One of the three tests was conducted in the quarry pit.
- The vehicle weights and speeds during the test program were representative of the stone crushing industry.
- The silt and moisture contents of the road surfaces were representative of the stone crushing industry.
- The surface characteristics of stone crushing plant haul roads are different from other types of unpaved roads due to the frequent watering, the compaction caused by the heavy duty trucks, and the high degree of road maintenance provided by plant operators.

A comparison of Equation 1 with the measured PM_{10} emission factors at the three stone crushing plants is shown in Figure 1. The R^2 correlation coefficient for this equation is approximately 59%. A comparison of the measured PM_{10} emission factors with the draft unpaved road equation is shown in Figure 2. The R^2 correlation coefficient is 54%, slightly lower than for NSA's Equation 1. This means that the NSA equation explains the variability of the data slightly better than the EPA equation.

The EPA unpaved road equation appears to have a significant bias to higher-than-observed PM_{10} emissions for stone crushing plant plants having high haul road moisture levels. This bias is indicated by the intercept of the linear regression line with the y-axis at a value of approximately 2.0 lbs/VMT. We believe that this bias is due to the fact that the material present in the silt at stone crushing plants is inherently more wettable than the silt present on rural unpaved roads (e.g. clay), western surface coal mines (e.g. coal dust and clay), and iron & steel plants (e.g. slag). Use of the new unpaved road equation may penalize the operators of stone crushing plants that are the most conscientious in maintaining high moisture levels on their haul roads.

The emission factor data obtained in the NSA sponsored tests appear to be more representative of PM_{10} and $PM_{2.5}$ emissions from stone crushing industries. This is indicated by the more reasonable form of the relationship shown between the predicted and observed emission factor data shown in Figure 1.

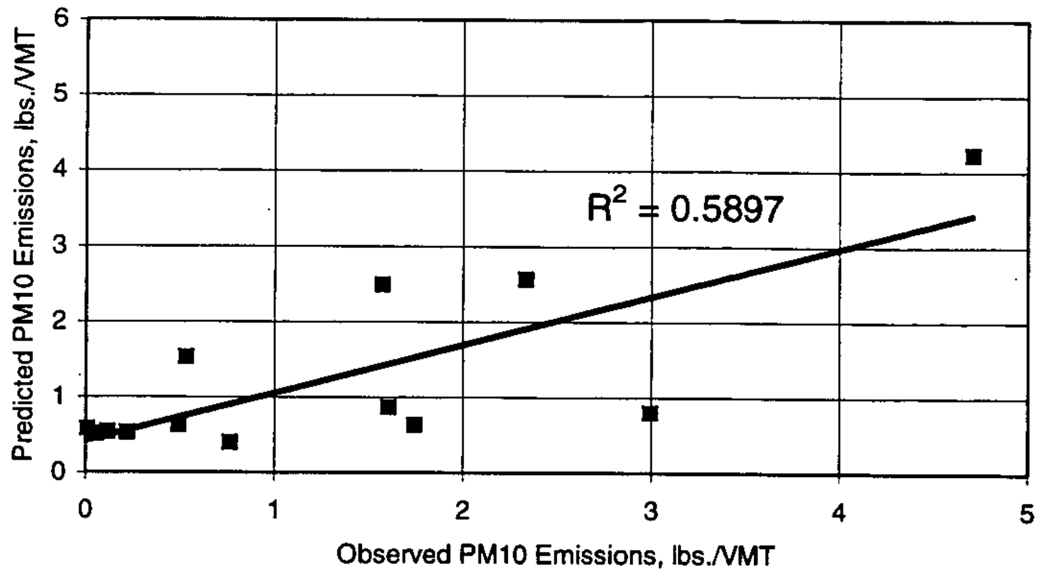

Figure 1. Comparison of NSA test data and NSA's Equation 1

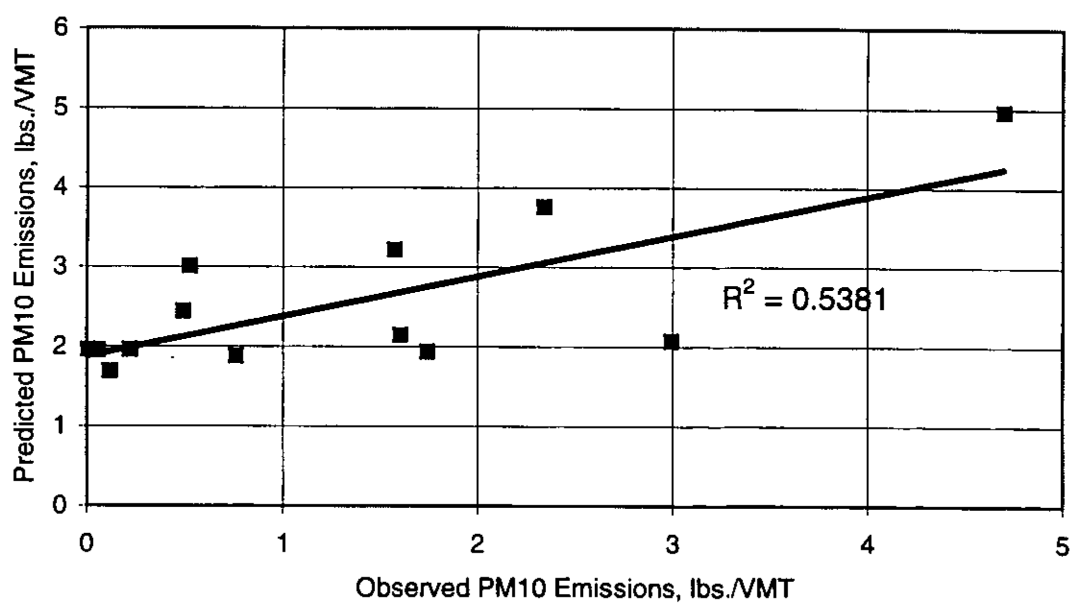

Figure 2. Comparison of NSA test data and the draft unpaved road equation

2. General Comments

Road Surface Moisture Levels

We believe that the EPA draft equation in its present form underestimates the benefits of moisture. Extrapolation of the curve defined by the equation to the 20% moisture level yields predicted PM_{10} emission factors in the range of 1.0 lbs/VMT as shown in Figure 3. Air Control Techniques, P.C. believe that the new equation over-predicts PM_{10} emissions at high moisture levels.

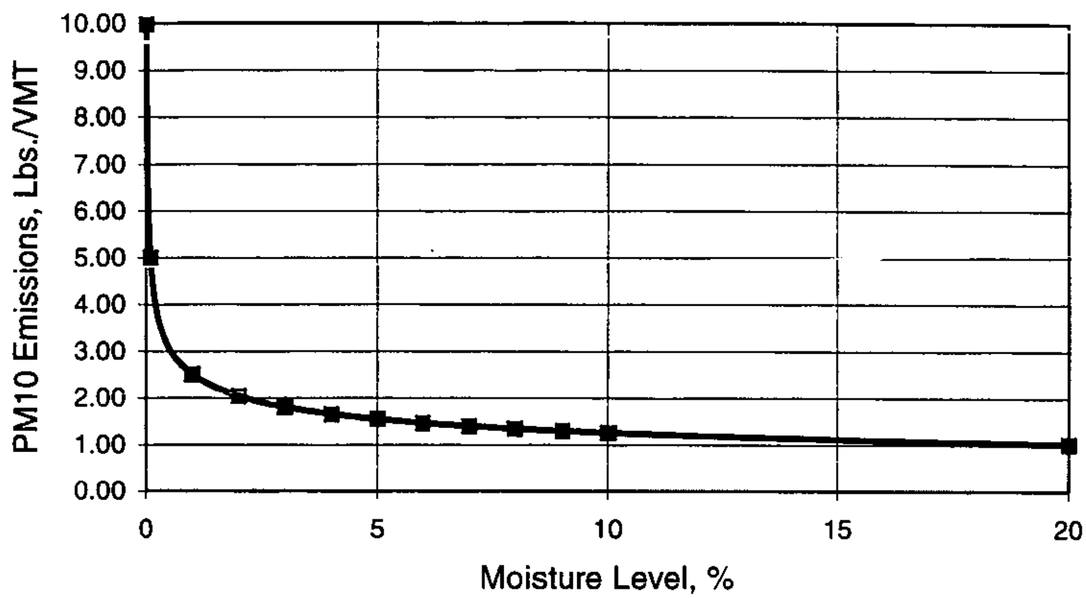

Figure 3. PM_{10} Emissions Predicted by the Draft Section 13.2.2 Unpaved Road Equation as a Function of the Moisture Content (Table 13.2.2-3 Specified Range: 0.03% to 20%)

The curve generated by the equation should approach very low emission factor values at twenty percent moisture levels. The particulate emissions from essentially all unpaved road surfaces should be very low at this very high moisture level. The mathematical form of the equation should be reviewed to determine if there is a more appropriate exponent for moisture that provides a better representation of emissions from highly moist unpaved road surfaces.

Despite the apparent deficiencies at high moisture levels, the equation appears to have the proper form for low moisture levels. As indicated in Figure 3, the predicted emissions have an asymptotic relationship with moisture at levels below approximately 0.3%. We have observed the same relationship in tests conducted for the National Stone Association.

Precipitation Factor

We agree with the inclusion of the precipitation factor, [(365-p)/365] in Equation 2 of Draft Section 13.2.2, and with the statement that, "*...all roads are subject to some natural mitigation because of rainfall and other precipitation.*" However, it would be helpful to add a statement that the precipitation days should include all days that the road surface is covered by snow or ice, irregardless of the amount of precipitation occurring on each specific day.

Vehicle Speed and Other Factors

It is apparent in the Emission Factor Documentation report and in the draft Section 13.2.2 that the EPA and MRI authors are not entirely confident in the form of the new unpaved road equation. For example, the following statement is included in Section 13.2.2.3.

> "Although vehicle speed does not appear as a correction parameter, it is obvious to anyone who has driven on an unpaved road that (visible) emissions increase with vehicle speed. "

Air Control Techniques, P.C. agrees with this comment regarding the importance of the speed factor. Furthermore, we believe that there are a number of other important factors that have a direct and significant impact on PM_{10} and $PM_{2.5}$ emissions. A partial list of these factors include the following.

- Vehicle road clearance and the associated magnitude of the turbulent wake as a function of the vehicle speed
- The tire tread characteristics with respect to the tendency to pick-up and entrain particles into the turbulent wake of the vehicle
- The tire tangential velocity with respect to the tendency to release particles from the tire into the turbulent wake of the vehicle
- The actual pressure exerted by the vehicle tire on the road surface that causes pulverization of silt particles to form PM_{10} and $PM_{2.5}$ particles
- The grindability of the silt particles
- The extent of compaction of the road surface under various wet suppression and/or natural precipitation conditions
- The extent to which tailpipe exhaust contributes to particle entrainment into the turbulent wake of the vehicle

Obviously, neither EPA nor NSA has the budget necessary to accurately analyze the possible impact of all of these important variables. Accordingly, Air Control Techniques, P.C. recommends that EPA conduct a fundamental particle formation and emission study using modern computational fluid dynamic modeling (CFD) techniques. These are "First Principle" models that are being actively used in a wide variety of aerospace design projects, automotive design projects, process equipment design projects, and air pollution control equipment optimization projects. We have had the opportunity to work on a number of projects involving CFD, and we are very impressed with the capability and accuracy of this technology. CFD would provide an economical way to provide a sound technical basis to the unpaved road equation. For too long, this equation has been based simply on layer after layer of empirical studies concerning only a few of the important variables affecting emissions. There is now a readily available technology to provide improved emission factor equations.

I hope that these comments are helpful in finalizing draft Section 13.2.2.

Sincerely,

John Richards, Ph.D., P.E. and Todd Brozell, P.E.
Air Control Techniques, P.C.

State of North Carolina
Department of Environment,
and Natural Resources
Division of Air Quality

James B. Hunt, Jr., Governor
Wayne McDevitt, Secretary
Alan Klimek, P.E., Director

October 22, 1997

Mr. Ronald E. Myers
U.S. Environmental Protection Agency
Emission Factors & Inventory Group
Mail Drop 14
Research Triangle Park, NC 27711

Dear Ron:

As usual, the state of North Carolina, Division of Air Quality appreciates the opportunity to provide technical comments on proposed revisions to emission factors and other inventory guidance. These comments are specifically addressed toward Section 13.2.2 of AP-42 regarding proposed revisions to "Unpaved Roads." The first comments below are addressed toward the Draft Section itself with some additional comments directed toward the background document. First, let me say that even during this electronic age, it would facilitate review to have a hard copy provided to eliminate with the retrieval and printout hassle.

I have enclosed a copy of my mark-up (marked pages only), but these are some of the major comments. The opening sentence of the section has little relevance and should be stricken. To strengthen the opening and to make it clear as to the revised coverage of this section (i.e., to aggregate, coal and other industries), this should be explicitly stated along with a summary of what sections are replaced. The revision should also include instructions to remove the sections replaced or updates of those sections, if applicable. See further comments on this in the general comments at the end of this letter.

Table 13.2.2-1 could use some additional clarity. For example, "yard area" should clearly state that this is the storage area, "Haul" and "Access" should clearly indicate that these are to the pit or wherever. Is "mean" in the header an arithmetic or geometric variety? Can more definition be given to the road surface "dirt?" Again, additional explanation of what the new information in the table are as opposed to old, etc. should be added to provide clarity to the user who might be familiar with using the old tables in separate sections.

Page ---3: The first paragraph does not seem to describe satisfactorily what was done. Additional detail and clarity with a reference to the further discussions in the background report might be helpful. Also on same page, I suggest writing out each equation (PM-30, PM-10, PM-2.5) separately for clarity. Footnote meaning or equivalence of PM-30, and drop PM-15 as it has little relevance/meaning. I do not believe these resulting equations technically merit the "A" and "B" ratings and should be downgraded at least a letter due to the statistics in the background report and personal judgement.

Page ---5: The discussion talks about defaults but stops short of a "presumptive default" equation or expression for crude approximations. Since this is likely to be done anyway, I suggest providing such an equation with calculated extremes that can occur if applied without regard to real input data.

Page ---8: The first full Paragraph discusses collecting new road samples after 6 months of use. I sincerely doubt that anyone will likely do this. It is difficult to even get a facility to take samples at all to estimate emissions.

Page ---10: The section does not explain "Class A pan evaporation," and it should. Some other word changes recommended on enclosed copies.

Page ---12: How does one determine "ground inventory?" Is there a rule of thumb for default?

Background Report:

Page 1-1: The Second Edition of AP-42 was published in 1972. The earlier "Duprey" edition was in 1968 or '69. Earlier versions of similar documents were issued in 1965 or so. However, I don't believe fugitive dusts were addressed until the Third Edition, or perhaps a supplement to the Second or Third Edition.

In the definitions section, "filterable particulate" should be included for completeness. I would suggest dropping the IP or PM-15 as it is not now used and could be confusing.

In Section 3, measurement methods are discussed. However, the "stone association" method seems avoided somewhat. Since it has been used and the data evaluated, it should be included in the descriptions. Here and in Section 4, the evaluations seema bit biased against data not collected by MRI. Their data may be better or not, but "outside" tests seem more rigorously critiqued than the other tests. Comments may be valid, but need to be equal and balanced in presentation so as to not give this impression. For example, "unacceptable" is a judgement given without any documentation of reasons. Also, it is not reasonable that road widths and such basic information not included in test reports, even by the same contractor, are not recoverable in some fashion.

Page 4-29 and thereabouts: Would it not make sense to view the data bases for PM-30, PM-10 and PM-2.5 separately and independently? There may likely be forces (e.g. static) acting upon the different sized particles that would best be represented by this treatment. With the statistics presented on page 4-30&31, the "A" rating on page 4-29 does not seem warranted!

Mid-page 4-37: "0.5 percent" seems to materialize out of the air. Explain "pan evaporation" and its relevance on the next page.

General Observations:

There continues to be a generally insufficient level of information and detail for confidently estimating emissions from fugitive dust sources of all types. This includes information which would assist in relating sources more closely with their ambient impact. The parameters upon which the emissions should be based are fairly intuitive and the existing equations seem to address those. However, there is a gap of acceptance of these emissions as being part of the "real world" of sources which are emitting into the ambient air and for which we are comfortable with emissions being well correlated with their ambient impact. The complexity of resulting equations generally precludes a majority of facilities from estimating their emissions in this manner. The availability of a simple, stable, defensible and usable (user friendly) computerized model to accomplish this would be of assistance, but perhaps be only a partial solution. It might be helpful to develop several (based on aridity, soil characteristics, etc.) models which could represent different parts of the country and types of facilities and make the calculations simpler, although somewhat more crude. Facilities and agencies are somewhat geared to permit conditions, so this might provide a means to categorize further the estimation of emissions, application of controls and operations.

Reading the section, I could not help but wonder if some future reviews and updates should not address this problem a little differently. For example, would an approach to separate the mechanical lifting forces and the air turbulent forces in the analysis be productive? Also, for PM-10 and PM-2.5, I doubt if it is still appropriate to look at just silt analysis. I am sure silt is still a crude and somewhat commonly availablae indicator, but the size particles being simulated are so much smaller than silt that one can not help but wonder if there is not a finer delineation within "silt" that is necessary before a determination of this sector can be appropriately made.

This report on fugitives from unpaved roads does not sufficiently show the comparison of old parameters and results with the newer ones. I recommend that each estimation process, including those for aggregate operations, coal mines, paved roads, etc. be examined in a case study comparison approach so the reader can view them side by side and evaluate the impacts of the revisions. One is understandably reluactant to adapt and apply a new set of numbers without having some concern about and evaluation for what this will do to the existing data structure and integrity built up over the previous years of application. A clear concise comparison detailed in the background report and summarized in the sections themselves would facilitate this level of confidence. A cross reference to any applicable (EIIP) estimation methods would be helpful.

Again, thanks for the opportunity to review and provide input to this process.

Sincerely,

Jim Southerland, Engineer II

cc: Laura Butler, Chief, Permits Section
Brock Nicholson, Chief, Planning Section

EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 13.2.2
Unpaved Roads

1. INTRODUCTION

The document *Compilation of Air Pollutant Emission Factors* (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State and local air pollution control programs, and industry.

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Emission factors usually are expressed as the weight of pollutant divided by the unit weight, volume, distance, or duration of the activity that emits the pollutant. The emission factors presented in AP-42 may be appropriate to use in a number of situations, such as making source-specific emission estimates for area wide inventories for dispersion modeling, developing control strategies, screening sources for compliance purposes, establishing operating permit fees, and making permit applicability determinations. The purpose of this report is to provide background information from test reports and other information to support revisions to AP-42 Section 13.2.2, Unpaved Roads.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a characterization of unpaved road emission sources and a description of the technology used to control emissions resulting from unpaved roads. Section 3 is a review of emission data collection and emission measurement procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission equations and methods of emission factor determination. Section 4 details how the revised AP-42 section was developed. It includes the review of specific data sets, a description of how candidate the emission equation was developed, and a summary of changes to the AP-42 section. Section 5 presents the AP-42 Section 13.2.2, Unpaved Roads.

Throughout this report, the principal pollutant of interest is PM-10—particulate matter (PM) no greater than 10 μmA (microns in aerodynamic diameter). PM-10 forms the basis for the current National Ambient Air Quality Standards (NAAQS) for particulate matter. PM-10 thus represents the particle size range that is of the greatest regulatory interest. Because formal establishment of PM-10 as the standard basis for the NAAQS occurred in 1987, many earlier emission tests (and in fact the current version of the unpaved road emission factor) have been referenced to other particle size ranges, such as,

TSP Total Suspended Particulate, as measured by the standard high-volume (hi-vol) air sampler. Total suspended particulate, which encompasses a relatively coarse size range, was the basis for the previous NAAQS for PM. Wind tunnel studies have shown that the particle mass capture efficiency curve for the hi-vol sampler is very broad, extending from 100 percent capture of particles smaller than 10 micrometers to a few percent capture of particles as large as 100 micrometers. Also, the capture efficiency curve varies with wind speed and wind direction, relative to roof ridge orientation. Thus, the hi-vol sampler does not provide definitive particle size information for emission factors. However, an effective cutpoint of 30 μm aerodynamic diameter is frequently assigned to the standard hi-vol sampler. reference?

SP Suspended Particulate, which is often used as a surrogate for TSP, is defined as PM with an aerodynamic diameter no greater than 30 μmA. SP may also be denoted as "PM-30."

IP Inhalable Particulate is defined as PM with an aerodynamic diameter no greater than 15 μmA. IP may also be denoted as "PM-15."

FP Fine Particulate is defined as PM with an aerodynamic diameter no greater than 2.5 μmA. FP may also be denoted as "PM-2.5."

The EPA promulgated new PM NAAQS based on PM-2.5, in July 1997.

What about Method 5 Particulate – Filterable

3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

To reduce the amount of literature collected to a final group of references from which emission factors could be developed, the following general criteria were used.

1. Emissions data must be from a primary reference.

a. Source testing must be from a referenced study that does not reiterate information from previous studies.

b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.

2. The referenced study must contain test results based on more than one test run.

3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions.

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

3.2 METHODS OF EMISSION FACTOR DETERMINATION[2]

Fugitive dust emission rates and particle size distributions are difficult to quantify because of the diffuse and variable nature of such sources and the wide range of particle size involved including particles which deposit immediately adjacent to the source. Standard source testing methods, which are designed for application to confined flows under steady state, forced-flow conditions, are not suitable for measurement of fugitive emissions unless the plume can be drawn into a forced-flow system. The following presents a brief overview of applicable measurement techniques.

1. In attempting to quantify a large area source, overlapping of plumes from upwind (background) sources may preclude the determination of the specific contribution of the area source.

2. Because of the impracticality of adjusting the locations of the sampling array for shifts in wind direction during sampling, it cannot be assumed that plume position is fixed in the application of the dispersion model.

3. The usual assumption that an area source is uniformly emitting does not allow for realistic representation of spatial variation in source activity.

4. The typical use of uncalibrated atmospheric dispersion models introduces the possibility of substantial error (a factor of three according to Reference 4) in the calculated emission rate, even if the stringent requirement of unobstructed dispersion from a simplified (e.g., constant emission rate from a single point) source configuration is met.

On an even more fundamental level, typical traffic volumes on unpaved roads are far too low to represent the road as a steady, uniformly emitting line source for dispersion analysis purposes. A far better representation (but one which, unfortunately, is not available at this time) would view the unpaved road source as a series of discrete moving point sources.

Just as importantly, it is not clear that "cosine correction" used to account for the effect that an oblique wind direction has on line sources is applicable to the case of an unpaved road. As the plume is released, dispersion occurs in all three cartestian coordinate directions. Only dispersion in the direction parallel to the plume centerline would be negligible. Depending on the direction a vehicle is traveling, an oblique wind would appear to dilute or "concentrate" the plume mass seen by the samplers, as compared to the case of a perpendicular wind. Correction for each plume depends upon the magnitude and direction of the wind relative to vehicle velocity vector.

The other measurement technique, exposure profiling, offers distinct advantages for source-specific quantification of fugitive emissions from open dust sources. The method uses the isokinetic profiling concept that is the basis for conventional (ducted) source testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the effective cross section of the fugitive emissions plume. This technique uses a mass-balance calculation scheme similar

To characterize emissions from unpaved roads, one could use the geometric mean emission factor (i.e., the arithmetic mean of the log-transformed data). However, attempting to characterize emissions from data spanning several orders of magnitude, from extremely large mine haul trucks to light-duty vehicles on county roads, with a single valued emission factor is futile. As an alternative to a single valued mean, an emission factor may be presented in the form of a predictive equation derived by regression analysis of test data.

The general method employed in regression anlaysis is to first examine the physical forces that affect the dependent variable, to construct an empirical model reflective of those forces, then to use regression to provide a best fit. Such an equation mathematically relates emissions to parameters which characterize those measurable physical parameters having the most affect on the emissions. Possible parameters considered may be grouped into three categories:

1. Measures of source activity or energy expended (e.g., the speed, number of wheels, and weight of vehicles traveling on an unpaved road). As a practical matter useful vehicle-related parameters should be observable at a distance under normal traffic conditions. Most secondary parameters such as tire size, pressure, etc., are correlated with gross vehicle characteristics such as vehicle weight as related to the type of vehicle (light duty automobile, tractor trailer, etc.).

2. Properties of the material being disturbed (e.g., the content of suspendable fines in the surface material on an unpaved road or the moisture content of the surface material).

3. Climatic parameters (e.g., number of precipitation-free days per year during which emissions tend to be at a maximum).

An emission factor equation is useful if it is successful in "explaining" much of the observed variance in emission factor values on the basis of corresponding variances in specific source parameters. This enables more reliable estimates of source emissions on a site-specific basis. In general, an equation's success in explaining variance is gauged by the R-squared value. If an equation has an R-squared value of 0.47, then it is said to "explain" 47 percent of the variance in the set of emission factors.

It should be noted, however, that a high value of R^2 may sometimes prove misleading in developing an emission factor equation for a particular data set. For example, an equation may be "fine tuned" to the developmental data set by including an additional correction parameter, but in a manner that is contrary to the physical phenomena of the dust generation process. This was illustrated in a field study conducted for the Arizona Department of Environmental Quality (as described in Section 4) that found that inclusion of moisture and silt content as correction parameters would require that they enter into the equation in a manner opposite to common sense. That is to say, emissions would increase with increasing moisture content and would decrease with increasing silt content. In that instance, it is important to recognize that the goal of an emission factor equation is not to provide a near-perfect fit to the emission measurements in the developmental data base, but rather to provide reasonably reliable estimates of emissions for situations where no test data are available.

A generic emission factor equation is one that is developed for a source operation defined on the basis of a single dust generation mechanism that crosses industry lines. Clearly, vehicle travel over unpaved roads is not only a common operation in almost all industries but also represents a general, public source of particulate emissions.

Unpaved road source conditions encompass extreme variations. For example, average vehicle weights on unpaved roads (ranging from country roads to mining haul roads) easily span two orders of magnitude. Furthermore, there is also a wide range in surface material properties. Silt and moisture contents for the available test data span one and two orders of magnitude, respectively. Not surprisingly, these correction parameters (like the emission factor values) are better characterized by a log-normal rather than (arithmetic) normal distribution.

Furthermore, normal and log-normal distributions appear to fit other vehicle-related variables (speed and number of wheels) equally well. Because standard tests of significance assume normal parent populations, regression of log-transformed data is far more appropriate than regression of untransformed values. The log-linear regression results in a multiplicative model.

To establish its applicability, a generic equation should be developed from test data obtained in different industries. As will be discussed in Section 4, the approach taken to develop a new unpaved road equation has been to combine (to the extent possible) all emission tests of vehicles traveling over an unpaved surface. The combination is made without regard to previous groupings in AP-42. In particular, tests at surface coal mines are combined with tests of unpaved roads within other industries and tests of publicly accessible unpaved roads.

3.3 EMISSION DATA AND EMISSION FACTOR QUALITY RATING SCHEME USED FOR THIS SOURCE CATEGORY[1,2,5]

As part of the analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The uncontrolled emission factor quality rating scheme used for this source category represents a refinement of the rating system developed by EPA for AP-42 emission factors. The scheme entails the rating of test data quality followed by the rating of the emission factor(s) developed from the test data, as described below.

In the past, test data that were developed from well documented, sound methodologies were viewed equally and assigned an A rating. Although side-by-side studies would better define the differences in precision between upwind/downwind and profiling methodologies, historical experience has granted a greater degree of confidence in the ability of profiling to characterize the full particulate emissions plume. In this document, test data using sound, well documented profiling methodologies were assigned an A rating. Test data using sound, well documented upwind/downwind methodologies were assigned a B rating.

In evaluating whether an upwind-downwind sampling strategy qualifies as a sound methodology, the following minimum test requirements are used. At least five particulate measuring devices must be operated during a test, with one device located upwind and the others located at two downwind and three crosswind distances. The requirement of measurements at crosswind distances is waived for the case of line sources. Also wind direction and speed must be monitored concurrently on-site.

For upwind/downwind testing, it is generally assumed wind speed and direction are constant. To maintain a likeness of constant conditions, the downwind sampler should be shut down when the wind speed drops below 75 percent or raises above 125 percent of the predetermined design speed for periods longer than 3 minutes. Once the wind speed has returned to the acceptble range of 90 percent to 110 percent for 2 minutes, the downwind sampler should be restarted. Samplers should also be shut down when the wind direction varies by 10° or more from the predetermined design direction for longer than 3 minutes. Once the wind direction has returned to the acceptable range for two minutes, the samplers should be restarted. General procedure includes shutting down the upwind sampler during the same periods the downwind samples are shut down.[5]

The minimum requirements for a sound exposure profiling program are the following. A one-dimensional, vertical grid of at least three samplers is sufficient for measurement of emissions from line or high volume air sampler [illegible] a cyclone preseparator measured upwind concentrations at a 2 m height. Warm wire anemometers, located [illegible] heights of 1 and 5 m, measured wind speed. Road widths were not reported.

The unpaved road testing focused on particulate emissions from scraper travel and light-duty vehicles. Six uncontrolled scraper tests and three uncontrolled light duty vehicle tests were completed. In addition, watering was utilized as a control for two controlled scraper tests. The test data were assigned an "A" rating. Table 4-3 presents summary test data and Table 4-4 presents detailed test information.

4.2.3 Reference 3

Air Control Techniques, "PM10, PM2.5, and PM1 Emission Factors for Haul Roads at Two Stone Crushing Plants," for National Stone Association, Washington, D.C., November 1995.

This test program presents the results of sampling at two stone crushing plant quarries in August 1995. This study was undertaken to accurately measure PM-10, PM-2.5, and PM-1 emissions from a controlled haul road at a stone quarry. Testing occurred at Martin Marietta's Garner and Lemon Springs quarries in North Carolina.

Not a proper characterization?

The study used an upwind-downwind profiling technique that varied from the more commonly used exposure profiling method. Downwind samples were drawn into 10 sample nozzles 8 to 10 inches in diameter that joined a single downcomer connected to an 18 in. horizontal duct. The vertical sampling occurred approximately 3 m downwind of the source. The system maintained a total gas flow rate of approximately 2,500 acfm. Sampling occurred along the 18 in. horizontal duct using EPA Method 201A for in-stack measurements of PM-10. Particle distribution for downwind measurements were collected with a cascade impactor and a nephelometer. Upwind measurements were made using a hi-vol sampler at a height of 15 ft, a cascade impactor, and a nephelometer placed only a few meters upwind. The roads were 30 ft wide at both test sites. Analysis included polarizing light microscopy (PLM) that measured particles of combustion products. Wind direction was required to be ±60° of perpendicular to the line source.

Three emission tests were completed at both Garner and Lemon Springs. All samples were considered controlled through water application during the test periods. Specific water application rates were not reported, although the watering is said to have occurred approximately every 2.5 to 3 hours. Table 4-5 presents summary test data and Table 4-6 presents detailed test information. Noncombustible particulate for PM-10 and from 30 to 60 percent for TSP. A summary of emissions data is presented in Table 4-7 and detailed test information is presented in Table 4-8.

The study evaluated the independent haul road test data against the AP-42 Western Surface Coal Mine (Fourth Edition, Section 8.24, September 1988), the AP-42 Unpaved Road (Equation 2-1), and the Wyoming Department of Environmental Quality emission factor models and found none to adequately estimate independent emissions. With the exception of the generic AP-42 unpaved road emission factor (i.e., Equation 2-1) for PM-30, each model considered exhibited a systematic bias toward over- or under-prediction. It is important to note that the AP-42 Section 8.24 (now Section 11.9) haul road emission factor equation (Equation 4-1) generally performed no better in predicting the independent haul road emission factor results than did the "generic" unpaved road equation (Equation 2-1) in AP-42 Section 11.2 (now Section 13.2).

AP-42, Section 8.24, Haul Truck Emission Equation (now Section 11.9)

$$E_{30} = 0.0019\,(w)^{3.4}\,(L)^{0.2} \qquad \text{Equation 4-1}$$

where:

E_{30} = TSP emissions

w = mean number of wheels

L = land surface silt loading (g/m^2)

AP-42, Section 8.24 Vehicle Traffic (light/medium duty) Equation (now Section 11.9)

$$E_{30} = \frac{1.63}{(M)^{4.0}} \qquad \text{Equation 4-2}$$

where:

M = material moisture content (%)

Criteria? Against what standards?

The 1992 field study also provided new independent test data against which the performance of the Section 8.24 (now Section 11.9) factor (Equation 4-2) for light- to medium-duty traffic could be assessed. That same model was found to be capable of providing unacceptable estimates in some cases. This is believed to be the result of the model's dependence on the fourth power of moisture content. Again, the generic AP-42 unpaved road emission factor equation (Equation 2-1) performed at least as well as the equation in the surface

Need to demonstrate w/real #'s in comparisons

coal mining section (Equation 4-2). As noted in Section 4.3 of this report, these findings prompted thinking to combine all unpaved travel emission tests into one large data set for emission factor development.

The test data were assigned a rating of A. The report included adequate detail and the methodology meets the requirements for a sound exposure profiling system.

4.2.5 Reference 5

Entropy, "PM10 Emission Factors for a Haul Road at a Granite Stone Crushing Plant," for National Stone Association, Washington, D.C., December 1994.

This test report presents test data from measurements at a granite quarry in Knightdale, North Carolina. The testing program occurred in October 1994 and focused on PM-10 emissions from an unpaved haul road.

The testing protocols followed what the report termed a "push-pull method." Four 36-inch diameter circulating fans were utilized on the upwind side of the road and large hoods were located downwind to capture particulate emissions. Two sets of two hoods stacked vertically were collocated. A set of hoods consisted of two hoods each four ft high by seven ft wide with one located 2 ft and the other seven ft above the ground. The road width was 40 ft. Emissions captured in a set of hoods were drawn through a common 12 inch duct and sampled for PM-10 using EPA Method 201A. One hi-vol PM-10 ambient sampler was located upwind of the circulating fans. Wind speed and wind direction were also monitored.

Three controlled tests and four uncontrolled tests were performed. All seven tests utilized both sets of hoods and the results from both sets were averaged for the emission factor calculations. Testing was discontinued when wind speeds exceeded 3 mph. Controlled tests utilized water as the dust suppressant. For the controlled tests, watering occurred on average every 3.6 hr, however, the water application rate was not reported. Table 4-9 presents summary test data and Table 4-10 presents detailed test information.

Need to show technical reasons before the conclusion.

The "push-pull method" used for this study is not considered an accepted methodology for measuring open source particulate emissions. The colocated hoods showed an order of magnitude difference between the left and right hoods in the concentrations sampled in three out of seven tests. Strong evidence of recirculation of emissions to the upwind sampler is provided by the fact that the upwind concentrations increased by roughly an order of magnitude from the controlled to the uncontrolled tests. The low sampling height at relatively low wind conditions used for this test program potentially allows the particulate plume to pass over the sampling device without capture. The test data were assigned a "D" rating and were not used in the development of the AP-42 emission factor equation.

Maybe have been too harsh
How would data have influenced the results

4.2.6 Reference 6

Midwest Research Institute, "Unpaved Road Emission Impact,"for Arizona Department of Environmental Quality, March 1991.

This study performed field sampling on Arizona rural roads in Pima, Pinal, and Yuma counties. The study also recommended a mathematical model to estimate emissions from unpaved rural roads for arid and semiarid regions, based on a review of historical data as well as Arizona-specific field sampling results. Particle emission sizes of interest in this study were TSP and PM-10. Contrary to expectation, the examination of the historical data base did not find a systematic underprediction of emissions from unpaved roads in the arid portions of the Western United States.

Exposure profiling formed the basis of the measurement technique used at the Arizona sampling sites. For this study, two downwind arrays were deployed 5 m from the road. Each array had three sampling heads located at heights of 1, 3, and 5 m. One downwind unit was fitted with cyclone preseparators. The other downwind unit was equipped with cyclones for half the sampling periods and with standard high volume roofs for the other sampling periods. In addition, one pair each of high volume and dichotomous samplers were operated at a 100 ft downwind distance. No road widths were reported. Upwind measurements were obtained with a vertical array containing two sampling heads, a standard hi-vol sampler, and a dichotomous sampler. Wind speed was measured with warm wire anemometers at two heights (1 and 5 m), and wind direction was measured at a single height.

Surely MRI knows!

A total of 27 PM-10 and 9 TSP emission tests were conducted during May and June 1990. Vehicle passes were controlled during testing periods and three vehicle speeds were tested (35, 45, and 55 mph). The test data were assigned an "A" rating. Table 4-11 presents summary test data and Table 4-12 presents detailed test information. The report examined how well the data developed in the field tests agreed with the current version of the AP-42 emission factor.

Although the AP-42 equation provided reasonably accurate results when applied to the field tests conducted in this study, another emission factor model was developed. 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. As a result of the numerous industrial road tests, the data base generally reflected heavier vehicles than are common on rural roads. Given the interest in rural unpaved road emissions in Arizona, development of an empirical relationship specific to that situation was warranted.

4.2.7 Reference 7

Midwest Research Institute, "Roadway Emissions Field Tests at US Steels Fairless Works," for U.S. Steel Corporation, May 1990.

This testing program focused on paved and unpaved road particulate emissions at an integrated iron and steel plant near Philadelphia, Pennsylvania, in November 1989. Exposure profiling was used to characterize one unpaved road (Site "X") located near the center of the facility and used principally as a "shortcut" by light-duty vehicles.

Two tests were conducted using a profiling array, with sample heights from 1.5 m to 6.0 m, that measures downwind mass flux. A high-volume, parallel-slot cascade impactor was employed to measure the downwind particle distribution and a hi-vol sampler was utilized to determine the downwind TSP mass fraction. Road width was not reported. The upwind particle size distribution was determined with a standard high-volume/impactor combination.

The unpaved road was treated with chemical suppressants prior to and throughout the testing period. Therefore, the results of this test program were not included in the development of an uncontrolled unpaved road emission equation. The data may be used to estimate the degree of dust control provided by the chemical suppressants. The control efficiencies for PM-10 were estimated to be 80 to 90 percent. Control efficiencies for TSP were estimated at 70 percent to 80 percent for the unpaved road chemical suppressants. Table 4-13 presents summary information and Table 4-14 presents detailed test information.

4.2.8 Reference 8

<u>Midwest Research Institute, "Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads," for U. S. EPA, EPA-600/2-87-102, November 1987.</u>

This study obtained data on the control effectiveness of common dust suppressants used in the iron and steel industry. Tests were conducted from May through November, 1985, at LTV's Indiana Harbor Works in East Chicago, Indiana, and at Armco's Kansas City Works in Missouri. The testing program measured control performance for five chemical dust suppressants including two petroleum resin products (Coherex® and Generic 2), a emulsified asphalt (Petro Tac), an acrylic cement (Soil Sement), and a calcium chloride solution.

The exposure profiling methodology was utilized for all testing. The downwind exposure profiler contained sampling heads at 1.5, 3.0, 4.5, and 6.0 m. Particle size distribution was determined both upwind and downwind with high volume cascade impactors. Wind speed was monitored at two heights and wind direction was monitored at a single height. Road width was not reported.

A total of 64 tests were completed with seven uncontrolled tests and 57 controlled tests. Suppressants tested at Indiana Harbor Works were initially applied as follows: Petro Tac at 0.44 gal/yd^2, Coherex® at 0.56 gal/yd^2, and calcium chloride at 0.25 gal/yd^2. All five suppressants were tested at the Kansas City Works facility and were initially applied at the following rates: Petro Tac at 0.21 gal/yd^2, Coherex® at 0.21 gal/yd^2, Soil Sement at 0.16 gal/yd^2, Generic at 0.14 gal/yd^2, and calcium chloride at 0.24 gal/yd^2. A rating of "A" was assigned to the data. Testing followed an acceptable methodology and the test report was well documented.

Total particulate, IP, PM-10, and PM-2.5 were measured during this study. A control efficiency of 50 percent or greater was measured for all chemicals tested. Reapplication of the suppressant resulted in a notably higher level of control. A cost-effectiveness comparison found little variation between suppressants under the test conditions with the exception of a nonfavorable comparison of calcium chloride. Table 4-15 presents summary test data and Table 4-16 presents detailed test information.

The report also discussed the development of models to estimate the control efficiency of different chemical dust suppressants. As was discussed at the end of Section 2, various suppressants do not appear to affect the road surface characteristics in the same way. As a result, this makes performance models based on surface physical parameters unfeasible.

4.2.9 Reference 9

DRAFT

Midwest Research Institute, "Fugitive Emission Measurement of Coal Yard Traffic at a Power Plant," for Confidential Client, December 1985.

This study included seven tests of controlled, unpaved surfaces and four tests of uncontrolled, unpaved surfaces at a power plant. Data were given an "A" rating. Airborne particle size fractions of interest in this study are total particulate, TSP, IP, PM-10, and PM-2.5. A section of road within the facility's coal yard was tested in August 1985. The road was a permanent ramp up the main stockpile and is used by scrapers for both stockpiling and reclaiming operations.

Particulate emissions were characterized using three downwind exposure profilers, each consisting of four profiling heads at heights of 1.5, 3.0, 4.5 and 6.0 m. (The use of three profiling systems allowed continuous testing after water application by staggering the operation of the samplers.) Three high-volume, parallel-slot cascade impactors equipped with cyclone preseparators were used to characterize the downwind particle size distribution at a height of 2.2 m. One cyclone/impactor combination was used to characterize the upwind particle size distribution and total particulate concentration. Wind speed was measured with warm-wire anemometers at two heights (3 and 6 m) and wind direction was measured at a single height (4.5 m). Also, incoming solar radiation was measured with a mechanical pyranograph. Road width was not reported.

For the controlled tests, the road and surrounding areas were watered for approximately 30 minutes before the start of air sampling. Water was applied to the surface at a mean rate of 0.46 gal/yd^2 and found to provide effective control for 3 to 4 hours with 35 vehicle passes/hr. The control efficiency for TSP averaged 74 percent over the 3 hours and the PM-10 control efficiency averaged 72 percent over 3 hours. The control efficiency closely correlated to the surface moisture content, with a higher moisture content increasing the control efficiency. A summary of the emissions data is presented in Table 4-17 and detailed test information is presented in Table 4-18.

4.2.10 Reference 10

Midwest Research Institute, "Critical Review of Open Source Particulate Emission Measurements--Part II - Field Comparison," for Southern Research Institute, August 1984.

This report presents test results from a June, 1984, test at U.S. Steel's Gary Works in Gary, Indiana. The study was conducted to compare exposure profiling methodologies as used by five independent testing organizations to characterize fugitive emissions originating from vehicular traffic. The source tested was a paved road simulated as an unpaved road through the addition of exceptionally high road surface loading (600,000 lb/mile).

An exposure profiler with 5 sampling heads (located at heights of 1.5, 3.0, 4.5, 6.0, and 7.5 m) was used to characterize downwind emissions. Particle sizing was determined using cyclone/impactors located alongside the exposure profiler. Particle sizes of interest in this study included total particulate (TP), <30 μm, <15 μm, <10 μm , and <2.5μm in aerodynamic diameter. One cyclone/impactor and one cyclone were deployed upwind for background measurements. Warm wire anemometers measured wind speed at two heights (1.5 and 4.5 m). The road was reported to be 30 ft wide.

The material used to cover the road surface was a mixture of clay, iron ore and boiler ash. Reasonably good agreement was found between the AP-42 unpaved road emission factor equation and the emission data collected for the simulated unpaved road. However, the report noted that this was a surprising result for a number of reasons. First, the material (a mixture of clay, iron ore and boiler ash) used to simulate the surface is not typical of unpaved roads. There were also concerns about the homogeneity of the material spread over the five test sections. These problems were further complicated by the fact that the source conditions were not at a steady-state. Instead, the surface loading (mass of material per unit area) steadily decreased throughout the week of emission testing.

The three controlled conditions in this study included a 20 percent solution of emulsified asphalt (Petro Tac) applied at 0.7 gal/yd^2, water applied at 0.43 gal/yd^2, and a 20 percent solution of petroleum resin (Coherex®) applied at 0.83 gal/yd^2 followed by a repeat application of 12 percent solution 44 days later.

The control effectiveness was reported as the number of vehicle passes that occurred as the control efficiency decayed to zero. The initial asphalt emulsion application had an estimated lifetime of 91,000 vehicle passes for PM-10, the initial petroleum resin application had an estimated lifetime of 7,700 vehicle passes for PM-10, and the water application had an estimated lifetime of 560 vehicle passes for PM-10. Also, a reapplication of the petroleum resin had an estimated lifetime of 23,000 vehicle passes for PM-10.

relevance to this work ??

A cost effectiveness was calculated for each of the three controls as follows: the Petro Tac initial application was \$0.06/lb of PM-10 reduced; the Coherex® initial application was \$0.64/ lb of PM-10 reduced; the Coherex® reapplication was \$0.16/lb of PM-10 reduced; and the water application was \$1.30/lb of PM-10 reduced.

4.2.14 <u>Reference 14</u>

Midwest Research Institute, "Improved Emission Factors for Fugitive Dust From Western Surface Coal Mining Sources" for U. S. Environmental Protection Agency, Cincinnati, OH, July 1981.

This study was conducted to develop emission factors for major surface coal mining activities occurring in the western United States. Results are reported of testing conducted in 1979 and 1980 at three surface coal mines located in Wyoming, North Dakota, and New Mexico. Sampling was conducted on the following mining operations: drilling, blasting, coal loading, bulldozing, dragline operations, haul trucks, light- and medium-duty trucks, scrapers, graders, and wind erosion of exposed areas. Particulate sizes measured include, TSP, IP, and PM-2.5.

Exposure profiling was used to measure emissions from line source activities such as vehicle traffic on unpaved roads and from scraping and grading. Comparisons of data from profiling and upwind-downwind methods were made for scrapers and haul roads. A modified exposure profiling methodology was utilized for blasting emission measurements, and a wind tunnel was used to measure wind erosion emissions. Area source emissions such as coal loading were tested with an upwind/downwind methodology.

Experiment 14 was conducted on the limestone road, but it is not know whether at the same location as experiments 16 and 17. Experiment 18 was conducted at the glacial road.

Although specific data reduction methods are not described, it is assumed that a linear profile was used to characterize exposure values. As noted earlier, this would lead to maximum exposure at ground level and to a systematic high bias in the emission factors reported.

Because supporting documentation is not available, these data were not used during development of the emission factor equation.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTOR EQUATION

For unpaved roads, an emission factor equation is much more successful than a single-valued average in predicting particulate emissions at different sites with varying source parameters. This section describes the development of the emission factor equation that will be proposed for the updated AP-42 Unpaved Road section.

Various road surface and vehicle characteristics might have an impact on the particulate emissions from unpaved roads. Those parameters most likely to influence the particle emissions, while at the same time are able to be measured in a practical manner, are considered for the emission equation development. The possible parameters may be grouped into three categories: (a) measure of source activity (b) properties of the material being disturbed and (c) climatic parameters.

The measure of source activity includes the speed and weight of the vehicles traveling on the unpaved road. This category would also include the number of wheels of the vehicles in contact with the unpaved road. Subparameters that affect the particle emissions might also be considered; however, cost conscience efforts and clarity considerations for potential emission equation users have narrowed in-depth reviews of these subparameters. These subparameters may include the following: the turbulence created by the aerodynamics and clearance of the individual vehicle traveling on the unpaved road; the unique characterisics of the tire such as width, pressure, and tread design; angle of wheels compared to vehicle thrust; and wheel slippage over the unpaved road surface. Also, if extensive detailed traffic data were available for 15,000+ vehicle passes in the current data set, it would be possible to consider the relation of emissions of tangential wheel velocity compared to vehicle speed.

The properties of the material being disturbed includes moisture content and the content of the suspendable fines in the surface material. Although difficult to characterize within the magnitude of the available data, emissions could potentially be affected by interactions between dust particles of different physical characteristics. Conditions of the unpaved road may also be considered such as the characteristics of the road base (e.g., compacted, hardbase, washboard). Difficult to characterize variability in road conditions and resultant complexity of the emission equation were considered as basis for not including the road base characteristics in the emission factor equation.

Climatic characterization is generally reflected by the precipitation-free days per year on which emissions tend to be at a maximum. The radiant energy of the sun may be important when determining the control efficiency of watering, and in effect the average moisture content of the surface material. Direct moisture measurements are appropriate in this case.

The parameters readily measureable and applicable to a general unpaved road equation include surface silt content, surface moisture content, mean vehicle weight, mean vehicle speed, and mean number of wheels. Discussion of the analysis of these parameters continues later in this section.

The development of a revised unpaved road emission factor equation was built upon findings from the reviewed data sets. First, the decision was made to include all tests of vehicles traveling over unpaved surfaces. For example, tests of scrapers in the "travel mode" between cut and fill areas were included. Also, tests of very large off-road haul trucks used in the mining industry were also included in the developmental data set. On the other hand, graders blading an unpaved road were not included because of the low speed and the additional road surface disturbance involved. This decision had the effect of greatly expanding the historical data base. Not only are far more data available, but the data encompass a wider range of vehicle weights and travel speeds.

The decision to composite the data sets was based on findings from Reference 4, which dealt with the western surface coal mining industry. It was found that the general unpaved road emission factor equation (Equation 2-1) performed as well in estimating emissions from haul truck and light- to medium-duty vehicles as did factors developed specifically for those sources within western surface coal mines.

Next, the decision was made to add tests of watered roads to tests of uncontrolled roads, because moisture content is also affected by natural mitigation resulting from climatic factors. Chemically controlled unpaved roads were not included because those treatments cause lasting physical changes to the road surface. A review of the measurable physical characteristics (silt content and moisture content) of chemically controlled unpaved roads found no identifiable trends. Reference 8 examined the historical data base and concluded that a general control estimation method based on surface characteristics was not feasible.

The inclusion of both uncontrolled and watered roads was based on findings in the Reference 4 study. That study and a later review included moisture as a potential correction parameter in developing a predictive equation for unpaved roads. It was found that both the old (Reference 14, circa 1980) and new (Reference 4, 1992) haul truck data could be successfully fitted with one equation that applied to both watered and uncontrolled surfaces. The decision was also supported by a similar approach taken in developing the current AP-42 paved road equation. In that case controlled and uncontrolled tests were combined.

Inclusion of watered surfaces in the data base recognizes a fundamental difference in how the addition of water controls emissions (as opposed to the addition of other types of suppressants). First, the addition of water is a short-term control measure and is similar to the effect of rain. In addition, it causes no permanent change in the road surface characteristics. To an extent, one could argue that a road subject to frequent rain is no different than a road which is routinely watered.

Finally, the decision was made to focus on PM-10 emission tests. Because Equation 2-1 was developed earlier than the 1987 promulgation of the PM-10 NAAQSs, this represents a major departure from the way in which the current AP-42 factor was developed. The focus on PM-10 was also the approach taken in developing the newest AP-42 emission factor for paved roads. The approach requires that the models developed for different particle size ranges be "consistent," in the sense discussed below.

As a first step, the "developmental" data base was prepared from the test reports discussed in the previous section, with the following exceptions:

1. No test data were included from Reference 5. As noted earlier, these data were rated "D."

2. No data were included from Reference 7, because the unpaved road considered had been previously treated with a chemical dust suppressant. Also, individual tests of chemical dust suppressants in other references were not included.

Equations 4-1 and 4-2 represent the two candidate emission factor equations considered in this study. Initially, preference was given to Equation 4-1 because the inclusion of speed was viewed as providing additional predictive accuracy for instances involving very slow or very fast traffic. Furthermore, the resulting equation would (like the current AP-42 model) allow one to gauge the effect of speed reduction as a control technique. Equation 4-1 was initially chosen and validation of that model proceeded.

However, in the validation, it was found that almost no additional predictive accuracy was achieved and that the equation does not permit actual estimates of the effects of speed reduction. The inclusion of speed was highly dependent on the data set being used. For example, exclusion of only one or two low-speed tests from the data resulted in speed not entering the regression at even the 15 percent level of significance. On the other hand, dropping those tests had no effect on the other terms in the model. Thus, the four-parameter model (Equation 4-1) appeared to be relatively unstable.

Furthermore, the power to which speed is raised is not consistent with past studies. In Reference 6 and other older studies designed to assess the influence of vehicle speed on PM emissions, powers between 1 and 2 have been found. Note, however, that those studies were able to separately consider different speeds by supplying "captive" traffic during testing.

This is in pointed contrast to how the effect of speed is gauged in this study. Here, because data from many studies have been assembled and because the vast majority of tests do not rely on "captive" traffic, it is not possible to isolate the effect of speed on emissions. Without the benefit of captive traffic, it is not surprising that weight and speed are highly intercorrelated in the data set. Furthermore, speed and emissions are not significantly correlated in the developmental data set. In fact, there is a negative (although not significant) correlation between emission factor and speed.

It is crucially important to keep in mind that predictive accuracy is the goal of any emission factor equation. With this in mind, the predicted-to-actual ratios for Equation 4-1 were compared to those for Equation 4-2. The summary statistics follow:

	Equation 4-1 (with speed term)	Equation 4-2 (no speed term)
Minimum	0.104	0.100
Maximum	30.1	27.4

Geometric Mean	1.02	0.986
Geometric Std. Dev.	2.74	2.71

(Note that geometric rather than arithmetic statistics are used here. The reason for this choice is explained in Section 4.5.1). In comparing the two sets of statistics, it is clear that the inclusion of a speed term in Equation 4-1 lends almost no additional accuracy.

Nevertheless, it is obvious to anyone who has driven on an unpaved road that vehicle speed affects emissions, with faster vehicles generating more dust than slower ones. For this reason, it was decided to incorporate the findings of the captive traffic studies into the AP-42 section, independent of the emission factor equation.

So decision was that statistics were not valid?

In summary, the following emission factor equation is recommended for estimating PM-10 emissions from vehicles traveling over unpaved surfaces:

$$E_{10} = 1.6\ (s/12)^{0.8}\ (W/3)^{0.4}/(M/1)^{0.3} \qquad (4\text{-}3)$$

where:

E_{10} = PM-10 emission factor (lb/VMT)
s = surface material silt content (%)
W = mean vehicle weight (tons)
M = surface material moisture content (%)

Note that the "normalizing factors" of 12 percent silt and 3 tons are the same as for the current AP-42 model. This allows one to compare the leading term of 1.6 lb/VMT in Equation 4-3 to the factor of 2.1 lb/VMT inherent in the current version of the unpaved road predictive model.[d] This agrees with an earlier finding that "re-centering" the current factor to available PM-10 data would require reducing the leading term by about 30 percent.

$$E_{TSP} = 5.3\ (s/12)^{0.8}\ (W/3)^{0.5}/\ (M/1)^{0.4} \qquad (4\text{-}4)$$

[d] That is, the leading value of 5.9 (in Equation 2-1) times the aerodynamic particle size multiplier of 0.36 for PM-10.

	DRAFTGeometric mean ratio	
	PM-2.5 / PM-10	PM-15 / PM-10
Uncontrolled (n = 108)	0.140	1.53
Watered (n=20)	0.196	1.46
Overall (n=128)	0.148	1.52

No significant difference was found between the ratios for watered versus uncontrolled conditions, so the overall mean was applied. Furthermore, no significant correlation (at the 5 percent level) was found between either ratio and emission factor, silt, moisture, weight, speed, or number of wheels.

In summary, the following emission factor equation is recommended for inclusion in AP-42:

$$E = k\,(s/12)^{a}\,(W/3)^{b}\,(M/1)^{c} \qquad (4\text{-}5)$$

where: k, a, b and c are empirical constants given below and

E = size-specific emission factor (lb/vmt)
s = surface material silt content (%)
W = mean vehicle weight (tons)
M = surface material moisture content (%)

The parameters for size-specific emission factors in Equation 4-5 are given below:

Empirical constant	PM-2.5	PM-10	PM-15	PM-30
k	0.24	1.6	2.4	5.3
a	0.8	0.8	0.8	0.8
b	0.4	0.4	0.4	0.5
c	-0.3	-0.3	-0.3	-0.4

Based on the rating system given in Section 3.5, both the PM-10 and PM-30 emission factors are rated "A." The remaining factors are downgraded one letter because they were developed by scaling an A-rated model.

Would it not make a difference to view the PM 15, 30 PM 10 and PM 2.5 separately as "independent" data bases? Particles may act differently due only to size (eg static forces)...

BS! Such variability and low r²s does not warrant a result equal to stack testing a gas fired boilers!!

4.3.1 Validation Studies

DRAFT

A series of validation studies were undertaken to examine the predictive accuracy of the various emission factors recommended in the preceding section. Validation focused on the PM-10 model.

This section discusses the performance of the model primarily in terms of the predicted-to-measured ratio:

$$\frac{\text{emission factor predicted by model}}{\text{measured emission factor}}$$

As a practical matter, because of the log-linear regression used to develop the emission factor models, the log of the predicted-to-measured ratio is identical to the "residual" or error term:

residual = log(predicted) - log(measured) = log(predicted-to-measured)

Throughout this section, summary statistics are presented in terms of geometric mean and standard deviation. This follows directly from the use of log-linear regression. Furthermore, use of the geometric mean is clearly more appropriate to describe ratios than the arithmetic mean for the following reason. Unlike the arithmetic average, the geometric clearly represents the tendency of the ratio. For example, consider the following 10 (hypothetical) ratios:

Case	Predicted-to-measured	Measured-to-Predicted
1	0.678	1.47
2	1.48	0.68
3	2.76	0.36
4	0.885	1.13
5	0.754	1.33
6	0.248	4.03
7	1.87	0.53
8	0.126	7.94
9	1.76	0.57
10	3.15	0.32
Arithmetic mean	1.37	1.84
Geometric mean	0.95	1.05

This alone shows it does not warrant an A rating!

By using the arithmetic mean of the predicted-to-measured ratio of 1.37, one could argue that the predictions were about 37 percent higher than the measured. This would lead one to naturally expect that the measured values were roughly 37 percent lower than the predictions. However, it is seen that the arithmetic mean of the measured-to-predicted ratio is in fact 1.84 which is greater than 1.37. On the other hand, the geometric mean has the property that it is equal to the inverse of the mean for the inverse ratio.

In addition, because of the log-linear regression, the residuals are log-normally distributed. For this reason, logarithmic plots of the residuals are presented.

The first two PM-10 validations used the data base assembled for developing the model. The first made use of a cross-validation analysis of the PM-10 data set. In this approach, each data point is eliminated one at a time. The regression obtained from the "reduced" data base is used to estimate the missing data value. In this way, a set of "n" quasi-independent observations is obtained from the data set of "n" tests.

The PM-10 cross-validation (CV) shows that the model is fairly accurate for a very broad range of source conditions. Table 4-31 indicates that, although the model may slightly under- or overpredict emission for some specific subset of the data base, the general agreement is quite good. The CV analysis further found that, for the quasi-independent estimates of the measured emission factors:

1. 52 percent are within a factor of 2;
2. 73 percent are within a factor of 3;
3. 90 percent are within a factor of 5; and
4. 98 percent are within a factor of 10.

} ie NOT within realm of what one "expects" of A.

Plots of the residuals versus the PM-10 emission factor, silt, moisture, weight, speed and wheels are presented in Figures 4-1 through 4-6, respectively. In examining the PM-10 residuals (i.e., the error between the predicted and measured observed emission factors), it was found that Equation 4-5 tends to overpredict the lowest and underpredict the highest measured factors. In other words, the model appears to have a systematic bias at the extremes of the parent data base. This tendency is expected of models developed from regression techniques.

Compare the results of the "rejected" tests to their results.

The only other significant relationship found for the residuals in the PM-10 cross-validation involved the tendency of the equation to overpredict emissions for very slow speeds. The equation does not exhibit this bias for mean vehicle speeds 15 mph and higher. Figures 4-7 and 4-8 present separate residual plots for average vehicle speeds below and at 15 mph or higher, respectively. For the 19 tests conducted with an

Show distribution of each parameter about it's mean by stats similar to average speed less than 15 mph, the emission factor equation overpredicted by approximately 80 percent. In contrast, at speeds higher than 15 mph (and especially for speeds 45 to 55 mph) the residuals are symetrically distributed about the line of perfect agreement.

The finding that the equation overpredicts for very slow speeds also influences how to account for the emission reduction due to speed control. This overprediction suggests that speed reduction has a near linear effect on emissions. That is, for an approximately 50 percent reduction (i.e., from 30 mph to less than 15 mph) in speed, the emission factor is roughly 50 percent lower than expected (i.e., overpredicted by about 80 percent), this is consistent with the linear reduction based on the current AP-42 factor (Equation 2-1). For these reasons, a linear effect for speed reduction is included in the revised AP-42 section.

Is this not ignoring the statistics and replacing them with the "gut"?

A limited second validation of the PM-10 factor reserved approximately 20 to 25 percent of the data base for validation purposes. Test data were randomly selected for inclusion in either the "development" or the "validation" data set. Two separate random selections were performed. The development data set is used to develop the relationship which is used to estimate tests in the validation set. The first development set led to the following predictive equation for PM-10:

$$E = 1.55\ (s/12)^{0.78}\ (W/3)^{0.44}\ /\ M^{0.35} \qquad (4\text{-}6)$$

and Development Set 2 led to the following equation for PM-10:

$$E = 1.72\ (s/12)^{0.80}\ (W/3)^{0.43}\ /\ M^{0.26} \qquad (4\text{-}7)$$

Note that both development sets led to equations very similar to that in Equation 4-3. When the two models were used to predict data in the validation sets, the following summary statistics resulted:

Validation set	No. of cases	Ratio of predicted to measured			
		Minimum	Maximum	Geo. mean	Geo. std.dev.
1	n = 41	0.123	29.3	0.926	2.92
2	n = 40	0.125	6.58	1.27	2.63

Unlike the quasi-independent estimates obtained in the cross-validation, the above truly represent independent applications of an emission factor model developed through stepwise regression technique. For measured value observed is to be expected. Nevertheless, both the PM-2.5 and PM-15 factors in Equation 4-5 provide very acceptable estimates of measured emission factors.

4.4 DEVELOPMENT OF DEFAULT VALUES FOR ROAD SURFACE MATERIAL PROPERTIES

As noted earlier, all previous versions of the AP-42 unpaved road emission factor have included the road surface silt content as an input variable. The predictive equations recommended in the last section are no exception. AP-42 Section 13.2 has always stressed the importance of using site-specific input parameters to develop emission estimates. Recognizing that not all users will have access to site-specific information, AP-42 has included methods to allow readers to determine default values appropriate to their situation.[e]

Table 13.2.2-1 currently in AP-42 contains default silt information for various applications. As part of this update, the table was modified to (a) include updated information on construction sites and log yards and (b) reformat the information for publicly accessible roads. Item (a) was a relatively straightforward process. On the other hand, item (b) required a thorough reexamination, as described below.

Furthermore, it was necessary to develop default information for moisture content. Because moisture content is raised to such a low power (exponent of 0.3 in Equation 4-3), the use of default values should not result in unacceptable levels of uncertainty in the resulting emission estimates. For example, for uncontrolled industrial roads, when the recommended default value of 1 percent moisture is used, then 96 percent of the resulting emission factor estimates are within a factor of 2; 2 percent of the resulting emission factor estimates are within a factor of 1.5; and 52 percent of the resulting emission factor estimates are within a factor of 1.25 of the emission factor estimate based on the site-specific moisture content. Similarly, when a default value of 0.5 percent is used for publicly accessible roads in the developmental data set, all 43 of the resulting emission factor estimates are within a factor of 2 of the value based on site-specific moisture content.

In order to develop default information for publicly accessible unpaved roads, a data set of available silt and moisture contents was assembled. The 78 data points were collected either as part of a field emission

[e] The inclusion of the surface moisture content as an input variable is not considered to represent an undue burden on the users of AP-42. In particular, the methods presented in AP-42 Appendix C.2 require oven drying before sieving. In other words, determination of the silt content of a road surface sample requires that the moisture content of the sample also be determined. Thus, users of AP-42 who have already determined site-specific values for road surface silt content should have corresponding moisture content information available as well.

3. gravel vs. dirt roads

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were undertaken to determine if there existed significant differences in either moisture or silt content. The small-sample comparison of means test was used with the level of significance set at 10 percent. When appropriate, a one-sided alternative hypothesis was used. For example, one could reasonably expect, on an a priori basis, that on average

1. gravel roads have lower silt contents than dirt roads; and
2. moisture contents are lower in the western U.S. than in the East

When there was no a priori reason available, a two-sided alternative hypothesis was selected. For example, there was no reason to suspect that one set of gravel roads would have higher silt contents than the other. In that case, the alternative hypothesis selected was that the mean silt contents for eastern vs. western gravel roads are not equal.

Given the limitations ~~on the available~~ data set, it is not particularly surprising that the pairwise comparisons led to somewhat contradictory findings. For example, although the data set indicated that eastern dirt roads had a higher average moisture content than eastern gravel roads, that result was not found for western roads or for roads overall. Similarly, gravel surfaces were found to have a lower mean silt content than dirt when (a) only eastern roads and (b) all roads were compared. That is, no significant difference was found for silt contents between western gravel and dirt roads. Results from the pairwise comparisons are summarized below. In the table, "S" and "M" indicate that a significant different (10 percent level of significance) in the mean value of the silt and moisture content, respectively, was found in the comparison.

Comparison of gravel vs. dirt			Comparison of East vs. West		
East	S	M	Gravel	--	--
West		--	Dirt	--	M
Overall	S	--	Overall	--	--

In keeping with the findings summarized above, it was decided to provide separate default silt values for gravel and dirt roads, for use throughout the United States (i.e., no distinction between east and west). Furthermore, only one default moisture content would be provided for use on any type of publicly accessible unpaved road in the country. The default values for silt content are based on the corresponding mean values in the assembled data set:

	Mean Silt Content
Gravel Roads	6.4 percent
Dirt Roads	11 percent

The mean overall moisture content for the data set is 1.1 percent. However, this value substantially differs from the mean moisture content of 0.6 percent for tests of emissions from publicly accessible unpaved roads. It is recommended that this not serve as the basis for a default value in AP-42. Instead, a default value of 0.5 percent is recommended for publicly accessible unpaved roads.

4.5 SUMMARY OF CHANGES TO AP-42 SECTION

4.5.1 Section Narrative

The major revisions to AP-42 Section 13.2.2, Unpaved Roads, are as follows:

1. Text surrounding the emission factor equation was revised to reflect the new equation and provide more background information on how the equation was derived.

2. The discussion on defaults and quality ratings was substantially expanded. In particular, there is a description of the model's performance when used to predict emissions from very slow-moving traffic and a presentation of a default value for moisture content.

3. The extrapolation to annual conditions (incorporating natural mitigation) has been revised to reflect the variables contained in the new equation.

4. Section 13.2.2.3, "Controls," was re-organized and re-written. The section now begins with an overview of three basic control methods (vehicle restrictions, surface improvement, and surface treatment). Extensive new material was added to address the effect of speed reduction and watering on fugitive dust emissions from unpaved roads. A new method for "prospective" analysis based on class A pan evaporation was added. Slight revisions were made to the material presented for chemical unpaved road dust suppressants.

5. The revised Table 13.2.2-1 is as follows [bold indicates additions, strikeouts indicate deletions]:

Explain

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9/3/97

[Draft] Table 13.2.2-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road Use Or Surface Material	Plant Sites	No. Of Samples	Silt Content (%)	
				Range	Mean
Copper smelting	Plant road	1	3	16 - 19	17
Iron and steel production	Plant road	19	135	0.2 - 19	6.0
Sand and gravel processing	Plant road (process or non-process area?)	1	3	4.1 - 6.0	4.8
	[Yard area	**1**	**1**	**-**	**7.1]**
Stone quarrying and ~~processing~~	Plant road (NON-PIT)	2	10	2.4 - 16	10
	~~Haul road~~	~~1~~	~~10~~	~~5.0 - 15~~	~~9.6~~
	[Haul road (TO PIT)	**4**	**20**	**5.0-15**	**8.3]**
Taconite mining and processing	Service road	1	8	2.4 - 7.1	4.3
	Haul road	1	12	3.9 - 9.7	5.8
Western surface coal mining	Haul road (to/from pit)	3	21	2.8 - 18	8.4
	Access road (no/few large trucks?)	2	2	4.9 - 5.3	5.1
	Scraper route	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
[Construction sites	**Scraper routes**	**7**	**20**	**0.56-23**	**8.5]**
[Lumber sawmills	**Log yards**	**2**	**2**	**4.8-12**	**8.4]**
~~Rural roads~~	~~Gravel/crushed limestone~~	~~3~~	~~9~~	~~5.0 - 13~~	~~8.9~~
	~~Dirt~~	~~7~~	~~32~~	~~1.6 - 68~~	~~12~~
~~Municipal roads~~	~~Unspecified~~	~~3~~	~~26~~	~~0.4 - 13~~	~~5.7~~
Municipal solid waste landfills	Disposal routes	4	20	2.2 - 21	6.4
[Publicly accessible roads	**Gravel/crushed limestone**	**9**	**46**	**0.10-15**	**6.4**
	Dirt	**8**	**24**	**0.83-68**	**11]**

[a] References 1,5-16.

What do data show for east/west site w/o regard to activity at site?

Constants for Equation 1 based on the stated aerodynamic particle size

Constant	PM-2.5	PM-10	PM-15	PM-30
k (lb/VMT)	0.24	1.6	2.4	5.3
a	0.8	0.8	0.8	0.8
b	0.4	0.4	0.4	0.5
c	-0.3	-0.3	-0.3	-0.4
Quality rating	B	A	B	A

Write 'em out!
make it as easy/simple to
follow as possible

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This is preliminary material, in draft form, for purposes of review. This material must not be quoted, cited, or in any other way considered or used as final work.

used for real application until final and approval

13.2.2 Unpaved Roads

13.2.2.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

Would an alternate approach be to look at the mechanical lifting and air forces separately?

13.2.2.2 Emissions Calculation And Correction Parameters[1-5]

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on source parameters that characterize the condition of a particular road and the associated vehicle traffic. Characterization of these source parameters allow for "correction" of emission estimates to specific road and traffic conditions.

Dust emissions from unpaved roads have been found to vary directly with the fraction of silt (particles smaller than 75 micrometers [μm] in diameter) in the road surface materials.[1] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen, using the ASTM-C-136 method. Table 13.2.2-1 summarizes measured silt values for industrial and public unpaved roads.

For PM-10 and PM-2.5, is "silt" still the appropriate variable for future work? May be finer segregation is needed

Since the silt content of a rural dirt road will vary with geographic location, it should be measured for use in projecting emissions. As a conservative approximation, the silt content of the parent soil in the area can be used. Tests, however, show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

i.e. what variations in size occur within "SILT"?

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Draft Table 13.2.2-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road Use Or Surface Material	Plant Sites	No. Of Samples	Silt Content (%)	
				Range	Mean
Copper smelting	Plant road	1	3	16 - 19	17
Iron and steel production	Plant road	19	135	0.2 - 19	6.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
	Yard area	1	1	-	7.1
Stone quarrying and processing	Plant road	2	10	2.4 - 16	10
	Haul road	4	20	5.0-15	8.3
Taconite mining and processing	Service road	1	8	2.4 - 7.1	4.3
	Haul road	1	12	3.9 - 9.7	5.8
Western surface coal mining	Haul road	3	21	2.8 - 18	8.4
	Access road	2	2	4.9 - 5.3	5.1
	Scraper route	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Construction sites	Scraper routes	7	20	0.56-23	8.5
Lumber sawmills	Log yards	2	2	4.8-12	8.4
Municipal solid waste landfills	Disposal routes	4	20	2.2 - 21	6.4
Publicly accessible roads	Gravel/crushed limestone	9	46	0.1-15	6.4
	Dirt	8	24	0.83-68	11

[a]References 1,5-16.

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A stepwise regression of the results from field measurements of PM-10 emissions and TSP emissions (or its surrogate - PM-30 emissions) was used to develop the predictive equation given below for size-specific emissions from vehicles traveling over unpaved surfaces. Both uncontrolled and watered roads were included in the data base of 180 PM-10 and 92 TSP tests. Estimates of PM-2.5 and PM-15 emissions were developed from the PM-10 predictive equation and mean PM-2.5 to PM-10 ratios and PM-15 to PM-10 ratios. Refer to Background Report?

This does not seem to describe sufficiently what was done.

The following empirical expression may be used to estimate the quantity in pounds (lb) of size-specific particulate emissions from an unpaved road, per vehicle mile traveled (VMT):

$$E = k\,(s/12)^{a}\,(W/3)^{b}\,(M/1)^{c} \qquad (1)$$

where k, a, b and c are empirical constants (Reference 6) given below and

E = size-specific emission factor (lb/VMT)
s = surface material silt content (%)
W = mean vehicle weight (tons)
M = surface material moisture content (%)

Write out each equation. PM-15 Not needed

The source characteristics s, W and M are referred to as correction parameters for adjusting the emission estimates to local conditions. The metric conversion from lb/VMT to grams (g) per vehicle kilometer traveled (VKT) is as follows:

$$1 \text{ lb/VMT} = 281.9 \text{ g/VKT}$$

The constants for Equation 1 based on the stated aerodynamic particle sizes are shown in Table 13.2.2-2.

Draft Table 13.2.2-2. CONSTANTS FOR EQUATION 1

Constant	PM-2.5	PM-10	PM-15	PM-30*
k (lb/VMT)	0.24	1.6	2.4	5.3
a	0.8	0.8	0.8	0.8
b	0.4	0.4	0.4	0.5
c	-0.3	-0.3	-0.3	-0.4
Quality rating	B	A	B	A

* Assumed equivalent to TSP

Table 13.2.2-2 also contains the quality ratings for the various size-specific versions of Equation 1. The equation retains the assigned quality rating, if applied within the ranges of source conditions, shown in Table 13.2.2-3, that were tested in developing the equation:

used in Prudopty

Draft Table 13.2.2-3. RANGE OF SOURCE CONDITIONS FOR EQUATION 1

Surface Silt Content, %	Mean Vehicle Weight		Mean Vehicle Speed		Mean No. of Wheels	Surface Moisture Content, %
	Mg	ton	km/hr	mph		
1.2-35	1.4-260	1.5-290	8-88[a]	5-55[a]	4-7[a]	0.03-20

[a] See discussion in text.

As noted earlier, Equation 1 was developed from tests of traffic on unpaved surfaces, either uncontrolled or watered. Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall or watering, because of traffic-enhanced natural evaporation. (Factors influencing how fast a road dries are discussed in Section 13.2.2.3, below.) The quality ratings given above pertain to the mid-range of the measured source conditions for the equation. A higher mean vehicle weight and a higher than normal traffic rate may be justified when performing a worst-case analysis of emissions from unpaved roads.

It is important to note that the vehicle-related source conditions refer to the average weight, speed, and number of wheels for all vehicles traveling the road. For example, if 98 percent of traffic on the road are 2-ton cars and trucks while the remaining 2 percent consists of 20-ton trucks, then the mean weight is 2.4 tons. More specifically, Equation 1 is *not* intended to be used to calculate a separate emission factor for each vehicle class within a mix of traffic on a given unpaved road. That is, in the example, one should *not* determine one factor for the 2-ton vehicles and a second factor for the 20-ton trucks. Instead, only one emission factor should be calculated that represents the "fleet" average of 2.4 tons for all vehicles traveling the road.

Furthermore, although mean vehicle speed and the mean number of wheels do not explicitly appear in the predictive equation, these variables should be considered when determining quality ratings. During the validation of Equation 1, it was found that the predictive equation tends to overpredict emissions for very slow mean vehicle speeds. The equation does not exhibit this bias for mean vehicle speeds of at least 15 mph.

For an average vehicle speed less than 15 mph, ~~it is recommended that~~ the result from Equation 1 could be multiplied by the following factor for a reasonable correction, but to be conservative it is best to use it as presented. (15 - S)/15 where S is average vehicle speed (mph). The quality rating should be downgraded 1 letter

Moreover, to retain the quality ratings when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt and moisture contents are given in AP-42 Appendices C.1 and C.2. Vehicle-related parameters should be developed by recording visual observations of traffic. In some cases, vehicle parameters for industrial unpaved roads can be determined by reviewing maintenance records or other information sources at the facility.

In the event that site-specific values for correction parameters cannot be obtained, then default values may be used. A default value of 2.2 tons is recommended for the mean vehicle weight on publicly accessible unpaved roads. (It is assumed that readers addressing industrial roads have access to the information needed to develop average vehicle information for their facility.) In the absence of site-specific silt content information, an appropriate mean value from Table 13.2.2-1 may be used as a default value, but the quality rating of the equation is reduced by two letters. Because of significant differences found between different types of road surfaces and between different areas of the country, use of the default moisture content value of 0.5 percent for dry conditions is discouraged. The quality rating should be downgraded two letters when the default moisture content value is used.

The effect of routine watering to control emissions from unpaved roads is discussed below in Section 13.2.2.3, "Controls". However, all roads are subject to some natural mitigation because of rainfall and other precipitation. Equation 1 can be extrapolated to annual average uncontrolled conditions (but including natural mitigation) under the simplifying assumption that emissions occur at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable (more than 0.254 mm [0.01 inch]) precipitation:

$$E_{ext} = k\,(s/12)^a\,(W/3)^b\,(M_{dry}/1)^c\,[(365 - p) / 365] \qquad (2)$$

where s, W, k, a, b and c are as given earlier and

E_{ext} = annual size-specific emission factor extrapolated for natural mitigation, lb/VMT
M_{dry} = surface material moisture content under dry conditions, %
p = number of days with at least 0.254 mm (0.01 in) of precipitation per year (see below)

The quality ratings for Equation 2 are two letters lower than those given earlier for Equation 1.

DRAFT

Equation 1, the control measure must effectively reduce the fleet average speed. In order to substantially reduce the speed of all vehicles, this control option is most applicable to rural public roads. However, effective enforcement of the new speed limit may prove problematic.

The control efficiency afforded by speed reduction should be considered as linear. Thus, if the average speed is effectively reduced by 30 percent (e.g., from 50 to 35 mph), then a control efficiency of 30 percent should be applied to the emission factor. Past testing programs have used "captive" traffic to tightly control vehicular characteristics. These tests involve very short periods (1 to 2 hr) of increased or reduced travel speeds. Under these conditions , it was found that emissions depend upon speed raised to a power between 1 and 2. However, if the long-term, average speed is reduced on an unpaved road, the road surface silt content can be expected to change. In other words, the silt content will reach a new equilibrium condition as the grinding of material is balanced by the emission process. It is strongly recommended that, at the end of 6 months, a new road surface sample be collected and analyzed (in the manner described in Appendices C.1 and C.2). The new surface silt content should then be used in Equation 1 for calculation of a new uncontrolled emission factor, without further adjustment for speed.

You think anyone will do this?

Surface improvements. Control options in this category alter the road surface. As opposed to the "surface treatments" discussed below, improvements are relatively "permanent" and do not require periodic retreatment.

The most obvious surface improvement is paving an unpaved road. This option is quite expensive and is probably most applicable to relatively short stretches of unpaved road with at least several hundred vehicle passes per day. Furthermore, if the newly paved road is located near unpaved areas or is used to transport material, it is essential that the control plan address routine cleaning of the newly paved road surface.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions. The predictive emission factor equation for paved roads, given in Section 13.2.4, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto unpaved shoulders (berms) also must be taken into account in estimating the control efficiency of paving.

$$C = 100 - [(0.0012\ A\ D\ T) / I] \quad (3)$$

where: C = average control efficiency (%)

A = mean annual class A pan evaporation, as discussed below (in.)

D = average hourly daytime traffic rate (vehicles/hr)

I = water application intensity (gal/yd^2)

T = time between water applications (hr)

explain?

Figure 13.2.2-2 presents the geographical distribution for Class A pan evaporation for the United States. The above equation should be used for prospective analyses and for designing watering programs for existing roadways. The quality rating of an emission factor for a watered road that is based on Equation 3 should be downgraded 2 letters.

As opposed to watering, chemical dust suppressants have much less frequent reapplication requirements. These materials suppress emissions by changing the physical characteristics of the existing road surface material. Many chemical unpaved road dust suppressants form a hardened surface that binds particles together. After several applications, a treated road often resembles a paved road except that the surface is not uniformly flat. Because the improved surface results in more grinding of small particles, the silt content of loose material on a highly controlled surface may be substantially higher than when the surface was uncontrolled. For this reason, Equation 1 cannot be used to estimate emissions from chemically stabilized roads. Should the road be allowed to return to an uncontrolled state with no visible signs of large-scale cementing of material, Equation 1 could then be used to obtain conservatively high emission estimates.

The control effectiveness of chemical dust suppressants ~~depends~~ appears to depend on a) the dilution rate used in the mixture; b) the application rate (volume of solution per unit road surface area); c) the time between applications; d) the size, speed and amount of traffic during the period between applications; and e) meteorological conditions (rainfall, freeze/thaw cycles, etc.) during the period. Other factors that affect the performance of dust suppressants include other traffic characteristics (e.g., cornering, "track-on" from unpaved areas) and road characteristics (e.g., bearing strength, grade). The variabilities in the above factors and differences between individual dust control products make the control efficiencies of chemical dust suppressants difficult to ~~calculate~~ estimate. Past field testing of emissions from controlled unpaved roads has shown that chemical dust suppressants provide a general overall PM-10 control efficiency of about 80 percent when applied at regular intervals.

DRAFT

Petroleum resin products historically have been the dust suppressants (besides water) most widely used on industrial unpaved roads. Figure 13.2.2-3 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads.[19] Several items should be noted:

1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (*not solution*) applied since the start of the dust control season.

2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 13.2.2-3 presents control efficiency values averaged over 2 common application intervals, 2 weeks and 1 month. Other application intervals will require interpolation.

3. Note that zero efficiency is assigned until the ground inventory reaches 0.05 gallon per square yard (gal/yd^2). determined how? what's a rule of thumb as default?

As an example of the application of Figure 13.2.2-3, suppose that the equation was used to estimate an emission factor of 7.1 lb/VMT for PM-10 from a particular road. Also, suppose that, starting on May 1, the road is treated with 0.221 gal/yd^2 of a solution (1 part petroleum resin to 5 parts water) on the first of each month through September. Then, the average controlled emission factors, shown in Table 13.2.2-4, are found:

Draft Table 13.2-2-4. EXAMPLE OF AVERAGE CONTROLLED EMISSION FACTORS FOR SPECIFIC CONDITIONS

Period	Ground Inventory, gal/yd^2	Average Control Efficiency, %[a]	Average Controlled Emission Factor, lb/VMT
May	0.037	0	7.1
June	0.073	62	2.7
July	0.11	68	2.3
August	0.15	74	1.8
September	0.18	80	1.4

[a]From Figure 13.2.2-3, ≤ 10 μm. Zero efficiency assigned if ground inventory is less than 0.05 gal/yd^2.
1 lb/VMT = 281.9 g/VKT. 1 gal/yd^2 = 4.531 L/m^2.

Rons Comments
Rcvd 9/19/97

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Date: September 12, 1997

Subject: Review and Update of AP-42 Sections in Chapters 11, 12, and 13 Covering Mineral Products Industries, Metallurgical Industries and Miscellaneous Sources
EPA Contract 68-D2-0159, Work Assignment 4-02
MRI Project 4604-02

From: Greg Muleski BLS for

To: Ron Myers
EPA/EFIG/EMAD (MD-14)
U. S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

Attached is an addendum to the report entitled "Emission Factor Documentation for AP-42, Sections 11.2.5 and 11.2.6" (dated March 8, 1993). That report consolidated sections 11.2.5 (Urban Paved Roads) and 11.2.6 (Industrial Paved Roads)into a single paved road section (now numbered 13.2.1). Because it relied on "old" data supporting sections 11.2.5 and 11.2.6, the March 8, 1993 only discussed the additional test data reviewed in the process of updating the paved road emission factor equation. In other words, the 1993 report did not describe the older paved road test data, which had been discussed in previous AP-42 updates.

However, since the time that the March 8, 1993 became available, users of the TTN 2000 have inquired about the test data not described in the report. Presentation of that data is a key feature of the addendum attached to this memo. The addendum also updates the public paved road silt loading data base as well as AP-42 Section 13.2.1 itself.

Also attached is a copy of the comment/response log prepared for the March 8, 1993 report. Comments were provided by:

1. William Barnard of E. H. Pechan;
2. Gary Neuroth of the Arizona DEQ; and
3. Doug Cole of Idaho DEQ.

Copies of their letters are attached as well. The log presents the verbatim comments of the reviewers as well as MRI's response to the comment.

This memo, the addendum and the comment/response log are also being submitted in electronic form, so that those materials can be posted on EPA's BBS.

1.0 ADDENDUM NO. 1--PAVED ROADS SECTIONS 13.2.1

This document is an addendum to *Emission Factor Documentation for AP-42, Sections 11.2.5 and 11.2.6, Paved Roads*, EPA Contract No. 68-D0-0123, Assignment 44, dated March 8, 1993 and prepared for the Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency (EPA). Since the preparation of the 1993 document, the Fifth edition of AP-42 incorporated Sections 11.2.5, Paved Urban Roads, and 11.2.6, Industrial Paved Roads, into Section 13.2.1, Paved Roads. An update to AP-42 Section 13.2.1 is warranted to address the U. S. EPA's recent focus on particulate matter (PM) emissions less than 2.5 μm in aerodynamic diameter (PM-2.5) and to permit the reexamination of test information on public road surface silt loadings.

Information in this Addendum includes descriptions of the test reports used to develop the current emission factor equation in AP-42, Section 13.2.1; a narrative of the reexamination of the road surface silt loading data base; and a summary of changes included in the AP-42 Paved Road Section including the new emission factor equation multiplier for PM-2.5. The format for this Addendum is as follows: (a) Section 1.1 - Test Report Descriptions, (b) Section 1.2 - Revision of the Public Paved Road Silt Loading Default Values, (c) Section 1.3 - Summary of Changes to AP-42 Section 13.2.1, (d) Section 2 - a copy of the revised AP-42 Section 13.2.1, (e) Attachment 1 - Comments/Response Logs for external review comments on the March 8, 1993 Paved Road Background Document , and (e) Attachment 2 - Public Paved Road Surface Loading AP-42 data base.

1.1 <u>Section 1--Test Report Descriptions</u>

Test reports containing data used to develop the paved road emission factor equation in the March 8, 1993, Paved Road Background Document, are discussed in the following subsections. Summary emission data and detailed test data from each of the four test reports are provided along with a brief description of each test site and test methodology.

Profiling methodologies are used for these test reports and include the following test parameters: (a) downwind test equipment should be located approximately 5 meters from the source, (b) background equipment should be located approximately 15 meters upwind of the source, (c) wind direction must remain within 45° of perpendicular to the path of the moving source for two consecutive 10 minute averaging periods during testing, (d) mean wind speed must not move outside of the 4 to 20 mph range more than 20 percent of the sampling period, (e) and no disturbances should exist immediately upwind or downwind of the testing location. When following standard testing methodologies some vehicle heights may exceed the height of the sampling equipment; however, the fact that the emissions originate at the road curve and the emission plume can be characterized as decreasing with height indicates the total plume can be estimated. Vehicle heights are not generally reported in the source test reports. Analyses for silt content of the road surface follow methodologies described in Appendix C.1 and Appendix C.2 of AP-42. Moisture content was reported for several of these paved road studies. Variations from the generally accepted test methodology stated above or any other nontraditional methodology are discussed within the individual test report reviews. Test reports were not down graded on their qualities ratings due to unreported data if it was not significant to the paved road emission factor equation development.

1.1.1 Reference 1 - Midwest Research Institute, Roadway Emissions Field Tests at US Steel's Fairless Works, for U.S. Steel Corporation, May 1990.

This testing program focused on paved and unpaved road PM emissions at an integrated iron and steel plant near Philadelphia, Pennsylvania, in November 1989. Exposure profiling was used to characterize emissions from two paved roads. Site C-1 was located along the main access route and had a mix of light- and medium-duty vehicles. Site E-2 was located near the southwest corner of the plant and the traffic consisted mostly of plant equipment.

Tests were conducted using a profiling array, with four sampling heights from 1.5 m to 6.0 m, for measuring the downwind mass flux of airborne PM. A high-volume sampler with a parallel-slot cascade impactor and a cyclone preseparator (cutpoint of 15 μmA) was employed to measure the downwind particle size distribution, and a standard high-volume sampler was utilized to determine the downwind mass fraction of total suspended particulate matter (TSP). The upwind (background) particle size distribution was determined with a high-volume cyclone/ impactor combination. Warm wire anemometers at two heights measured wind speed.

Eight tests were conducted at Site C-1 and four tests were conducted at Site E-2. The paved road test sites were considered uncontrolled. The road width, moisture content, and mean number of wheels were not reported. The test data are assigned an A rating. Table A1-1 presents summary information and Table A1-2 presents detailed test information. Warm wire anemometers at two heights measured wind speed.

1.1.2 Reference 2 - Midwest Research Institute, *Paved Road Particulate Emissions - Source Category Report*, for U.S. EPA, July 1984

This document reports the results of testing of paved roads conducted in 1980 at sites in Kansas City, MO, St. Louis, MO, Tonganoxie, KS, and Granite City, IL. Paved road test sites included commercial/industrial roads, commercial/residential roads, expressways, and a street in a rural town. The expanded measurement program reported in this document was used to develop emission factors for paved roads and focused on the following particle sizes: PM-15 (inhalable particulate matter [IP]), PM-10, and PM-2.5.

Total airborne PM emissions were characterized using an exposure profiler containing four sampling heads. High-volume samplers with size selective inlets (SSI) having a cutpoint of 15 μmA were

TABLE A1-1. SUMMARY INFORMATION FOR REFERENCE 1

Operation	Location	State	Test dates	No. of tests	TSP emission factor, lb/VMT		PM-10 emission factor, lb/VMT	
					Geom. mean	Range	Geom. mean	Range
Vehicle traffic	AU-X (Unpaved road)	PA	11/89	2	0.61	0.39-0.96	0.16	0.14-0.18
Vehicle traffic	Paved road	PA	11/89	6	0.033	0.012-0.12	0.0095	0.0009-0.036
Vehicle traffic	Paved road	PA	11/89	4	0.078	0.033-0.30	0.022	0.0071-0.036

1 lb/VMT = 281.9 g/VKT.

TABLE A1-2. DETAILED INFORMATION FROM PAVED ROAD TESTS FOR REFERENCE 1

Test runs	PM-10 emission factor, lb/VMT	Duration, min	Meterorology		Vehicle characteristics			Silt loading, g/m^2	Silt, %
			Temperature, °F	Mean wind speed, mph	No. of vehicle passes	Mean vehicle weight, ton	Mean vehicle speed[a]		
AU-C-3	0.00497	103	50	12	836	5.5	(27)	0.42	10
AU-C-4	0.0355	147	63	11	1057	6.0	(2	0.52	12
AU-C-5	0.0337	120	62	14	963	3.9	29	0.23	9.7
AU-C-6	0.00816[c]	187	39	14	685	6.2	(27)	0.23	8.6
AU-C-7	0.000887	96	42	12	703	3.0	(27)	0.26	7.7
AU-C-8	0.0174	218	40	15	779	2.0	(27)	0.15	9.9
AU-E-1	0.00709	154	43	12	210	12	15	4.0	17
AU-E-2	0.0234	89	44	13	373	5.1	16	4.0	17
AU-E-3	0.0355	118	41	9.3	330	2.6	(15)	2.2	18
AU-E-4	0.0199	130	41	9.3	364	2.6	(15)	1.3	15

[a]Value in parentheses is the average speed measured for test road during the field exercise.
[b]Test conducted on a paved road surface vacuum-swept five times per week.
[c]Mean TSP/TP or PM10/TP ratio applied.
1 lb/VMT = 281.9 g/VKT.
1 g/m^2 = 1.434 gr/ft^2

used to characterize upwind and downwind PM-15 concentrations. A high-volume sampler with a SSI and an cascade impactor was also located downwind to characterize particle size distribution within the PM-15 component. Upwind and downwind standard high-volume samplers measured TSP concentrations. Warm wire anemometers at two heights measured wind speed.

A total of 19 paved road emission tests were conducted in four cities. These included four tests of commercial/industrial paved roads, ten tests of commercial/residential paved roads, four expressway tests, and one test of a street in a rural town. Additionally, as part of this study, 81 dust samples were collected in 12 cities. The mean number of vehicle wheels was not reported. The test data are assigned an A rating. Table A1-3 presents summary test data and Table A1-4 presents detailed test information.

1.1.3 Reference 3 - Midwest Research Institute, *Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads*, for U. S. EPA, January 1983

This document reports the results of testing conducted in 1981 and 1982 at industrial unpaved and paved roads and at rural unpaved roads. Unpaved industrial roads were tested at a sand and gravel processing facility in Kansas, a copper smelting facility in Arizona, and both a concrete batch and asphalt batch plant in Missouri. The study was conducted to increase the existing data base for size-specific PM emissions. The following particle sizes were of specific interest for the study: PM-15, PM-10, and PM-2.5.

Exposure profiling was utilized to characterize total PM emissions. Five sampling heads, located at heights of up to 5 m, were deployed on the profiler. A standard high-volume sampler and a high-volume sampler with an SSI (cutpoint of 15 μmA) were also deployed downwind. In addition, two high-volume cyclone/impactors were operated to measure particle size distribution. A standard high-volume sampler, a high-volume sampler with an SSI, and a high-volume cyclone/impactor were utilized to characterize the upwind TSP and PM-15 concentrations and the particle size distribution within the PM-15 fraction. Wind speed was monitored with warm wire anemometers.

A total of 18 paved road tests and 21 unpaved road tests are completed. The test data are assigned an A rating. Industrial paved road tests were conducted as follows: three unpaved road tests at the sand and gravel processing plant, three paved road tests at the copper smelting plant, four paved road tests at the asphalt batch facility, and three paved road tests at the concrete batch facility. The industrial road tests were considered uncontrolled and were conducted with heavy duty vehicles at the sand and gravel processing plant and with medium duty vehicles at the asphalt batch, concrete batch, and copper smelting plants. Table A1-5 presents summary test data and Table A1-6 presents detailed test information.

TABLE A1-3. SUMMARY INFORMATION FOR REFERENCE 2

Operation	State	Test dates	No. of tests	PM-15 emission factor, lb/VMT		PM-10 emission factor, lb/VMT		PM-2.5 emission factor, lb/VMT	
				Geom. mean	Range	Geom. mean	Range	Geom. mean	Range
Commercial/Industrial	MO	2/80	4	0.0078	0.0036 - 0.013	0.0068	0.0034 - 0.011	0.0045	0.0030 - 0.0063
Commercial/Residential	MO, IL	2/80	10	0.0021	0.0006 - 0.012	0.0017	0.0004 - 0.0093	0.0011	0.0002 - 0.0037
Expressway	MO	5/80	4	0.0004	0.0002 - 0.0008	0.0004	0.0002 - 0.0007	0.0002	0.0001 - 0.0003
Rural Town	KS	3/80	1	0.031	0.031	0.025	0.025	0.005	0.005

1 lb/VMT = 281.9 g/VKT.

Ref 1 & 2 data
R² = -.63
A = .0762
B = -.01969
PM10 = -ln x + .076

15 .022857
25 .0127947
35 6.166426x10⁻³
45 1.215635x10⁻³
55 -
48 ~ 0

PM-10
x̄ = 9.5488 x10⁻³
σ = .011319

geo
x̄ 29.478
σ = 1.438

TABLE A1-4. DETAILED INFORMATION FOR PAVED ROAD TESTS FOR REFERENCE 2

Category	Run test No.	PM-10 emission factor, lb/VMT	Duration, min.	Temp., °F	Mean wind speed, mph	Road width, ft	No. of vehicle passes	Mean vehicle speed, mph	Mean vehicle weight, tons	Silt loading, g/m^2	Silt (%)
Commercial/Industrial	M-1	0.0110	120	28	7.4	44	2,627	30	5.6	0.46	10.7
Commercial/Industrial	M-2	0.00340	86	27	6.5	44	2,166	30	3.8	0.26	6.2
Commercial/Industrial	M-3	0.00781	120	28	7.8	44	2,144	30	4.5	0.15	3.5
Commercial/Industrial	M-9	0.00712	136	50	7.4	44	3,248	30	4.1	0.29	12.2
Commercial/Residential	M-4	0.000400	240	38	7.8	36	2,763	35	2.1	0.43	18.8
Commercial/Residential	M-5	0.00153	226	53	2.2	36	2,473	35	2.2	1.00	21.4
Commercial/Residential	M-6	0.00304	281	35	5.6	36	3,204	30	2.1	0.68	21.7
Commercial/Residential	M-13	0.00680	194	60	2.7	22	5,190	35	2.7	0.11	13.7
Commercial/Residential	M-14	0.00301	178	55	9.2	22	3,940	35	2.7	0.079	-
Commercial/Residential	M-15	0.00323	135	77	11.4	22	4,040	35	2.7	0.047	8.1
Commercial/Residential	M-17	0.00582	150	75	4.0	40	3,390	30	2.0	0.83	5.7
Commercial/Residential	M-18	0.000800	172	75	5.1	40	3,670	30	2.0	0.73	7.1
Commercial/Residential	M-19	0.000390	488	70	2.7	20	5,800	30	2.4	0.93	8.6
Expressway	M-10	0.000390	182	60	2.9	96	11,148	55	4.5	0.022	-
Expressway	M-11	0.000700	181	56	8.7	96	11,099	55	4.8	0.022	-
Expressway	M-12	0.000190	150	65	4.7	96	9,812	55	3.8	0.022	-
Expressway	M-16	0.000530	254	70	4.0	96	15,430	55	4.3	0.022	-
Rural Town	M-8	0.0247	345	50	4.7	30	1,975	20	2.2	2.50	14.5

1 lb/VMT = 281.9 g/VKT.
1 g/m^2 = 1.434 gr/ft^2

$\bar{X} = 4.492 \times 10^{-3}$
σ_{n-1} 5.961 $\times 10^{-3}$

geo $\bar{X} = 35.02$, $\sigma = .2787$
norm $\bar{X} = 36$, $\sigma = 10.82$

$\bar{X} = .472$, σ .608
geo $\bar{X}$ .19, σ 4.71

$R^2 = .239$
$A = -6.209$
$B = .512$
$\ln \frac{PM\text{-}10}{silt} = .512 \ln V - 6.209$
15 → 8.067 $\times 10^{-3}$
25 → .01048
35 → .0124
45 = .0142
65 = .0157

$R^2 = -.67$
$A = .056048$
$B = -.014497$
$PM10 = -.014 \ln X + .056$
15 → 0.01679
25 → 9.382 $\times 10^{-3}$
35 → 4.504 $\times 10^{-3}$
45 → 8.609 $\times 10^{-4}$
55 (@ 47) = 0

TABLE A1-5. SUMMARY OF PAVED ROAD EMISSION FACTORS FOR REFERENCE 3

Industrial category	Type	TP, lb/VMT		PM-15, lb/VMT		PM-10, lb/VMT		PM-2.5, lb/VMT	
		Geo. mean	Range	Geo. mean	Range	Geo. mean	Range	Geo. mean	Range
Asphalt Batching	Medium duty	1.83	0.750-3.65	0.437	0.124-0.741	0.295	0.0801-0.441	0.130	0.0427-0.214
Concrete Batching	Medium duty	4.74	2.25-7.23	1.66	0.976-2.34	1.17	0.699-1.63	0.381	0.200-0.562
Copper Smelting	Medium duty	11.2	7.07-15.7	4.01	2.02-5.56	2.78	1.35-3.86	0.607	0.260-0.846
Sand and Gravel Processing	Medium dDuty	5.50	4.35-6.64	1.02	0.783-1.26	0.633	0.513-0.753	0.203	0.194-0.211

1 lb/VMT = 281.9 g/VKT.

TABLE A1-6. DETAILED INFORMATION FOR PAVED ROAD TESTS FOR REFERENCE 3

Run No.	Industrial category	Traffic	PM-10 emission factor, lb/VMT	Duration, min.	Mean wind speed, mph	Road width, ft	No. of vehicle passes	Vehicle characteristics: Mean vehicle weight, tons	Vehicle characteristics: No. of wheels	Vehicle characteristics: Mean vehicle speed, mph	Moisture content, %	Silt loading, g/m²	Silt, %
Y-1	Asphalt Batching	Medium Duty	0.257	274	5.37	13.8	47	3.6	6	10	0.22	91	2.6
Y-2	Asphalt Batching	Medium Duty	0.401	344	4.70	14.1	76	3.7	7	10	0.51	76	2.7
Y-3	Asphalt Batching	Medium Duty	0.0801	95	6.04	14.1	100	3.8	6.5	10	0.32	193	4.6
Y-4	Asphalt Batching	Medium Duty	0.441	102	5.59	14.1	150	3.7	6	10	0.32	193	4.6
Z-1	Concrete Batching	Medium Duty	0.699	170	6.71	24.3	149	8.0	10	10	a	11.3	6.0
Z-2	Concrete Batching	Medium Duty	1.63	143	9.84	24.9	161	8.0	10	15	a	12.4	5.2
Z-3	Concrete Batching	Medium Duty	4.01	109	9.62	24.9	62	8.0	10	15	a	12.4	5.2
AC-4	Copper Smelting	Medium Duty	3.86	38	8.72	34.8	45	5.7	7.4	10	0.43	287	19.8
AC-5	Copper Smelting	Medium Duty	3.13	36	9.62	34.8	36	7.0	6.2	15	0.43	188	15.4
AC-6	Copper Smelting	Medium Duty	1.35	33	4.92	34.8	42	3.1	4.2	20	0.53	400	21.7
AD-1	Sand and Gravel	Heavy Duty	3.27	110	7.61	12.1	11	42	11	23	a	94.8	6.4
AD-2	Sand and Gravel	Heavy Duty	0.753	69	5.15	12.1	16	39	17	23	a	63.6	7.9
AD-3	Sand and Gravel	Heavy Duty	0.513	76	3.13	12.1	20	40	15	23	a	52.6	7.0

1 lb/VMT = 281.9 g/VKT.
1 g/m² = 1.434 gr/ft²
a Not measured.

$\bar{X}$ = 1.568
σ_{n-1} 1.463

r^2 = .157
A = .450477774
B = .450286891
PM-10 = ln v + B

$\bar{X}$ = 11.98
σ_{n-1} = 1.78
$\bar{X}$ = 14.92
σ_{n-1} 5.5296

1.1.4 Reference 4 - Midwest Research Institute, *Iron and Steel Plant Open Source Fugitive Emission Control Evaluation*, for U. S. EPA, August 1983

This test report centered on the measurement of the effectiveness of different control techniques for PM emissions from fugitive dust sources in the iron and steel industry. The test program was performed at two integrated iron and steel plants, one located in Houston, Texas, and the other in Middletown, Ohio. Control techniques to reduce emissions from paved roads, unpaved roads, and coal storage piles were evaluated. For paved roads, control techniques included vacuum sweeping, water flushing, and flushing with broom sweeping. Particle emission sizes of interest in this study were total PM, PM-15, and PM-2.5.

The exposure profiling method was used to measure paved road particulate emissions at the Iron and Steel plants. For this study, a profiler with four or five sampling heads located at heights of 1 to 5 m was deployed. Two high-volume cascade impactors with cyclone preseparators (cutpoint of 15 μmA), one at 1 m and the other at 3 m, measured the downwind particle size distribution. A standard high-volume sampler and an additional high-volume sampler fitted with a SSI (cutpoint of 15 μmA) were located downwind at a height 2 m. One standard high-volume sampler and two high-volume samplers with SSIs were located upwind for measurement of background concentrations of TSP and PM-15.

Twenty-three paved road tests of controlled and uncontrolled emissions were performed. These included 11 uncontrolled tests, 4 vacuum sweeping tests, 4 water flushing tests, and 4 flushing and broom sweeping tests. For paved roads, this test report does not present vehicle speeds, mean number of wheels, or moisture contents. Because vehicle speeds and moisture content do not figure into the emission equation, the test data are assigned an A rating. Table A1-7 presents summary test data and Table A1-8 presents detailed test information. The PM-10 emission factors presented in Table A1-8 were calculated from the PM-15 and PM-2.5 data using logarithmic interpolation.

After vacuum sweeping, emissions were reduced slightly more than 50 percent for two test runs and less than 16 percent for two test runs. Water flushing applied at 0.48 gal/yd^2 achieved emission reductions ranging from 30 percent to 70 percent. Flushing at 0.48 gal/yd^2 combined with broom sweeping resulted in emission reductions ranging from 35 percent to 90 percent.

TABLE A1-7. SUMMARY OF PAVED ROAD EMISSION FACTORS FROM REFERENCE 4

Control method	Location	State	Test date	No. of tests	TP, lb/VMT		PM-15, lb/VMT		PM-2.5, lb/VMT	
					Geo mean	Range	Geo mean	Range	Geo mean	Range
None	A,D,F,J	OH	7/80, 10/80, & 11/80	7	1.22	0.29-5.50	0.38	0.13-2.14	0.10	0.04-0.52
Vacuum Sweeping	A	OH	10/80 & 11/80	4	0.87	0.53-1.46	0.45	0.27-0.87	0.14	0.08-0.26
Water Flushing	D,L	TX	6/81	4	1.43	1.30-1.74	0.47	0.32-0.65	0.08	0.08-0.09
Flushing & Broom Sweep	K,L,M	TX	6/81	4	0.96	0.54-2.03	0.20	0.10-0.49	0.07	0.04-0.13
None	L,M	TX	6/81	4	3.12	0.83-5.46	0.92	0.31-1.83	0.26	0.06-0.62

1 lb/VMT = 281.9 g/VKT.

TABLE A1-8. DETAILED INFORMATION FOR PAVED ROAD TESTS FROM REFERENCE 4

Site	Test Run No.	Control method	PM-10 emission factor, lb/VMT	Duration, min.	Temp., °F	Mean wind speed, mph	No. of vehicle passes	Mean vehicle weight, tons	Silt loading, g/m^2	Silt, %
A	F-34	None	0.536	62	90	4.2	79	28	2.79	16
A	F-35	None	0.849	127	90	7.5	130	25	2.03	10.4
A	F-36	VS	0.147	335	50	5.9	263	3.3	0.202	18.3
A	F-37	VS	0.209	241	50	4.8	199	17	0.043	26.4
A	F-38	VS	0.430	127	50	4.5	141	18	0.217	27.9
A	F-39	VS	0.686	215	50	6.4	190	18	0.441	19.6
D	F-61	None	1.35	108	40	11.0	93	40	17.9	21.0
D	F-62	None	0.929	77	45	12.1	94	36	14.4	20.3
D	F-74	WF	1.32	205	50	9.0	67	29	5.59	9.45
F	F-27	None	0.357	91	100	9.5	158	14	17.7	35.7
F	F-45	None	0.608	135	50	4.0	172	16	5.11	28.4
J	F-32	none	0.144	259	90	5.8	301	14	0.117	13.4
K	B-52	FBS	0.0946	60	90	2.9	119	12	7.19	34.3
L	B-50	FBS	0.230	104	90	5.6	123	9.4	13.6	28.2
L	B-51	FBS	0.435	93	90	4.2	127	11	13.6	28.2
L	B-54	WF	0.268	101	90	5.4	118	10	3.77	22.6
L	B-55	WF	0.575	82	90	8.5	98	11	6.29	19.6
L	B-56	WF	0.398	61	90	6.3	118	9.2	2.40	11.2
L	B-58	None	1.08	96	90	6.7	67	18	10.4	17.9
M	B-53	FBS	0.161	81	90	5.3	72	20	--	9.94
M	B-57	0.554	None	101	90	3.6	68	12	2.32	6.45
M	B-59	0.993	None	114	90	6.1	67	11	2.06	14.0
M	B-60	1.18	None	112	90	5.0	50	12	3.19	13.5

[a]Average of 2+ values
[b]Sample used for more than 1 run.
[c]PM-10 emission factors were calculated from the PM-15 and PM-2.5 data using logarithmic interpolation.
VS = Vacuum sweeping; WF = Water flushing; FBS = Water flushing and broom sweeping; 1 lb/VMT = 281.9 g/VKT; 1 g/m^2 = 1.434 gr/ft^2

References for Section 1

1. *Roadway Emissions Field Tests at U.S. Steel's Fairless Works*, U.S. Steel Corporation, Fairless Hills, PA, USX Purchase Order No. 146-0001191-0068, May 1990.

2. *Paved Road Particulate Emissions—Source Category Report*, U. S. Environmental Protection Agency, Research Triangle Park, NC, EPA Contract No. 68-02-3158, Assignment 19, July 1984.

3. *Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads*, U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA Contract No. 68-02-3158, Assignment 12, January 1983.

4. *Iron and Steel Plant Open Source Fugitive Emission Control Evaluation*, U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA Contract No. 68-02-3177, Assignment 4, August 1983.

5. *Emission Factor Documentation for AP-42, Sections 11.2.5 and 11.2.6—Paved Roads*, EPA Contract No. 68-D0-0123, Midwest Research Institute, Kansas City, MO, March 1993.

Where is the data from the Denver studies? Is that in the previous background report?

1.2 Revision of the Public Paved Road Silt Loading Default Values

During the preparation of the March 8, 1993 Paved Road Background Document[1], the available public road silt loading ("sL") values from test reports dated 1992 and earlier were assembled into a data base. Appendices C.1 and C.2 to AP-42 describe the sampling and analysis procedures, respectively, used to determine sL values.

Although hundreds of public paved road sL measurements had been collected from 1980 until 1992 [2-10], the paved road sL data base was limited in its usefulness for various reasons:

1. Almost two-thirds of the available data had been collected in one state (Montana).

2. Only Montana had collected extensive data that addressed temporal variation of sL. While this provided very useful information on the annual cycle of silt loadings, the data were not generally transferable to most regions in the United States.

3. There had been no uniformity in either the sampling/analysis methods used to generate sL values or in schemes used to report roadway classifications.

4. Examination of the data base did not reveal any meaningful relationship between silt loading and other variables (such as average daily traffic [ADT], road class, etc.). For example, a significant negative correlation was found between sL and ADT for roads with ADTs of 5,000 or more. However, on further investigation of that road class, it was found that there was a significant positive and a significant negative correlation over the first and second halves, respectively, of the calendar year.

5. There were strong reasons to suspect that the assembled data base was skewed towards high values:

- The majority of measurements were collected during the first calendar half (which was found to have substantially higher values than the second half).
- There was anecdotal information that at least some of the sampling programs focused on suspected trouble spots that were heavily loaded (such as after snow/ice storms, near construction sites, etc.).

Note that the assembled data base was composed of "point values" of silt loading. Here the term "point value" is used to denote samples collected at a specific point along a roadway and at a single point in time. In this sense, the term is contrasted with "composite" samples, for which increments from different roadways and/or from different times are aggregated in a single vacuum bag. The resulting composite sample thus represents a spatially or temporally averaged value of silt loading. At the time the data base was assembled, two sets of spatial averages were available –one set covering the South Coast Air Quality Management District (REF 11) and another from three study areas in Oregon (REF 12). Because of their composite nature, these measurements were not included in the data base assembled for the 1993 background document.

This implies that a composite sample is superior to point values. Composite values may have as many limitations as unrelated point values without full documentation of significant site characteristics. The roads will have mixed speed limits, mixed ADT per lane, mixed curbing etc.

No report of the number of lanes to ADT/lane
" " " speeds or speed limit
No report of actual or potential trackout locations near the sample collection area
No report of significant " (sanding, meteorological parameters immediately prior to sampling)

Point values may have superior usefulness if the site characteristics are adequately documented (ADT/lanes, speed, trackout locations, sand additions etc.)

Although there were strong reasons to suspect that the assembled data base was ~~skewed~~ biased towards high values, independent data were not available to confirm the suspicions. Since the time that the background document was prepared, a number of field sampling programs have been undertaken, including:

TABLE A2-1. PAVED ROAD SILT LOADING
STUDIES SINCE THE 1993 BACKGROUND REPORT

Reference	Study description
13	A characterization of control measures to reduce mud/dirt carryout onto paved roads from a construction site in Kansas City
14	Collection of late winter/early spring silt loadings in the Pocatello, Idaho area, emphasizing post-storm conditions
15	A yearlong study to define temporal variations of silt loading on roads in the Reno, Nevada area.
16	Collection of sets of spatially averaged silt loadings in four study areas of the desert southwest: South Coast, Coachella Valley, Las Vegas, Bakersfield
17	An ongoing study to track silt loading trends over a yearlong period in the Pocatello, Idaho area

Note that the first two studies in Table A2-1 were directed to higher values of sL due to their focus on mud/dirt carryout and post-winter storm conditions. As such, results from these two studies were excluded from further consideration in revising the public road silt loading values. Data from the second Pocatello study (Reference 17) were not available at the time of this addendum.

Results from References 15 and 16, together with results from the composite samples in References 11 and 12 and the silt loading values from the recent PM-2.5/PM-10 study[18] for baseline road surface conditions (i.e., not immediately after road sanding), formed the basis for revising the default values for public paved road silt loading. Summary statistics for this data set follow:

Individual sample results should be presented as well. If available road characteristics (such as ADT, # lanes, speed limit) should be presented as well

TABLE A2-2. SUMMARY STATISTICS FOR RECENT PAVED ROAD SILT LOADING STUDIES

Data set	Sample size	Silt loading, g/m^2				
		Range	Geo. mean	Geo. std. dev.	Median	90th percentile
High ADT[a]	50	0.01 - 1.02	0.093	3.13	0.086	0.38
Low ADT	103	0.054 - 6.82	0.41	2.64	0.39	1.52
Overall	169[b]	0.01 - 6.82	0.26	3.34	0.27	1.05

[a]In this context, high ADT refers to roadways with at least 5,000 vehicles per day.
[b]The overall data set includes 16 spatially average samples that included increments from both high and low ADT roads.

When the results in Table A2-2 are compared to those presented in Table 13.2.1-2 of AP-42, it becomes immediately apparent that the current default guidance in Section 13.2 leads to overly conservative values for silt loading. Values in the newer data set are roughly 5 times lower than those in the data set compiled for the 1993 background document. Consequently, it is recommended that AP-42 Table 13.2.1-2 be modified to include the (rounded) median values from Table A2-2 for "normal" conditions. However, the newer data set also indicates that substantially higher than "normal" silt loadings can occur on public paved roads. As a result, it is further recommended that the modified AP-42 table present the former median values for the January-to-June period as suitable for use when estimates of elevated silt loading (e.g., after snow/ice controls or near trackout areas) are desired.

Additional revisions are recommended for default values for limited access roads. Reference 18 presents the results from not only baseline sampling, but also samples collected immediately after sanding an interstate highway in Denver:

Baseline: 0.0127 g/m^2

After sanding: 0.184 g/m^2

After averaging the baseline with the older data for limited access roads, the recommended default for limited access roads under "normal" conditions is 0.015 g/m^2. Furthermore, the section text has been revised to suggest a default value of 0.2 g/m^2 for short periods of time following the application of snow/ice controls (antiskid abrasives) to limited access roads.

References for Section 1.2

1. *Emission Factor Documentation For AP-42, Sections 11.2.5 and 11.2.6 — Paved Roads*, EPA Contract No. 68-D0-0123, Midwest Research Institute, Kansas City, MO, March 1993.

2. Cowherd, Jr., and P. J. Englehart, *Paved Road Particulate Emissions*, EPA-600/7-84-077, U.S. Environmental Protection Agency, Cincinnati, OH, July 1984.

3. *Montana Street Sampling Data*, Montana Department Of Health And Environmental Sciences, Helena, MT, July 1992.

4. *Street Sanding Emissions And Control Study*, PEI Associates, Inc., Cincinnati, OH, October 1989.

5. *Evaluation Of PM-10 Emission Factors For Paved Streets*, Harding Lawson Associates, Denver, CO, October 1991.

6. *Street Sanding Emissions And Control Study*, RTP Environmental Associates, Inc., Denver, CO, July 1990.

7. *Post-storm Measurement Results — Salt Lake County Road Dust Silt Loading Winter 1991/92 Measurement Program*, Aerovironment, Inc., Monrovia, CA, June 1992.

8. Written communication from Harold Glasser, Department of Health, Clark County (NV).

9. *PM-10 Emissions Inventory Data For The Maricopa And Pima Planning Areas*, EPA Contract No. 68-02-3888, Engineering-Science, Pasadena, CA, January 1987.

10. *Characterization Of PM-10 Emissions From Antiskid Materials Applied To Ice- And Snow-covered Roadways*, EPA Contract No. 68-D0-0137, Midwest Research Institute, Kansas City, MO, October 1992.

11. *Open Fugitive Dust PM10 Control Strategies Study*, South Coast Air Quality Management District Contract No. 90059, Midwest Research Institute, Kansas City, MO, July 1990.

12. *Oregon Fugitive Dust Emission Inventory*, EPA Contract No. 68-D0-0123, Work Assignment No. 24, Midwest Research Institute, Kansas City, MO, January 1992.

13. *Characterization of Mud/Dirt Carryout onto Paved Roads from Construction and Demolition Activities*, EPA Contract No. 68-D2-0159, Work Assignment No. I-04, Midwest Research Institute, Kansas City, MO, December, 1995.

14. Letter Report to Doug Cole, Idaho Operations Office, EPA Region 10, dated April 30, 1993, EPA Contract 68-D0-0123, Work Assignment II-76.

15. Personal communication with Andy Goodrich of Washoe County Department of Health, Reno, NV.

16. *Improvement of Specific Emission Factors (BACM Project No. 1)*, South Coast Air Quality Management District Contract No. 95040, Midwest Research Institute, Kansas City, MO, March 1996.

17. Personal communication with J. Light, c/o Bannock Planning Organization, Pocatello, ID.

18. *Fugitive Particulate Matter Emissions*, EPA Contract No. 68-D2-0159, Work Assignment No. 4-06, Midwest Research Institute, Kansas City, MO, April 1997.

1.3 Summary of Changes to AP-42 Section 13.2.1

Although the equation for particulate emissions from paved roads remains unchanged, the PM-2.5 multiplier has been updated based on findings in Reference 22. The PM-2.5 multiplier update is reflected in the list of particle size multipliers for the paved road equation. Also, the default silt loading (sL) values for public paved roads have been updated. Table 13.2.1-2 has been revised along with associated text to reflect this new analysis. The silt loading data base, formerly presented as Table 13.2.1-3, will only be available as an electronic file. also the newer data base

Section 13.2.1 follows with text removed from the old AP-42 version striked out and new text in bold. Although not shown here, no changes were made to Figure 13.2.1-1, and Figures 13.2.1-2 through 13.2.1-7 (showing the silt loading frequency distribution) have been removed from the AP-42 section.

13.2.1 Paved Roads

The majority of these emissions come from the engine exhaust and resuspended road dust.

13.2.1.1 General

Particulate emissions occur whenever vehicles travel over a paved surface, such as a road or parking lot. In general terms, particulate emissions from paved roads originate from the loose material present on the surface. In turn, that surface loading, as it is moved or removed, is continuously replenished by other sources. At industrial sites, surface loading is replenished by spillage of material and trackout from unpaved roads and staging areas. Figure 13.2.1-1 illustrates several transfer processes occurring on public streets.

Various field studies have found that public streets and highways, as well as roadways at industrial facilities, can be major sources of the atmospheric particulate matter within an area.[1-9] Of particular interest in many parts of the United States are the increased levels of emissions from public paved roads when the equilibrium between deposition and removal processes is upset. This situation can occur for various reasons, including application of snow and ice controls, carryout from construction activities in the area, and wind and/or water erosion from surrounding unstabilized areas.

13.2.1.2 Emissions And Correction Parameters

Dust emissions from paved roads have been found to vary with what is termed the "silt loading" present on the road surface as well as the average weight of vehicles traveling the road. The term silt loading (sL) refers to the mass of silt-size material (equal to or less than 75 micrometers [µm] in physical diameter) per unit area of the travel surface.[4-5] The total road surface dust loading is that of loose material that can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. The silt fraction is determined by measuring the proportion of the loose dry surface dust that passes through a 200-mesh screen, using the ASTM-C-136 method. Silt loading is the product of the silt fraction and the total loading, and is abbreviated "sL". Additional details on the sampling and analysis of such material are provided in AP-42 Appendices C.1 and C.2.

However, for the majority of the county and during the majority of the year, the road surface loadings are at a much lower equilibrium level. This equilibrium level is dependent upon many characteristics of the road, ~~the~~ characteristics of the area near the road and the traffic using the road. It is believed that the most significant characteristics influencing road surface loadings are speed, track out sites, vehicle volume per lane and the predominant type of vehicle using the road. Other characteristics also may influence the road surface loadings.

The surface sL provides a reasonable means of characterizing seasonal variability in a paved road emission inventory.[9] In many areas of the country, road surface loadings are heaviest during the late winter and early spring months when the residual loading from snow/ice controls is greatest. ~~Surface loadings are~~

13.2.1.3 Predictive Emission Factor Equations[10]

The quantity of dust emissions from vehicle traffic on a paved road may be estimated using the following empirical expression:

$$E = k\,(sL/2)^{0.65}\,(W/3)^{1.5}$$

where:

E = particulate emission factor (having units matching the units of k)

k = base emission factor for particle size range and units of interest (see below)

sL = road surface silt loading (grams per square meter) (g/m^2)

W = average weight (tons) of the vehicles traveling the road

It is important to note that Equation 1 calls for the average weight of all vehicles traveling the road. For example, if 99 percent of traffic on the road are 2 Mg cars/trucks while the remaining 1 percent consists of 20 Mg trucks, then the mean weight "W" is 2.2 Mg. More specifically, Equation 1 is *not* intended to be used to calculate a separate emission factor for each vehicle weight class. Instead, only one emission factor should be calculated to represent the "fleet" average weight of all vehicles traveling the road.

The particle size multiplier (k) above varies with aerodynamic size range as ~~follows:~~ **shown in Table 13.2.1-1.**

Table 13.2.1-1. PARTICLE SIZE MULTIPLIERS FOR PAVED ROAD EQUATION

Size range[a]	Multiplier k[b]		
	g/VKT	g/VMT	lb/VMT
PM-2.5[c]	~~2.1~~	~~3.3~~	~~0.0073~~
	1.1	**1.8**	**0.0040**
PM-10	4.6	7.3	0.016
PM-15	5.5	9.0	0.020
PM-30[cd]	24	38	0.082

[a] Refers to airborne particulate matter (PM-x) with an aerodynamic diameter equal to or less than x micrometers.

[b] Units shown are grams per vehicle kilometer traveled (g/VKT), grams per vehicle mile traveled (g/VMT), and pounds per vehicle mile traveled (lb/VMT). The multiplier k includes the ~~conversion~~ values to convert from the mixed units into the units of interest.

[c] **Ratio of PM-2.5 to PM-10 taken from Reference 22.**

[cd] PM-30 is sometimes termed "suspendable particulate" (SP) and is often used as a surrogate for TSP.

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The above equation is based on a regression analysis of numerous emission tests, including 65 tests for PM-10.[10] Sources tested include public paved roads, as well as controlled and uncontrolled industrial paved roads. No tests of "stop-and-go" traffic were available for inclusion in the data base. The equations retain the quality rating of A (B for PM-2.5), if applied within the range of source conditions that were tested in developing the equation as follows:

Silt loading:	0.02 - 400 g/m^2
	0.03 - 570 grains/square foot (ft^2)
Mean vehicle weight:	1.8 - 38 megagrams (Mg)
	2.0 - 42 tons
Mean vehicle speed:	16 - 88 kilometers per hour (kph)
	10 - 55 miles per hour (mph)

To retain the quality rating for the emission factor equation when it is applied to a specific paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. **With the exception of limited access roadways, which are difficult to sample, the collection and use of site-specific sL data for public paved road emission inventories are strongly recommended**. The field and laboratory procedures for determining surface material silt content and surface dust loading are summarized in Appendices C.1 and C.2. In the event that site-specific values cannot be obtained, an appropriate value for an industrial road may be selected from the mean values given in Table 13.2.1-1, but the quality rating of the equation should be reduced by 1 level. Also, recall that Equation 1 refers to emissions due to freely flowing (not stop-and-go) traffic.

~~With the exception of limited access roadways, which are difficult to sample, the collection and use of site-specific sL data fr public paved road emission inventories are strongly recommended. Although hundreds of public paved road sL measurements have been made since 1980,[8, 14-21] uniformity has been lacking in sampling equipment and analysis techniques, in roadway classification schemes, and in the types of data reported.[10] The assembled data set (described below) does not yield any readily identifiable, coherent relationship between sL and road class, average daily traffic (ADT), etc., even though an inverse relationship between sL and ADT had been found for a subclass of curbed paved roads in urban areas.[8] The absence of such a relationship in the composite data set is believed to be due to the blending of data (industrial and nonindustrial, uncontrolled, and controlled, and so on). Further complicating any analysis is the fact that, in many parts of the country, paved road sL varies greatly over the course of the year, probably because of cyclic variations in mud/dirt carryout and in use of anti-skid materials. For example,~~

repeated sampling of the same roads over a period of 3 calendar years at 4 Montana municipalities indicated a noticeable annual cycle. In those areas, silt loading declines during the first 2 calendar quarters and increases during the fourth quarter.

Figure 13.2.1-2 and Figure 13.2.1-3 present the cumulative frequency distribution for the public paved road sL data base assembled during the preparation of this AP-42 section.[10] The data base includes samples taken from roads that were treated with sand and other snow/ice controls. Roadways are grouped into high- and low-ADT sets, with 5000 vehicles per day being the approximate cutpoint. Figure 13.2.1-2 and Figure 13.2.1-3, respectively, present the cumulative frequency distributions for high- and low-ADT roads.

In the absence of site-specific sL data to serve as input to a public paved road inventory, conservatively high emission estimates can be obtained by using the following values taken from the figures. For annual conditions, the median sL values of 0.4 g/m^2 can be used for high-ADT roads (excluding limited access roads that are discussed below) and 2.5 g/m^2 for low-ADT roads. Worst-case loadings can be estimated for high-ADT (excluding limited access roads) and low-ADT roads, respectively, with the 90th percentile values of 7 and 25 g/m^2. Figure 13.2.1-4, Figure 13.2.1-5, Figure 13.2.1-6, and Figure 13.2.1-7 present similar cumulative frequency distribution information for high- and low-ADT roads, except that the sets were divided based on whether the sample was collected during the first or second half of the year. Information on the 50th and 90th percentile values is summarized in Table 13.2.1-2.

Table 13.2.1-2 (Metric Units). PERCENTILES FOR NONINDUSTRIAL SILT LOADING (g/m^2) DATA BASE

Averaging Period	High-ADT Roads		Low-ADT Roads	
	50th	90th	50th	90th
Annual	0.4	7	2.5	25
January-June	0.5	14	3	30
July-December	0.3	3	1.5	5

During the preparation of the background document (Reference 10), public road silt loading values from 1992 and earlier were assembled into a data base. This data base is available as __________. Although hundreds of public paved road sL measurements had been collected, there was no uniformity in sampling equipment and analysis techniques, in roadway classification schemes, and in the types of data reported. Not surprisingly, the data set did not yield a coherent relationship between sL and road class, average daily traffic (ADT), etc., even though an inverse

relationship between sL and ADT has been found for a subclass of curbed paved roads in urban areas. Further complicating the analysis is the fact that, in many parts of the country, paved road sL varies greatly over the course of the year, probably because of cyclic variations in mud/dirt carryout and in use of anti-skid materials. Although there were strong reasons to suspect that the assembled data base was skewed towards high values, independent data were not available to confirm the suspicions.

Since the time that the background document was prepared, new field sampling programs have shown that the assembled sL data set is biased high for "normal" situations. Just as importantly, however, the newer programs confirm that substantially higher than "normal" silt loadings can occur on public paved roads. As a result, two sets of default values are provided in Table 13.2.1-2, one for "normal" conditions and another for worst-case conditions (such as after winter storm seasons or in areas with substantial mud/dirt trackout).

Table 13.2.1-2 (Metric Units). RECOMMENDED DEFAULT SILT LOADING (g/m^2) VALUES FOR PUBLIC PAVED ROADS[a]

	High ADT roads[b]	Low ADT roads
Normal conditions	0.1	0.4
Worst-case conditions[c]	0.5	3

[a] Excluding limited access roads. See discussion in text. 1 g/m^2 is equal to 1.43 $grains/ft^2$
[b] High ADT refers to roads with at least 5,000 vehicles per day.
[c] For conditions such as post-winter-storm or areas with substantial mud/dirt carryout.

~~In the event that sL values are taken from any of the cumulative frequency distribution figures, the quality ratings for the emission estimates should be downgraded 2 levels.~~

In the event that default sL values are used the quality ratings for the equation should be downgraded 2 levels.

~~As an alternative method of selecting sL values in the absence of site-specific data, users can review the public (I. e., nonindustrial) paved road sL data base presented in Table 13.2.1-3 and can select values that are appropriate for the roads and seasons of interest. Table 13.2.1-3 presents paved road surface loading values together with the city, state, road name, collection date (samples collected from the same road during the same month are averaged), road ADT if reported, classification of the roadway, etc. Recommendation of this approach recognizes that end users of AP-42 are capable of identifying roads in the data base that are similar to roads in the area being inventoried. In the event that sL values are developed in this way, and that the selection process is fully described, then the quality ratings for the emission estimates should be downgraded only 1 level.~~

Limited access roadways pose severe logistical difficulties in terms of surface sampling, and few sL data are available for such roads. Nevertheless, the available data do not suggest great variation in sL for limited access roadways from 1 part of the country to another. For annual conditions, a default value of ~~0.02~~ **0.015** g/m^2 is recommended for limited access roadways.[9,22] Even fewer of the available data correspond to worst-case situations, and elevated loadings are observed to be quickly depleted because of high ADT rates. A default value of ~~0.1~~ **0.2** g/m^2 is recommended for short periods of time following application of snow/ice controls to limited access roads.[22]

13.2.1.4 Controls[6,~~22~~ 23]

Because of the importance of the surface loading, control techniques for paved roads attempt either to prevent material from being deposited onto the surface (preventive controls) or to remove from the travel lanes any material that has been deposited (mitigative controls). Regulations requiring the covering of loads in trucks, or the paving of access areas to unpaved lots or construction sites, are preventive measures. Examples of mitigative controls include vacuum sweeping, water flushing, and broom sweeping and flushing.

In general, preventive controls are usually more cost effective than mitigative controls. The cost-effectiveness of mitigative controls falls off dramatically as the size of an area to be treated increases. That is to say, the number and length of public roads within most areas of interest preclude any widespread and routine use of mitigative controls. On the other hand, because of the more limited scope of roads at an industrial site, mitigative measures may be used quite successfully (especially in situations where truck spillage occurs). Note, however, that public agencies could make effective use of mitigative controls to remove sand/salt from roads after the winter ends.

Because available controls will affect the sL, controlled emission factors may be obtained by substituting controlled silt loading values into the equation. (Emission factors from controlled industrial roads were used in the development of the equation.) The collection of surface loading samples from treated, as well as baseline (untreated), roads provides a means to track effectiveness of the controls over time.

References For Section 13.2.1

1. D. R. Dunbar, *Resuspension Of Particulate Matter*, EPA-450/2-76-031, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

2. R. Bohn, *et al.*, *Fugitive Emissions From Integrated Iron And Steel Plants*, EPA-600/2-78-050, U. S. Environmental Protection Agency, Cincinnati, OH, March 1978.

3. C. Cowherd, Jr., *et al.*, *Iron And Steel Plant Open Dust Source Fugitive Emission Evaluation*, EPA-600/2-79-103, U. S. Environmental Protection Agency, Cincinnati, OH, May 1979.

4. C. Cowherd, Jr., *et al.*, *Quantification Of Dust Entrainment From Paved Roadways*, EPA-450/3-77-027, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1977.

5. *Size Specific Particulate Emission Factors For Uncontrolled Industrial And Rural Roads*, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

6. T. Cuscino, Jr., *et al.*, *Iron And Steel Plant Open Source Fugitive Emission Control Evaluation*, EPA-600/2-83-110, U. S. Environmental Protection Agency, Cincinnati, OH, October 1983.

7. J. P. Reider, *Size-specific Particulate Emission Factors For Uncontrolled Industrial And Rural Roads*, EPA Contract 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

8. C. Cowherd, Jr., and P. J. Englehart, *Paved Road Particulate Emissions*, EPA-600/7-84-077, U. S. Environmental Protection Agency, Cincinnati, OH, July 1984.

9. C. Cowherd, Jr., and P. J. Englehart, *Size Specific Particulate Emission Factors For Industrial And Rural Roads*, EPA-600/7-85-038, U. S. Environmental Protection Agency, Cincinnati, OH, September 1985.

10. *Emission Factor Documentation For AP-42, Sections 11.2.5 and 11.2.6 — Paved Roads*, EPA Contract No. 68-D0-0123, Midwest Research Institute, Kansas City, MO, March 1993.

11. *Evaluation Of Open Dust Sources In The Vicinity Of Buffalo, New York*, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March 1979.

12. *PM-10 Emission Inventory Of Landfills In The Lake Calumet Area*, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, MO, September 1987.

13. *Chicago Area Particulate Matter Emission Inventory — Sampling And Analysis*, Contract No. 68-02-4395, Midwest Research Institute, Kansas City, MO, May 1988.

14. *Montana Street Sampling Data*, Montana Department Of Health And Environmental Sciences, Helena, MT, July 1992.

15. *Street Sanding Emissions And Control Study*, PEI Associates, Inc., Cincinnati, OH, October 1989.

16. *Evaluation Of PM-10 Emission Factors For Paved Streets*, Harding Lawson Associates, Denver, CO, October 1991.

17. *Street Sanding Emissions And Control Study*, RTP Environmental Associates, Inc., Denver, CO, July 1990.

18. *Post-storm Measurement Results — Salt Lake County Road Dust Silt Loading Winter 1991/92 Measurement Program*, Aerovironment, Inc., Monrovia, CA, June 1992.

19. Written communication from Harold Glasser, Department of Health, Clark County (NV).

20. *PM-10 Emissions Inventory Data For The Maricopa And Pima Planning Areas*, EPA Contract No. 68-02-3888, Engineering-Science, Pasadena, CA, January 1987.

21. *Characterization Of PM-10 Emissions From Antiskid Materials Applied To Ice- And Snow-covered Roadways*, EPA Contract No. 68-D0-0137, Midwest Research Institute, Kansas City, MO, October 1992.

22. *Fugitive Particulate Matter Emissions*, EPA Contract No. 68-D2-0159, Work Assignment No. 4-06, Midwest Research Institute, Kansas City, MO, April 1997.

23. C. Cowherd, Jr., *et al., Control Of Open Fugitive Dust Sources*, EPA-450/3-88-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

24. Written communication from G. Muleski, Midwest Research Institute, Kansas City, MO, to R. Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 12, 1997.

2. Prospposed AP-42 section 13.2.1

The proposed AP-42 Section for paved roads is presented on the following pages as it would appear in the document.

13.2.1 Paved Roads

13.2.1.1 General

Particulate emissions occur whenever vehicles travel over a paved surface, such as a road or parking lot. In general terms, particulate emissions from paved roads originate from the loose material present on the surface. In turn, that surface loading, as it is moved or removed, is continuously replenished by other sources. At industrial sites, surface loading is replenished by spillage of material and trackout from unpaved roads and staging areas. Figure 13.2.1-1 illustrates several transfer processes occurring on public streets.

Various field studies have found that public streets and highways, as well as roadways at industrial facilities, can be major sources of the atmospheric particulate matter within an area.[1-9] Of particular interest in many parts of the United States are the increased levels of emissions from public paved roads when the equilibrium between deposition and removal processes is upset. This situation can occur for various reasons, including application of snow and ice controls, carryout from construction activities in the area, and wind and/or water erosion from surrounding unstabilized areas.

13.2.1.2 Emissions And Correction Parameters

Dust emissions from paved roads have been found to vary with what is termed the "silt loading" present on the road surface as well as the average weight of vehicles traveling the road. The term silt loading (sL) refers to the mass of silt-size material (equal to or less than 75 micrometers [µm] in physical diameter) per unit area of the travel surface.[4-5] The total road surface dust loading is that of loose material that can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. The silt fraction is determined by measuring the proportion of the loose dry surface dust that passes through a 200-mesh screen, using the ASTM-C-136 method. Silt loading is the product of the silt fraction and the total loading, and is abbreviated "sL". Additional details on the sampling and analysis of such material are provided in AP-42 Appendices C.1 and C.2.

The surface sL provides a reasonable means of characterizing seasonal variability in a paved road emission inventory.[9] In many areas of the country, road surface loadings are heaviest during the late winter and early spring months when the residual loading from snow/ice controls is greatest.

13.2.1.3 Predictive Emission Factor Equations[10]

The quantity of dust emissions from vehicle traffic on a paved road may be estimated using the following empirical expression:

$$E=k\ (sL/2)^{0.65}\ (W/3)^{1.5} \qquad (1)$$

where:

E = particulate emission factor (having units matching the units of k)

k = base emission factor for particle size range and units of interest (see below)

sL = road surface silt loading (grams per square meter) (g/m^2)

W = average weight (tons) of the vehicles traveling the road

It is important to note that Equation 1 calls for the average weight of all vehicles traveling the road. For example, if 99 percent of traffic on the road are 2 Mg cars/trucks while the remaining 1 percent consists of 20 Mg trucks, then the mean weight "W" is 2.2 Mg. More specifically, Equation 1 is *not* intended to be used to calculate a separate emission factor for each vehicle weight class. Instead, only one emission factor should be calculated to represent the "fleet" average weight of all vehicles traveling the road.

The particle size multiplier (k) above varies with aerodynamic size range as shown in Table 13.2.1-1.

Table 13.2-1.1. PARTICLE SIZE MULTIPLIERS FOR PAVED ROAD EQUATION

Size range[a]	Multiplier k[b]		
	g/VKT	g/VMT	lb/VMT
PM-2.5[c]	1.1	1.8	0.0040
PM-10	4.6	7.3	0.016
PM-15	5.5	9.0	0.020
PM-30[d]	24	38	0.082

[a] Refers to airborne particulate matter (PM-x) with an aerodynamic diameter equal to or less than x micrometers.

[b] Units shown are grams per vehicle kilometer traveled (g/VKT), grams per vehicle mile traveled (g/VMT), and pounds per vehicle mile traveled (lb/VMT). The multiplier k includes unit conversions to produce emission factors for the indicated size range and units from the mixed units required in the equation 1.

[c] Ratio of PM-2.5 to PM-10 taken from Reference 22.

[d] PM-30 is sometimes termed "suspendable particulate" (SP) and is often used as a surrogate for TSP.

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The above equation is based on a regression analysis of numerous emission tests, including 65 tests for PM-10.[10] Sources tested include public paved roads, as well as controlled and uncontrolled industrial paved roads. No tests of "stop-and-go" traffic were available for inclusion in the data base. The equations retain the quality rating of A (B for PM-2.5), if applied within the range of source conditions that were tested in developing the equation as follows:

Silt loading:	0.02 - 400 g/m^2
	0.03 - 570 grains/square foot (ft^2)
Mean vehicle weight:	1.8 - 38 megagrams (Mg)
	2.0 - 42 tons
Mean vehicle speed:	16 - 88 kilometers per hour (kph)
	10 - 55 miles per hour (mph)

To retain the quality rating for the emission factor equation when it is applied to a specific paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. With the exception of limited access roadways, which are difficult to sample, the collection and use of site-specific sL data for public paved road emission inventories are strongly recommended. The field and laboratory procedures for determining surface material silt content and surface dust loading are summarized in Appendices C.1 and C.2. In the event that site-specific values cannot be obtained, an appropriate value for an industrial road may be selected from the mean values given in Table 13.2.1-1, but the quality rating of the equation should be reduced by 1 level. Also, recall that Equation 1 refers to emissions due to freely flowing (not stop-and-go) traffic.

During the preparation of the background document (Reference 10), public road silt loading values from 1992 and earlier were assembled into a data base. This data base is available as __________. Although hundreds of public paved road sL measurements had been collected, there was no uniformity in sampling equipment and analysis techniques, in roadway classification schemes, and in the types of data reported. Not surprisingly, the data set did not yield a coherent relationship between sL and road class, average daily traffic (ADT), etc., even though an inverse relationship between sL and ADT has been found for a subclass of curbed paved roads in urban areas. Further complicating the analysis is the fact that, in many parts of the country, paved road sL varies greatly over the course of the year, probably because of cyclic variations in mud/dirt carryout and in use of anti-skid materials. Although there were strong reasons to suspect that the assembled data base was skewed towards high values, independent data were not available to confirm the suspicions.

Since the time that the background document was prepared, new field sampling programs have shown that the assembled sL data set is biased high for "normal" situations. Just as importantly, however, the newer programs confirm that substantially higher than "normal" silt loadings can occur on public paved roads. As a result, two sets of default values are provided in Table 13.2.1-2, one for "normal" conditions and another for worst-case conditions (such as after winter storm seasons or in areas with substantial mud/dirt trackout).

Table 13.2.1-2 (Metric Units). RECOMMENDED DEFAULT SILT LOADING (g/m^2) VALUES FOR PUBLIC PAVED ROADS[a]

	High ADT roads[b]	Low ADT roads
Normal conditions	0.1	0.4
Worst-case conditions[c]	0.5	3

[a] Excluding limited access roads. See discussion in text. 1 g/m^2 is equal to 1.43 $grains/ft^2$

[b] High ADT refers to roads with at least 5,000 vehicles per day.

[c] For conditions such as post-winter-storm or areas with substantial mud/dirt carryout.

In the event that default sL values are used, the quality ratings for the equation should be downgraded 2 levels.

Limited access roadways pose severe logistical difficulties in terms of surface sampling, and few sL data are available for such roads. Nevertheless, the available data do not suggest great variation in sL for limited access roadways from 1 part of the country to another. For annual conditions, a default value of 0.015 g/m^2 is recommended for limited access roadways.[9,22] Even fewer of the available data correspond to worst-case situations, and elevated loadings are observed to be quickly depleted because of high ADT rates. A default value of 0.2 g/m^2 is recommended for short periods of time following application of snow/ice controls to limited access roads.[22]

13.2.1.4 Controls[6,23]

Because of the importance of the surface loading, control techniques for paved roads attempt either to prevent material from being deposited onto the surface (preventive controls) or to remove from the travel lanes any material that has been deposited (mitigative controls). Regulations requiring the covering of loads in trucks, or the paving of access areas to unpaved lots or construction sites, are preventive measures. Examples of mitigative controls include vacuum sweeping, water flushing, and broom sweeping and flushing.

and as the time for the silt loading of the road to return to equilibrium conditions decreases.

In general, preventive controls are usually more cost effective than mitigative controls. The cost-effectiveness of mitigative controls falls off dramatically as the size of an area to be treated increases. That is to say, the number and length of public roads within most areas of interest preclude any widespread and routine use of mitigative controls. On the other hand, because of the more limited scope of roads at an industrial site, mitigative measures may be used quite successfully (especially in situations where truck spillage occurs). Note, however, that public agencies could make effective use of mitigative controls to remove sand/salt from roads after the winter ends.

Because available controls will affect the sL, controlled emission factors may be obtained by substituting controlled silt loading values into the equation. (Emission factors from controlled industrial roads were used in the development of the equation.) The collection of surface loading samples from treated, as well as baseline (untreated), roads provides a means to track effectiveness of the controls over time.

References For Section 13.2.1

1. D. R. Dunbar, *Resuspension Of Particulate Matter*, EPA-450/2-76-031, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

2. R. Bohn, *et al.*, *Fugitive Emissions From Integrated Iron And Steel Plants*, EPA-600/2-78-050, U. S. Environmental Protection Agency, Cincinnati, OH, March 1978.

3. C. Cowherd, Jr., *et al.*, *Iron And Steel Plant Open Dust Source Fugitive Emission Evaluation*, EPA-600/2-79-103, U. S. Environmental Protection Agency, Cincinnati, OH, May 1979.

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5. *Size Specific Particulate Emission Factors For Uncontrolled Industrial And Rural Roads*, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

6. T. Cuscino, Jr., *et al.*, *Iron And Steel Plant Open Source Fugitive Emission Control Evaluation*, EPA-600/2-83-110, U. S. Environmental Protection Agency, Cincinnati, OH, October 1983.

7. J. P. Reider, *Size-specific Particulate Emission Factors For Uncontrolled Industrial And Rural Roads*, EPA Contract 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

8. C. Cowherd, Jr., and P. J. Englehart, *Paved Road Particulate Emissions*, EPA-600/7-84-077, U. S. Environmental Protection Agency, Cincinnati, OH, July 1984.

9. C. Cowherd, Jr., and P. J. Englehart, *Size Specific Particulate Emission Factors For Industrial And Rural Roads*, EPA-600/7-85-038, U. S. Environmental Protection Agency, Cincinnati, OH, September 1985.

10. *Emission Factor Documentation For AP-42, Sections 11.2.5 and 11.2.6 — Paved Roads*, EPA Contract No. 68-D0-0123, Midwest Research Institute, Kansas City, MO, March 1993.

11. *Evaluation Of Open Dust Sources In The Vicinity Of Buffalo, New York*, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March 1979.

12. *PM-10 Emission Inventory Of Landfills In The Lake Calumet Area*, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, MO, September 1987.

13. *Chicago Area Particulate Matter Emission Inventory — Sampling And Analysis*, Contract No. 68-02-4395, Midwest Research Institute, Kansas City, MO, May 1988.

14. *Montana Street Sampling Data*, Montana Department Of Health And Environmental Sciences, Helena, MT, July 1992.

15. *Street Sanding Emissions And Control Study*, PEI Associates, Inc., Cincinnati, OH, October 1989.

16. *Evaluation Of PM-10 Emission Factors For Paved Streets*, Harding Lawson Associates, Denver, CO, October 1991.

17. *Street Sanding Emissions And Control Study*, RTP Environmental Associates, Inc., Denver, CO, July 1990.

18. *Post-storm Measurement Results — Salt Lake County Road Dust Silt Loading Winter 1991/92 Measurement Program*, Aerovironment, Inc., Monrovia, CA, June 1992.

19. Written communication from Harold Glasser, Department of Health, Clark County (NV).

20. *PM-10 Emissions Inventory Data For The Maricopa And Pima Planning Areas*, EPA Contract No. 68-02-3888, Engineering-Science, Pasadena, CA, January 1987.

21. *Characterization Of PM-10 Emissions From Antiskid Materials Applied To Ice- And Snow-Covered Roadways*, EPA Contract No. 68-D0-0137, Midwest Research Institute, Kansas City, MO, October 1992.

22. *Fugitive Particulate Matter Emissions*, EPA Contract No. 68-D2-0159, Work Assignment No. 4-06, Midwest Research Institute, Kansas City, MO, April 1997.

23. C. Cowherd, Jr., *et al., Control Of Open Fugitive Dust Sources*, EPA-450/3-88-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

24. Written communication from G. Muleski, Midwest Research Institute, Kansas City, MO, to R. Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 12, 1997.

Attachment 1

**Comment/Response Log for March 8, 1993,
Paved Road Background Document**

RESPONSE TO COMMENTS MADE IN ATTACHMENTS TO WILLIAM R. BARNARD LETTER OF MAY 12, 1993
PAVED ROADS

COMMENT	RESPONSE
1. Page 2-2, 1st paragraph, sentence that starts "In addition..." change from "can be often heavily loaded" to "can often be..." Page 2-2, In definitions of equation 2-1, change "s=surface material content silt" to read "surface material silt content" Page 2-4, 1st paragraph at the top, sentence that begins "The industrial road augmentation factor..." change "was included to take into account for..." to "was included to account for..."	1 These all address typographical errors or recommended wording changes to the background document. Changes will be made in any revision to the background document.
2. Although I know that you are simply "quoting" AP-42, it is very confusing to the reader that in equation 2-1, s = surface material silt content and L = surface material loading, but in equation 2-3, sL = road surface silt loading and has the same units as L alone in equation 2-1.	2. MRI agrees that the use of "sL" and the combination of "s" and "L" can prove confusing. Because the revised AP-42 section will replace all three paved road equations currently contained in Sections 11.2.5 and 11.2.6, "sL" will be used in only one sense thus eliminating any confusion.
3. I would suggest moving most of section 3 forward (to become section 2) and would place section 2 as the new section 3. It would seem more logical to have a general description of the ratings system prior to summarizing the existing information, including the current ratings for current AP-42 emission factors. I also think that sections 3.0 and 3.1 would be better "tagged" onto the end of section 2 and the remaining current section 3 moved to section 2 as indicated above.	3. MRI will consider the merit of reorganizing the background document prior to any revision to the report.
4. In the discussion on page 2-6, the indication is that the reformulated emission factor will include data using controls. Although a rationale is given for this, I strongly question the wisdom of this approach. If controlled and uncontrolled information is used to generate the emission factor, then it becomes extremely difficult to perform any control strategy analyses for SIP purposes using an emission factor that may already incorporate some level of control. There is virtually no data on how much the various control options for paved roads reduce silt content (which is the information needed with the new approach), while there is limited data on overall control efficiency. Although I know that most of the control approaches are aimed at reducing the silt loading, what happens if you are wrong and the silt loading is not really the controlling factor for paved road emissions?	4. MRI firmly believes that the approach employed in the background document is "best" in the sense that the approach • addresses confusion that may result from having two or more different paved road models might be used to estimate emissions in various size ranges from roads at a single facility, municipality, etc. • recognizes the very dynamic nature of silt loading in that emissions are reduced substantially (i.e., "controlled") through rainfall. To a very real extent, a truly "uncontrolled" paved road would have to be completely sheltered from the direct rain and water runoff. • provides the regulatory and regulated communities a cost-effective means (through relatively inexpensive surface sampling) to evaluate seasonal variations in emissions and the efficiency of control programs • recognizes that there is a far larger data base in which efficiency is tied to reduction in silt loading rather than reduction in the emission factor With reference to the potential for mistaking the importance of silt loading, please see discussion on page 4-20. As stated there, the most notable features about the correlation matrix are the high degree of interdependence between (i) emisison factor; (ii) speed: and (iii) silt loading; and, the low degree of interdependence between (a) silt loading and weight and (b) weight and speed. The selection of combination (a) over combination (b) is explained at the bottom of page 4-20.

RESPONSE TO COMMENTS MADE IN ATTACHMENTS TO WILLIAM R. BARNARD LETTER OF MAY 12, 1993
PAVED ROADS (continued)

COMMENT	RESPONSE
5. I think another criteria should be added to all reviews and AP-42 chapter development efforts. All primary source reports should contain sufficient information and data so that all data reduction procedures and/or calculations can be verified. Frequently, even when information has been given in fugitive emission factor development reports, the data cannot be used to give reproducible results using the data reduction/calculation methods presented. Section 2, page 2-6 next to last paragraph indicates that previous test data were included in the reexamination and that no distinction was made between public and industrial roads or controlled/uncontrolled tests. However, on page 3-2, the top paragraph indicates that "earlier controlled industrial road test data were reexamined in addition to new data." Which is it? In section 4, it looks like all data were reviewed. Be consistent.	5. Please see the discussion in response 6 regarding independent calculation of exposure profiling test results. MRI does not see the two statements as contradictory; however, there may be some confusion about the meaning of terms such as "reexamined" or "reviewed". The background document does not make any hard and fast distinctions between terms such as "considered," "(re)examined," or "reviewed." Simply put, data are first examined -- or equivalently, "reviewed" or "considered" -- to decide from which data emission factors will be developed. New data (from test reports I, II and III) were examined. In addition, MRI reconsidered field test results that had been available during the earlier updates of this section (in 1983 and, to a lesser extent, 1987) but not used (because of the "controlled" nature of the surface) to develop an emission factor. The reasons for including the controlled tests in the current update are described in the background document and in the previous response.

RESPONSE TO COMMENTS MADE IN ATTACHMENTS TO WILLIAM R. BARNARD LETTER OF MAY 12, 1993
PAVED ROADS (continued)

COMMENT	RESPONSE
6. Page 3-2, item #2 in the section 3-2 list. What do EPA method 5 front-half and back-half have to do with fugitives? A better example of incompatible methods should be found.	6. This text is drawn verbatim from the EPA guideline document for development of AP-42 sections. MRI will revise this passage to better reflect the particulars involved with paved road testing procedures in any new version of the background document.
A great deal of the discussion on upwind-downwind tends to deal with drawbacks to using this method. However, it can be utilized with standardized, wind tunnel certified sampling devices and really requires little more meteorological data than exposure profiling (wind speed and direction vs. wind speed). Equal time should be devoted towards drawbacks/uncertainties associated with exposure profiling.	It is important to recall that exposure profiling represents a sampling approach rather than any specific type of sampler. In other words, "standardized, wind tunnel certified samplers" can (and have been) used in exposure profiling programs. The reviewer is quite right in stating that upwind/downwind (UW/DW) approach requires little more meteorlolgical data than exposure profiling. As a matter of fact, MRI requires that wind direction be monitored throughout any exposure profiling test.
For instance, the samplers used for exposure profiling have never been wind tunnel certified for size cutpoints to the best of my knowledge (i.e., never published). Also, I have never been able to successfully duplicate the "spatial integration of measurements" even when data and example calculations have been provided. In the case of PM-10, how can you truly estimate the visual extent of the plume to insure that at least 90% is captured? I believe that visually estimating the extent of 10 micron particles (mainly invisible) would be extremely difficult. Finally, the discussion of exposure profiling should discuss the relative error (as was done for upwind-downwind). The overall tone of the discussion tends to sound "heavy-handed" and biased towards the method that MRI developed rather than an objective presentation of the two methodologies which is what an objective review should do.	The important distinction to be drawn between the UW/DW and the exposure profiling methods involves how data are used to characterize the source. The background document discusses basic limitations of using uncalibrated dispersion models to estimate emission strength. Beyond the relatively simple discussion presented in the background document, UW/DW suffers other fundamental limitations. For example, traffic on many roads is too low to pose a steady, uniformly emitting line source as required in dispersion models. A better representation would view the source as a series of discrete moving point source. Even assuming the source is reasonably steady in nature, the modeled line source/wind geometry does not necessarily properly account for dispersion from the moving point sources. As the plume is released, dispersion occurs in all three cartestian coordinate directions. Only dispersion in the direction parallel to the plume centerline would be negligible. Depending on the direction a vehicle is traveling, an oblique wind would appear to "dilute" or "concentrate" the plume as seen by the UW/DW samplers. Correction for each plume depends upon the magnitude and direction of the wind relative to vehicle velocity vector. In other words, if two vehicles passed in opposite directions at the same time, one plume would be concentrated and the other diluted. Because the exposure profiling approach focuses on the mass flux through a plane, concentration/dilution issues are not a concern. As noted earlier, standardized samplers can be and have been readily used in the exposure profiling arrays. Because of the interest in total particulate and size-specific factors, MRI has traditionally used directional samplers operated isokinetically, together with aerodynamic particle sizing instruments. (In addition to manufacturer tests for the cascade impactors, the cyclone preseparator has been wind tunnel tested. Results are reported in Baxter et al 1986.) The Southern Research Institute (SoRI) collaborative study (Pyle and McClain 1986) examined many issues associated with exposure profiling. The authors duplicated MRI's and four other organization's calculations from 11 test runs on a "simulated" unpaved road. In addition, SoRI investigated potential errors associated with isokinetic tracking, different particle sizing approaches, maximum sampling height, spatial integration schemes, etc.

COMMENT	RESPONSE
7. Page 3-9, next to last sentence says, "sin specific source parameters" should say "in specific source parameters" Page 3-11, top of page "virtual point source missions" should be "virtual point source emissions"	7. These changes will be made to any subsequent version of the background document.
8. On page 3-11, one of the criteria used for evaluating emission factor data is "industry representativeness." Why are we concerned about industry representativeness as a criteria in developing a new emission factor when the new emission factor is to be reflective of emissions from any paved road, regardless of whether industrial or public?	8. As stated above, this text is drawn verbatim from the EPA guideline document. The passage will be revised in any subsequent version of the background document.
9. Page 4-7, 1st full paragraph indicates that the Test Report I does not fully meet the minimum requirements for upwind-downwind sampling (i.e., a minimum of 4 samplers). The description of the sampling set-up says that even when 6 samplers were used they were set up identically with one at 20 m and a pair at 5 m on each side of the road. This means 3 samplers on upwind side at 2 distances and 3 on downwind at 2 distances. On page 3-10, next to last paragraph, the minimum test requirements for upwind-downwind are stated as 1 device upwind (satisfied here by 3 at 2 distances) and the others at 2 downwind (satisfied here by the 5 m and 20 m distances) and 3 crosswind. The requirement for crosswind distances is waived for line sources. A paved road is a line source, thus this report does meet the minimum requirements for sampling and should be included in the analysis.	9. MRI mistakenly stated in the background document that "neither" sampling configuration met minimum requirements. Only the <u>second</u> configuration (described on page 4-4) failed to meet minimum requirements because the sources tested were not truly line sources. Instead, the halves of each road segment were considered separately. Test Report I did not explain how far samplers were separated from the end of segments nor did it describe any attempt to prevent tracking of material from one segment to another. (See, for example, Figure 2-3 of Test Report I.) Thirty-two of the 69 emission tests used the second configuration.
10 In the discussion of Test Report II, the text indicates that only 1 particle size device is used to determine a PM-10 emission factor. Are the investigators really sure that there is no variability in the distribution of the PM-10 concentration (flux) with height? Unpaved road studies performed as part of NAPAP indicate otherwise.	10. Test Report II's use of single height for particle sizing measurements resulted from the limited number of devices available. MRI has found in numerous past studies and one would certainly expect the PM-10 fraction to increase with height in the plume. To at least partially account for this, the single height was selected to approximate the height in a dust plum at which half the mass emissions pass above and half below.
11. Figure 4-3 is really a table.	11. MRI called this a "figure" because it is a photocopy of two different outputs from a computer program. No change is planned.
12. Table 4-5, the multiple R^2 for PM-15 = .765, but "Figure" 4-3 indicates it should be .772.	12. To ensure that the different size fractions had functional forms similar to that for PM-10, all final models were "forced" to have the same exponents for silt loading and weight. Thus, the ℓn-transformed emission factors were regressed against the term $0.65 \ln sL + 1.5 \ln W$ with the line-of-fit forced to pass through the origin to determine the final form. The lower R^2 results from the fact that the final factor is not "best" in an independent least-squares sense.

COMMENT	RESPONSE
13. Based upon the discussion above concerning inclusion of Test Report I and due to the fact that it was considered good enough for validation, what would the emission factor equation look like if that data was included?	13. Inclusion of the Test Report I data could be expected to lower the exponent for "sL" for the PM-10 equation from 0.65 to approximately 0.5. At a summer 1992 meeting with the commentor, Chuck Masser, Tom Pace, and Robin Dunkins, we discussed how, the discussion in Zimmer 1991 notwithstanding, Test Report I emission rates exhibited a strong dependence on silt loading. (Figure 4-2 of the background document clearly shows this.) It is also important to recall that primary reason for not including Test Report I data was that only PM-10 factors were available.
14. On page 4-23, the validation results indicate that at least 50% of the data are outside the factor of 3 range. Does this mean that the factor of 2 used for rating (see Table 3-1) is unrealistic for rating emission factors and that a more appropriate lower end would be 3 rather than 2?	14. Page 4-23 states that "a little over half" of the quasi-independent values are within a factor of 3. This certainly does not indicate that "at least 50% ... are outside" that range. A rough scaling of Figure 4-4 on page suggests that approximately 57% ≈ 60% are within a factor of 3. Table 3-1 pertains to single-valued emission factors. The quality ratings for predictive equations are assigned following the scheme presented in Table 3-2.
15. Why is the equation on the first page of the proposed new section 11.2.x different from the new one derived in the report (equation on page 4-22). Specifically, why is sL divided by 2 and W by 3? Why doesn't the equation on page 4-22 have an equation number as earlier equations did?	15. The background document discusses a "working" form for the model. By that is meant all emission factors are measured in g/VMT, all silt loadings are in g/m^2, and so on. For example, in order to be exactly precise, one must either • consider silt loading and weight "nondimensionalized" by implicit division by 1 g/m^2 and 1 ton respectively or $\frac{g \cdot m^{1.3}}{g^{0.65} \cdot tons^{1.5} \cdot veh\text{-}mile} = \frac{g^{0.35} \cdot m^{1.3}}{tons^{1.5} \cdot veh\text{-}mile}$ The working versions of models are used to establish properties of candidate emission factors. On the other hand, once a factor has been selected, the AP-42 section must present a final product. In the AP-42 sections, nondimensionalization occurs through the explicit division by the "default" values of 2 g/m^2 and 3 tons. Furthermore, k is expressed in a variety of compatible units. One can readily verify that all working and final expressions result in the same emission factor for the same input values. An equation number will be added on page 4-22 in any subsequent version of the background document.

References

Baxter, T. E. et al. 1986. "Calibration of Cyclone for Monitoring Inhalable Particles," Journal of Environmental Engineering, 112, 3, pp. 468-478.

Pyle, B. E. and J. D. McCain 1986. Critical Review of Open Source Particulate Emission Measurements -- Part II: Field Comparison. Work Assignment 002, EPA Contract 68-02-3936. February 1986.

Zimmer, R. A. 1991."Evaluation of PM10 Emission Factors for Paved Streets." Harding Lawson and Associates report for the Regional Air Quality Council (Denver). October 1991.

RESPONSE TO COMMENTS MADE IN ATTACHMENTS TO WILLIAM R. BARNARD LETTER OF MAY 12, 1993
CONSTRUCTION ACTIVITIES

COMMENT	RESPONSE
Specific comments	
1. On page v, there is a superscript 8 in the Section 3.3 line of the Table of Contents. On page vi, there is a superscript in #2-3 line of Tables list	1. These all address typographical errors or recommended wording changes to the background document. These changes will be made in any subsequent version of the background document.
2. As with the Paved Roads document, I'd probably flip-flop Sections 2 and 3, although the reason for switching them is less compelling in this document, since there are few if any references to the previous AP-42 emission factor quality rating.	2. MRI will consider the merit of reorganizing the background document prior to any revision to the report.
Comments on Section 2	
3. Page 2-1 In the discussion of the number of construction industries, you list 2.0 million, instead of 2 million. The decimal point implies some level of significant figures. Is that level really there?	3. Reference 1 in the background document should not be the Statistical Abstract but rather the 1987 Census of Construction Industries. This will be corrected in any revision. The 1987 Census uses the expression "nearly 2.0 million construction establishments." Any subsequent version of the background document will incorporate that phrasing.
4. Unless total value of business done is the way that Statistical Abstract describes the information presented on page 2-1 and 2-2, I'd say total revenue.	4. The Statistical Abstract reports "value of construction [contract]." The Census of Construction Industries uses the term "value of construction work." Subsequent version of the background document will use "value of construction work."
5. Page 2-5 "unpaved travel rates"? - middle of last paragraph	5. This is a typographical error and should read "travel routes." The change will be made in a subsequent revision to the background document.
Comments on Section 3	
6. I think another criteria should be added to all reviews and AP-42 chapter development efforts. All primary source reports should contain sufficient information and data so that all data reduction procedures and/or calculations can be verified. Frequently, even when information has been given in fugitive emission factor development reports, the data cannot be used to give reproducible results using the data reduction/calculation methods presented.	6. Please see response 6 in the paved road comment log regarding independent calculation of exposure profiling test results.
7. Page 3-1 near the bottom. The 1987 Censu s of Construction Industries, United States Summary is listed as reference 1, however, reference 1 is the Statistical Abstract of the U.S. for 1992.	7. As noted in response 3, Reference 1 should read U.S. Department of Commerce, Bureau of the Census. "1987 Census of Construction Industries." Geographic Area Series, CC87-A-10. Washington, D. C. October 1990.

RESPONSE TO COMMENTS MADE IN ATTACHMENTS TO WILLIAM R. BARNARD LETTER OF MAY 12, 1993
CONSTRUCTION ACTIVITIES (continued)

COMMENT	RESPONSE
8. Page 3-6, change "unless the plume can be draw..." to "unless the plume can be drawn" Page 3-9, next to last sentence change "when characterize source conditions" to "which characterize source conditions"	8. These changes will be made in any subsequent version of the background document.
Comments on Section 4	
9. All discussions of reviewed emission factors should clearly delineate whether the emission factor being discussed is for TSP or PM-10. Page 4-5, last paragraph, says that upwind-downwind sampling was used to determine TSP emission factors in Table 4-2, but the table caption says they are PM-10 emission factors.	9. The background document will be reviewed to identify points where PM10/TSP could be confused. The entries are in fact PM-10 emission factors based on Referemce 12's reanalysis of TSP emission factors contained in Test Report III. Statements will be corrected in any subsequent version of the background document.
10. Page 4-6, last sentence of first paragraph, says that a minimum of 4 samplers are required but on Page 3-11 the minimum number is specified as 5.	10. MRI does not see the two statements as contradictory. Page 3-11 calls for "at least five ... with one device located upwind." Consequently at least 4 should be deployed downwind. Page 4-6 states that "two samplers ... were used downwind rather than the minimum of four."
11. Page 4-6, last paragraph before section 4.2.2, either give it a B or a C rating. Probably deserves a C	11. MRI agrees that "C" is appropriate.
12. In the revised section for AP-42, the discussion concerning equation 1 indicates that the emission factor can be used for PM-10, but this is a TSP emission factor. No discussion is provided to indicate what factor should be applied to provide PM-10 emission estimates.	12. The intention in the revised AP-42 section is to allow readers to use Equation (1) to not only estimate TSP emissions but also to conservatively estimate PM-10 emissions. The discussion on page 11.2.4-2 recognizes that this approach may result in too high a PM-10 estimate and recommends estimating emissions on the basis of component operations.

COMMENTS MADE IN MAY 24, 1992, LETTER FROM DOUGLAS P. COLLINS, IDAHO DEQ PAVED ROADS

COMMENT	RESPONSE
The 90th percentile, as a worst case scenario, appears to overestimate emissions, especially if used to generate a daily total emission rate. To assume that all streets, on any day, would be carrying a 90th percentile silt loading seems unlikely.	MRI agrees that it is highly unlikely that all roads in an area will be at the 90th percentile at once. As noted in the AP-42 section and the comments below, sL values specific to the site and situation of interest would be preferred.
The temporal scale of January to June, and July to December, does not reflect annual increase and decrease of silt loadings in Idaho. Increased silt loadings from the application of anti skid materials starts with the first significant snow fall, usually in November, and lasts until about April, when many road departments mechanically remove excess road debris.	During the preparation of the AP-42 Section, MRI considered using different groupings, such as winter/spring vs. summer/fall or November-through-March vs. April-through-October. The other grouping schemes all failed to adequately account for differences seen in the sL values; furthermore, the other schemes called for a subjective decision -- such as: When does "winter" begin at a specific site? -- or failed to take into account weather patterns during a particular sampling year -- such as: Was November 1991 particularly snowy or warm? Because the sL data base was a secondary objective in the program, project resources were insufficient to devote much effort in resolving weather patterns. Consequently, calendar year halves were selected to avoid subjective decisions.
Not all counties in Idaho require vehicle weights to be recorded with the title or registration. Therefore it is a best guess as to what the average vehicle weight might be. Some guidelines, references, or suggested values, or range of values would be helpful.	For most public roads with "normal" mixes of cars, trucks and buses, one can probably expect the average weight not vary outside the range of 2.0 to 2.5 tons.
The preferred method for determining silt loading value is to collect your own representative samples. Appendices, in the past, have addressed how to take and analyze the samples, but do not provide a methodology to set up a sampling study. A methodology that lays out guidelines on the number of sites, number of samples, precision and accuracy, QA/QC, meterological considerations, and other parameters needed to conduct an adequate road silt sampling project would be of help. These guidelines could address both larger studyies for determining specific silt loading values, an a limited study for trying to narrow down the options presented in using the 50th to 90th percentile used in the revised AP-42.	MRI agrees that some sort of "case study" would be quite useful to the regulatory community. The current version of Appendix D to AP-42 is necessarily vague on where and how many samples should be collected and even on the type of equipment to be used in sampling, because site-specific considerations may affect decisions. A case study that considered • three different size cities (e.g., Phoenix, Reno, and Pocatello) and, • and 2 or 3 levels of effort (for example, a two-month long program for $10,000 versus a multiyear program for $70,000). would be of great practical benefit.
Use of the public paved road sL data base (not yet provided) would seem to be a good intermediate choice between getting site specific data and using the the revised AP-42 values, providing the selection criteria used can adequately reflect the area of interest. Selection information might include: the amount of anti-skid material used, percent of silt in anti skid material, average number of applications per season, application equipment used, application rate, and the size and location of the area where the data was collected.	At present, the revised paved road section recognizes that end users of AP-42 are the most capable in selecting roads in the data base that are similar to roads of interest in their jurisdictions. Although site-specific sL values would be most preferred, MRI believes that the new approach represents an improvement.
When compared to the current AP-42 section in use, selecting a winter time silt loading value from the revised section feels more comfortable. The 50th to 90th percentile range appears to accurately reflect the range of silt loadings that can be found on Idaho roads, and even though the value range is fairly large, it does let you know when you are in the ball park.	MRI agrees.

COMMENTS MADE IN MAY 27, 1992, LETTER FROM GARY NEUROTH, ARIZONA DEQ PAVED ROADS

COMMENT	RESPONSE
The "MRI accepted" data base contains little, if any, data for relatively high volume, high speed roads typically found in urban areas. For example, roads with daily traffic volumes over 10,000 with speeds over 35 mph.	Figures 1 and 2 compare the speed/silt loading ranges in the AP-42 data base and data from the PEI Denver study (Test Report I in the background document). As can be seen, the AP-42 data contains slightly more tests within the range of the PEI data. This is not to say that the current paved road emission factor data base does not suffer from certain limitations. As MRI has pointed out, the present paved road emission factor models do not explicitly reference characteristics that are likely to influence emission levels, such as • Vehicle mix -- It is likely that particulate matter emission levels are higher for roads/areas where diesel and/or poorly maintained older vehicles are prevalent. At present, however, neither the current Section 11.2.5 or Section 11.2.6 PM_{10} emission factor distinguishes between roads with different vehicle mixes. The recommended revision, on the other hand, at least partially accounts for vehicle mix by the inclusion of the "weight term." Still, no direct distinction is made for different diesel/gasoline ratios, etc. • Vehicle speed -- As the comment points out, it is likely that, all other factors being equal, high ADT roads should have different emission characteristics than low ADT roads. However, both the AP-42 and the PEI baseline data bases show a very strong interrelationship between silt loading and vehicle speed. Thus, the effects of high-speed (and, by inference, high-ADT) are at least partially accounted for by the inclusion of silt loading as an input parameter. (Also, please see the response to comment 4 in the log for the letter from Pechan and Associates. • Traffic flow characteristics -- The AP-42 paved road data base and all current or revised emission factor models apply only to freely flowing traffic; no provision is made for the presumably higher emissions due to stop-and-go traffic.
As you are probably aware, the Federal Highway Administration is presentaly funding research conducted by Desert Research Institute (DRI) to characterize emissions from paved roads. My staff is currently assisting DRI conducting roadside testing in Scottsdale, Arizona. In October 1993, our Department plans to conduct roadside PM_{10} sampling at several locations in the Phoenix metro area using a 3-dimensional sampling array similar to the MRI configuration. I've enclosed a copy of our proposed study plan, which I believe has two inherent advantages that promise to yield a better data base than that used to derive the AP-42 emission factors for urban areas: (1) saqmpling will be conducted on roads selected to represent a majority of the urban VMT (2) PM_{10} samples will be collected continuously using Tapedred Element Oscillating Microbalance (TEOM) samplers which will provide a larger number of data points with shorter averaging times allowing tighter specification on variables such as wind and traffic.	In light of the above response, MRI certainly recognizes the need for additional field investigation. Furthermore, MRI also recognizes the need that, as new information becomes available, the paved road emission factor should be evaluated in terms of its performance in estimatin • evaluated in terms of its performance in estimating independent emissions data • reformulated, as needed, depending upon the results of the evaluation

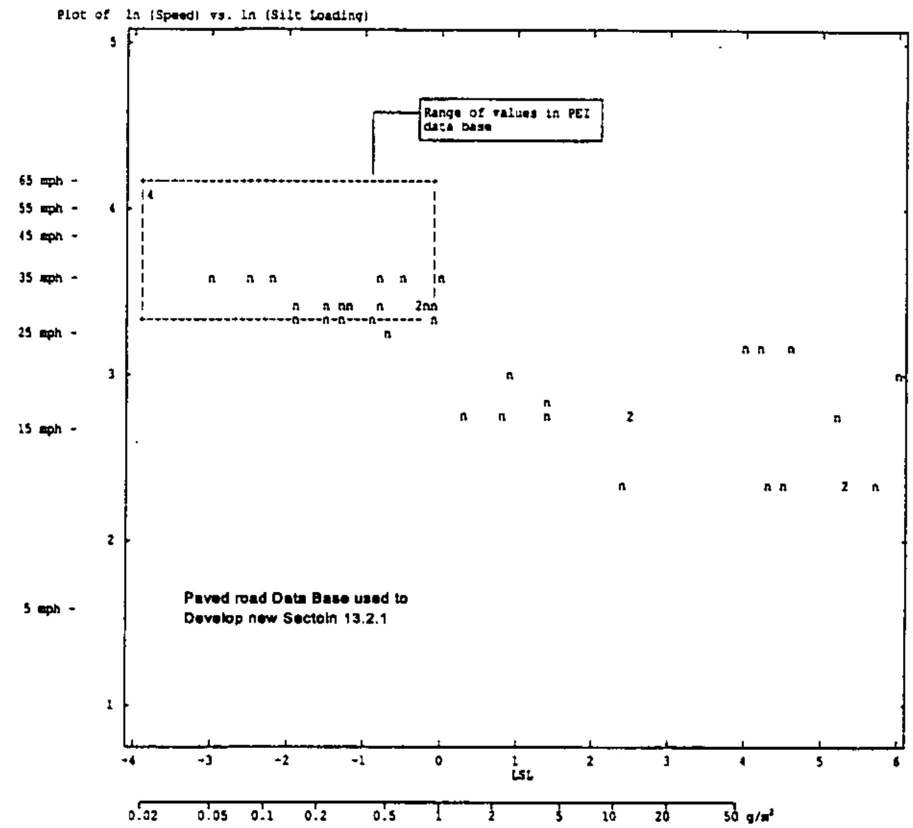

Figure 1. PLOT OF AVERAGE VEHICLE SPEED vs. SILT LOADING IN THE AP-42 PAVED ROAD EMISSION FACTOR DATA BASE (Fully logarithmic)

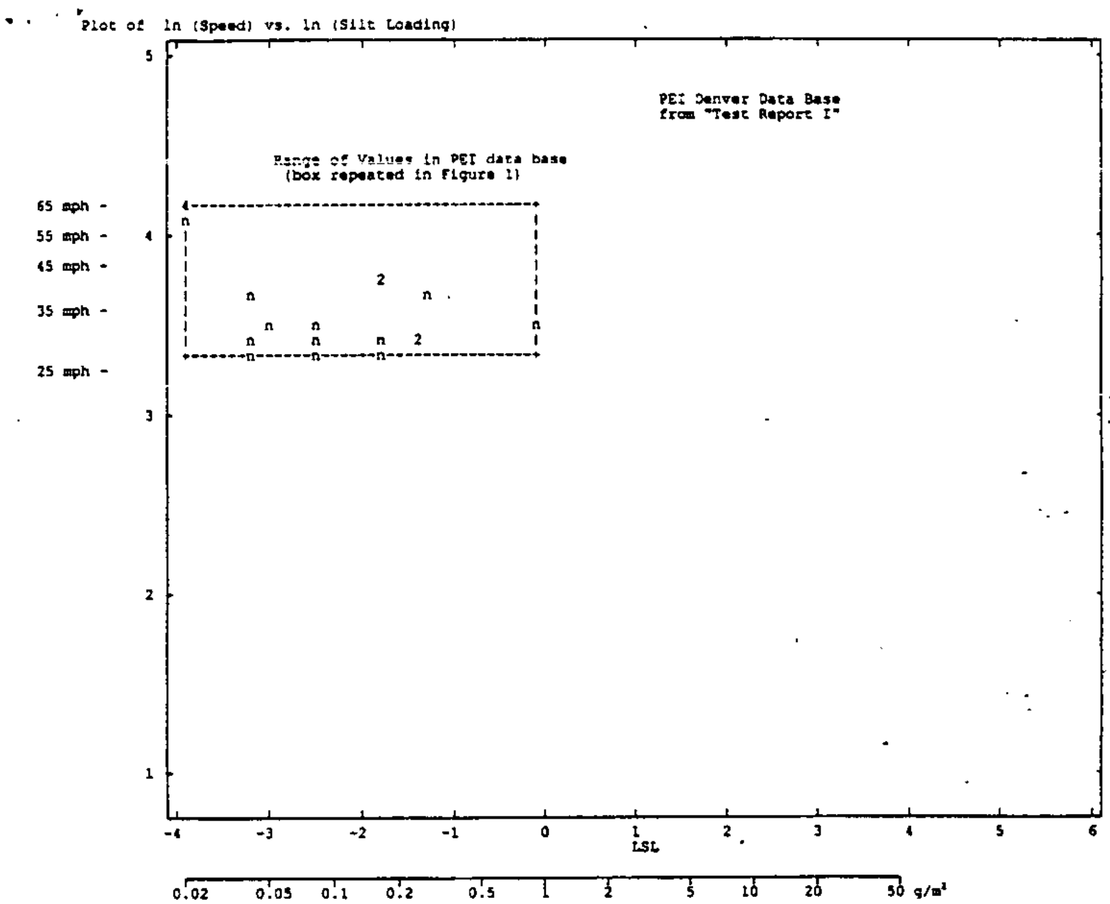

Figure 2. PLOT OF AVERAGE VEHICLE SPEED vs. SILT LOADING IN THE PEI BASELINE EMISSION FACTOR DATA BASE (Fully logarithmic)

Attachment 2.

Public Paved Road Surface Loading
Presented as Appendix X in March 8, 1993
Paved Road Background Document

TABLE A2-1. PUBLIC PAVED ROAD SURFACE LOADING DATA BASE (DETAILED INFORMATION)

STATE	CITY	STREET	CLASS	DATE	ADT	SILT LOADING (g/m*m)	SILT %	TOTAL LOADING (g/m*m)	SILT LOADING SUMMARY
The following data from		Reference 1							
MT	Billings	-----	Rural	Apr-78	50	0.6	18.5	3.4	
MT	Billings	Yellowstone	Residential	Apr-78	115	0.5	14.3	3.5	
MT	Missoula	Bancroft	Residential	Apr-78	4000	8.4	33.9	24.9	
MT	Butte	1st St	Residential	Apr-78	679	24.6	10.6	232.4	
MT	Butte	N Park Pl	Residential	Apr-78	60	103.7	7	1480.8	
MT	Billings	Grand Ave	Collector	Apr-78	6453	1.6	19.1	13.05	2 samples, range: 1.0 - 2.2
MT	Billings	4th Ave E	Collector	Apr-78	3328	7.7	7.7	99.5	
MT	Missoula	6th St	Collector	Apr-78	3655	26	62.9	6	
MT	Butte	Harrison	Arterial	Apr-78	22849	1.9	5	37.3	
MT	Missoula	Hiway 93	Arterial	Apr-78	18870	1.9	55.9	3.3	
MT	Butte	Montana	Arterial	Apr-78	13529	0.8	6.6	11.9	
MT	East Helena	Thurman	Residential	Apr-83	140	13.1	4.3	305.2	
MT	East Helena	1st St	Local	Apr-83	780	4	13.6	29	
MT	East Helena	Montana	Collector	Apr-83	2700	8.2	9.4	86.6	
MT	East Helena	Main St	Collector	Apr-83	1360	4.7	8.4	55.3	
MT	Libby	6th	Local	Mar-88	1310	-----	14.8	-----	
MT	Libby	5th	Local	Mar-88	331	-----	16.5	-----	
MT	Libby	Champion Int So g	Collector	Mar-88	800	-----	27.5	-----	
MT	Libby	Mineral Ave	Collector	Mar-88	5900	7	16	43.5	
MT	Libby	Main Ave btwn 6th	Collector	Mar-88	536	61	20.4	299.2	
MT	Libby	California	Collector	Mar-88	4500	-----	12.1	-----	
MT	Libby	US 2	Arterial	Mar-88	10850	-----	12.3	-----	
MT	Butte	Garfield Ave	Residential	Apr-88	562	2.1	10.9	19.3	
MT	Butte	Continental Dr	Arterial	Apr-88	5272	0.9	10.1	8.8	
MT	Butte	Garfield Ave	Residential	Jun-89	562	1	8.7	11.2	
MT	Butte	So Park Ave	Residential	Jun-89	60	2.8	10.9	25.5	
MT	Butte	Continental Dr	Arterial	Jun-89	5272	7.2	3.6	197.6	
MT	East Helena	Morton St	Local	Aug-89	250	1.7	6.8	24.6	
MT	East Helena	Main St	Collector	Aug-89	2316	0.7	4.1	17	
MT	East Helena	US 12	Arterial	Aug-89	7900	2.1	12.5	16.5	
MT	Columbia Fall	7th St	Residential	Mar-90	390	-----	9.5	-----	
MT	Columbia Fall	4th St	Residential	Mar-90	400	13.8	14.3	131.5	
MT	Columbia Fall	3rd Ave	Residential	Mar-90	50	-----	14.3	-----	
MT	Columbia Fall	4th Ave	Residential	Mar-90	1720	-----	5.4	-----	
MT	Columbia Fall	CF Forest	Local	Mar-90	240	-----	16.3	-----	
MT	Columbia Fall	12th Ave	Collector	Mar-90	1510	-----	8.8	-----	
MT	Columbia Fall	3rd St	Collector	Mar-90	1945	-----	7	-----	
MT	Columbia Fall	Nucleus	Collector	Mar-90	4730	15.4	10	153.9	
MT	Columbia Fall	Plum Creek	Collector	Mar-90	316	-----	6.2	-----	

TABLE A2-1. (continued)

STATE	CITY	STREET	CLASS	DATE	ADT	SILT LOADING (g/m*m)	SILT %	TOTAL LOADING (g/m*m)	SILT LOADING SUMMARY
MT	Columbia Fall	6th Ave	Collector	Mar-90	1764	-----	4.2	-----	
MT	Columbia Fall	US 2	Arterial	Mar-90	13110	2.7	18.7	14.6	
MT	East Helena	Morton	Residential	Jul-90	250	1.6	17	9.3	
MT	East Helena	Main St	Collector	Jul-90	2316	5.6	10.6	52.5	
MT	East Helena	US 12	Arterial	Jul-90	7900	3.2	15.4	20.9	
MT	Columbia Fall	4th Ave	Local	Aug-90	400	1.5	4	37.7	
MT	Libby	Main Ave 4th &	Collector	Aug-90	530	2.4	17.9	13.2	
MT	Columbia Fall	Nucleus	Collector	Aug-90	5730	0.8	5.3	16	
MT	Columbia Fall	US 2	Arterial	Aug-90	13039	0.2	7	2.9	
MT	East Helena	Morton	Local	Oct-90	250	3.4	10.2	33.6	
MT	East Helena	Main	Collector	Oct-90	2316	4.5	5.6	81.3	
MT	East Helena	US 12	Arterial	Oct-90	7900	0.6	13.9	4.3	
MT	Columbia Fall	Nucleus	Collector	11/6/90	5670	5.2	13.5	38	
MT	Columbia Fall	US 2	Arterial	11/6/90	15890	1.7	24.1	7.2	
MT	Libby	US 2	Arterial	12/8/90	10000	21.5	9.6	223.9	
MT	Libby	Main Ave 4th &	Collector	12/9/90	530	13.6	27.1	50.3	
MT	Butte	Texas	Collector	12/13/90	3070	1	15.4	6.4	
MT	East Helena	King	Local	Jan-91	75	1	3.4	30.6	
MT	East Helena	Prickly Pear	Local	Jan-91	425	12	1.8	666.5	
MT	East Helena	Morton	Local	Jan-91	250	14.1	3.5	402.3	
MT	East Helena	Main St	Collector	Jan-91	2316	36.7	12.1	303.4	
MT	East Helena	US 12	Arterial	Jan-91	7900	0.8	14	5.6	
MT	Thompson Fall	Preston	Local	1/23/90	920	9.2	9.9	93	
MT	Thompson Fall	Highway 200	Collector	1/23/90	5000	33.3	27.2	122.2	
MT	East Helena	Seaver Park Rd	Local	Feb-91	150	21.6	7.1	304.7	
MT	East Helena	New Lake Helena D	Collector	Feb-91	2140	19.2	9	213.4	
MT	East Helena	Porter	Collector	Feb-91	850	74.4	7.7	966.8	
MT	Libby	Main Ave 4th &	Collector	2/14/91	530	33.3	18.7	178.2	
MT	Libby	US 2	Arterial	2/17/91	10000	69.3	21	330.3	
MT	Butte	Texas	Collector	2/21/91	3070	1.2	11	10.9	
MT	Butte	Harrison	Arterial	2/21/91	22849	2.9	7.9	36.6	
MT	Kalispell	3rd btwn Main & 1	Collector	2/24/91	2653	30.5	24.8	122.9	
MT	Kalispell	Main	Arterial	2/24/91	14730	17.4	20.4	85.2	
MT	Thompson Fall	Preston	Local	2/25/91	920	35.7	17.9	199.6	
MT	Thompson Fall	Highway 200	Collector	2/25/91	5000	66.8	17.8	375.3	
MT	Helena	Montana	Arterial	Mar-91	21900	15.4	6.2	248.3	
MT	Kalispell	3rd btwn Main & 1	Collector	3/9/91	2653	39.1	29.1	134.5	
MT	Columbia Fall	Nucleus	Collector	Mar-91	5670	30.1	17	174.6	2 samples, range: 0.8 - 0.8
MT	Kalispell	Main	Arterial	3/9/91	14730	17.6	24.7	71.4	
MT	Thompson Fall	Preston	Local	Mar-91	920	4.4	8.3	51	2 samples, range: 2.8 - 5.9

TABLE A2-1. (continued)

STATE	CITY	STREET	CLASS	DATE	ADT	SILT LOADING (g/m*m)	SILT %	TOTAL LOADING (g/m*m)	SILT LOADING SUMMARY
MT	Thompson Fall	Highway 200	Collector	Mar-91	5000	4.3	15.5	28.9	2 samples, range: 1.0 - 7.5
MT	Libby	Main Ave 4th &	Collector	Mar-91	530	14.8	33.1	44.9	2 samples, range: 13.5 - 16.1
MT	Libby	US 2	Arterial	Mar-91	11963	20	19.5	111.9	3 samples, range: 11.4 - 32.4
MT	East Helena	Morton	Local	Apr-91	250	4.3	8.8	48.7	
MT	East Helena	US 12	Arterial	Apr-91	7900	0.5	8.7	5.7	
MT	Thompson Fall	Preston	Local	Apr-91	920	1.2	15.7	6.3	4 samples, range: 0.3 - 4.0
MT	Thompson Fall	Highway 200	Collector	4/4/91	5000	2	13.4	14.7	2 samples, range: 1.1 - 2.2
MT	Libby	Main Ave 4th &	Collector	Apr-91	530	3.5	44	7.8	2 samples, range: 2.5 - 4.4
MT	Libby	US 2	Arterial	Apr-91	12945	11.8	20.5	57.2	4 samples, range: 1.2 - 22.9
MT	Kalispell	3rd btwn Main & 1	Collector	4/14/91	2653	15.1	37.1	40.9	
MT	Columbia Fall	Nucleus	Collector	Apr-91	5670	9	19.8	47.6	
MT	Kalispell	Main	Arterial	4/14/91	14730	13	44.5	29.4	
MT	Columbia Fall	Nucleus	Collector	May-91	5670	2.4	17.5	15.9	4 samples, range: 1.3 - 3.8
MT	Columbia Fall	US 2	Arterial	May-91	14712	5.5	20.7	24.8	5 samples, range: 1.5 - 14.2
MT	Libby	Main Ave 4th &	Collector	5/19/91	530	1.7	31	5.7	
MT	Libby	Main Ave 4th &	Collector	6/27/91	530	1.7	24.3	7.1	
MT	Libby	US 2	Arterial	6/27/91	10000	3.8	12.6	30.6	
MT	East Helena	Morton	Local	Jul-91	250	1.7	11.4	15.3	
MT	East Helena	Main	Collector	Jul-91	2316	8.8	11	79.7	
MT	Thompson Fall	Preston	Local	7/9/91	920	10.9	11	98.7	
MT	Thompson Fall	Highway 200	Collector	7/9/91	5000	2.1	8.1	25.9	
MT	Helena	Montana	Arterial	7/17/91	21900	0.9	4.7	19.4	
MT	Butte	Texas	Collector	7/26/91	3070	2.5	28.2	8.9	
MT	Butte	Harrison	Arterial	7/26/91	22849	1.6	28.2	5.8	
MT	Kalispell	3rd btwn Main & 1	Collector	8/3/91	2653	5.8	23	25.3	
MT	Kalispell	Main	Arterial	8/3/91	14730	4	21	19.3	
MT	Columbia Fall	US 2	Arterial	8/11/91	15890	0.1	5.6	2.3	
MT	Missoula	Russel btwn 4th &	Road	8/30/91	5270	1.6	8.3	19.3	
MT	East Helena	US 12	Arterial	8/30/91	7900	7	20.5	34.3	
MT	Butte	Texas	Collector	10/3/91	3070	1	17.7	5.4	
MT	Butte	Harrison	Arterial	10/3/91	22849	2.1	23.1	9.1	
MT	Kalispell	3rd btwn Main & 1	Collector	10/6/91	2653	10	31.3	31.9	
MT	Kalispell	Main	Arterial	10/6/91	14730	4.3	27.7	15.7	
MT	East Helena	Morton	Local	10/16/91	250	1.8	31	5.9	
MT	East Helena	Main St	Collector	10/16/91	2316	1.6	20.5	7.7	
MT	East Helena	US 12	Arterial	10/16/91	7900	1	6.7	14.9	
MT	Columbia Fall	Nucleus	Collector	10/20/91	5670	1.9	13.9	13.3	
MT	Columbia Fall	US 2	Arterial	10/20/91	15890	1.2	11.3	10.2	
MT	Kalispell 3r	d btwn Main & 1	Collector	11/6/91	2653	2.2	12.3	17.8	
MT	Kalispell	Main	Arterial	11/28/91	14730	2.7	8.6	30.8	

TABLE A2-1. (continued)

STATE	CITY	STREET	CLASS	DATE	ADT	SILT LOADING (g/m*m)	SILT %	TOTAL LOADING (g/m*m)	SILT LOADING SUMMARY
MT	Thompson Fall	Preston	Local	12/17/91	920	4	18.1	22.5	
MT	Thompson Fall	Highway 200	Collector	12/17/91	5000	1.5	13.2	11.6	
MT	Butte	Texas	Collector	2/2/92	3070	19.1	11.6	164.5	
MT	Butte	Harrison	Arterial	2/2/92	22849	8.3	12	69.3	
MT	East Helena	Morton	Local	2/3/92	250	78.3	9.5	824.7	
MT	Libby	W 4th St	Local	2/3/92	350	36.3	56.3	64.5	
MT	Libby	Main Ave 4th &	Collector	2/3/92	530	10.7	49.9	21.4	
MT	East Helena	Main St	Collector	2/3/92	2316	57.9	14.8	391	
MT	Columbia Fall	Nucleus	Collector	2/3/92	5670	29.2	20.1	145.4	
MT	Columbia Fall	US 2	Arterial	Feb-92	12945	51.3	32.2	143.1	2 samples, range: 13.0 - 89.5
MT	East Helena	US 12	Arterial	2/3/92	7900	2.9	14.3	20.7	
MT	Thompson Fall	Preston	Local	2/22/92	920	0.5	18	2.6	
MT	Thompson Fall	Highway 200	Collector	2/22/92	5000	1.2	14.6	8.1	
MT	Kalispell	3rd btwn 2nd & 3r	Local	3/15/92	450	40.2	11.9	338	
MT	Kalispell	3rd btwn Main & 1	Collector	3/15/92	2653	81.1	37.3	217.3	
MT	Kalispell	Main	Arterial	3/15/92	14730	16.5	32.1	51.3	
MT	Thompson Fall	Preston	Local	Apr-92	920	0.43	14.9	3.2	
MT	Thompson Fall	Highway 200	Collector	Apr-92	5000	0.8	18.2	4.7	3 samples, range: 0.4 - 1.0
MT	Kalispell	3rd btwn 2nd & 3r	Local	4/26/92	450	20.9	45.8	45.5	
MT	Kalispell	3rd btwn Main & 1	Collector	4/26/92	2653	19.2	50.9	37.7	
MT	Kalispell	Main	Arterial	4/26/92	14730	10.7	33.5	32.1	
MT	Kalispell	3rd btwn 2nd & 3r	Local	May-92	450	8.3	35.6	23.5	3 samples, range: 6.6 - 10.3
MT	Kalispell	3rd btwn Main & 1	Collector	May-92	2653	8.5	32.4	25.8	3 samples, range: 6.3 - 11.4
MT	Kalispell	Main	Arterial	May-92	14730	5.1	23.6	21.7	3 samples, range: 3.8 - 5.9
MT	Libby	W 4th St	Local	5/11/92	350	13.4	56.5	23.7	
MT	Libby	Main Ave 4th &	Collector	5/11/92	530	5.6	58.9	9.4	
MT	Libby	US 2	Arterial	May-92	12945	10.4	25.6	29.4	
MT	East Helena	Morton	Local	5/15/92	250	6.9	6.7	103	
MT	East Helena	Main St	Collector	5/15/92	2316	6.4	10.2	62.8	
MT	East Helena	US 12	Arterial	5/15/92	7900	1.2	6.9	17	
MT	Columbia Fall	Nucleus	Collector	5/25/92	5670	1	21.7	4.5	
MT	Missoula	Inez btwn 4th & 5	Local	6/4/92	500	1	17.4	5.6	
MT	Missoula	Russel btwn 3rd &	Collector	6/4/92	5270	15.2	. 14	108.4	
MT	Missoula	3rd btwn Prince &	Arterial	6/4/92	12000	2	13.1	15.7	
The following data from		Reference 2 & 3							
CO	Denver	E. Colfax	Principal Arte	Mar-89	1994 *	0.21	2	19.9	4 samples, range: 0.04-0.47
CO	Denver	E. Colfax	Principal Arte	Apr-89	2228 *	0.73	1.7	106.7	18 samples, range: 0.08-1.78
CO	Denver	York St	Principal Arte	Apr-89	780 *	0.86	1.2	74.8	2 samples, range: 0.83 - 0.89

TABLE A2-1. (continued)

STATE	CITY	STREET	CLASS	DATE	ADT	SILT LOADING (g/m*m)	SILT %	TOTAL LOADING (g/m*m)	SILT LOADING SUMMARY
CO	Denver	E. Belleview	Principal Arte	Apr-89	-----	0.07	4.2	2	3 samples, range: 0.03-0.09
CO	Denver	I-225	Expressway +	Apr-89	4731 *	0.02	3.6	0.4	3 samples, range: 0.01-0.02
CO	Denver	W. Evans	Principal Arte	May-89	1905 *	0.76	1.9	74	11 samples, range: 0.03 - 2.24
CO	Denver	W. Evans	Principal Arte	Jun-89	1655 *	0.71	1.2	66.1	12 samples, range: 0.07 - 3.34
CO	Denver	E. Louisiana	Minor Arterial	Jun-89	515 *	0.14	4.66	3.5	5 samples, range: 0.08 - 0.24
The following data from		Reference 4 & 3							
CO	Denver	E. Louisiana	Minor Arterial	Jan-90	-----	1.44 *	-----	-----	6 samples, range: 0.12-2.0
CO	Denver	E. Jewell Ave	Collector +	1/24/90	-----	2.24 *	-----	-----	
CO	Denver St	ate Highway 36	Expressway +	1/30/90	-----	0.56 *	-----	-----	2 samples, range: 0.56 - 0.56
CO	Denver St	ate Highway 36	Expressway +	2/1/90	-----	1.92 *	-----	-----	4 samples, range: 1.92-1.92
CO	Denver	W. Evans Ave	Principal Arte	2/3/90	-----	1.64 *	-----	-----	2 samples, range: 1.64-1.64
CO	Denver	E. Mexico St	Local +	2/7/90	-----	2.58 *	-----	-----	3 samples, range: 2.58 - 2.58
CO	Denver	E. Colfax Ave	Principal Arte	Feb-90	-----	0.09 *	-----	-----	16 samples, range: 0.02 - 0.17
CO	Denver St	ate Highway 36	Expressway +	Mar-90	-----	-----	-----	-----	7 samples
CO	Denver E.	Louisiana Ave	Minor Arterial	3/10/90	-----	-----	-----	-----	3 samples
CO	Denver	W. Evans Ave	Principal Arte	Mar-90	-----	1.27 *	-----	-----	5 samples, range: 0.07 - 3.38
CO	Denver	W. Colfax Ave	Principal Arte	Mar-90	-----	0.41 *	-----	-----	21 samples, range: 0.04 - 2.61
CO	Denver	Parker Rd	Local +	Apr-90	-----	0.05 *	-----	-----	6 samples, range: 0.01 - 0.11
CO	Denver	W. Byron Pl	Principal Arte	Apr-90	-----	0.3 *	-----	-----	6 samples, range: 0.21 - 0.35
CO	Denver	E. Colfax Ave	Principal Arte	4/18/90	-----	0.21 *	-----	-----	
The following data from		Reference 5							
UT	Salt Lake Cou	700 East	Arterial	*	42340	0.137	11.5	1.187	4 samples, range: 0.107-0.162
UT	Salt Lake Cou	State St	Collector	*	27140	0.238	17	1.692	4 samples, range: 0.212-0.357
UT	Salt Lake Cou	I-80	Freeway	*	77040	0.023	21.4	0.1	5 samples, range: 0.011 - 0.034
UT	Salt Lake Cou	I-15	Freeway	*	146180	0.036	23.5	0.419	6 samples, range: 0.078 - 0.126
UT	Salt Lake Cou	400 East	Local	*	5000	1.967	4.07	46.043	14 samples, range: 0.177 - 5.772
The following data from		Reference 6							

TABLE A2-1. (continued)

STATE	CITY	STREET	CLASS	DATE	ADT	SILT LOADING (g/m*m)	SILT %	TOTAL LOADING (g/m*m)	SILT LOADING SUMMARY
NV	Las Vegas	Lake Mead	Major	7/15/87	-----	0.81	12.4	6.51	
NV	Las Vegas	Perliter	Local	7/15/87	-----	2.23	31.2	7.14	
NV	Las Vegas	Bruce	Collector	7/15/87	-----	1.64	26.1	6.3	
NV	Las Vegas	Stewart	Major	9/29/87	-----	0.38	24	1.63	3 samples, range: 0.24 - 0.46
NV	Las Vegas	Ambler	Local	9/29/87	-----	1.38	23	6.32	3 samples, range: 0.64 - 2.00
NV	Las Vegas	28th St	Collector	9/29/87	-----	0.52	15.8	3.4	3 samples, range: 0.51 - 0.54
NV	Las Vegas	Lake Mead	Major	10/7/87	-----	0.19	14.9	1.26	2 samples, range: 0.17 - 0.20
NV	Las Vegas	Perliter	Local	10/7/87	-----	1.5	31.9	4.76	2 samples, range: 1.48 - 1.52
NV	Las Vegas	Bruce	Collector	10/7/87	-----	0.9	24.1	3.74	2 samples, range: 0.76 - 1.03
The following data from		Reference 7							
AZ	Phoenix	Broadway	Arterial	*	-----	0.127	12.2	1.071	
AZ	Phoenix	South Central	Arterial	*	-----	0.085	5	1.726	
AZ	Phoenix	Indian School & 2	Arterial	*	-----	0.035	3.1	1.021	
AZ	Glendale	43rd & Vista	Arterial	*	-----	0.042	3.9	1.049	
AZ	Glendale	59th & Peoria	Arterial	*	-----	0.099	8.2	1.183	
AZ	Mesa	Mesa Drive	Arterial	*	-----	0.099	8.9	1.085	
AZ	Mesa	E. McKellips & Ol	Arterial	*	-----	0.014	17	0.092	
AZ	Phoenix	17th & Highland	Collector	*	-----	0.028	13.4	0.232	
AZ	Mesa	3rd & Miller	Collector	*	-----	0.07	11.8	0.627	
AZ	Phoenix	Avalon & 25th	Collector	*	-----	0.528	11.1	4.79	
AZ	Phoenix	Apache	Collector	*	-----	0.282	6.4	4.367	
AZ	Phoenix	28th St & E. G	Collector	*	-----	0.035	2.3	1.479	
AZ	Pima County	6th Ave	Collector	*	-----	1.282	6.417	19.961	
AZ	Pima County	Speedway Blvd	Arterial	*	-----	0.401	8.117	4.937	
AZ	Pima County	22nd St	Arterial	*	-----	0.028	16.529	0.176	
AZ	Pima County	Amklam Rd	Collector	*	-----	0.014	5.506	0.197	
AZ	Pima County	Fort Lowel Rd	Arterial	*	-----	0.113	3.509	3.268	
AZ	Pima County	Oracle Rd	Arterial	*	-----	0.014	1.556	0.725	
AZ	Pima County	Inn Rd	Arterial	*	-----	0.021	18.756	0.127	
AZ	Pima County	Orange Grove	Arterial	*	-----	0.162	21.989	0.725	
AZ	Pima County	La Canada	Arterial	*	-----	0.106	3.975	2.571	
The following data from		Reference 8							
KS	Kansas City	7th	Arterial	Feb-80	-----	0.29	6.8	4.2	3 samples, range: 0.15 - 0.46
MO	Kansas City	Volker	Arterial	Feb-80	-----	0.67	20.1	3.5	3 samples, range: 0.43 -1.00

TABLE A2-1. (continued)

STATE	CITY	STREET	CLASS	DATE	ADT	SILT LOADING (g/m*m)	SILT %	TOTAL LOADING (g/m*m)	SILT LOADING SUMMARY
MO	Kansas City	Rockhill	Arterial	Feb-80	-----	0.68	21.7	3.3	
KS	Tonganoxie	4th	Collector	Mar-80	-----	2.5	14.5	17.1	
KS	Kansas City	7th	Arterial	Mar-80	-----	0.29	12.2	2.4	
MO	St. Louis	I-44	Expressway	May-80	-----	0.02	-----	-----	4 samples, range: 0.02
MO	St. Louis	Kingshighway	Collector	May-80	-----	0.08	10.9	0.7	3 samples, range: 0.05 - 0.11
IL	GraniteCity	24th	Arterial	May-80	-----	0.78	6.4	12.3	2 samples, range: 0.73 - 0.83
IL	GraniteCity	Benton	Collector	May-80	-----	0.93	8.6	10.8	
The following data from		Reference 9							
MN	Duluth	US53north	Highway	3/19/92	5000	0.23	28	1.94	8 samples, range: 0.04 - 0.77
MN	Duluth	US53south	Highway	2/26/92	5000	0.24	13.4	2.3	5 samples, range: 0.05 - 0.37
The following data from		Reference 10							
CO	Aspen	Aspen	Local	3/18/92	-----	3.56 *	24	14.81	* Samples said to be wet sieved
CO	Aspen	Aspen	Collector	3/30/92	-----	12.05 *	24	50.23	
CO	Aspen	Aspen	Collector	4/1/92	-----	5.97 *	21.1	29.16	8 samples, range: 2.65 - 9.10
CO	Aspen	Highway 82	Major Arterial	4/6/92	-----	6.1 *	12	50.08	2 samples, range: 4.55 - 7.65
CO	Aspen	Knollwood	Local	4/1/92	-----	7.9 *	8	96.01	2 samples, range: 5.21 - 10.59
CO	Aspen	Main	Major Arterial	4/2/92	-----	7.68 *	21.7	35.9	3 samples, range: 5.58 - 9.30
CO	Aspen	Maroon Creek Rd	Minor Arterial	3/30/92	-----	2.07 *	9	23.03	
CO	Aspen	Maroon Creek Rd	Minor Arterial	4/1/92	-----	2.78 *	8.9	30.35	7 samples, range: 0.96 - 6.41
CO	Aspen	South Mill	Collector	4/1/92	-----	9.05 *	25	36.21	

"-----" denotes missing information.

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TABLE A2-2. PUBLIC PAVED ROAD SURFACE LOADING DATA BASE

STATE	CLASS	DATE	ADT	SL	SILT	TL	# SAMPLES
MT	1	Apr-78	50	0.6	18.5	3.4	1
MT	2	Apr-78	115	0.5	14.3	3.5	1
MT	2	Apr-78	4000	8.4	33.9	24.9	1
MT	2	Apr-78	679	24.6	10.6	232.4	1
MT	2	Apr-78	60	103.7	7	1480.8	1
MT	3	Apr-78	6453	1.6	19.1	13.05	2
MT	3	Apr-78	3328	7.7	7.7	99.5	1
MT	3	Apr-78	3655	26	62.9	6	1
MT	4	Apr-78	22849	1.9	5	37.3	1
MT	4	Apr-78	18870	1.9	55.9	3.3	1
MT	4	Apr-78	13529	0.8	6.6	11.9	1
MT	2	Apr-83	140	13.1	4.3	305.2	1
MT	5	Apr-83	780	4	13.6	29	1
MT	3	Apr-83	2700	8.2	9.4	86.6	1
MT	3	Apr-83	1360	4.7	8.4	55.3	1
MT	5	Mar-88	1310	.	14.8	.	1
MT	5	Mar-88	331	.	16.5	.	1
MT	3	Mar-88	800	.	27.5	.	1
MT	3	Mar-88	5900	7	16	43.5	1
MT	3	Mar-88	536	61	20.4	299.2	1
MT	3	Mar-88	4500	.	12.1	.	1
MT	4	Mar-88	10850	.	12.3	.	1
MT	2	Apr-88	562	2.1	10.9	19.3	1
MT	4	Apr-88	5272	0.9	10.1	8.8	1
MT	2	Jun-89	562	1	8.7	11.2	1
MT	2	Jun-89	60	2.8	10.9	25.5	1
MT	4	Jun-89	5272	7.2	3.6	197.6	1
MT	5	Aug-89	250	1.7	6.8	24.6	1
MT	3	Aug-89	2316	0.7	4.1	17	1
MT	4	Aug-89	7900	2.1	12.5	16.5	1
MT	2	Mar-90	390	.	9.5	.	1
MT	2	Mar-90	400	18.8	14.3	131.5	1
MT	2	Mar-90	50	.	14.3	.	1
MT	2	Mar-90	1720	.	5.4	.	1
MT	5	Mar-90	240	.	16.3	.	1
MT	3	Mar-90	1510	.	8.8	.	1
MT	3	Mar-90	1945	.	7	.	1

TABLE A2-2. (continued)

STATE	CLASS	DATE	ADT	SL	SILT	TL	# SAMPLES
MT	3	Mar-90	4730	15.4	10	153.9	1
MT	3	Mar-90	316	.	6.2	.	1
MT	3	Mar-90	1764	.	4.2	.	1
MT	4	Mar-90	13110	2.7	18.7	14.6	1
MT	2	Jul-90	250	1.6	17	9.3	1
MT	3	Jul-90	2316	5.6	10.6	52.5	1
MT	4	Jul-90	790	3.2	15.4	20.9	1
MT	5	Aug-90	400	1.5	4	37.7	1
MT	3	Aug-90	530	2.4	17.9	13.2	1
MT	3	Aug-90	5730	0.8	5.3	16	1
MT	4	Aug-90	13039	0.2	7	2.9	1
MT	5	Oct-90	250	3.4	10.2	33.6	1
MT	3	Oct-90	2316	4.5	5.6	81.3	1
MT	4	Oct-90	7900	0.6	13.9	4.3	1
MT	3	11/6/90	5670	5.2	13.5	38	1
MT	4	11/6/90	15890	1.7	24.1	7.2	1
MT	4	12/8/90	10000	21.5	9.6	223.9	1
MT	3	12/9/90	530	13.6	27.1	50.3	1
MT	3	12/13/90	3070	1	15.4	6.4	1
MT	5	Jan-91	75	1	3.4	30.6	1
MT	5	Jan-91	425	12	1.8	666.5	1
MT	5	Jan-91	250	14.1	3.5	402.3	1
MT	3	Jan-91	2316	36.7	12.1	303.4	1
MT	4	Jan-91	7900	0.8	14	5.6	1
MT	5	1/23/91	920	9.2	9.9	93	1
MT	3	1/23/91	5000	33.3	27.2	122.2	1
MT	5	Feb-91	150	21.6	7.1	304.7	1
MT	3	Feb-91	2140	19.2	9	213.4	1
MT	3	Feb-91	850	74.4	7.7	966.8	1
MT	3	2/14/91	530	33.3	18.7	178.2	1
MT	4	2/17/91	10000	69.3	21	330.3	1
MT	3	2/21/91	3070	1.2	11	10.9	1
MT	4	2/21/91	22849	2.9	7.9	36.6	1
MT	3	2/24/91	2653	30.5	24.8	122.9	1
MT	4	2/24/91	14730	17.4	20.4	85.2	1
MT	5	2/25/91	920	35.7	17.9	199.6	1
MT	3	2/25/91	5000	66.8	17.8	375.3	1
MT	4	Mar-91	21900	15.4	6.2	248.3	1
MT	3	3/9/91	2653	39.1	29.1	134.5	1

TABLE A2-2. (continued)

STATE	CLASS	DATE	ADT	SL	SILT	TL	# SAMPLES
MT	4	5/15/92	7900	1.2	6.9	17	1
MT	3	5/25/92	5670	1	21.7	4.5	1
MT	5	6/4/92	500	1	17.4	5.6	1
MT	3	6/4/92	5270	15.2	14	108.4	1
MT	4	6/4/92	12000	2	13.1	15.7	1
CO	6	Mar-89	1994	0.21	2	19.9	4
CO	6	Apr-89	2228	0.73	1.7	106.7	18
CO	6	Apr-89	780	0.86	1.2	74.8	2
CO	6	Apr-89	.	0.07	4.2	2	3
CO	7	Apr-89	4731	0.02	3.6	0.4	3
CO	6	May-89	1905	0.76	1.9	74	11
CO	6	Jun-89	1655	0.71	1.2	66.1	12
CO	8	Jun-89	515	0.14	4.66	3.5	5
CO	8	Oct-90	.	1.44	.	.	6
CO	3	1/24/90	.	2.24	.	.	1
CO	7	1/30/90	.	0.56	.	.	2
CO	7	2/1/90	.	1.92	.	.	4
CO	6	2/3/90	.	1.64	.	.	2
CO	5	2/7/90	.	2.58	.	.	3
CO	6	Feb-90	.	0.9	.	.	16
CO	7	Mar-90	.	.	.	.	7
CO	8	3/10/90	.	.	.	.	3
CO	6	Mar-90	.	1.27	.	.	5
CO	6	Mar-90	.	0.41	.	.	21
CO	5	Apr-90	.	0.05	.	.	6
CO	6	Apr-90	.	0.3	.	.	6
CO	6	4/18/90	.	0.21	.	.	1
UT	4	.	42340	0.137	11.5	1.187	4
UT	3	.	27140	0.288	17	1.692	4
UT	9	.	77040	0.023	21.4	0.1	5
UT	9	.	146180	0.096	23.5	0.419	6
UT	5	.	5000	1.967	4.07	46.043	14
NV	10	7/15/87	.	0.81	12.4	6.51	1
NV	5	7/15/87	.	2.23	31.2	7.14	1
NV	3	7/15/87	.	1.64	26.1	6.3	1
NV	10	9/29/87	.	0.38	24	1.63	3

TABLE A2-2. (continued)

STATE	CLASS	DATE	ADT	SL	SILT	TL	# SAMPLES
NV	5	9/29/87	.	1.38	23	6.32	3
NV	3	9/29/87	.	0.52	15.8	3.4	3
NV	10	10/7/87		0.19	14.9	1.26	2
NV	5	10/7/87	.	1.5	31.9	4.76	2
NV	3	10/7/87	.	0.9	24.1	3.74	2
AZ	4	.	.	0.127	12.2	1.071	1
AZ	4	.	.	0.085	5	1.726	1
AZ	4	.	.	0.035	3.1	1.021	1
AZ	4	.	.	0.042	3.9	1.049	1
AZ	4	.	.	0.099	8.2	1.183	1
AZ	4	.	.	0.099	8.9	1.085	1
AZ	4	.	.	0.014	17	0.092	1
AZ	3	.	.	0.028	13.4	0.232	1
AZ	3	.	.	0.07	11.8	0.627	1
AZ	3	.	.	0.528	11.1	4.79	1
AZ	3	.	.	0.282	6.4	4.367	1
AZ	3	.	.	0.035	2.3	1.479	1
AZ	3	.	.	1.282	6.417	19.961	1
AZ	4	.	.	0.401	8.117	4.937	1
AZ	4	.	.	0.028	16.529	0.176	1
AZ	3	.	.	0.014	5.506	0.197	1
AZ	4	.	.	0.113	3.509	3.268	1
AZ	4	.	.	0.014	1.556	0.725	1
AZ	4	.	.	0.021	18.756	0.127	1
AZ	4	.	.	0.162	21.989	0.725	1
AZ	4	.	.	0.106	3.975	2.571	1
KS	4	Feb-80	.	0.29	6.8	4.2	3
MO	4	Feb-80	.	0.67	20.1	3.5	3
MO	4	Feb-80	.	0.68	21.7	3.3	1
KS	3	Mar-80	.	2.5	14.5	17.1	1
KS	4	Mar-80	.	0.29	12.2	2.4	1
MO	7	May-80		0.02	.	.	4
MO	3	May-80		0.08	10.9	0.7	3
IL	4	May-80		0.78	6.4	12.3	2
IL	3	May-80		0.93	8.6	10.8	1
MN	11	3/19/92	5000	0.23	28	1.94	8

TABLE A2-2. (continued)

STATE	CLASS	DATE	ADT	SL	SILT	TL	# SAMPLES
MT	3	Mar-91	5670	30.1	17	174.6	2
MT	4	3/9/91	14730	17.6	24.7	71.4	1
MT	5	Mar-91	920	4.4	8.3	51	2
MT	3	Mar-91	5000	4.3	15.5	28.9	2
MT	3	Mar-91	530	14.8	33.1	44.9	2
MT	4	Mar-91	11963	20	19.5	111.9	3
MT	5	Apr-91	250	4.3	8.8	48.7	1
MT	4	Apr-91	7900	0.5	8.7	5.7	1
MT	5	Apr-91	920	1.2	15.7	6.3	4
MT	3	4/4/91	5000	2	13.4	14.7	2
MT	3	Apr-91	530	3.5	44	7.8	2
MT	4	Apr-91	12945	11.8	20.5	57.2	4
MT	3	4/14/91	2653	15.1	37.1	40.9	1
MT	3	Apr-91	5670	9	19.8	47.6	1
MT	4	4/14/91	14730	13	44.5	29.4	1
MT	3	May-00	5670	2.4	17.5	15.9	4
MT	4	50	14712	5.5	20.7	24.8	5
MT	3	5/19/91	530	1.7	31	5.7	1
MT	3	6/27/91	530	1.7	24.3	7.1	1
MT	4	6/27/91	10000	3.8	12.6	30.6	1
MT	5	Jul-91	250	1.7	11.4	15.3	1
MT	3	Jul-91	2316	8.8	11	79.7	1
MT	5	7/9/91	920	10.9	11	98.7	1
MT	3	7/9/91	5000	2.1	8.1	25.9	1
MT	4	7/17/91	21900	0.9	4.7	19.4	1
MT	3	7/26/91	3070	2.5	28.2	8.9	1
MT	4	7/26/91	22849	1.6	28.2	5.8	1
MT	3	8/3/91	2653	5.8	23	25.3	1
MT	4	8/3/91	14730	4	21	19.3	1
MT	4	8/11/91	15890	0.1	5.6	2.3	1
MT	3	8/3/91	5270	1.6	8.3	19.3	1
MT	4	8/3/91	7900	7	20.5	34.3	1
MT	3	10/3/91	3070	1	17.7	5.4	1
MT	4	10/3/91	22849	2.1	23.1	9.1	1
MT	3	10/6/91	2653	10	31.3	31.9	1
MT	4	10/6/91	14730	4.3	27.7	15.7	1

TABLE A2-2. (continued)

STATE	CLASS	DATE	ADT	SL	SILT	TL	# SAMPLES
MT	5	10/16/91	250	1.8	31	5.9	1
MT	3	10/16/91	2316	1.6	20.5	7.7	1
MT	4	10/16/91	7900	1	6.7	14.9	1
MT	3	10/20/91	5670	1.9	13.9	13.3	1
MT	4	10/20/91	15890	1.2	11.3	10.2	1
MT	3	11/6/91	2653	2.2	12.3	17.8	1
MT	4	11/28/91	14730	2.7	8.6	30.8	1
MT	5	12/17/91	920	4	18.1	22.5	1
MT	3	12/17/91	5000	1.5	13.2	11.6	1
MT	3	2/2/92	3070	19.1	11.6	164.5	1
MT	4	2/2/92	22849	8.3	12	69.3	1
MT	5	2/3/92	250	78.3	9.5	824.7	1
MT	5	2/3/92	350	36.3	56.3	64.5	1
MT	3	2/3/92	530	10.7	49.9	21.4	1
MT	3	2/3/92	2316	57.9	14.8	391	1
MT	3	2/3/92	5670	29.2	20.1	145.4	1
MT	4	Feb-92	12945	51.3	32.2	143.1	2
MT	4	2/3/92	7900	2.9	14.3	20.7	1
MT	5	Feb-92	920	0.5	18	2.6	1
MT	3	2/22/92	5000	1.2	14.6	8.1	1
MT	5	3/15/92	450	40.2	11.9	338	1
MT	3	3/15/92	2653	81.1	37.3	217.3	1
MT	4	3/15/92	14730	16.5	32.1	51.3	1
MT	5	Apr-92	920	0.43	14.9	3.2	1
MT	3	Apr-92	5000	0.8	18.2	4.7	3
MT	5	4/26/92	450	20.9	45.8	45.5	1
MT	3	4/26/92	2653	19.2	50.9	37.7	1
MT	4	4/26/92	14730	10.7	33.5	32.1	1
MT	5	May-92	450	8.3	35.6	23.5	3
MT	3	May-92	2653	8.5	32.4	25.8	3
MT	4	May-92	14730	5.1	23.6	21.7	3
MT	5	5/11/92	350	13.4	56.5	23.7	1
MT	3	5/11/92	530	5.6	58.9	9.4	1
MT	4	May-92	12945	10.4	25.6	29.4	1
MT	5	5/15/92	250	6.9	6.7	103	1
MT	3	5/15/92	2316	6.4	10.2	62.8	1

TABLE A2-2. (continued)

STATE	CLASS	DATE	ADT	SL	SILT	TL	# SAMPLES
MN	11	2/26/92	5000	0.24	13.4	2.3	5
CO	5	3/18/92		3.56	24	14.81	1
CO	3	3/30/92	.	12.05	24	50.23	1
CO	3	4/1/92	.	5.97	21.1	29.16	8
CO	10	4/6/92	.	6.1	12	50.08	2
CO	5	4/1/92		7.9	8	96.01	2
CO	10	4/2/92	.	7.68	21.7	35.9	3
CO	8	3/30/92	.	2.07	9	23.03	1
CO	8	4/1/92	.	2.78	8.9	30.35	7
CO	3	4/1/92	.	9.05	25	36.21	1