Emission Factor Documentation for AP-42, Section 13.2.1

Paved Roads

Monitoring Policy Group
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency

June 2010

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NOTICE

This document is a draft product. However, it should not be construed to represent Agency policy. It is has been circulated for comments on its technical merit.

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SECTION 1

INTRODUCTION

The document "Compilation of Air Pollutant Emissions Factors" (AP-42) has been published by the U.S. Environmental Protection Agency (EPA) since 1968. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is periodically updated by EPA to respond to new emission factor needs of EPA, State, and local air pollution control programs and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of activity of the source. The uses for the emission factors reported in AP-42 include:

1. Estimates of area-wide emissions.
2. Estimates of emissions for a specific facility.
3. Evaluation of emissions relative to ambient air quality.

The purpose of this report is to compile the existing background report and supplements into a single report, provide an update of the background information from test reports and other information to support preparation of a revised AP-42 section to replace existing Section 13.2.1, "Paved Roads," dated November 2006.

The principal pollutant of interest in this report is "particulate matter" (PM), with special emphasis placed on "PM_{10}"—particulate matter no greater than 10 μmA (micrometers in aerodynamic diameter) and $PM_{2.5}$. PM_{10} and $PM_{2.5}$ form the basis for the current National Ambient Air Quality Standards (NAAQSs) for particulate matter.

PM_{10} and $PM_{2.5}$ thus represent the two size ranges of particulate matter that are of greatest regulatory interest. Nevertheless, formal establishment of PM_{10} and $PM_{2.5}$ as the standard basis is relatively recent, and many emission tests have referenced other particle size ranges. Other size ranges employed in this report are:

TSP Total Suspended Particulate, as measured by the standard high-volume (hi-vol) air sampler. TSP was the basis for the previous NAAQSs for particulate matter. TSP consists of a relatively coarse particle size fraction. While the particle capture characteristics of the hi-vol sampler are dependent upon approach wind velocity, the effective D50 (i.e., 50% of the particles are captured and 50% are not) varies roughly from 25 to 50 µmA.

SP Suspended Particulate, which is used as a surrogate for TSP. Defined as PM no greater than 30 µmA. SP also may be denoted as "PM_{30}."

IP Inhalable Particulate, defined as PM no greater than 15 µmA. Throughout the late 1970s and the early 1980s, it was clear that EPA intended to revise the NAAQSs to reflect a particle size range finer than TSP. What was not clear was the size fraction that would be eventually used, with values between 7 and 15 µmA frequently mentioned. Thus, many field studies were conducted using IP emission measurements because it was believed that IP would be the basis for the new NAAQS. IP may also be represented by "PM_{15}."

FP Fine Particulate, defined as PM no greater than 2.5 µmA. FP also may be denoted as "$PM_{2.5}$."

This background report consists of five sections. Section 1 provides an introduction to the report. Section 2 presents descriptions of the paved road source types and emissions from those sources as well as a brief history of the current AP-42 emission factors. Section 3 is a review of emissions data collection and analysis procedures; it describes the literature search, the screening of emission test reports, and the quality rating system for both emission data and emission factors. Section 4 details the development of paved road emission factors for the draft AP-42 section; it includes the review of specific data sets and the results of data analysis. Section 5 presents the AP-42 section for paved roads.

SECTION 2

SOURCE DESCRIPTION

Particulate emissions occur whenever vehicles travel over a paved surface, such as public and industrial roads and parking lots. These emissions may originate from material previously deposited on the travel surface, resuspension of material carried by the vehicle, deposits from undercarriages, engine exhaust gases or tire and brake wear. Depending on the road surface characteristics, vehicle mix, the most significant emissions may arise from the surface material loading (measured as mass of material per unit area), or a combination of engine exhaust, brake and tire emissions. Surface loading is in turn replenished by other sources (e.g., pavement wear, deposition of material from vehicles, deposition from other nearby sources, carryout from surrounding unpaved areas, and litter). Because of the importance of the surface loading, available control techniques either attempt to prevent material from being deposited on the surface or to remove (from the travel lanes) any material that has been deposited.

2.1 PUBLIC AND INDUSTRIAL ROADS

While the mechanisms of particle deposition and resuspension are largely the same for public and industrial roads, there can be major differences in surface loading characteristics, emission levels, traffic characteristics, and viable control options. For the purpose of estimating particulate emissions and determining control programs, the distinction between public and industrial roads is not a question of ownership but rather a question of surface loading and traffic characteristics.

Although public roads generally tend to have lower surface loadings than industrial roads, the fact that these roads have far greater traffic volumes may result in a substantial contribution to the measured air quality in certain areas. In addition, public roads in industrial areas can be often heavily loaded and traveled by heavy vehicles. In that instance, better emission estimates might be obtained by treating these roads as industrial roads through the use of a silt loading and average vehicle weight appropriate for the road segment. In extreme cases, public roads, industrial road, or parking lots may have such a high surface loadings that the paved surface is covered with loose material and in extreme cases is mistaken for an unpaved surface. In that event, use of a paved road emission factor may actually result in a higher estimate than that obtained from the unpaved road emission factor, and the road is better characterized as unpaved in nature rather than paved.

2.2 REVIEW OF PAST AND CURRENT PAVED ROAD EMISSION FACTORS

2.2.1 September 1985 through January 1995.

From September 1985 through January 1995, AP-42 currently contained two sections concerning paved road fugitive emissions. The first, Section 11.2.5, is entitled "Urban Paved Roads" and was first drafted in 1984 using test results from public paved roads.[2] Emission factors are given in the form of the following equation:

$$E = k\ (sL/0.5)^{p} \tag{2-1}$$

where:

	E	=	particulate emission factor (g/VKT)
	s	=	surface material content silt, defined as particles < 75 µm in diameter (%)
	L	=	surface material loading, defined as mass of particles per unit area of the travel surface (g/m^2)
	k	=	base emission factor (g/VKT)
	p	=	exponent (dimensionless)

The factors k and p are given by

Particle size fraction	k (g/VKT)	p
TSP	5.87	0.9
PM-15	2.54	0.8
PM-10	2.28	0.8
PM-2.5	1.02	0.6

The form of the emission factor model is reasonably consistent throughout all particle size fractions of interest.

The urban paved road emission factors represented by Equation 2-1 did not change since their inclusion in the 4th Edition (September 1985) and the January 1995 revision. It should be noted that these emission factors were not quality rated "A" through "E." (See Section 3 for an overview of the AP-42 quality rating scheme.)

Section 11.2.6, "Industrial Paved Roads," was first published in 1983[3] and was slightly modified in Supplement B (1988) to the 4th Edition. Section 11.2.6 contained three distinct sets of emission factor models as described below.

$$E = 0.022\, I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{280}\right)\left(\frac{W}{2.7}\right)^{0.7} \qquad (2\text{-}2)$$

For TSP, the following equation is recommended:

where:	E	=	emission factor (kg/VKT)
	I	=	industrial augmentation factor (dimensionless)
	n	=	number of traffic lanes (dimensionless)
	s	=	surface material silt content (%)
	L	=	surface material loading across all traffic lanes (kg/km)
	W	=	average vehicle weight (Mg)

The basic form of Equation 2-2 dates from a 1979 report[4] and was originally included in Supplement 14 to AP-42 (May 1983). The version used in AP-42 was slightly revised in that the leading term (i.e., 0.022 in Eq. [2-2]) was reduced by 14%. The industrial road augmentation factor (I) was included to take into account for higher emissions from industrial roads than from urban roads; it varied from 1 to 7. The emission factor equation was rated "B" for cases with I = 1 and "D" otherwise.

For smaller particle size ranges, models somewhat similar to those in Eq. (2-1) were recommended:

$$E = k\,(sL/12)^{0.3} \qquad (2\text{-}3)$$

where:	E	=	emission factor (kg/VKT)

k	=	base emission factor (kg/VKT), see below
sL	=	road surface silt loading (g/m^2)

The base emission factor (k) above varied with aerodynamic size range as follows:

Particle size fraction	k (g/VKT)
PM-15	0.28
PM-10	0.22
PM-2.5	0.081

These models represented by Equation 2-3 were first developed in 1984[3] from 15 emission tests of uncontrolled paved roads and they were rated "A."

During the development of Eq. (2-3), tests of light-duty traffic on heavily loaded road surfaces were identified as a separate subset, for which separate single-valued emission factors were developed. Section 11.2.6 recommended the following for light-duty (less than 4 tons) vehicles traveling over roads where the surface material was dry and the road was heavily loaded (silt loading greater than 15 g/m^2):

$$E = k \qquad (2\text{-}4)$$

where:	E	=	emission factor (kg/VKT)
	k	=	single-valued factor depending on particle size range of interest (see below)

Particle size fraction	k (g/VKT)
PM-15	0.12
PM-10	0.093

The single-valued emission factors was quality rated "C."

During the time that AP-42 had four methods for estimating emissions from paved roads (Sections 11.2.5 and 11.2.6), users of AP-42 noted difficulty selecting the appropriate emission factor model to use in their applications.[5,6,7] For example, inventories of industrial facilities (particularly of iron and steel plants) conducted throughout the 1980s yielded measured silt loading values substantially lower than those in the Section 11.2.6 data base. In extreme cases when the models were used with silt loading values outside the range for which they were developed, estimated PM-10 emission factors were larger than the corresponding TSP emission factors.

Furthermore, the distinction between "urban" and "industrial" paved roads was blurred. For the purpose of estimating emissions, it was gradually realized that source emission levels are not a question of ownership but rather a question of surface loading and traffic characteristics. Confirmatory evidence was obtained in a 1989 field program[5] which found that paved roads at an iron and steel facility far more closely resembled "urban" roads rather than "industrial" roads in terms of emission characteristics.

Finally, it was unknown how well the emission factors of that time performed for cases of increased surface loading on public roads, such as after application of antiskid materials or within areas of trackout from unpaved areas.[6] These situations were of considerable interest to several state and local regulatory agencies, most notably in the western United States.

2.2.2 January 1995 through October 2002

The January 1995 update attempted to correct as many of the shortcomings of the previous versions as possible. To that end, the update employed an approach slightly different than that used in the past. In addition to reviewing test data obtained since the September 1988 update,[8] the test data used for both of the 1988 sections were also included for reexamination in the final data set. In assembling the data base, no distinction was made between public and industrial roads or between controlled and uncontrolled tests, with the anticipation that the reformulated emission factor will be applicable over a far greater range of source conditions.

The inclusion of controlled tests represented a break with EPA previous guidelines for preparing AP-42 sections[9]. Those guidelines presented a clear preference that only uncontrolled tests be used to develop an emission factor. However, the principal control measures for paved roads seek to reduce the value of an independent variable in the emission factor equation, i.e., the silt loading.

The revised emissions factor equation published in the January 1995 update of the paved road section included silt loading, average vehicle weight and a particle size multiplier as independent variables. The resulting equation was:

$$E = k\left(sL / 2\right)^{0.65}\left(W / 3\right)^{1.5}$$

where: E = particulate emission factor (having units matching the units of k),

k = particle size multiplier for particle size range and units of interest (see below),

sL = road surface silt loading (grams per square meter) (g/m2), and

W = average weight (tons) of the vehicles traveling the road.

The selection of the value for the independent variable for the particle size multiplier was based upon the units of the emissions factor desired and the size range for the emissions.

Particle Size Multipliers for Paved Road Equation

Size Range	Multiplier k		
	g/VKT	g/VMT	lb/VMT
$PM_{2.5}$	2.1	3.3	0.0073
PM_{10}	4.6	7.3	0.016
PM_{15}	5.5	9.0	0.020
PM_{30}	24	38	0.082

2.2.3 October 2002 through December 2003

Prior to October 2002, the basis of the particle sizing information for paved roads emissions factors was high volume sampler impactors data. While the initial particle sizing was performed by cyclones, subsequent particle sizing was performed by slotted impactors. The impactor data had biases created by particle bounce and reintrainment. As such particle sizing below 10 µm was questioned. In October 2002, a three city paved and unpaved road emissions study was completed that evaluated particle sizing at 10 and 2.5 µm and assessed the default values for silt loading. The results of the three city study formed the basis for revising the $PM_{2.5}$ particle size multiplier k from 2.1 g/VKT (3.3 g/VMT or 0.0073 lb/VMT) to 1.1 g/VKT (1.8 g/VMT or 0.0040 lb/VMT). The form of the predictive equation and the exponents for silt loading and average vehicle weight were unchanged. The changes in the October 2002 revision provided recommended default silt loading data for normal and worst case public paved roads based upon the updated silt loading values for public paved roads. The remaining numerical revisions that were made in the emissions factor for paved roads included an adjustment for the normal mitigation effects due to rain events. For long term average conditions, a 25% reduction in the particulate emissions was included for every day that there was measureable rain for that day. A similar adjustment was included that used hourly time intervals rather that a daily time interval.

2.2.4 December 2003 through November 2006

The December 2003 revision of the AP-42 Section for paved roads incorporated a constant in the predictive equation for particulate emissions factors. The AP-42 equations prior to December 2003 estimated PM emissions from re-entrained road dust, and vehicle exhaust, brakewear and tirewear emissions. In the December 2003 revision of the section, the component of emissions due to exhaust, brakewear and tirewear were separated from the composite fugitive dust emission factor equation. The first stated reason for the separation was to eliminate the possibility of double counting emissions. With the introduction of EPA’s Mobile6.2 model, estimates of PM emissions from exhaust, brakewear and tirewear were calculated based upon the vehicle mix, vehicle speed and road class. The double counting of emissions was a possibility when both the fugitive dust emission factors from AP-42 and Mobile6.2 were used to estimate emissions from vehicle traffic on paved roads. The second stated reason was to incorporate decreases in particulate matter emissions from the exhaust of newer vehicle models and fuel sources. Since the majority of data supporting the paved road emission factor equation was developed at the time prior to when the vehicles in the fleet incorporated significant reductions of particulate matter emissions. A technical memorandum provided the basis for estimating PM emissions due to exhaust, break wear and tire wear. The technical memorandum used estimated emissions from a 1980's model year vehicle fleet since the emissions tests supporting the emissions factors equation were performed in the early 1980's to early 1990's. It was believed that since 1980, there have been and will continue to be improvements in vehicles and fuel that will result in a decrease in PM emissions from engine exhaust. Depending on the emissions factors units desired, the constant that was included in the emissions factor equation had values of 0.2119 g/VKT, 0.1317 g/VMT or 0.00047 lb/VMT for PM_{30}, PM_{15} and PM_{10} emissions. For PM2.5 emissions, depending on the required emissions factors units, the constant used in the equation had values of 0.1617 g/VKT, 0.1005 g/VMT or 0.00036 lb/VMT.

2.2.5 November 2006 through May 2010

In November 2006, the particle size multiplier k was lowered to 0.66 g/VKT, 1.1 g/VMT or 0.0024 depending on the needed units for the emissions factor. The revision was based upon a broad based assessment of the biases associated with the cyclone/impactor method for particulate sizes less than 10 μm in aerodynamic diameter. While the December 2003 update revised the particle size multiplier, the update was based upon limited test data. In addition, the impact of biased emissions factor ratios for $PM_{2.5}$ impacted fugitive sources other than paved roads. The impact was due to particle bounce from the cascade impactor stages to the backup filter potentially inflating $PM_{2.5}$ concentrations. The impact was possible even though steps were taken to minimize particle bounce in the earlier studies. The assessment study was sponsored by the Western Regional Air Partnership and conducted by the Midwest Research Institute (MRI). The testing was conducted at MRI's Aerosol Test Facility (ATF) in Deramus Field Station in Grandview, Missouri using surface dust collected from seven locations in five western states. The tests provided the basis for comparing the average $PM_{2.5}$ concentration and the collocated PM_{10} concentration. The study compared the fine fraction ratios derived from FRM samplers to those derived from the cyclone/impactor method. The cyclone/impactor samplers and operating method used in the study were the same as those that generated the original AP-42 emission factors and associated $PM_{2.5}$ /PM_{10} ratios. The study consisted of 100 test runs covering PM_{10} concentration from approximately 0.3 mg/m^3 to 7 mg/m^3.

2.2.6 **May 2010**

This update recommends an updated equation for paved roads that is based upon additional test data that was conducted on roads with slow moving traffic and stop and go traffic. The emissions tests were performed for the Corn Refiners Association by Midwest Research Institute (MRI). The testing focused on PM10 emissions at four corn processing facilities.

SECTION 3

GENERAL DATA REVIEW AND ANALYSIS

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.

3.1 LITERATURE SEARCH AND SCREENING

Review of available literature identified three paved road testing programs (presented later as Table 4-1) since the time of the last Section 11.2 update.[8] The individual programs are discussed in detail in the next section. In addition, as discussed at the end of Section 2, earlier controlled industrial road test data were reexamined. The previous update[8] noted that Eq. (2-4) yielded quite good estimates for emissions from vacuum swept and water flushed roads. Furthermore, it became apparent that previous distinctions between "industrial" and "urban" roads had become blurred as interest focused on heavily loaded urban roads (e.g., after snow/ice controls) and on cleaner industrial roads (as the result of plant-wide control programs).

3.2 EMISSION DATA QUALITY RATING SYSTEM

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 (i.e., comparison of EPA Method 5 front-half with EPA Method 5 front- and back-half).

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

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

5. Test series in which it is not clear whether the emissions were measured before or after the control device.

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 was 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

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

A—Excellent: Developed only from A-rated 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-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- and 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 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- and B-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 always noted.

The use of these criteria is somewhat subjective and depends to an extent on the individual reviewer.

3.4 METHODS OF EMISSION FACTOR DETERMINATION

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 draw into a forced-flow system. The following presents a brief overview of applicable measurement techniques. More detail can be found in earlier AP-42 updates.[8,10]

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.[10] 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 recorded for input to this dispersion equation. At a minimum the wind direction and speed must be recorded on-site.

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 11) 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.

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 about 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 height above ground level.

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% 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% 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

Emissions factors are typically derived from the ratio of the emissions to an activity level. It is assumed that the emissions are linearly proportional to the selected activity level. Usually the final emission factor for a given source operation, is the arithmetic average of the individual emission factors calculated from each test of that source type. In rare instances, the range of individual emission factor values is also presented.

As an improvement over the presentation of a final emission factor as a single-valued arithmetic mean, an emission factor may be presented in the form of a predictive equation derived by regression analysis of test data. The use of a predictive equation with a relatively good correlation coefficient (R^2) provides a means for improving the accuracy of the emissions factor in estimating the actual emissions when the independent variables are known. Such an equation mathematically relates emissions to parameters when characterize source conditions. These parameters may be grouped into three categories:

1. Measures of source activity or energy expended (e.g., the speed and weight of a vehicle 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).

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 variance sin specific source parameters. This enables more reliable estimates of source emissions on a site-specific basis.

A generic emission factor equation is one that is developed for a source operation defined on the basis of a single dust generation mechanism which 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.

3.5 EMISSION FACTOR QUALITY RATING SCHEME USED IN THIS STUDY

The uncontrolled emission factor quality rating scheme used in this study is somewhat different than was used in earlier updates[8,11] of this section and 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 use of the same rating assessment of source test data quality followed by an initial rating assessment of the emission factor(s) based on the number and quality of the underlying source test data.

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

In evaluating whether an upwind-downwind sampling strategy qualified as a sound methodology, the following minimum test system requirements were used. At least five particulate measuring devices must be operated during a test, with one device located upwind and the other 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 were 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 missions. At least one upwind sampler must be operated to measure background concentration, and wind speed must be measured on-site.

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.

Following the assignment of the individual source test quality ratings, the factor quality rating of the single-valued emission factor will be evaluated. Recently approximately 20 “A” and “B” rated source test reports have been required to justify a factor quality rating of “A”. Each halving of the number of source test reports results in a one letter grade reduction in the final factor quality rating. Several of the source test reports used as the basis for the emissions factor development include measurements conducted at different locations. To the extent that there are more than two tests at the different locations and that the different locations within a given reference represent differences in source conditions, each of the different source conditions will be counted as an independent test. The development of the paved road emissions factor differs from typical in that it includes the use of stepwise multiple non linear regression. Following the initial factor quality rating, the adjusted correlation coefficient will be used to increase the emissions factor quality rating. Only correlation coefficients above 0.4 will be used to increase the emissions factor quality rating.

SECTION 4
AP-42 SECTION DEVELOPMENT

4.1 REVISIONS TO SECTION NARRATIVE

The draft AP-42 presented later in this background document is intended to replace the current version of Section 13.2.1 "Paved Roads" in AP-42. The last update of this section is dated November 2006. The general form of the emissions factor equation presented in the paved road section has been consistent since the January 1995 major revision. Since this date revisions have been made addressing the influence of rain events, estimating default silt loading levels for various classes of roads, separating particulate emissions associated with the roads verses those associated with the vehicles and addressing biases in the measurement of PM2.5 with devices that use impactors to perform particulate sizing.

4.2 POLLUTANT EMISSION FACTOR DEVELOPMENT

This update to Sections 13.2.1 is planned to address the application of the emissions factor equation addressing only the component associated with paved road surface materials and at speeds lower than 10 miles per hour. In order to achieve this goal, the following general approach was taken

1. Assemble the available test data for paved roads in a single data base, making no distinction between public and industrial roads or between controlled and uncontrolled roads.
2. Develop PM_{10} and $PM_{2.5}$ engine, tire wear and brake ware emissions estimates for each of the available data sets. For each of the available data sets, estimate the emissions associated with the road surface material by subtracting the engine, tire wear and brake wear from the measured PM10 emissions.

2. Conduct a series of stepwise linear regression analyses of the revised and adjusted data base to assess the most critical parameters and to develop an emission factor model with:
   - silt loading,
   - mean vehicle weight, and,
   - mean travel speeds

   as potential correction parameters.

3. Conduct an appropriate validation study of the reformulated model.

4.2.1 Review of Specific Data Sets

4.2.1.1 Street Sanding Emissions And Control Study, PEI Associates, Inc., Cincinnati, OH, October 1989. (Reference 15)

This test program was undertaken to characterize PM-10 emissions from six streets that were periodically sanded for anti-skid control within the Denver area. The primary objective was given as development of a predictive algorithm for clean and sanded streets, with a secondary objective stated as defining the effectiveness of control measures. Summary information is given in Table 4-1.

Sampling employed six to eight 8 PM-10 samplers equipped with volumetric flow control. Samplers were arranged in two upwind/downwind configurations. The "basic" configuration consisted of six samplers arranged in identical patterns upwind and downwind of the test road, with one sampler and one pair of samplers at nominal distances of 20 and 5 m, respectively, from the road.

The second configuration was used for tests of control measure effectiveness. The road segment was divided into two halves, corresponding to the treated and experimental control (untreated) portions. Identical sampling arrays were again used upwind and downwind on both halves, at nominal distances of 20 and 5 m. Because this array employed all eight samplers available, no collocation was possible for the second configuration.

TABLE 4-1. SUMMARY INFORMATION FOR TEST REPORT I

Operation	Location	State	Test dates	No. of tests	PM_{10} emission factor (g/VKT)	
					Geom. mean	Range
Vehicle traffic	Colfax	Colorado	3-4/89	17	1.33	0.53-9.01
Vehicle traffic	York St.	Colorado	4/89	1	1.07	1.07
Vehicle traffic	Belleview	Colorado	4/89	4	1.62	1.10-4.77
Vehicle traffic	I-225	Colorado	4/89	9	0.31	0.17-0.51
Vehicle traffic	Evans	Colorado	5-6/89	29	1.06	0.21-7.83
Vehicle traffic	Louisiana	Colorado	6/89	7	0.96	0.42-1.73

In addition to the PM-10 concentration measurements, several other types of samples were collected:

- Wind speed/direction and incoming solar radiation were collected on-site, and the results were combined to estimate atmospheric stability class needed to calculate emission factors.

- Colorado Air Pollution Control Division (APCD) representatives collected traffic data, including traffic counts, travel speeds, and percentage of heavy-duty vehicles.

- Vacuums with disposable paper bags were used to collect the loose material from the road surface. In addition to samples taken from the travel lanes, the field crew took daily samples of material adjacent to curbs and periodic duplicate samples.

The study collected PM-10 concentration data on 24 different days and calculated a total of 69 different emission rates for baseline, sanded and controlled paved road surfaces. Emission factors were obtained by back-calculation from the CALINE3 dispersion model[12] together with a series of assumptions involving mixing widths and heights and an effective release height. Although data collected at the 20 m distance were used to evaluate results, the test report did not describe any sensitivity analysis to determine how dependent the emission rates were on the underlying assumptions.

The testing program found difficulty in defining "upwind" concentrations for several of the runs, including cases with wind reversals or winds nearly parallel to the roadway orientation. A total of eight of the 69 tests required that either an average concentration from other test days or a downwind concentration be used to define "upwind" conditions. In addition, the test report described another seven runs as invalid for reasons such as wet road surfaces, nearby dust sources or concentrations increasing with downwind distance.

A series of stepwise regression analyses were conducted, with different predictive equations presented for (a) baseline conditions, (b) sanded roads, and (c) roads swept to remove the sand applied, and (d) all conditions combined. In each case, only one independent variable was included in the predictive equation: silt loading, for cases (a) and (d); and time since treatment, for (b) and (c).

In general, Reference 15 is reasonably well documented in terms of describing test conditions, sampling methodology, data reduction and analysis. A chief limitation lies in the fact that neither sampling configuration fully met minimum requirements for the upwind-downwind method presented in Section 3.4. Specifically, only two or three samplers were used downwind rather than the minimum of four.

Furthermore, a later report[6] drawing upon the results from Reference 15 and 17 effectively eliminated 24% of the combined baseline tests because of wind directions. In addition, the later report[6] noted that the baseline data should be considered as "conservatively high" because roughly 70% of the data were calculated assuming the most unstable atmospheric class (which results in the highest backcalculated emission factor). Because of these limitations, the emission data have been given an overall rating of "D."

4.2.1.2 **RTP Environmental Associates 1990.** ***Street Sanding Emissions and Control Study, prepared for the Colorado Department of Health*****. July 1990. (Reference 17)**

This test program was quite similar to that described in Reference 15 cited in paragraph 4.2.1.1 and used an essentially identical methodology. In fact, the two test reports are very similar in outline, and many passages in the two reports are identical. The primary objective was given as expanding the data base in Reference 15 to further develop predictive algorithms for clean and sanded streets. Summary information is given in Table 4-2.

The test program employed the same two basic PM_{10} sampling arrays as did Reference 15. A third configuration was used for "profile" tests, in which additional samplers were placed at 10 and 20 ft heights. (Analysis of results from elevated samplers is not presented in Reference 17.)

TABLE 4-2. SUMMARY INFORMATION FOR REFERENCE 17

Operation	Location	State	Test dates	No. of test	PM-10 emission factor (g/VKT)	
					Geom. mean	Range
Vehicle traffic	Mexico	Colorado	2/90	3	2.75	1.08-6.45
Vehicle traffic	State Hwy 36	Colorado	1-3/90	13	1.31	0.14-4.18
Vehicle traffic	Colfax	Colorado	2-4/90	41	1.32	0.27-5.04
Vehicle traffic	Park Rd.	Colorado	4/90	11	1.26	0.69-3.33
Vehicle traffic	Evans	Colorado	2-3/90	11	2.10	0.87-7.27
Vehicle traffic	Louisiana	Colorado	1,3/90	9	3.24	1.40-5.66
Vehicle traffic	Jewell	Colorado	1/90	1	6.36	6.36
Vehicle traffic	Bryon	Colorado	4/90	3	8.38	5.53-14.72

As was the case in Reference 15, additional samples were collected including:

- Wind speed/direction were collected on-site, and the results used in estimating atmospheric stability class needed to calculate emissions factors. (Unlike Reference 15, solar radiation measurements were not collected.)

- Traffic data, including traffic counts, travel speeds, and percentages of heavy-duty vehicles were collected.

- Vacuums with disposable paper bags were used to collect the loose material from the road surface. The program developed an extensive set of collocated samples of material along the edges of the roadway.

The study collected PM_{10} concentration data on 33 days and calculated a total of 131 different emission rates for baseline, sanded and controlled paved road surfaces. Emission factors were obtained by back-calculation from the CALINE3 dispersion model[12] together with essentially the same assumptions as those in Reference 15. This report also noted the same difficulty as Reference 15 in defining "upwind" concentrations in cases with wind reversals or winds nearly parallel to the roadway orientation. Unlike Reference 15, however, this report does not provide readily available information on how many tests used either an average concentration from other test days or a downwind concentration to define "upwind" conditions. Reference 6 does, however, describe seven tests as invalid because of filter problems or because upwind concentrations were higher than downwind values.

As with the Reference 15 program, a series of stepwise regression analyses were conducted. This test program combined data from Reference 15 and 17 and considered predictive equations for (a) baseline conditions, (b) sanded roads, and (c) roads swept to remove the sand applied, and (d) all conditions combined.

Unlike Reference 15, however, Reference 17 appears to present silt loading values that are based on wet sieving (see page 8 of the test report) rather than the dry sieving technique (as described in Appendix E to AP-42) routinely used in fugitive dust tests. (MRI could not obtain any clarifying information during telephone calls to the testing organization and the laboratory that analyzed the samples.) Wet sieving disaggregates composite particles and results from the two types of sieving are not comparable.

There is additional confusion over the silt loading values given in Reference 17 for cleaning tests. Specifically, the same silt loading value is associated with both the treatment and the experimental control. This point could not be clarified during telephone conversation with the testing organization. Attempts to clarify using test report appendices were unsuccessful. Two appendices appear to interchange silt loading with silt percentage. More importantly, it could not be determined whether the surface sample results reported in Appendix D to Reference 17 pertain to treated or the experimental control segment, and with which emission rate a silt loading should be associated.

Reference 17 contains substantial amounts of information, but is not particularly well documented in terms of describing test conditions, sampling methodology, data reduction and analysis. In addition, the same limitations mentioned in connection with Reference 15 are equally applicable to Reference 17, as follows:

- not meeting the minimum number of samplers.
- numerous tests conducted under variable wind conditions.
- frequent use (70% to 80% of the tests) of the most unstable atmospheric stability class in the CALINE 3 model which will result in the highest calculated emission rate.

Because of these limitations, emission rate data have been given an overall rating of "D." Furthermore, the silt loading data in this report are considered suspect for reasons noted above.

4.2.1.3. 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. (Reference 6)**

This study evaluated paved road control techniques at two different iron and steel plants. (See Tables 9 and 10 in Reference 8.) Data were quality rated as "A," and uncontrolled test results were incorporated into the data base for Section 11.2.6 published in 1983. The only use of the controlled test results, however, was the following addition to Section 11.2.6.4 in 1988:

Comment [RM1]: It is unclear which reference this means and what the tables state.

> "Although there are relatively few quantitative data on emissions from controlled paved roads, those that are available indicate that adequate estimates generally may be obtained by substituting controlled loading values into .. [Equations (2-2) and (2-3)].... The major exception to this is water flushing combined with broom sweeping. In that case, the equations tend to overestimate emissions substantially (by an average factor of 4 or more)."

In the current update, the controlled emission factors have been used as part of the overall data base to develop predictive models. Although PM-10 emission data are not specifically presented in the report, appropriate values were previously developed by log-normal interpolation of the PM_{15} and $PM_{2.5}$ factors.[8]

4.2.1.4 G. E. Muleski, ***Measurement of Fugitive Dust Emissions from Prilled Sulfur Handling, Final Report,*** **MRI Project No. 7995-L, Prepared for Gardinier, Inc., June 1984 (Reference 30)**

This was first report identified to suggest that heavily loaded paved roads may be better considered as unpaved in terms of emission estimates. The program produced three tests of emissions from end-loader travel over paved surfaces. Two of the three tests were conducted on very heavily loaded surface, while the third was on a cleaned paved surface. (See Tables 20 and 21 of the 1987 update.)[8]

No PM-10 emission factors were reported; results were presented for total particulate (TP) and suspended particulate (SP, or PM-30). Data were quality rated "A" in the 1987 report.

Because no PM-10 data were given, Test Report 5 data were most directly useful as independent data against which the TSP emission factor model (Eq. (2-2)) could be assessed. This comparison showed generally good agreement between predicted and observed with agreement becoming better as source conditions approached those in the underlying data base.

The 1987 update[8] developed PM-10 emission factors based on information contained in the test report. When compared to the single valued factors (Equation [2-4]), agreement for the first two tests was within a factor of approximately two. The third test—that of the cleaned surface—could not be used to assess the performance of either Eq. (2-1) or Eq. (2-3) because the surface loading value could not be converted to the necessary units with information presented in the report.

4.2.1.5 T. F. Eckle and D. L. Trozzo, *Verification of the Efficiency of a Road-Dust Emission-Reduction Program by Exposure Profile Measurement,* Presented at EPA/AISI Symposium on Iron and Steel Pollution Abatement, Cleveland, Ohio, October 1984. (Reference 31)

This paper discussed the development of an exposure profiling system as well as an evaluation of the effectiveness of a paved road vacuum sweeping program. Because no reference is made to an earlier test report, this paper is considered to be the original source of the test data. Although ten uncontrolled and five controlled tests are mentioned, test data are reported only in terms of averages. (See Tables 24 and 25 in Reference 8.) Only TSP emission factors are presented. Although data were obtained using a sound methodology, data were rated "C" because of inadequate detail in the paper.

Averaged data from Test Report 8 were used in an independent assessment of Eq. (2-2). Although only average emission levels could be compared, the data suggested that TSP emissions could be estimated within very acceptable limits.

4.2.1.6 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. (bref01_13s0201_jan1995.pdf) (Reference 1)

This 1989 field program used exposure profiling to characterize emissions from paved roads at an integrated iron and steel plant near Philadelphia, Pennsylvania, in November 1989. In many respects, this program arose because of uncertainties with paved road emission factor models used outside their range of applicability. During the preparation of an alternative emission reduction ("bubble") plan for the plant, questions arose about the use of AP-42 equations and other EPA guidance[13] in estimating roadway emissions involved in the emissions trade. This program provided site-specific data to support the bubble plan. This testing program also represented the first exposure profiling data to supplement the AP-42 paved road data base since the 1984 revision. Site "C" was located along the main access route and had a mix of light- and medium-duty vehicles. Site "E" was located near the southwest corner of the plant and the traffic consisted mostly of plant equipment. Table 4-3 provides summary information and Table 4-4 provides detailed information.

The program involved two paved road test sites. The first (site "C") was along the four-lane main access route to the plant. Average daily traffic (ADT) had been estimated as more than 4,000 vehicle passes per day, with most vehicles representative of "foreign" equipment (i.e., cars, pickups, and semi-trailers rather than plant haul trucks and other equipment). Site "E," on the other hand, was located near the iron- and steel-making facilities and had both lower ADT and heavier vehicles than site "C." The plant regularly vacuum swept paved roads, and two cleaning frequencies (two times and five times per week) were considered during the test program.

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 4-3 presents summary information and Table 4-4 presents detailed test information. Warm wire anemometers at two heights measured wind speed.

Depending on traffic characteristics of the road being tested, a 6 to 7.5 m high profiling array was used to measure downwind mass flux. This array consisted of four or five total particulate sampling heads spaced at 1.5 m heights and was positioned at a nominal 5 m distance downwind from the road. 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 height for downwind sizing devices (2.2 m) was selected after review of prior test results. It approximated the height in a roadway dust plume at which half the mass emissions pass above and half below. The upwind (background) particle size distribution was determined with a high-volume cyclone/ impactor combination. Warm wire anemometers at two heights measured wind speed.

Additional samples included:

- Average wind speeds at two heights and wind direction at one height were recorded during testing to maintain isokinetic sampling.
- Traffic data, including traffic counts, travel speeds, and vehicle class were recorded manually.
- Vacuums with disposable paper bags were used to collect the loose material from the road surface.

The sampling equipment met the requirements of a sound exposure profiling methodology specified in Section 3.4 so that the emission test data are rated "A." The test report presents emission factors for total particulate (TP), total suspended particulate (TSP) and PM_{10}, for the ten paved road emission tests conducted.

Reference 1 found that the emission factors and silt loadings more closely resembled those in the "urban" rather than the "industrial" data base. That is to say, emissions agreed more closely with factors estimated by the methods of September 1985 AP-42 Section 11.2.5 than by methods in Section 11.2.6. Given the traffic rate of 4000 vehicles per day at Site "C," this

TABLE 4-3. 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 4-4. DETAILED INFORMATION FROM PAVED ROAD TESTS FOR REFERENCE 1

Test runs	PM-10 emission factor, lb/VMT	Duration, min	Meteorology		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	25	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[b]	8.6
AU-C-7	0.000887	96	42	12	703	3.0	(27)	0.26[b]	7.7
AU-C-8	0.0174	218	40	15	779	2.0	(27)	0.15[b]	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

finding was not terribly surprising. What was far more surprising was that emissions at Site "E" were also more "urban" than "industrial." Although the TSP and PM_{10} models in Section 11.2.5 showed a slight tendency to underpredict, the Section 11.2.6 PM_{10} model overestimated measured emissions by at least an order of magnitude. The performance of the industrial TSP model, on the other hand, was only slightly poorer than that for the urban TSP model.

4.2.1.7 Midwest Research Institute, *Paved Road Particulate Emissions - Source Category Report*, for U.S. EPA, July 1984. (bref02_13s0201_jan1995.pdf)- Reference 2

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 used to characterize upwind and downwind PM-15 concentrations. A high-volume sampler with a SSI and a 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 4-5 presents summary test data and Table 4-6 presents detailed test information.

TABLE 4-5. 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.

TABLE 4-6. 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

4.2.1.8 Midwest Research Institute, *Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads,* for U. S. EPA, January 1983. Reference 4 (AP-42 Ref 5)

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 4-7 presents summary test data and Table 4-8 presents detailed test information.

TABLE 4-7. 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 Duty	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 4-8. 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			Moisture content, %	Silt loading, g/m^2	Silt, %
								Mean vehicle weight, tons	No. of wheels	Mean vehicle speed, mph			
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/m^2 = 1.434 gr/ft^2

a Not measured

4.2.1.9. Midwest Research Institute, *Iron and Steel Plant Open Source Fugitive Emission Control Evaluation*, for U. S. EPA, August 1983, Reference 3 – (AP-42 Ref 3)

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 above 15 MPH and moisture content are not expected to influence the emissions equation, the test data are assigned an A rating. Table 4-9 presents summary test data and Table 4-10 presents detailed test information. The PM-10 emission factors presented in Table 4-10 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

TABLE 4-9. 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 4-10. 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	8.3	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[a]
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[b]
L	B-51	FBS	0.435	93	90	4.2	127	11	13.6	28.2[b]
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[a]
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[a]
M	B-59	0.993	None	114	90	6.1	67	11	2.06	14.0[a]
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

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.

4.2.1.10. Midwest Research Institute, *Fugitive Particulate Matter Emissions* for U.S. Environmental Protection Agency, Emission Factor and Inventory Group, April 15, 1997. Reference 5

This reference documents the performance of six field studies characterizing the vehicle emissions from three unpaved roads and three paved roads. Testing of unpaved roads was performed in Kansas City, MO; Raleigh, NC; and Reno, NV. Testing of paved roads was performed in Denver, CO; Raleigh, NC; and Reno, NV. Midwest Research Institute measured the emission rates for PM_{10} and $PM_{2.5}$ at all six locations based upon a plume profiling methodology. The test data are assigned an A rating.

Plume profiling calculates emission rates using a conservation of mass approach. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area time) of airborne particulate integrated over the time of measurement or, equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure are as follows. The concentration of PM_{10} measured by a sampler is compared to the wind speed and corrected to standard conditions. The concentration for each sampler is multiplied by the wind velocity and sampling duration to obtain the exposure for each sampling height. The exposure is integrated over the plume-effective cross section. The quantity obtained represents the total passage of airborne particulate matter (i.e., mass flux) due to the source. The exposure is set to zero at the maximum effective height of the plume where the net concentration equals zero). The maximum effective height of the plume is found by linear extrapolation of the uppermost net concentrations to a value of zero. Although at ground level the wind velocity is zero, for calculation, the exposure value at ground level is set equal to the value at a height of 1 m. The integration is then performed from 1 m to the plume height, H, using Simpson's approximation.

Testing in Denver CO was conducted to characterize emissions from a high speed (55 mph speed limit) limited access interstate road and a medium speed (40 mph speed limit) one lane road (two lanes with a wide median). For this part of the study, a profiler with four or five sampling heads located at heights of 1, 3, 5 and 7 m were deployed. One high-volume cascade impactor with cyclone preseparators (cutpoint of 10 μmA) and two dichotomous samplers were used to measured the downwind particle size distribution. All of the particle sizing samplers were located at 2 m above ground level. A single set of the same sampling equipment was located at 2 m above ground level and upwind for measurement of background concentrations of TSP, PM_{10} and $PM_{2.5}$. To the extent possible, each of the emission tests was performed during periods following snowfall, after the test road surface had dried. In most cases, sand application was ordered, because the relatively light snow conditions characteristic of the 1996 winter did not trigger routine sand application.

This test program also assessed the potential bias associated with particle sizing using the historical impactors that followed the cyclone pre-separator. The use of the dichotomous samplers consistently yielded a lower ratio of $PM_{2.5}$ to PM_{10} ratio than were measured by the cyclone/impactor samplers. The $PM_{2.5}/PM_{10}$ ratios measured by the dichotomous samplers are presented to the right of the PM_{10} emissions factors column in Table 4-11. Where two values are presented in the column, these are the ratios measured at two different heights. The ratios range from 0.26 to 0.37. As a result of this study, the constant in the $PM_{2.5}$ emissions factor equation was revised to 25% of the PM_{10} constant.

TABLE 4-11. DETAILED INFORMATION FOR PAVED ROAD TESTS FROM REFERENCE 5

Site	Test Run No.	Road Speed [1]	PM_{10} emission factor, (g/VKT)	$PM_{2.5}/PM_{10}$ Ratio	Duration, min.	Temp., °F	Mean wind speed, mph	No. of vehicle passes	Mean vehicle weight, tons	Silt loading, g/m^2	Silt, %
CO	BH-1	55	1.08	0.20	163	18	2.7	6,561	2.2	0.184	9.4
CO	BH-2	55	0.102	0.34	360	37	17.0	17,568	2.2	0.0127	41.0
CO	BH-3	55	-	0.16	360	46	17.2	14,616	-	0.0127	41.0
CO	BH-4	55	-		Blank	-	-	-	-	-	-
CO	BH-5	40	-		Blank	-	-	-	-	-	-
CO	BH-6	40	4.68	0.03	240	48	3.1	3,112	2.2	1.47	1.2
NC	BJ-6	45	0.301	0.27/0.34	450	71	8.2	14,670	2.2	0.060	52
NC	BJ-7	45	1.94	0.44/0.44	143	68	9.4	3,748	2.2	0.060	52
NC	BJ-9	45		0.6/0.14	178	71	5.3	4,616	2.2	0.060	52
NC	BJ-10	45		0.44/0.33	288	68	3.7	10,218	2.2	0.060	52
NV	BJ-11	45		0.68/0.47	387	75	5.1	13,216	2.2	0.060	52
NV	BK-7	45	0.57	0.29/0.33	420	89	7.3	7,394	2.2	0.082	3.4
NV	BK-8	45	0.44	0.26/0.34	270	87	6.1	5,747	2.2	0.082	3.4
NV	BK-9	45	-	0.13/0.38	240	90	2.6	4,622	-	0.082	3.4

[1] Road Speed is the posted speed limit for the road segment.

4.2.1.11. Paved Road Modifications to AP-42, Background Documentation For Corn Refiners Association, Inc. Washington, DC 20006 MRI Project No. 310842, May 20, 2008. Reference 6

The Corn Refiners Association (CRA) funded four paved road PM-10 test programs because site conditions did not match source conditions underlying the AP-42 emission factor equation. The sites enforce speed limits of 5 or 15 mph and employ road sweeping programs to manage the build up of silt on the roadways. In addition, plants experience traffic queues (i.e., stop-and-go traffic) during periods with high corn receipts. The combination of heavy trucks (delivering corn to the facilities) and fairly low silt loading (sL) values on the plant roads was not typical of the AP-42 data base. Given these differences, the member companies undertook testing to develop more representative emission factors. Midwest Research Institute designed and conducted the test programs at all four facilities.

Reference 6 compiles test data and information from references 7, 8, 9 & 10. In addition, reference 6 proposes an expansion of the allowable speed parameters supported in the paved road equation. Lastly, reference 6 proposes a revised equation for paved roads to reflect the expanded test information. The data upon which the proposed equation was based included emissions associated with the trucks (engine exhaust, tire wear and brake wear) and with material deposited on the roadway. Since testing documented in references 7 through 10 were conducted at facilities with very similar operating conditions using test procedures that were nearly identical, the following description provides background for all four test programs.

All four testing programs employed the same exposure profiling method used to develop the test data underlying the emission factor predictive equations for both paved and unpaved roads. In each program, a test plan was submitted to the state agency for comment and review prior to the start of testing. The final test reports and supporting information were also submitted to state agencies. Because low emission levels were expected (due to low sL and slow speeds), several precautions were taken to assure reliable quantification. First, long sampling durations were employed. Samplers were operated up to 5 hours to collect adequate sample mass. Second, to ensure adequate traffic during test periods, the facilities provided “drone” passes by corn semi-trailers. Drone traffic mimicked the actual traffic except those trucks returned to staging areas without emptying corn. In addition, testing applied "lessons learned" throughout the programs. For example, when it became apparent how difficult it could be to separate net PM-10 concentrations (i.e., due to traffic on the road) from background (upwind) concentrations, changes were made in equipment deployment. The use of identical upwind and downwind vertical sampling arrays permitted better definition of the net contribution of roadway emissions.

In addition to PM-10 concentrations, each sampling program samples included:

- Measurement of average wind speeds at two heights and wind direction at one height for 5-minute intervals throughout the test period.
- Manual recording of traffic counts by vehicle type. The host facilities provided information on vehicle weights and corn receipts.
- Collection of road surface material by vacuums with disposable paper bags. The material collected within the bag was sieved to determine the surface silt loading.

Reference 6 states that the four test programs conducted by CRA produced 14 and 8 PM-10 emission factor values for slowly moving and stop-and-go traffic, respectively. Other observations in this report includes: that in all but one of the 22 cases, the AP-42 emission factor overestimated the measured value; that for some tests, "stop-and-go" emission factors were substantially greater than the "slowly moving" factor (presumably because of the diesel exhaust as trucks moved from a dead stop) but that there was no significant difference between "slowly moving" and "stop-and-go" results on average.

Furthermore, Tables 4-12, 4-13, and 4-15 use bold font to indicate those tests that used identical upwind and downwind vertical sampling arrays. Those tests provided better definition of net PM-10 mass thus producing more accurate emission factors. Although these test results tended to be lower than the other emission factors, the two sets on average did not differ significantly.

4.2.1.12 Midwest Research Institute, *Emission Tests of Paved Road Traffic at Minnesota Corn Processors Marshall, Minnesota Facility,* McVehil-Monnett Associates, July 6, 2001. Reference 7 (ref_29c13s0201_2010.pdf)

Truck traffic flow at the Minnesota Corn Processor's (MCP's) Marshall, Minnesota facility was characterized as either slowly moving (5 mph enforced speed limit) or stop-and-go in nature. In this testing program, data was collected over 5 days during April of 2001. During this period, three stop-and-go traffic situations and six slowly moving traffic instances were examined. Truck traffic progressing through the test site was held to two lanes for queued traffic. Silt content (sL, measured by MCP), truck weight, and number of passes, along with other pertinent data was recorded for each run. For all runs, a vertical network of samplers was operated downwind. The last test period used a vertical array of samplers upwind to better characterize upwind concentrations and to provide a more accurate calculation of the net PM-10 emission factor.

The results of this testing program are summarized in Table 4-12. The test data are assigned an A rating. The test report remarked that the emission factors obtained were far below the value (0.453 lb/VMT) used in the plant emission inventory. Use of test-specific silt loading and vehicle weight did not significantly improve the predictive accuracy of the AP-42 factor. The tests found no discernable relationship between emission levels and either silt loading or vehicle weight. Finally, it was noted that the shape of the exposure profile was more likely due to diesel exhaust than re-entrained road dust.

Table 4-12. Summary of Emissions Data from MCP's Marshall, Minnesota Facility (Test Report 1)

Run	Test condition	Traffic rate (veh/hr)	Traffic speed (mph)[a]	Mean vehicle weight, W (tons)	Surface silt loading, sL (g/m^2)	Measured PM-10 emission factor (lb/VMT)
CE-1	Stop-and-go	38	NA	36	1.16	0.059
CE-2	Stop-and-go	32	NA	36	0.86	0.14
CE-11	Slowly moving	35	5	12	1.34	0.34
CE-3	Stop-and-go	47	NA	39	0.86	0.10
CE-13	Slowly moving	48	5	13	1.34	0.051
CE-15	Slowly moving	30	5	40	1.91	0.14
CE-16	Slowly moving	28	5	40	1.41	0.17
CE-17	Slowly moving	29	5	40	2.93	0.091
CE-19	**Slowly moving**	**61**	**5**	**38**	**0.76**	**0.041**

[a] Vehicle speed was maintained at the plant limit of 5 mph. NA = Not applicable.
Bold entries indicate that identical vertical sampling arrays were used to better isolate the source contribution.

4.2.1.12. Midwest Research Institute, *Emission Tests of Paved Road Traffic at Minnesota Corn Processors Columbus, Nebraska Facility*, McVehil-Monnett Associates, July 13, 2001. Reference 8. (ref_32c13s0201_2010.pdf)

Truck traffic flow at MCP's Columbus, Nebraska facility was characterized as either slowly moving (5 mph enforced speed limit) or stop-and-go in nature. Between June 12 and 15, 2001, four tests each of stop-and-go and slowly moving traffic were performed. Trucks entered by the north gate and traveled past a vertical sampling array en route to a staggered queue at which a second vertical sampling array was positioned. In this way, testing evaluated both source conditions (stop-and-go and slowing moving) at once. Building on experience from testing at the MCP Marshall facility, the last two runs, CF-4 and CF-5, used identical upwind and downwind vertical sampling arrays to better characterize background concentrations. In that case, only one condition could be evaluated during a test. The results of the MCP Columbus test program are summarized in Table 4-13. The test data are assigned an "A" rating.

4.2.1.13. Midwest Research Institute, *Emission Tests of Paved Road Traffic at Cargill Sweeteners North America Blair, Nebraska Facility*, McVehil-Monnett Associates, November 27, 2002. Referenc 9, (ref_30c13s0201_2010.pdf)

This report describes a testing program conducted at Cargill's Blair, Nebraska facility during August 2002. The plant used a regular sweeping program to reduce surface loadings on paved roads. Testing relied on regular corn truck traffic at the site, although the plant provided a limited amount of "drone" traffic. The test data are assigned an "A" rating.

Eight PM-10 emission tests were attempted. The test report describes difficulty encountered in isolating net PM-10 mass due to traffic on the test road. During test plan review, the Nebraska Department of Environmental Quality requested a change in test site to allow two trucks to pass by at the same time. The original site would have permitted upwind monitoring in the immediate vicinity of the tests road, but this was not possible at the second location. Furthermore, steeply sloping ground on the upwind side of the test road prevented use of a

Table 4-13. Summary of Emissions Data from MCP's Columbus, Nebraska Facility (Test Report 2)

Run[a]	Test condition	Traffic rate (veh/hr)	Traffic speed (mph)[b]	Mean vehicle weight, W (tons)	Surface silt loading, sL (g/m^2)	Measured PM-10 emission factor (lb/VMT)
CF-1/N	Low Speed	47	5.0	40	0.97	0.011
CF-1/S	Stop-and-go	47	NA	40	0.97	0.043
CF-2/N	Slowly moving	66	5.3	41	0.81	0.036
CF-2/S	Stop-and-go	66	NA	41	0.81	0.14
CF-3/N	Slowly moving	54	5.1	41	0.63	0.0024
CF-3/S	Stop-and-go	54	NA	41	0.63	0.051
CF-4/N	**Slowly moving**	**86**	**4.7**	**41**	**1.1**	**0.0068**
CF-5/N	**Stop-and-go**	**52**	**NA**	**41**	**1.4**	**0.036**

[a] Suffix indicates whether tests was conducted on the North or South portion of the corn haul road. Trucks were held in a queue toward the south; trucks entering the north gate traveled passed the north sampling array to reach the queue.

[b] Speed of moving trucks determined by accumulating time required to travel a measured distance. NA = not applicable.

Bold entries indicate that identical vertical sampling arrays were used to better isolate the source contribution.

vertical background sampling array (as used at the two MCP plants) to better isolate the source contribution.

The results are summarized in Table 4-14. Only two tests (CI-7 and CI-8) had net mass attributed to the source. In the remaining instances, the measured downwind PM-10 concentrations were lower than upwind values. It was stated that this was believed to be an undesired result from moving the test source. Runs CI-7 and CI-8 showed the measured emission factor to be much lower than that predicted by the AP-42 equation. Comments in the report indicated that exposure profiles showed a maximum more likely due to diesel exhaust than from re-entrained surface road dust.

4.2.1.14. Midwest Research Institute, *Emission Tests of Paved Road Traffic at ADM's Marshall, Minnesota Facility*, McVehil-Monnett Associates, December 5, 2003. Reference 10. (ref_31c13s0201_2010.pdf)

The test program at ADM's Marshall MN facility represented the last test by the Corn Refiners Association. By September 2003, the Marshall facility had implemented a road sweeping program. Three tests of PM-10 emissions were conducted, one from stop-and-go traffic and two from slowly moving traffic. Because of experience gained from the earlier tests, identical vertical networks of samplers were operated downwind and upwind during each test.

The results of this testing program are summarized in Table 4-15. The test data are assigned an A rating. Measured emission factors were all significantly lower than that predicted by the AP-42 equation. The test report also remarked that the measured emission rates were independent of traffic rate, while the AP-42 factor implies a linear dependency between the emission and traffic rates.

Table 1-14. Summary of Emissions Data from Cargill's Blair, Nebraska Facility (Test Report 3)

Run	Test condition	Traffic rate (veh/hr)	Traffic speed (mph)[a]	Mean vehicle weight, W (tons)	Surface silt loading, sL (g/m^2)[b]	Measured PM_{10} emission factor (lb/VMT)[c]
CI-1	Low Speed	45	13.4 / 16.8	26	0.06	-
CI-2	Low Speed	45	12.8 / 16.9	26	0.06	-
CI-3	Slowly moving	60[d]	13.6 / 12.7	27	0.06	-
CI-4	Low Speed	60[d]	13.5 / 15.5	27	0.06	-
CI-7	Slowly moving	47	15.2 / 16.2	27	0.05	0.0036
CI-8	Low Speed	47	13.6 / 16.1	27	0.05	0.0066
CI-11	Low Speed	56	13.5 / 12.7	27	0.025	-
CI-12	Low Speed	56		27	0.25	-

[a] Vehicle speed for inbound (loaded) /outbound (empty) trucks determined by accumulating time required to travel a measured distance.

[b] Surface silt loading sample information provided by Cargill.

[c] "-" indicates that no net mass was attributed to the test road traffic.

[d] Twenty of 238 total passes were by "drone" trucks.

Table 4-15. Summary of Emissions Data from ADM's Marshall, Minnesota Facility (Test Report 4)

Run	Test Condition	Traffic rate (veh/hr)	Traffic speed (mph)[a]	Mean vehicle weight, W (tons)	Surface silt loading, sL (g/m^2)	Measured PM_{10} emission factor (lb/VMT)
CM-1	**Slowly moving**	**154**	**NA**	**40**	**0.72**	**0.014**
CM-2	**Stop-and-go**	**42**	**NA**	**40**	**0.72**	**0.14**
CM-4	**Slowly moving**	**156**	**5**	**40**	**0.70**	**0.016**

[a] Vehicles speeds maintained at plant limit of 5 mph. NA = not applicable.

Bold entries indicate that identical vertical sampling arrays were used to better isolate the source contribution.

4.2.1.15. E.H. Pechan & Associates, Inc., *Recommendations for Emission Factor Equations in AP-42 Paved Roads Section: TECHNICAL MEMORANDUM* August 21, 2003; Reference 12,

(http://www.epa.gov/ttn/chief/ap42/ch13/related/pavedroadstechmemo_082103.pdf)

This technical memorandum documents the procedure that was used to separate the various components of paved road particulate matter emissions into two components. One component includes the emissions from exhaust, brake wear and tire wear. The other component includes the particulate matter reentrained from the road surface. The combined paved road particulate matter emissions were estimated with the empirical equation published in the October 2002 AP-42 Section for Paved Roads. The vehicle exhaust, brakewear and tirewear emission factors were obtained from the MOBILE6.2 model. A typical vehicle fleet and fuel source from 1980 was utilized for the model runs. The assumption included a vehicle fleet for July 1980, a gasoline sulfur content of 300 ppm, a diesel sulfur content of 500 ppm and no use of reformulated gas. The vehicle fleet assumptions used in the analysis are presented in Table 4-16. The model was run to estimate PM_{10} and $PM_{2.5}$ emission factors in g/VMT for each vehicle class at speeds of 25, 30, 35, 40, 45, 50, 55, and 60 mph. Within vehicle classes, the greatest standard deviation was lower than 0.04% of the emissions factor. Based on the low relative standard deviation, it was assumed that the vehicle speed was not a factor in exhaust, brakewear and tirewear PM emissions. Table 4-16 presents the vehicle fleet characteristics used in the model and the calculated average PM_{10} and $PM_{2.5}$ emission factors for exhaust, brakewear and tirewear for each class of vehicle.

Table 4-16: Vehicle Fleet Assumptions Used in 2003 MOBILE6.2 Model

Vehicle Type	LDGV	LDGT12	LDGT34	LDGT	HDGV	LDDV	LDDT	HDDV	MC
GVWR	3,075	4,105	7,000		35,000	3,705	6,000	70,000	550
VMT Distribution	0.6748	0.1477	0.0758		0.0365	0.0088	0.0118	0.0352	0.0094
PM_{10} Emissions Factor	0.1053	0.1061	0.2746	0.1632	0.3825	0.7206	0.7206	2.1227	0.0922
$PM_{2.5}$ Emissions Factor	0.0686	0.0690	0.1851	0.1084	0.2576	0.6519	0.6521	1.9272	0.0590

The contractor developed "AP-42 Composite" PM_{10} and $PM_{2.5}$ emission factors using the October 2002 AP-42 paved roads emission factor equation with the mean vehicle weight set at 3.74 tons (a value they indicated was typical of the 1980 paved road vehicle fleet. The contractor used silt loadings ranging from 0.02 to 400 g/m^2 for calculating the emissions factors. The contractor also calculated the fleet average PM_{10} and $PM_{2.5}$ emission factors for exhaust, brakewear and tirewear by summing the products of the VMT Distribution ratio and the PM_{10} and $PM_{2.5}$ emission factors for each vehicle class. The calculated fleet average values were 0.2119 for PM_{10} and 0.1617 for $PM_{2.5}$. The contractor then subtracted the fleet average emissions factors for exhaust, brakewear and tirewear from the "AP-42 Composite" emissions factors to produce an emission factor for only the re-entrained road dust component. The contractor noted that the while the stated applicable silt loadings for the October 2002 AP-42 paved road equation ranged from 0.02 to 400 g/m^2, the $PM_{2.5}$ emissions factor became negative at silt loadings less than 0.029 g/m^2. They stated that since negative emissions were not physically possible, the equation they recommended was only valid for silt loading ranging from 0.03 to 400 g/m^2. While no test data are associated with this report, the report does provide estimates of engine exhaust, tire wear and brake wear derived from an EPA emissions model which is based upon emissions testing by a validated test method on multiple vehicles for each type of vehicle. As a result, emissions estimates by vehicle class are assigned an A rating. Because the use of a national average vehicle fleet emissions estimate does not provide emissions that are representative of the mix of vehicle classes measured during the above test reports, the composite emissions estimates are assigned a C rating.

4.2.1.16. E-mail communication between Ron Myers of EPA/OAQPS/SPPD/MPG, RTP, NC and Prashanth Gururaja and Ed Glover of EPA/OTAQ/ASD/HDOC re. Diesel exhaust, tire and brake wear for low speed stop and go traffic; January 2009 through May 2009. Reference 13, (OTAQ_Diesel_PMresult.pdf).

This e-mail communication and spreadsheet file concerns estimates of PM_{10} emissions associated with slow moving and stop and go diesel engine semi-trailer trucks. The purpose of the request was to provide a means to disaggregate the consolidated PM emissions measured of trucks during delivery of product at corn storage and transfer facilities. The request stated that the trucks were 18 wheel semitrailers of about ten years of age, were queued for the delivery of their load to a transfer or processing facility and that the estimated vehicle speed averaged about 1 mph but that they were stopped most of the time. $PM_{2.5}$ emissions were estimated using the MOVES mobile source emissions model. The trucks modeled were approximately ten years old, traveling at an average of 1.5 mph on level pavement. Emissions were estimated at 11.06035 g/hour or 8.789778 g/VMT. PM_{10} emissions were estimated to be approximately 3% greater than $PM_{2.5}$ emissions. While no test data are associated with this report, the report does provide estimates of engine exhaust, tire wear and brake wear derived from an EPA emissions model which is based upon emissions testing by a validated test method on multiple vehicles for the specific type of vehicle measured during the Corn Refiners Association Studies. As a result, emissions estimates for slow moving trucks are assigned an A rating.

4.2.1.17. Midwest Research Institute; *Analysis of the Fine Fraction of Particulate Matter in Fugitive Dust*; Western Governors' Association - Western Regional Air Partnership (WRAP); October 12, 2005. Reference 14, http://www.epa.gov/ttn/chief/ap42/ch13/related/mri_final_fine_fraction_dust_report.pdf)

This project was conducted by Midwest Research Institute for the Western Regional Air Partnership to provide more accurate $PM_{2.5}$ and PM_{10} fugitive dust emissions inventories for regional haze regulatory purposes to address the significant contribution of fugitive dust to visibility impairment. The results of this project were expected to affect the quantity of dust apportioned to the fine versus coarse size modes. It was stated that the results would be helpful in developing accurate emission inventories for PM nonattainment, maintenance, and action plan areas in the WRAP region. Finally, it was stated that the results may be used to seek modifications to the EPA's AP-42 emission factors to ensure widespread availability of the information developed in the study.

During the first testing phase of the project, $PM_{2.5}$ measurements using the high-volume cascade impactors were compared to simultaneous measurements obtained using EPA reference-method samplers for $PM_{2.5}$. The tests were conducted in a flow-through wind tunnel and exposure chamber, where concentration level and uniformity were controlled. With the same test setup, a second phase of testing was performed with reference method samplers, for the purpose of measuring $PM_{2.5}$ to PM_{10} ratios for fugitive dust from different geologic sources in the West. The testing provided information on the magnitude and variability of $PM_{2.5}$ to PM_{10} ratios for source materials that were recognized as problematic with regard to application of mitigative dust control measures.

Three dust source materials were tested under the first Phase of the study. The three dust source materials included an Owens Dry Lake surface soil, and two Arizona road dust reference standards (one coarse and one fine fraction material). Fixed PM_{10} concentration levels in the range of 1, 2.5, and 5 milligrams per cubic meter (each with its naturally occurring $PM_{2.5}$ level) were tested. It was stated that those PM_{10} concentration levels were selected as representative of dust plume concentrations under which major particle mass contributions to plume samples occur in emission factor development. The ratios of $PM_{2.5}$ to PM_{10} for fugitive dust from different geologic soil types were measured. A total of seven source materials were tested. The materials included Alaska river bed sediment, Arizona alluvial channel, Arizona agricultural soil, New Mexico unpaved landfill road dust, New Mexico grazing soil, California Salton Sea shoreline soil, and Wyoming unpaved road surface material. Test results included the calculation of the average $PM_{2.5}$ concentration and the collocated PM_{10} concentration. It was intended that any variation in $PM_{2.5}/PM_{10}$ ratio be evaluated as a function of the test soil properties (for example, position in soil texture triangle).

A total of 100 individual tests were performed, including 17 blank runs (for quality assurance purposes). The results of the testing are well documented and the documentation is sufficient to assess that the study was well designed and implemented. This was a laboratory study designed to assess those emissions sources that were considered to have the greatest influence in PM_{10} and $PM_{2.5}$ non attainment areas. As a result, the study is assigned a quality rating of B when applied within the bounds of the type of surface material that was available and for dust generation characteristics comparable to those used in the study. The study included no paved road surface material and was weighted toward higher particulate matter concentrations. Since the study was a laboratory study, did not include any paved road surface materials, and was weighted toward higher particulate concentrations, it is assigned a quality rating of "D" when used for paved roads.

The results of the Phase I testing indicated that the $PM_{2.5}$ concentrations measured by the cyclone/impactor system were consistently biased by a factor of about 2 relative the $PM_{2.5}$ concentrations measured by the Partisol samplers. While there was some data separation of different test materials, the second phase testing showed a tendency of the measured $PM_{2.5}/PM_{10}$ ratio to decrease with increasing PM_{10} concentration. At PM_{10} concentrations above 1.0 mg/m^3 the $PM_{2.5}/PM_{10}$ ratio was between 0.1 and 0.15. The $PM_{2.5}/PM_{10}$ ratio increased to about 0.35 as the PM_{10} concentration approached about 0.5 mg/m^3.

4.1.2.18. Midwest Research Institute; *Background Document for Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Dust Emission Factors*; Western Governors' Association - Western Regional Air Partnership (WRAP); November 1, 2006. Referenc 15, (http://www.epa.gov/ttn/chief/ap42/ch13/bgdocs/b13s02.pdf)

This report summarizes the results of the October 2005 WRAP study which evaluated the $PM_{2.5}/PM_{10}$ ratio measured by the cyclone/impactor system and measured by the Partisol samplers. While no additional analyses of the laboratory study were performed, suggested $PM_{2.5}/PM_{10}$ ratios were made for use in revising existing AP-42 emissions factor parameters for $PM_{2.5}$ dust emissions factor equations in Sections 13.2.1 (paved roads), 13.2.2 (unpaved roads), 13.2.3 (material transfer and storage piles), 13.2.4 (windblown dust) and 13.2.5 (industrial wind erosion). A revised $PM_{2.5}/PM_{10}$ ratio of 0.15 was recommended for the paved roads emissions factor.

4.1.2.19. Technical Memorandum from William B. Kuykendal to File, Subject: *Decisions on Final AP-42 Section 13.2.1 "Paved Roads"*, October 10, 2002. Reference 32, (http://www.epa.gov/ttn/chief/ap42/ch13/related/rel_c13s0201.pdf)

This technical memorandum to the files summarizes and responds to comments on an October 2001, EPA proposed revision of Section 13.2.1 "Paved Roads" for AP-42 and request for comments. The memorandum also presents EPA's decisions and rational supporting these decisions for the final changes leading to the final section. The proposed revisions to the section included an adjustment for rain events (comparable to the adjustment in the unpaved road section) which in essence "zeroed" the emissions on days that more than 0.01 inch of rain was recorded. In addition, the proposed revisions included the separation of vehicle engine exhaust, breakwear an tirewear as recommended in the E. H. Pechan Technical Memorandum of August 21, 2003. The memorandum includes attachments with the detailed comments that lead to the final revision of the emissions factor equation. The final changes to the emissions factor equation included:

- the subtraction of 0.2119 g/VMT for engine exhaust, brakewear and tirewear,
- an adjustment of (1- (P/4N)) for rain events (P = number of rain days and N = number of days in period), and
- an adjustment of (1- (1.2P/N)) for rain events (P = number of rain hours and N = number of hours in period).

4.2.2. **EMISSIONS FACTOR DEVELOPMENT.**

A total of 93 individual tests are available. All tests quantified PM_{10} emissions. Lastly, plume profiling was the test method. Of these, 71 emissions tests included mean vehicle weight, road silt loading, and vehicle speed. The remaining tests included all of these parameters except vehicle speed. These emissions tests measured PM_{10} emissions associated with engine exhaust, tire wear, brake wear and material deposited on the road surface. Policy decisions within EPA make it necessary to separate particulate matter emissions associated with the operation of the vehicles (engine exhaust, tire wear and brake wear) and those associated with the road surface characteristics. These policy decisions are based in part on the recent and future efforts to control engine exhaust emissions. Many of the emissions tests performed to quantify particulate matter emissions from paved roads were conducted in the mid 1980's to middle 1990's. Several of the emissions studies have experienced comparable upwind and downwind concentrations with downwind particulate that appears to consist of a large percentage of organic or carbonaceous material. The first separation of vehicle associated emissions and pavement associated emissions was in the 2003 update. This update used the national VMT weighted fleet average PM_{10} emissions factor of 0.1317 g/VMT to subtract from the existing emissions factor equation as a means of separating the emissions from engine exhaust, tire wear and brake wear from the composite paved road emissions factor. A fleet average vehicle weight of 3.75 tons is associated with this emissions factor. Since the average vehicle weight used in the development of the paved road emissions factor equation was about 10 tons, the PM10 emissions factor for engine exhaust, tire wear and brake wear probably underestimated these emissions. In addition, because of the range and variation in mean vehicle weight, the use of an average for adjustment value introduces excessive error in the estimated road dust emissions estimates. Improved test specific adjustments for vehicle exhaust, tire wear and brake wear can be made since (1) average vehicle weights are available for each test series, (2) PM_{10} emissions factors estimates for each vehicle class are available from the 2003 Technical Report and (3) PM_{10} emissions estimates for slowly moving and stop and go truck traffic are available. By subtracting the estimated test specific vehicle emissions from the measured emissions prior to performing the stepwise multiple regression, emissions associated with the road surface material will be isolated.

4.2.2.1. Compilation and Adjustment of Final Data Base.

In keeping with the results from the data set review, a final data base was compiled by combining the following sets:

1. The January 1983 EPA data base,
2. the August 1983 EPA data base,
3. the July 1984 EPA data base,
4. the May 1990 USX data base,
5. the April 1997 EPA data base, and
6. the May 2008 CRA data base.

While several of the test reports include detailed information on the number of light duty vehicles, moderate weight trucks and heavy weight trucks, none provide detailed information on vehicle class as used to estimate emissions of vehicle exhaust, tire wear and break wear. For this assessment the vehicle classes will be separated into two vehicle classes. One group of vehicle class will include the six classes of light duty vehicles/trucks and motorcycles. The other group of vehicle class includes gas and diesel heavy duty trucks. Other assumptions used to estimate vehicle associated emissions include:

- The test fleet includes a mixture of light duty vehicles, heavy duty gas trucks and heavy duty diesel trucks when the average vehicle weight is less than 23 tons.
- The test fleet includes a mixture of light duty vehicles and heavy duty diesel trucks when the average vehicle weight is between 23 tons and 35 tons.
- The test fleet includes only heavy duty diesel trucks when the average vehicle weight is more than 35 tons.

First, the average vehicle weight and emissions are determined for the two classes of vehicles used to estimate the adjustment for the measured emissions. The vehicle weights, VMT distribution and emissions presented in Table 4-16 are used to calculate the average vehicle weight and emissions. The VMT adjusted gross vehicle weight is calculated for each class of vehicle by multiplying the VMT distribution by the average gross vehicle weight for the class. The individual vehicle class VMT adjusted gross vehicle weights are summed to arrive at the two VMT adjusted gross vehicle weights used in this assessment. For light duty vehicles, the VMT adjusted gross vehicle weight is 3320 pounds. For heavy duty trucks, the VMT adjusted gross vehicle weight is 3742 pounds. The sums of the VMT distributions for these two classes of vehicles are obtained by summing the individual VMT distributions for the two classes of vehicles used in this assessment. For light duty vehicles, the VMT distribution is 0.928. For heavy duty trucks, the VMT distribution is 0.0717. Dividing the VMT adjusted gross vehicle weights by the VMT distributions and converting to tons yields the average vehicle weights for the two classes of vehicles. For light duty vehicles, the average gross vehicle weight is 1.79 tons. For the combination of heavy duty gas and diesel trucks, the average gross vehicle weight is 26.09 tons. The average emissions for the two classes of vehicle are calculated in a similar manner. The emissions factors for the two classes are calculated by summing the individual classes. For light duty vehicles, the VMT adjusted emissions factor is 0.1232 g/VMT. For heavy duty trucks, the VMT adjusted emissions factor is 0.0887 g/VMT. Dividing the VMT adjusted emissions factor by the VMT distributions yields the average emissions factor for the two classes of vehicles. For light duty vehicles, the average emissions factor is 0.1328 g/VMT. For a mixture of heavy duty gas and diesel trucks, the average emissions factor is 1.2368 g/VMT. For only heavy duty diesel trucks, the emissions factor is 2.1227 g/VMT (from Table 4-16).

Next, an algorithm is developed to provide test run specific ratios of light duty vehicles and heavy duty trucks. The algorithm is developed by solving the following two equations.

$$W_t = (R_{LD} \times W_{LD}) + (R_{HD} \times R_{HD})$$

$$1.00 = R_{LD} + R_{HD}$$

where: W_t = Test report average vehicle weight

W_{LD} = Average Light Duty Vehicle Weight (1.78848 tons)

R_{HD} = Average Heavy Duty Truck Weight (26.09135 tons)

R_{LD} = Light duty vehicle ratio

R_{HD} = Heavy duty truck ratio

For test runs where the average vehicle weight is less than 23 tons, the resulting algorithm to estimate the ratio of heavy duty gas/diesel trucks in each test series is:

$$R_{HD} = (W_t - 1.78848) / (26.09135 - 1.78848)$$

For tests where the average vehicle weight is more than 23 tons, the resulting algorithm to estimate the ratio of heavy duty diesel trucks in each test series is:

$$R_{HD} = (W_t - 1.78848) / (35 - 1.78848)$$

Summing the emissions factors from heavy duty trucks and light duty vehicles provides an estimate of the total engine exhaust; tire wear and brake wear emissions for the test run. Multiplying the ratio of heavy duty trucks in a test series by 1.2368 g/VMT when average vehicle weight is less than 23 tons or 2.1227 g/VMT when average vehicle weight is over 23 tons yields the portion of emissions due to heavy duty trucks. Multiplying the ratio of light duty vehicles in a test series by 0.1328 g/VMT yields the portion of emissions due to light duty vehicles.

During very low vehicle speeds or when vehicles are moving intermittently, emissions are estimated from the hourly emissions estimates for heavy duty diesel trucks. By dividing the hourly emissions estimate by the average vehicle speed, an estimated emissions factor for the test run is produced. This test run specific emissions factor estimate for engine exhaust, tire wear and brake wear is subtracted from the test run measured emissions factor to produce the test run specific emissions factor due to road surface material. To allow log transformation of the data, values of zero or less were set to 0.02 g/VMT. Table 4-17 presents the final dependent and independent variables for all of the useable test series that were assembled for developing the paved road emissions factor equation. It should be noted that there were 10 out of the 93 available data sets where the estimated emissions from engine exhaust, tire wear and break wear were equal to or comparable to the measured emissions. Tests of high speed traffic dominated the lowest site specific emissions factor tests. Four of the six test runs where the average vehicle speed was 55 mph had estimated engine exhaust, tire wear and break wear emissions greater than the measured emissions. The emissions of another test run with vehicle speeds of 55 mph were over 80% engine exhaust, tire wear and break wear emissions. The silt level for the last run was greater than all other 55 mph data sets and was performed to characterize emissions from a road that had been sanded for traction control. For slightly slower moving traffic (40 – 45 mph), three of the five test runs had significant percentage of engine exhaust, tire wear and brake wear emissions. One of the remaining two runs had silt levels greater than 60% of the entire data set and the test was performed to characterize emissions from a road that had been sanded for traction control.

Graphical presentations of the final PM_{10} data base are shown in Figures 4-1 and 4-2. Because of the large range of silt loadings and estimated emissions factors, the data are plotted on a logarithmic scale. Figure 4-1 presents the data base by silt loading with nine ranges of average vehicle weight depicted with different shape and color data points. Figure 4-2 presents the data base by average vehicle weight with eight ranges of silt loading depicted with different shape and color data points. From the graphical presentation, it is evident that PM10 emissions factors are influenced by both road silt loading and vehicle weight. However, it appears that emissions factors are influenced more by the road surface silt loading than by vehicle weight.

Table 4-17. Final Paved Roads Emissions Factor Data Set

Reference	Run ID	Silt loading (g/m2)	Speed (mph)	Weight (tons)	Downwind Concentration mg/m^3	Measured PM-10 Emission factor (g/VMT)	Estimated Fraction Heavy Duty Vehicles	Estimated Engine, brake, tire emission factor (g/VMT)	Estimated PM-10 Road Dust Emission factor (g/VMT)
USX 5/1990	AUC3	0.42	27	5.5	0.011	2.25	0.153	0.3014	1.949
	AUC4	0.52	25	6	0.04	16.1	0.173	0.3241	15.776
	AUC5	0.23	29	3.9	0.07	15.3	0.087	0.2287	15.071
	AUC6	0.23	27	6.2	0.03	3.7	0.182	0.3332	3.367
	AUC7	0.26	27	3	0.01	0.402	0.050	0.1878	0.214
	AUC8	0.15	27	2	0.03	7.88	0.009	0.1424	7.738
	AUE1	4	15	12	0.01	3.22	0.420	0.5967	2.623
	AUE2	4	16	5.1	0.6	10.6	0.136	0.2832	10.317
	AUE3	2.2	15	2.6	0.08	16.1	0.033	0.1696	15.930
	AUE4	1.3	15	2.6	0.06	9.01	0.033	0.1696	8.840
EPA 7/1984	M-1	0.46	30	5.6	0.124	4.99	0.157	0.3059	4.684
	M-2	0.26	30	3.8	0.033	1.55	0.083	0.2242	1.326
	M-3	0.147	30	4.5	0.070	3.54	0.112	0.2560	3.284
	M-4	0.432	35	2.1	0.030	0.177	0.013	0.1469	0.030
	M-5	1.01	35	2.2	0.090	0.692	0.017	0.1515	0.541
	M-6	0.716	30	2.1	0.063	1.38	0.013	0.1469	1.233
	M-7	0.59	35	2.3	0.130	4.22	0.021	0.1560	4.064
	M-8	2.48	20	2.2	0.120	11.2	0.017	0.1515	11.049
	M-9	0.293	30	4.1	0.130	3.24	0.095	0.2378	3.002
	M-10	0.022	55	4.5	0.104	0.177	0.112	0.2560	0.020
	M-11	0.022	55	4.8	0.080	0.322	0.124	0.2696	0.052
	M-12	0.022	55	3.8	0.080	0.084	0.083	0.2242	0.020
	M-13	0.11	35	2.7	0.065	0.306	0.038	0.1742	0.132
	M-14	0.079	35	2.7	0.030	1.37	0.038	0.1742	1.196
	M-15	0.049	35	2.7	0.090	1.47	0.038	0.1742	1.296
	M-16	0.022	55	4.3	0.060	0.241	0.103	0.2469	0.020
	M-17	0.809	30	2	0.056	2.64	0.009	0.1424	2.498

Reference	Run ID	Silt loading (g/m2)	Speed (mph)	Weight (tons)	Downwind Concentration mg/m^3	Measured PM-10 Emission factor (g/VMT)	Estimated Fraction Heavy Duty Vehicles	Estimated Engine, brake, tire emission factor (g/VMT)	Estimated PM-10 Road Dust Emission factor (g/VMT)
	M-18	0.731	30	2	0.080	0.37	0.009	0.1424	0.228
	M-19	0.929	30	2.4	0.050	0.177	0.025	0.1606	0.016
EPA 1/1983	Y1	90.7	10	3.6		117	0.075	0.2151	116.785
	Y2	76.1	10	3.7		182	0.079	0.2196	181.780
	Y3	193	10	3.8		36.3	0.083	0.2242	36.076
	Y4	193	10	3.7		200	0.079	0.2196	199.780
	Z1	11.3	10	8		317	0.256	0.4150	316.585
	Z2	12.4	15	8		740	0.256	0.4150	739.585
	Z3	12.4	15	8		1820	0.256	0.4150	1819.585
	AC4	287	10	5.7		1750	0.161	0.3105	1749.690
	AC5	188	15	7		1420	0.214	0.3695	1419.630
	AC6	399	20	3.1		613	0.054	0.1924	612.808
	AD1	94.8	23	42		1480	1.000	2.1227	1477.877
	AD2	63.6	23	39		342	1.000	2.1227	339.877
	AD3	52.9	23	40		233	1.000	2.1227	230.877
EPA 8/1983	F34	2.78	NR	28	0.552	188	0.789	1.7033	186.297
	F35	2.03	NR	25	0.057	298	0.699	1.5235	296.476
	F36	0.201	NR	8.3	0.134	54.7	0.268	0.4286	54.271
	F37	0.417	NR	17	0.163	77.2	0.626	0.8238	76.376
	F38	0.218	NR	18	0.301	167	0.667	0.8692	166.131
	F39	0.441	NR	18	0.177	253	0.667	0.8692	252.131
	F27	14.8	NR	14	0.531	130	0.502	0.6875	129.312
	F32	0.117	NR	14	0.138	53.1	0.502	0.6875	52.412
	F61	17.9	NR	40	0.327	463	1.000	2.1227	460.877
	F45	5.11	NR	16	0.744	212	0.585	0.7784	211.222
	F62	14.4	NR	36	0.294	317	1.000	2.1227	314.877
	F74	5.59	NR	29	0.114	545	0.819	1.7632	543.237
	B52	7.19	NR	12	0.102	35.4	0.420	0.5967	34.803

Reference	Run ID	Silt loading (g/m2)	Speed (mph)	Weight (tons)	Downwind Concentration mg/m^3	Measured PM-10 Emission factor (g/VMT)	Estimated Fraction Heavy Duty Vehicles	Estimated Engine, brake, tire emission factor (g/VMT)	Estimated PM-10 Road Dust Emission factor (g/VMT)
	B50	13.6	NR	9.4	0.225	82.1	0.313	0.4786	81.621
	B51	13.6	NR	11	0.410	140	0.379	0.5512	139.449
	B54	3.77	NR	10	0.187	93.3	0.338	0.5058	92.794
	B55	6.3	NR	11	0.295	183	0.379	0.5512	182.449
	B56	2.4	NR	9.2	0.229	126	0.305	0.4695	125.531
	B58	10.4	NR	18	0.190	368	0.667	0.8692	367.131
	B57	2.32	NR	12	0.358	195	0.420	0.5967	194.403
	B59	2.06	NR	11	0.149	348	0.379	0.5512	347.449
	B60	3.19	NR	12	0.339	439	0.420	0.5967	438.403
EPA 4/1997	BH1	0.184	55	2.2	0.233	1.08	0.017	0.1515	0.929
	BH2	0.0127	55	2.2	0.030	0.102	0.017	0.1515	0.020
	BH6	1.47	40	2.2	0.300	4.68	0.017	0.1515	4.529
	BJ6	0.06	45	2.2	0.045	0.301	0.017	0.1515	0.150
	BJ7	0.06	45	2.2	0.130	1.94	0.017	0.1515	1.789
	BK7	0.082	45	2.2	0.033	0.57	0.017	0.1515	0.419
	BK8	0.082	45	2.2	0.033	0.44	0.017	0.1515	0.289
CRA 5/2008	CE-1	1.16	1	36	0.050	27	1.000	11.06	15.940
	CE-2	0.86	1	36	0.075	64	1.000	11.06	52.940
	CE-11	1.34	5	12	0.200	154	0.420	2.212	151.788
	CE-3	0.86	1	39	0.070	45	1.000	11.06	33.940
	CE-15	1.91	5	40	0.065	63.5	1.000	2.212	61.288
	CE-16	1.41	5	40	0.050	77.1	1.000	2.212	74.888
	CE-17	2.93	5	40	0.040	41.3	1.000	2.212	39.088
	CE-19	0.76	5	38	0.040	18.6	1.000	2.212	16.388
	CE-12	1.34	5	13	0.085	23.1	0.461	2.212	20.888
	CF-1N	0.97	5	40	0.035	4.99	1.000	2.212	2.778
	CF-1/South	0.97	1	40	0.040	19.5	1.000	11.06	8.440
	CF-2N	0.81	5.3	41	0.044	16.3	1.000	2.0868	14.213

Reference	Run ID	Silt loading (g/m2)	Speed (mph)	Weight (tons)	Downwind Concentration mg/m^3	Measured PM-10 Emission factor (g/VMT)	Estimated Fraction Heavy Duty Vehicles	Estimated Engine, brake, tire emission factor (g/VMT)	Estimated PM-10 Road Dust Emission factor (g/VMT)
	CF-2/South	0.81	1	41	0.080	63.5	1.000	11.06	52.440
	CF-3N	0.63	5.1	41	0.015	1.09	1.000	2.1686	0.020
	CF-3/South	0.63	1	41	0.025	23.1	1.000	11.06	12.040
	CF-4N	1.1	4.7	41	0.019	3.08	1.000	2.3532	0.727
	CF-5	1.4	1	41	0.030	16.3	1.000	11.06	5.240
	CI-7	0.05	15.3	27	0.030	1.63	0.759	1.6434	0.020
	CI-8	0.05	15.3	27	0.030	2.99	0.759	1.6434	1.347
	CM-1	0.72	5	39.8	0.035	6.35	1.000	2.212	4.138
	CM-2	0.72	1	39.6	0.050	6.35	1.000	11.06	0.020
	CM-4	0.7	5	39.5	0.035	7.26	1.000	2.212	5.048

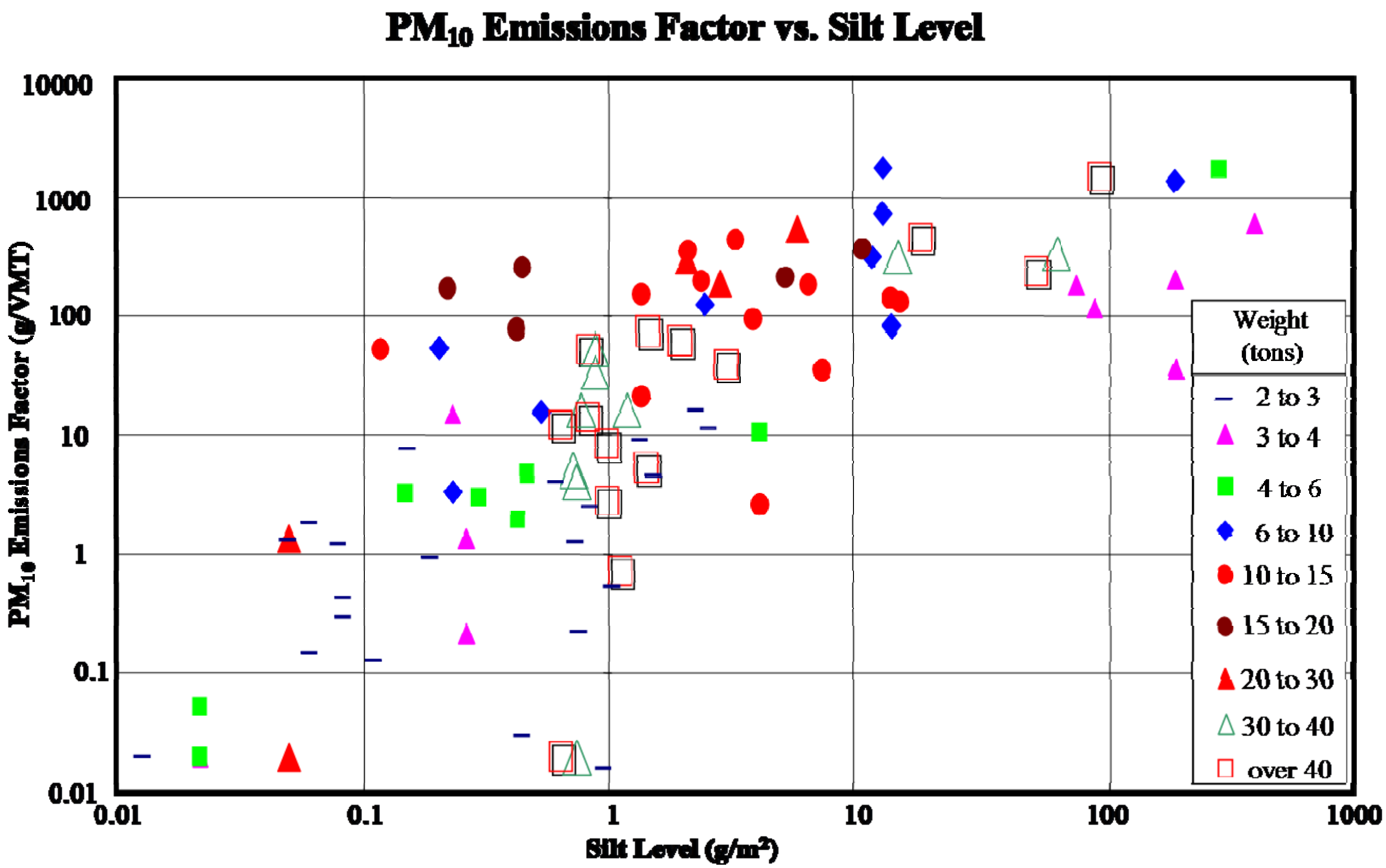

Figure 4-1 PM_{10} Emissions Factor Data Base (93 test runs).

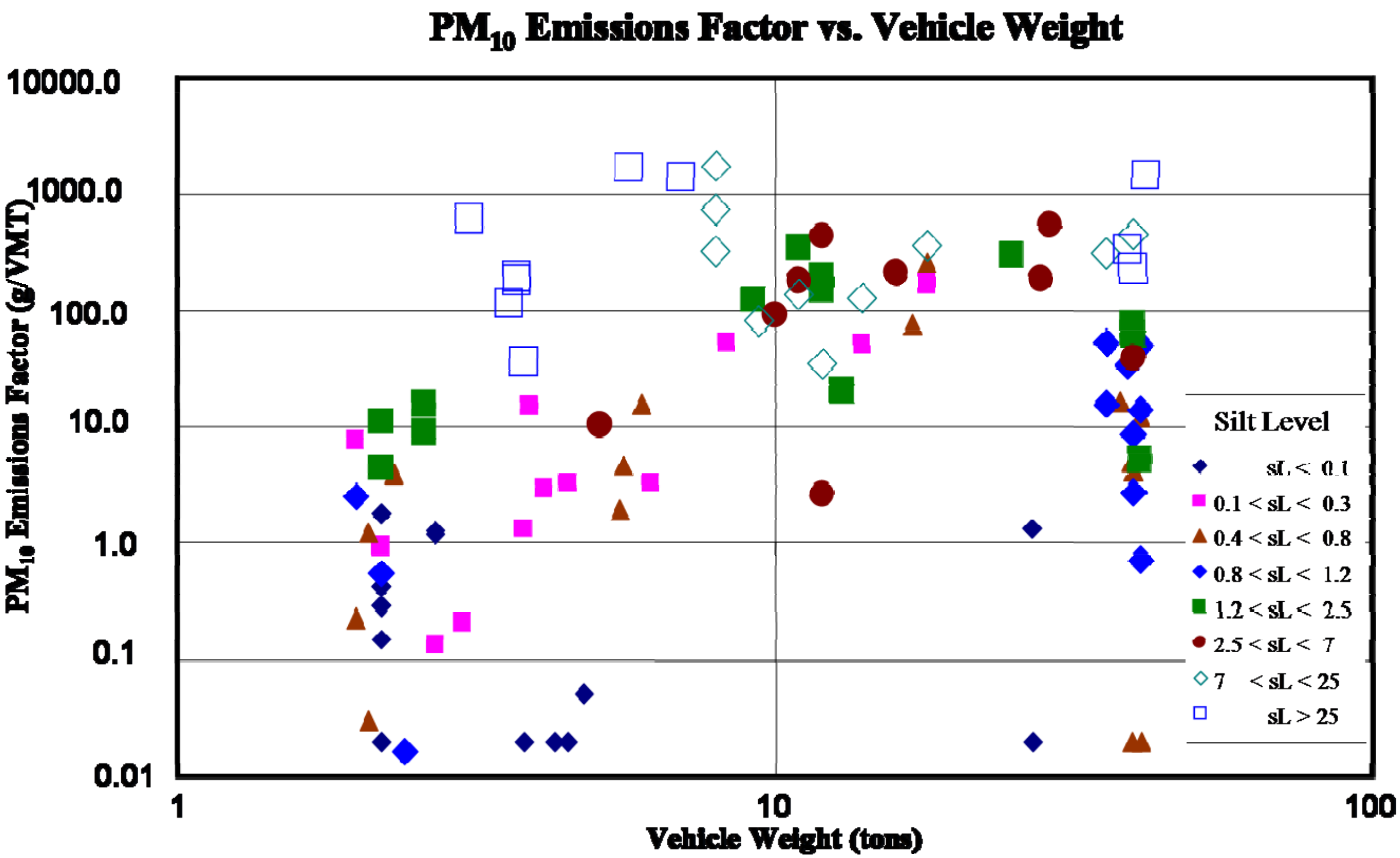

Figure 4-2 PM$_{10}$ Emissions Factor Data Base (93 test runs).

4.2.2.2. Emission Factor Development.

Stepwise multiple linear regression was used to develop a predictive model with the final data set. The potential correction factors included:

- silt loading, sL
- mean vehicle weight, W
- mean vehicle speed, S

All variables were log-transformed in order to obtain a multiplicative model as in the past. Table 4-18 presents the correlation matrix of the log-transformed independent and dependent variables. The most notable feature of the correlation matrix is the high degree of correlation between silt loading and emissions factors. The correlation between emissions factor, weight and speed is much lower than with silt loading. The high correlation between weight and speed is believed to be the result of the large data collected by the corn refiners association to characterize emissions at terminals. This suggests that obtaining accurate silt loading information is the most important independent variable to obtain for accurately estimating emissions factors.

Table 4-18 Correlation Matrix for log-transformed PM10 data.

	PM-10 Emission factor (g/vmt)	Silt loading (g/m2)	Weight (tons)	Speed (mph)
PM-10 Emission factor (g/VMT)	1			
Silt loading (g/m^2)	0.7918	1		
Weight (tons)	0.2745	0.1838	1	
Speed (mph)	-0.3339	-0.2783	-0.7784	1

The initial regression analysis evaluated the independent variables of silt level and average vehicle weight. The stepwise regression was first performed using the “Regression” function in the “Analysis Tool” of Excel. Since the speed term was not included, the entire data set of 93 test runs were included in the analysis. Table 4-19 shows the output from Excel. The predicted exponents for silt and weight are 0.92 and 0.91 respectively and have an adjusted coefficient of determination (R^2) of 0.57. The second regression step, used the adjusted emissions factors as the dependent variables and a single independent variable that was the silt loading (divided by 2) and weight (divided by 3) raised to their respective exponents. Table 4-

20 shows the output from Excel. The predicted multiplier for the predictive equation is 4.10 and the associated adjusted R^2 is 0.32. As a result, if only silt loading and average vehicle weight were used, the predictive equation would be:

$$EF = 4.10\left(\frac{sL}{2}\right)^{0.92}\left(\frac{W}{3}\right)^{0.91}$$

While it is expected that speed and silt loading would be highly inter-correlated under normal conditions. Many of the paved roads in the data base had external influences affecting the silt loading. In some cases, sand was used to improve traction during cold weather. In other cases, there was active removal of deposited silt from the road. It is believed that these external influences affecting the silt loading were the principal reasons that the correlation between these two independent variables was only -0.28. To evaluate the viability of including speed as an additional term in the predictive equation, the 1983 EPA data set was excluded from the analysis and the remaining 71 test data runs were used in the stepwise regression analysis. Table 4-21 shows the output from Excel. The predicted exponents for silt, weight and speed are 0.98, 0.53 and 0.16 respectively and have an adjusted R^2 of 0.61. The second regression step, used the adjusted emissions factors as the dependent variables and a single independent variable that was the silt loading (divided by 2), weight (divided by 3) and speed (divided by 30) raised to their respective exponents. Table 4-22 shows the output from Excel. The predicted multiplier for the predictive equation is 6.79 and the associated adjusted R^2 is 0.44. While the addition of the speed term produces little difference in the adjusted R^2 for the slope (exponent portion) of the predictive equation, the speed term does provide a modest improvement of the adjusted R^2 for the final equation. As a result, the three parameter equation is selected for the new predictive equation. When silt loading, average vehicle weight and speed in the development process, the predictive equation would be:

$$EF = 6.79\left(\frac{sL}{2}\right)^{0.98}\left(\frac{W}{3}\right)^{0.53}\left(\frac{S}{30}\right)^{0.16}$$

Where: EF is in g/VMT,
sL is in g/m^2,
W is in tons and
S is in mph.

Table 4-19. Initial Regression Analysis using Silt Loading and Weight.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7632
R Square	0.5824
Adjusted R Square	0.5668
Standard Error	2.0682
Observations	93

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	542.8875	271.4438	63.4588	6.42153E-18
Residual	91	389.2504	4.2775		
Total	93	932.1379			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Silt loading (g/m2)	0.9240	0.0934	9.8923	0.0000	0.7385	1.1096
Weight (tons)	0.9051	0.0883	10.2489	0.0000	0.7297	1.0806

Table 4-20. Second Regression Analysis using Silt Loading and Weight.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.5782
R Square	0.3343
Adjusted R Square	0.3234
Standard Error	282.63
Observations	93

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3690191.28	3690191.28	46.20	1.086E-09
Residual	92	7348732.32	79877.53		
Total	93	11038923.60			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Silt/Weight	4.098226	0.4725	8.6738	1.41E-13	3.1598	5.0366

Table 4-21. Initial Regression Analysis using Silt Loading, Weight and Speed.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8002
R Square	0.6404
Adjusted R Square	0.6151
Standard Error	1.9308
Observations	71

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	451.4629	150.4876	40.3658	5.12E-15
Residual	68	253.5105	3.7281		
Total	71	704.9734			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Silt loading (g/m2)	0.9804	0.0951	10.3065	1.57E-15	0.7906	1.1702
Weight (tons)	0.5298	0.1269	4.1770	8.61E-05	0.2767	0.7830
Speed (mph)	0.1594	0.1057	1.5074	0.1363	-0.0516	0.3704

Table 4-22. Second Regression Analysis using Silt Loading, Weight and Speed.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6764
R Square	0.4575
Adjusted R Square	0.4432
Standard Error	285.3151
Observations	71

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4804841.24	4804841.24	59.0241	7.60E-11
Residual	70	5698331.03	81404.72		
Total	71	10503172.27			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A
Silt/weight/speed	6.7871	0.7779	8.7245	8.47E-13	5.2355	8.3386

The range of conditions which existed at the test sites used in developing the equation was as follows:

Silt loading:	0.03 - 400 g/m2
	0.01 - 570 grains/square foot (ft2)
Mean vehicle weight:	1.8 - 38 megagrams (Mg)
	2.0 - 42 tons
Mean vehicle speed:	1 - 88 kilometers per hour (kph)
	1 - 55 miles per hour (mph)

An assessment of the performance of the predictive equation is difficult since the range of silt loadings and the associated emissions factors spans five orders of magnitude. This is further complicated by the focus of many of the field tests. Approximately half of the field test locations were selected either due to concerns that these sources were major contributors to air quality impacts, or were selected because of elevated road silt levels to allow the measurement of a difference from background concentrations of particulate matter. Another complication is that PM emissions of the vehicle exhaust were not measured during the tests and a modeled national average emission factor or rate was subtracted to arrive at the road dust emissions. Lastly, the use of three independent variables makes it difficult to show the performance characteristics graphically.

One can assess the performance of the predictive equation by calculating the average predicted to actual ratio and producing the cumulative distribution of these ratios. For the three parameter equation, the average predicted to actual ratio is 13.8. This is significantly lower than the average predicted to actual ratio of 277 for the previous two parameter equation when applied to the existing data. It should be noted that the previous equation subtracted the national average engine exhaust from the resulting equation. Figure 4-3 depicts the cumulative distribution of the predicted to actual ratios for both the previous equation and the new equation. Figure 4-4 presents this same information but with ranges of silt loading depicted through the use of different shapes and colors for the markers of the data. Figure 4-5 is this same information but with ranges of vehicle weights depicted with different markers. It is difficult to discern any differences below the ratio of 1.0. Above the ratio of 1.0 the increased variation of the older

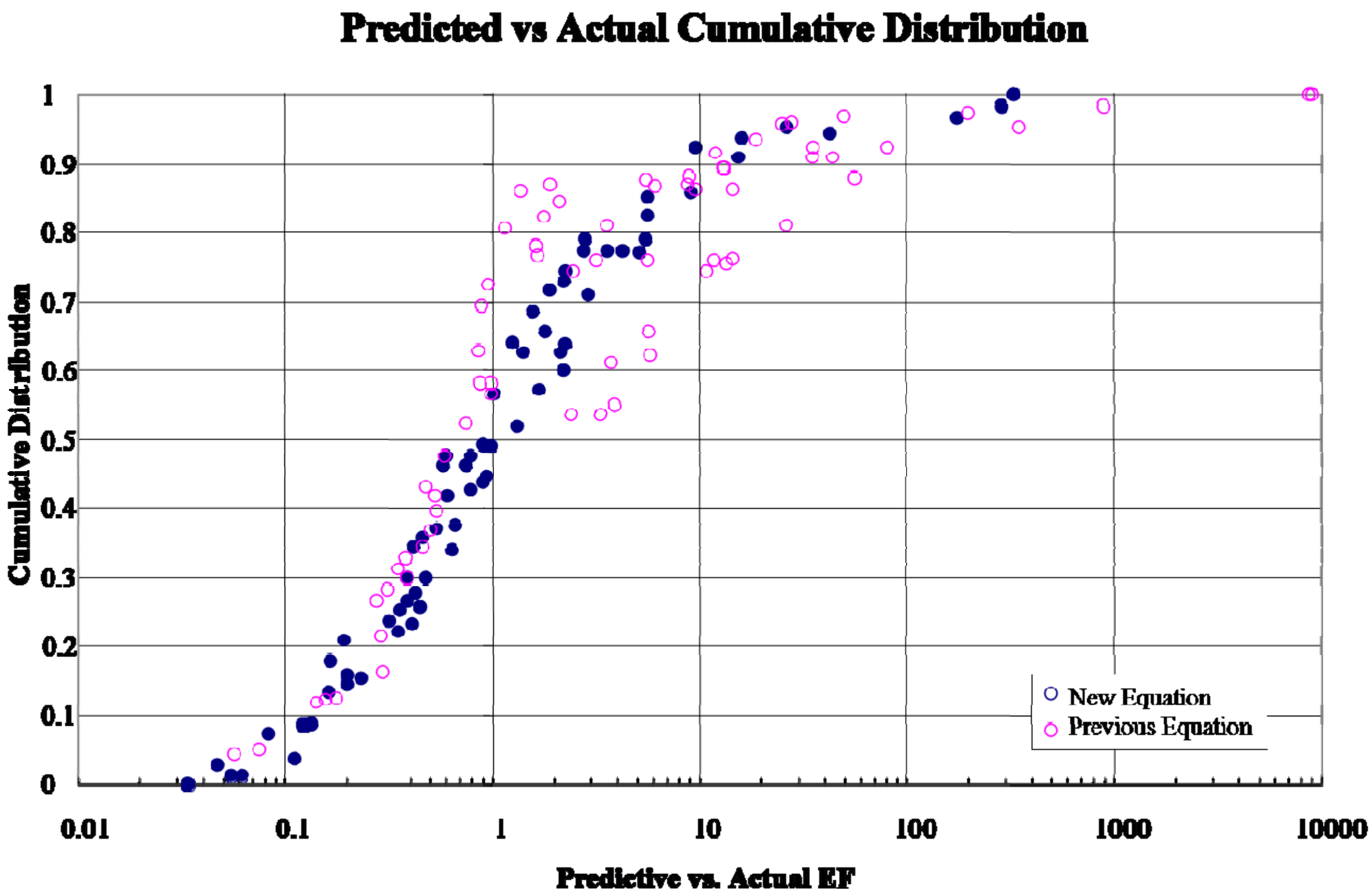

Figure 4-3 Cumulative Distribution of Predicted vs. Actual PM_{10} EFs.

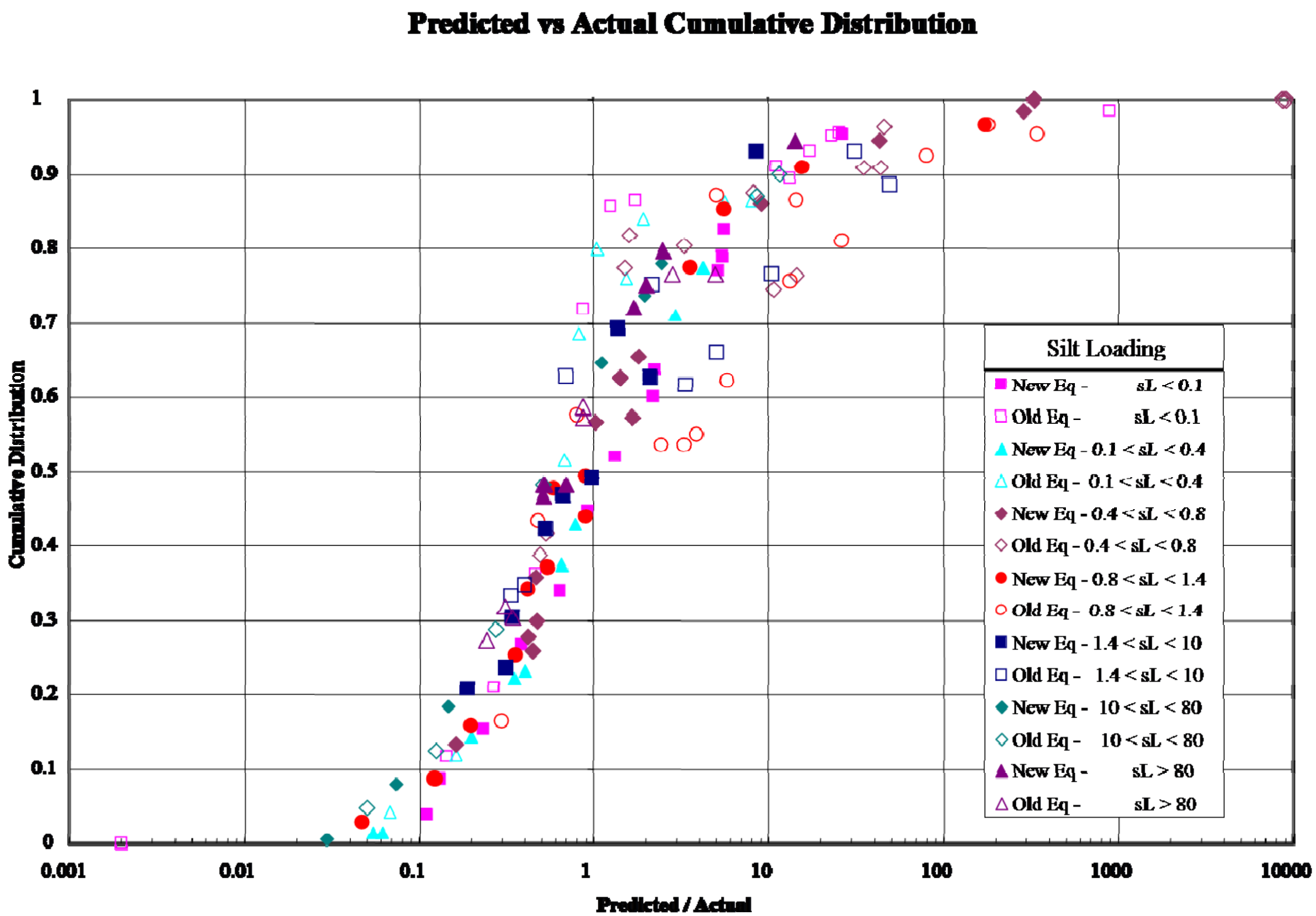

Figure 4-4 Cumulative Distribution of Predicted vs. Actual PM_{10} EFs with Silt Loadings.

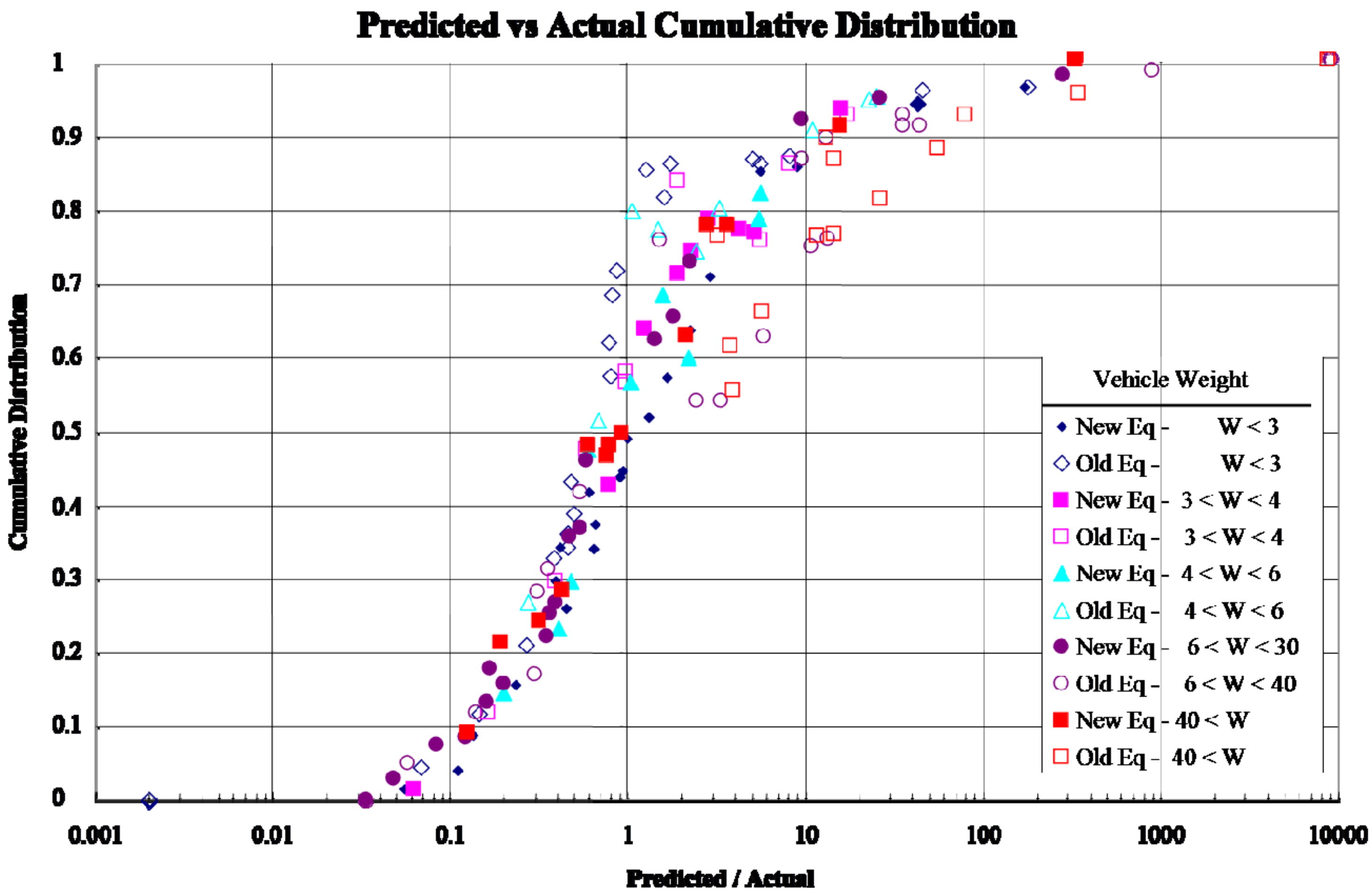

Figure 4-5 Cumulative Distribution of Predicted vs. Actual PM_{10} EFs with Average Vehicle Weight.

equation is evident. Middle and lower silt loadings appear to have a greater variation in the predicted to actual ratios when the older equation is used. Vehicle weights appear to have a measurable influence on spread of the cumulative distribution when the older equation is used.

Another means of assessing the performance of the regression equations is to compare the calculated results of the equations to the actual value measured. With a large range of measured emissions factors, comparing the relative percent difference between the results of the equation and the measured value places the differences in the smallest measured value and the largest measured value on comparable terms. Three comparisons were made to assess the relative predictive performance of the existing equation to the previous equation. As shown with the average percent error for the entire population in Table 4-23, the new equation provides an improved estimate of the measured emissions over the previous equation. When the performance of the equation is evaluated within classes of the independent variables, the new equation shows comparable or improved performance in all groups of the variables except two.

Figure 4-6 through Figure 4-9 provide graphical indications of the performance of the two equations to estimate the actual emissions. The first two figures show the relationship of emissions to the road surface silt loading. Figure 4-6 provides this information with the addition of average vehicle weight and Figure 4-7 provides this information with the addition of average vehicle speed. In both figures the estimated emissions factors predicted by the previous equations show a greater spread than the new equations estimates. Figure 4-8 shows the influence of vehicle weight on the emissions factors. The spread of the data is much greater than is demonstrated in the figures with silt as the ordinate. One can see a general increase in emissions with silt loading. This is probably due to the greater influence that silt loading has on the emissions. Figure 4-9 shows the influence of speed on the emissions factors. As with vehicle weight, there is a greater spread of the emissions factor than when silt is the primary dependent variable graphed. One can also see a weak relationship between silt loading and average vehicle speed.

Table 4-23. Comparison of Previous and New Equations for Estimating Paved Road Dust Emissions.

	Predictive Performance of Paved Road Dust Emissions Equations					
	Average Relative Percent Error [1]			Relative Standard Deviation		
	Old Equation vs Actual	New Equation vs Actual	Old Equation vs New Equation	Old Equation vs Actual	New Equation vs Actual	Old Equation vs New Equation
Population Average	27,630	1,280	26,340	5.3	4.3	5.4
By Classes of Silt Loading (g/m^2)						
≤ 0.2	1,220	1,150	70	3.5	3.6	6.0
0.2 – 0.75	530	67	470	2.0	4.0	1.7
0.75 – 1.5	104,720	3,550	101,170	2.7	2.8	2.7
1.5 – 50	6,160	380	5,790	2.0	1.6	2.1
≥ 50	188,760	7,590	181,220	0.89	0.77	0.89
By Classes of Average Weight (ton)						
2 - 3	1,100	1,070	40	3.6	3.6	5.2
3 – 5	590	240	350	1.5	1.7	2.4
5 – 10	3.7	-50	53	29.9	-1.0	1.5
10 – 40	77,270	2,420	74,840	3.2	3.2	3.2
≥ 40	71,200	2,650	68,550	3.4	3.4	3.4
By Classes of Average Speed (mph)						
< 10	87,360	2,970	84,400	3.0	3.1	3.0
10 – 25	4,530	240	4,300	4.2	2.7	4.4
25 – 45	1,230	1,120	110	0.047	0.039	0.13
45	-3.8	-27	23	-15.3	-1.7	0.6
55	1,150	250	890	1.0	0.8	1.1

[1] Relative Percent Error = (((Result 1 EF) – (Result 2 EF)}/Actual EF)x100.
[2] Relative Standard Deviation = Standard Deviation / Average

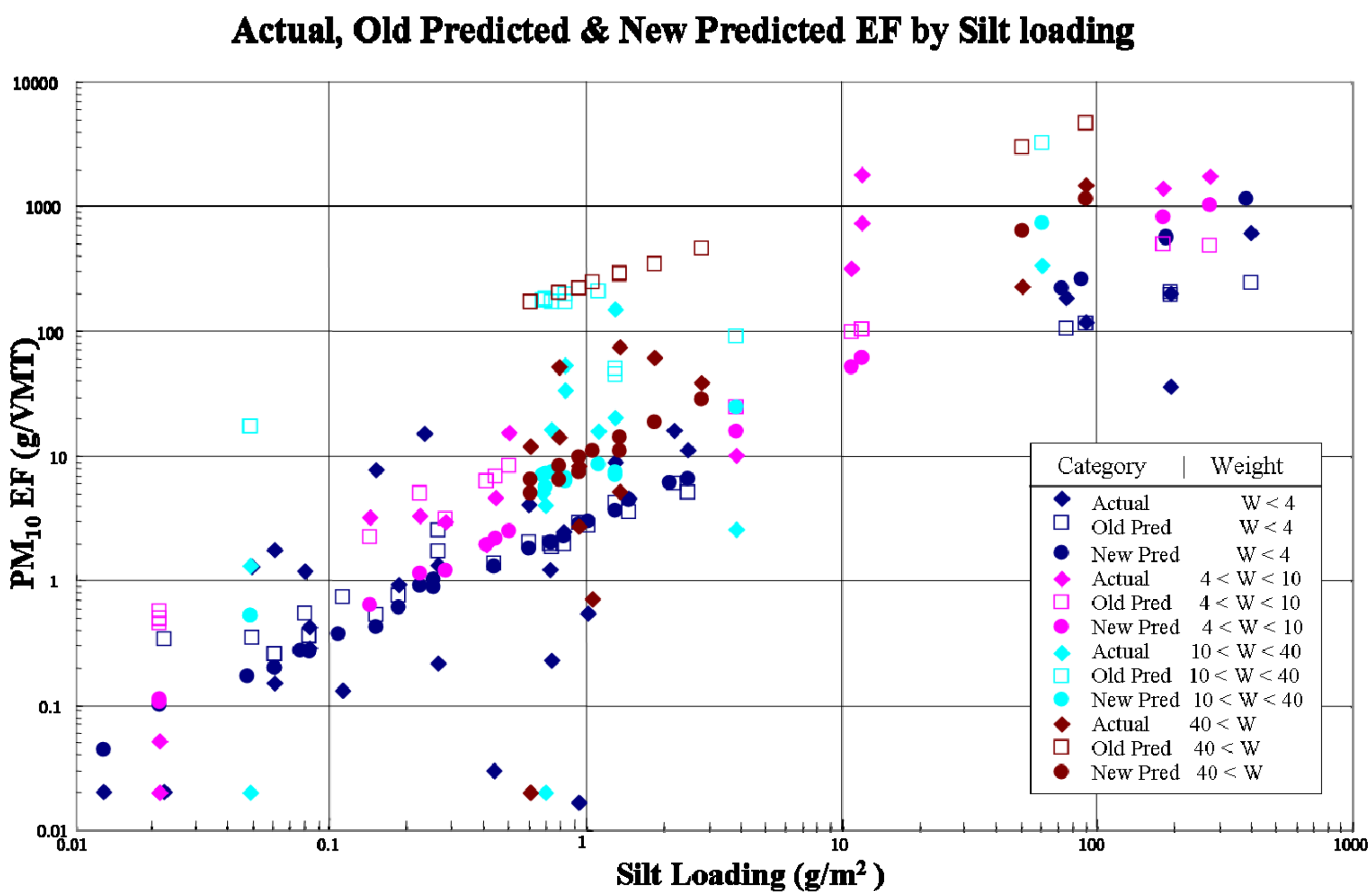

Figure 4-6 Predicted and Actual PM_{10} emission verses Silt Loading and Average Vehicle Weight.

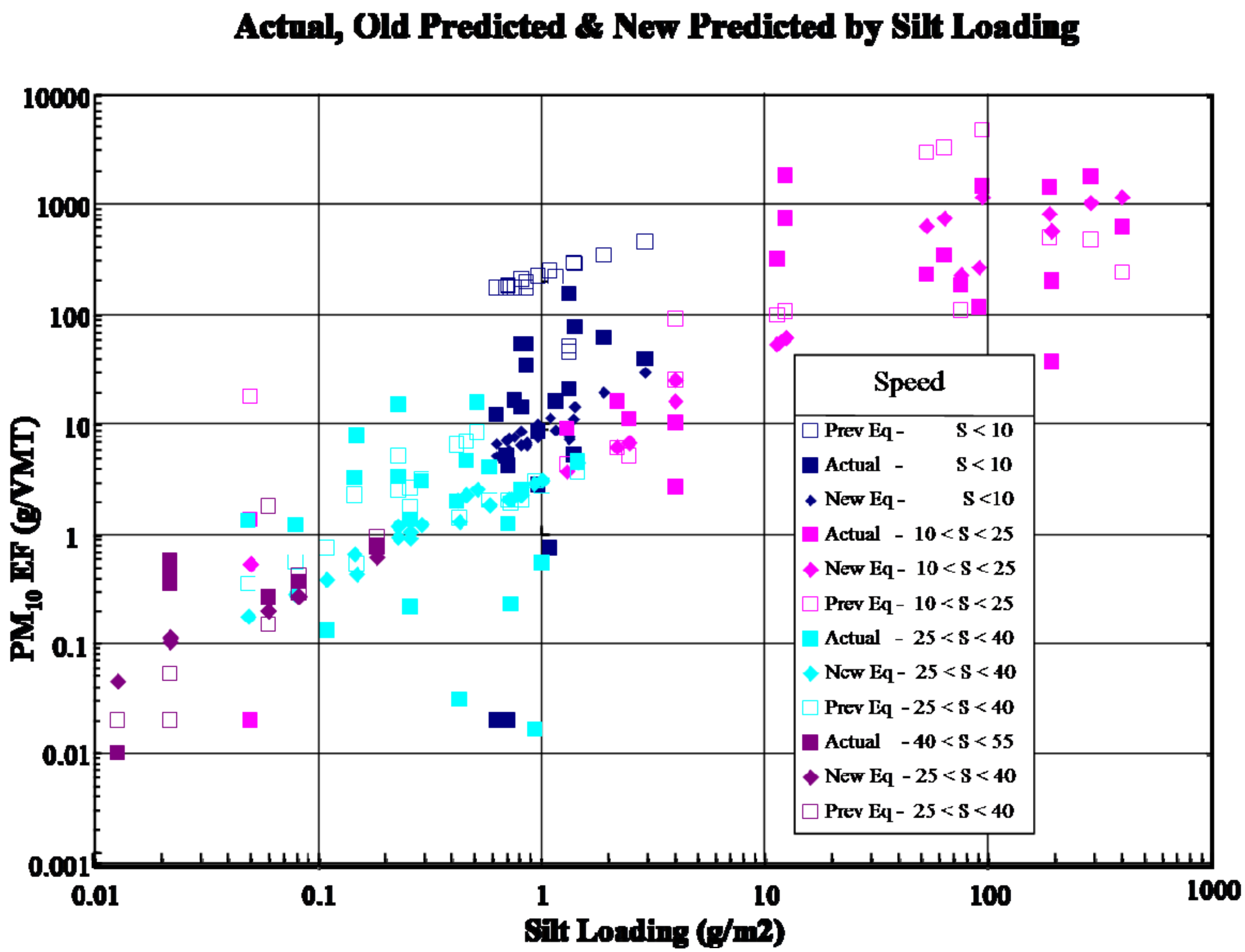

Figure 4-7 Predicted and Actual PM_{10} emission verses Silt Loading and Vehicle Speed.

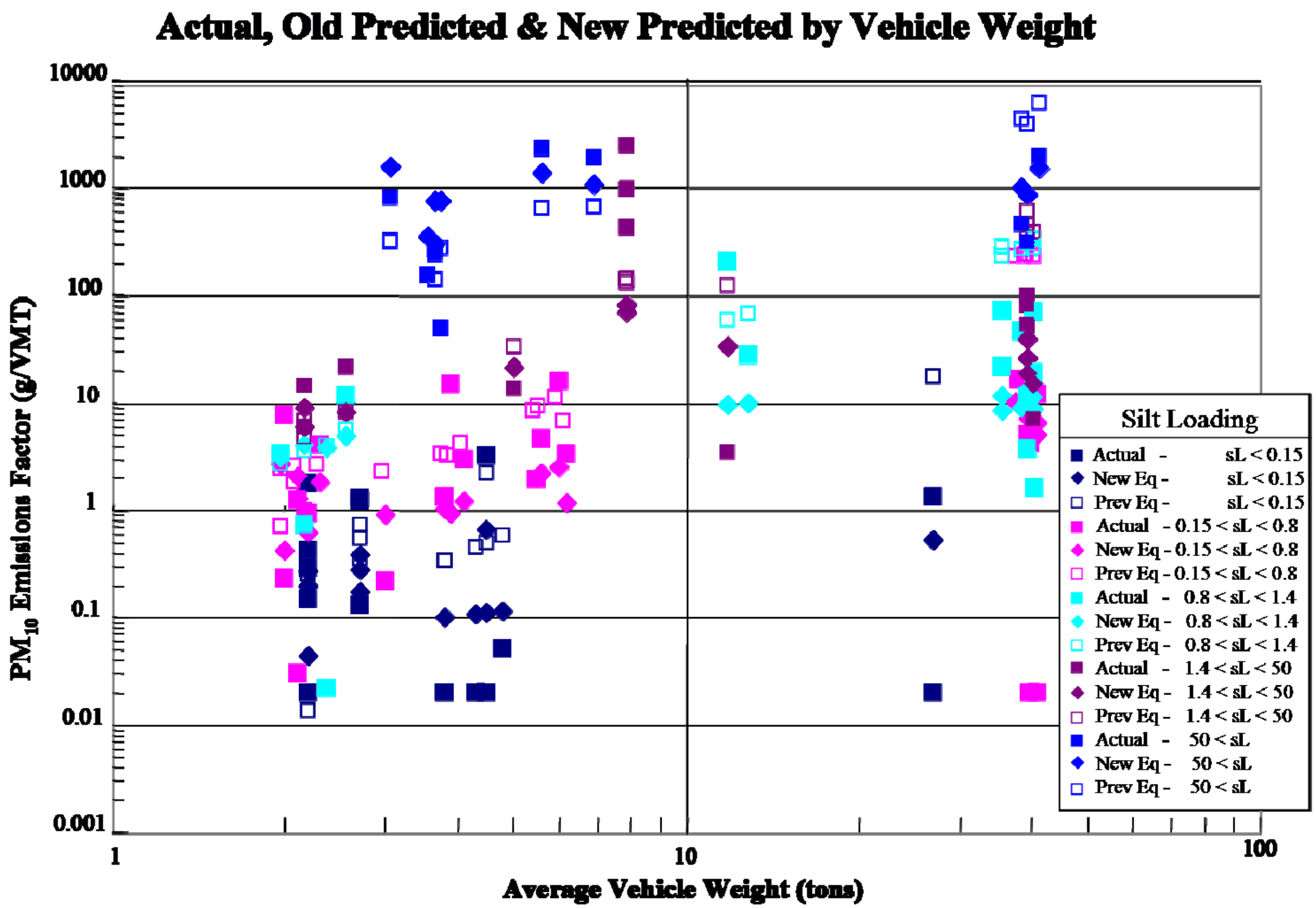

Figure 4-8 Predicted and Actual PM_{10} emission verses Vehicle Weight and Silt Loading.

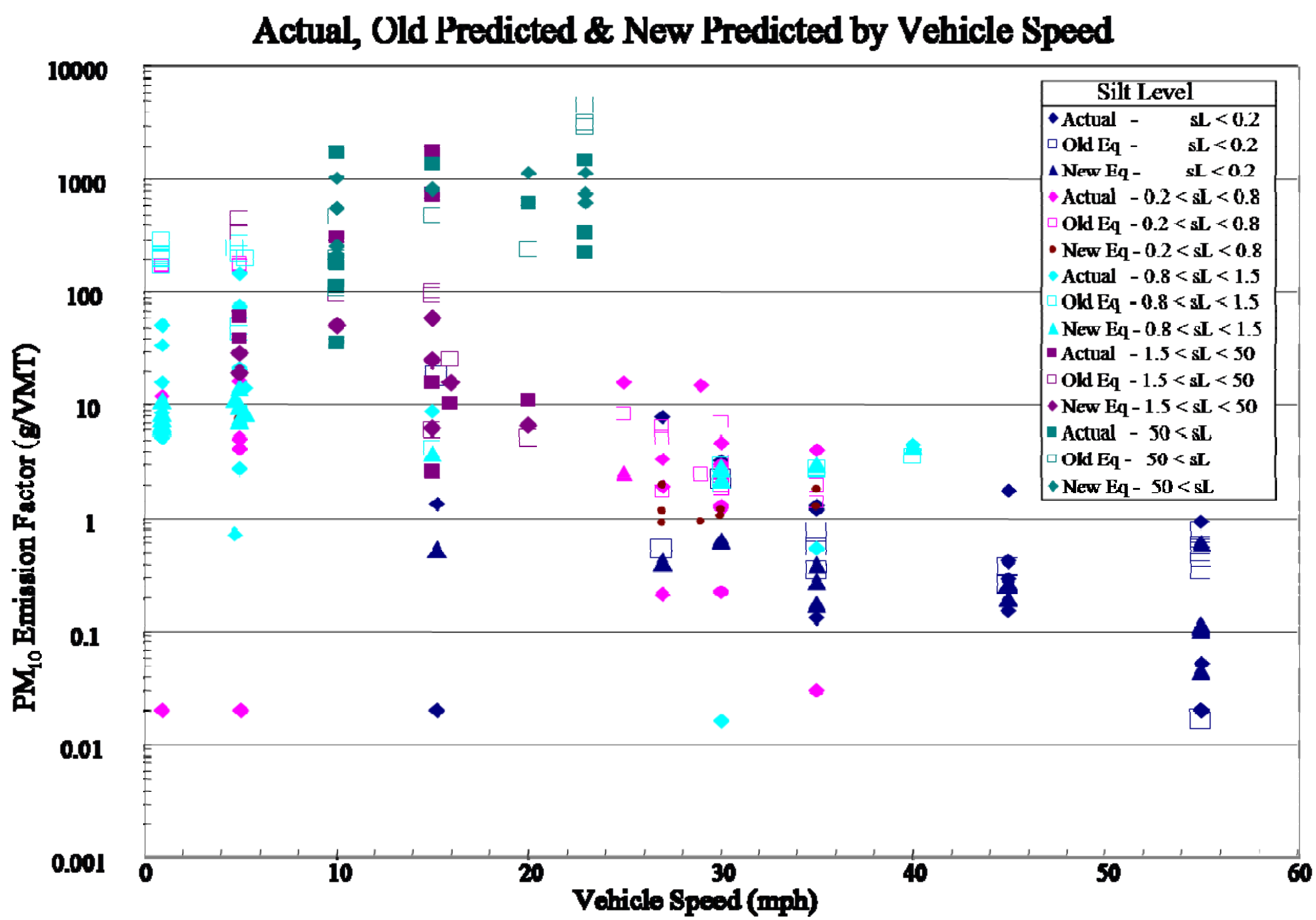

Figure 4-9 Predicted and Actual PM_{10} emission verses Vehicle Speed and Silt Loading.

4.2.2.3 Emissions Factor Quality Rating Assessment.

All of the source test data used to develop the emissions factor equation were rated A since the test procedures used were profiling tests and were all well documented. While only six reports are available that provide documentation of emissions factors for paved roads, these test reports contain the results of 17 different road conditions. The reports and the number of test conditions documented in the report are:

- USX 5/1990 - 2 tests (sL ~.3 & sL > 2),
- EPA 7/1984 - 2 tests (30 mph & 55 mph)
- EPA 1/1983 - 4 tests (<15 mph, >20 mph, W < 3 tons, W 5-8 tons, W > 30 tons)
- EPA 8/1983 - 2 tests for two parameter equation, 0 for three (no speed info)
- EPA 4/97 - 3 tests (speed 55, 45), 3 locations,
- CRA 5/2008 - 4 tests (4 locations, 2 speeds,)

However, since the EPA 8/1983 report does not contain information on the average speed of the vehicles in the study, none of the tests documented in that report is usable for the three factor equation. The remaining five reports contain the results of 15 different road conditions. While all of the tests were performed on paved roads, the ranges of conditions (silt loading, vehicle speed and vehicle weight) were diverse. An assessment of the variation associated with the data and the impact of that variation on a single value emissions factor. The average of all the adjusted emissions factors is 140 g/VMT and the standard deviation is 387. A relative standard deviation of 3 is greater than many other factors. As a result, the number of tests needed to achieve the predictive accuracy of the mean is greater. The availability of 15 A or B rated test reports would normally justify an initial assignment of a factor rating of B. However, the greater variability of the underlying data justifies a single value factor rating of C.

The stepwise regression of the available data indicated that a large portion of the variation of the emissions factor was due to the large range of the road silt loading that existed at the test locations. The first regression step estimates the exponents associated with the three parameter equation. The adjusted correlation coefficient (R2) for the exponents is 0.62. This indicates that approximately 62% of the variations in the emissions factors are due to the silt level, vehicle weight and speed. The second step in the regression identifies the constant associated with the equation. The adjusted correlation coefficient (R2) for the final equation is

0.44. While this is not as high as is typically used to justify the use of the equation results, it follows a regression with a greater correlation coefficient. As a result of the improved ability of the equation to estimate the measured values over the single value emissions factor, a quality rating of B is assigned to the equation.

4.2.2.4 Assignment of equation parameters for PM30 and PM2.5.

While several of the reports include measurements of $PM_{2.5}$, the WRAP studies suggest that many of these measurements are in error due to particle bounce issues with the impactor stages. The results of the WRAP study indicated that the $PM_{2.5}$ concentrations measured by the cyclone/impactor system were consistently biased by a factor of about 2 relative the $PM_{2.5}$ concentrations measured by the Partisol samplers. The second phase of the WRAP showed a tendency of the measured $PM_{2.5}/PM_{10}$ ratio to decrease with increasing PM_{10} concentration. At PM_{10} concentrations above 1.0 mg/m^3 the $PM_{2.5}/PM_{10}$ ratio was between 0.1 and 0.15. The $PM_{2.5}/PM_{10}$ ratio increased to about 0.35 as the PM_{10} concentration approached about 0.5 mg/m^3. While some of the paved road test data encountered concentrations above 1.0 mg/m^3 much of the test data consisted of measured concentrations below 0.5 mg/m^3. The paved road emissions factor for $PM_{2.5}$ was revised to 15% of the calculated PM_{10} emissions factor in 2008. It is not clear whether the WRAP study assessed the PM_{10} concentrations measured during the paved roads testing prior to their recommendations for revising the $PM_{2.5}$ emissions factors. As shown in Table 4-17 the PM_{10} concentrations associated with 58 of the 71 test runs used to develop the three parameter emissions factor equation. Many of these test runs involve traffic volumes that would produce fairly constant particulate concentrations. Also, of these 58 test runs, only three runs were the highest PM_{10} concentrations greater than 0.5 mg/m^3. An earlier report (Reference 5) measured $PM_{2.5}/PM_{10}$ ratios during field tests. The range of $PM_{2.5}/PM_{10}$ ratios were from 0.25 to 0.37. Since essentially all of the measured PM_{10} concentrations used for the stepwise regression were below 0.5 mg/m^3 and the ratios measured during field sampling of paved road emissions were between 0.25 and 0.37, the recommended $PM_{2.5}$ emissions factor is 25% of the PM_{10} emissions factor. Since there is little measured $PM_{2.5}$ data, an emissions factor quality rating of "D" is assigned.

While a stepwise regression could be performed to estimate the PM_{30} emissions factor equation, it is believed that the number of available data would be significantly less and a comparable confidence in the resulting equation could not be achieved. The ratio of PM_{30} to PM_{10} presented in the present AP-42 section is 5.2 and is proposed for the revised equation.

4.2.2.5. Assignment of a precipitation correction factor.

As is presented in Reference 32, a correction parameter for precipitation events was included in the revision of the AP-42 section in October 2002. As recommended in the Technical Memorandum to the files, the correction parameters are retained in this version of the AP-42 section.

4.3 DEVELOPMENT OF OTHER MATERIAL IN AP-42 SECTION

Concurrent with the development of the revised AP-42 section for paved roads, a separate effort was conducted to assemble a silt loading data base for nonindustrial roads. Over the past 10 years, numerous organizations have collected silt loading samples from public paved roads. Unfortunately, uniformity—in sampling and analysis methodology as well as roadway classification schemes—has been sorely lacking in these studies.

Silt loading data were compiled in the following manner. Persons knowledgeable about PM-10 at each EPA regional office were asked to identify sL data for public roads. In many instances, the EPA representatives identified state/local air regulatory personnel who were then asked to supply the data. Given that the relative importance of PM-10 emissions from public sources is greater in the western United States, it is not surprising that most of the data are from that area of the country. What is surprising, perhaps, is that Montana has collected roughly two-thirds of all data. Furthermore, only Montana had data collected from the same road over extended periods of time, thus permitting examination of temporal variation.

The assembled data set did not yield any readily identifiable, coherent relationship between silt loading and road class, average daily traffic (ADT), etc. Much of the difficulty is probably due to the fact that not all variables were reported by each organization. Further complicating the analysis is the fact that, in many parts of the country, paved road silt loading varies greatly over the course of the year. Recall that repeated sampling at Montana municipalities indicated a very noticeable annual cycle. Nevertheless, it is questionable whether the seasonal variation noted in the Montana data base could successfully predict variations for many other sites. While one could possibly expect similar variations for, say, Idaho or Wyoming roads, there is far less reason to suspect a similar cycle in, say, Maine or Michigan, in the absence of additional information.

Because no meaningful relationship could be established between sL and an independent variable, the decision was made to directly employ the nonindustrial data base in the AP-42 section. The draft AP-42 section presents the cumulative frequency distribution for the sL data base, with subdivisions into (a) low-ADT (< 5000 vehicles/day) and high-ADT roads and (b) first and second halves of the year. Suggested default values are based on the 50th and 90th percentile values.

The second use of the assembled data set recognizes that the end users of AP-42 are the most capable in identifying which roads in the data base are similar to roads of interest to them. The draft AP-42 section presents the 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. Readers of AP-42 are invited to review the data base and to select values that they deem appropriate for the roads and seasons of interest.

4.3 References for Section 4

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