Background Document for Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Dust Emission Factors

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Responses to Comments Received on Proposed AP-42 Revisions

Commenter and Date	Source Category	Comment	Response
John Hayden, National Stone, Sand and Gravel Association (NSSGA); June 14, 2006	Unpaved Roads	NSSGA-sponsored tests (report dated Oct. 15, 2004) at California aggregate producing plants support the proposed fine fractions.	This comment reference a test report prepared by Air Control Techniques for the National Stone, Sand & Gravel Association, dated October 4, 2004. The report gives the results of tests to determine unpaved road emissions factors for controlled (wet suppression only) haul roads at two aggregate processing plants. A variation of the plume profiling method using TEOM continuous monitors with PM-2.5 and PM-10 inlets was employed. Tests with road surface moisture content below 1.5 percent were considered to be uncontrolled. Based on the example PM-10 concentration profiles presented in the report, the maximum roadside PM-10 dust concentrations in the subject study were in the range of 300 micrograms per cubic meter. This is an order of magnitude lower than the concentrations typically found in other unpaved road emission factor studies. For the range of plume concentrations measured in the NSSGA-sponsored test program, an average fine fraction (PM-2.5/PM-10 ratio) of 0.15 was reported. This fine fraction value is consistent with the results of the MRI dust tunnel testing in the same concentration range. At plume concentrations more typical of unpaved road emission factor studies, the proposed value of 0.1 is applicable. There is no need for any revisions to the proposed changes to AP-42 as a result of the cited study.
Hao Quinn, Sacramento Metro AQMD; July 20, 2006	Paved vs. unpaved roads	For a particular industrial facility, the PM-10 emission factor equations show higher emissions from paved roads rather than unpaved roads.	***This comment does not relate to the proposed changes to the fine particle fractions***. It is possible that the emissions from a heavily loaded paved road can exceed emissions from an unpaved road with a low-to-moderate silt content at the same industrial facility, even if traveled by the same vehicles. This is the case in the cited example, for which the paved road silt loading is 70 g/m^2.

Commenter and Date	Source Category	Comment	Response
Brian Leahy, Horizon Environmental; July 26, 2006	Unpaved roads	The k value for PM-2.5 does not appear to have changed in the proposed revision.	The latest (2003) approved AP-42 k values for PM-2.5 in Table 13.2.2-2 are 0.23 and 0.27 lb/VMT for industrial and public roads, respectively. The proposed values are 0.15 and 0.18 lb/VMT, which are equivalent to 10 percent of the respective k values for PM-10. There is no need for revisions to the proposed changes to AP-42 as a result of this comment.
Shengxin Jin, NYSDOT Environmental Analysis Bureau; undated	Paved roads	The conversion of proposed k values from g/VMT to g/VKT does not appear correct	Regarding the revised k values for PM-2.5, when the k value of 0.66 g/VKT is multiplied by 1.6 km/mi, it becomes 1.06 g/VMT, which rounds to 1.1 g/VKT given in the proposed revision. Because the k values are given only to two significant figures, the converted values can vary by up to five digits in the second figure, depending on which direction the units conversion is made. For example, when k value of 1.1 g/VKT is divided by 1.6 km/mi, the resulting value rounds to 0.69 g/VKT, but if 1.06 g/VKT is divided by 1.6 km/mi, the resulting value rounds to 0.66 g/VKT. There is no need for revisions to the proposed changes to AP-42 as a result of this comment.
		The stated silt loading impact of antiskid abrasive does not appear correct	***This comment does not relate to the proposed changes to the fine particle fractions***. The commenter is correct in that 500 lb/mi of antiskid abrasive with a 1% silt content produces a silt loading in the range of 0.5 g/m^2 rather than 2 g/m^2. EPA may elect to make a separate modification to correct this discrepancy at a later time.

Proposed Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Dust Emission Factors

ABSTRACT

A number of fugitive dust studies have indicated that the $PM_{2.5}$ / PM_{10} ratios measured by US EPA federal reference method (FRM) samplers are significantly lower than predicted by AP-42 emission factors. As a result, the $PM_{2.5}$ emission estimates are biased high. The controlled exposure study described in this report was conducted to compare fine fraction ratios derived from FRM samplers to those derived from the cyclone/impactor method that had been used to develop AP-42 emission factors for fugitive dust sources. The study was conducted by the Midwest Research Institute using the same cyclone/impactor samplers and operating method that generated the original AP-42 emission factors and associated $PM_{2.5}$ / PM_{10} ratios. This study was sponsored by the Western Regional Air Partnership.

The study found that concentration measurements used to develop $PM_{2.5}$ emission factors in AP-42 were biased high by a factor of two, as compared to $PM_{2.5}$ measurements from FRM samplers. This factor-of-two bias helps to explain why researchers have often seen a discrepancy in the proportion of fugitive dust found in $PM_{2.5}$ emission inventories and modeled ambient air impacts, as compared to the proportion on ambient filter samples. This study also shows that the $PM_{2.5}$ / PM_{10} ratios for fugitive dust should be in the range of 0.1 to 0.15. Currently, the ratios in AP-42 range from 0.15 to 0.4 for most fugitive dust sources.

It is recommended that the results of this study be used to revise the AP-42 $PM_{2.5}$ emission factors for the following four fugitive dust source categories: paved roads, unpaved roads (public and industrial), aggregate handling and storage piles, and industrial wind erosion (AP-42 Sections 13.2.1, 13.2.2, 13.2.4, & 13.2.5, respectively). Emission estimates for other fugitive dust producing activities, such as construction and demolition will also be affected since they are based on these four source categories.

INTRODUCTION

The Dust Emissions Joint Forum (DEJF) of the Western Regional Air Partnership (WRAP) is engaged in gathering and improving data pertaining to the $PM_{2.5}$ and PM_{10} components of fugitive dust emissions. Most of the $PM_{2.5}$ emission factors in EPA's AP-42 guidance for fugitive dust sources (USEPA, 2005) were determined by using high-volume samplers, each fitted with a cyclone precollector and cascade impactor. Typically, AP-42 recommends that $PM_{2.5}$ emission factors for dust sources be calculated by using PM_{10} emission factor equations along with $PM_{2.5}/PM_{10}$ ratios that have been published by EPA in AP-42.

Beginning with the introduction of the cyclone/impactor method, it was realized particle bounce from the cascade impactor stages to the backup filter may have resulted in inflated $PM_{2.5}$ concentrations, even though steps were taken to minimize particle bounce. This led to an EPA-funded field study in the late 1990s (MRI, 1997) to gather comparative particle sizing data in dust plumes downwind of paved and unpaved roads around the country. The test results indicated that dichotomous samplers produced consistently lower $PM_{2.5}/PM_{10}$ ratios than generated with the cyclone/impactor system. Dichotomous samplers are federal reference method (FRM) samplers that are used to measure compliance with federal air quality standards for particulate matter measured as $PM_{2.5}$ and PM_{10}. Pending the eventual collection of additional data, the decision was made that the true ratios would best be represented by an averaging of the cyclone/impactor data with the dichotomous sampler data.

Based on the results of the EPA-funded field program, modifications were made to the appropriate sections of AP-42 for dust emissions from paved and unpaved roads. The $PM_{2.5}/PM_{10}$ ratio for emissions from unpaved roads (dominated by fugitive dust) was reduced from 0.26 to 0.15, and the $PM_{2.5}/PM_{10}$ ratio for the dust component of emissions from paved roads was reduced from 0.46 to 0.25. In the 2003 revision to AP-42, the non-dust component of paved road emissions was assigned a $PM_{2.5}/PM_{10}$ ratio of 0.76, accounting for vehicle exhaust and brake and tire wear.

Subsequent to the modifications of the $PM_{2.5}/PM_{10}$ ratios in AP-42, additional field test results (mostly from ambient air samplers) indicated that further reductions to the ratios were warranted (Pace, 2005). For example, ambient air monitoring data suggested that the fine fraction dust mass is of the order of 10 percent of the PM_{10} mass, based on chemical fingerprinting of the collected fine and coarse fractions of PM_{10} impacted by dust sources. It is important to note, however, that particle size data applicable to fugitive dust emission factors should be gathered either from the emissions plume or near the point where emissions are generated (within 10 m of the downwind edge of the source).

METHODOLOGY

This led DEJF to fund Midwest Research Institute (MRI) in conducting a controlled study of particle sizing in dust plumes. The objective of the study was to resolve the fine particle bias in the cyclone/impactor system, so that reliable $PM_{2.5}/PM_{10}$ ratios could be developed for as many dust source categories as possible. For this purpose, an air exposure chamber connected to a recirculating supply air stream was used in conjunction with a fluidization system for generating well-mixed dust plumes from a variety of western soils and road surface materials. R&P Model 2000 Partisol samplers were selected as the ground-truthing FRM samplers for PM_{10} and $PM_{2.5}$.

This study was performed in two phases (see below), as described in the attached test report (Cowherd and Donaldson, 2005). The test report serves as the background document to support the recommended revisions to AP-42, and it contains all the quality assurance procedures and results of the testing.

Phase I – Compare $PM_{2.5}$ Measured by Cyclone/Impactor to FRM Sampler

In the first testing phase of the project, $PM_{2.5}$ measurements using the high-volume cascade impactors were compared to simultaneous measurements obtained with EPA FRM samplers for $PM_{2.5}$. As stated above, these tests were conducted in a flow-through wind tunnel and exposure chamber, where the PM_{10} concentration level and uniformity were controlled. The results of the tests provided the basis for quantifying more effectively any sampling bias associated with the cascade impactor system.

Phase 2 – Compare $PM_{2.5}$ to PM_{10} Ratios for Different Geologic Soils

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. This testing provided needed information on the magnitude and variability of this ratio, especially for source materials that are recognized as problematic with regard to application of mitigative dust control measures.

RESULTS

The tests that were performed are listed in Tables 6 and 7 of the attached report. The Phase I tests were performed in March and April of 2005. The Phase II tests were performed in June through August of 2005. A total of 100 individual tests were performed, including 17 blank runs (for quality assurance purposes). The raw and intermediate test data are summarized in the tables presented in Appendix A of the attached report.

Based on the 100 wind tunnel tests that were performed in the wind tunnel study, the findings support the following conclusions:

1. $PM_{2.5}$ concentrations measured by the high-volume cyclone/impactor system used to develop AP-42 emission factors for fugitive dust sources have a positive bias by a factor of 2, as compared to the $PM_{2.5}$ concentration measurements from reference-method samplers (see Figure 1). The geometric mean bias is 2.01 and the arithmetic mean bias is 2.15.
2. The $PM_{2.5}$ bias associated with the cyclone/impactor system, as measured under controlled laboratory conditions with dust concentrations held at nearly steady values, closely replicates the bias observed in the prior EPA-funded field study at distributed geographic locations across the country.

3. The $PM_{2.5}/PM_{10}$ ratios measured by the FRM samplers in the current study for a variety of western soils show a decrease in magnitude with increasing PM_{10} concentration (see Figure 2). Soils with a nominally spherical shape are observed to have somewhat lower ratios (at given PM_{10} concentrations) than soils with angular shape. A very similar dependence of $PM_{2.5}/PM_{10}$ ratio on PM_{10} concentration was also observed in the prior field study that used dichotomous samplers as FRM devices.
4. The test data from the current study support a $PM_{2.5}/PM_{10}$ ratio in the range of 0.1 to 0.15 for typical uncontrolled fugitive dust sources (see Figure 2). The $PM_{2.5}/PM_{10}$ ratio of 0.1 is also supported by numerous other studies including the prior EPA-funded field study that used dichotomous samplers as reference devices. It is possible that a ratio as low as 0.05 (as was found in the prior field tests of unpaved road emission factors) might be appropriate for very dusty sources, but this would require extrapolation of the current test data from the wind tunnel study.

DISCUSSION

Peer Review

The test report on the wind tunnel study (Cowherd and Donaldson, 2005) was issued first in draft form for external peer review. Three peer reviewers (having no prior contact with the study) were selected by the DEJF: Patrick Gaffney (California Air Resources Board), John Kinsey (U.S. Environmental Protection Agency), and Mel Zeldin (Private Consultant). In addition, peer review comments were provided by Duane Ono (Great Basin UAPCD) and Richard Countess (Countess Environmental) who helped to develop this study. After the review comments on the draft test report were received, comment/ response logs were prepared by MRI, listing each comment and the response to each comment. The next step was to modify the draft test report in accordance with the responses to the review comments. The final test report was issued on October 12, 2005.

Recommended Particle Size Ratios

Based on the results of the WRAP/DEJF study (see attached test report) and the prior EPA-funded field study, it is proposed that new $PM_{2.5}/PM_{10}$ ratios be adopted for several categories of (uncontrolled) fugitive dust sources, as addressed in AP-42. The proposed ratios (given to the nearest 0.05) are summarized in Table 1. It should be noted that these fine fraction ratios and the emission factors could change in the future if field studies show other differences than those identified through this study.

The proposed $PM_{2.5}/PM_{10}$ ratios in Table 1, apply to dry surface materials, having moisture contents in the range of 1% or less. Such materials when exposed to energetic disturbances produce dust plumes with core PM_{10} concentrations in the range of 5,000 micrograms per cubic meter, near the point of emissions generation. The wind tunnel test data show that dust plumes with lower core concentrations have higher $PM_{2.5}/PM_{10}$

ratios. This might occur, for example, at higher soil (or other surface material) moisture contents. However, the emissions from such sources typically are substantially lower with correspondingly less impact on the ambient environment.

Table 1. Proposed Particle Size Ratios for AP-42

Fugitive dust source category	AP-42 section	$PM_{2.5}/PM_{10}$ Ratio	
		Current	Proposed
Paved Roads	13.2.1	0.25	0.15
Unpaved Roads (Public & Industrial)	13.2.2	0.15	0.1
Construction & Demolition	–	0.208 [1]	0.1
Aggregate Handling & Storage Piles	13.2.4	0.314	0.1 (traffic) 0.15 (transfer)
Industrial Wind Erosion	13.2.5	0.40	0.15
Agricultural Tilling	–	0.222 [2]	0.2 (no change)
Open Area Wind Erosion	–	-	0.15

Notes:

1 AP-42 Section 13.2.3 suggests using emission factors for individual dust producing activities, e.g., materials handling and unpaved roads. The WRAP Fugitive Dust Handbook recommends using a fine fraction ratio of 0.208 from a report prepared for the US EPA, Estimating Particulate Matter Emissions from Construction Operations (MRI, 1999).

2 Agricultural tilling was dropped from the 5th edition of AP-42. The WRAP Fugitive Dust Handbook recommends using a fine fraction ratio of 0.222 from Section 7.4 of the California Air Resources Board's Emission Inventory Methodology (CARB, 2003).

The justification for each proposed ratio in Table 1 is provided by source category in the sections below. In each case, reference is made to test reports that contain supporting data.

Paved Roads

For the dust component of particulate emissions from paved roads, a $PM_{2.5}/PM_{10}$ ratio of 0.15 is recommended. The proposed ratio is based on the factor-of-two bias in the cyclone/impactor data for the wind tunnel study, which tested western soils and road surface materials. As shown in Table 1, the current AP-42 ratio is 0.25. It should be recalled that the nondust component of paved road particulate emissions has been assigned a much higher ratio of 0.76, based on inputs from the EPA's MOBILE 6 model.

Unpaved Roads

For the dust component of particulate emissions from unpaved roads, which dominates the total particulate emissions from this source category, a $PM_{2.5}/PM_{10}$ ratio of 0.1 is recommended. The proposed ratio is justified from the test results of the wind tunnel study for a variety of western surface materials. It is also consistent with the factor-of-two bias in the cyclone/impactor data from the wind tunnel study and with the results of the prior field study that used dichotomous samplers as FRM devices (MRI, 1997).

Construction and Demolition

The dust component of particulate emissions from construction and demolition dominate the total particulate emissions from this source category. A $PM_{2.5}/PM_{10}$ ratio of 0.1 is recommended for dust emissions from construction and demolition. The proposed ratio is justified by the fact that the dominant dust source associated with construction and demolition projects is emissions from vehicle travel over unpaved surfaces. This is shown by case studies that calculate particulate emissions from representative construction activities (road, building, and nonbuilding construction). For example, the fine fraction ratio for scraper travel averages about 0.2 (Muleski et al., 2005), before correcting for the factor-of- two bias in the cyclone/impactor system. Moreover this includes the diesel emissions that are contained within the fine fraction component.

It should be noted that if large open areas are disturbed (such as in land clearing) and left unprotected, and the areas are exposed to high winds, open area wind erosion can also be an important contributor to dust emissions from this source category. The recommended fine fraction ratio identified below should be used for the open area wind erosion component.

Aggregate Handling and Storage Piles

Although usually not a major source in comparison with traffic around storage piles, the transfer of aggregate associated with bucket loaders and unloaders or conveyor transfer points is addressed directly in this section of AP-42. A $PM_{2.5}/PM_{10}$ ratio of 0.15 is recommended for transfer operations. This is half the current value in AP-42 and reflects adjustment for the factor-of-two bias in the cyclone/impactor test results.

The dominant dust component of particulate emissions from aggregate handling and storage piles typically consists of loader and truck traffic around the storage piles. AP-42 refers the reader to the unpaved roads section to find appropriate emission factors. A $PM_{2.5}/PM_{10}$ ratio of 0.1 is recommended for this source. The proposed ratio is consistent with that recommended above for traffic on unpaved surfaces.

Industrial Wind Erosion

For the dust component of particulate emissions from industrial wind erosion, a $PM_{2.5}/PM_{10}$ ratio of 0.15 is recommended. Industrial wind erosion is associated with crushed aggregate materials, such as coal or metallic ore piles. Examples would include open storage piles at mining operations. The proposed ratio is justified by portable wind tunnel tests of industrial aggregate materials which produced $PM_{2.5}/PM_{10}$ ratios averaging 0.4, as indicated by the current AP-42 fine fraction ratio given in Table 1. When these results are corrected for the bias associated with the cyclone/impactor system at very high PM_{10} concentrations observed in the effluent from the portable wind tunnel (exceeding 10,000 $\mu g/m^3$), the result is 0.15.

Agricultural Tilling

For the dust component of particulate emissions from agricultural tilling and related land preparation activities, which dominates the total particulate emissions from this source category, no new $PM_{2.5}/PM_{10}$ ratio can be recommended at this time, because of the lack of published test data. However, the current factor of 0.2, as listed in Table 1, appears to be generally consistent with the results of the current wind tunnel tests. It was found that the agricultural soils tested in the wind tunnel produced slightly higher ratios than the other test materials. In addition, the dust plume core concentrations from agricultural operations are generally observed to be less intense because of the lower equipment speeds involved and the lack of repeated travel over the same routes.

Open Area Wind Erosion

For the dust component of particulate emissions from open area wind erosion (not currently addressed in AP-42), a $PM_{2.5}/PM_{10}$ ratio of 0.15 is recommended. Open area wind erosion is associated with exposed soils that have been disturbed, removing the protection afforded by natural crusting. Examples would include freshly tilled agricultural fields prior to planting of crops. The proposed ratio is justified by wind tunnel tests of exposed soils (MRI, 1994), which produced $PM_{2.5}/PM_{10}$ ratios averaging 0.3. When these results are corrected for the bias associated with the cyclone/impactor system, the ratio becomes 0.15. This is consistent with the $PM_{2.5}/PM_{10}$ ratios in the range of 0.12 measured during dust storms on Owens Dry Lake (Ono, 2005).

Specific Revisions to AP-42

This section presents a listing of specific revisions to AP-42, for the purpose of incorporating the proposed $PM_{2.5}/PM_{10}$ ratios. As shown in Table 2, five subsections of AP-42 Section 13.2, Fugitive Dust, are impacted by the proposed changes. However, one of the five sections (13.2.3, Heavy Construction Operations) is impacted only indirectly because it refers to other sections of AP-42 for fugitive dust emission factors.

In most cases, the change in the $PM_{2.5}/PM_{10}$ ratio is accomplished by changing the appropriate PM-2.5 particle size multiplier (k-factor) for the respective emission factor equation. In addition, the changes need to be referenced to the WRAP test report (Cowherd and Donaldson, 2005).

Table 2. Specific revisions to AP-42 that are incorporated into the AP-42 sections included in Attachment A.

Source category	Sub-section	Title	Revision	Comments
13.2.1 Paved Roads	13.2.1.3	*Predictive Emission Factor Equation*	In Table 13.2.1-1, reduce k values for PM-2.5 by 40 percent, e.g., the new value is 1.1 g/VMT (and equivalent values for the other units)	Add ref. number for WRAP test report
	13.2.1.5	*Changes since Fifth Edition*	Modify statement (1) to reflect change in fine fraction	
		References	Add WRAP test report as Ref. 22	
13.2.2 Unpaved Roads	13.2.2.2	*Emission Calculation and Correction Parameters*	In Table 13.2.2-2, reduce k values for PM-2.5 by 33%, e.g., the new value is 0.15 lb/VMT for industrial roads and 0.18 lb/VMT for public roads (and equivalent values for the other units)	Add ref. number for WRAP test report
	13.2.2.4	*Updates since Fifth Edition*	Add sentences describing change in fine fraction	
		References	Add WRAP test report	
13.2.3 Heavy Construction Operations	–	–	No changes required	Refers to other AP-42 sections for emission factors
13.2.4 Aggregate Handling and Storage Piles	13.2.4.3	*Predictive Emission Factor Equations*	In k-factor table for Equation 1 for transfer operations, change PM-2.5 multiplier to 0.053 (dimensionless)	Add ref. number for WRAP test report
		References	Add WRAP test report	
13.2.5 Industrial Wind Erosion	13.2.5.2	*Emissions and Correction Parameters*	In k-factor table for Equation 1, change PM-2.5 multiplier to 0.075 (dimensionless)	Add ref. number for WRAP test report
		References	Add WRAP test report	

CONCLUSION

This study found that concentration measurements used to develop $PM_{2.5}$ emission factors for AP-42 were biased high by a factor of two, as compared to $PM_{2.5}$ measurements from FRM samplers. This factor-of-two bias helps to explain why researchers have often seen a similar discrepancy in the proportion of fugitive dust found in $PM_{2.5}$ emission inventories and modeled ambient impacts, as compared to the proportion observed on ambient filter samples. This study also shows that the $PM_{2.5}$ / PM_{10} ratios for fugitive dust should be in the range of 0.1 to 0.15. Currently, the fine fraction ratios in AP-42 range from 0.15 to 0.4 for most fugitive dust sources.

It is recommended that the results of this study by used to revise the AP-42 $PM_{2.5}$ emission factors for the following four fugitive dust source categories: paved roads, unpaved roads (public and industrial), aggregate handling and storage piles, and industrial wind erosion (AP-42 Sections 13.2.1, 13.2.2, 13.2.4, & 13.2.5, respectively). Emission estimates for other fugitive dust producing activities, such as construction and demolition, will also be affected since they are based on these four source categories. It is recommended that revisions to the current AP-42 sections for these fugitive dust sources be adopted as shown in Attachment A to this report.

IMPLICATIONS

The proposed revisions to AP-42 are needed to ensure the most accurate $PM_{2.5}$ and PM_{10} fugitive dust emissions inventories that are possible for regional haze regulatory purposes, given the available resources and the significant contribution of fugitive dust to visibility impairment. In particular, the revisions will affect the quantity of dust apportioned to the fine ($PM_{2.5}$) versus coarse ($PM_{2.5-10}$) size modes, which have significantly different effects on visibility and long-range transport potentials. This will reduce $PM_{2.5}$ emission estimates for fugitive dust sources to about half their current level. It will also increase the coarse-mode size fraction for fugitive dust, which would be important in the event that a PM coarse standard is adopted by the US EPA and emission inventories are developed.

The revisions will be helpful in developing accurate emission inventories for PM nonattainment, maintenance, and action plan areas throughout the country. Finally, the proposed modifications to the fine fractions associated with EPA's AP-42 emission factors will ensure widespread availability of the most recent and accurate scientific information.

References

Cowherd, C. and J. Donaldson. 2005. *Analysis of the Fine Fraction of Particulate Matter in Fugitive Dust.* Final report prepared for the Western Governors' Association, Western Regional Air Partnership (WRAP), MRI Project No. 110397, October 12, 2005. **[Describes wind tunnel study to determine fine fraction ratios]**

Midwest Research Institute. 1994. *OU3 Wind tunnel Study: Test Report.* Prepared for EG&G Rocky Flats, Golden CO. **[Describes portable wind tunnel tests of emissions from soils and sediments]**

Midwest Research Institute. 1997. *Fugitive Particulate Matter Emissions*. Final report prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park NC. April, 1997. **[Prior emission factor field study for paved and unpaved roads, comparing performance of cyclone/impactor system with reference method samplers for PM2.5]**

Muleski, G. E., C. Cowherd, and J. S. Kinsey. 2005. "Particulate Emissions from Construction Activities," *J. Air & Waste Manage. Assoc.* **55:** 772-783. **[Summarizes field test results for emissions from major components of construction projects]**

Ono, Duane. 2005. "Ambient PM2.5/PM10 ratios for Dust Events from the Keeler Dunes." Great Basin UAPCD, Bishop, CA. **[Describes FRM test results for high-wind events on Owens Dry Lake]**

Pace, T. G. 2005. "Examination of Multiplier Used to Estimate $PM_{2.5}$ Fugitive Dust Emissions from PM_{10}." Presented at the EPA Emission Inventory Conference. Las Vegas NV. April 2005. **[Summarizes other field studies that can be used to develop $PM_{2.5}/PM_{10}$ ratios for fugitive dust emissions]**

USEPA. 2005. *Compilation of Air Pollutant Emission Factors, AP-42.* 6th Edition. Research Triangle Park, NC. **[EPA's emission factor handbook]**

CARB, 2003. *Emission Inventory Procedural Manual Volume III: Methods for Assessing Area Source Emissions,* California Air Resources Board, Sacramento, CA. November. **[Summarizes the recommended calculation procedures for agricultural emissions and other sources]**

Midwest Research Institute. 1999. *Estimating Particulate Matter Emissions from Construction Operations*. Prepared for USEPA, Research Triangle Park NC, September. **[Gives field test results for construction operations]**

Figure 1. Phase I test results show that the Cyclone/ Impactor method measured $PM_{2.5}$ concentrations that were two times higher than those measured by Federal Reference Method samplers when simultaneously exposed to the well-mixed dust environment in the wind tunnel.

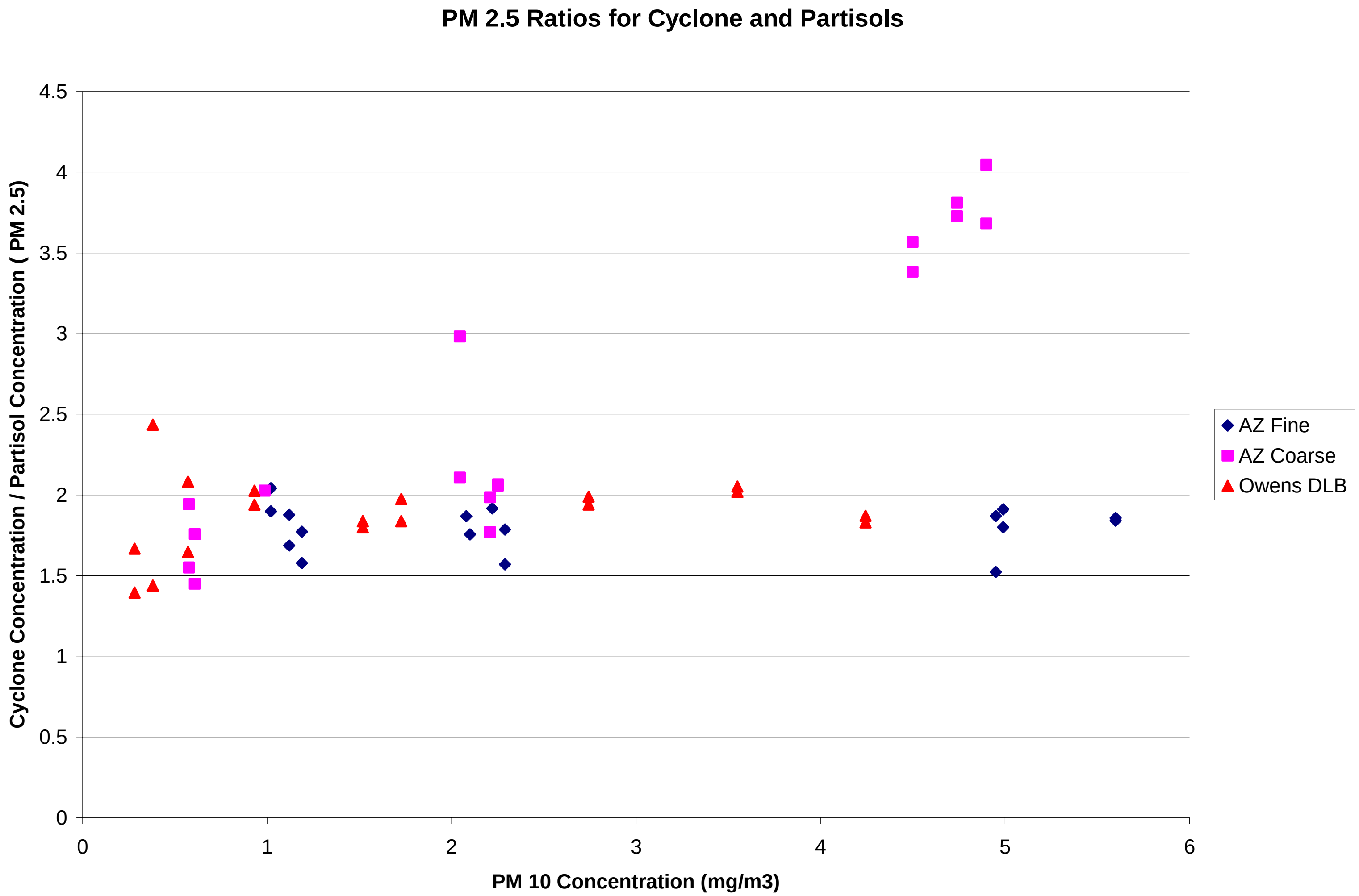

Figure 2. Phase II tests show that the $PM_{2.5}/PM_{10}$ ratio decreased with increasing PM concentrations, and could be expected to be in the range of 0.1 at concentrations that are typical of fugitive dust emission plumes.