Examination of the Multiplier Used to Estimate PM2.5 Fugitive Dust Emissions from PM10

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Background and Overview

The major sources of fugitive dust emissions are paved and unpaved roads, construction, agricultural operations, minerals industries and wind erosion from both agricultural and non agricultural lands. Fugitive dust in the ambient air is predominantly comprised of coarse particles (between 10 and 2.5um) and is a relatively minor part of fine PM, i.e., PM2.5. However, the emissions inventory suggests that about one half of primary PM2.5 emissions are from fugitive dust, and these emissions contribute to the overestimation of ambient PM2.5 concentrations by air quality models. This overestimation creates problems for those involved in PM2.5, regional haze and PM Coarse analyses. Most experts agree that this overestimation is due to a combination of shortcomings in the inventory-modeling process: 1) the multiplier used to "scale" or infer PM2.5 from PM10 emissions in the inventory, 2) faulty emission factor algorithms, 3) imprecise or difficult to obtain activity data to apply these algorithms (including inability to account for the effect of actual meteorological conditions on emissions), and 4) modeling deficiencies (especially in the treatment of particles near their point of emissions). A method was developed to improve the treatment of particles near their point of release (Pace 2004)[1]. Also, work is underway in some areas to improve activity data for fugitive dust categories in some areas. The emissions algorithms for paved and unpaved roads were revised within the past few years to incorporate minor improvements. This paper reviews the current data related to the multiplier used to "scale" or infer PM2.5 from PM10 emissions in the inventory.

EPA, States and Tribes develop emission estimates for the fugitive dust categories based on emission factors previously developed for the EPA, mostly by the Midwest Research Institute (MRI). Essentially all of the data that form the basis for EPA's PM10 fugitive dust emission factors were collected by MRI using cascade impactors. There are several hundred test runs for PM10 from paved and unpaved roads, but limited field test data are available for other categories. Algorithms were developed to relate PM10 emissions to certain variables such as road types, surface conditions, moisture and vehicle speed and these are described in AP-42 (US EPA 2005). The algorithms incorporate a set of PM2.5 to PM10 multipliers, or ratios to estimate PM2.5 fugitive dust emissions as a fraction of PM10 emission estimates because there were insufficient data to develop PM2.5 algorithms separately. In fact, there were only 3 test sites (NC, CO & NV) that collected any PM2.5 samples around roads, and other categories have even less data.

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[1] The methodology suggests that it is appropriate to adjust the fraction of dust emissions available for transport away from the vicinity of the source to account for particles removed near the source by land cover and other mechanisms while the plume is very compact and close to the ground. Nationally, this adjustment averages around 50%, but varies locally depending on the land cover. While this method will help provide closure between the modeling and monitored data, the modeled concentrations of crustal matter will still be substantially higher than the measured values until other potential sources of error (such as the PM2.5**:** PM10 multiplier are addressed.

Issues have been raised regarding potentially significant biases in the PM2.5 cascade impactor measurements made by MRI (US EPA 1981, WRAP 2004). These biases are mainly attributed to carryover of larger particles into the lower and backup stages of the impactors, creating a bias toward fine particles. MRI has tried to address these concerns over the years, primarily by greasing the impaction surfaces, but once a monolayer of particles coats the greased substrate, particle bounce and carryover can reoccur. Thus, the carryover issue remains unresolved and bias is still believed to occur.

Biases have also been attributed to the dichotomous sampler (dichot), an instrument occasionally used to estimate PM2.5 to PM10 ratios. In an ambient sampling study in Phoenix, researchers saw a carryover of coarse mass into the fine fraction due to the cut point inefficiency of the sampler. They estimated the carryover to be 10% of the fine mass in a typical urban setting. In theory, the carryover would be substantially higher than 10% if the sampler had been directly in the plume of a fugitive dust source (Vanderpool 2004). Other researchers have noted that the dichots may have a cut point higher than design especially in dust plumes and under high wind conditions. Also, heavily loaded filters are more likely to lose some of the sample during handling and electrostatic charges may exacerbate particle loss. Since these issues would result in a mix of high and low potential biases to the PM2.5 to PM10 ratio, the real net bias (if any) in dichot-derived ratios is not known.

In 1996, MRI recommended interim revisions to the PM2.5 to PM 10 multipliers for various fugitive dust categories. These interim ratios varied from 0.15 to 0.25 depending on the source category, as shown in Table 1. The MRI recommendations were based on limited supporting data and broad assumptions, as the Table shows. They proposed additional testing and also noted that a review of ambient data may justify further changes to the multipliers (Cowherd and Kuykendal 1996). Note that the grand average multiplier (weighted for emissions) is about 0.17.

Category	Multiplier (PM 2.5 / PM10)	Supporting Data
Wind Erosion (Ag)	0.15	Analogy to industrial wind erosion
Ag Crops	0.20	DRI Dust Resuspension & UCD ~ 0.12 for Harvesting
Ag Livestock	0.15	No Data
Wind Erosion (non Ag)	0.25	Reduced from MRI wind tunnel result of .40 (felt biased)
Construction	0.15	Construction dominated by unpaved roads
Paved Roads	0.25	Reduced 0.46 to 0.25 assuming 1/2 is exhaust
Unpaved Roads	0.15	AZDEQ Dichot test (0.25), NAPAP/Ill Water Survey (0.10) & Pedco/MRI dichot data at coal mines (0.15)

Table 1. Interim multipliers to estimate PM2.5 from PM10 in the NEI (Cowherd and Kuykendal 1996)

While the interim particle size adjustment factors generally represented a substantial downward adjustment of AP-42 particle size multipliers, many concerns still exist about the apparent overestimation of PM2.5 emissions and the validity of the ratios. This paper summarizes a growing body of scientific evidence indicating that the interim multipliers still overestimate the PM2.5 to PM 10 ratio. For example, there are several issues related to the basis for the recommendations in Table 1 that warrant further review and there are several new sets of source-oriented measurements to consider. Also, the body of ambient data presents a compelling case that the fugitive dust-modeling systems as typically applied do substantially overestimate crustal material. None of this new insight relies on the old cascade impactor data that was initially used to develop the multipliers. An ongoing testing program sponsored by the Western Regional Air Partnership (WRAP) will provide additional information on this bias (WRAP 2004).

PM2.5:PM10 Multiplier for Paved Roads

In 2003, the US EPA revised the AP-42 Section for Paved Roads based in part on MRI tests conducted in 1997 in three cities (US EPA 1997 and 2003). These tests did not originally correct for the presence of tailpipe exhaust within the dust plume (Cowherd and Kuykendal 2004). In the 2003 revision, corrections for vehicle exhaust; tire and brake wear are estimated and incorporated into the algorithms. The net result of the 2003 revision is that paved road fugitive dust emissions are very small for interstates, freeways and major arterials in the 2002 NEI. However, the minor arterials, collectors and local roads collectively emit almost 300,000 TPY of PM2.5 nationally and the PM2.5 to PM10 multiplier ratio is 0.2. This multiplier is based in part on cascade impactor results.

<u>Transportation Research Board (TRB) / National Research Council Field Study</u> – This study analyzed ambient samples taken near eight paved roadway locations (predominantly minor arterials, collectors and local streets) using source apportionment. The results show that fugitive dust comprised only 27% on average of the PM2.5 mass measured adjacent to these roadways. The remainder was from exhaust, brake and tire wear. More important, the average ratio of PM2.5 fugitive dust to PM10 fugitive dust emitted from these test roads was 0.1, considerably lower than the ratio 0.2 for minor arterials, collectors and local roads recommended in the 2003 revision to AP-42. (Transportation Research Board, 2003).

<u>Dust Traker Tests in Idaho</u> – The Desert Research Institute (DRI) used the Dust Traker in Treasure Valley, Idaho to estimate PM10 and PM2.5 emissions from paved and unpaved roads. In this study, they measured both PM2.5 and PM10 and found the PM2.5: PM10 ratio to be 0.06 for both paved and unpaved roads (Kuhns 2002).

<u>Emissions Measurements on a Paved Road Outside a Construction Site Entrance</u> **-** MRI measured emissions from a paved road located just outside of a construction site in Kansas City under contract to the US EPA (Muleski 2003). In this study, the PM2.5 to PM10 ratio was only 0.03. The EPA Project Manager believes that the lower ratio found in this study is attributable at least in part to use in this study of a new design hybrid sampler instead of the high volume cascade impactor that MRI has customarily used (Kinsey 2004). When the two devices were collocated in a road dust plume during

preliminary testing, the PM2.5 concentration measured by the hybrid sampler was a factor of ~ 3 lower than that measured by the impactor.

PM Multiplier for Unpaved Roads

Clarification of Original PEDCo/MRI Surface Coal Mining Report **-** In Table 1 above, MRI relied in part on PEDCo/MRI upwind-downwind source testing using the dichotomous sampler as a basis for the unpaved road recommendation (US EPA 1981). They cited a PM2.5: PM10 ratio of 0.15 for light and medium duty vehicles on unpaved roads in that study. This value was cited in Cowherd and Kuykendal (1996). However, in a subsequent EPA report PEDCo re-analyzed the joint MRI/PEDCo study data for PM2.5, PM10 and PM15and found that the ratio of PM2.5 to PM10 was actually 0.10 (U.S. EPA 1983). Thus, the ratio 0.15 cited by Cowherd and Kuykendal in 1996 appears to be based on an error that was corrected in a subsequent report.

Unpaved Roads (and Earthmoving) at a Wyoming Surface Coal Mine - AP-42 Section 11.9 was revised in October 1998, based on new testing at a mine in Wyoming. This report contains results of testing conducted on unpaved roads and grader and scraper operations for PM15 and PM2.5. Based on this data and the ratio of PM10 to PM15 determined in the PEDCo study, the average ratio of PM2.5 to PM10 was 0.12 for light and medium duty vehicles and 0.04 to 0.08 for scrapers and graders respectively (U.S. EPA 1998).

Midwest Research Institute (MRI) Testing in 3 Cities – This testing was done in Denver, Reno and Raleigh by MRI and they collected data using both Cascade impactors and dichotomous samplers. In it, the average ratio using the impactor was 0.25, while the ratio using collocated source-oriented dichotomous samplers was 0.07. The report cites issues with both dichot and impactors (US EPA 1997).

Miscellaneous References **-** In 1988, Allen Williams at the Illinois Water Survey evaluated dichot tests near unpaved roads and determined the PM2.5 to PM10 ratio to be 0.10 (Williams 1988). As stated previously, the Dust Tracker tests in Idaho used a ratio multiplier of 0.06 for both unpaved and paved roads (Kuhns 2002). Also, the Arizona DEQ studied fugitive dust around unpaved roads and found the PM2.5 to PM10 ratio to be 0.25 (AZ DEQ 1990). The AZ DEQ data point seems to be an outlier and its importance is diminished because the report could not be located to verify the reference contained in MRI's interim recommendations.

PM2.5 Multiplier for Construction, Agricultural Operations and Windblown Dust

In the interim recommendations, MRI used the same data to support unpaved roads and construction, posing construction activities are dominated by unpaved road emissions. As noted above, the Wyoming surface coal mining study reported average ratio of PM2.5 to PM10 was 0.12 for light and medium duty vehicles and 0.04 to 0.8 for scrapers and graders respectively (U.S. EPA 1998). The scraper and grader operations for removal of overburden at mines are very similar to construction-related earthmoving. In tests of agricultural field dust in CA, Lowell Ashbaugh reported the ratio of PM2.5 to PM10 to be 0.12 (Ashbaugh 2004). The Great Basins AQCD has conducted extensive source-oriented particle measurements in Keeler, CA on the edge of Owens Lake. At this site, dominated by windblown dust from the dry lake bed, they found the ratio of PM2.5 to PM10 to be “around or less than 0.10” (Ono, 2004).

PM2.5 Multiplier – Indications from Ambient Observations and Other Information
IMPROVE Ambient Network **-** The Interagency Monitoring of Protected Visual Environments (IMPROVE) program "reconstructs" the soil component of PM2.5 at each site based on the abundance of soil-related elements at each site. It also measures coarse mass and some researchers assume this to be essentially all soil. However, in practice, the coarse mass contains some limited amounts of nitrate and other non-soil compounds. Using data from IMPROVE for 1999-2002, the ratio of fine soil to total soil (fine soil + coarse mass) was calculated to be 0.11 (IMPROVE 2004). This could be low due the presence of other species in small amounts in the coarse fraction, but conservatively, the fine soil to coarse soil ratio is not likely to be higher than 0.12.

Ambient Trace Elements in the San Joaquin Valley (SJV) - In 2003, Richard Countess estimated the PM2.5/PM10 ratio based on SJV ambient measurements of trace elements. The average ratio for aluminum and silicon was 0.05; for calcium, titanium and iron the ratio ranged from 0.10 to 0.16. Countess estimated that a species-weighted ratio would be 0.06, based on the relative abundances of these elements in fugitive dust (Countess 2003). This suggests that the ratio of fugitive dust in the PM2.5 size fraction relative to the PM10 size fraction (based on ambient measurements in the San Joaquin Valley) is approximately one-third of 0.17 the emissions-weighted multiplier in Table 1.

Resuspended Soil Samples **-** Researchers in the San Joaquin Valley collected bulk samples of dust from a number of sources in the area. The samples were resuspended in a special recirculation chamber where a cyclone sampler measured the potential of the soil samples to emit dust in the PM2.5 and PM10 size ranges. The relationship of PM2.5 and PM10 emission potential was well correlated over a range of soil types (R^2 = 0.94, PM2.5 = .09 *PM10 + 0.13) suggesting that PM2.5/PM10 is close to 0.10 or 10% (Carvacho 2002). As noted above, sampler bias, if any could introduce errors in the above analyses.

Researchers at the Desert Research Institute also resuspended soil samples in their laboratory in 1986. This testing resulted in the following ratio data: paved roads, 0.2; unpaved roads 0.15; agricultural soil 0.2; and sand/gravel 0.4. However, the dust resuspension chamber used by DRI didn’t recirculate the airflow to maintain a uniform size distribution throughout the sample collection process and the ratios are believed to be biased high (Etyemezian 2004).

The indications from ambient measurements and resuspension chambers could be subject to a range of errors and bias. For example, ambient ratio of PM2.5: PM10 would reflect any and all processes that act on the particle size distribution during transport from the sources to the ambient monitors and the ratio would be affected by sampler or analytical bias, if any. There could also be errors in the PM2.5: PM10 emissions multipliers. When viewed in context of these caveats the data do seem to support a lower ratio of PM2.5: PM10

Summary

A number of source-oriented measurements of PM2.5 and PM10 have been reported since the 1996 work by Cowherd and Kuykendal. These have been discussed above and are briefly summarized below. Also, ambient measurements and other indications of the PM2.5 and PM10 size fractions are summarized.

Paved roads - The PM2.5 to PM10 ratio in the TRB study was 0.10, averaged across eight sites in 2 cities. Dust tracker tests in Idaho averaged 0.06 and at a dirty construction site entrance, the ratio averaged only 0.03. Overall, the ratio ranged from 0.03 to 0.10 although the TRB study (0.10) is the deemed the most representative of typical road conditions nationally. A site-weighted average of these paved road data is 0.09.

Unpaved roads - The rework of the 1981 surface coal mining study dichot data (by PEDCo) suggests a ratio of 0.10 while the more recent study in Wyoming resulted in a ratio of 0.12 for unpaved roads. The Illinois Water Survey tests also indicated an average ratio of 0.10. Overall, the range of the PEDCO and Illinois measurements is 0.10 to 0.12.

Construction, agriculture and windblown dust - These categories don't have an abundance of data on which to base a multiplier. The midpoint of the surface mining grader/scraper operations (assumed similar to construction operations) is 0.08. Agricultural operations are reportedly 0.12 based on only San Joaquin Valley testing. The Owens Lake ratio is 0.10 for windblown dust. A fairly consistent midpoint value for these categories is 0.1.

Ambient Data and other Indicators - The PM2.5: PM10 ratio for ambient samples at IMPROVE sites averaged 0.11 and in the SJV the average was 0.06. The average ratio for soil samples in the SJV was 0.1. Dust sampling in an air recirculation chamber also yielded a ratio of about 0.10. Overall, these data support a ratio of between 0.6 and 0.11 with a mid-point around 0.1.

Table 2 summarizes this review of the PM2.5 to PM10 source-oriented and ambient measurements. The new data and reanalysis of the old data seem to converge around a multiplier of 0.1, or 10%, when averaged across all source categories. Thus, the newly acquired information consistently supports a lower multiplier than is currently in use. However, recommendation of a specific value for the multiplier should await the results of the testing that is being done for the WRAP Fugitive Dust Forum (WRAP 2004). These results are expected in late spring, 2005. It is suggested that once this test report is available, all the available data be considered collectively and a consensus multiplier be developed. Ideally, this consensus would be developed through the collaborative efforts of the researchers that have been studying fugitive dust and the relationship among the size fractions.

Fugitive Dust Category	Current Multiplier	Range of New Data	Midpoint of New Data
Paved Road Tests (All)	**0.2** for lower traffic roads;	**0.03 to 0.10**	**0.09** for lower traffic roads;
Unpaved Road Tests (Public and Industrial)	**0.15**	**0.10 to 0.12**	**0.11**
Other Category Tests (Construction, Agricultural Operations and Windblown Dust)	**0.15 to 0.20**	**0.06 to 0.12**	**0.1**
General Indications Based on Ambient Measurements and Other Tests	**0.15 to 0.25**	**0.06 to 0.11**	**0.1**

Table 2. Data Related to the PM2.5 to PM10 Size Multipliers for use in NEI

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