Correlating Federal Reference Method and Continuous $PM_{2.5}$ Monitors in the MARAMA Region

The following paragraphs have been extracted from the final draft report titled *Correlating Federal Reference Method and Continuous $PM_{2.5}$ Monitors in the MARAMA Region.* The report was prepared by the Mid-Atlantic Regional Air Management Association (MARAMA). For a full copy of the report, please contact Mia Lueth at MARAMA at (410) 467-0170 or at mlueth@marama.org. Questions or comments regarding the report should be directed to Bill Gillespie at (410) 467-0170 or bgillespie@marama.org.

Preface

This report summarizes the types of FRM and continuous $PM_{2.5}$ monitors operated by state and local air quality programs in the MARAMA region, describes the method used to correlate FRM and continuous monitors, and provides preliminary correlations for eleven monitoring sites. A major goal of the report was to determine how well FRM and continuous monitor track each other at monitoring sites throughout the region and how FRM/continuous correlations are similar or different site-to-site. To accomplish this, a generally accepted method for correlating FRM and continuous data was consistently applied to monitoring data at each site studied.

While the correlations developed in this report are adequate for the purposes of generally comparing the differences between FRM and continuous monitors operated in the region, they should be considered preliminary correlations. Although State and local staff have reviewed the data used to develop correlations found in this report, final quality assurance of the data has not been performed. In addition, the analytical method used to develop correlations did not include rigorous application of a statistical technique for identifying outliers. Additional data, final quality assurance of the data, application of rigorous techniques for identifying outliers, and other improvements or refinements could improve the quality of the correlations that have been developed.

1.0 Executive Summary

Since the promulgation of the National Ambient Air Quality Standards for fine particulate matter ($PM_{2.5}$) in 1997, there has been increasing interest in how to measure this pollutant in the atmosphere. Currently, there are a variety of methods for monitoring $PM_{2.5}$. EPA approved Federal Reference Methods (FRM) are filter-based methods that generally produce data of good accuracy and precision. Unfortunately, data from a FRM monitor may not be available until four to twelve weeks after the actual measurement was made. Because of the delay in obtaining data, FRM data cannot be used to calculate the Air Quality Index (AQI) or otherwise help inform air quality managers or the public when current air quality is poor or deteriorating. FRM monitoring networks for $PM_{2.5}$ are also expensive and labor intensive to operate and maintain. Continuous monitors, that use a variety of techniques to measure $PM_{2.5}$, have the advantage of providing near real-time data. If their data can be correlated to FRM measurements, continuous data can be used to calculate the AQI and provide real-time information about air quality.

On October 1, 2003, EPA and state and local agencies implemented year-round air quality forecasting in major cities across the United States. The new program considers all criteria pollutants in air quality forecasts, with special emphasis on ozone and $PM_{2.5}$ -- the pollutants most often responsible for poor air quality. With the initiation of the year-round forecasting program, there has been increasing interest in correlating continuous $PM_{2.5}$ monitoring data with FRM monitoring data. Continuous data can provide air quality managers with reliable information about $PM_{2.5}$ concentrations as air quality episodes occur and provide forecasters with accurate data on which to base their forecasts.

To help MARAMA members better understand the nature of $PM_{2.5}$ measurements, and to help support forecasting programs in MARAMA states, MARAMA's Executive Board asked MARAMA to work with MARAMA members to correlate FRM and continuous monitors in MARAMA region.

This report provides information about the types of $PM_{2.5}$ monitors operated in the MARAMA region and summarizes early work to correlate FRM and continuous measurements in the region. With the assistance of state and local agencies, MARAMA developed correlations for eleven monitoring sites. Correlations were developed for monitors in Allegheny County, PA; Arendtsville, PA; Baltimore, MD; Camden and Elizabeth, NJ; Charlotte, NC; Hampton and Richmond, VA; Moundsville, WV; and Wilmington, DE. In developing correlations, MARAMA followed the approach outlined in the EPA document: *Data Quality Objectives (DQOs) for Relating Federal Reference Method (FRM) and Continuous $PM_{2.5}$ Measurements to Report an Air Quality Index (AQI)*, EPA-454/B-02-002, November 2002.

At all the sites studied, summer data (June, July, and August) produced good correlation equations. R^2 values for these correlations were at or greater than 0.94. In general, during summer months, continuous monitors overstate FRM monitors by small amounts, but good correlation equations can be developed to correct for these differences. In the winter, the degree of correlation between continuous and FRM monitors is much poorer than in the summer in most cases. At some monitoring sites, R^2 values for winter correlations were less than 0.80 the accept/reject criteria established in EPA's Data Quality Objectives document. In addition to the strength of the correlation, indicated by the R^2 value, it is important to consider the slope and intercept of the correlation equation and the size of the adjustment that will be made to continuous data when the equation is applied. Ideally, a correlation equation would have a slope of 1.0 and a y-intercept of zero. At some locations, the slope of the winter correlation equation is 1.5, increasing measured continuous values 50 percent. At many monitoring sites, application of the winter correlation equation would increase continuous monitor values 15 percent or more.

While the seasonal approach to correlating monitors is valuable and an improvement over simply applying a correlation equation based on an entire year of data, it has limitations. At some locations, it may be inadequate in winter or other cold weather periods when strong correlations cannot be established.   Seasonal correlations may be inaccurate when applied during periods of unseasonable weather.

In the short-term, MARAMA members recommend taking the following steps to improve $PM_{2.5}$ monitoring in the region.

- State and local agencies should continue their efforts to understand the differences between their FRM and continuous $PM_{2.5}$ monitors. Continuing to collect good data from stable, well-maintained equipment will improve correlations, and will help further explain differences between measurements.

- State and local agencies should continue their evaluations of “cold” Beta Attenuation Monitors (BAM). These monitors show some promise of producing real-time data that replicates FRM measurements.

- Studies should be conducted to determine whether ambient temperature, relative humidity, and other meteorological parameters can be used to improve correlations between continuous and FRM monitors. These studies may produce improved correlations and useful information on how $PM_{2.5}$ concentration varies with these parameters.

- Studies that compare FRM and continuous $PM_{2.5}$ data with speciation data may provide important information that can be used to improve correlations between FRM and continuous monitors and speed the development of improved continuous methods.

In the long-term, MARAMA members recommend the development of robust continuous methods that accurately measure $PM_{2.5}$ concentration. Large-scale deployment of continuous federal reference methods could produce significant savings in equipment and personnel costs. Large-scale adoption of equivalent continuous methods would also allow expansion of the current $PM_{2.5}$ monitoring network. Such an expansion would improve our knowledge and understanding of $PM_{2.5}$ pollution and greatly facilitate $PM_{2.5}$ mapping and forecasting.

7.0 Conclusions and Recommendations

7.1. Guidance for Developing Good Correlations

While the task of correlating FRM and continuous monitors is conceptually straightforward, the actual task of developing a good correlation often requires judgment. Developing correlations helps reveal the strengths and weaknesses of current $PM_{2.5}$ monitoring methods.

Establishing a strong correlation between a FRM and a continuous $PM_{2.5}$ monitor requires a few key things. First, it entails high quality monitoring instruments and a strong monitoring program that operates correctly and consistently over long periods. To obtain a strong correlation, monitors must be rigorously serviced and maintained. From an analytical perspective, the best correlations are obtained when monitoring data are plotted and regularly reviewed to identify “suspect” data, to determine if a monitor is out of calibration, and to cull out missing values, extreme values, and outliers. Next, since correlations are a function of season and seasonal weather patterns frequently change, small datasets for only one season may not be representative of future seasons. Data collected over several years or more produces datasets most likely to produce strong correlation equations. Finally, the best datasets and correlations are developed when the staff who devise correlations work closely with monitoring field personnel so that data analysts become familiar with the types of field problems that may affect data quality and/or produce anomalies.

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7.2. Regional Comparisons

Table 18 summarizes the correlation equations developed for nine $PM_{2.5}$ monitoring sites in the MARAMA region. The equations are sorted by R^2 value, with higher R^2 values indicating better correlations. As the table shows, the best correlations are those for the summer months of June, July, and August. The R^2 value for the summer months is 0.94 or better and in three cases as high as 0.99. The R^2 is poorest in the winter, generally poor in the spring, and in some cases poor in the fall. R^2 values can range well below 0.80, the acceptance/rejection criteria established in EPA's Data Quality Objectives document.

Table 19 summarizes the correlation equations sorted by slope. An ideal correlation would have a slope of 1.0 and a y-intercept of zero. Without considering the intercept, slopes less than 1.0 indicate the continuous measurement is greater than the FRM measurement. Slopes greater than 1.0 indicate the continuous measurement is less than the FRM measurement. Table 19 shows that, in general, continuous monitors overstate FRM monitors somewhat in the summer and significantly understate FRM monitors in the winter. In the spring and fall, continuous monitors may over or understate FRM monitors depending on location and other factors. What is most striking is the large discrepancy between FRM and continuous monitors in the winter. At some locations, continuous monitors can understate a co-located FRM monitor by as much as 50 percent in the winter.

7.3. The Limitations of a Seasonal Approach

Correcting continuous monitoring data to make it "FRM-like" by increasing values by as much as 50 percent gives one pause. When adjusting the data, should the correlation equation (and the large 50 percent correction) be rigorously applied throughout the winter period, regardless of what the weather is like? Alternatively, should some other correlation equation be applied when the observed weather is less "winter-like?" In addition, at the change of every season, there is the issue of "Which correlation equation shall I apply?" For example, on December 1, the beginning of the winter season, should the winter correlation equation be applied or, if the weather is unseasonably mild, the fall equation? Seasonal equations differ in significant ways and produce significantly different estimates of FRM value.

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While a seasonal approach to correlating monitors is valuable and an improvement over simply applying a correlation equation based on an entire year of data, it has limitations. From a human health perspective, in the MARAMA region, the seasonal approach offers good correlation equations during the summer when $PM_{2.5}$ concentrations are highest. During the summer months, when air quality forecasters and the public need accurate real-time information on $PM_{2.5}$ levels, the seasonal approach provides reasonably good estimates of real-time FRM concentrations. During winter periods however, when larger adjustments must be applied to continuous data and these adjustments are known with less certainty, the seasonal approach is less appealing. Though less frequent and generally less severe, high $PM_{2.5}$ episodes do occur in winter. When wintertime $PM_{2.5}$ episodes occur, agencies are uncomfortable applying large corrections to real-time data. During cold weather months, air quality staff would like to have the same confidence in applying corrections to continuous data that they have in the summer months.

More broadly, state and local air quality managers and forecasters would like to have continuous monitoring methods in place that provide accurate $PM_{2.5}$ data regardless of season. As Dirk Felton from the New York Department of Environmental Conservation and George Allen from NESCAUM have frequently said, "The best correction is no correction." – the best situation would be one where the monitoring methods agree and not correction is necessary. As Dirk Felton is quick to point out, corrections only work "on average" and cannot account for the specific conditions observed at a monitor over a specific time period. Given the limitations of correlating FRM and continuous data, it is important that monitoring community work toward the development of $PM_{2.5}$ monitoring methods that produce easily comparable results method-to-method.

In recent years, continuous monitoring methods for $PM_{2.5}$ have improved considerably. Today, these methods have significant cost and operational advantages. In addition, they provide important information about the diurnal fluctuation of $PM_{2.5}$ concentrations. In many locations however, observed differences between the FRM and continuous methods must be explained and resolved before continuous monitors can become federal reference methods themselves and be used to determine an area's attainment or non-attainment of the National Ambient Air Quality Standard for $PM_{2.5}$.

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7.4 Implications of Poor Correlations on EPA's AIRNow Program and Air Quality Forecasting

As noted previously, robust correlation equations can be developed for the summer months in the Mid-Atlantic Region when $PM_{2.5}$ concentrations often peak and are of greatest concern. If carefully developed correlations are applied to continuous data during the summer, air quality information reported on the AIRNow web site and state and local web sites will represent real-time air quality with reasonable accuracy.

In the wintertime and to some extent in the fall and spring, however, when only poor quality correlations can be developed and when the corrections that need to be applied to continuous data are relatively large, information reported on the AIRNow web site and/or state and local web sites may differ from the corresponding FRM concentration. Until the disparities between FRM and continuous methods are well understood, reporting wintertime real-time $PM_{2.5}$ concentrations will continue to be task involving a large amount of uncertainty.

The uncertainty of wintertime, real-time continuous measurements is a very real problem for air quality forecasters trying to predict tomorrow's $PM_{2.5}$ concentration. Most air quality forecasts depend on knowing current air quality and knowing something about the air quality of air being transported into the forecast area. When there is little confidence in real-time $PM_{2.5}$ measurements, formulating a good $PM_{2.5}$ forecast is difficult at best.

It can be expected that correlations will improve as more is learned about monitor performance, monitor operations, and the factors that cause disparities between monitoring instruments. There are already sites where good correlations have been established for all four seasons of the year.

7.5. Areas for Further Work

Several areas of work should be pursued to improve the accuracy of $PM_{2.5}$ monitoring. First, further methods development work is needed to understand the strengths and weaknesses of the federal reference method and continuous methods and why results from these methods sometimes differ by large amounts. While this work is principally the responsibility of EPA, some state and local agencies have initiated limited work in this area. Current work is focusing on how the two methods differ in their measurement of water, nitrate and carbon species. The New Jersey Department of Environmental Protection is running chamber tests to try to explain why FRM and continuous monitors report different results when exposed to the same aerosols.

While methods development work progresses, several other steps can be taken to help reconcile the two monitoring methods. Using ambient temperature and/or relative humidity data to help correlate continuous and FRM measurements might be explored as a means of adjusting continuous $PM_{2.5}$ data. By recording 24-hour average continuous $PM_{2.5}$ concentration, ambient station temperature, and relative humidity, it may be possible to develop a correlation between those variables and daily FRM measurements. Since differences between FRM and continuous measurements are most likely a function of aerosol composition, comparing FRM and continuous monitoring data and speciation data may prove to be the best approach to improving the correlation between the two monitoring methods. Determining which atmospheric constituents are over or underreported and/or are going undetected by the various methods could facilitate the development of new, improved monitoring methods. The work funded by EPA's "Supersite" program may prove helpful.

Additional work should also be conducted to see if improved Beta Attenuation Monitors (BAMs) can accurately and reliably monitor $PM_{2.5}$ and produce FRM-like output. Early work by the State of Delaware, operating a "cold BAM" shows promise. The California Air Resources Board has recently reported success with their network of thirteen Beta Attenuation Monitors.

7.5. Recommendations

Pursuing the following recommendations will improve the understanding of $PM_{2.5}$ monitoring and help explain observed differences between the FRM and continuous monitoring methods.

7.5.1. Short-term Recommendations

1. State and local agencies should continue their effort to understand the differences between their FRM and continuous $PM_{2.5}$ monitors. Continuing to collect good data from stable, well-maintained equipment will improve correlations and will help further explain differences in monitoring data.

2. State and local agencies should continue their evaluations of "cold" Beta Attenuation Monitors. These monitors show promise of producing real-time data that replicates FRM measurements.

3. Where data are available, studies should be conducted to determine whether ambient temperature, relative humidity, or other meteorological data can be used to improve correlations between continuous and FRM monitors. These studies may provide improved correlations and useful information on how $PM_{2.5}$ concentrations vary with these parameters.

4. Studies that compare FRM and continuous $PM_{2.5}$ data with speciation data may provide important information that can be used to improve correlations between FRM and continuous monitors and speed the development of improved $PM_{2.5}$ monitoring methods.

7.5.2. Long-term Recommendations

The monitoring community's long-term goal is the development of robust continuous methods that accurately measure $PM_{2.5}$ concentration. Large-scale deployment of continuous federal reference methods could produce significant savings in equipment and personnel costs. Large-scale adoption of equivalent continuous methods would also allow expansion of the current $PM_{2.5}$ monitoring network. Such an expansion would improve our knowledge and understanding of $PM_{2.5}$ pollution and greatly facilitate $PM_{2.5}$ mapping and forecasting.

Table 18. Correlation Equations Sorted by R^2

AIRS#	State and Site Name	Season	Days	Regression Equation	R2	FRM Monitor	Cont. Monitor
100032004	Wilmington, DE	Summer	92	0.91CM - 3.0	0.99	Anderson RAAS-300	Anderson BAM
340070003	Camden, NJ	Summer	29	0.97CM - 0.68	0.99	R&P 2025	R&P 1400a
340390004	Elizabeth, NJ	Summer	84	0.98CM - 0.83	0.98	R&P 2025	R&P 1400a
540511002	Moundsville, WV	Summer	69	1.00CM + 1.9	0.98	R&P 2025	R&P 1400a
510870014	Richmond, VA	Summer	68	0.95CM - 0.45	0.98	R&P 2025	R&P 1400a
420030064	Liberty, Alleghy. Co., PA	Summer	246	0.97CM + 2.1	0.97	R&P 2025	R&P 1400a
371190041	Garinger, NC	Summer	221	0.98CM - 0.08	0.97	R&P 2025	R&P 1400a
371190041	Garinger, NC	Fall	232	0.99CM - 0.41	0.97	R&P 2025	R&P 1400a
516500004	Hampton, VA	Summer	75	1.1CM - 1.1	0.96	R&P 2025	R&P 1400a
516500004	Hampton, VA	Fall	68	1.1CM - 1.8	0.96	R&P 2025	R&P 1400a
420030008	Lawrenceville, Alleghy. Co., PA	Summer	243	0.93CM + 2.2	0.96	R&P 2025	R&P 1400a
420030064	Liberty, Alleghy. Co., PA	Spring	170	1.1CM + 0.62	0.96	R&P 2025	R&P 1400a
100032004	Wilmington, DE	Winter	90	1.1CM - 0.73	0.95	Anderson RAAS-300	Anderson BAM
420010001	Arendtsville, PA	Fall	147	0.95CM - 0.24	0.95	R&P 2025	R&P 1400a
540511002	Moundsville, WV	Fall	57	1.00CM + 1.7	0.95	R&P 2025	R&P 1400a
420010001	Arendtsville, PA	Summer	158	0.99CM - 0.78	0.94	R&P 2025	R&P 1400a
371190041	Garinger, NC	Spring	222	0.90CM + 0.53	0.93	R&P 2025	R&P 1400a
420030064	Liberty, Alleghy. Co., PA	Winter	150	1.3CM + 2.0	0.93	R&P 2025	R&P 1400a
245100040	Baltimore, MD	Summer	92	0.86CM + 2.0	0.93	Anderson RAAS-300	R&P 1400a
420030064	Liberty, Alleghy. Co., PA	Fall	232	1.1CM + 1.1	0.92	R&P 2025	R&P 1400a
510870014	Richmond, VA	Fall	78	1.0CM - 1.0	0.92	R&P 2025	R&P 1400a
516500004	Hampton, VA	Spring	75	1.0CM - 1.8	0.91	R&P 2025	R&P 1400a
245100040	Baltimore, MD	Winter	90	1.4CM + 1.4	0.90	Anderson RAAS-300	R&P 1400a
245100040	Baltimore, MD	Fall	91	1.0CM + 1.9	0.90	Anderson RAAS-300	R&P 1400a
540511002	Moundsville, WV	Winter	51	1.2CM + 0.92	0.90	R&P 2025	R&P 1400a
510870014	Richmond, VA	Spring	81	0.90CM - 0.62	0.90	R&P 2025	R&P 1400a
420030008	Lawrenceville, Alleghy. Co., PA	Fall	219	0.93CM + 2.7	0.85	R&P 2025	R&P 1400a
540511002	Moundsville, WV	Spring	74	0.85CM + 1.5	0.85	R&P 2025	R&P 1400a
371190041	Garinger, NC	Winter	160	1.2CM - 1.3	0.85	R&P 2025	R&P 1400a
420030008	Lawrenceville, Alleghy. Co., PA	Spring	171	0.84CM + 3.3	0.85	R&P 2025	R&P 1400a
100032004	Wilmington, DE	Spring	92	1.1CM - 4.4	0.84	Anderson RAAS-300	Anderson BAM
100032004	Wilmington, DE	Fall	60	1.0CM - 3.1	0.83	Anderson RAAS-300	Anderson BAM
340070003	Camden, NJ	Fall	57	0.85CM + 1.4	0.83	R&P 2025	R&P 1400a
420010001	Arendtsville, PA	Spring	176	1.0CM - 0.33	0.82	R&P 2025	R&P 1400a
340390004	Elizabeth, NJ	Spring	115	1.2CM - 1.6	0.82	R&P 2025	R&P 1400a
420010001	Arendtsville, PA	Winter	116	1.3 - 2.0	0.81	R&P 2025	R&P 1400a
340390004	Elizabeth, NJ	Fall	170	0.89CM + 0.56	0.79	R&P 2025	R&P 1400a
245100040	Baltimore, MD	Spring	88	1.0CM + 2.2	0.79	Anderson RAAS-300	R&P 1400a
340390004	Elizabeth, NJ	Winter	140	1.4CM - 1.4	0.78	R&P 2025	R&P 1400a
340070003	Camden, NJ	Winter	52	1.5CM - 2.5	0.78	R&P 2025	R&P 1400a

Table 18. Correlation Equations Sorted by R^2 (continued)

AIRS#	State and Site Name	Season	Days	Regression Equation	R2	FRM Monitor	Cont. Monitor
510870014	Richmond, VA	Winter	77	1.3CM - 2.7	0.73	R&P 2025	R&P 1400a
340070003	Camden, NJ	Spring	38	1.0CM - 0.90	0.72	R&P 2025	R&P 1400a
516500004	Hampton, VA	Winter	76	1.3CM - 2.5	0.72	R&P 2025	R&P 1400a
420030008	Lawrenceville, Alleghy. Co., PA	Winter	159	0.91CM + 4.7	0.61	R&P 2025	R&P 1400a

Table 19. Correlation Equations Sorted by Slope

AIRS #	State and Site Name	Season	Days	Regression Equation	R2	FRM Monitor	Cont. Monitor
420030008	Lawrenceville, Alleghy. Co., PA	Spring	171	0.84CM + 3.3	0.85	R&P 2025	R&P 1400a
340070003	Camden, NJ	Fall	57	0.85CM + 1.4	0.83	R&P 2025	R&P 1400a
540511002	Moundsville, WV	Spring	74	0.85CM + 1.5	0.85	R&P 2025	R&P 1400a
245100040	Baltimore, MD	Summer	92	0.86CM + 2.0	0.93	Anderson RAAS-300	R&P 1400a
340390004	Elizabeth, NJ	Fall	170	0.89CM + 0.56	0.79	R&P 2025	R&P 1400a
510870014	Richmond, VA	Spring	81	0.90CM - 0.62	0.90	R&P 2025	R&P 1400a
371190041	Garinger, NC	Spring	222	0.90CM + 0.53	0.93	R&P 2025	R&P 1400a
100032004	Wilmington, DE	Summer	92	0.91CM - 3.0	0.99	Anderson RAAS-300	Anderson BAM
420030008	Lawrenceville, Alleghy. Co., PA	Winter	159	0.91CM + 4.7	0.61	R&P 2025	R&P 1400a
420030008	Lawrenceville, Alleghy. Co., PA	Summer	243	0.93CM + 2.2	0.96	R&P 2025	R&P 1400a
420030008	Lawrenceville, Alleghy. Co., PA	Fall	219	0.93CM + 2.7	0.85	R&P 2025	R&P 1400a
420010001	Arendtsville, PA	Fall	147	0.95CM - 0.24	0.95	R&P 2025	R&P 1400a
510870014	Richmond, VA	Summer	68	0.95CM - 0.45	0.98	R&P 2025	R&P 1400a
340070003	Camden, NJ	Summer	29	0.97CM - 0.68	0.99	R&P 2025	R&P 1400a
420030064	Liberty, Alleghy. Co., PA	Summer	246	0.97CM + 2.1	0.97	R&P 2025	R&P 1400a
371190041	Garinger, NC	Summer	221	0.98CM - 0.08	0.97	R&P 2025	R&P 1400a
340390004	Elizabeth, NJ	Summer	84	0.98CM - 0.83	0.98	R&P 2025	R&P 1400a
371190041	Garinger, NC	Fall	232	0.99CM - 0.41	0.97	R&P 2025	R&P 1400a
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