Review of the Potential to Reduce or Provide a More Cost Efficient Means to Implement the $PM_{2.5}$ Performance Evaluation Program

DRAFT

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Intent of Paper

During the June 2, 2005 Ambient Air Monitoring Steering Committee Meeting, OAQPS was asked to look at whether the costs associated with the $PM_{2.5}$ Performance Evaluation Program (PEP) could be reduced, either through a reduction in the number of audits or by providing a different implementation scheme that would reduce implementation costs. This paper provides a description of the process OAQPS used to evaluate the question of reducing the number of PEP audits and provides a few options and recommendations for incorporation into the planned rulemaking to 40 CFR Part 58.

Background

Unlike for the gaseous criteria pollutants, where one can use a standard of known concentration to estimate precision and bias and perform this at every site, for the particulate matter pollutants, one must rely on duplicate measurements at a representative sample of sites for estimates of both precision and bias. Precision is estimated using collocated sampling; bias is estimated using the PEP. Since only a portion of the monitoring sites are represented, the precision and bias estimates are assessed at the reporting organization level. In order to provide an adequate level of confidence in our estimates of precision and bias, an adequate number of collocation and PEP samples must be collected.

The PEP is a quality assurance activity which is used to evaluate measurement system bias of the fine particle ($PM_{2.5}$) monitoring network. The pertinent regulations for this performance evaluation are found in 40 CFR Part 58, Appendix A. The strategy is to collocate a portable FRM $PM_{2.5}$ air sampling instrument with an established primary sampler at a routine air monitoring site, operate both samplers over the same time period but with different personnel and different weighing laboratories, and then compare the results. In the original promulgation, the performance evaluation was required at every site at a frequency of six times per year. EPA believed this would have allowed an adequate assessment of bias at the site level. However, due to criticism of the burden of this requirement, the PEP was revised to its current form of 25 percent of the monitors within each reporting organization network at a frequency of four times per year. The data from the routine monitors and PEP monitors are compared for each reporting organization in order to determine whether the bias estimate for the reporting organization is within the data quality objective of +/- 10 percent.

Approach

First, the study question was restated:

> "Can the $PM_{2.5}$ PEP audits be reduced without adversely affecting the confidence in the 3-year bias estimate at the reporting organization level?"

Since our data quality objectives are based upon assessments of precision and bias at a 3-year level of aggregation per reporting organization, we need to have enough representative data at this level of aggregation to make a reasonable assessment of bias.

Over the past few years, the QA Strategy Workgroup has been reviewing and developing revisions to the Ambient Air Monitoring Program Quality System requirements found in 40 CFR Part 58 Appendix A. The planned revisions have included the statistics used in our estimates of precision and bias and the move towards using confidence limits rather than simple averages over various time periods (quarters/years). One advantage of the new statistics is that it provides monitoring organizations some flexibility in choosing how frequently the quality control checks need to be performed. In the report that was generated to explain the new statistics[1] a matrix table was developed to demonstrate how one could determine how many QC samples, such as the biweekly one-point QC check, were needed to ensure that the DQO would be met. The following is an excerpt from this document.

> *For ozone and other gases, the proposed precision and bias estimates are both made from the biweekly checks. Table 1 shows how many of those checks are needed to confidently (90 percent) establish that both the precision and bias are less than 10 percent. In this way, one knows that both the precision and the bias are controlled to at most 10 percent, provided the sample size is at least the number shown in Table 1. For Table 1, one-sided 90 percent confidence limits about the precision estimate were assumed. This statistic matches the current use for the* $PM_{2.5}$ *precision estimates in CFR.*

Table 1. Conservative Number of Precision and Bias Checks Needed to Yield Both an Absolute Bias Upper Bound of at Most 10 percent and an Upper bound of at most 10 percent for the Precision.

Minimum sample size		Precision Point Estimate				
		5%	6%	7%	8%	9%
Bias Pt. Est.	5%	8	8	12	24	87
	6%	12	12	12	24	87
	7%	20	20	20	24	87
	8%	43	43	43	43	87
	9%	166	166	166	166	166

This sample size matrix approach was used to answer our study question. This was accomplished by:

1. **Developing a matrix table with precision and bias ranges of 15 percent and 9.5 percent, respectively.** Since the DQO for bias (provided by the PEP) is +/-10 percent, the bias side of the matrix table could not exceed 10 percent since it is impossible to determine how many samples are needed to control a bias estimate to 10 percent if the current estimate is over 10 percent. Table 2 represents the matrix table that was used for this evaluation.

2. **Data aggregation/data reduction-** Precision and bias data from the calendar years 2002-2004 were used to provide appropriate reporting organization estimates. Any precision and bias data were excluded if their concentrations were < 3 ug/m^3. In addition, bias outliers for each reporting organization were identified using a univariate outlier test and removed prior to data evaluation.

3. **Providing 3-year precision and bias estimates at the reporting organization level.** Statistics used in the precision and bias estimates are provided in Appendix A.

[1] Proposal: A New Method for Estimating Precision and Bias for Gaseous Automated Methods for the Ambient Air Monitoring Program, 7/2003

4. **Determination of number of PEP pairs necessary for assessment purposes.** The matrix table was used to identify the required number of PEP visits over a 3-year period needed to obtain 90 percent confidence that the bias DQO of +/-10 percent is being met.

Table 2. PEP Sample Size Requirements Based on Reporting Organization Precision and Bias Estimates

		BIAS															
		2	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**9**	**9.5**
	1													3	3	4	9
	1.5											3	3	3	4	6	17
	2									3	3	3	3	4	5	9	28
P	**2.5**							3	3	3	3	3	4	5	7	12	43
R	**3**				3	3	3	3	3	3	3	4	4	6	9	17	61
E	**3.5**		3	3	3	3	3	3	3	3	4	4	5	7	11	22	82
C	**4**	3	3	3	3	3	3	3	3	4	4	5	6	9	14	28	107
I	**4.5**	3	3	3	3	3	3	3	4	4	5	6	7	10	17	35	135
S	**5**	3	3	3	3	3	3	4	4	5	5	7	9	12	20	43	166
I	**5.5**	3	3	3	3	3	4	4	5	5	6	7	10	14	24	52	201
O	**6**	3	3	3	4	4	4	4	5	6	7	9	11	17	28	61	238
N	**6.5**	3	3	4	4	4	4	5	5	6	8	10	13	19	33	71	279
	7	3	4	4	4	4	5	5	6	7	9	11	15	22	38	82	324
C	**7.5**	4	4	4	4	5	5	6	7	8	9	12	17	25	43	94	371
V	**8**	4	4	4	5	5	5	6	7	9	10	14	19	28	49	107	422
	8.5	4	4	4	5	5	6	7	8	9	12	15	21	32	55	120	476
U	**9**	4	4	5	5	6	6	7	9	10	13	17	23	35	61	135	534
P	**9.5**	4	5	5	6	6	7	8	9	11	14	18	26	39	68	150	595
P	**10**	5	5	5	6	7	7	9	10	12	15	20	28	43	75	166	659
E	**10.5**	5	5	6	6	7	8	9	11	13	17	22	31	47	82	183	726
R	**11**	5	6	6	7	7	9	10	12	14	18	24	34	52	90	201	797
	11.5	5	6	6	7	8	9	11	13	15	20	26	37	56	98	219	871
B	**12**	6	6	7	8	9	10	11	14	17	21	28	40	61	107	238	948
O	**12.5**	6	7	7	8	9	10	12	15	18	23	30	43	66	116	258	1028
U	**13**	6	7	8	9	10	11	13	16	19	25	33	46	71	125	279	1112
N	**13.5**	7	7	8	9	10	12	14	17	21	26	35	50	77	135	301	1199
D	**14**	7	8	9	10	11	13	15	18	22	28	38	53	82	145	324	1289
	14.5	7	8	9	10	11	13	16	19	23	30	40	57	88	155	347	1383
	15	8	9	9	11	12	14	17	20	25	32	43	61	94	166	371	1480

Statistical Background

Generation of Matrix Table

For the purpose of calculating optimal sample sizes, a sample size matrix was iteratively generated to yield a statistically calculated sample size given a specific precision and bias scenario. The matrix indicates the smallest sample size needed to assure that the upper confidence limit on bias will be below 10 percent given the current estimate of precision and bias for a reporting organization.

The sample size matrix is generated using an algorithm in SAS and creates various potential precision and bias scenarios. The precision and bias scenarios begin at a minimum of 1 percent and 2 percent, respectively, and increase to values of 15 percent and 9.5 percent. Possible sample sizes range from 3 to 1480. The algorithm used to create the matrix iteratively increases the sample size by one through each loop and calculates upper confidence limits for the current sample size and one sample size smaller for a specific precision and bias scenario. For each precision and bias scenario, the sample size begins at 3 and is increased by one until the 90 percent upper confidence limit calculated by sample size ‘n’ is below 10 percent and the 90 percent upper confidence limit calculated by a sample size ‘n-1’ is above 10 percent. This assures that the matrix sample size ‘n’ is the smallest sample size that can be used where the 90 percent upper confidence limit is still below 10 percent.

Given a specific reporting organization precision and bias estimate, one can use this matrix as a guide to approximate sample size, **assuming that the bias estimate is already less than 10 percent.** As the reporting organization precision and bias estimates get closer to 15 percent or 10 percent respectively, more samples are required to ensure that 90 percent of the time the bias estimate is below 10 percent. When the bias estimate is greater than 10 percent, the sample matrix cannot be used since the initial estimate is already above 10 percent.

The matrix is generated using the following equations:

The 90 percent upper confidence limit on the bias for sample size ‘n’ is calculated by Equation 1a:

$$bias\_1_{UCL} = m + t_{0.90,(n-1)} \cdot \frac{s_d}{\sqrt{n}} \qquad \textbf{Equation 1a}$$

The 90 percent upper confidence limit on the bias for sample size ‘n-1’ is calculated by Equation 1b:

$$bias\_2_{UCL} = m + t_{0.90,(n-2)} \cdot \frac{s_d}{\sqrt{(n-1)}} \qquad \textbf{Equation 1b}$$

Both Equation 1a and 1b use a standard deviation of the percent differences, d_i, calculated in Equation 2 below:

$$s_d = \sqrt{\frac{n \cdot \sum_{i=1}^{n} d_i^{\,2} - \left(\sum_{i=1}^{n} d_i\right)^2}{(n-1) \cdot n}} \qquad \textbf{Equation 2}$$

where the percent difference (or individual bias), d_i, is described in Equation 5 in Appendix A

When $bias\_1_{UCL}$ is under 10 percent and $bias\_2_{UCL}$ is above 10 percent, one can be 90 percent confident that the bias value that is under 10 percent is at most 10 percent when using a sample size of n.

Precision and Bias Estimates.

The precision value that feeds into the sample size matrix above is based on the proposed precision upper bound statistic, while the bias value is based on the mean absolute value of the individual bias estimates. The relevant precision and bias equations can be found in Appendix A of this document. For this study, precision and bias sample pairs are considered valid when both paired value concentrations are greater than 3ug/m^3 . In addition, a univariate outlier test was run on the individual bias estimates for each reporting organization.

Outliers were located and filtered out if data points were a certain distance away from the interquartile range (bulk of the data). Any outlier identified from the test was excluded from the reporting organization bias estimate. Table 3 identifies the frequency of excluded outliers within a reporting organization.

Data Evaluation

Table 3 provides the estimates of precision and bias for the CY 2002-2004 $PM_{2.5}$ data. Definitions for the columns are provided below:

Column	Variable	Comment
1	Rep Org	Reporting Organization
2	State	State
3	Sites 02-04	Number of SLAMS sites active in 2002-2004
4	Req PEP Checks	Required PEP checks in a 3 year period (25% of sites*4/year*3 years)
5	PEP Checks	Valid PEP audits performed in the 3 year period
6	Outlier	Number of individual bias estimates (percent difference >$\pm$50) that were removed from the dataset at a reporting organization level.
7	Prec Checks	Number of collocated precision checks in the 3-year period
8	Mean Abs Bias	Mean absolute bias
9	CV_ub	Precision coefficient of variation 90% upper confidence bound.
10	Matrix	Number of PEP audits required based on the sampling matrix
11	Diff	Difference between the matrix value and the PEP requirement (Matrix - REQ PEP Check=Diff)
12	Matrix >	A value of 1 signifying when matrix value was greater than the required PEP number
13	Matrix <	A value of 1 signifying when matrix value was less than the required PEP number

Since we are using confidence limits and small samples tend to increase the width of confidence limits, we made a decision not to evaluate any reporting organization that did not have at least 7 valid PEP/routine pairs after outliers and values < 3 ug/m^3 were removed. The 23 unevaluated reporting organizations are highlighted in green in Table 3. Additionally, there were 2 reporting organizations (see Table 3) with > 7 PEP/routine pairs that did not report precision data to AQS and therefore could not be used in the evaluation.

For each reporting organization, the CV_ub and the mean absolute bias values were used in the matrix table to determine the number of PEP audits needed to ensure, with 90 percent confidence, the DQO will be met. Example:

> For the first site with 7 valid PEP/routine pairs in Table 3 (Rep. Org. 0012), the intersection of the bias value of 3.09 percent and the precision value of 4.08 percent on the matrix yields a value of 3 audit pairs to ensure that 90 percent of the time the bias estimate of 3.09 percent will be less than 10 percent. For reporting organizations that had either the precision or bias estimates beyond the matrix table, the extreme value for that row or column was used since the sample number would have been greater than this extreme value. For example, if the reporting organization had a bias estimate of 6.5 percent and a precision estimate of 16 percent, the matrix estimate for that reporting organization would be 32 samples which relates to the intersection of 6.5 (bias) and 15 (precision).

The “Diff” column in Table 3 provides the difference based on the subtraction of the number of currently required PEP checks from the matrix estimate for each reporting organization. A positive value indicates where the matrix has required more PEP audits than the current requirement (a value of “1” is placed in the “Matrix >” column); a negative value indicates that the matrix required fewer PEP audits than the current requirement (a value of “1” is placed in the “Matrix <” column). In the case described above (Rep. Org.

0012), the matrix required 6 fewer samples then the current PEP requirement. The next two columns ("Matrix >" and "Matrix <") are used to summarize the number of sites where more or less audits than the current required PEP checks are needed.

Upon evaluation of the data, a number of observations can be made:

- For reporting organizations with greater than 7 valid PEP/routine pairs and reported both precision and bias values, 32 needed more audits than the current PEP requirement, 50 required fewer and 2 sites had the same number of audits for the matrix and PEP requirement.

- We noticed that at around 20 PEP audits, there was a tendency for the matrix to require less audits then the PEP requirement. For reporting organizations with > 20 PEP audits, 11 reporting organizations needed more audits and 31 required fewer audits than the PEP requirement. This observation may infer that around 20 valid audits may be appropriate to provide bias 3-year estimates with satisfactory confidence.

Next Step– finding an appropriate and consistent sample size

Our evaluation of the sample size matrix (Table 2) information suggested that selecting a consistent sample size for reporting organizations could ensure more statistically sound bias assessments while reducing program costs. In answering the study question, two objectives remained critical: 1) that the sample size is adequate to provide an appropriate level of confidence in the bias estimate, and 2) ensuring the bias estimate is representative of the reporting organization.

In order to select an appropriate sample size, we evaluated the 2002-2004 $PM_{2.5}$ data base used to generate Table 3. To get an idea of the national bias average, averaging the mean absolute value of the bias estimates from the filtered data for each reporting organization provided us with a national average bias of ~7.6 percent. Since individual reporting organizations bias estimates values can change quarterly and yearly, and our DQOs are based on national estimates, we felt using this national estimate was justified. We then posed the question:

> "How many samples would it take to ensure that 90 percent of the time, a bias estimate 7.6 percent would not be >10 percent?"

In order to answer this question we needed to have a variability parameter that varies by reporting organization to feed into the confidence limit width equation. Since we had much more collocated precision data at our disposal, we used this data to generate our confidence limits with the assumption that the uncertainty between collocated routine samplers is indicative of the uncertainty between the two samplers used to assess bias (PEP/routine sampler). The widths of confidence limits were calculated for each bias value using this assumption and are shown in Table 4 in the column labeled "CLimit 24 90%". We generated 90 percent confidence limit CLimits by varying samples sizes until we came to the sample size number where the national average CLimit was 2.4 percent or less. This sample size would ensure that 90 percent of the time, the national bias estimate of 7.6 percent would not be >10 percent. A sample size of 24 samples produced the appropriate CLimit. Considering a reporting organization with 24 samples and a national mean bias value of ~7.60 percent, we can be sure that this bias value in reality lies somewhere between 5.2 percent and 10 percent. 24 samples equate to 8 PEP audits each year per reporting organization over the 3-year period. However, in order to allow for incomplete data, we propose 9 PEP audits a year or 27 over a three year period. The sample size of 27 would be allocated across the sites in the reporting organization in a manner that takes into account the logistical costs of implementation but must also be accomplished in a manner that provides for adequate spatial and temporal representation of the reporting organization. This paper does not address this issue but believes that 27 audits could be implemented in a manner that would achieve the representativeness objective.

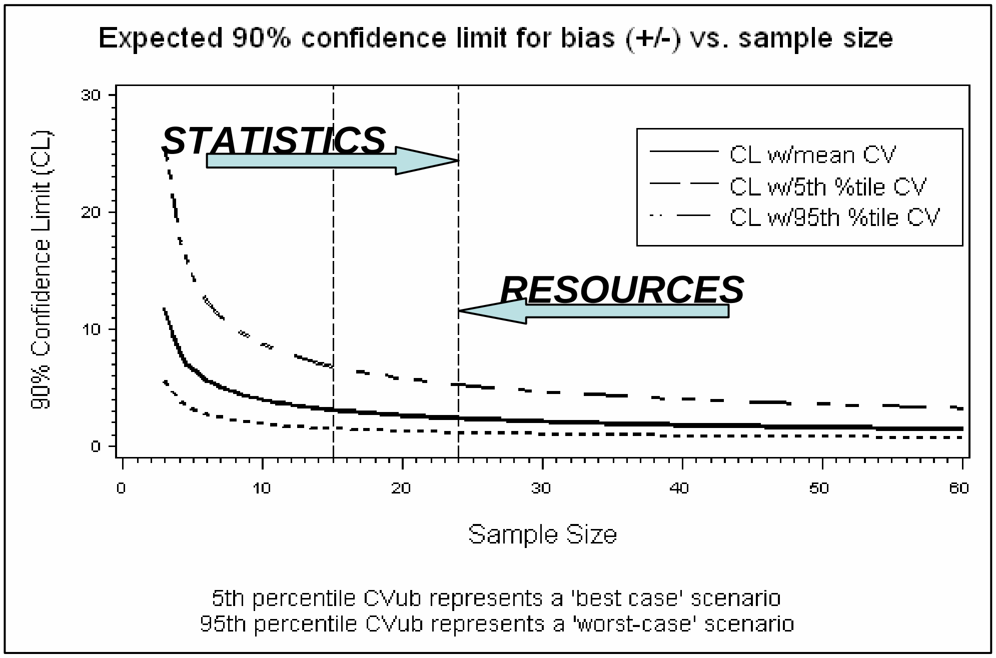

Figure 1. $PM_{2.5}$ Bias uncertainty based on sample size

Figure 1 provides a representation of the confidence one might have in the bias estimates based on sample size. The three lines graphed in the figure use the CLimits generated in Table 3. The upper line represents a worse case scenario (estimate from the 95th percentile) CLimit of the reporting organization data, the middle line is based on the mean CLimit (which was used in the evaluation above), and the lower line presents the best case scenario (the 5th percentile of the data). Using the national mean bias estimate (7.6 percent), the intersection of 24 samples (PEP audits) would yield a confidence limit of ± 2.4 percent. The idea behind the graph is to find an area away from the inflection point which yields reasonable and acceptable confidence while not wasting resources by taking more samples with little return as far as improving the confidence of the bias estimate. We feel that 24 PEP audits per reporting organization provide a good balance between data adequacy and cost efficiency.

Last Step - A sample size for smaller monitoring organizations

The proposed 27 audit sample approach provides an adequate compromise for representativeness and sample frequency. When a reporting organization only has a few monitoring sites, providing a representative estimate of bias it not as significant since we tend to sample a higher percentage of the sites in a small organizations network. Taking this to the extreme, a reporting organization with 1 site would have to take 24 valid samples at that site over a three year period. We propose that monitoring organizations with fewer than 5 sites perform a minimum of 15 audits. In order to account for incompleteness, as described in the 24 audit scenario, we propose planning for 18 audits. Plotting a sample size of 15 on Figure 1 puts us close to the inflection of the middle curve but is considered a reasonable risk for smaller reporting organizations in lieu of more complete sampling representation at each site.

Allowing for one data loss event each year while requiring one more audit than actually needed allows reporting organizations to have one audit credit per year in case it is needed in the future. This audit credit acts as a "spare" to be used to compensate for unexpected data loss events without increasing the resources already allocated to each reporting organization. Using this "18/27"approach we can reduce the PEP from the current required audits of 3237 (over 3 years) to about 2466 which relates to a 24 percent audit reduction (about 250) a year.

Conclusions

$PM_{2.5}$ precision and bias are estimated at the reporting organization level. The data evaluation suggests that we could provide better estimates of reporting organization bias with a more consistent distribution of auditing across reporting organizations. The data evaluation revealed an anticipated pattern: large reporting organizations can reduce their sampling and small reporting organizations need to sample more.

Our evaluation of the proposed PEP sampling reformation identified the issue of discrepant representativeness within a reporting organization. To perform a successful assessment, one must be confident that the data collected is representative of the target population. By increasing our samples within a small reporting organization, we are improving representativeness within the target population. However, representativeness is compromised for larger reporting organizations when reductions in sampling occur. It is also important to note that these larger reporting organizations also tend to be more heterogeneous across a larger area. An optimized sampling design for large reporting organizations may involve stratification by design value and consideration of important spatial and geographic characteristics. Discussions regarding the most appropriate sampling design for assessing bias across a large reporting organization are in progress.

Recommendations (assumed to be implemented starting in 2007)

Revise PEP requirement to the "18/27" audit scheme. This would allow for one extra audit to accommodate historically-documented data incompleteness issues within the PEP and routine monitoring programs. Every 3 years, precision and bias data will be evaluated to determine whether adjustments in the sampling scheme are needed.

Select appropriate sites to represent the reporting organizations. Since we do not use concentrations < 3 ug/m^3, we will only select sites that have a good chance of providing a concentration above this value. Since we have plenty of routine concentration data from all sites within a reporting organization, we can appropriately select the sites that will provide the best opportunity to be representative of the reporting organization.

Consolidation of reporting organizations- Some states would benefit by consolidating their networks into one or fewer reporting organizations. The states of Ohio, Florida, and California may be good candidates for consolidation. Some years ago the term reporting organization started to be used by monitoring organizations to identify the organization responsible for reporting data to AQS and therefore lost its original meaning. The revision in CFR to add the term **primary quality assurance organization** was developed in order to restore its original meaning. This new term uses the old definition and gives the monitoring organizations another opportunity for consolidation which would reduce the PEP audit requirements.

Provide a better implementation scheme to reduce travel costs- OAQPS will look at ways to implement the program more efficiently, taking into account representative needs of a reporting organization from a spatial, temporal, and concentration context. For example, for large reporting organizations the PEP may be able to reduce travel expenses by performing audits at a specific geographic area one year, and then moving to a different geographic area the next. This scheme is beyond the scope of this paper, but could be presented upon further evaluation.

The proposed sampling technique for the PEP program strengthens our assessments of bias while providing for an overall reduction in the audit requirements. By implementing the program as proposed, PEP audits can be reduced without adversely affecting the confidence in the 3-year bias estimate at the reporting organization level. In strengthening our bias assessments, we are strengthening the PEP program and its mission.

Table 3- 2002-2004 PM2.5 Reporting Organization Precision and Bias Estimates for sites with > 7 valid PEP audits

Rep_Org	State	Sites 02-04	Req PEP Checks	PEP checks	Outlier	Prec checks	Mean Abs bias	CV_ub	Matrix	Diff	Matrix >	Matrix <
0121	FL	3	9	0	0							
0274	FL	2	6	0	0							
0394	FL	1	3	0	0							
0779	NC	1	3	0	0							
0833	FL	2	6	0	0							
561	MO	4	12	1	0	65	8.33	4.10				
1124	VI	2	6	1	0		22.92					
709	CA	1	3	3	0	75	5.49	18.23				
1224	FL	2	6	3	0	186	9.36	4.87				
170	TN	1	3	4	0	301	6.63	2.96				
300	AL	1	3	4	0	169	7.07	2.69				
391	FL	1	3	4	0	164	10.34	9.34				
393	FL	1	3	4	0	185	10.73	5.07				
549	KY	3	9	4	0	506	3.12	7.16				
581	TN	4	12	4	0	142	2.01	6.26				
809	OH	4	12	4	0	131	2.90	7.11				
951	FL	1	3	4	0	147	19.20	8.23				
1226	FL	1	3	4	0	128	11.55	5.18				
220	OH	3	9	5	1	150	4.02	8.45				
595	OH	1	3	5	1	150	1.77	6.08				
151	OH	2	6	6	0	158	3.38	5.54				
458	CA	2	6	6	1	36	1.78	10.11				
880	OH	2	6	6	0	148	4.49	8.90				
12	OH	3	9	7	1	169	3.09	4.08	3	-6		1
395	FL	2	6	7	0	159	7.54	8.96	23	17	1	
403	NC	3	9	7	0	249	2.27	5.05	3	-6		1
805	OH	5	15	7	1	160	4.20	15.44	12	-3	1	
820	NC	2	6	7	0	142	9.06	5.37	52	46	1	
867	FL	3	9	7	0	186	10.20	5.33	201	192	1	
544	FL	2	6	8	0	136	6.75	4.41	6	0		
550	AL	4	12	8	0	370	4.31	3.98	4	-8		1
682	TN	3	9	8	0	151	6.54	6.86	11	2	1	
874	IA	4	12	8	0	224	6.86	5.54	7	-5		1
986	MO	1	3	8	1	179	7.05	3.96	5	2	1	
491	FL	2	6	9	3	159	6.25	5.53	5	-1		1
0017	NM	2	6	10	0		17.24					
807	OH	2	6	10	0	129	8.13	7.31	25	19	1	
864	AZ	2	6	10	1	142	9.54	17.44	1480	1474	1	
258	IL	9	27	11	0	468	7.61	9.34	26	-1		1
861	PA	5	15	11	1	149	8.67	8.87	61	46	1	
1150	WV	6	18	11	2	327	2.27	2.94	3	-15		1
1188	WY	5	15	11	2	169	8.74	5.05	20	5	1	
0350	DC	3	9	12	1		2.16					
392	FL	3	9	12	1	172	9.26	5.72	52	43	1	
396	FL	6	18	12	0	167	4.31	6.66	4	-14		1
481	HI	6	18	12	0	149	12.91	15.04	1480	1462	1	

Rep_Org	State	Sites 02-04	Req PEP Checks	PEP checks	Outlier	Prec checks	Mean Abs bias	CV_ub	Matrix	Diff	Matrix >	Matrix <
669	NC	3	9	12	0	154	4.00	4.83	3	-6		1
812	OK	5	15	12	0	61	10.64	5.98	238	223	1	
990	MO	3	9	12	0	766	8.52	3.68	11	2	1	
1025	TN	7	21	12	0	451	10.36	6.26	279	258	1	
1138	NV	1	3	12	0	174	6.74	2.20	3	0		
15	AK	7	21	13	2	327	4.68	10.35	8	-13		1
53	AZ	7	21	13	1	250	14.84	18.99	1480	1459	1	
226	NV	6	18	13	0	99	4.35	12.88	11	-7		1
634	OH	3	9	13	1	161	4.16	3.82	3	-6		1
287	OH	5	15	14	1	149	4.69	5.28	4	-11		1
523	IN	7	21	14	0	231	4.60	5.15	4	-17		1
635	ME	6	18	14	0	306	22.47	5.64	201	183	1	
992	MO	3	9	14	0	158	7.31	4.29	7	-2		1
1119	VT	6	18	14	2	311	2.78	4.03	3	-15		1
673	TN	5	15	15	0	144	10.34	7.44	371	356	1	
613	IA	3	9	16	1	221	11.68	4.59	135	126	1	
782	ND	8	24	16	0	81	12.60	5.86	238	214	1	
816	NE	3	9	17	2	257	7.24	12.67	30	21	1	
1151	WV	5	15	18	2	349	4.07	4.44	3	-12		1
730	MT	10	30	19	1	272	7.60	7.95	19	-11		1
1259	OH	11	33	19	0	453	5.84	3.01	3	-30		1
229	OH	9	27	20	2	307	5.15	7.69	6	-21		1
762	NH	12	36	20	1	351	5.21	7.58	6	-30		1
907	RI	8	24	20	1	206	7.58	12.70	43	19	1	
294	DE	7	21	21	0	148	3.91	5.19	3	-18		1
942	CA	11	33	21	1	213	7.54	5.23	9	-24		1
889	PR	15	45	22	0	229	20.33	13.24	1112	1067	1	
251	CT	12	36	24	2	341	7.54	6.81	15	-21		1
973	SD	12	36	24	3	496	24.74	10.12	659	623	1	
752	NE	11	33	25	1	264	10.48	8.52	476	443	1	
1175	WI	25	75	26	3	571	4.44	4.05	3	-72		1
21	PA	8	24	27	2	418	5.51	3.92	3	-21		1
513	IL	28	84	27	0	757	11.14	8.56	476	392	1	
511	ID/WA	12	36	28	2	385	7.15	6.23	9	-27		1
700	MN	25	75	29	3	578	6.52	8.09	10	-65		1
1118	CA	15	45	29	2	457	4.02	6.61	4	-41		1
240	CO	14	42	30	2	392	7.36	9.70	26	-16		1
588	MO	14	42	34	0	796	5.24	3.32	3	-39		1
13	AL	13	39	35	3	476	4.51	4.89	3	-36		1
584	KY	17	51	36	4	568	6.90	6.34	10	-41		1
764	NJ	21	63	41	3	441	8.46	7.12	38	-25		1
971	SC	14	42	42	5	723	4.13	4.11	3	-39		1
972	CA	17	51	42	4	596	4.62	4.51	3	-48		1
1113	UT	17	51	42	2	611	8.40	8.22	49	-2		1
1127	VA	21	63	42	1	929	5.16	7.58	6	-57		1
55	AR	24	72	43	7	462	8.42	2.14	5	-67		1
86	CA	15	45	44	1	240	6.21	4.95	5	-40		1
660	MA	24	72	44	3	995	9.23	14.93	371	299	1	

Rep_Org	State	Sites 02-04	Req PEP Checks	PEP checks	Outlier	Prec checks	Mean Abs bias	CV_ub	Matrix	Diff	Matrix >	Matrix <
703	MS	17	51	44	0	483	8.04	7.04	22	-29		1
1001	LA	25	75	44	3	645	12.39	5.92	238	163	1	
145	CA	30	90	45	2	646	8.85	10.53	183	93	1	
1136	WA	22	66	45	4	603	5.37	4.48	4	-62		1
685	MI	28	84	48	10	678	6.50	6.27	8	-76		1
437	GA	23	69	49	5	444	3.51	4.88	3	-66		1
563	KS	13	39	49	5	616	8.48	8.73	55	16	1	
776	NC	23	69	50	2	815	7.80	8.30	32	-37		1
1080	IA	15	45	54	1	861	9.64	6.55	279	234	1	
1002	MD	20	60	58	5	437	7.62	5.51	10	-50		1
520	IN	34	102	64	7	765	5.38	4.26	4	-98		1
851	PA	25	75	71	6	772	4.03	4.66	3	-72		1
821	OR	32	96	81	2	721	7.62	4.09	6	-90		1
1035	TX	56	168	87	1	1354	7.78	7.97	28	-140		1
768	NY	53	159	99	5	647	9.75	5.62	201	42	1	
Summary		**1079**	**3237**	**2313**	**146**	**35809**	**7.62**	**6.93**	**10969**	**7882**	**32**	**50**

Table 4- 2002-04 PM2.5 Summary of Climit Values Associated a Sample Size of 24 and 90% Confidence

Rep_Org	State	Sites 02-04	Mean Abs bias	CV_ub	Climit 24 90%
0121	FL	3			
0274	FL	2			
0394	FL	1			
0779	NC	1			
0833	FL	2			
561	MO	4	8.33	4.10	1.43
1124	VI	2	22.92		
709	CA	1	5.49	18.23	6.38
1224	FL	2	9.36	4.87	1.70
170	TN	1	6.63	2.96	1.04
300	AL	1	7.07	2.69	0.94
391	FL	1	10.34	9.34	3.27
393	FL	1	10.73	5.07	1.77
549	KY	3	3.12	7.16	2.51
581	TN	4	2.01	6.26	2.19
809	OH	4	2.90	7.11	2.49
951	FL	1	19.20	8.23	2.88
1226	FL	1	11.55	5.18	1.81
220	OH	3	4.02	8.45	2.96
595	OH	1	1.77	6.08	2.13
151	OH	2	3.38	5.54	1.94
458	CA	2	1.78	10.11	3.54
880	OH	2	4.49	8.90	3.11
12	OH	3	3.09	4.08	1.43
395	FL	2	7.54	8.96	3.13
403	NC	3	2.27	5.05	1.77
805	OH	5	4.20	15.44	5.40
820	NC	2	9.06	5.37	1.88
867	FL	3	10.20	5.33	1.87
544	FL	2	6.75	4.41	1.54
550	AL	4	4.31	3.98	1.39
682	TN	3	6.54	6.86	2.40
874	IA	4	6.86	5.54	1.94
986	MO	1	7.05	3.96	1.38
491	FL	2	6.25	5.53	1.94
0017	NM	2	17.24		
807	OH	2	8.13	7.31	2.56
864	AZ	2	9.54	17.44	6.10
258	IL	9	7.61	9.34	3.27
861	PA	5	8.67	8.87	3.10
1150	WV	6	2.27	2.94	1.03
1188	WY	5	8.74	5.05	1.77
0350	DC	3	2.16		
392	FL	3	9.26	5.72	2.00
396	FL	6	4.31	6.66	2.33
481	HI	6	12.91	15.04	5.26

669	NC	3	4.00	4.83	1.69
812	OK	5	10.64	5.98	2.09
990	MO	3	8.52	3.68	1.29
1025	TN	7	10.36	6.26	2.19
1138	NV	1	6.74	2.20	0.77
15	AK	7	4.68	10.35	3.62
53	AZ	7	14.84	18.99	6.64
226	NV	6	4.35	12.88	4.51
634	OH	3	4.16	3.82	1.34
287	OH	5	4.69	5.28	1.85
523	IN	7	4.60	5.15	1.80
635	ME	6	22.47	5.64	1.97
992	MO	3	7.31	4.29	1.50
1119	VT	6	2.78	4.03	1.41
673	TN	5	10.34	7.44	2.60
613	IA	3	11.68	4.59	1.61
782	ND	8	12.60	5.86	2.05
816	NE	3	7.24	12.67	4.43
1151	WV	5	4.07	4.44	1.55
730	MT	10	7.60	7.95	2.78
1259	OH	11	5.84	3.01	1.05
229	OH	9	5.15	7.69	2.69
762	NH	12	5.21	7.58	2.65
907	RI	8	7.58	12.70	4.44
294	DE	7	3.91	5.19	1.82
942	CA	11	7.54	5.23	1.83
889	PR	15	20.33	13.24	4.63
251	CT	12	7.54	6.81	2.38
973	SD	12	24.74	10.12	3.54
752	NE	11	10.48	8.52	2.98
1175	WI	25	4.44	4.05	1.42
21	PA	8	5.51	3.92	1.37
513	IL	28	11.14	8.56	2.99
511	ID/WA	12	7.15	6.23	2.18
700	MN	25	6.52	8.09	2.83
1118	CA	15	4.02	6.61	2.31
240	CO	14	7.36	9.70	3.39
588	MO	14	5.24	3.32	1.16
13	AL	13	4.51	4.89	1.71
584	KY	17	6.90	6.34	2.22
764	NJ	21	8.46	7.12	2.49
971	SC	14	4.13	4.11	1.44
972	CA	17	4.62	4.51	1.58
1113	UT	17	8.40	8.22	2.87
1127	VA	21	5.16	7.58	2.65
55	AR	24	8.42	2.14	0.75
86	CA	15	6.21	4.95	1.73
660	MA	24	9.23	14.93	5.22
703	MS	17	8.04	7.04	2.46
1001	LA	25	12.39	5.92	2.07

145	CA	30	8.85	10.53	3.68
1136	WA	22	5.37	4.48	1.57
685	MI	28	6.50	6.27	2.19
437	GA	23	3.51	4.88	1.71
563	KS	13	8.48	8.73	3.05
776	NC	23	7.80	8.30	2.90
1080	IA	15	9.64	6.55	2.29
1002	MD	20	7.62	5.51	1.93
520	IN	34	5.38	4.26	1.49
851	PA	25	4.03	4.66	1.63
821	OR	32	7.62	4.09	1.43
1035	TX	56	7.78	7.97	2.79
768	NY	53	9.75	5.62	1.97
Summary		**1079**	**7.62**	**6.93**	**2.42**

Appendix A

Precision and Bias Statistical Calculations

Precision --

Precision is estimated via duplicate measurements from collocated samplers of the same type. Precision is aggregated at the reporting organization level quarterly, annually, and at the 3-year level. For each collocated data pair, the relative percent difference, d_i, is calculated by Equation 3.

$$d_i = \frac{X_i - Y_i}{\left(X_i + Y_i\right)/2} \cdot 100 \qquad \text{Equation 3}$$

where X_i is the concentration of the primary sampler and Y_i is the concentration value from the audit sampler

The precision upper bound statistic, CV_{ub}, is a standard deviation with a 90 percent upper confidence limit (Equation 4).

$$CV_{ub} = \sqrt{\frac{n \cdot \sum_{i=1}^{n} d_i^{\,2} - \left(\sum_{i=1}^{n} d_i\right)^2}{(n-1) \cdot n}} \cdot \sqrt{\frac{n-1}{\chi^2_{0.10,(n-1)}}} \qquad \text{Equation 4}$$

Bias --

PEP audits are performed by a PEP audit sampler to find measurement bias in the routine sampler relative to the audit sampler. This is calculated below as a percent difference or individual bias, d_i, where i represents a specific sampler (Equation 5).

$$d_i = \frac{Y_i - X_i}{X_i} \cdot 100 \qquad \text{Equation 5}$$

where X_i represents the audit sampler and Y_i represents the routine sampler

The bias value is based on the average individual bias and is calculated as m in equation 6 below:

$$m = \frac{1}{n} \cdot \sum_{i=1}^{n} d_i \qquad \text{Equation 6}$$