EPA's updated metrics for characterizing bias and precision in the $PM_{2.5}$ national monitoring network

How have these changes impacted estimated trends in network bias and precision?

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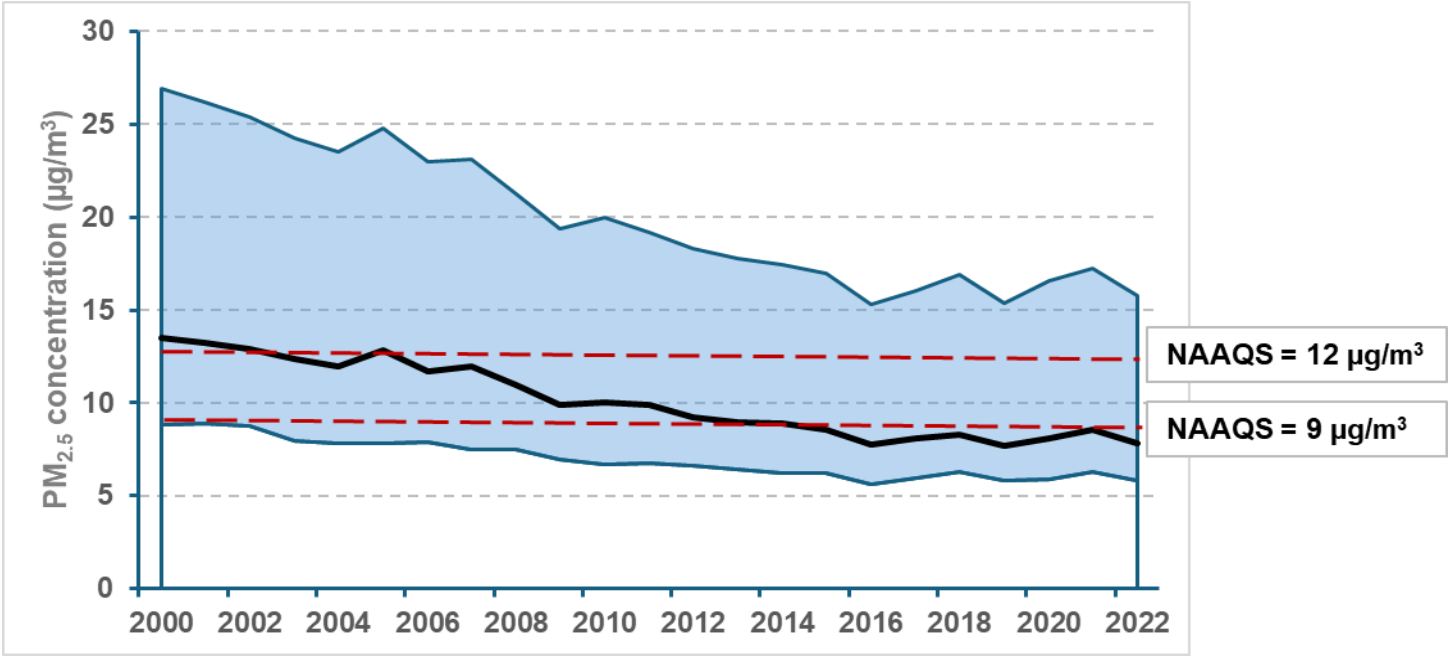
The national distribution of $PM_{2.5}$ concentrations has been declining over time

- 42% decline in annual mean $PM_{2.5}$ concentration occurred from 2000 to 2022.
- Regionally, declining trends ranged from 11% (Northwest) to 51% (Ohio Valley).
- Nearly 10% of annual $PM_{2.5}$ measurements at network sites are at 5 µg/m³ or below.
  - Concentrations below 3 µg/m³ were being excluded when calculating network bias and precision estimates.

Source: https://www.epa.gov/air-trends/particulate-matter-pm25-trends



Plot of seasonally-weighted annual mean $PM_{2.5}$ concentration, with 10th and 90th percentiles (using data from 361 monitoring sites).

Also, recent studies suggest adverse health effects from $PM_{2.5}$ exposure occur below the previous NAAQS standard of 12 µg/m³, and the prevalence of these effects declines as concentrations decline to even lower levels.

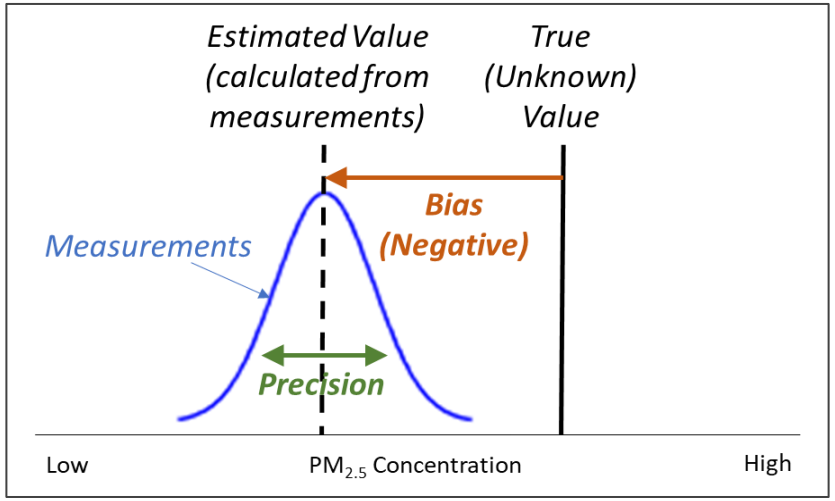
89 FR 16202 (March 6, 2024): Reconsideration of the National Ambient Air Quality Standards (NAAQS) for Particulate Matter

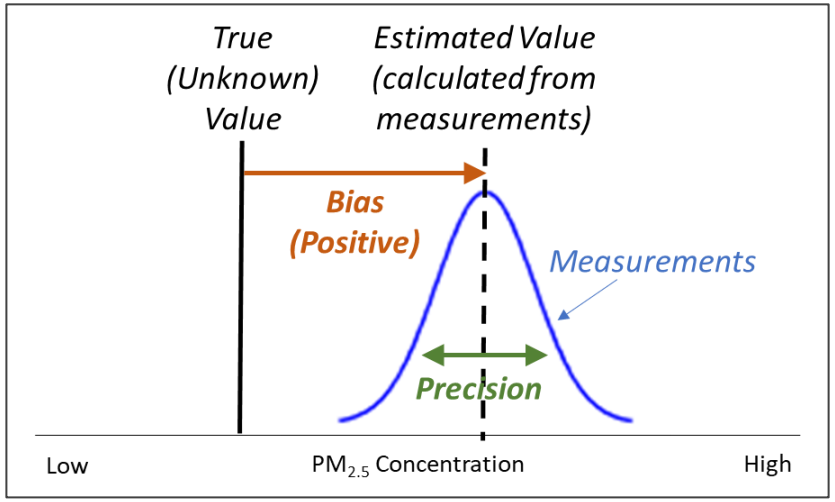
- The 3-year annual average $PM_{2.5}$ concentration is not to exceed **9 µg/m³** at a given community-oriented monitoring site.
  - Reduced from 12 µg/m³.
  - No other $PM_{2.5}$ NAAQS were revised.
- Part VII(C): Changes to **40 CFR Part 58 Appendix A** (*QA Requirements for Monitors used in Evaluations of NAAQS*)
  - (Section 3.2.4) The minimum $PM_{2.5}$ concentration measurement that is acceptable to include in network bias and precision estimates was reduced from **3 µg/m³** to **2 µg/m³**.
  - (Sections 4.2.1 and 4.2.5) Equations for estimating $PM_{2.5}$ network bias and precision were revised to better handle low $PM_{2.5}$ concentrations.

What is bias and precision?

- **Bias** is the <u>systematic or persistent distortion</u> present in a measurement process which causes error in one direction.
  - A constant shift in average measurement from the true concentration, expressed as a ***percentage of the true concentration***.
  - Estimating bias requires "true concentration" to be known or estimated under strict quality criteria.
- **Precision** is the extent of mutual agreement (or variation) among individual measurements <u>taken under the same conditions</u>.
  - A measure of average scatter of individual data points from their mean concentration, expressed as a ***percentage relative to the mean*** (coefficient of variation, or CV)

Bias is directional (positive or negative). Precision is non-negative.





Focus of this presentation

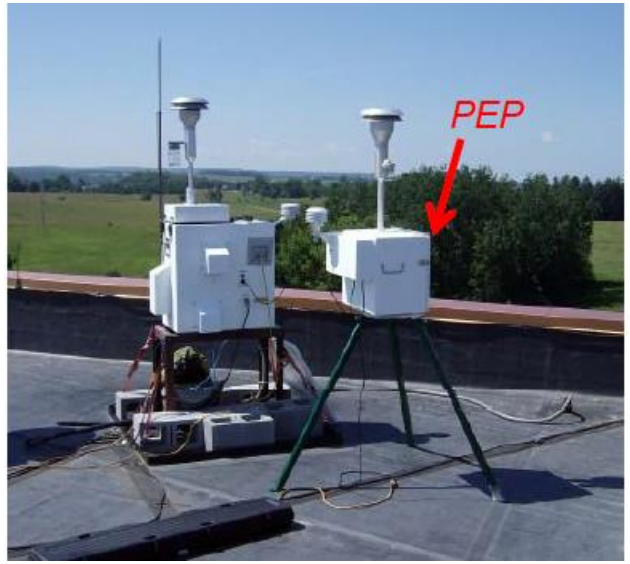
- How do $PM_{2.5}$ network bias and precision estimates, and trends in these estimates over time, change upon ...
  - EPA's recent modifications to the bias and precision formulas?
  - EPA's lowering of the minimum acceptable $PM_{2.5}$ concentration from 3 to 2 µg/m^3?
- Does the rate of PQAO adherence to EPA's bias and precision DQOs improve with these changes?
- How do the changes due to calculation method differ for sites with different average $PM_{2.5}$ concentrations?

Bias in the $PM_{2.5}$ national monitoring network

How have estimates changed with this year's revisions to 40 CFR Part 58 Appendix A?

Bias estimation in the $PM_{2.5}$ national network: *EPA's $PM_{2.5}$ Performance Evaluation Program (PEP)*

- The PEP provides a "gold standard" reference for purposes of characterizing *total measurement system bias* (i.e., bias introduced by field sampling AND laboratory filter weighing).
- A PEP sampler is collocated with a network (routine) sampler, and both simultaneously collect an ambient air sample to determine $PM_{2.5}$ concentration.
  - The routine sample is analyzed under normal protocols.
  - The PEP filter is weighed by EPA's National $PM_{2.5}$-PEP gravimetric lab (Athens, GA) under strict quality system requirements.
- Annually, 5 or 8 PEP sampling events are to occur per PQAO – approx. 600 events nationally (~86 PQAOs)



Bias estimation: What has changed?

Bias is calculated annually across sites within a PQAO.

	Prior calculation	New calculation
① Difference in measurements between routine and collocated PEP samplers (i = 1, ..., n sample pairs)	$d_i = \frac{routine - PEP}{PEP} \times 100\%$	$s_i = \frac{routine - PEP}{\sqrt{PEP}}$
② **Bias metric (%)**	$\frac{\sum_{i=1}^{n} d_i}{n}$	$\frac{\sum_{i=1}^{n} s_i}{n \times \sqrt{NAAQS}} \times 100\%$ (percent at the NAAQS)
Data Quality Objective for bias (acceptance criterion for bias metric)	Within ±10%	Within ±10% (no change)
Lowest acceptable value for $PM_{2.5}$ concentration (*routine* and *PEP*) in bias calculations	3 µg/m³	2 µg/m³

Interpreting the revised bias estimate

- ***Percent bias when the true $PM_{2.5}$ concentration is at the annual NAAQS.***
- SIMPLE EXAMPLE: At a given site, the measured $PM_{2.5}$ concentration from the network sampler is **4 µg/m³**, while the collocated PEP sampler measures **2 µg/m³** over the same 24-hour sampling period.
  - $$d_i = \frac{routine - PEP}{PEP} \times 100\% = \frac{4-2}{2} \times 100\% = \mathbf{100\%}$$ (old bias equation – would not have been calculated due to PEP conc. < 3 µg/m³)
  - $$s_i = \frac{routine - PEP}{\sqrt{PEP}} = \frac{4-2}{\sqrt{2}} = \mathbf{1.41}$$
  - $$\frac{\sum_{i=1}^{n} s_i}{n \times \sqrt{NAAQS}} \times 100\% = \frac{1.41}{1 \times \sqrt{9}} \times 100\% = \mathbf{47\%}$$ (revised bias equation)

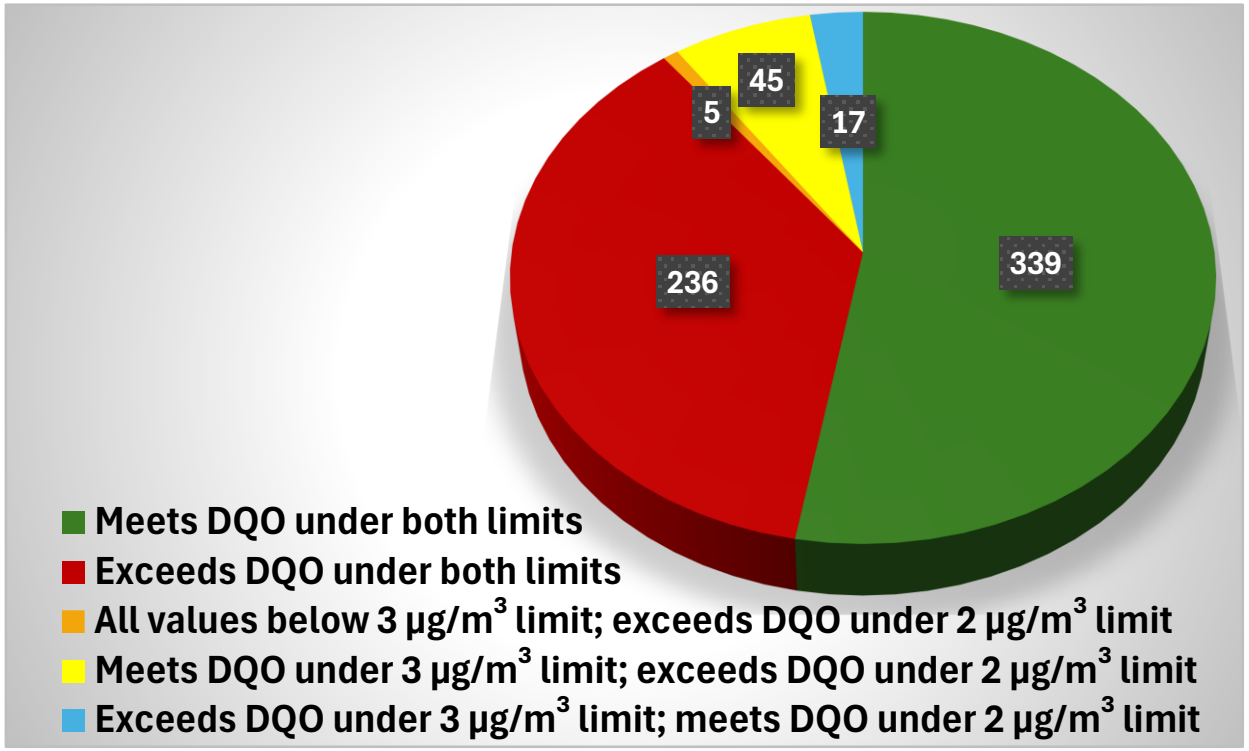
Note: The value of the revised bias equation will change if the $PM_{2.5}$ concentration in the denominator is changed from the NAAQS to something else.

Impact of reducing the minimum acceptable $PM_{2.5}$ concentration on assessing the bias DQO

- 642 DQO assessments (combinations of PQAO and year, from 2016 to 2023).
- Upon lowering the minimum acceptable $PM_{2.5}$ concentration from 3 to 2 µg/m^3,
  - 90% of the assessments result in no change to the DQO assessment outcome (green, red).
  - 7% move from meeting (or not able to calculate) to exceeding the DQO (orange, yellow).
  - <3% move from exceeding to meeting the DQO (blue).

NOTE: The PREVIOUS bias equations are used here.

 # PQAO/year combinations: 2016 to 2023

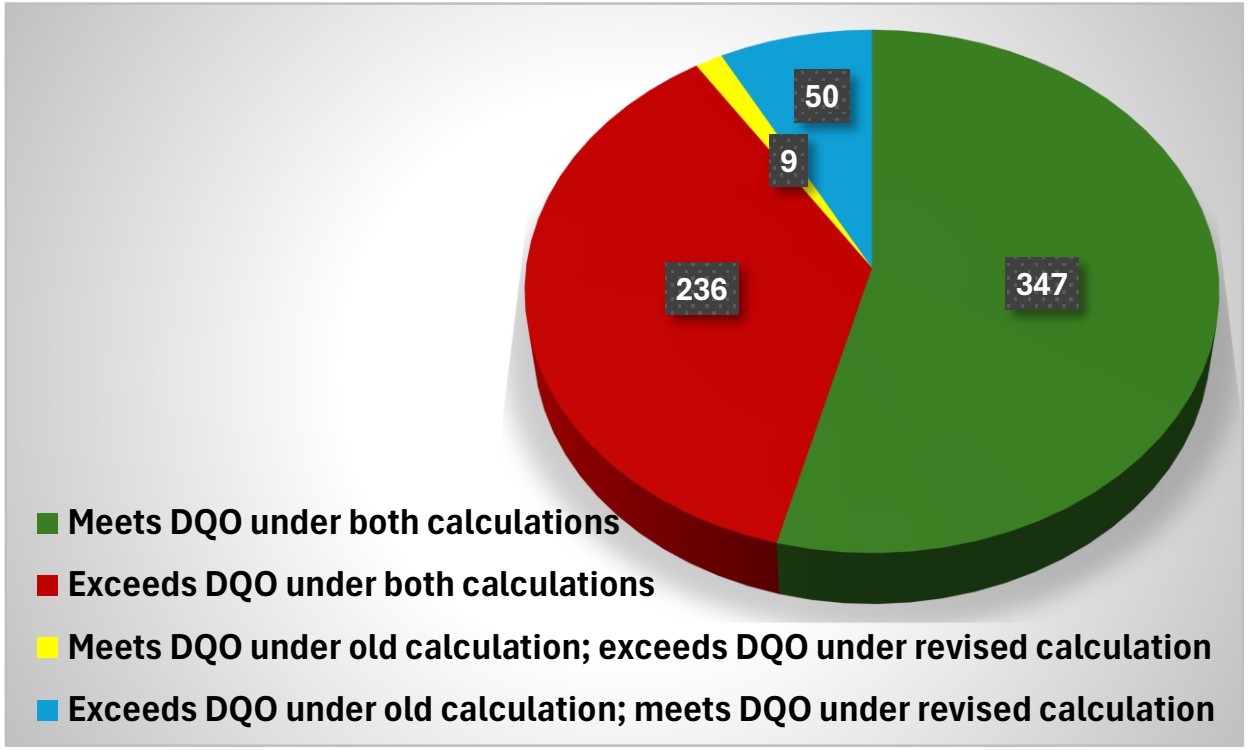


Impact of revising the bias equations on assessing the bias DQO

- 642 DQO assessments (combinations of PQAO and year, from 2016 to 2023).
- Upon revising the bias equations,
  - 91% of the assessments result in no change to the DQO assessment outcome (green, red).
  - 1% move from meeting to exceeding the DQO (yellow).
  - 8% move from exceeding to meeting the DQO (blue).

NOTE: A minimum acceptable concentration of 2 µg/m³ is assumed here.

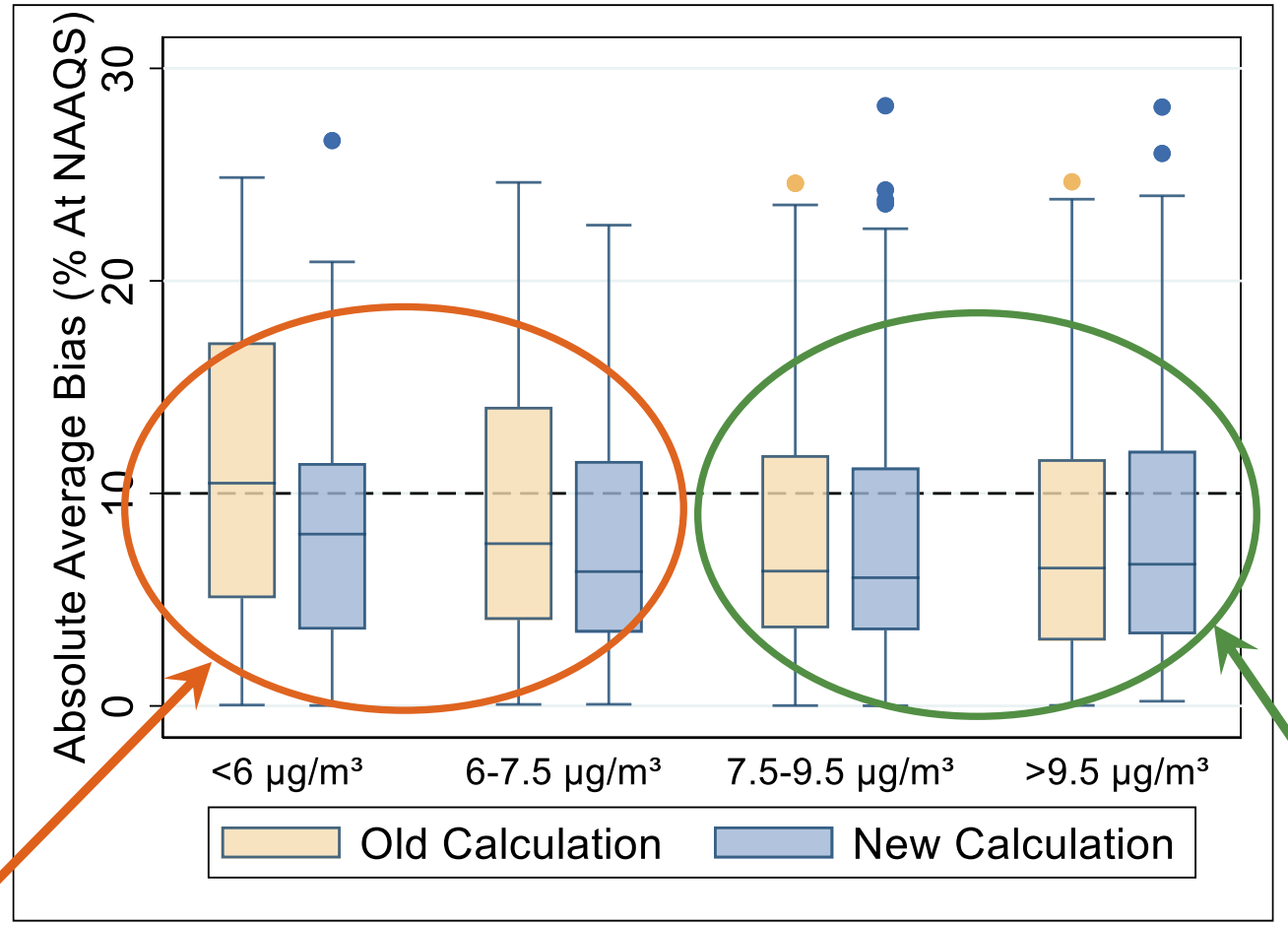
PQAO/year combinations: 2016 to 2023



Impact of revising the bias equations on assessing the bias DQO

 # PQAO/year combinations: 2016 to 2023

Breakdown of quartiles by average $PM_{2.5}$ concentration at the site.



Bias values reduced for lower average $PM_{2.5}$ concentrations

Bias values relatively unchanged for higher average $PM_{2.5}$ concentrations

NOTE: A minimum acceptable concentration of 2 µg/m³ is assumed here.

PQAO/year combinations are included in this plot if the calculated value using the old equation is less than 25%.

Distribution of Average Bias by Calculation Type and Average $PM_{2.5}$ concentration (across all PQAO/year combinations) – Dashed Line Indicates Bias DQO

Precision in the $PM_{2.5}$ national monitoring network

How have estimates changed with this year's revisions to 40 CFR Part 58 Appendix A?

Precision estimation in the $PM_{2.5}$ national network

- To generate precision data, each PQAO must collocate a $PM_{2.5}$ sampler next to its routine network sampler at 15% of its network sites
  - Collocation types and numbers must also consider the type of routine network sampler (FRM, FEM)
- Standard protocols used to collect samples simultaneously from the collocated samplers and to analyze them for $PM_{2.5}$ concentration
  - Precision sample is collected every 12 days (~30 samples per year at each collocated site)
  - Approximately 7,500 to 8,000 samples for measuring precision were required across the network each year
- PQAOs upload both $PM_{2.5}$ concentrations to AQS
  - Precision and routine sample measurements must be clearly distinguished

Precision estimation: What has changed?

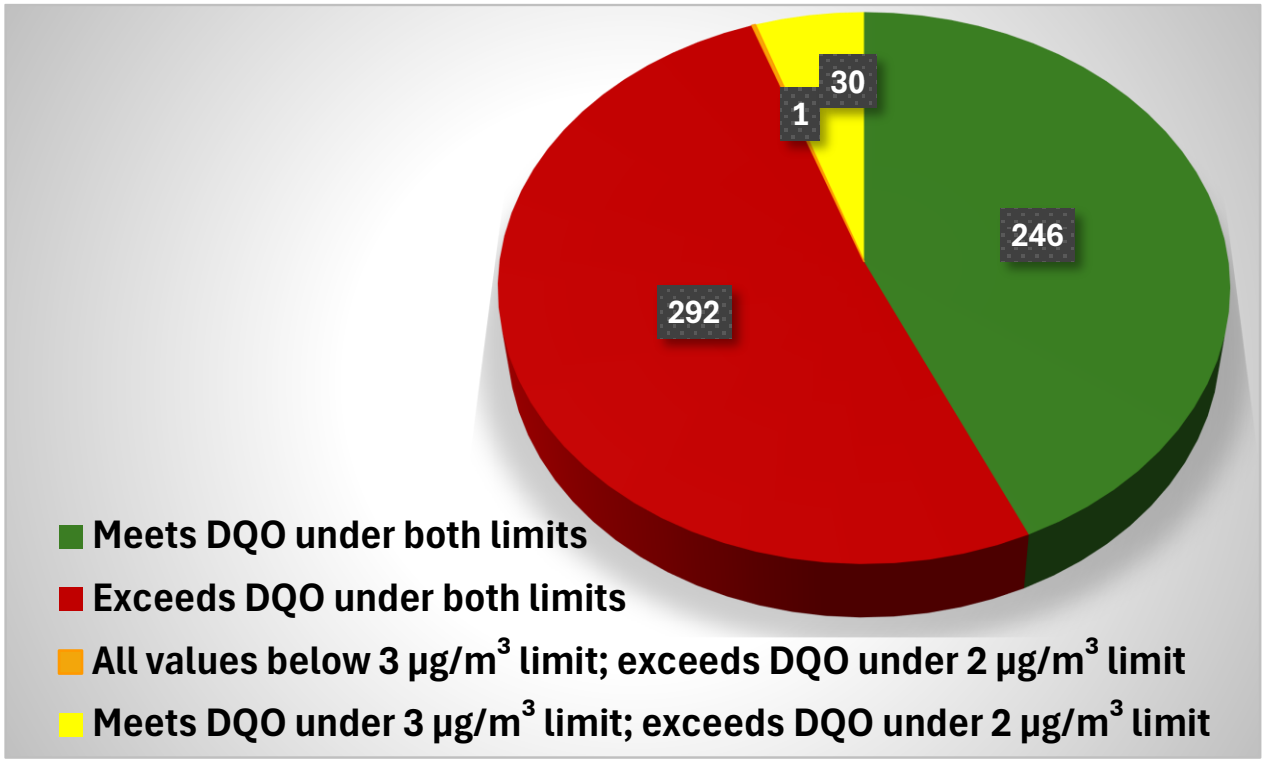
	Prior calculation	New calculation
1 Difference in measurements between collocated samplers (i = 1, ..., n sample pairs)	$d_i = \frac{X_i - Y_i}{(X_i + Y_i)/2} \times 100\%$	$t_i = \frac{X_i - Y_i}{\sqrt{(X_i + Y_i)/2}}$
2 **Precision metric** (90% upper confidence limit on coefficient of variation)	$\sqrt{\frac{n\sum_{i=1}^{n} d_i^2 - \left(\sum_{i=1}^{n} d_i\right)^2}{2n(n-1)}} \times \sqrt{\frac{n-1}{\chi^2_{0.1,n-1}}}$	$\sqrt{\frac{n\sum_{i=1}^{n} t_i^2 - \left(\sum_{i=1}^{n} t_i\right)^2}{2n(n-1)}} \times \sqrt{\frac{n-1}{NAAQS \times \chi^2_{0.1,n-1}}} \times 100\%$
Data Quality Objective for precision (acceptance criterion for precision metric)	Less than 10%	Less than 10% (no change)
Lowest acceptable value for $PM_{2.5}$ concentration (X and Y) in precision calculations	3 µg/m^3	2 µg/m^3

Impact of reducing the minimum acceptable $PM_{2.5}$ concentration on assessing the precision DQO

- 569 DQO assessments (combinations of PQAO and year, from 2016 to 2023).
- Upon lowering the minimum acceptable $PM_{2.5}$ concentration from 3 to 2 µg/m^3,
  - 95% of the assessments result in no change to the DQO assessment outcome (green, red).
  - 5% move from meeting (or cannot calculate) to exceeding the DQO (orange, yellow).
  - No PQAOs move from exceeding to meeting the DQO in any year.

NOTE: The PREVIOUS precision equations are used here.

PQAO/year combinations: 2016 to 2023

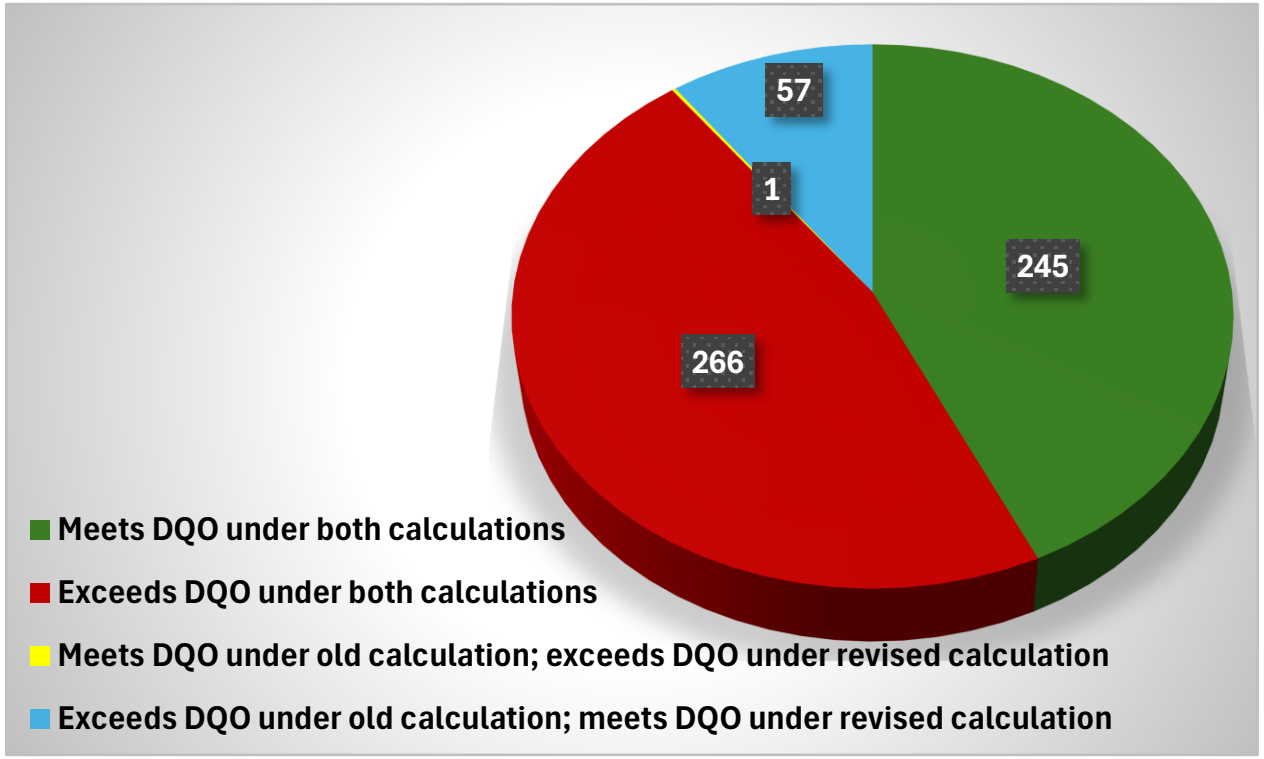


Impact of revising the precision equations on assessing the precision DQO

- 569 DQO assessments (combinations of PQAO and year, from 2016 to 2023).
- Upon revising the precision equations,
  - 90% of the assessments result in no change to the DQO assessment outcome (green, red).
  - 0.1% (1 assessment) moves from meeting to exceeding the DQO (yellow).
  - 10% move from exceeding to meeting the DQO (blue).

NOTE: A minimum acceptable concentration of 2 µg/m³ is assumed here.

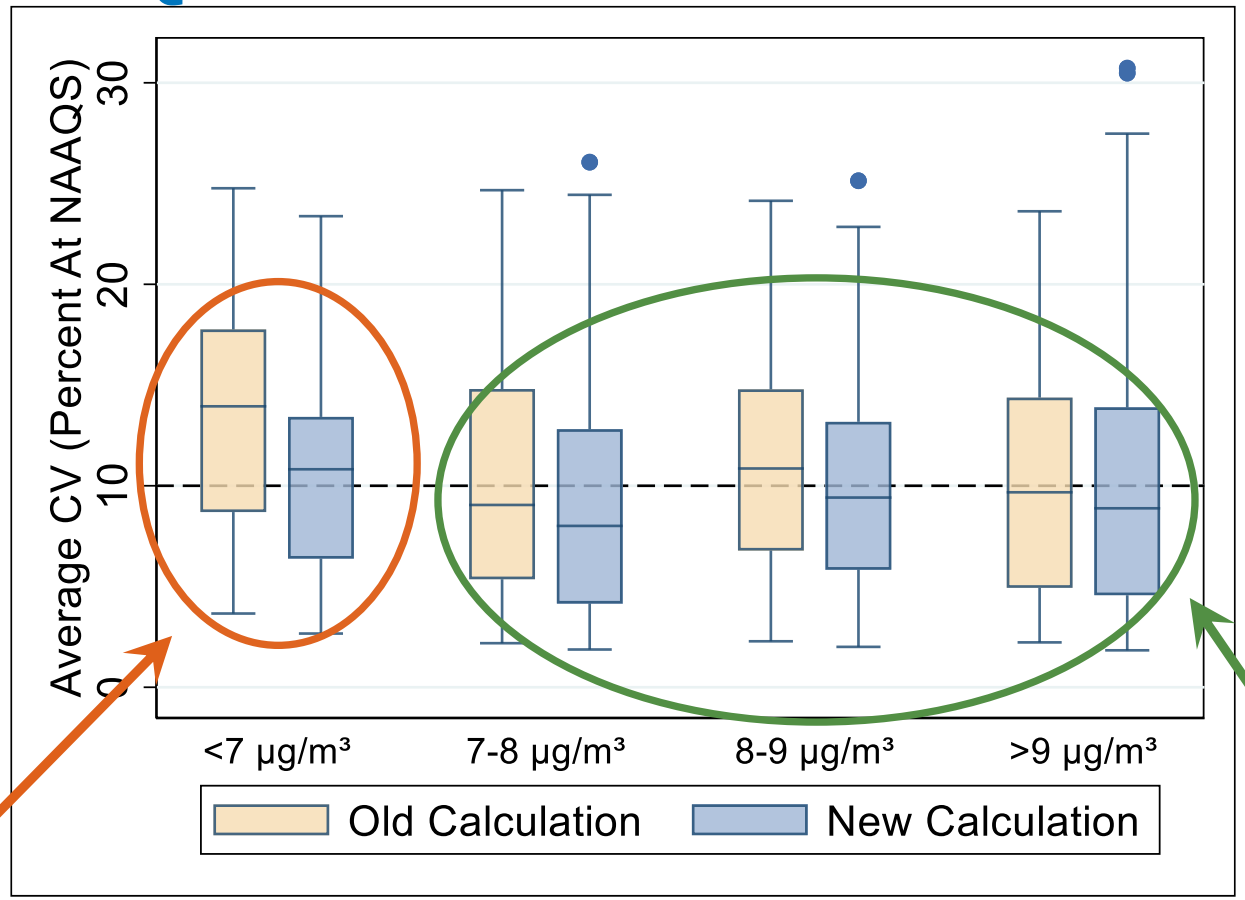
PQAO/year combinations: 2016 to 2023



Impact of revising the precision equations on assessing the precision DQO

 # PQAO/year combinations: 2016 to 2023

Breakdown of quartiles by average $PM_{2.5}$ concentration at the site.



Distribution of Average CV by Calculation Type and Average $PM_{2.5}$ concentration (across all PQAO/year combinations) – Dashed Line Indicates Precision DQO

NOTE: A minimum acceptable concentration of 2 µg/m³ is assumed here.

PQAO/year combinations are included in this plot if the calculated value using the old equation is less than 25%.

Precision values reduced for low average $PM_{2.5}$ concentrations

Precision values reduced (to a lesser degree) for higher average $PM_{2.5}$ concentrations

Key conclusions from this investigation

- At least 90% of the bias and precision DQO assessments from the past 8 years would have no change in the outcome upon implementing the 2024 Appendix A revisions.
- The revisions to the bias and precision equations lead to a higher rate of moving from DQO violation to adherence, compared to vice versa.
- The reduction in the minimum acceptable $PM_{2.5}$ concentration from 3 to 2 $\mu g/m^3$ resulted in nearly no movement from violation to adherence for the precision DQO, and in only a 3% movement from violation to adherence for the bias DQO.

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It can be done

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