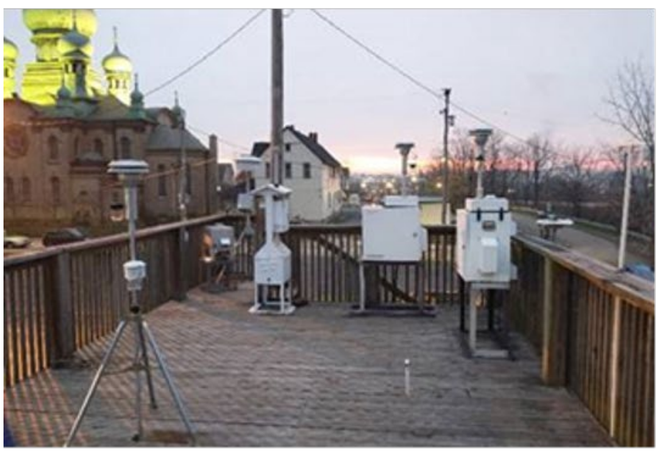
5-Year Monitoring Network Assessment

for the Region 5 States:

Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin

2025 Final Report – DRAFT FOLLOWING STATE REVIEW

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Executive Summary

As required by 40 CFR Part 58.10(d), a regional assessment of air quality monitoring for criteria pollutants was performed to provide the state and local networks with information on (1) whether their networks still meet the monitoring objectives, (2) whether new sites are needed, (3) whether existing sites are no longer needed, and (4) whether new technologies are appropriate for incorporating into the network.

Because the data analyses performed for this network assessment are potentially useful for many more purposes than this project, the state air monitoring agencies chose to present the bulk of this assessment online. The data are presented in an interactive ArcGIS Story Map that is accessible to anyone through the following link: https://arcg.is/1u4DCS1. Maps of the networks for each pollutant are available through the Story Map. The adequacy of current networks was assessed with a number of analyses, including area served, population served, cluster analysis, exceedance probability, design value, trend magnitude and direction, gridded emission inventory analysis, length of record, and number of parameters monitored. For fine particulate matter ($PM_{2.5}$), the assessment also examined trends over time and space in the chemical composition of fine particulates. The assessment also presents a continuous map of fused satellite-model-observation-based estimates of ground $PM_{2.5}$ concentrations, which provide insight into concentrations away from monitors.

This assessment evaluates the use of low-cost air quality sensors in the region and provides some best practices for their effective use. In addition, this assessment presents new tools to plot air toxics data over time and mapped over space. The assessment also evaluates how monitoring networks have been and may be impacted by extreme weather events and presents some lessons learned about how to protect monitoring assets from such events. Finally, the assessment includes a set of criteria that monitoring agencies should consider and a template to help make decisions about alterations to the ambient air monitoring network.

Key findings from the assessment are:

<u>Are state monitoring networks adequate?</u>

1. State monitoring networks meet or exceed U.S. Environmental Protection Agency (EPA) requirements.
2. Despite meeting all requirements, monitoring networks are not intended or able to address questions related to variations in air quality over fine spatial scales.

<u>Should new monitoring sites be added?</u>

3. New monitoring sites could be added only with additional, permanent sources of funding.

Can any existing sites be shut down?

4. Some monitors could likely be shut down without losing crucial information about regional-scale pollution.
5. No ozone monitors meet EPA's criteria for shutting down a monitor, and only 17 $PM_{2.5}$ monitors meet the shut-down criteria for both the annual and $PM_{2.5}$ NAAQS.
6. This assessment provides a template to help guide monitoring agencies through decisions about whether to shut down, relocate, or add monitors.

Should monitoring agencies incorporate any new technologies?

7. Low-cost air quality sensors can help provide better spatial coverage of some pollutants but have much poorer data quality than regulatory monitors. Sensors must be used very carefully to ensure data is meaningful and reliable.

What additional issues should monitoring agencies consider?

8. Air monitoring agencies should plan to make their monitoring networks more resilient to extreme weather events.

Introduction

As required by 40 CFR Part 58.10(d), a regional assessment of air quality monitoring for criteria pollutants was performed to provide the state and local networks with information on (1) whether their networks still meet the monitoring objectives, (2) whether new sites are needed, (3) whether existing sites are no longer needed, and (4) whether new technologies are appropriate for incorporating into the network. The assessment's recommendations are nonbinding and are intended to help inform the state and local agencies of the relative strengths and weaknesses of their networks.

Because the data for the networks is used for many more purposes than this 5-year assessment, the states chose to present the bulk of this assessment online as an ArcGIS Story Map. The flexibility of the web interface increases the usability of both the raw data and the results of the individual analyses. This interface allows the user to zoom in to an area of interest or zoom out for a region-wide perspective. Users can also click on individual monitors and bring up detailed data for that monitor. This data is important in many contexts, and we are pleased to make it widely available in an easy-to-use platform for state, local, and federal monitoring and policy staff, as well as the general public.

This assessment focused on ozone and $PM_{2.5}$ because those are the criteria pollutants that present by far the greatest threat to public health in the region. Other pollutant monitoring is assessed more qualitatively. Note that there is an appendix at the end of the Story Map that gives additional details about the methodology used for many of the analyses.

Overview of Current Networks and Monitoring Objectives

The state, local, and tribal agencies in EPA Region 5 currently operate roughly 400 criteria pollutant monitoring sites. Maps of the networks for each pollutant are available in the Introduction section of the Story Map. Since the last 5-year assessment in 2020, the states have begun collecting most parameters for the redesigned Photochemical Assessment Monitoring Stations (PAMS) network[1], including operating auto-GC instruments to measure hourly volatile organic compounds (VOCs) and ceilometers to measure boundary layer height. Additionally, several states have converted more of their 24-hour filter-based $PM_{2.5}$ monitors to continuous monitors, and Michigan added enhanced monitoring at the Holland site (260050003), including black carbon, direct nitrogen dioxide (NO_2), and mixing height by ceilometer. Monitoring agencies were also able to upgrade a lot of monitoring equipment using federal funds from the Inflation Reduction Act and the American Recovery and Reinvestment Act. A current challenge is balancing public expectations of real-time air quality data with the limitations of stagnant or shrinking budgets and low-cost sensor performance. Future changes to monitoring networks are anticipated in response to the 2024 $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) revision and accompanying EPA updates to 40 CFR Part 58 included in the Reconsideration of the National Ambient Air Quality Standards for Particulate Matter.

The adequacy of current networks was assessed with a number of analyses. EPA's monitoring regulations (Appendix D to 40 CFR Part 58) identify three general monitoring objectives: (a) provide data to the public in a timely manner, (b) support compliance with the NAAQS and control strategy development, and (c) support air pollution research studies. For each objective, several analyses provided a technical basis on which to determine adequacy. Table 1 outlines the objectives and sub-objectives and then lists the components of the network assessment that address each objective; note that objective (b) has been split into two parts. The next section of this report outlines the individual analyses conducted, and the conclusions section pulls this information together to address whether the monitoring networks adequately address these objectives.

[1] Note that Indiana began this collection in 2019.

Table 1. Monitoring objectives and corresponding data analysis in the network assessment.

Objective	Sub-objective	Analysis in Assessment
Provide data to public in timely manner	Public reporting, including spatial representations of data	Spatial analyses, including: Area and population served, Clustering of monitors, Length of records, Number of parameters, Air toxics data tools
Support compliance with the NAAQS	Attainment analysis	Concentration-based analyses, including: Design values, Design value trends, Exceedance probability, Emissions inventory maps, Satellite-derived $PM_{2.5}$ maps
Support control strategy development	Characterize regional concentrations; track progress	Spatial analyses (above), and: $PM_{2.5}$ chemical composition, Emissions inventory maps, Air toxics data tools (for VOC precursors)
Support air pollution research		Emissions inventory analysis and $PM_{2.5}$ chemical composition analysis (and analyses listed above)

ArcGIS Story Map

The main online tool developed for the network assessment is an interactive Story Map built on ESRI's ArcGIS Online platform (https://arcg.is/1u4DCS1). Most of the analyses performed as part of this assessment are presented as layers that can be selected and viewed on the map. Data for this tool are primarily shown just for the Region 5 states, although some data is shown for the entire country. Users can view data for the region as a whole or zoom to an area of interest. Popup boxes for each monitor or feature provide location, site ids, design values, and other associated information. Additional layers (described further below) include nonattainment areas, gridded emissions, and analysis results. It is also possible to download the underlying data for most maps.

The maps (described further below) include nonattainment areas for all criteria pollutants; monitoring networks for criteria and non-criteria pollutants, gridded emissions for sulfur dioxide (SO_2), nitrogen oxides (NOx), VOCs, ammonia, and directly emitted $PM_{2.5}$; design values for ozone and $PM_{2.5}$; and many others. Principal components analysis and cluster analysis by core based statistical area (CBSA) show which monitors are most closely related and measuring similar air masses. Tools to examine trends and spatial distribution of air toxics, as well as cancer risks from EPA's Air Toxics Screening Assessment, are included. The assessment also includes sections examining the use of low-cost sensors and risks to monitoring networks from extreme weather events. The sections are described in greater detail below. Each section has its own tab in the Story Map, which allows rapid navigation through the Story Map.

Introduction

The assessment begins with an overview of air quality monitoring and its role in air quality management. The assessment then presents maps of current nonattainment areas for each criteria pollutant as the first 'chapter' of the Story Map. These maps provide background information explaining the distribution of some pollutants, which helps drive monitor siting. Figure 1 shows the map of the 2015 ozone NAAQS nonattainment and maintenance areas as an example. Layers for each pollutant can be turned on or off. These layers reflect the most recent maps available from EPA, and the most recent regulatory data is available from EPA's Green Book. The introduction then presents a summary of the status of the monitoring networks, which includes a map of the locations of all of the roughly 400 criteria pollutants monitors (Figure 2). Individual pollutant networks can be selected. The monitoring networks are most extensive for ozone and PM2.5, which pose the greatest risk to public health. This section also discusses the current funding situation for monitoring networks and the need for continued EPA support for the $PM_{2.5}$ Chemical Speciation Network (CSN). This introductory section ends with information about navigating through the Story Map and how to access layers, legends, and underlying data.

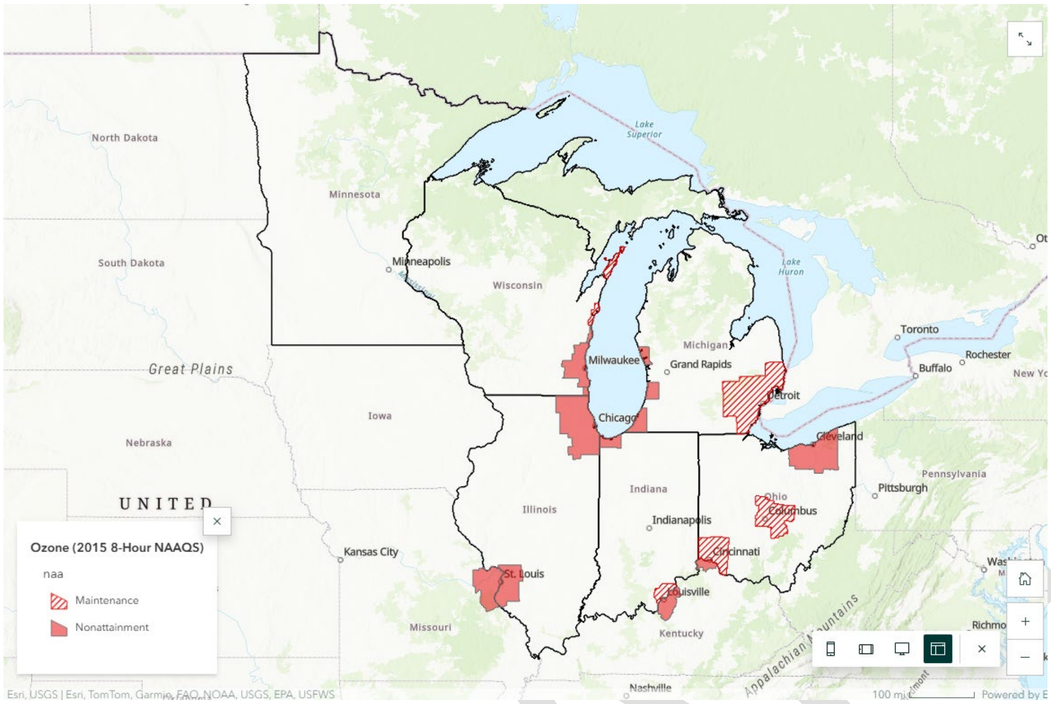

Figure 1. Example of nonattainment and maintenance area map layers, shown for the 2015 ozone NAAQS.

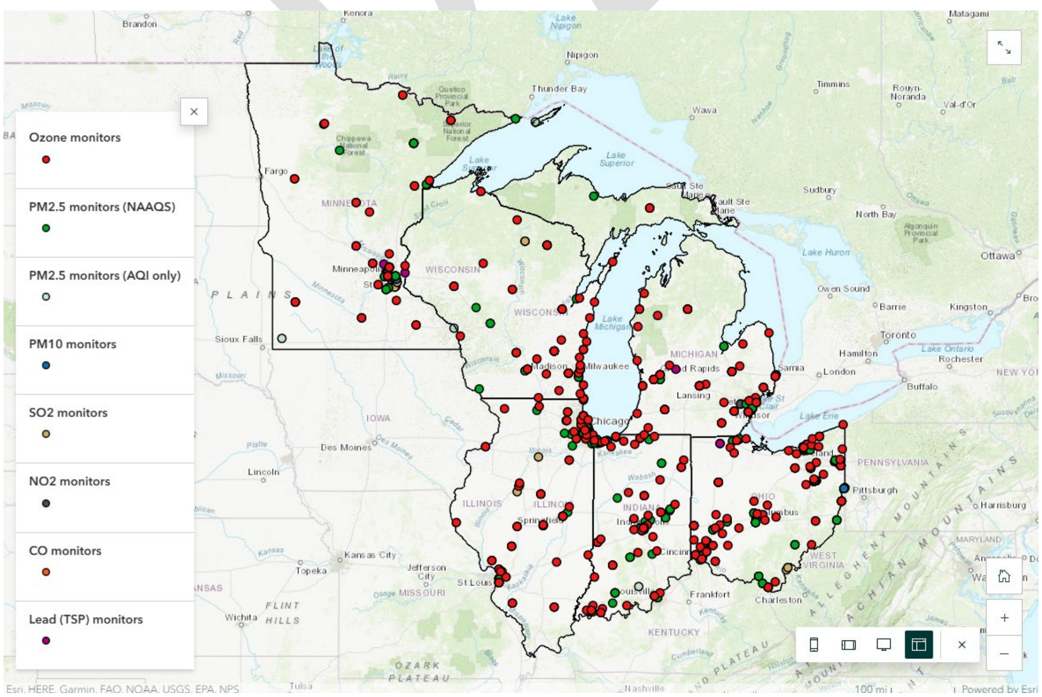

Figure 2. Map of all criteria pollutant monitors.

Monitoring Networks

Maps of the various networks make up the Monitoring Networks section of the Story Map. The section opens with a map showing the length of the monitoring record at each criteria pollutant site (Figure 3). Monitoring records range in length from 1 year to 59 years for a lead monitor in Minneapolis. Long-running monitors are especially valuable because currently monitored pollutant concentrations can be put into historical context. The next map in the section shows the number of parameters measured at each (Figure 4). Some sites measure only one pollutant, others have multiple monitors and measure many pollutants. Having multiple pollutant species measured at the same site can make that site more valuable to analysts who use the data to interpret related health impacts and determine the emission sources contributing to a community's air pollution. Maintaining a monitoring site requires a considerable investment of staff time and operating costs, so it is often advantageous to maximize the number of parameters measured at each site and minimize the number of sites collecting just one or two parameters.

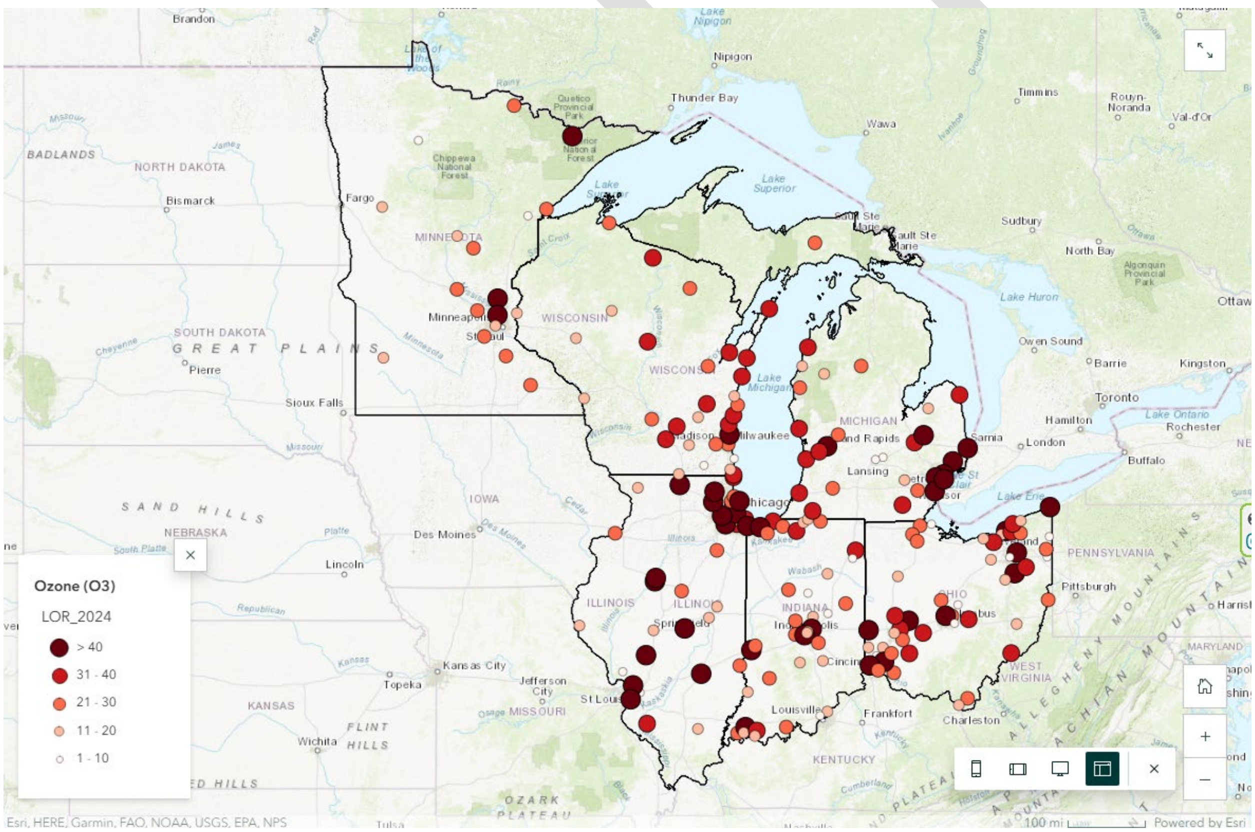

Figure 3. Example map showing the length of the monitoring record (in years) at each site, with ozone monitors shown as an example.

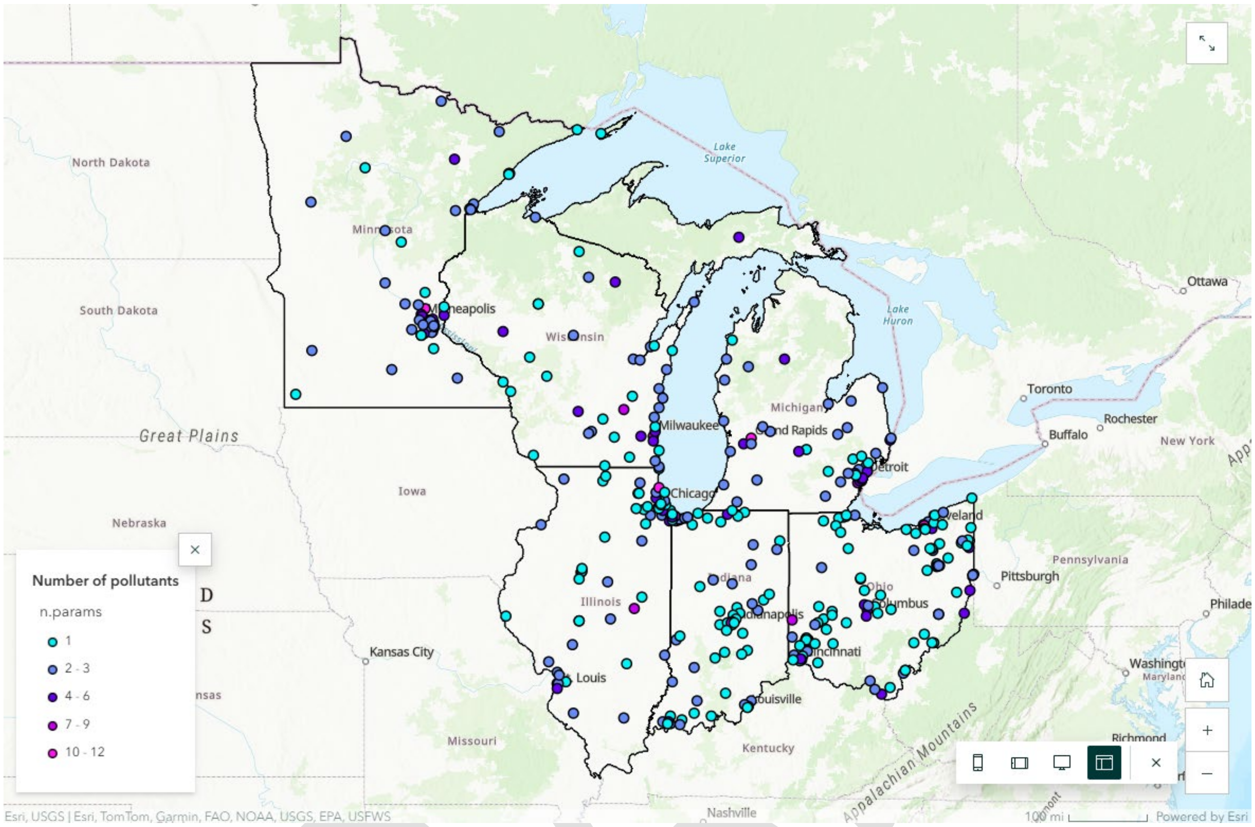

Figure 4. Map of the number of pollutants monitored at each monitoring site. Note that each non-criteria pollutant network site is counted as one "pollutant" for this purpose, regardless of how many pollutants are measured by that network.

This section also shows the distribution of non-criteria pollutant monitoring networks. These networks include:

- The National Core multipollutant monitoring stations (NCORE) network (Figure 5),
- The Photochemical Assessment Monitoring Stations (PAMS) program,
- The Clean Air Status and Trends Network (CASTNET),
- The Near-Road Monitoring Network,
- Air toxics monitoring networks,
- The $PM_{2.5}$ Chemical Speciation Network (CSN),
- The Interagency Monitoring of Protected Visual Environments (IMPROVE) network, and
- Meteorological monitoring networks.

Figure 5. Example map of the non-criteria pollutant monitoring networks, showing the NCore network as an example.

Ozone and $PM_{2.5}$ Monitoring

The assessment contains separate tabs for ozone monitoring analyses and for $PM_{2.5}$ monitoring analyses. Most of the elements of these two tabs are similar, but the $PM_{2.5}$ section contains two additional types of information not available for ozone. For many parts of the $PM_{2.5}$ section, the Story Map includes maps for both the annual and daily $PM_{2.5}$ NAAQS. Both sections begin with a map of design values for the 2021-2023 set of years (Figure 6). The design value is the statistic that is compared with the level of the NAAQS. Monitoring sites with high design values are important because they reflect higher risks to public health from pollutant exposure and may lead to nonattainment status for the NAAQS. Both ozone and annual $PM_{2.5}$ had some sites with design values exceeding the NAAQS; no daily $PM_{2.5}$ design values exceeded that NAAQS. The next map shows the trends in the design values from 2010 to 2023, with trends classified as increasing, decreasing, no trend, or NA (insufficient data) (Figure 7). Most sites had decreasing design values or no trend for all of the NAAQS. No $PM_{2.5}$ sites showed increasing trends, and only a small number of ozone sizes had increasing design values. Details of the annual design values and the trends analysis, including a figure, are available by clicking on the site symbol.

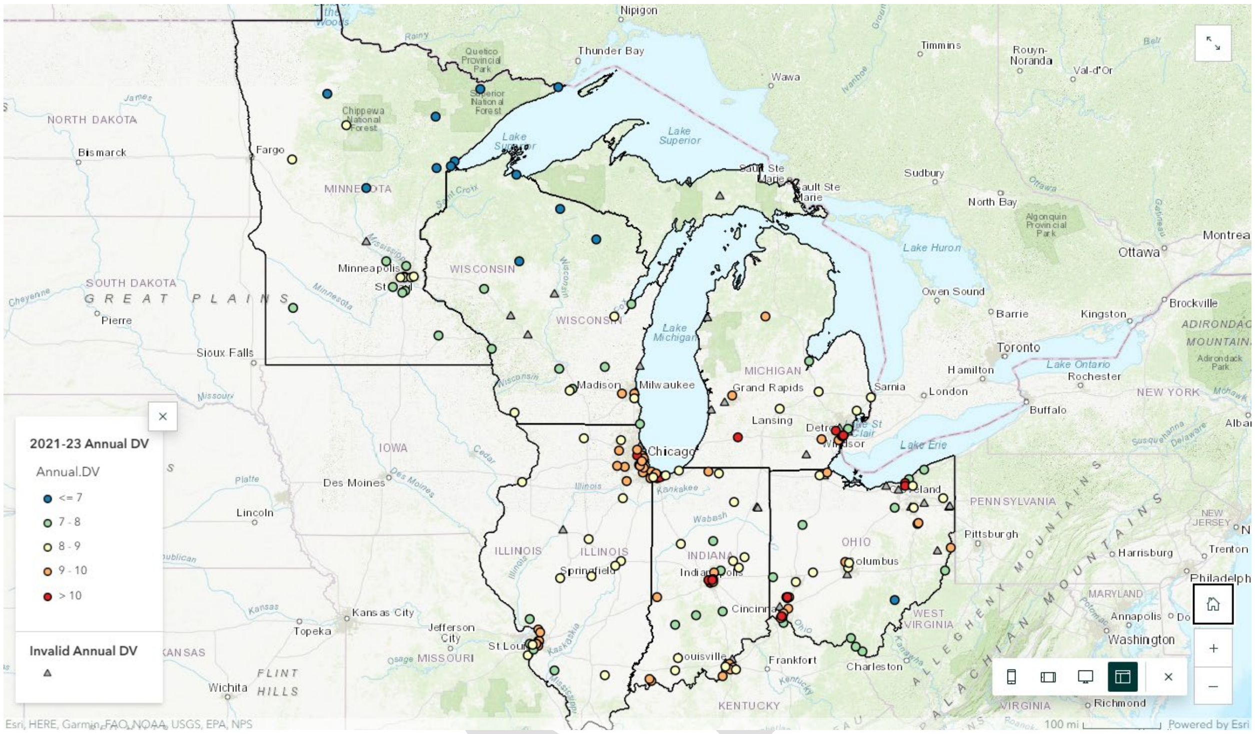

Figure 6. Example map of 2021-2023 design values, with design values for the annual $PM_{2.5}$ NAAQS shown.

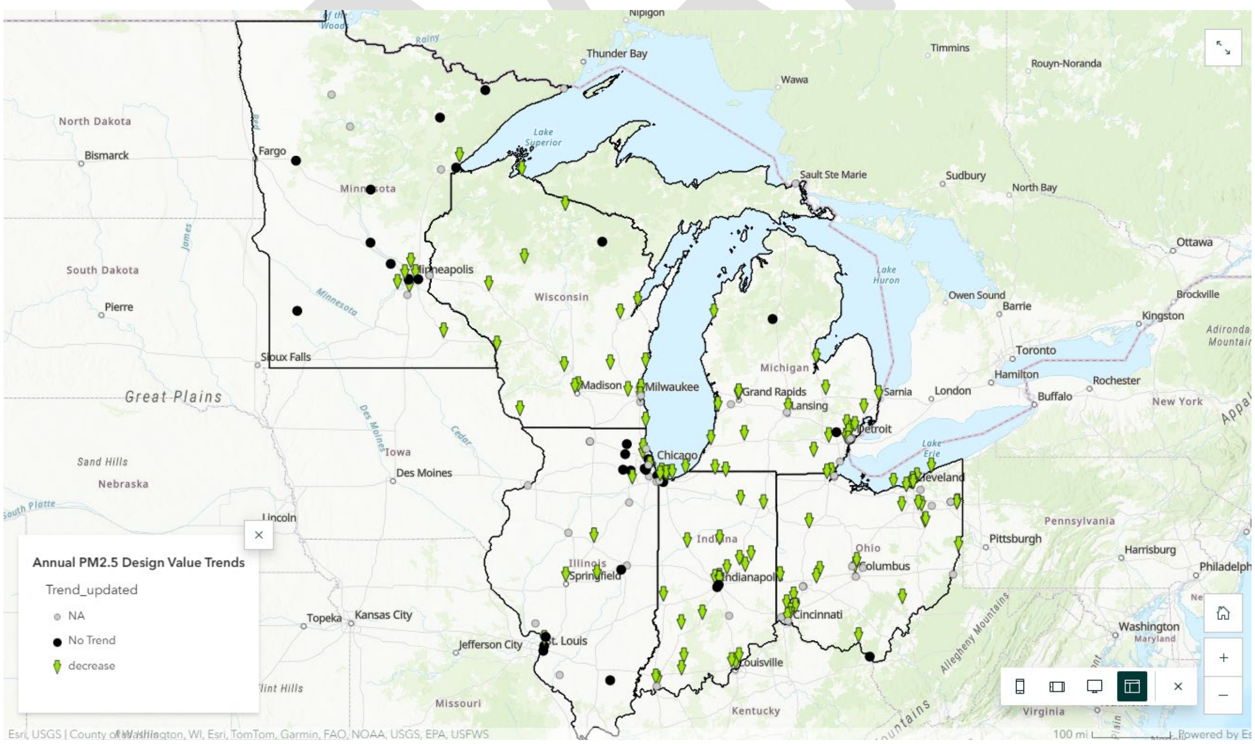

Figure 7. Example map of design value trends for 2010 through 2023, shown for the annual $PM_{2.5}$ NAAQS. There were no monitors with increasing trends.

Both the ozone and $PM_{2.5}$ sections include an analysis of the area and population represented by each monitoring site, conducted using a spatial analysis technique known as Voronoi or Thiessen polygons. The shape and size of each polygon is dependent on the proximity of the nearest neighboring monitors to a particular site. All points within a polygon are closer to the monitor in that polygon than to any other monitor. Once the polygons are calculated, the area encompassed by each is calculated. In addition, the population residing within the polygon is determined from U.S. Census data.

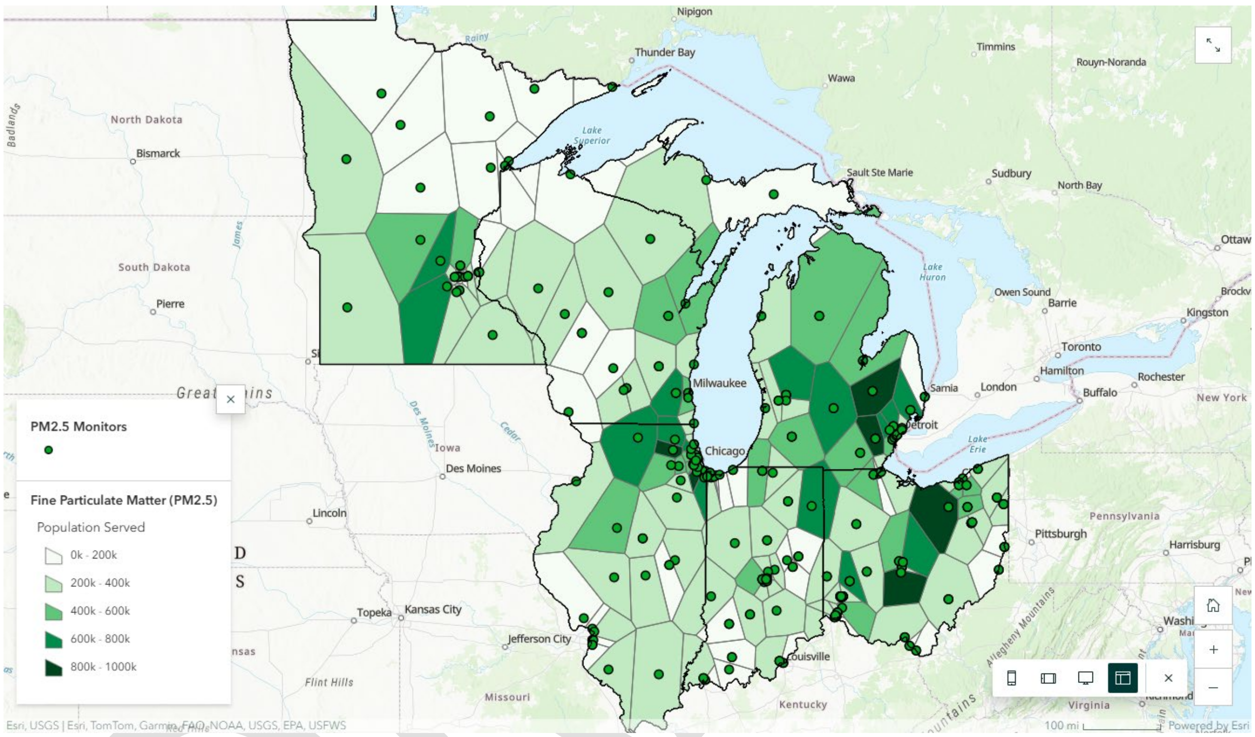

Figure 8. Example Voronoi polygons showing the population served by each $PM_{2.5}$ monitor.

The assessment also evaluates the exceedance probability of ozone and $PM_{2.5}$ monitors as a way of testing whether the monitor could be eligible to be shut down or relocated. In order for a criteria pollutant monitor to be shut down, EPA requires that monitors meet the following conditions:

1. The monitor must have showed attainment during the previous five years.
2. The probability must be less than 10% that the monitor will exceed 80% of the applicable NAAQS during the next three years based on the concentrations, trends, and variability observed in the past.
3. The monitor must not be specifically required by an attainment or a maintenance plan.
4. The monitor must not be the last monitor in a nonattainment area or maintenance area that contains a contingency measure triggered by an air quality concentration in the latest attainment or maintenance plan adopted by the state and approved by EPA.

The probabilities listed in bullet 2 were calculated using the method described in EPA-454/D-07-001, Ambient Air Monitoring Network Assessment Guidance, for the 2019-2023 design values (Figure 9). The values plotted are the upper confidence bound (at the 90% confidence interval) for the mean design values, expressed as a fraction of the standard level. If the values are less than 0.8 (80%), then the monitor meets criterion #2 above and may be eligible to be shut down. No ozone monitors met this condition, but 17 $PM_{2.5}$ monitors met this criterion for both the annual and daily $PM_{2.5}$ NAAQS. (See the appendix for a list of these monitors.) These monitors may be eligible to be shut down without an exception from the Regional Administrator assuming they meet the other criteria outlined above.

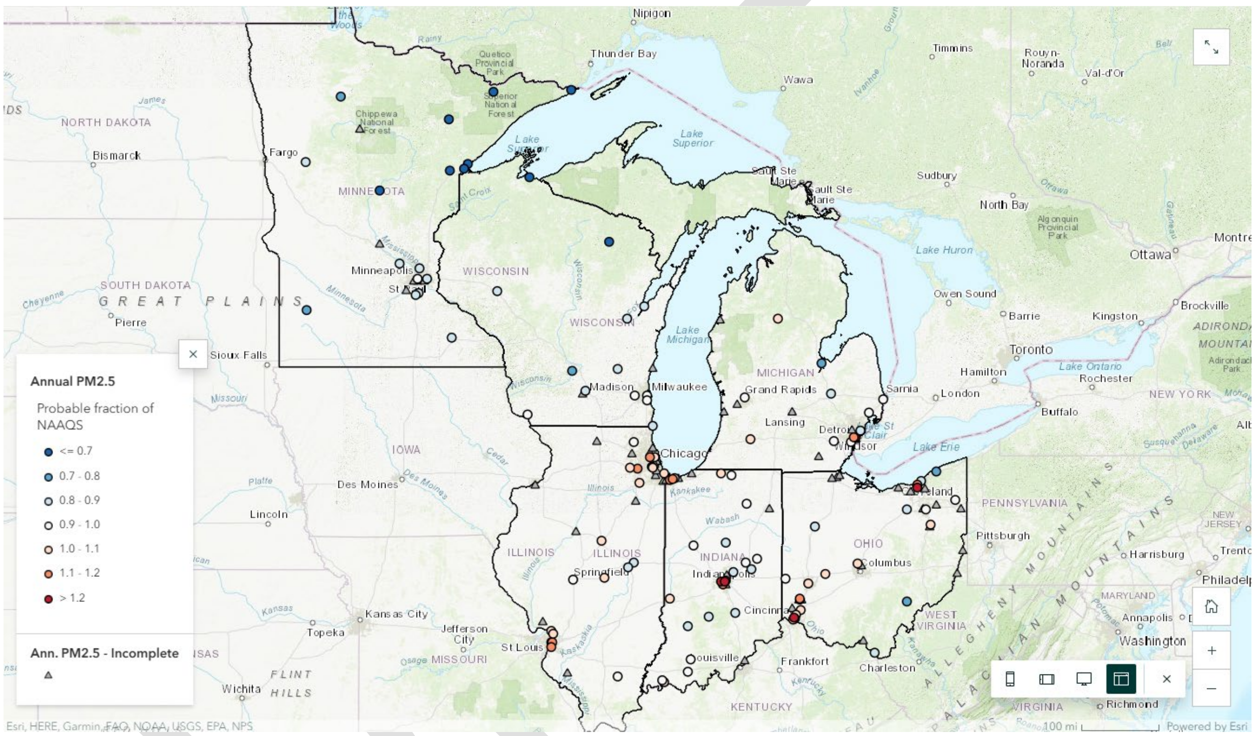

Figure 9. Example exceedance probability map for the annual $PM_{2.5}$ NAAQS. The values plotted are the upper confidence bound (at the 90% confidence interval) for the mean design values, expressed as a fraction of the standard level.

In addition to these components, the $PM_{2.5}$ monitoring section also contains maps and plots of the chemical composition of $PM_{2.5}$ over time in the summer and winter. $PM_{2.5}$ is composed of a complex mixture of different chemical components, and different compounds may dominate under different conditions. It is crucial to know the chemical composition of $PM_{2.5}$ to understand what emission sources are contributing to the $PM_{2.5}$. Having this knowledge is essential if states need to develop control strategies to lower emissions in order to attain the $PM_{2.5}$ NAAQS. The figures show that currently in the Great Lakes region, organic matter (OM) is the most important component in the summer (Figure 10), and ammonium nitrate (AmmNO3) is most important in the winter. Over time, concentrations of ammonium sulfate (AmmSO4) have decreased dramatically (Figure 11), particularly in the summer.

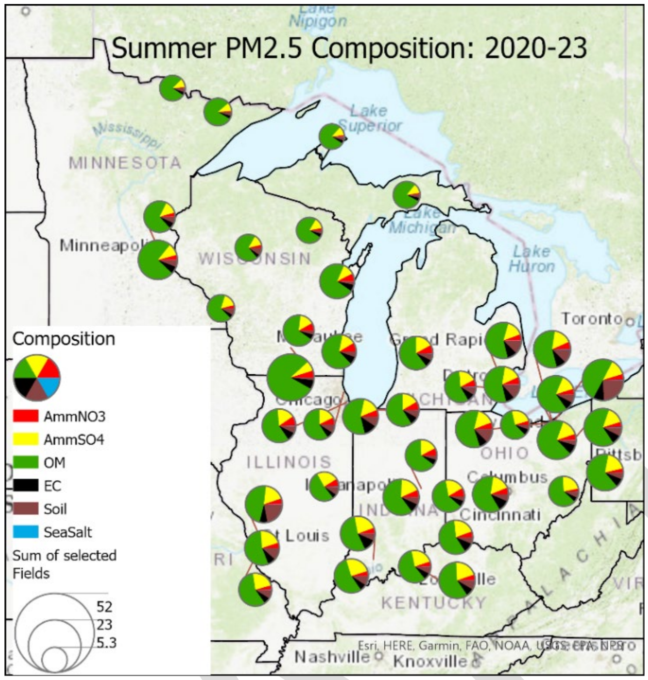

Figure 10. Example map of the chemical composition of $PM_{2.5}$ in the summer in 2020-2023. Maps are also shown for the winter and zoomed in on urban areas with more than one monitor. Note that these maps are not interactive.

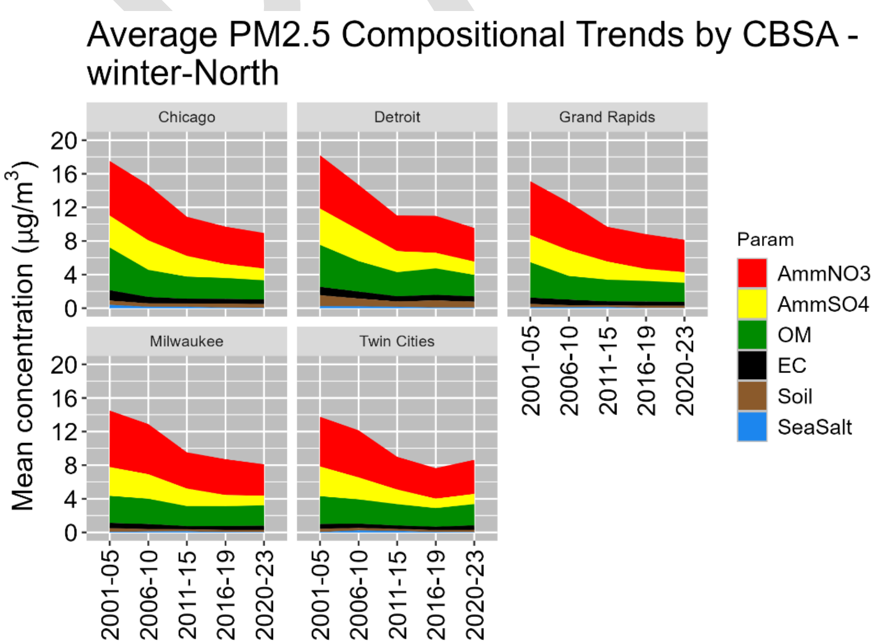

Figure 11. Example figure of changes in $PM_{2.5}$ chemical composition over time in the winter in northern cities. Figures are also available for southern cities, rural areas, and for the summer.

The $PM_{2.5}$ section also includes a map of satellite-derived estimated $PM_{2.5}$ concentrations for 2022, combined with the locations of $PM_{2.5}$ monitors (Figure 12). Satellite-derived observations of aerosols provide information about levels of particulates around the region, not just at regulatory monitors. Satellites provide the possibility of evaluating $PM_{2.5}$ concentrations continuously around the region, which could inform future placement of monitors, sensors, or areas of study. The satellite data was processed by the Atmospheric Composition and Analysis Group at Washington University in St. Louis using machine learning with modeled and observed data to estimate ground-level concentrations.

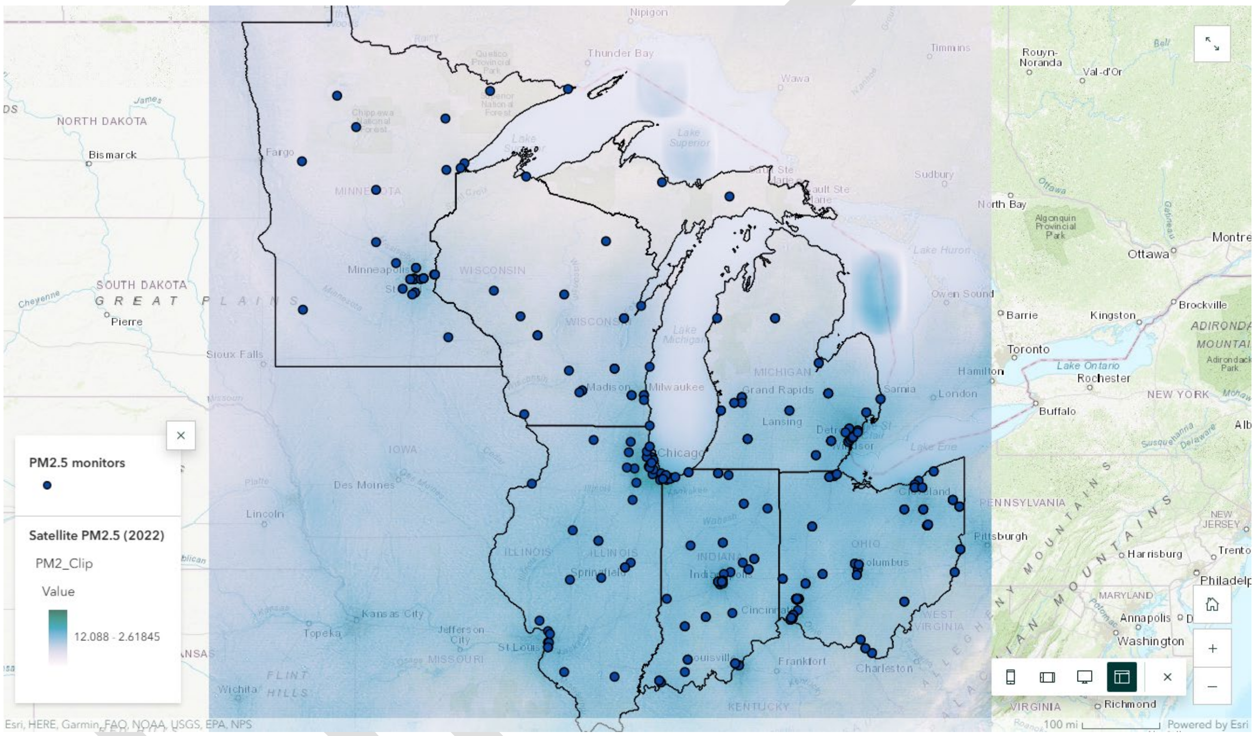

Figure 12. Satellite-estimated ground-level $PM_{2.5}$ concentrations for 2022 (from Washington University in St. Louis) plotted with $PM_{2.5}$ monitors. Annual average concentrations range from 2.6 μg/m³ (light purple) to 12.1 μg/m³ (dark green).

Emissions

Comparison of the locations of emissions sources with the locations of air pollution monitors can facilitate evaluation of whether the monitoring networks adequately capture the locations of highest emissions. Emissions density maps can help determine whether there are areas of higher emissions that might benefit from additional monitoring, or areas upwind of high concentrations that should be monitored for better characterization of urban-rural differences or adequate spatial characterization. This assessment includes maps of emissions of NOx, VOCs,

SO_2, directly emitted $PM_{2.5}$, and ammonia (NH_3) from the LADCO 2016 emissions inventory[2] plotted on the national 12-km grid used for photochemical modeling. The locations of monitors of related pollutants (e.g., the emitted pollutant and/or pollutants that are formed from the emitted pollutant) are plotted on top of the maps of emissions (Figure 13). For example, the map of NOx emissions includes maps of nitrogen dioxide (NO_2) monitors, as well as of ozone and $PM_{2.5}$ monitors since these two secondary pollutants are formed from reactions of NOx in the atmosphere.

The maps show that emissions of NOx, most VOCs, and directly emitted $PM_{2.5}$ are greatest in urban areas, which are also where most of the air quality monitors are located. This suggests that at the high level, the monitors are appropriately located. The placement of the SO_2 monitors in general coincides with areas of highest emissions near major point sources, so that high concentrations of SO_2 will be recorded by the monitor for comparison with the NAAQS. A few areas of high 2016 SO_2 emissions are not close to monitors and may warrant investigation. Emissions of biogenic VOCs are also important in some heavily forested areas. Monitoring of VOCs and their reaction products (ozone and $PM_{2.5}$) may not be adequate to measure the impacts of these natural pollutants. Finally, emissions of ammonia are greatest in rural, agricultural areas, however, monitoring of ammonia is very sparse and limited to a few sites that measure 2-week average concentrations via the Ammonia Monitoring Network (AMON). Since ammonia is an important precursor of $PM_{2.5}$, it would be helpful to have better methods and more monitors to measure ammonia concentrations in the ambient air.

[2] 2016 emissions are the most recent available. However, emissions of many pollutants have decreased significantly since 2016. This means the magnitude of emissions shown here is no longer relevant, but the spatial distribution of emissions should remain fairly similar.

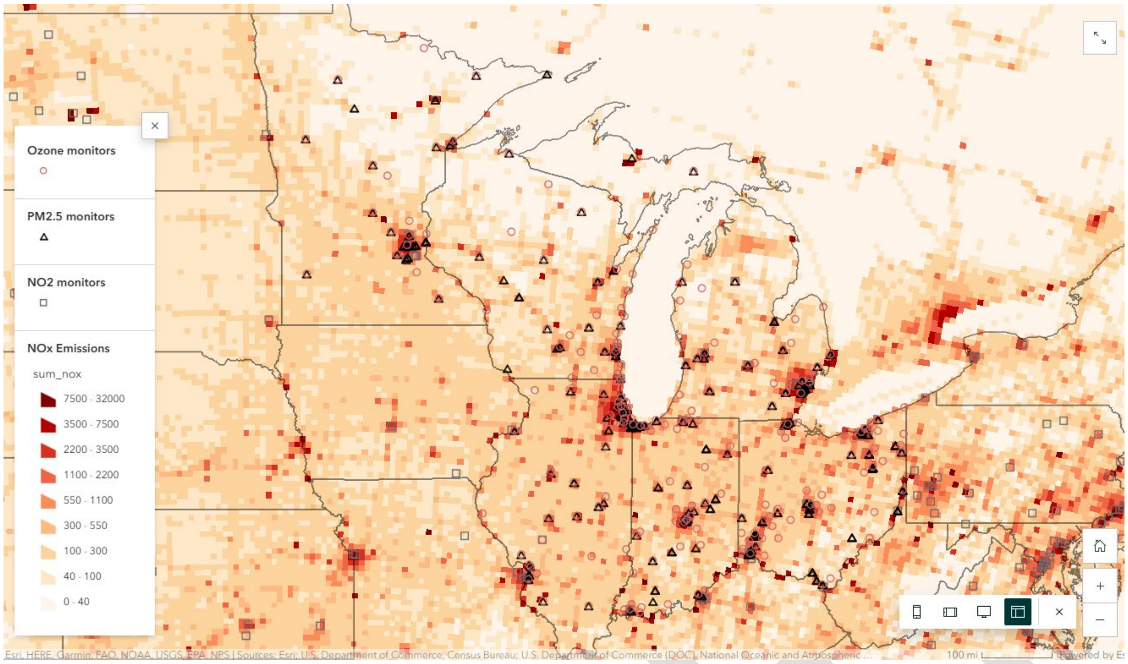

Figure 13. Example map of emissions of NOx from the LADCO 2016 emissions inventory plotted with the locations of monitors of related pollutants: NO_2, $PM_{2.5}$, and ozone.

Monitor Clusters

Cluster analysis was performed for ozone and $PM_{2.5}$ monitors in each urban area to see which monitors are closely related based on annual average concentrations. The degree of clustering can be used to evaluate how much unique information is provided by monitors. The distance on the two axes (Dim1 and Dim2) correspond to differences between the monitors (Figure 14). Monitors that group near each other in the plots have concentrations that track each other, whereas monitors that are distant from each other have different patterns. The more tightly the monitors cluster and the more monitors in any given cluster, the more likely that there are more monitors than needed in that category. Many monitor clusters in the region contained just a few monitors, suggesting that the loss of any monitor would lead to a loss of information about that pollutant. However, some clusters contained up to 8 or 10 monitors; some of the monitors in these clusters could likely be shut down without significant loss of information about pollutant concentrations and trends in these areas.

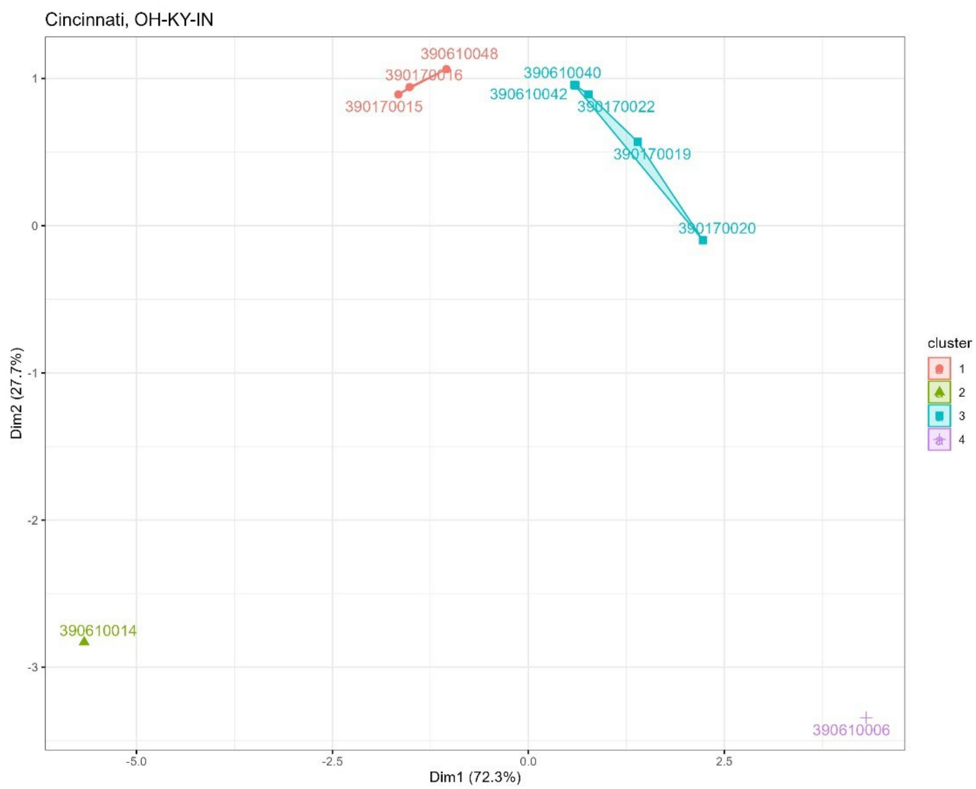

Figure 14. Example plot of clusters of $PM_{2.5}$ monitors for the Cincinnati, OH-KY-IN CBSA.

Low-Cost Sensors

Air quality sensors provide a relatively low-cost way to track and understand air quality conditions. Air sensors are much less expensive and easier to operate compared to regulatory monitors. However, the data quality from sensors is much lower than that from regulatory monitors and cannot be used as the basis for regulatory decisions. Sensor data can be difficult to interpret. This section presents how air quality sensors are being used in the Great Lakes region, discusses the benefits and limitations of sensors, outlines some best practices for use of sensors and sensor-derived data, and provides links to additional resources. This section includes:

- A map of PurpleAir sensors in the region from EPA's Fire and Smoke map (Figure 15),
- A map of the location of EPA Region 5's Sensor Loan Program projects,
- A photo of the deployment of four different sensors and one regulatory monitor and a discussion of how monitoring agencies in the region are using sensors,
- A discussion of the benefits and limitations of sensors,
- A list of best practices for the use of sensors, and
- Links to additional resources.

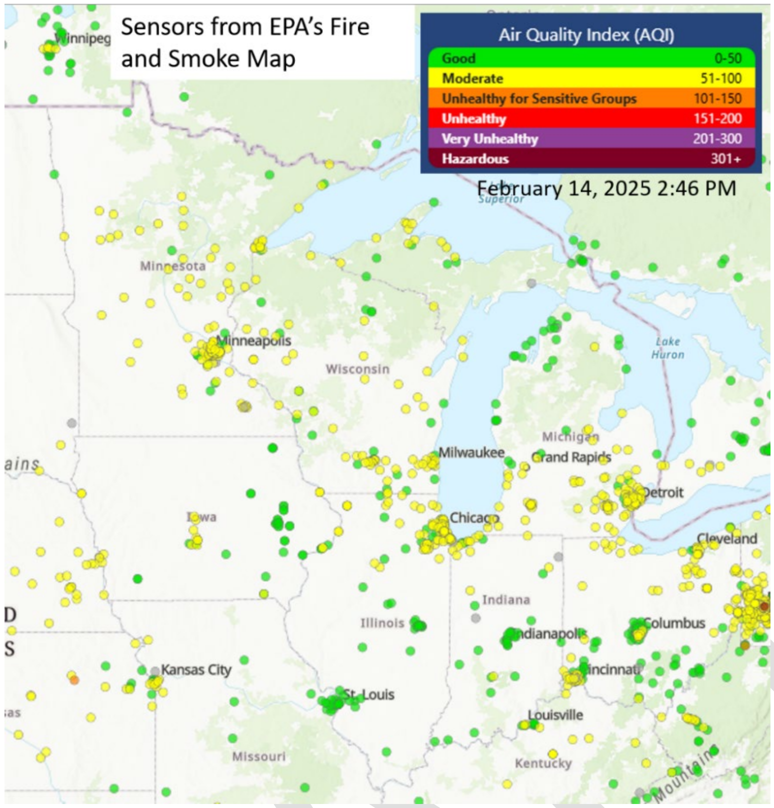

Figure 15. Map of a subset of air quality sensors in the region, color-coded by their air quality index. Data from February 14, 2025 at 2:46 pm is shown as an example. The image is from the AirNow Fire and Smoke Map and primarily includes Purple Air sensors.

Air Toxics and Risk

Air toxics are pollutants that cause or may cause cancer or have other serious health impacts, including contributing to birth defects or causing other reproductive problems. Air toxics do not have nationwide, enforceable, ambient standards like criteria pollutants, but the emissions of some air toxics (known as hazardous air pollutants) are regulated under the Clean Air Act. This section includes two new, interactive apps to explore annual average concentrations of air toxics around the region. One app allows the graphing of annual average concentrations of user-selected air toxics over time (2010 to 2023) for selected sites in a selected CBSA (Figure 16). The other app maps out annual average concentrations of a user-selected pollutant for a selected year (Figure 17). This section also includes a map of the location of air toxics monitors with the cancer risk distribution (Figure 18).

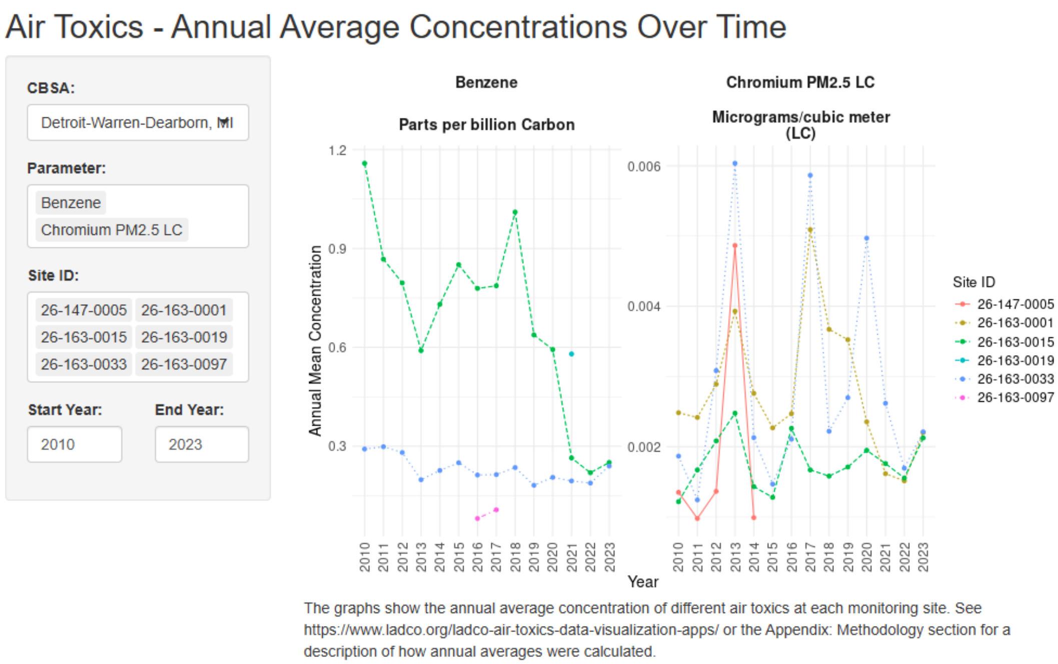

Figure 16. Example output of the interactive app showing air toxics concentrations over time. The app shows annual concentrations of chosen air toxics plotted by year for selected monitors in a selected CBSA.

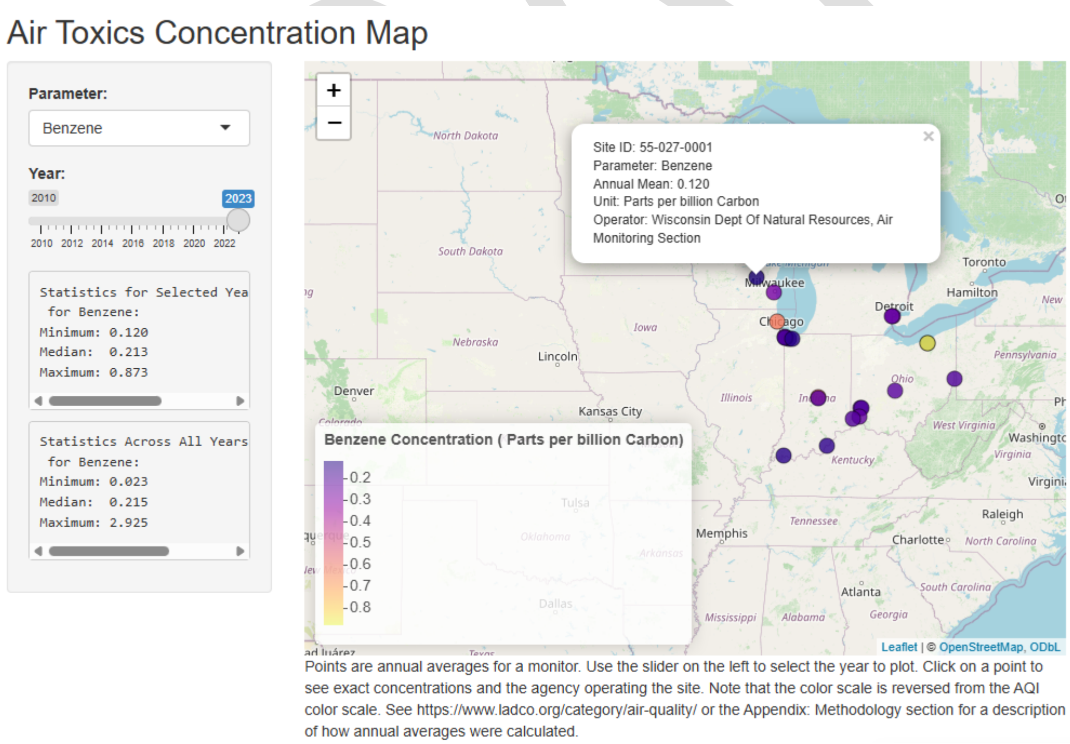

Figure 17. Example output of the interactive app mapping out air toxics concentrations. The app shows the annual average concentrations for selected pollutant in a selected year.

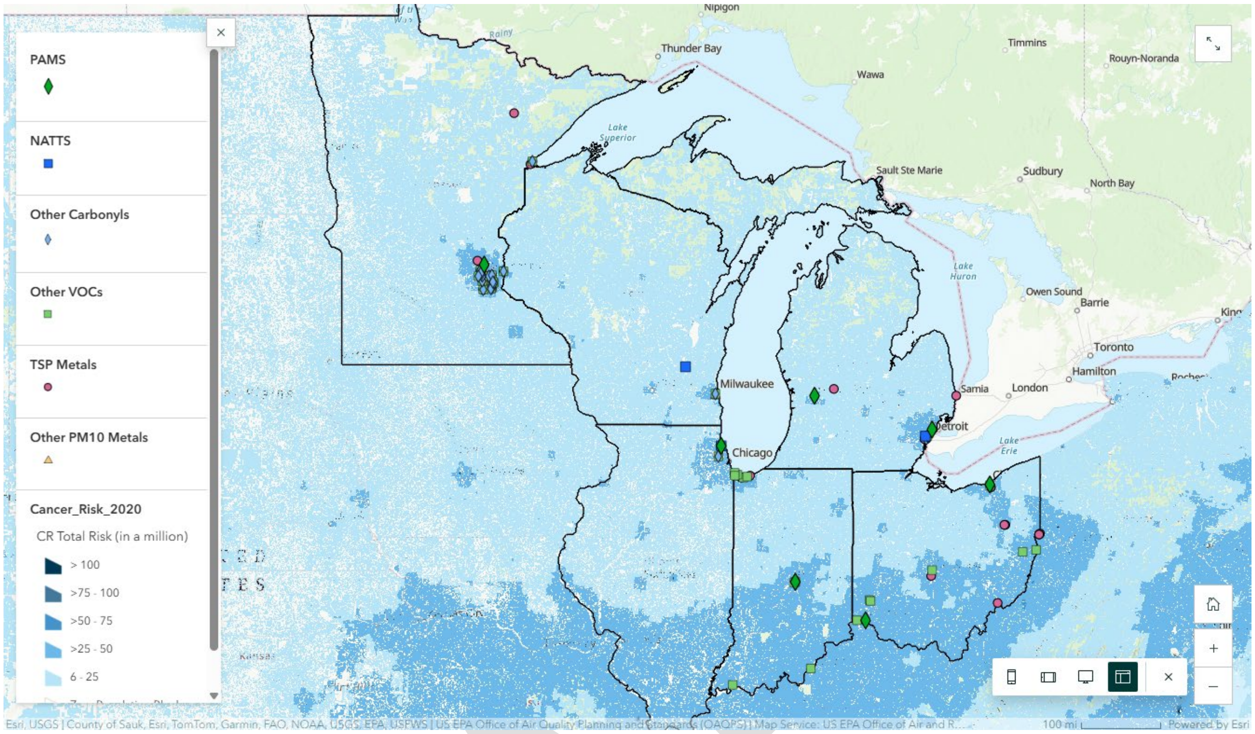

Figure 18. Map of the locations of air toxics monitors on top of cancer risk from EPA's Air Toxics Screening Assessment.

Impacts from Extreme Weather

This section discusses how different types of extreme weather events may impact air monitors. It also discusses steps monitoring agencies may take to minimize disruptions as a result of these events. This section includes considerations of impacts from:

- High temperature and humidity
- Strong storms and wind
- Flooding, including a figure showing which monitors are located in floodplains (see Figure 18)
- Winter weather
- Fire events, including figures showing the spatial extent of smoke impacts on $PM_{2.5}$ in June 2023 and the annual average smoke impacts from 2006 to 2023.

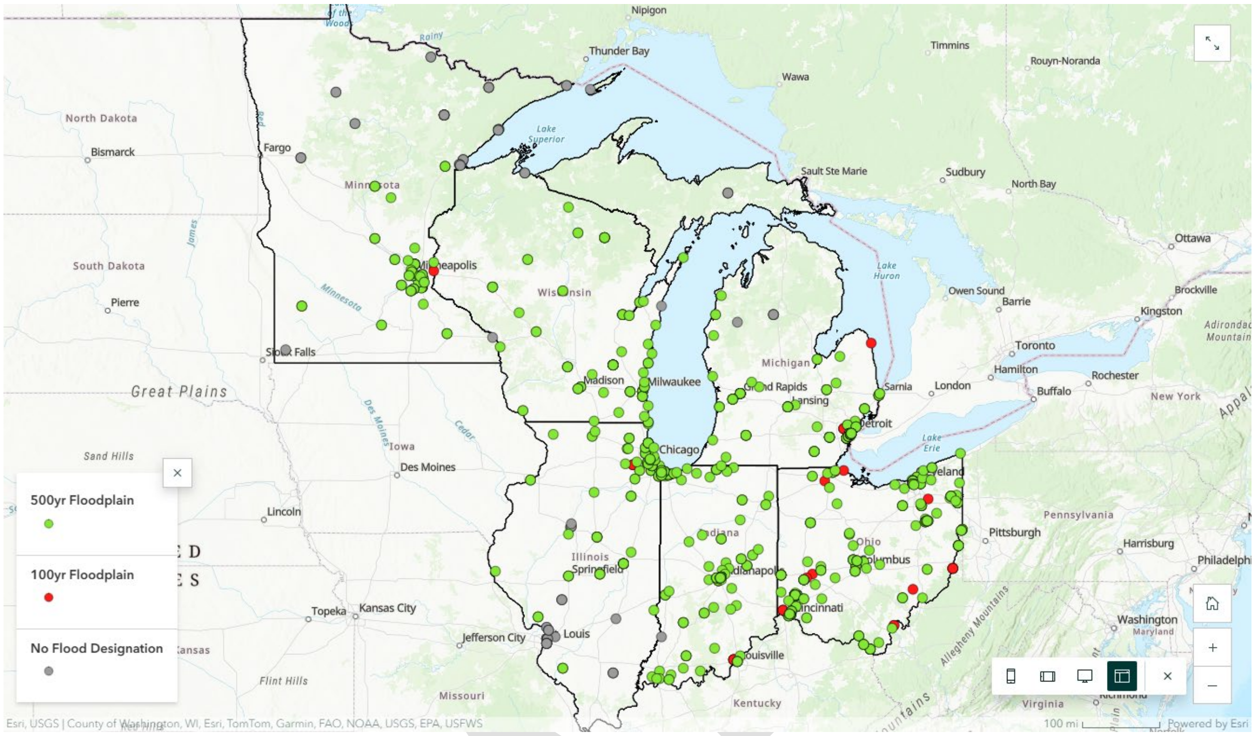

Figure 19. Map identifying whether air quality monitors are in 100-year or 500-year floodplains or are in an area without a floodplain designation.

Network Modification Considerations

Unlike in previous network assessments, this assessment does not attempt to rank the importance of monitors based on a combination of different criteria. It is difficult-to-impossible for any single ranking to adequately consider all of the relevant factors, particularly since different monitors may be needed for different purposes, which would imply a different set of rankings be considered. Instead, the assessment includes a set of criteria that monitoring agencies could consider when making decisions about whether to shut down or relocate monitors. This approach allows monitoring agencies to focus on the criteria relevant for their particular monitor(s) and not be distracted - or have a rating influenced - by factors that are not relevant for that situation.

The suggested considerations include factors related to air quality, the uniqueness and impact of a monitor, pollutant emission sources, regulatory requirements for the monitor, and technical and community considerations. Not all of these criteria will be relevant for all monitors and areas, and other considerations not listed here may be important for some locations. Many of these criteria are presented elsewhere in this network assessment, such that data pulled from this assessment can help inform an evaluation. These criteria should assist agencies in making decisions that consider the particular needs of that location, community, and agency. The list of considerations and a monitor evaluation template can be accessed here.

Overall Conclusions

Are state monitoring networks adequate?

State monitoring networks meet or exceed EPA requirements. The criteria pollutant monitoring networks generally are adequate to meet EPA's minimum criteria. States operate more air monitors than required by EPA, as demonstrated in detail in each state's annual network plan. (See the Introduction of the Story Map for links to these network plans.) In addition, comparison of monitoring locations with emissions maps demonstrate that most of the monitors are located in the areas of peak emissions, including urban areas or near major point sources. Analysis of fused satellite-model-observation data for $PM_{2.5}$ confirms this for this pollutant. The monitoring networks also provide some coverage in rural areas, particularly for ozone and $PM_{2.5}$, which helps provide information about background levels of pollutants.

Despite meeting all requirements, monitoring networks are not intended or able to address questions related to variations in air quality over fine spatial scales. Regulatory monitoring networks will always be limited by the high costs (financial and personnel time) of operating and maintaining the high-quality equipment. Because of these constraints, it is not possible to deploy enough monitors to track all of the important variations in pollution on small spatial scales, such as near busy roadways or warehouses. In addition, networks don't provide good coverage of ammonia in general or of VOCs in areas of high biogenic emissions. Both pollutants are important precursors to $PM_{2.5}$, making understanding their concentrations and distribution increasingly important given the new $PM_{2.5}$ NAAQS. VOCs are also important ozone precursors.

Should new monitoring sites be added?

New monitoring sites could be added only with additional, permanent sources of funding. EPA funding for monitoring networks has been stagnant to shrinking for decades while monitoring requirements have increased. Monitoring agencies have been doing "more with less" for many years and do not have the resources to maintain existing monitoring networks or expand their networks without additional support.

Can any existing sites be shut down?

The analyses in this assessment suggest that some monitors could likely be shut down without losing crucial information about regional-scale pollution. State network plans show that monitoring agencies operate more monitors than are required by EPA. Furthermore, correlation and cluster analyses show that pollutant concentrations are closely correlated in many areas. This indicates that pollutant levels at multiple monitors closely track each other such that each monitor is not providing unique information.

However, no ozone monitors meet EPA's criteria for shutting down a monitor, and only 17 $PM_{2.5}$ monitors meet the criteria for both the annual and $PM_{2.5}$ NAAQS. Shutdowns of $PM_{2.5}$ and ozone sites are very difficult if not impossible because of extremely stringent criteria set by EPA. Even when sites are identified as highly correlated and of low value, most have a higher than 10% probability of measuring 80% of the NAAQS and are consequently not eligible. This analysis did not identify any of the more than 200 ozone monitors that met that criterion. EPA should consider relaxing this requirement so states can shut down highly correlated monitors in dense urban networks where multiple monitors are measuring the same air mass and not providing unique information. The current criteria for shutdowns give too much emphasis to high concentrations and not enough to the relative value of each site in terms of the airshed it monitors.

In contrast to ozone, 17 $PM_{2.5}$ sites meet the exceedance threshold criterion for both the annual and daily NAAQS. Some of these sites may be candidates for shutdowns if they are not required for other reasons. However, most of the monitors that met these criteria are located in small towns or rural parts of Minnesota and Wisconsin, not in large CBSAs with many monitors (see the Appendix). Shutdowns of rural or low concentration monitors must be done cautiously to avoid jeopardizing the important tasks of model validation and characterization of upwind and background concentrations. Photochemical modeling to develop emissions control programs for state implementation plans relies on those rural, upwind, and non-urban measurements of ozone, $PM_{2.5}$ mass, speciation, and precursor gases to provide defensible results. In particular, as concentrations fall, the role of background concentrations vs. local emissions becomes both more critical to understand and more difficult to distinguish, reinforcing the need for such measurements. Additionally, many of the potentially eligible monitors are operated by Tribes, who have their own motivations to operate their monitors.

This assessment provides a template to help guide monitoring agencies through decisions about whether to shut down, relocate, or add monitors. These considerations include the results of many of the analyses provided in this assessment as well as other factors.

Should monitoring agencies incorporate any new technologies?

Low-cost air quality sensors can help provide better spatial coverage of some pollutants, but sensors must be used very carefully to ensure data is meaningful and reliable. The use of low-cost sensors has continued to expand in the region. These sensors have a number of advantages over regulatory monitors, primarily in their affordability and accessibility. However, there remain serious concerns about the quality of the data they provide, the analytical limitations of the instruments, and other related issues. For these reasons, sensors cannot be used in place of regulatory monitors. This assessment recommends that monitoring agencies continue and expand their tests and use of sensors to provide additional information in combination with regulatory monitors. Furthermore, EPA and others should continue to support development and improvement of sensor technology. Careful use of air quality sensors could be particularly helpful at tracking fine-scale variations in pollution that require measurements in more locations than is feasible with regulatory monitors. To help support high-quality use of air sensors in the region, this assessment provides a list of benefits and limitations of sensors, as well as best practices for their use and links to more extensive resources to support their deployment.

What additional issues should monitoring agencies consider?

Air monitoring agencies should plan to make their monitoring networks more resilient to extreme weather events. This assessment discusses how monitoring networks have been and could be impacted by extreme weather, ranging from flooding to winter storms to wildfires. Monitoring agencies have developed some strategies to minimize the risk to their networks from these events. The assessment recommends that all agencies consider where their networks might be vulnerable to extreme weather events and develop plans to preserve the safety of their staff and integrity of their network and data if faced with such events.

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Appendix: Sites that meet EPA criteria for shutdown

This table lists currently operating $PM_{2.5}$ sites where the probability is less than 10% that the monitor will exceed 80% of both the annual and daily $PM_{2.5}$ NAAQS during the next three years based on the concentrations, trends, and variability observed in the past (design values from 2017-19 to 2021-23). No ozone sites met these criteria. This is not a recommendation for shutting down sites; that decision must be based on many additional considerations. In the table, the "Annual/Daily DV (upper bound)" is the upper confidence bound at the 90% confidence interval for the mean design values, expressed as a fraction of the standard level. If the values are less than 0.8 (80%), then the monitor meets the criteria outlined above and may be eligible to be shut down.

AQS Site ID	Local Site Name	CBSA Name	Ann. DV (upper bound)	Daily DV (upper bound)	2021-23 Ann. DV (μg/m^3)	2021-23 Daily DV (μg/m^3)
260170014	JENISON ST	Bay City, MI	0.782	0.566	7.3	21
270072304	Red Lake Nation	Bemidji, MN	0.747	0.799	6.9	30
270177417	Fond du Lac Band	Duluth, MN-WI	0.431	0.482	3.7	19
270317810	Grand Portage Band		0.471	0.458	2.7	17
270353204	Brainerd Lakes Regional Airport	Brainerd, MN	0.681	0.628	6.7	24
270750005	Boundary Waters		0.548	0.547	4.9	21
270834210	SW Minnesota Regional Airport	Marshall, MN	0.798	0.779	7.8	31
271377001	Virginia City Hall	Duluth, MN-WI	0.625	NA	6	NA
271377550	U of M - Duluth	Duluth, MN-WI	0.597	NA	4.5	20
271377554	Laura MacArthur School	Duluth, MN-WI	0.618	0.559	5.6	21
390090003	Gifford	Athens, OH	0.716	0.448	6.1	16
390850007	Painesville	Cleveland-Elyria, OH	0.781	0.563	7.2	22
550030010	BAD RIVER TRIBAL SCHOOL		0.569	0.499	5.4	19
550410007	POTAWATOMI		0.612	0.598	5.9	24
551110007	DEVILS LAKE PARK	Baraboo, WI	0.795	0.684	7.5	27

Data marked "NA" was invalid.