Guidance for Inhalation Exposures to Particulate Matter

Citation:
[ATSDR] Agency for Toxic Substances and Disease Registry. 2024. Guidance for Inhalation Exposures to Particulate Matter. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, June 2024

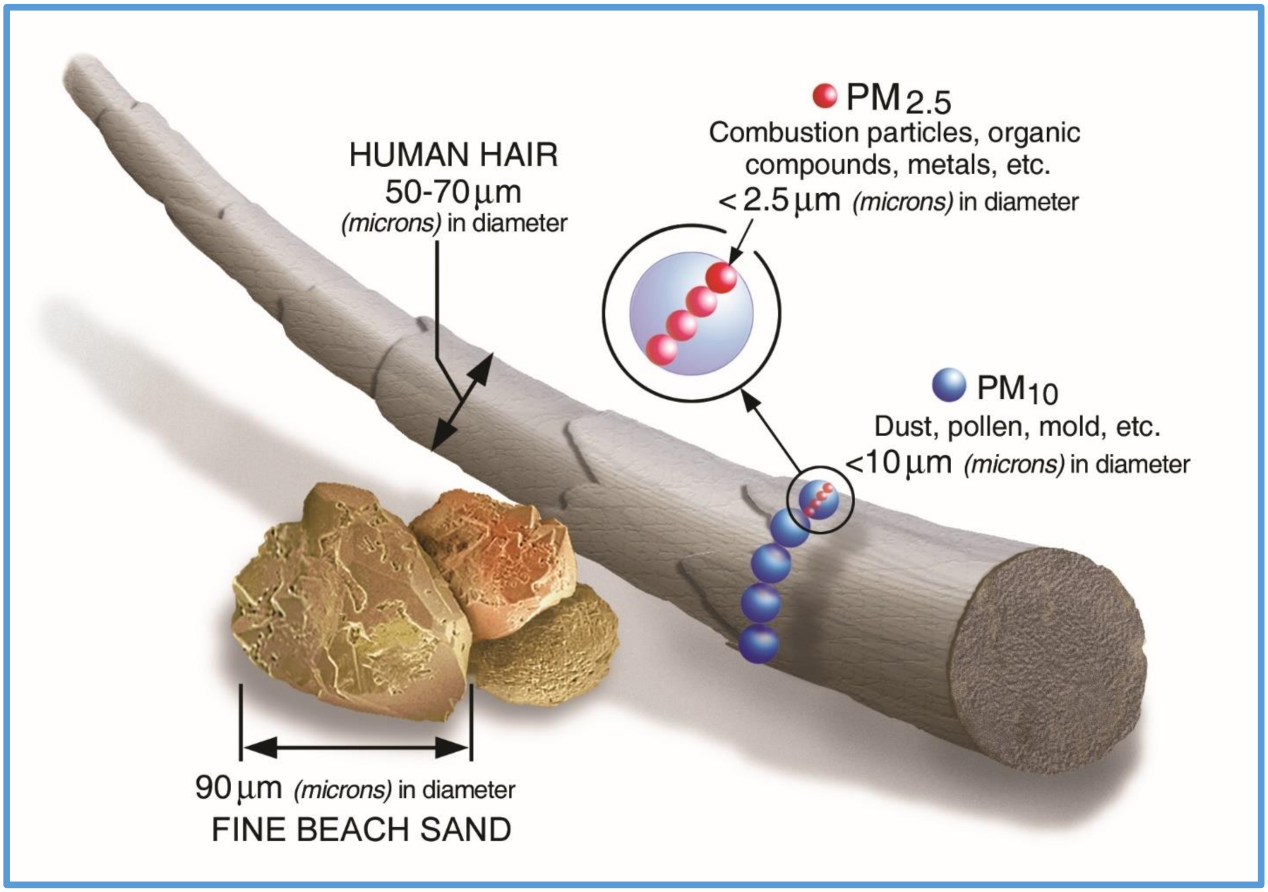
Contents

1. Introduction

1.1. Background

Particulate matter (PM) is the generic term for a broad class of chemically and physically diverse solid particles and liquid droplets found in the ambient air (Figure 1). Particles originate from a variety of anthropogenic sources, both stationary (e.g., coal-fired power plants) and mobile (e.g., cars and trucks), as well as from natural (e.g., dust storms) sources. In addition to being directly emitted into the air, particles can be formed in the atmosphere through complex reactions involving chemicals such as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). PM is a mixture of various components (e.g., metals, elemental carbon (EC), organic compounds (OC), etc.), and as such, its chemical and physical properties can vary greatly with time, region, meteorology, and source (U.S. EPA 2009). Note that these guidelines are for *non-speciated* PM, or PM reported as a total mass without distinguishing the morphology and chemical composition of the PM (e.g., diesel engine PM, specific heavy metals, polychlorinated biphenyls, acidic content of aerosols, etc.).

Figure 1. Schematic of Different Types of Particulate Matter



Source: U.S. EPA (https://www.epa.gov/pm-pollution/particulate-matter-pm-basics).

PM is generally classified into three categories: ultrafine particles (UFP; particles with a mean aerodynamic diameter (d_{ae}) of less than or equal to 0.1 micrometer (µm)), fine particles ($PM_{2.5}$; particles with a mean d_{ae} of less than or equal to 2.5 µm), and thoracic particles (PM_{10}; particles with a mean d_{ae} of less than or equal to 10 µm). Note that these size fractions are not mutually exclusive—the "cut point" of the size fraction includes all sizes below it. For example, ultrafine particles are a component of $PM_{2.5}$. Particles that fall within the size range between $PM_{2.5}$ and PM_{10}, are referred to as thoracic coarse particles ($PM_{10\text{-}2.5}$; particles with a mean d_{ae} of ≤10 µm and >2.5 µm). Particles ≤10 µm in aerodynamic diameter are considered respirable and pose the greatest health concern because some can penetrate deep into the lungs and enter the blood stream (U.S. EPA 2009). In ambient air, $PM_{2.5}$ tends to reflect regional air quality, with these smaller particles traveling greater distances within the ambient atmosphere and remaining in the atmosphere longer than larger particles and can be emitted directly from industry or formed indirectly through chemical reactions in the atmosphere. PM_{10} concentrations, however, generally reflect the contribution of larger particles attributable to local sources.

In this guidance, PM_{10} and $PM_{2.5}$ are addressed, but not UFP. UFP is not routinely characterized for residential exposure assessment investigations because of limited atmospheric lifetime, limitations in analysis, characterization of particles, and toxicity assessment, but it is an important area of current research. These limitations have thus far precluded the development of health-based screening values for UFP.

Exposure to respirable particles with an aerodynamic diameter less than 10 µm can affect both short- and long-term effects on cardiopulmonary function, morbidity, and mortality. Numerous scientific studies have linked particle pollution exposure to (U.S. EPA 2023a, WHO 2013):

- mortality and morbidity rate;
- ischemic heart disease, cerebrovascular disease, and heart failure;
- systemic inflammation, oxidative stress and alteration of the electrical processes of the heart (the biomarkers of which illustrate the contribution of $PM_{2.5}$ exposures to cardiovascular disease);
- respiratory effects (including aggravated asthma, decreased lung function, and symptoms such as coughing) and infections;
- diabetes; and
- impaired neurological development in children and "brain aging" and neurological disorders in adults.

ATSDR defines "sensitive" population subgroups as people who are more sensitive to the effects of inhalation exposure to pollutants such as pregnant women, children, and older adults (≥65 years).[1] In addition, "highly sensitive" population subgroups may include members of these groups or people in the general population that have pre-existing respiratory (e.g., asthma or chronic obstructive pulmonary disease (COPD)) or cardiovascular disease. For several reasons (e.g. greater urban and regional exposure in urbanized areas, less access to healthcare, greater prevalence of respiratory and cardiovascular disease), people of lower socioeconomic status are also more likely to have increased risk for adverse health outcomes from exposure to elevated PM (Pratt et al. 2015). Studies also show that there are both $PM_{2.5}$ exposure and health risk

[1] https://www.atsdr.cdc.gov/emes/public/docs/Sensitive%20Populations%20FS.pdf

disparities by race and ethnicity among minority populations, specifically Black populations (U.S. EPA 2022).

1.2. Purpose

These guidelines have been developed to aid health assessors in the evaluation of PM data during the data screening phase of the health assessment process. It is intended to provide health assessors with 1) some decision criteria for how to average PM data, 2) select appropriate comparison values to screen PM data, and 3) guidance on how to reach conclusions about whether a public health hazard can be attributed to PM exposure. Recommended public health statements are provided for informing precautionary personal actions and suggested language are provided for describing a finding that a site presents a public health hazard. Please note that evaluating PM in addition to other pollutants is not addressed in this guidance. Health assessors should refer to the ATSDR *Framework for Assessing Health Impacts of Multiple Chemicals and Other Stressors (Update) (2018)*[2] for specific methods of conducting a multi-pollutant risk evaluation.

2. Public Health Evaluation Approach for Particulate Data

2.1. Pre-evaluation

Before screening the data, health assessors should identify how the available data can be used to contribute to the characterization of health risks in the community being evaluated. To determine the applicability of the data for exposure assessment in carrying out a public health evaluation, the following should be considered:

1. *Monitor locations*
   - On-site monitors that represent occupational exposures to workers and are likely to be an over-estimate of community exposures from fugitive releases from site operations.
   - Perimeter or fenceline monitors are generally considered a proxy for the highest exposure estimate for a nearby community from fugitive or short stack emissions. With increasing stack height, combined with atmospheric transport and chemical reactions, health assessors should keep in mind that the area of maximum impact may be further within the adjacent community, not at the fence line.
   - Residential monitors measure ambient PM levels where the general population, including sensitive individuals, are exposed.
   - Modeled maximum impact monitors (monitors placed at the location predicted by modeling to have the highest concentrations) are intended to measure highest PM in air and are usually sited using air dispersion modeling.
2. *Frequency of downwind data collection/whether the data represent average or worst-case conditions*
   - Meteorological (Met) data collocated at or close to the monitor location can help health assessors determine whether the dataset they are evaluating represents exposures for the most impacted residents. Modeling can be used to inform ambient monitor placement in areas of high impact.
   - Meteorological (Met) data should reasonably represent similar conditions to those at the monitoring site but may or may not be collocated at the monitoring site. Note that

[2] https://www.atsdr.cdc.gov/interactionprofiles/ip-ga/ipga.pdf

U.S. EPA has siting requirements for stationary Met stations (see https://www.epa.gov/sites/default/files/2020-10/documents/volume_iv_meteorological_measurements.pdf).

3. *Air quality monitors used for background/data context*
   - In addition to using weather conditions to help health assessors interpret ambient air quality data, other area monitors can also help to put site-related PM data into context. If PM levels seem high at a given site but other area monitors up and downwind consistently have similarly high PM concentrations, the regional air quality for that city or geographic area may be poor (the PM is likely not coming solely from the facility being investigated). Looking at the data in context helps health assessors come to appropriate conclusions regarding the hazard posed by the site and helps to define appropriate health-protective recommendations.
   - Spatial assessments of multiple datasets can help identify other sources affecting air quality data. For example, evaluating concentration by wind direction may reveal the influence of sites beyond the one being evaluated. Recommendations can be made to more completely investigate other local or regional sources (e.g. traffic, electric power generating, and other facilities) and can lead to additional data collection and possible actions by regulatory agencies.

Health assessors should keep in mind that the evaluation of personal and community-related exposures to PM is complicated because it is a ubiquitous class of air pollutant with wide variation in both composition and concentration that is based on a mix of stationary, mobile, and natural sources. Some PM in a community is the result of long-range mass transport that may originate from multiple sources thousands of miles away (WHO 2006b). It is important for health assessors to provide qualitative and semi-quantitative perspective in their assessments by noting these limitations and acknowledging that many sources likely contribute to the PM measured near the site under investigation, especially PM_{10}, $PM_{2.5}$, and UFP that could be present from long-range transport. A spatial assessment of site and community data and a comparison of these data with general air quality monitors in the area can provide important context to the assessment of exposure.

Identifying whether the PM is source-related should be evaluated by considering:

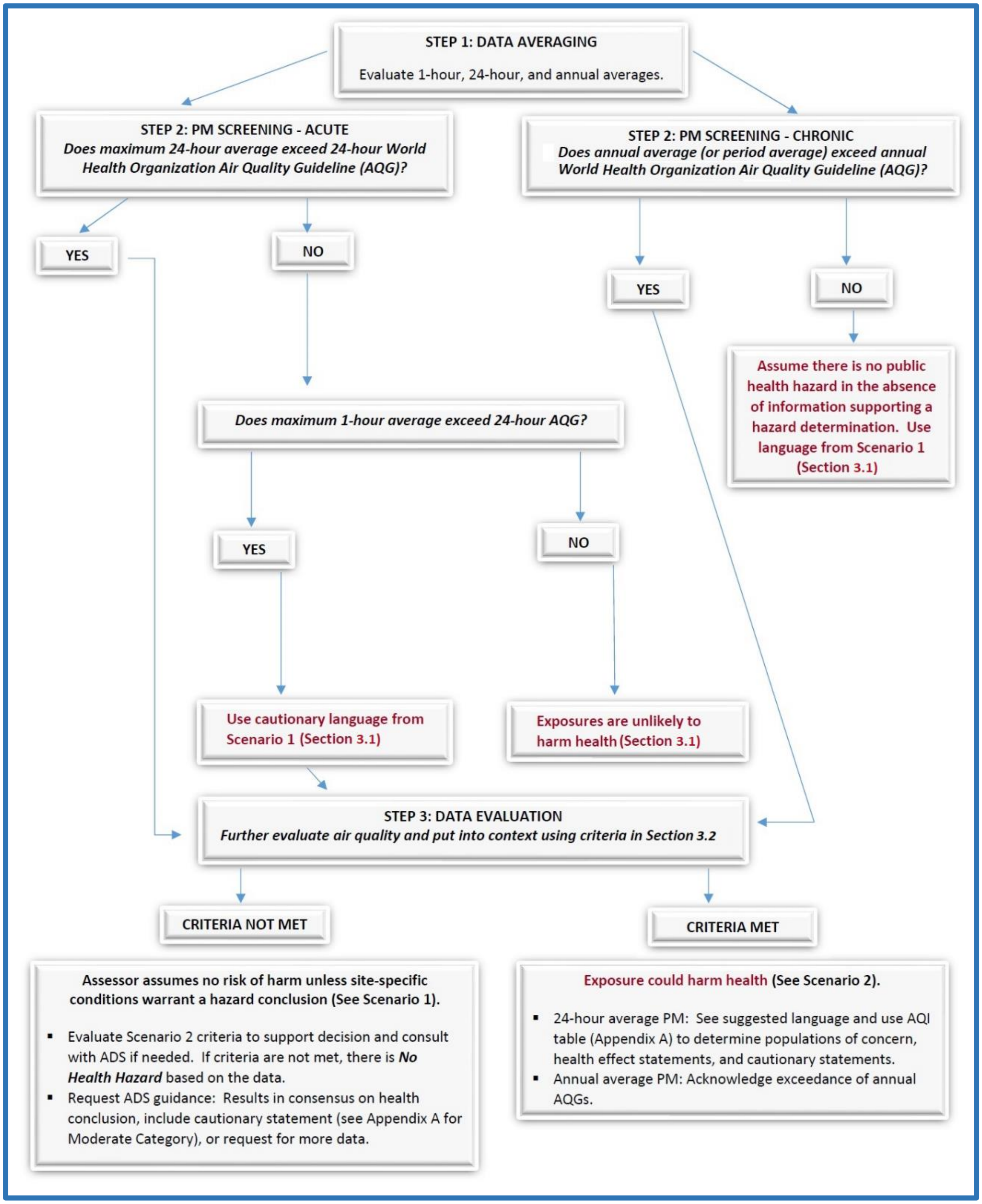
a. Sampling of PM data should align with knowledge about the characteristics of emissions from the source (e.g., continuous vs intermittent, hours of operation, etc.).
b. Whether there are other known sources of PM in the area (e.g., highways, industry, agriculture, desert).
c. Whether there is directionality in the data (meteorological data versus concentration at upwind/downwind locations).
d. If concentrations are relatively consistent, regardless of meteorological conditions, it may suggest that the PM monitor represents regional air quality rather than a site-related source.

Health assessors should also compare site data to available data from other locations in the United States. Recent and historic PM_{10} and $PM_{2.5}$ data are summarized by the U.S. EPA and are routinely shared with the public in the Our Nation's Air annual trends reports. Data and maps from these resources are presented in Appendix A. The health assessor is encouraged to put new PM data into this historic and geographic context to show how they compare to similar site scenarios.

2.2. Process for Assessing PM Data

Prior to analysis, data should be confirmed to have been properly validated and be of high quality. Three steps are outlined for the assessment of PM data: Data Averaging, Screening, and Data Evaluation. See Figure 2 on the following page for a visual representation of this process.

*Figure 2. Decision Tree for PM Assessments**



*See page 8 for a discussion of data evaluation for <24-hour samples

Health assessors should be aware that PM data are collected both as discrete and continuous data, depending on the technology being used. Continuous data are generally reported hourly but can be reported in other time increments. Filter-based samples are generally collected over a 24-hour period and may not be collected over consecutive days (and one-in-three- and one-in-six-day sampling are also common). However, filter-based sampling can also take place over other averaging times as warranted by site-specific objectives.

2.2.1. Step 1: Data Averaging

As a first step, the health assessor must appropriately average the data prior to comparing them to equivalent averaging times of screening values. Since more data points yield more accurate averaging, it is preferable to use the most highly resolved increment for averaging into 1-hour, 24-hour, study period, and annual averages. For example, if data are collected in 1-minute increments, one can average those measurements into a 1-hour, 24-hour, study period, and annual averages.

2.2.2. Step 2: PM Screening

In Step 2, health assessors select contaminants for further evaluation by comparing them to health-based comparison values (CV). ATSDR does not have a Minimal Risk Level (MRL) value for PM that can be used as the basis for an ATSDR-derived CV. This guidance identifies provisional CVs for PM that can be used for health assessment purposes.

The assessment of PM exposure can be challenging because 1) includes emissions from natural and anthropogenic sources and is therefore ubiquitous across every region of the world, whether or not there is a nearby attributable source; and 2) since susceptibility to PM exposure is highly variable from person to person, and since there are no known threshold of effect from exposure to PM of varying composition, it is unlikely that any standard or guideline value could lead to complete protection for everyone (WHO 2006a). These factors make establishing a health-based comparison value for PM complex.

> While regulatory values exist, such as U.S. EPA's National Ambient Air Quality Standards (NAAQS) for PM, their purpose is to set regulatory limits for six criteria pollutants, including PM, for ambient air in the United States. However, as a general practice, ATSDR uses the most health-protective comparison value available for screening purposes. For PM, the most health-protective screening values established are the Air Quality Guidelines (AQGs) from the World Health Organization (WHO) in Geneva.

WHO's AQGs are based on health effects associated with PM exposure. For evaluating PM data at sites, the WHO AQGs listed in Table 1 should be used for PM screening. The PM air concentration for the appropriate data averaging timeframe for the specific PM size fraction should be selected as the screening value. While WHO has used a statistical manipulation of the AQG values to establish target ambient air concentrations (e.g., the 24-hour $PM_{2.5}$ AQG is the 99^{th} percentile value over a given year), ATSDR and state cooperative agreement health assessors should use the unadjusted values in Table 1 for PM screening. Note that acute durations (≤24-hour averages) are evaluated with 24-hour AQGs, while chronic exposures to PM are evaluated with annual AQGs. ATSDR often predicts "chronic" exposures with relatively brief air sampling periods. For example, exposure investigations (EIs) have often used data collected over weeks or months in downwind conditions to estimate long term exposure under highest exposure conditions. The appropriateness of extrapolating acute or chronic health implications from available data should be discussed along with the general attributes of the dataset during the scoping process with a PM subject matter expert (SME). This discussion helps determine the most appropriate analysis for the dataset being reviewed. PM has seasonal trends, and limited data sets may over- or under-estimate PM exposures. Examples include elevated $PM_{2.5}$ and PM_{10} in summer months in some areas of the country, or elevations of $PM_{2.5}$ (such as EC, OC, and nitrates or sulfates) in winter or summer months, respectively.

*Table 1. ATSDR PM Screening Values: World Health Organization Particulate Matter Air Quality Guidelines (AQGs)**

PM Air Pollutant Metric	WHO	ATSDR CV
PM_{10}	45 µg/m^3 (24-hour)† 15 µg/m^3 (annual)	NA
$PM_{2.5}$	15 µg/m^3 (24-hour)† 5 µg/m^3(annual)	NA

CV - Comparison value; µg/m³ – micrograms per cubic meter; PM – particulate matter.
NA – Not Available: ATSDR does not have CV for PM.
*WHO 2021
† These screening levels reflect the numeric value of the WHO AQGs for 24-hours

2.2.2.1. Special consideration: Short-term exposure studies of ≤24-hour exposures

ATSDR health assessors often receive data collected over shorter durations than 24 hours, but no sub-acute AQG exists for exposures that occur for less than 24 hours. Continuous PM_{10} and $PM_{2.5}$ data are frequently collected and reported over hourly durations. If data are reported in increments less than an hour, data should be averaged hourly. Hourly data highlight the variability of PM concentrations over the course of a day and may identify temporal trends of peak concentrations of PM that are not obvious when evaluating 24-hour averages. In these instances, it is appropriate to compare these short term (≤ 24 hour) exposures to the acute AQGs. The rationale for this approach is discussed below.

The 2019 PM U.S. EPA Integrated Science Assessment (ISA) reviewed studies of short-term (≤24-hour exposures) PM exposure in the scientific literature and their association with various health outcomes. The studies evaluated in the ISA led U.S. EPA (2019) to conclude that there is:

- sufficient evidence to conclude that a causal relationship exists between short-term and long-term $PM_{2.5}$ exposure and cardiovascular effects;
- likely to be causal relationship between short-term and long-term $PM_{2.5}$ exposure and respiratory effects;
- likely to be causal relationship between long-term $PM_{2.5}$ exposure and neurological effects and cancer;
- a suggestive causal determination for short-term $PM_{10-2.5}$ exposure and cardiovascular effects, respiratory effects, and mortality;
- mounting evidence that $PM_{2.5}$ and $PM_{10-2.5}$ may impair nervous system function to varying degrees depending on the size fraction; and
- evidence that $PM_{2.5}$ likely causes cancer and $PM_{10-2.5}$ has evidence that is suggestive that it has carcinogenic potential.

In Summary:

Screening annual averages:
Screen long term (>1 year, or if appropriate, shorter durations (see Section 2.2.2)) average of $PM_{2.5}$ and PM_{10}*against the annual average AQG.

Screening 24-hour averages:
Whenever possible, screen the 24-hour $PM_{2.5}$ and PM_{10} against the 24-hour AQG.

Screening ≤24-hour averages:
Use 24-hour AQG for $PM_{2.5}$ and PM_{10} and cite the 2019 U.S. EPA ISA using the suggested precautionary language: *Given that the literature suggests effects have been observed at concentrations at or below the 24-hour AQG for $PM_{2.5}$ and PM_{10} (see U.S. EPA, 2019), AQGs can be compared to sample durations as short as 1-hour*.

**For PM1- levels exceeding the annual AQG, see Section 2.2.3b*

U.S. EPA (2019) identified exposures and health outcomes from $PM_{2.5}$ that are considered causal or likely to be causal.[3] See Table 2, below.

[3] U.S. EPA. 2019. Integrated Science Assessment for Particulate Matter. Center for Public Health and Environmental Assessment Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC. Table 1-2.

*Table 2. Summary of PM2.5 and health outcome studies**

Endpoint, Exposure Duration	Endpoint Description	Mean ambient concentration range associated with effects
Respiratory, Short-term Exposure	Hospital admissions and ED visits for asthma, COPD, respiratory infections, and combinations of respiratory-related diseases	U.S. and Canada: 4.7−24. 6 μg/m³ Europe: 8.8−27.7 μg/m³ Asia: 11.8−69.9 μg/m³
Respiratory, Short-term Exposure	Respiratory mortality	U.S. and Canada: 7.9−19.9 μg/m³ Europe: 8.0−27.7 μg/m³ Asia: 11.8−69.9 μg/m³
Respiratory, Long-term Exposure	Decrement in lung function growth	6−28 μg/m³
Respiratory, Long-term Exposure	Asthma development in children	5.2−16.5 μg/m³
Respiratory, Long-term Exposure	Bronchitis symptoms in children with asthma	9.9−13.8 μg/m³
Respiratory, Long-term Exposure	Accelerated lung function decline in adults	9.5−17.8 μg/m³
Respiratory, Long-term Exposure	Respiratory mortality	6.3−23.6 μg/m³
Cardiovascular, Short-term Exposure	Ischemic Heart Disease	5.8−18.6 μg/m³
Cardiovascular, Short-term Exposure	Heart Failure	5.8−18.0 μg/m³
Cardiovascular, Short-term Exposure	General cardiovascular effects (over 2 hours)	24−325 μg/m³
Cardiovascular, Long-term Exposure	Cardiovascular mortality:	4.1−17.9 μg/m³
Cardiovascular, Long-term Exposure	Coronary events	13.4 μg/m³
Cardiovascular, Long-term Exposure	CAC	14.2 μg/m³
Cardiovascular, Long-term Exposure	CHD and stroke (people with pre-existing disease)	13.4−23.9 μg/m³
Neurological, Long-term Exposure	Brain volume	11.1−12.2 μg/m³
Neurological, Long-term Exposure	Cognition	8.5 (5-yr avg)−14.9 μg/m³
Neurological, Long-term Exposure	Autism	14.0−19.6 μg/m³
Cancer, Long-term Exposure	Lung cancer incidence and mortality	U.S. and Canada: 6.3−23.6 μg/m³ Europe: 6.6−31.0 μg/m³ Asia: 33.7 μg/m³
Mortality, Short-term Exposure	Total mortality	U.S. and Canada: 4.37−17.97 μg/m³ Europe: 13−27.7 μg/m³

		Asia: 11.8−69.9 μg/m³
Mortality, Long-term Exposure	Total mortality	ACS/HSC cohorts: 11.4−23.6 μg/m³ Medicare cohort: 8.12−12.0 μg/m³ Canadian cohorts: 8.7−9.1 μg/m³ Employment cohorts: 12.7−17.0 μg/m³

[*] Excerpted from: U.S. EPA. 2019. Integrated Science Assessment for Particulate Matter. Center for Public Health and Environmental Assessment Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC. Table 1-2.

The most recent U.S. EPA assessment (2022) found that research published since 2019 further supports evidence of causality between PM exposure and health effects. One $PM_{2.5}$ study showed a relationship between long-term exposure and total mortality at levels averaging 5.9 ug/m^3, which is lower than the concentrations shown on Table 2. Another $PM_{2.5}$ study provided evidence of both lung and cardiac function changes in young, healthy participants.

While fewer studies investigated health effects at ≤24-hour exposures, evidence suggests that similar health outcomes are possible, including:

- heart rate variability;
- vasoconstriction of arteries; and
- hemostatic markers indicating changes in the blood of healthy subjects or patients with coronary artery disease.

These effects were observed in single and multi-city continuous measurements where morbidity was assessed from the general population and in controlled human and animal exposure studies. The continuous or controlled acute exposures included durations of observation between 1 and 22 hours. Given that the literature suggests effects have been observed at concentrations at or below the 24-hour WHO AQG for $PM_{2.5}$ and PM_{10}, health assessors can apply these screening values to ambient concentrations collected over a duration as short as 1-hour. However, whenever possible, the health assessor should also calculate and compare 1-hour and 24-hour averages to the 24-hour AQG and annual averages to the annual AQG for $PM_{2.5}$ and PM_{10}. Exposure to daily averages has been better studied for all outcomes and has resulted in a more robust scientific database for the effect of PM on health outcomes. These associations are generally stronger for $PM_{2.5}$ than for PM_{10} (U.S. EPA 2019; WHO, 2013).

2.2.3. Step 3: Data Evaluation

2.2.3.1. Acute exposures

To evaluate acute exposures in a given dataset, health assessors should assess general air quality over the duration that sampling was conducted. U.S. EPA's PM Air Quality Index (AQI) is used nationally to designate real time threats to *unusually sensitive*[4] individuals, sensitive populations,

[4] The U.S.EPA does not have a formal definition of an *unusually sensitive* person, however, we know from scientific studies that there is inter-individual variability in responses to exposure to air pollution. For example, two people could respond differently to the same air pollution level: one person with asthma may experience some respiratory discomfort and maybe an asthma attack while another person with asthma exposed to the same level may not react at all. The intent of adding in the cautionary statement is to advise highly sensitive persons that they should

or the general public. Identifying the number of days during the sampling period being evaluated where ambient PM levels fall into these AQI categories can support a qualitative assessment of the frequency that poor air quality occurred in the monitoring area. This qualitative assessment puts exceedances of the AQGs in perspective. For example, if during screening, the health assessors identifies exceedances of the 24-hour AQGs, but those exceedances only occurred infrequently, the health assessor may choose to use cautionary statements indicating that any harm to sensitive individuals was limited to a few days over a year of sampling. However, if exceedances occur over substantial portion of the air samples, the health assessor should choose stronger hazard language.

Depending on the PM level, any single 24-hour period above the WHO AQG potentially could result in harmful effects for either highly sensitive or sensitive individuals, the general (healthy) public, or all for all groups. The frequency with which ambient PM fell into the various AQI categories can be presented by adding the number of days in a given sampling period that PM levels fall within the AQI categories shown in Appendix B. Additional perspective on how data near a site compare to areas not expected to be impacted by known sources of PM should also be provided (see Background Air Considerations section and Appendix A). Please consult with a PM SME for help interpreting acute exposures and the AQI categories in Appendix B.

Additional perspective on how data near a site compare to areas not expected to be impacted by known sources of PM should also be provided (see Background Air Considerations section and Appendix A).

Appendix B defines the following to be used in PM assessments:

- AQI Category and associated PM ranges
- Sensitive/highly sensitive group definition
- Health effects statements

The information in Appendix B should be included in a health consultation or health assessment. The cautionary statements in section 3.0 should be considered for use with the recommendations.

For 24-hour PM_{10} levels in the Moderate AQI range, health assessors should provide the public with a cautionary statement for highly sensitive persons (see Appendix B). The health effects statement for the moderate category should be added to a conclusion, basis for a conclusion, or public health action plan and the cautionary statement should be added as a recommendation. Note that the upper end of the AQI "Good" category slightly exceeds the 24-hour AQGs for PM_{10} and $PM_{2.5}$. This limitation should be acknowledged in the health consultation with the following caveat:

"The AQI is a tool used by U.S. EPA to categorize air quality threats in real time to local populations across the United States and is not intended to be used as a surrogate for a presentation of the scientific literature in health assessments. ATSDR uses the AQI only for the

always be cognizant of how they are feeling outdoors on days in the Moderate AQI Category. Instead of using the undefined term "*unusually* sensitive", ATSDR uses "*highly* sensitive" throughout this guidance.

purposes of qualitatively assessing the frequency of poor air quality days that may affect different segments of the population. AQI data can be used to support health conclusions made by evaluation of exceedances of screening values, an assessment of how exposures compare to those in the toxicological literature, and an assessment of other data that put these exceedances into context (such as background data or upwind data vs. downwind data, spatial analysis, etc.)."

2.2.3.2. Chronic exposures

There are no annual AQI designations to support health conclusions for chronic PM exposures exceeding the AQGs. As previously stated, for long-term health effects there are stronger correlations with $PM_{2.5}$ than with PM_{10} levels. However, WHO has maintained their annual average PM guideline level of **15 µg/m³** primarily to protect against harmful $PM_{2.5\text{-}10}$ exposures. If a health assessor is presented with ***only*** PM_{10} data, they should first evaluate the 24-hour averages and less than 24-hour averages (usually 1-hour) using the approach described above. Then annual average PM_{10} data should be compared to the annual WHO AQG to get a sense of whether the PM_{10} annual averages are a potential concern, but also note that many areas of the U.S. have annual average PM_{10} levels above the WHO guideline (see Appendix A).

To draw conclusions on annual PM_{10} data, health assessors should consult with one of the PM SMEs. Further, an assessment of background data, upwind data vs. downwind data, spatial analysis, etc. helps to determine the extent of contribution from a specific source to air quality and informs health-protective recommendations.

3. Integrating steps 1-3 and adding cautionary statements

Data evaluated in the PM assessment will fall into one of two scenarios. These scenarios and the appropriate next steps are detailed below. Refer to Figure 2 for an overview of the decision process for PM Assessment.

3.1. Scenario 1: The appropriately averaged data are consistently below AQGs

The assessor would conclude that exposures are not expected to harm the public in the absence of data and information indicating otherwise. Current science does support evidence that increases in harmful effects are possible for highly sensitive populations at concentrations below the AQGs.

Evaluating less than 24-hour PM data when the 24-hour average is below the AQGs. Neither the U.S. EPA nor the WHO have developed standards or guidelines for exposures to PM for durations less than 24-hours. However, 24-hour AQGs for $PM_{2.5}$ and PM_{10} can also be used for PM screening for shorter durations. Given that the literature suggests effects have been observed at concentrations at or below the 24-hour AQG for $PM_{2.5}$ and PM_{10} (see U.S. EPA 2019), AQGs can be compared to sample durations as short as 1-hour. Because a health conclusion is only made based on a sampling average equivalent to the AQG duration of 24-

hours, a cautionary statement to alert potentially sensitive populations can be added in the scenario where hourly averages may exceed the acute AQG, but the 24-hour average is below the acute AQG.

Suggested language**:**
Conclusion: "*PM_{10} levels had maximum 1-hour concentrations of over X,XXX µg/m^3: however, 24-hour averages were below the AQG. Exposure to PM levels above the AQG has the potential to trigger acute health conditions in highly sensitive and sensitive individuals, even over exposure periods of less than 24 hours (U.S. EPA 2012).*" OR
"*Individuals with cardiopulmonary illness may have a slightly increased risk of the exacerbation of their health conditions with intermittent short-term exposures to high concentrations of pollutants over acute durations (<24 hours). It is possible that shorter duration exposures (e.g. 1-hour) to very high PM concentrations could trigger an adverse acute response in these populations in the absence of an exceedance of the 24-hour AQG.*"

Recommendation: *See Appendix B; Example: Highly sensitive people and parents of highly sensitive children should consult the air quality forecast and consider reducing prolonged or heavy exertion on days where air quality is predicted to be poor.*

Consult with PM SME if help is needed to interpret acute (< 24-hour) data.

3.2. Scenario 2: The appropriately averaged data are above AQGs:

The assessor may conclude that harmful health effects are possible based on one or more of the following considerations:

1. Frequency of concentrations at levels of concern to specific populations at risk in the community. The health assessor should include the frequency of AQG exceedances as well as the frequency 24-hour averages fall within the various AQI categories.
2. Meteorological and spatial data indicating that a sole source is responsible for a great proportion of PM and levels approaching the PM CVs.
3. The dataset is small but meteorological and spatial data indicate that worst-case conditions are not necessarily occurring during the sampling period.
4. Sensitive individuals have an increased likelihood of experiencing health effects as a result of exposures (e.g., persons with severe asthma, COPD, and pre-existing respiratory or cardiovascular disease).

The outcome of this evaluation could include a conclusion that a health hazard does or does not exist, the inclusion of a cautionary statement for the public, and/or a request for additional sampling data to confirm whether a hazard may exist. The scenario should be prefaced with a statement about the representativeness of the data (e.g., it represents worst case conditions, it doesn't represent worst case conditions, the monitors were not operating when exposures were occurring, the facility installed pollution controls prior to monitoring beginning, etc.). An assessment of short-term exposure data should use cautionary language from the AQI table in Appendix B.

- **Short term (24 hour) averages:**

Suggested language**:**
Conclusion: "*Exposure to elevated concentrations of $PM_{2.5}$ and/or PM_{10} could harm public health because of an increased risk for adverse health effects among [insert site-specific population of concern].*
See Appendix B for AQI categories to evaluate air quality in the population being assessed and for possible additional language for the conclusion.
AND
Recommendation: "*Highly sensitive people should consult the air quality forecast and consider reducing prolonged or heavy exertion on days where air quality is predicted to be poor.*

- **Long term (annual) averages:**
Suggested language (long term):
Conclusion: *Prolonged exposures to PM above the AQGs may slightly increase the likelihood of harm for individuals with pre-existing health conditions, such as cardiopulmonary disease.*" [5]
AND
Recommendation: "*Sensitive individuals should consider reducing prolonged or heavy physical activity on days with moderate to unhealthy air quality*."
Health assessors can include a link to the AQI website where residents can look up projected air quality in their zip code at https://www.airnow.gov/aqi/aqi-basics/.

3.3. Example language

These guidelines supersede all previous screening values and screening approaches. Several ATSDR documents have been published evaluating PM exposures that include well-constructed write-ups of health implications. Health assessors are encouraged to review the language used in these documents to discuss the types of health effects possible at site-specific concentrations. Note that these documents may not have used the updated approach for PM assessment outlined in this guidance, so it is recommended to review these documents as examples for how to draft the document Health Implications section. Health assessors should always review the most recent U.S. EPA Integrated Science Assessment for PM when drafting this section to ensure the most recent science is presented in their document. Health Assessors should request guidance from an PM Subject Matter Expert if needed.

4. References

Dockery DW et al. (1993). An association between air pollution and mortality in six U.S. cities. *New England Journal of Medicine*, 329(24):1753–1759.

[5] To draw health conclusions on annual PM_{10} data, health assessors should consult with one the PM SMEs. This is because the strongest correlations with chronic PM exposures and adverse health outcomes are associated with smaller particle fraction sizes ($\leq PM_{2.5}$) and that the PM_{10} AQG is exceeded regularly across the United States.

Jerrett M et al. (2005). Spatial analysis of air pollution and mortality in Los Angeles. *Epidemiology*, 16(6):727–736.

Pope CA 3rd et al. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Journal of the American Medical Association*, 287(9):1132–1141.

Pratt G., Valdali M., Kvale D., et al. 2015. Traffic, air pollution, minority and socio-economic status: Addressing inequities in exposure and risk. *Int J Environ Res Public Health*, 12(5): 5355–5372.

U.S. EPA. 2009. Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Urban Visibility Impact Assessment. EPA-452/P-09-001. February 2009. Available at: https://www3.epa.gov/ttn/naaqs/standards/pm/data/20090227PMNAAQSWelfare.pdf.

U.S. EPA. 2012. Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. EPA/600/R-12/056F. December 2012. Available at http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=508978

U.S. EPA. 2019. Integrated Science Assessment for Particulate Matter. U.S. Environmental Protection Agency. EPA/ 600/R-08/139F. December 2019. Available at https://www.epa.gov/isa/integrated-science-assessment-isa-particulate-matter.

U.S. EPA. 2022. Supplement to the 2019 Integrated Science Assessment for Particulate Matter. U.S. Environmental Protection Agency. EPA/600/028. May 2022. Available at https://www.epa.gov/isa/integrated-science-assessment-isa-particulate-matter.

U.S. EPA. 2023a. Particulate Matter Pollution. Health and Environmental Effects. Updated August 2023. Available at https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.

U.S. EPA. 2023b. Our Nation's Air – Trends Through 2022. 2023. Available at: https://gispub.epa.gov/air/trendsreport/2023/#home

U.S. EPA. 2024. Pre-generated Data Files. April 2024. Available at: https://aqs.epa.gov/aqsweb/airdata/download_files.html

WHO. 2006a. WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide. Global Update: 2005. World Health Organization. 2006. Available at https://apps.who.int/iris/handle/10665/69477.

WHO. 2006b. Health Risks of Particulate Matter from Long-Range Transboundary Air Pollution. World Health Organization. Copenhagen, Denmark. Available at: https://www.who.int/publications/i/item/E88189.

WHO. 2013. Review of Evidence on Health Aspects of Air Pollution—REVIHAAP Project Technical Report. World Health Organization. 2013. Available at https://www.ncbi.nlm.nih.gov/books/NBK361805/.

WHO. 2021. Global Air Quality Guidelines. Particulate matter ($PM_{2.5}$ and PM_{10}), Ozone, Nitrogen dioxide, Sulfur dioxide, and Carbon Monoxide. Geneva: World Health Organization; 2021: License: CC BY=NCSA3.0 IGO.

Appendix A: Particulate Matter National Data Summaries from the U.S. EPA Air Quality System (AQS)

State and county environmental agencies that conduct regulatory air monitoring are required to submit their data to U.S. EPA's Air Quality System (AQS). U.S. EPA uses these data to determine attainment of the NAAQS and also for public air quality reports. Particulate matter data are included in EPA's annual report titled "Our Nation's Air" (EPA 2023b). These findings are summarized below and health assessors may access future versions national maps and individual site summaries, are presented in U.S. online (https://www.epa.gov/air-trends). Health assessors should use these resources to put their PM data into a regional and national context.

Figure A1 shows the 1990-2022 trend in peak 24-hour PM_{10} concentrations nation-wide. The data are based on the second highest 24-hour concentration at each monitoring site, which is the metric used by U.S. EPA to determine attainment of the PM_{10} 24-hour NAAQS of 150 ug/m^3. The figure shows the average and median concentration for each year for national trend sites, as well as the 10th and 90th percentiles. Underlying data are shown on Table A1 and are also accessible via the Our Nation's Air website. The average peak 24-hour PM_{10} concentration has declined 34% during the trend period. The annual average consistently exceeds the WHO AQG of 45 ug/m^3. The median peak 24-hour PM_{10} concentration has decreased 35% and has been approximately equal to the AQG since 2009.

The geographic distribution of peak 24-hour PM_{10} concentrations in 2022 is shown on Figure A2. This map is also located on the Our Nation's Air website where it is interactive (see: https://gispub.epa.gov/air/trendsreport/2023). Health assessors can click on individual monitor sites on the web map to see the peak PM_{10} concentration in 2022 or previous years. Note that the lowest concentration break point on the map is higher than the AQG of 45 ug/m^3, however it is evident that many urban areas have monitors with a PM_{10} 24-hour average higher than the AQG. Several locations, mostly in California and the Pacific Northwest, are reporting PM_{10} 24-hour peaks over 255 ug/m^{3,} i.e. more than five times the AQG.

U.S. EPA does not have an annual PM_{10} NAAQS and thus does not track trends for annual average PM_{10} concentrations. ATSDR pulled this information from AQS as presented on Table A3 (EPA 2024). ATSDR included all sites with sufficient data completeness and avoided duplicates by averaging data for multiple monitors at each site. Beginning in 2011, 56% of PM_{10} sites had an annual average higher than the AQG of 15 ug/m^3. The concentrations have slightly declined over the years to where 47% exceeded the AQG in 2022.

Figure A3 shows the 2000-2022 trend in peak 24-hour $PM_{2.5}$ concentrations nation-wide. The data are based on the 98th percentile of 24-hour concentration at each monitoring site over a 3-year period, which is the metric used by U.S. EPA to determine attainment of the $PM_{2.5}$ 24-hour NAAQS of 35 ug/m^3. The figure shows the average and median concentration for each rolling 3-year period for national trend sites, as well as the 10th and 90th percentiles. Underlying data are shown on Table A4 and are also accessible via the interactive graphics on the Our Nation's Air website. The median peak 24-hour $PM_{2.5}$ concentration has declined 46% since 2000, however it remains above the WHO AQG of 15 ug/m^3. The 90th and 10th percentiles have also decreased; the 10th percentile has consistently been below the AQG since 2014.

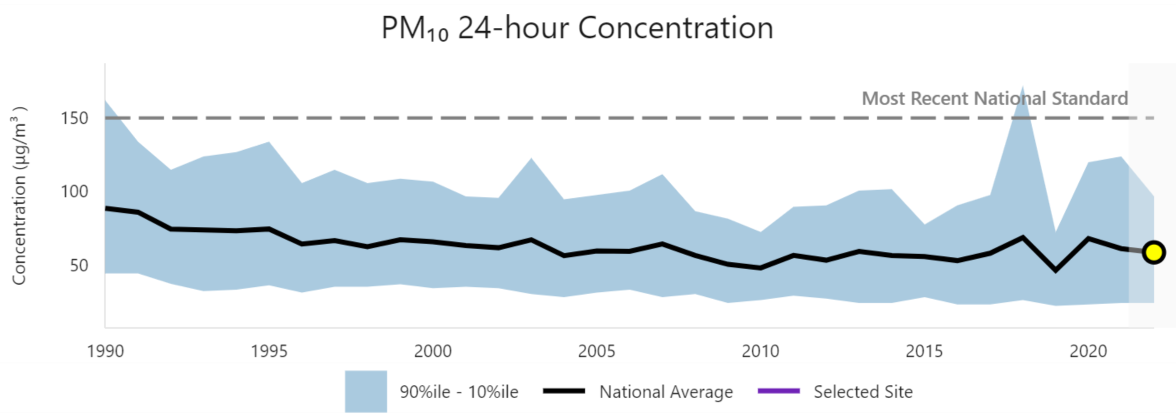
The geographic distribution of peak 24-hour $PM_{2.5}$ concentrations in 202221 is shown on Figure A4. Health assessors may access the interactive version of this map in the Our Nation's Air report online to determine whether monitor sites in the area of interest are exceeding the WHO AQG of 15 ug/m^3.

Figure A5 shows the 2000-2022 trend in annual average $PM_{2.5}$ concentrations nation-wide. The data are based on the 3-year average concentration at each monitoring site, which is used by U.S. EPA to determine attainment of the $PM_{2.5}$ annual NAAQS. U.S. EPA lowered the NAAQS from 12 to 9 ug/m^3 in February 2024 and is currently implementing this revised standard The previous NAAQS is marked on Figure A5. The figure shows the average and median concentration for each year for national trend sites, as well as the 10th and 90th percentiles. Underlying data are shown on Table A5 and are also accessible via the interactive graphics on the Our Nation's Air website. The median annual $PM_{2.5}$ concentration has declined 45% and remains above the WHO AQG of 5 ug/m^3 The 10th percentile also remains above the AQG.

The geographic distribution of annual average $PM_{2.5}$ concentrations in 2022 is shown on Figure A6. Health assessors may access the interactive version of this map in the Our Nation's Air report online to determine whether monitor sites in the area of interest are exceeding the WHO AQG of 5 ug/m^3.

The data presented in these figures and tables can be used by health assessors to place measured concentrations from a given site in context, both by the type of site and the year measurements were collected. It is expected that most sites will have some days that exceed the 24-hour screening levels and a discussion of typical concentrations at other sites in the United States may be useful to residents when evaluating measurements in their communities.

Figure A1. Peak 24-hour PM_{10} concentrations in the U.S., 1990-2022, ug/m^{3*}



*The "Most Recent National Standard" refers to the current 24-hour PM_{10} National Ambient Air Quality Standard of 150 ug/m^3. The data trend is based on monitoring sites nationwide measuring PM_{10} that have sufficient data to assess PM_{10} trends since 1990.

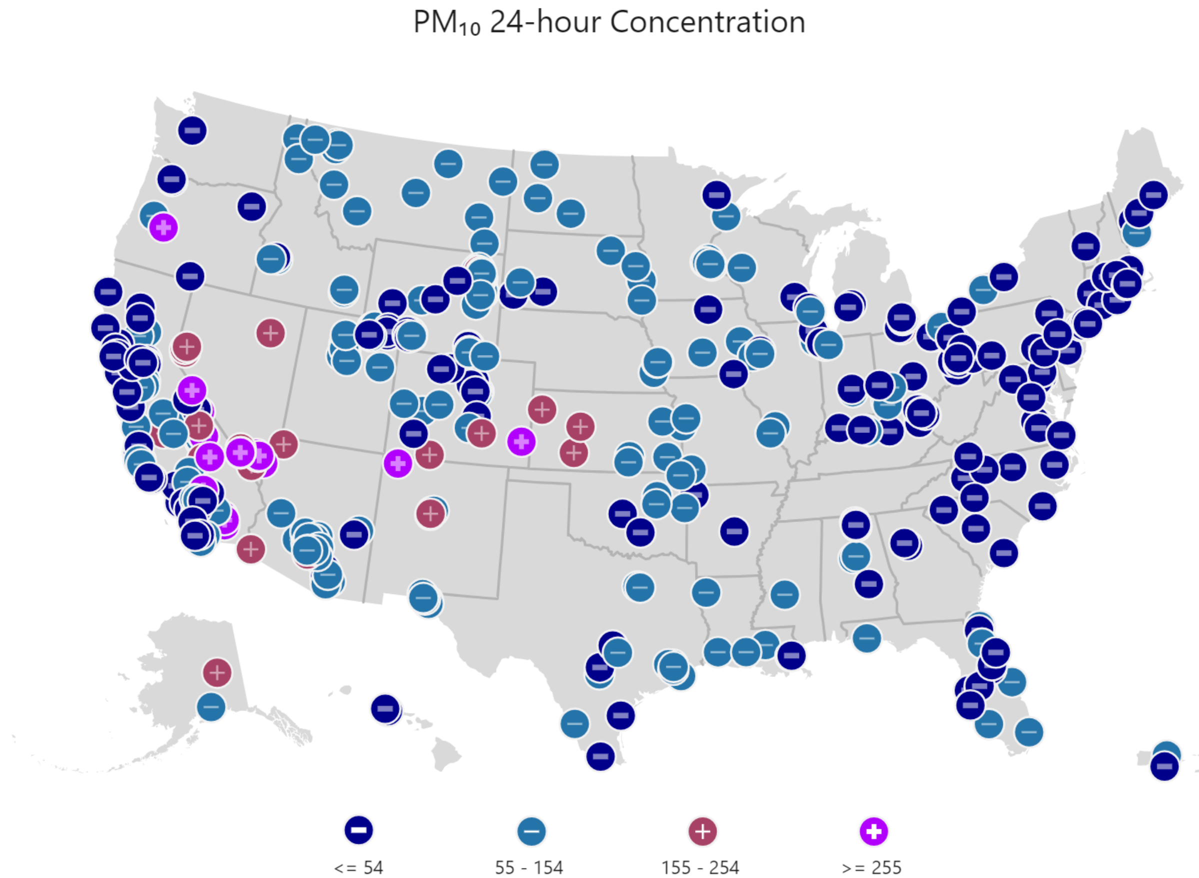
Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

Table A1. Peak 24-hour PM_{10} concentrations in the U.S., 1990-2022, ug/m^3

Year	Median	Average	90th percentile	10th percentile
1990	79	89	162	45
1991	81	86	134	45
1992	69	75	115	38
1993	66	74	124	33
1994	64	74	127	34
1995	63	75	134	37
1996	56	65	106	32
1997	59	67	115	36
1998	56	63	106	36
1999	56	68	109	38
2000	58	66	107	35
2001	55	64	97	36
2002	56	62	96	35
2003	56	68	123	31
2004	50	57	95	29
2005	56	60	98	32
2006	49	60	101	34
2007	57	65	112	29
2008	50	57	87	31
2009	45	51	82	25
2010	47	49	73	27
2011	46	57	90	30
2012	46	54	91	28
2013	42	60	101	25
2014	44	57	102	25
2015	46	56	78	29
2016	46	54	91	24
2017	52	59	98	24
2018	48	69	172	27
2019	45	47	73	23
2020	50	69	120	24
2021	49	62	124	25
2022	51	59	97	25

Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

Figure A2. Peak 24-hour PM_{10} concentrations in the U.S., 2022, ug/m^3



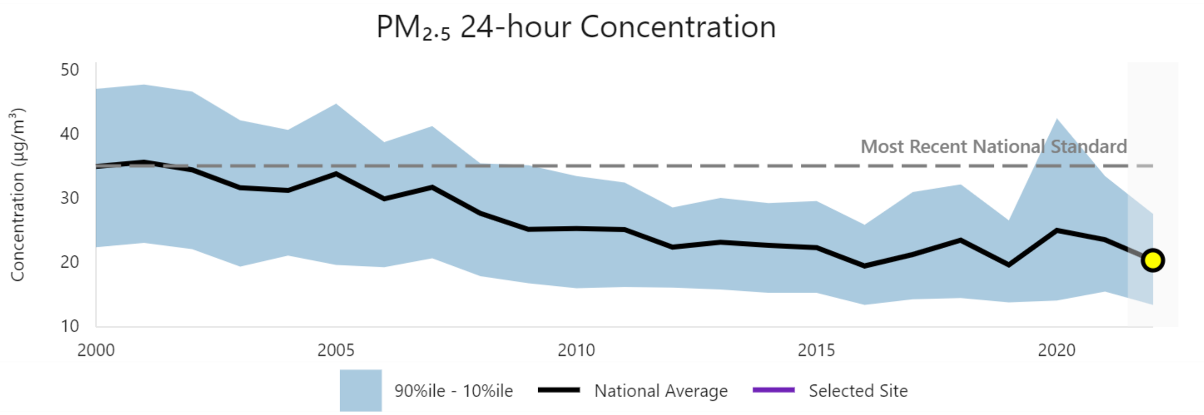
Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

Table A3. Percent of PM_{10} Monitoring Sites in the U.S. with Annual Average Concentration Exceeding WHO AQG, 2011-2020

Year	Number of Sites	Percent of Sites Exceeding AQG of 15 µg/m^3
2011	440	56
2012	487	57
2013	432	51
2014	370	51
2015	369	47
2016	355	47
2017	345	50
2018	373	48
2019	317	47
2020	213	71
2021	346	55
2022	346	47

Source: U.S. EPA. 2024. Pre-generated Data Files. April 2022. Available at: https://aqs.epa.gov/aqsweb/airdata/download_files.html

Figure A3. Peak 24-hour $PM_{2.5}$ concentrations in the U.S., 2000-2022, ug/m^{3}*



*The "Most Recent National Standard" refers to the current 24-hour $PM_{2.5}$ National Ambient Air Quality Standard of 35 ug/m^{3}. The data trend is based on monitoring sites nationwide measuring $PM_{2.5}$ that have sufficient data to assess $PM_{2.5}$ trends since 1990.
Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

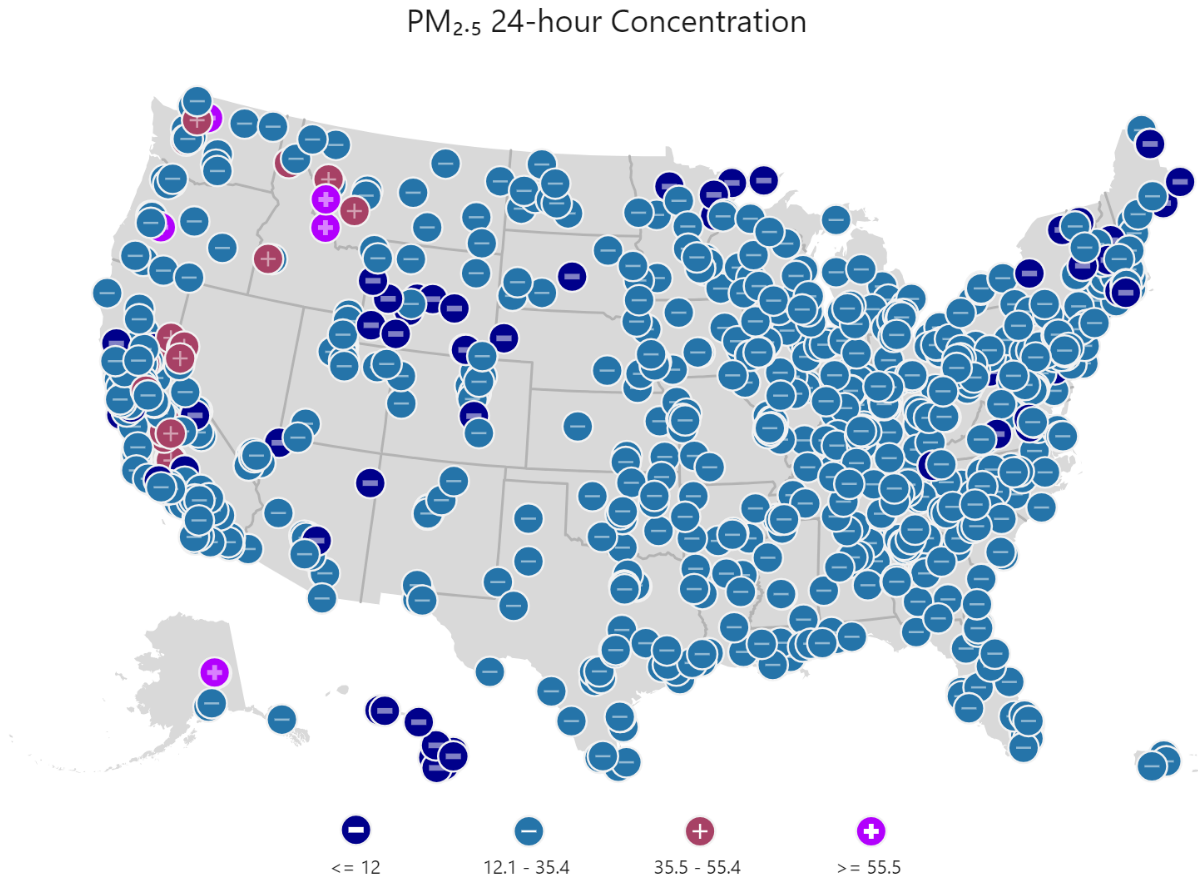
Table A4. Peak 24-hour $PM_{2.5}$ concentrations in the U.S., 2000-2022, ug/m^{3}

Averaging period	Median	Average	90th percentile	10th percentile
2000	33.7	35	47	22.3
2001	34.3	36	47.7	23
2002	33.2	34	46.6	22
2003	31.6	32	42.1	19.3
2004	30.5	31	40.6	21
2005	33.9	34	44.7	19.55
2006	29.8	30	38.7	19.2
2007	31.3	32	41.2	20.6
2008	26.9	28	35.4	17.8
2009	23.8	25	35.1	16.7
2010	24.6	25	33.4	15.9
2011	24.3	25	32.4	16.1
2012	21.4	22	28.5	16
2013	21	23	30	15.7
2014	21.2	23	29.2	15.2
2015	21.4	22	29.5	15.2
2016	18	19	25.8	13.3
2017	18.4	21	30.9	14.2
2018	19.7	23	32.1	14.4

2019	18.7	20	26.5	13.7
2020	19	25	42.4	14
2021	21.1	23	33.4	15.4
2022	18.2	20	27.5	13.3

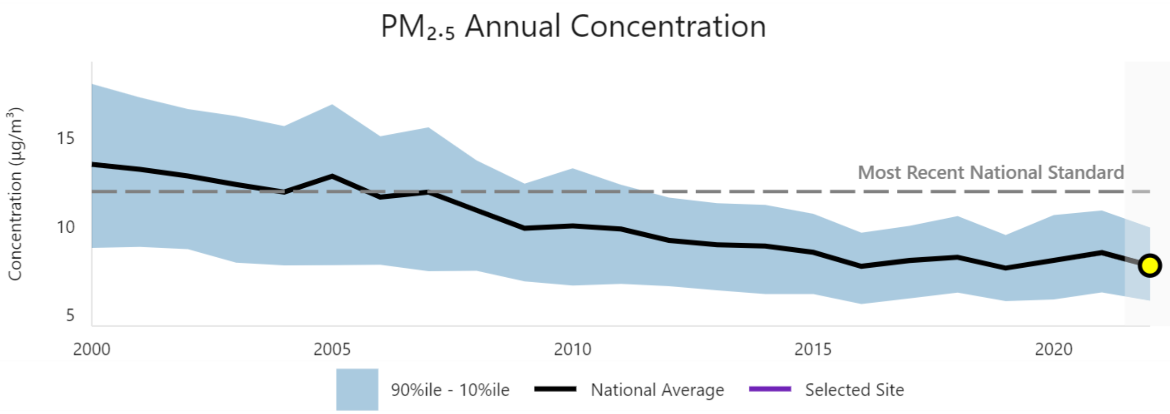
Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

Figure A4. Peak 24-hour $PM_{2.5}$ concentrations in the U.S., 2022, ug/m^3



Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2021

Figure A5. Annual average $PM_{2.5}$ concentrations in the U.S., 2000-2022, ug/m^{3*}



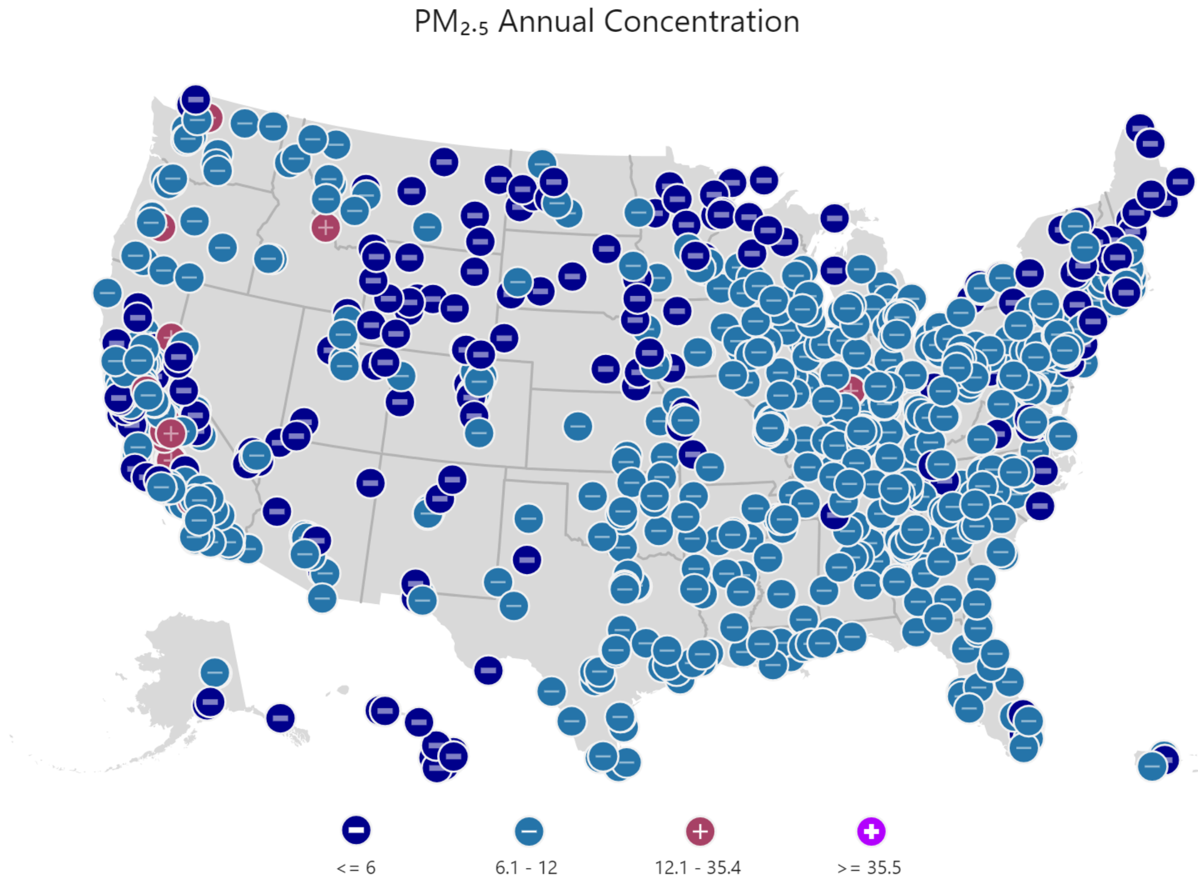
*The "Most Recent National Standard" refers to the previous annual $PM_{2.5}$ National Ambient Air Quality Standard of 12 ug/m^3, which was lowered to 9 ug/m^3 in February 2024. The data trend is based on monitoring sites nationwide measuring $PM_{2.5}$ that have sufficient data to assess $PM_{2.5}$ trends since 2000. Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

Table A5. Annual average $PM_{2.5}$ concentrations in the U.S., 2000-2022, ug/m^3

Averaging period	Median	Average	90th percentile	10th percentile
2000	14	14	18	8.8
2001	13	13	17	8.9
2002	13	13	17	8.8
2003	13	12	16	8.0
2004	12	12	16	7.8
-2005	13	13	17	7.8
2006	12	12	15	7.9
2007	12	12	16	7.5
2008	11	11	14	7.5
2009	9.9	10	12	6.9
2010	10	10	13	6.7
2011	10	10	12	6.8
2012	9.3	9.2	12	6.7
2013	8.9	9.0	11	6.4
2014	9.0	8.9	11	6.2
2015	8.6	8.6	11	6.2
2016	7.7	7.8	9.7	5.6
2017	7.9	8.1	10	6.0
2018	8.0	8.3	11	6.3
2019	7.6	7.7	9.5	5.8
2020	7.6	8.1	11	5.9
2021	8.3	8.5	11	6.3
2022	7.7	7.8	10	5.8

Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

Figure A6. Annual average $PM_{2.5}$ concentrations in the U.S., 2022, ug/m^3



Source: U.S. EPA. 2021a. Our Nation's Air – Trends Through 2022. 2023b. Available at: https://gispub.epa.gov/air/trendsreport/2023

Appendix B: U.S. Environmental Protection Agency Particulate Matter AQI designations and Health Statements*

AQI Category	24-hr PM_{10} Concentration (µg/m^3)	24-hr $PM_{2.5}$ Concentration (µg/m^3)	Conclusion	Recommendation†
Good	0 – 54	0 - 9	None.	None.
Moderate	55 – 154	9.1 - 35.4	**Exposures in this range cause:** 1. Respiratory symptoms in unusually sensitive individuals; 2. Exacerbation of cardiopulmonary disease.	Unusually sensitive* people should consider reducing prolonged or heavy exertion.
Unhealthy for Sensitive Groups	155 – 254	35.5 - 55.4	**Exposures in this range cause:** 1. Increased likelihood of respiratory symptoms in sensitive* groups; 2. Exacerbation of symptoms of or death from pre-existing cardiopulmonary disease.	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should reduce prolonged or heavy exertion.
Unhealthy	255 – 354	55.5 - 125.4	**Exposures in this range cause:** 1. Increased likelihood of respiratory symptoms in sensitive groups; 2. Exacerbation of symptoms of or death from pre-existing cardiopulmonary disease; and 3. Increased likelihood of respiratory effects in the general public.	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.
Very Unhealthy	355 – 424	125.5 – 225.4	**Exposures in this range cause:** 1. Increased likelihood of respiratory symptoms in sensitive groups; 2. Significant exacerbation of symptoms of or death from pre-existing cardiopulmonary disease; and 3. Significant increase in respiratory effects in general population.	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.
Hazardous	425 – 604	225.5+	**Exposures in this range cause:** 1. Serious aggravation of respiratory symptoms in sensitive groups; 2. Serious exacerbation of symptoms of or death from pre-existing cardiopulmonary disease; and	Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, children, and people of lower socioeconomic status should

			3. Serious risk of respiratory effects in general population.	remain indoors and keep activity levels low.

[*]Adapted from: https://www.airnow.gov/sites/default/files/2020-05/aqi-technical-assistance-document-sept2018.pdf and https://www.epa.gov/system/files/documents/2024-02/pm-naaqs-air-quality-index-fact-sheet.pdf

[†] For several reasons (e.g. greater urban and regional exposure in urbanized areas, less access to healthcare, greater prevalence of respiratory and cardiovascular disease), people of lower socioeconomic status are also more likely to have increased risk for adverse health outcomes from exposure to elevated PM (Pratt et al. 2015).

[‡] **Health Statements**

- **Sensitive Groups:** Pregnant women, children, and the elderly (≥65 years)
- **Highly Sensitive Groups:** Sensitive individuals or individuals in the general population with pre-existing health conditions that make them more susceptible to adverse health outcomes from exposure. Health assessors should assume U.S.EPA's term "unusual sensitivity" is a subjective term that suggests an individual's personal susceptibility based on their health status, sensory vulnerability, and pre-existing conditions at the time of exposure. ATSDR uses the term "highly sensitive" in place of "unusually sensitive".