Wisconsin Department of Natural Resources

2019 Wisconsin Air Quality Trends Report

Data from 2001-2018

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Acronyms and abbreviations

TABLE 1. Acronyms and abbreviations used in this report

Term	Definition
AQI	Air Quality Index
CO	Carbon monoxide
DNR	Wisconsin Department of Natural Resources
DRR	Data Requirements Rule for SO_2
DV	Design value
EPA	U.S. Environmental Protection Agency
hr	Hour
mo	Month
NAAQS	National Ambient Air Quality Standards
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides; NO + NO_2
O_3	Ozone
$PM_{2.5}$	Fine particles (particles 2.5 micrometers or smaller in size)
PM_{10}	Inhalable particles (particles 10 micrometers or smaller in size)
ppb	Parts per billion
ppm	Parts per million
SO_2	Sulfur dioxide
TSP	Total suspended particles
$\mu g/m^3$	Microgram per cubic meter
µm	Micrometer (micron)
VOCs	Volatile organic compounds
yr	Year

Report summary

The Wisconsin Department of Natural Resources (DNR) monitors ambient concentrations of several air pollutants throughout the state, including ground-level ozone, particle pollution, sulfur dioxide, nitrogen dioxide, lead, and carbon monoxide. These six pollutants are called criteria pollutants and are regulated by the U.S. Environmental Protection Agency (EPA). Monitored levels of criteria pollutants are compared against the National Ambient Air Quality Standards (NAAQS), set by EPA at levels protective of public health, to determine whether the standards are met. In addition to the criteria pollutants, DNR monitors air quality for a number of toxic compounds.

This year's Wisconsin Air Quality Trends Report presents official state monitoring data through 2018 for criteria air pollutants. The report includes over 15 years of ambient air monitoring data. The first version of the Trends Report was released in 2013, and the report is updated annually to incorporate the most current data available.

Inventory estimates of Wisconsin's air pollutant emissions from all source sectors, available in 3-year increments from 2002 to 2014, were first included in last year's report. Time series of Wisconsin point source emissions included in last year's report have been updated to include now-available 2017 data. Long-term trends in air quality and air pollutant emissions, such as those presented in this report, guide decisions about management of air quality issues at federal and state levels.

The report begins with an introduction to current air quality standards, followed by an overview of each criteria pollutant including the regulatory history of the pollutant standards and historical attainment status in Wisconsin. The next section presents emissions data for criteria pollutants and their precursors. The fourth section presents trends in monitoring data compared to the relevant NAAQS. Report appendices follow the main document and include graphs of county-level pollutant trends, tables showing percentage change in monitored pollutants over time, and a table detailing the site name abbreviations used in this document.

Highlights

Overall, concentrations of most criteria pollutants have decreased in all regions of the state since monitoring data have been collected. The decrease in pollutant concentrations is due to implementation of a variety of federal and state pollution control programs. Currently, 94 percent of Wisconsin's population lives in areas meeting all federal air quality standards. Exceptions include all or part of six counties located along the Lake Michigan shoreline (Kenosha, Milwaukee, Ozaukee, Sheboygan, Manitowoc and Door), which are designated as nonattainment for the 2008 and/or 2015 ozone NAAQS. Additionally, a small area around the city of Rhinelander in Oneida County remains designated as nonattainment for the sulfur dioxide standard. The DNR is committed to working with partners in Wisconsin and other states to meet the applicable federal NAAQS in these areas.

One of the many success stories highlighted in the report is the substantial reduction in fine particle pollution. All fine particle monitors in Wisconsin measured concentrations[1] well below the federal air quality standards (Fig. 1). As a result, all of Wisconsin is considered by EPA to be "in attainment" of federal fine particle standards. Since the early 2000s, fine particle concentrations have decreased by over 35 percent (Fig. 1).

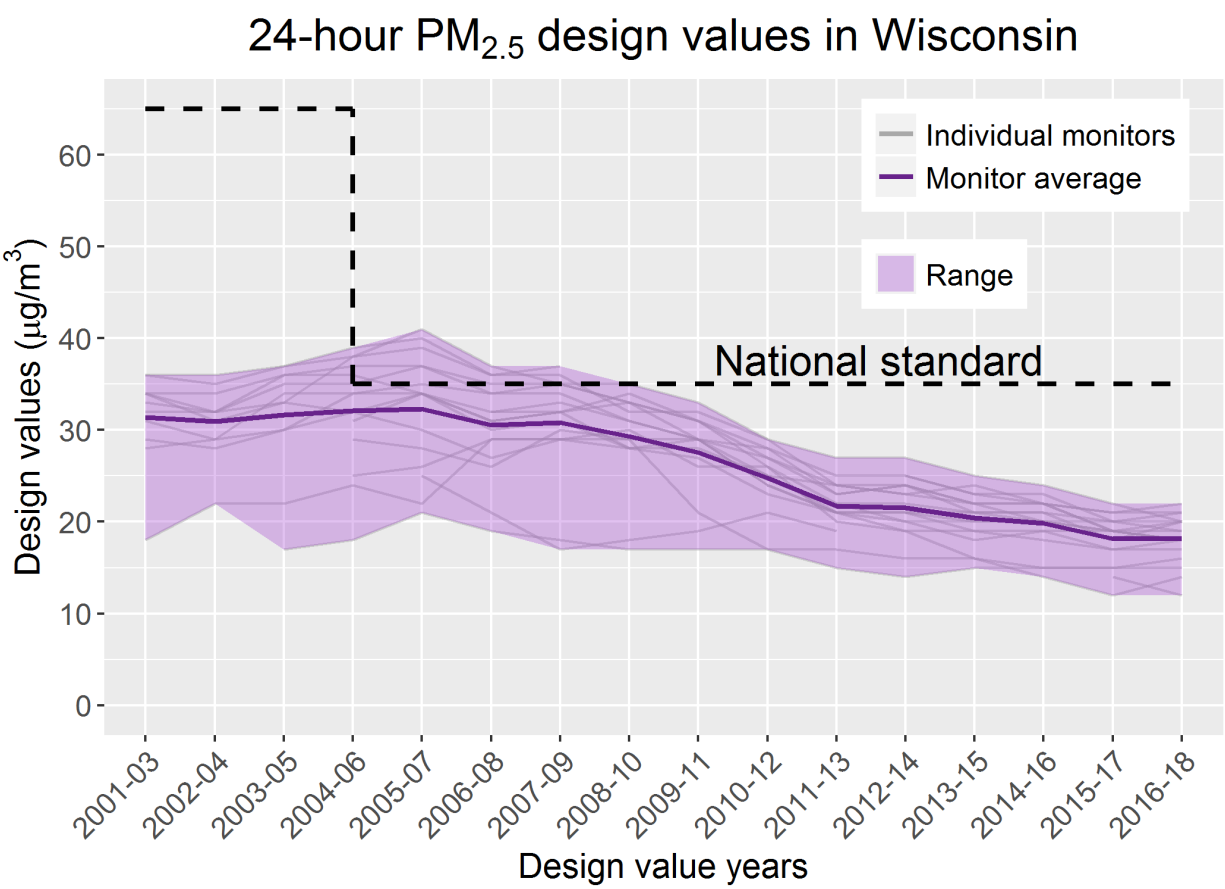

Figure 1. Trends in 24-hour fine particles[1]. The dark line shows the mean design value, the light lines show trends for each monitor, and the shaded area shows the range of values observed.

[1] Concentrations are reported as "design values", which are explained in the Background section of the main document.

Ozone pollution in the state has also decreased since the early 2000s (Fig. 2). Ozone is created by chemical reactions in the atmosphere between substances such as nitrogen oxides (NO_x) and volatile organic compounds (VOC), referred to as ozone precursors[2]. Emissions of these precursors have decreased by 50 percent since 2002 (Fig. 3). Overall, emissions of directly-emitted pollutants (as opposed to those that are produced by atmospheric chemical reactions) have decreased since 2002 (Fig. 3).

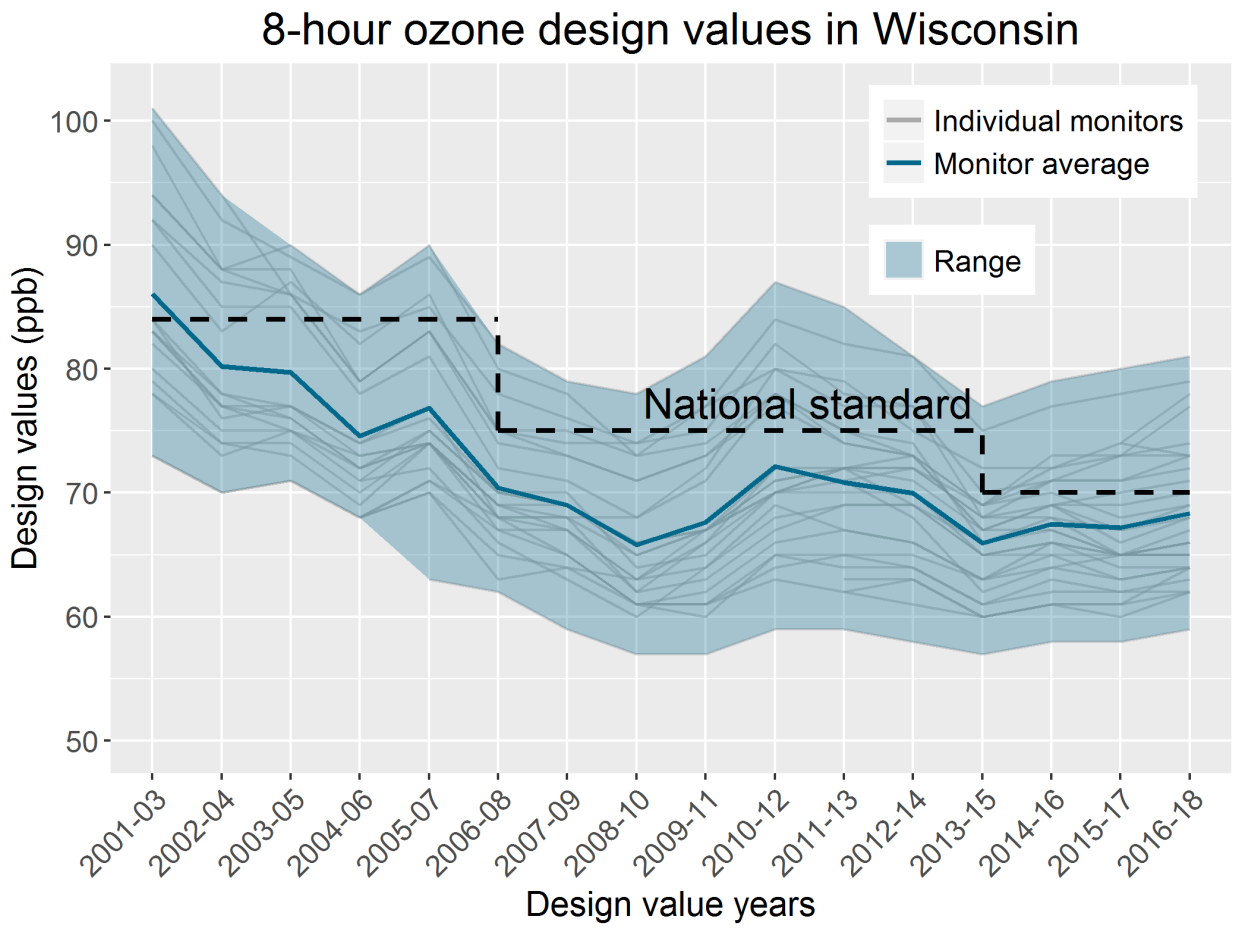

Figure 2. Trends in ozone[1]. The dark line shows the mean design value, the light lines show trends for each monitor, and the shaded area shows the range of values observed. Note that the design value axis is truncated at 50 ppb (rather than going down to zero) to allow for a clearer view of the differences among sites.

[2] Pollution sources (e.g., cars) do not directly emit ozone, but rather can emit precursors that form ozone.

Another notable finding is the substantial reduction in SO_2 emissions in Wisconsin since 2002. Total SO_2 emissions decreased by 68 percent from 2002 to 2014 (Fig. 3). SO_2 emissions from point sources (such as power plants, paper mills, and other industrial facilities) decreased even more, showing an 89 percent reduction from 2002 to 2017.

Finally, near-road monitoring in large metropolitan areas, including Milwaukee, has found NO_2 concentrations to be well below the NAAQS, despite the proximity of monitors to major roadways where emissions would be expected to be high. As a result, EPA eliminated planned future requirements for near-road NO_2 monitors in smaller metropolitan areas (such as Madison). EPA's decision to eliminate this requirement demonstrates that EPA is confident that NO_2 concentrations in all parts of the state and country are meeting health-based standards.

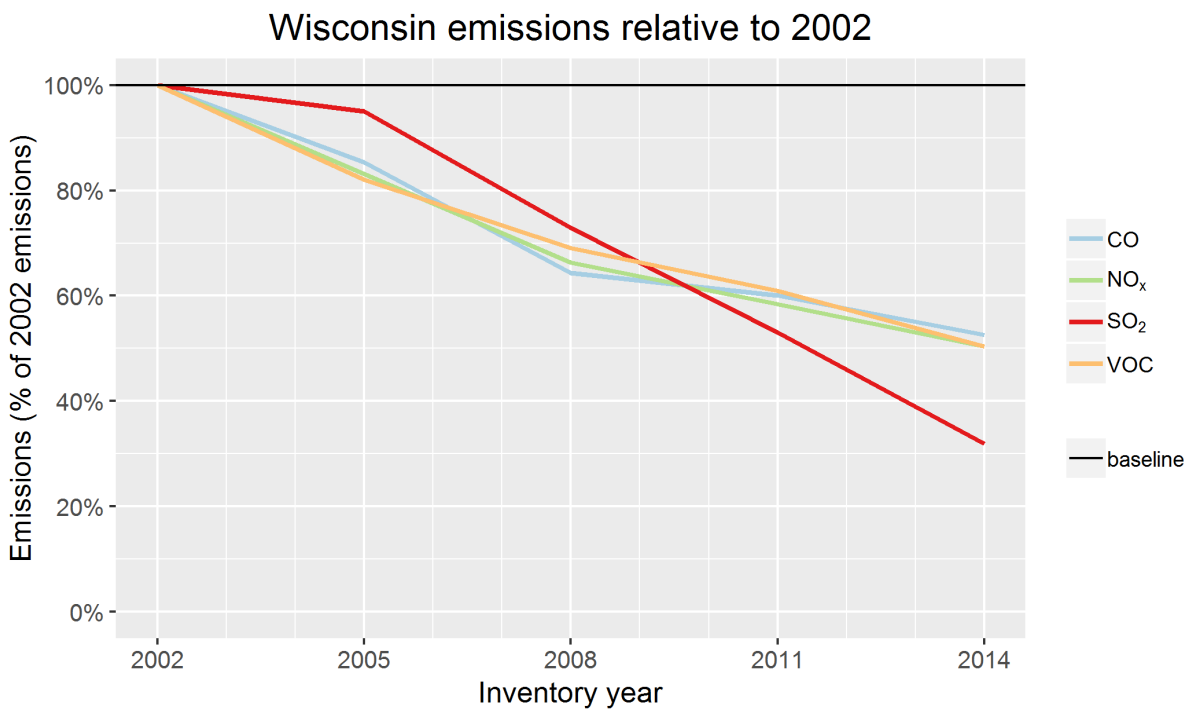

Figure 3. Trends in selected pollutant emissions[3] from all Wisconsin sources.[4] All values are compared to 2002 values (i.e., 2002 values = 100%).

Notable changes from the 2018 report

The most noteworthy change from last year's report is the addition of satellite data showing changes in NO_2 levels in the atmosphere in Wisconsin between 2006 and 2019.

[3] Data for pollutants with calculation methodologies that have changed substantially over time (i.e., ammonia and directly-emitted particulates) have not been included in this graph. See the Wisconsin emissions data section of the main document for information on the full suite of pollutants.

[4] Emissions data are from https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data. These data are based on National Emissions Inventory (NEI) data and have been adjusted to be directly comparable between the years. The NEI is conducted every three years, and 2014 is the most recent complete NEI inventory.

Background

National Ambient Air Quality Standards

The Clean Air Act requires EPA to set NAAQS for pollutants considered harmful to public health and the environment. There are two types of standards, primary and secondary. Primary standards are set at a level to protect human health, especially for people with respiratory conditions or particular sensitivity to pollutant exposure. Secondary standards are intended to protect public welfare, including preventing impaired visibility, structural damage to buildings and vegetative/livestock injury. For some pollutants, there are multiple primary standards (e.g., CO has 8-hr and 1-hr standards). The different standards allow EPA to track both long-term and short-term exposure to these pollutants. This report will focus on comparison of Wisconsin air monitoring data with the primary standards.

The current NAAQS for the six criteria pollutants regulated by EPA are shown in Table 2. Note that both the 2015 ozone NAAQS of 0.070 ppm and the 2008 NAAQS of 0.075 ppm currently remain in effect.

Design value calculations

A design value is a statistic that describes the air quality status of a given location relative to the level of a NAAQS. Design values are defined by EPA to be consistent with the individual NAAQS, and are based on data collected over long periods to ensure that typical pollutant concentrations are represented, rather than isolated spikes in concentrations. Design values are published annually on EPA's Air Quality Design Values webpage in late summer for data through the end of the previous year. The webpage can be found at: https://www.epa.gov/air-trends/air-quality-design-values.

The design values for criteria pollutants are calculated using methods specified for each standard, as shown in the "Averaging time" and "Definition" columns of Table 2. The paragraphs below explain how ozone and fine-particle design values are calculated.

TABLE 2. EPA criteria pollutants and National Ambient Air Quality Standards*

Pollutant		Primary / secondary	Averaging time**	Level	Definition**
Carbon monoxide		primary	8 hr	9 ppm	not to be exceeded more than once per year
			1 hr	35 ppm	
Lead		primary and secondary	3 mo	0.15 μg/m^3	maximum 3-mo mean over 3 yr
Nitrogen dioxide		primary	1 hr	100 ppb	annual 98th percentile value of daily maximum 1-hr concentrations, averaged over 3 yr
		primary and secondary	annual	53 ppb	annual mean
Ozone		primary and secondary	8 hr	0.070 ppm (2015 standard) 0.075 ppm (2008 standard)	annual fourth-highest daily maximum 8-hr concentration, averaged over 3 yr
Particulate matter	$PM_{2.5}$	primary	annual	12.0 μg/m^3	annual mean, averaged over 3 yr
		secondary	annual	15.0 μg/m^3	annual mean, averaged over 3 yr
		primary and secondary	24 hr	35 μg/m^3	annual 98th percentile value, averaged over 3 yr
	PM_{10}	primary and secondary	24 hr	150 μg/m^3	not to be exceeded more than once per year on average over 3 yr
Sulfur dioxide		primary	1 hr	75 ppb	annual 99th percentile value of daily maximum 1-hr concentrations, averaged over 3 yr
		secondary	3 hr	0.5 ppm	not to be exceeded more than once per year

* Based on https://www.epa.gov/criteria-air-pollutants/naaqs-table.
** hr = hour, mo = month, yr = year; 3-mo, 8-hr, and 3-hr averages are calculated as rolling averages; in contrast, annual averages are for the calendar year and 24-hr averages are for the calendar day (i.e., are not rolling)

Ozone

The metric used to determine compliance with the ozone NAAQS is the annual fourth-highest daily maximum eight-hour (8-hr) concentration, averaged over a period of three years (3 yr). Two ozone NAAQS are currently in effect, each with different methods of determining design values.

Under the 2008 ozone standard, individual days are first divided into twenty-four 8-hr periods. For example, midnight to 8 a.m. would be the first period, while 11 p.m. to 7 a.m. the following day would be the last period. The average ozone concentration during each 8-hr period is calculated, and the highest of the 24 average values is determined for each calendar day (i.e., the maximum 8-hr average value for the day). Figure 4 shows the highest 8-hr average value from each day at a monitoring site during an example ozone season. To obtain the design value, the fourth-highest daily maximum 8-hr value of the year is identified (circled value in Fig. 4) and then averaged with the fourth-highest values from the two previous consecutive years. For instance, a 2016-2018 ozone design value would be calculated by averaging the fourth-highest 8-hr maximum for 2018 with the fourth-highest values for 2016 and 2017.

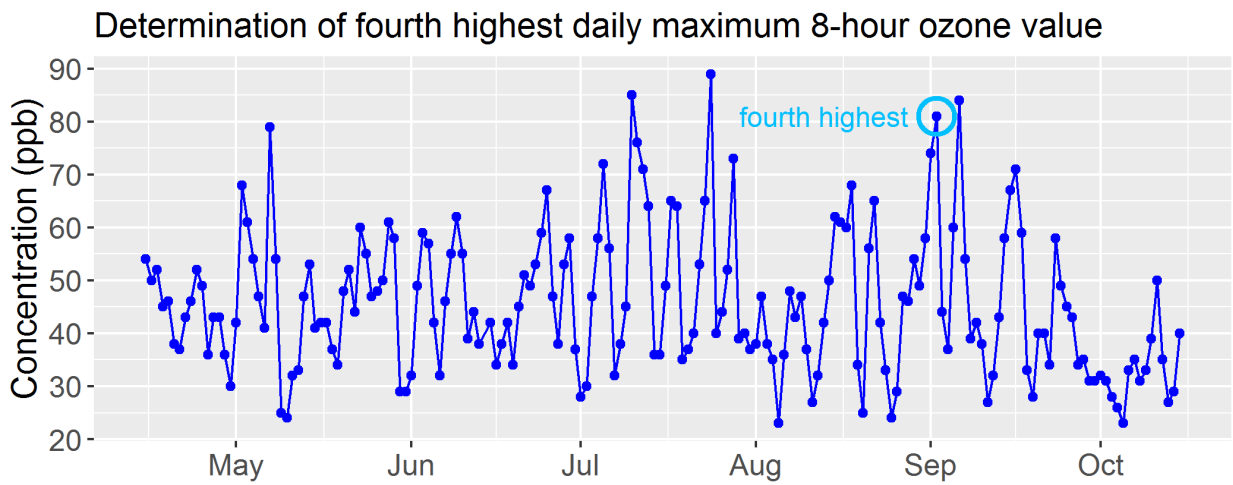

Figure 4. Example of a fourth-highest daily 8-hr maximum value identified for use in calculating an ozone design value.

Under the 2015 ozone standard, the procedure to calculate design values is similar to that used under the 2008 standard, but under the 2015 standard, 8-hr rolling averages are based on dividing individual days into 17 (rather than 24) 8-hr periods. The first of the 17 periods occurs between 7 a.m. to 3 p.m., and the last period occurs between 11 p.m. to 7 a.m. the following day. This change ensured that, when daily maximum 8-hour concentrations occurred in overlapping 8-hour periods over two consecutive days, the resulting design value would appropriately reflect that exposures experienced by individuals, in this case, only occurred once. In addition to changes in the number of 8-hr periods, design values calculated under the 2015 standard are compared to the 2015 NAAQS of 70 ppb, while design values calculated under the 2008 standard are compared to the 2008 NAAQS of 75 ppb to determine compliance with the standard.

Fine particles

For fine particles ($PM_{2.5}$), design values are calculated for comparison with both the annual NAAQS and the 24-hr NAAQS. The design value for the annual $PM_{2.5}$ NAAQS is the average of the annual means from three consecutive years, where each annual mean is the average of the four quarterly mean concentrations of that year. To obtain 24-hr NAAQS design values, the observation representing the 98th percentile of 24-hr (calendar-day) average concentrations of fine particles is determined for each year (e.g., Fig. 5) and averaged over three consecutive years. The 98th percentile value is the observed concentration below which 98 percent of observations are. Only two percent of observed concentrations are higher than this value. To calculate a 2016-2018 24-hr $PM_{2.5}$ design value, the 98th percentile value for 2018 would be averaged with 98th percentile values from 2016 and 2017. The resulting design value would be compared to the 24-hr $PM_{2.5}$ NAAQS of 35 µg/m^3.

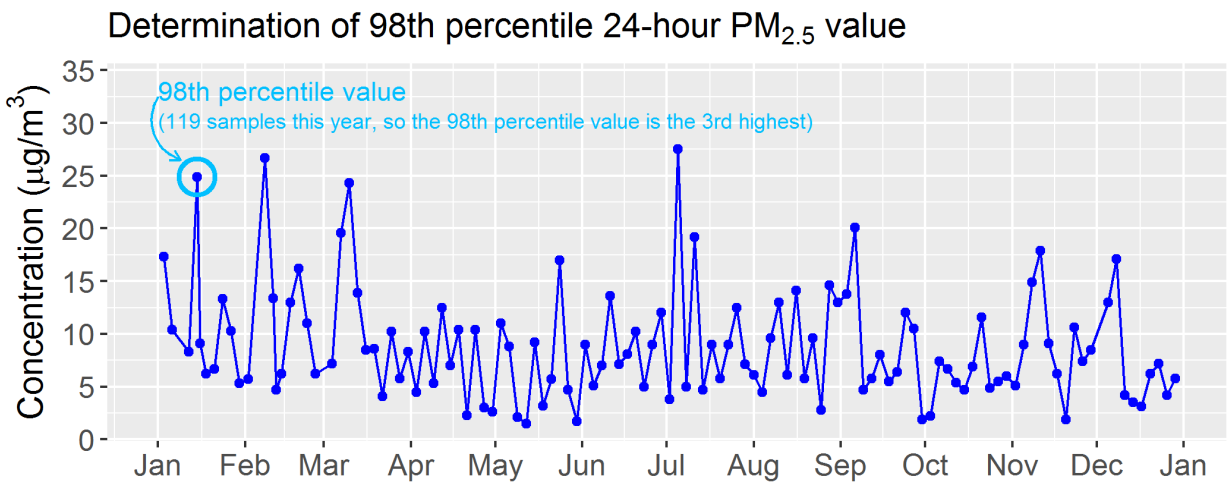

Figure 5. Example of a 98th percentile observation identified for use in calculating a 24-hr $PM_{2.5}$ design value.

Overview of pollutants

Ozone

Ozone, also known by its chemical formula O_3, is a naturally-occurring atmospheric molecule that contains three oxygen atoms. Ozone is unstable and is constantly produced and destroyed in the atmosphere through a variety of chemical reactions. Ozone is present in the Earth's upper atmosphere, as well as at ground level. High ozone concentrations in the upper atmosphere (stratosphere) filter out harmful ultraviolet rays from the sun. High concentrations of ozone at ground level, however, can have an adverse impact on health. Monitored values of ozone found in this report represent ground-level ozone.

Ground-level ozone is not directly emitted into the air; rather, it is created by photochemical reactions (atmospheric chemical reactions that occur in the presence of sunlight) between ozone precursors. The highest measured ozone concentrations typically occur downwind of urban areas on hot sunny days with light winds as a result of long-range transport of ozone and ozone precursors.

Ozone exposure can lead to or exacerbate numerous health issues, including chest pain, coughing, throat irritation, and airway inflammation. It also can reduce lung function and worsen bronchitis, emphysema and asthma. Children are at the greatest risk from exposure to ozone because their lungs are still developing. In Wisconsin, ozone is measured using a network of continuously operating monitors that provides the basis for air-quality forecasting and real-time health advisories.

Ozone concentrations in Wisconsin are significantly higher during the warmer months. As a result, the state's ozone monitoring season does not run throughout the entire year. For 2018, Wisconsin's ozone season ran from March 1 to October 15, with the exception of Kenosha County, where the ozone season

ran from March 1 to October 31[5]. On December 21, 2018, EPA waived Wisconsin's ozone monitoring requirements for the month of March for 24 of Wisconsin's 26 seasonal ozone monitors, the exceptions being the two monitors located in Kenosha County. This waiver was in response to the department's request to EPA, which used monitored ozone data from 2012 to 2018 to demonstrate that Wisconsin does not experience elevated levels of ozone in March. Beginning in 2019, the majority of Wisconsin's ozone monitors ran from April 1 to October 15. The Kenosha County ozone monitors continue to operate from March 1 to October 31 since they are part of the three-state Chicago ozone nonattainment area.

Regulatory history

In 1971, EPA issued a 1-hr standard of 0.08 ppm (effectively 84 ppb[6]) for "total photochemical oxidants," which included ozone. In 1979, EPA replaced this standard with a 1-hr standard for ozone set at 0.12 ppm (effectively 124 ppb[6]). In July 1997, EPA replaced the 1-hr ozone standard with an 8-hr standard of 0.08 ppm (effectively 84 ppb[6]) to protect the public against longer-term exposure. In March 2008, the 8-hr standard was lowered to 0.075 ppm (75 ppb). EPA further decreased the 8-hr standard to 0.070 ppm (70 ppb) effective December 28, 2015. The 2008 standard of 75 ppb remains in effect until it is revoked by EPA; therefore, both the 2008 and 2015 standards were in effect in 2018.

Wisconsin's attainment status history

While a number of Wisconsin counties have been designated as nonattainment with each ozone-related standard, the extent of the areas designated nonattainment has generally decreased with each successive standard. For example, 18 counties in Wisconsin were designated nonattainment with the 1971 1-hour standard for total photochemical oxidants. In contrast, only 12 Wisconsin counties were designated nonattainment for the 1979 1-hour ozone standard. When EPA completed a second round of designations under the 1979 1-hour ozone standard in 1990, the number of counties designated nonattainment in Wisconsin decreased to 11. This trend continued in 2004 when only 10 Wisconsin counties were designated nonattainment for the 1997 8-hour ozone standard. In 2012, only Sheboygan County and the eastern part of Kenosha County were designated nonattainment for the 2008 ozone NAAQS. In April 2018, EPA designated small portions of six lakeshore counties as nonattainment for the 2015 ozone NAAQS.[7]

Because of improvements in air quality, many counties that were originally designated nonattainment for a given standard were subsequently redesignated to attainment of that standard. For example, of the ten counties designated nonattainment for the 1997 standard, only one county was not redesignated to attainment before the standard was revoked in 2015. Nonattainment designations

[5] Kenosha County is part of the Chicago nonattainment area, and its ozone season is aligned with those of the other states in that area: Illinois and Indiana.

[6] Because older standards were set at the 0.01 ppm level, while the parameter was measured to the 0.001 ppm level, rounding conventions associated with attainment determination result in effective standards that appear to be slightly higher than the official published values. The official and effective standards are equivalent.

[7] Portions of Door, Manitowoc, Sheboygan, Ozaukee, Milwaukee and Kenosha counties were designated nonattainment for the 2015 ozone NAAQS. Maps of these nonattainment areas can be found at https://dnr.wi.gov/topic/AirQuality/documents/2015OzoneStandardMaps.pdf.

remain in effect for Sheboygan County and eastern Kenosha County for the 2008 ozone NAAQS, along with the newly designated areas for the 2015 ozone NAAQS.

Particulate matter ($PM_{2.5}$ and PM_{10})

Particulate matter, also known as PM, is made up of very small solid particles or liquid droplets in many shapes and sizes. These individual particles are so small they cannot be seen with the naked eye, but high concentrations of particles can reduce visibility. Particle pollution is classified based on particle diameter. There are two types of particles for which NAAQS have been set: fine particles (2.5 µm in diameter or smaller; $PM_{2.5}$), and inhalable particles (10 µm in diameter or smaller; PM_{10}) (Table 2).

Fine particles have different emission sources than larger inhalable particles and behave much like gases in the atmosphere. Most fine particles form in the atmosphere. Generally, larger inhalable particles are directly produced by mechanical processes, such as crushing and grinding. Particles of different sizes are transported differently and have different fates. Fine particles have longer lifetimes in the atmosphere (days to weeks), travel longer distances (hundreds to thousands of miles), and are more uniformly distributed over larger regions compared with larger particles.

There are two categories of particles, primary particles and secondary particles, which differ in how they are created. Primary particles are created directly by crushing or grinding processes or from combustion sources, such as vehicles, fires, or smokestacks. Secondary particles form when pollutants (e.g., sulfur oxides and nitrogen oxides) react in the atmosphere with ammonia and other gases. Secondary particles comprise the vast majority of fine particles while larger inhalable particles are almost entirely primary particles.

While all inhalable particles pose a health risk, fine particles pose the greatest risk because of their ability to penetrate deep into the respiratory tract or, for very fine particles, to enter the bloodstream. Studies have shown an association between fine particle exposure and premature death from heart or lung disease, as well as aggravated respiratory conditions, such as asthma and airway irritation. Individuals most sensitive to fine particle exposure include people with heart or lung disease, older adults and children.

Regulatory history

EPA's original 1971 standard for particle pollution set a limit for total suspended particles (TSP), which included both $PM_{2.5}$ and PM_{10}, as well as coarser particles. In 1987, EPA discontinued the standard for TSP and replaced it with two standards for PM_{10}, as described below. Wisconsin, however, retained its own 24-hr TSP standard until 2011.

$PM_{2.5}$

In 1997, EPA established an annual $PM_{2.5}$ standard of 15.0 µg/m^3 as well as a 24-hr (calendar-day) $PM_{2.5}$ standard of 65 µg/m^3. In 2006, the 24-hr standard was lowered to 35 µg/m^3. The annual standard was lowered to 12.0 µg/m^3 in 2012.

PM_{10}

In 1987, EPA established two PM_{10} standards: an annual standard of 50 µg/m^3 and a 24-hr (calendar-day) standard of 150 µg/m^3. In 2006, the 1987 annual PM_{10} standard was revoked. The 24-hr PM_{10} standard remains in effect today.

Wisconsin's attainment status history

$PM_{2.5}$

In 2009, EPA designated Milwaukee, Racine, and Waukesha counties as nonattainment for the 2006 NAAQS for 24-hr $PM_{2.5}$ based on monitoring data from 2006 to 2008. In April 2014, EPA redesignated these counties to attainment based on monitoring data collected between 2008 and 2011. Consequently, all counties in Wisconsin are currently in attainment for both the annual and 24-hr $PM_{2.5}$ NAAQS.

PM_{10}

Design values for PM_{10} in Wisconsin have not exceeded PM_{10} standards; consequently, there are no PM_{10} nonattainment areas in the state.

Sulfur dioxide (SO_2)

Sulfur dioxide (SO_2), a product of combustion, is one of a group of highly reactive gases known as oxides of sulfur. The largest emission source of SO_2 is fossil fuel combustion at power plants and other industrial facilities.

Exposure to SO_2 has been shown to cause a range of adverse respiratory effects including bronchoconstriction and increased asthma symptoms. Further, emission sources that contribute to high concentrations of SO_2 also contribute to the formation of other oxides of sulfur. Some of these oxides can react with other compounds in the atmosphere to form fine particles, which can penetrate deep into the lungs.

Regulatory history

EPA first set standards for SO_2 in 1971. An annual standard was set at 30 ppb and a 24-hr standard was set at 140 ppb. In 1996, EPA reviewed the standards without revision. In 2010, EPA established a new 1-hr standard at 75 ppb and revoked the annual and 24-hr standards because the 1-hr standard is more protective of public health.

Wisconsin's attainment status history

Portions of Brown, Dane, Marathon, Milwaukee, and Oneida Counties were designated nonattainment for the 1971 SO_2 NAAQS, and all areas were eventually redesignated to attainment. In 2013, EPA designated a portion of Oneida County as nonattainment for the 2010 SO_2 NAAQS. The rest of the state is designated attainment/unclassifiable except for Outagamie County. EPA will designate Outagamie County during its final round of designations in 2020.

Nitrogen dioxide (NO_2)

Nitrogen dioxide (NO_2) is a reactive byproduct of combustion produced mainly by vehicles, resulting in concentrations that are highest immediately adjacent to roadways. Nitrogen dioxide and nitric oxide (NO), collectively referred to as NO_x, are important precursors of ozone, which is generated when NO_x reacts with VOCs in the presence of sunlight.

Research indicates that direct exposure to NO_2 for short periods of time can result in respiratory issues such as airway inflammation and aggravated asthma. Longer-term exposure poses a risk of acute respiratory illness and inhibited lung development in children.

Regulatory history

In 1971, EPA set the original standard for NO_2 at 53 ppb based on an annual average. This standard is still in effect. In 2010, EPA established an additional 1-hr standard of 100 ppb and mandated the placement of NO_2 monitors near major roads in large urban areas, with installation in phases according to population. DNR added a near-road NO_2 monitor in Milwaukee that became operational January 1, 2014. Due to low NO_2 concentrations found at monitors nationwide, EPA eliminated the requirement that near-road monitors be installed in areas with populations between 500,000 and 1 million (e.g., Madison area).

Wisconsin's attainment status history

Design values in Wisconsin have not exceeded the NO_2 standards, and consequently there are no NO_2 nonattainment areas in the state.

Lead

Lead can be found in the atmosphere as well as in the water and soil. Before unleaded gasoline was introduced in 1980, vehicle emissions were the primary source of airborne lead. Today, lead is emitted mainly from industrial metal processing sources, as well as from the combustion of leaded aviation fuel.

Lead exposure can occur directly through contact with lead in the atmosphere. In addition, deposition of lead from the atmosphere into the soil or water bodies may cause this pollutant to accumulate in natural ecosystems and contaminate drinking water. The health effects of lead exposure in humans are numerous and well-documented. In general, neurological effects and developmental risks are the largest danger for children, whereas cardiovascular effects, such as heart disease and high blood pressure, commonly affect adults.

Regulatory history

The original lead standard, set by EPA in 1978, was 1.5 $\mu g/m^3$ on a calendar quarterly average basis. In 2008, this standard was replaced by a rolling three-month average and lowered to 0.15 $\mu g/m^3$. In 2016, after an extensive review period, EPA decided to retain the existing 2008 standard.

Wisconsin's attainment status history

Wisconsin uses a collection technique that measures lead content as a subset of total suspended particle samples as required by federal rule. During the past two decades, no areas in Wisconsin have had levels of lead that exceed the NAAQS, and the state has had no nonattainment areas.

Carbon monoxide (CO)

Carbon monoxide (CO) is a toxic gas that is well known as a potential danger in indoor environments; however, it is also emitted into the ambient air, primarily by mobile sources[8]. Under certain conditions, CO can react to form ground-level ozone.

In the short term, carbon monoxide exposure can reduce human respiratory efficiency. At extremely high concentrations, exposure can be fatal. People suffering from heart disease face increased risks from exposure to CO because their respiratory efficiency is already compromised.

Regulatory history

EPA originally set two standards for CO in 1971: an 8-hr standard of 9 ppm and a 1-hr standard of 35 ppm. These standards were reviewed in 1994 and 2011 and have remained unchanged.

Wisconsin's attainment status history

In the past, Wisconsin had nonattainment areas for CO in portions of Milwaukee and Winnebago counties. Both areas have since been redesignated to attainment. There are currently no CO nonattainment areas in the state.

Wisconsin emissions data

Pollutants monitored by DNR are either emitted directly from various sources or form in the atmosphere via chemical reactions between other emitted pollutants (known as "precursors"). EPA and states work together to develop a comprehensive inventory of air emission sources, the National Emissions Inventory (NEI), which is released every three years. The NEI is coordinated by EPA based on emissions estimates and emission model inputs provided by state, local and tribal air agencies and is supplemented by data developed by EPA. Examining Wisconsin's emissions of pollutants and pollutant precursors provides insight into the origin of the trends in monitored concentrations discussed later in this report, although monitored concentrations are also impacted by emissions from outside Wisconsin.

Total emissions

The graphs below show emissions from the last five NEI inventories, beginning with 2002 and ending with 2014, the most recent year for which complete NEI data are available. These graphs show the data aggregated into 13 source categories, which are listed in Table 3[9]. The data shown below reflect

[8] Mobile sources are primarily vehicles of all kinds (e.g., cars, trucks, boats, airplanes, trains, heavy equipment) but also include equipment with small engines such as lawn-care equipment and chain saws.

[9] For each graph, only categories that contributed at least 2.5 percent of total emissions of that pollutant are graphed individually. Smaller source categories are combined into a category labeled "Other".

adjustments EPA made to NEI data to improve consistency across inventories. EPA and states continually improve the methodology used to estimate emissions, which can lead to some notable inconsistencies in reported source category emissions between different NEI inventories. Source categories for which emissions methodology changed significantly between inventories are noted with an asterisk (*) in the figures below, and the discrepancies are explained in the text. Data used in graphs were downloaded from EPA's Air Pollutants Emissions Trends Data webpage: https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data.

Overall, emissions of most criteria pollutants and their precursors have decreased substantially since 2002. These reductions occurred due to implementation of a variety of federal and state pollution control programs.

Table 3. Emission source categories and their abbreviations.[10]

Emission Type	Emissions Source	Abbreviation
Stationary	Chemical and Allied Product Manufacturing	N/A*
	Fuel Combustion – Electric Utility	Fuel Comb. Elec.
	Fuel Combustion – Industrial	Fuel Comb. Indust.
	Fuel Combustion – Other	Fuel Comb. Other
	Metals Processing	N/A*
	Miscellaneous	Miscellaneous
	Other Industrial Processes	Other Industrial
	Petroleum and Related Industries	N/A*
	Solvent Utilization	Solvent Utilization
	Storage and Transport	Storage/Transport
	Waste Disposal and Recycling	Waste Disp./Recycl.
Mobile	Highway Vehicles	Highway Vehicles
	Off-Highway	Off-Highway

* N/A = not applicable; these categories emitted less than 2.5 percent of each pollutant's total emissions and have been grouped with other minor contributors into a category called "Other".

Gaseous criteria pollutants and precursors

Gaseous criteria pollutants directly impact human health and may also be precursors to other criteria pollutants. Ammonia (NH_3) and VOCs play a similar role in the atmosphere, as both pollutants and important precursors. For example, NO_x, CO and VOCs react in the presence of sunlight to create atmospheric ozone, while most fine particles form from reactions between NO_x, SO_2, VOCs and NH_3.

Emission data for each of these gaseous pollutants are shown below for NEI inventories from 2002 to 2014 (Fig. 6 to Fig. 10). Some highlights include:

- Total NO_x emissions decreased 50 percent since 2002, with the greatest reductions coming from fuel combustion at electric utilities and from highway vehicles.
- Emissions of VOCs also decreased 50 percent during this period.

[10] These source categories are one way that EPA reports NEI results. These classifications differ from the other commonly used NEI categories of point, area, onroad and nonroad.

- Emissions of SO_2 decreased by 68 percent from 2002 to 2014, with the largest reductions coming from the electric utility fuel combustion sector (emissions from large stationary sources decreased by 87 percent).
- Emissions of CO decreased by 47 percent over this same period, with most of the reductions coming from highway vehicles and the off-highway sector.

The apparent decrease in NH_3 emissions in 2014 (Fig. 10) is due to significant changes in EPA's inventory methodology for the "miscellaneous" sector that year, which mask any actual trends in emissions. Specifically, EPA changed its methodology for estimating fertilizer application NH_3 emissions between the 2011 and 2014 NEIs. EPA also used different emission factors for NH_3 emissions from livestock waste from dairy and beef cattle, hogs and poultry. Taken together, these changes account for the large change in reported NH_3 emissions from 2011 to 2014.

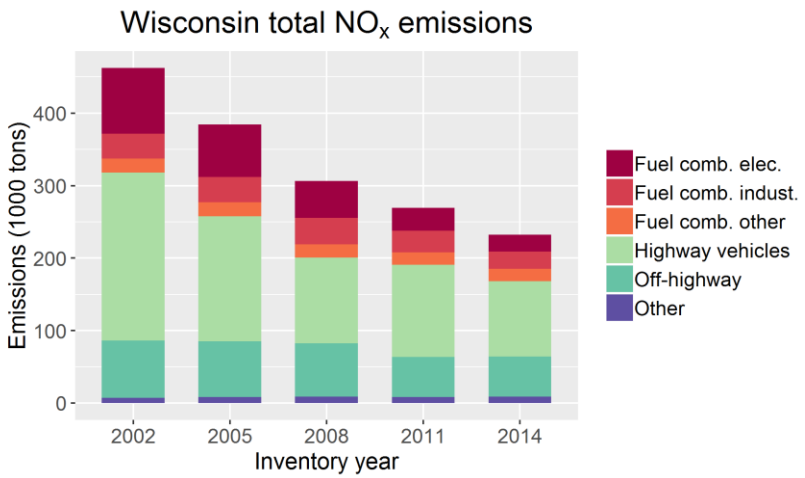

Figure 6. Emissions of NO_x from all sources in Wisconsin. See Table 3 for source category abbreviations.

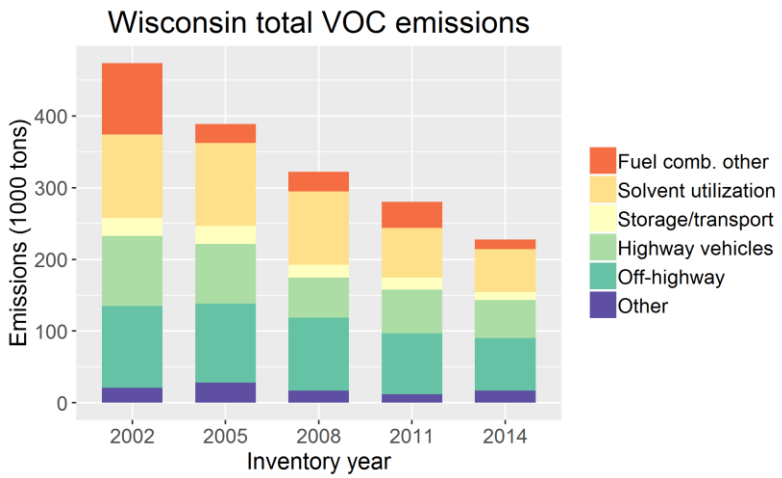

Figure 7. Emissions of VOCs from all sources in Wisconsin. See Table 3 for source category abbreviations.

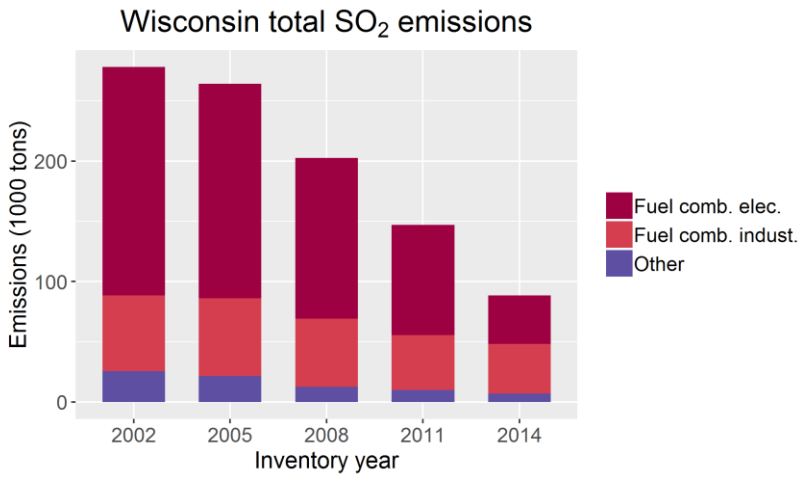

Figure 8. Emissions of SO_2 from all sources in Wisconsin. See Table 3 for source category abbreviations.

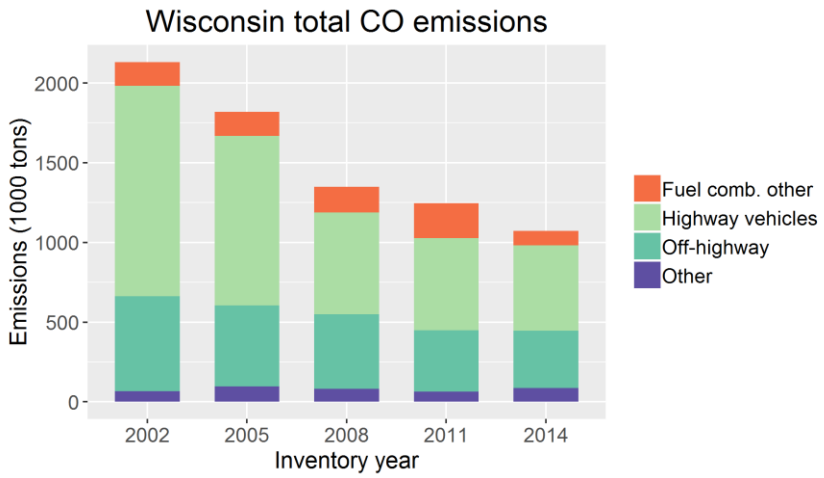

Figure 9. Emissions of CO from all sources in Wisconsin. See Table 3 for source category abbreviations.

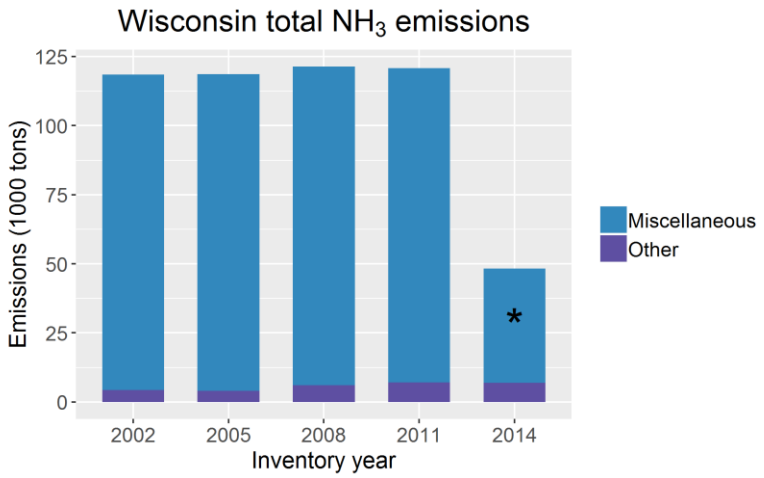

Figure 10. Emissions of NH_3 from all sources in Wisconsin. The asterisk (*) marks a sector for which EPA's inventory methodology changed significantly from the previous year. See Table 3 for source category abbreviations.

Primary particle emissions

The majority of $PM_{2.5}$ is produced from chemical reactions between precursor compounds in the atmosphere; however, a small portion of $PM_{2.5}$ is directly emitted into the atmosphere (i.e., are primary particles). Total directly-emitted $PM_{2.5}$ emissions as reported by the NEI are shown in Figure 11. The apparent increases in the 2011 and 2014 NEI are due to changes in EPA's inventory methodology those years, which mask any actual trends in emissions. Specifically, EPA changed its methodology for calculating emissions from residential wood combustion (part of the "fuel combustion - other" category) in both 2011 and 2014. In 2014, EPA also changed its methodology and data sources for calculating emissions from selected sources in the "miscellaneous" category.

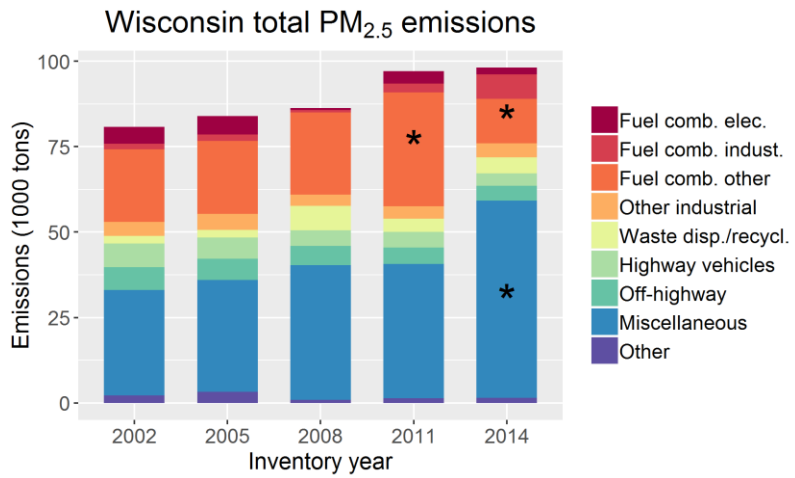

Figure 11. Emissions of $PM_{2.5}$ from all sources in Wisconsin. The asterisks (*) mark sectors for which EPA's inventory methodology changed significantly from the previous year. See Table 3 for source category abbreviations.

In contrast to $PM_{2.5}$, larger inhalable particles are emitted directly into the atmosphere. Total directly-emitted PM_{10} emissions data from the NEI are shown in Figure 12. The apparent increase in the 2014 NEI is due to a change in EPA's inventory methodology, rather than an actual increase in emissions. As discussed for $PM_{2.5}$, EPA also changed its methodology and data sources for calculating PM emissions from selected sources in the "miscellaneous" category; this change accounts for almost all the change observed between 2011 and 2014.

Because of the significant changes in EPA's methodology used to estimate emissions of both direct $PM_{2.5}$ and PM_{10}, it is not possible to determine trends in the emissions of either $PM_{2.5}$ or PM_{10} based on NEI data alone.

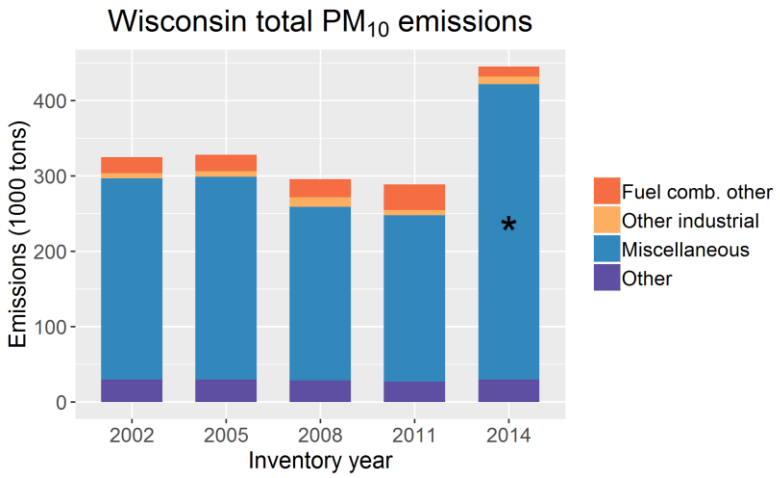

Figure 12. Emissions of PM_{10} from sources in Wisconsin. The asterisk (*) marks a sector for which EPA's inventory methodology changed significantly from the previous year. See Table 3 for source category abbreviations.

Lead

Lead can be emitted in either gaseous or particulate form. Emissions of lead decreased substantially since it was removed from gasoline and have remained low ever since. Because of the low emissions, reporting of lead emissions has been inconsistent from year to year, making it difficult to compare emissions over time. Accordingly, this report does not show lead emissions data. EPA also does not include lead emissions in its trends data. Lead emissions from sources in Wisconsin were less than 20 tons in each of the NEI years examined (2002 to 2014). These emissions are more than a thousand times smaller than those of the other criteria pollutants and precursors.

Point source emissions

Large stationary sources ("point sources") report their emissions on an annual basis, so statewide emissions data from these types of sources are available more frequently than emissions data from other sources. Figures 13 and 14 show point source emissions of criteria pollutants and their precursors from 2002 to 2017. The point source emissions data were downloaded from EPA's Emissions Inventory System (EIS) website (https://www.epa.gov/air-emissions-inventories/emissions-inventory-system-eis-gateway). The EIS website includes NEI data as well as point source emissions data submitted by the state to EIS for non-NEI years. The DNR was not required to submit point source inventory data to EIS for non-NEI years before 2009[11].

Point source emissions of most pollutants decreased from 2002 to 2017 (Figs 13 and 14), with reductions ranging from 37 percent for VOCs (12,174 tons reduced) to 89 percent for SO_2 (228,994 tons reduced). Ammonia emissions were extremely low but showed a small increase during this time.

[11] State data for previous years are available, however the methodology used for some pollutants was inconsistent with that used for the NEI inventories. These data are therefore not shown here.

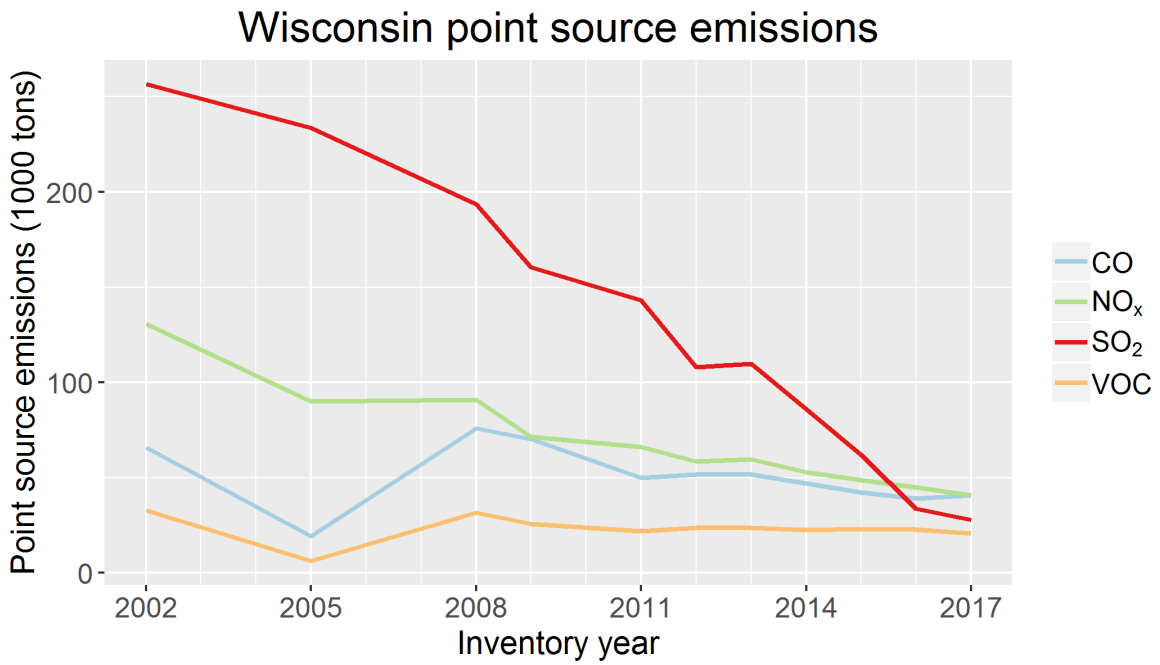

Figure 13. Emissions of the most abundant criteria pollutants and precursors from point sources[12] in Wisconsin.

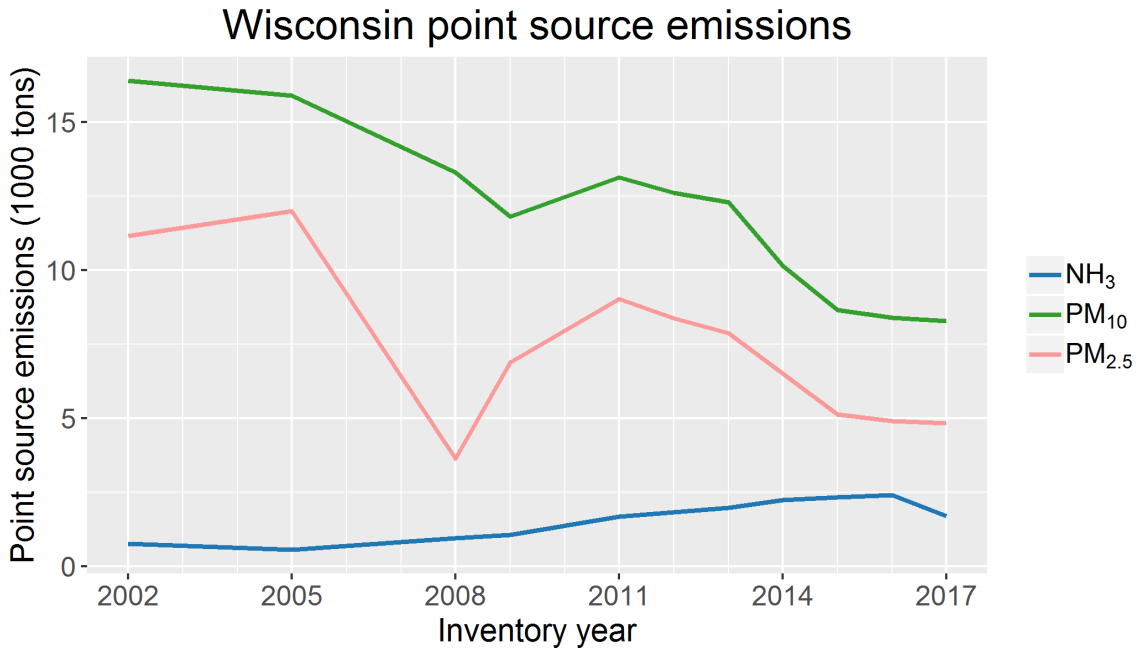

Figure 14. Emissions of the less abundant criteria pollutants and precursors from point sources[12] in Wisconsin.

[12] Note that point sources exist in all source categories shown in Figures 6 through 12 except for Highway Vehicles and Off-Highway.

Criteria pollutant trends

This section presents trends in Wisconsin monitoring data[13] for all six criteria pollutants since 2001 (as data are available). Design values are graphed for each monitoring site and compared against the relevant NAAQS to show how the state's air quality has changed over time. The data for ozone and fine particles are organized regionally to highlight differences in the geographic distribution of these regional pollutants.

The data presented are for pollutants that are currently monitored at active ambient air monitoring sites operated by DNR or tribal partners. If data are not shown for a particular design value period, it is because the design value was not valid, either because the monitor was not operational during that period or, in rare cases, data-completeness issues. Although the maps for each pollutant include all currently active monitoring sites in the state network, only sites with a valid design value for the most recent period (i.e., 2018 for 1-yr design values or 2016-2018 for 3-yr design values) will have values shown after the site name.

Historically, NAAQS attainment has been determined on a county-by-county basis. Trend plots by county are provided online at https://dnr.wi.gov/topic/airquality/trends.asp. This link is also provided in Appendix A.

Information on national air quality trends and how Wisconsin data compare to national averages can be found in EPA's trends report at https://gispub.epa.gov/air/trendsreport/2018/.

Ozone

Ozone in the lower atmosphere forms primarily as the result of reactions between NO_x and VOCs. These chemical reactions that produce ozone are strongly influenced by meteorological conditions. For example, ozone formation is greatest on days with elevated temperatures, high humidity and ample sunlight. Wind patterns also contribute to high ozone concentrations monitored in some areas of Wisconsin, like along the Lake Michigan shoreline.

The ozone precursors that affect Wisconsin may originate in other states, particularly those to the south. Wisconsin counties along Lake Michigan experience the highest ozone concentrations on days with southerly winds, which transport ozone precursors north to Wisconsin. These precursors can react over Lake Michigan to form high concentrations of ozone. When the land has warmed sufficiently, temperature gradients from the shoreline to the lake can create pressure differences, which cause an on-shore flow of air, or lake breeze. The lake breeze, in combination with southerly winds, push ozone formed over the lake onshore, causing ozone concentrations in Wisconsin to be closely correlated with the distance from the Lake Michigan shoreline. For this reason, ozone design values in this report are grouped based on their location into three distinct regions (as shown in Fig. 15):

1) **Lakeshore** – counties bordering Lake Michigan extending from the Illinois border through Door County, Wisconsin

[13] Data presented are design values which were downloaded from EPA's Design Value webpage (https://www.epa.gov/air-trends/air-quality-design-values).

2) **Inland** – counties in central and western Wisconsin
3) **Far North** – counties in the northern part of the state, including those near Lake Superior and the Upper Peninsula of Michigan

Figure 15 shows the most recently available ozone design values[14] for all ozone monitors in the state network. Four of 13 monitoring sites in the Lakeshore region observed design values for these years that were greater than the 2008 ozone NAAQS of 75 ppb. Warm, ozone-conducive summers in 2016 and 2018 combined with a lower 2015 standard resulted in 10 of 13 Lakeshore monitoring sites exceeding the 2015 NAAQS of 70 ppb for the 2016-2018 design value period. No sites in the Inland or Far North regions had design values exceeding either ozone standard for the 2016-2018 design value period.

[14] The 2016-2018 ozone design values shown in Figure 15 were calculated using methods associated with the 2015 NAAQS. When design values were calculated for the same years using methods from the 2008 NAAQS, results were nearly identical. The DNR will therefore consider design values presented in Figure 15 to be representative of design values calculated under the 2008 NAAQS when making comparisons to the 2008 standard in the discussion associated with the figure.

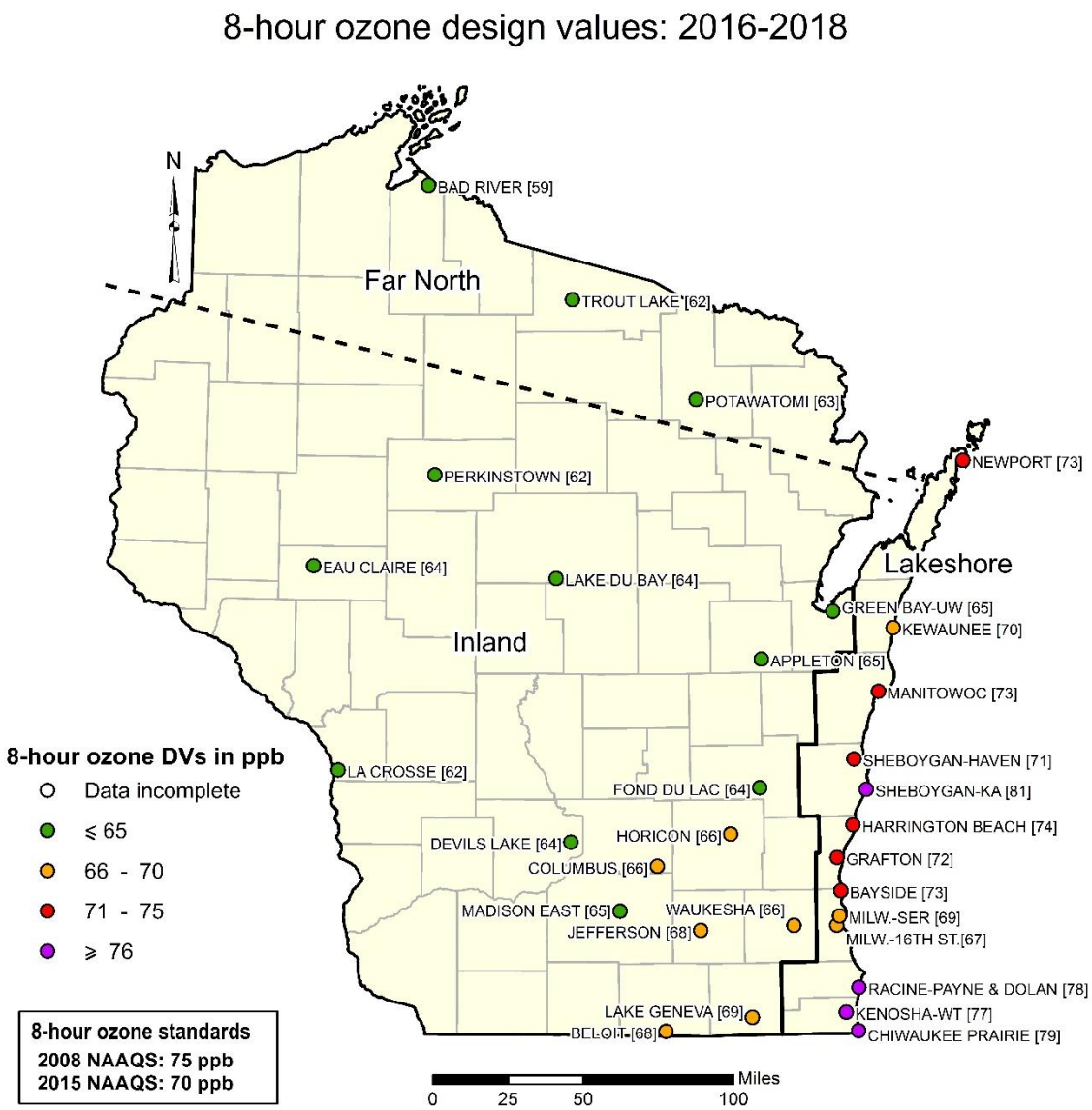

Figure 15. The 8-hr ozone design values for each monitoring site[15] for 2016-2018. Note that the Far North region includes the three sites shown, but its boundaries are not clearly defined.

Lakeshore region

Figure 16 shows trends in ozone design values for the Lakeshore region. The relationship between design values from different monitoring sites was generally consistent over time (e.g., the values from the Milwaukee-SER site were consistently greater than the values from the Milwaukee-16th St. site).

Figure 16 provides a visual representation of how ozone concentrations can be impacted by both chemistry and meteorology. For example, the economic recession in 2008-2009, and associated

[15] Full site names are provided in Appendix C. Shorter versions of these names are used in tables and figures throughout the remainder of the report.

reduction in ozone precursor emissions, contributed in part to the relatively steep decrease in ozone design values through 2010. Ozone design values during this period were also influenced by suboptimal conditions for ozone formation, as the summer of 2009 was unseasonably cool. In contrast, the summers of 2012, 2016 and 2018 were unusually warm; therefore, any design value that includes those years is elevated compared to other periods. Similar to the summer of 2009, the Lakeshore region was uncharacteristically cool during the summer of 2014. Ozone design values are slightly lower for this period as well. The sensitivity of design values to effects related to year-to-year variations in meteorological conditions and ozone precursor concentrations highlights the importance of considering long-term trends in air quality, in addition to design values, to guide decisions about management of air quality issues at federal and state levels.

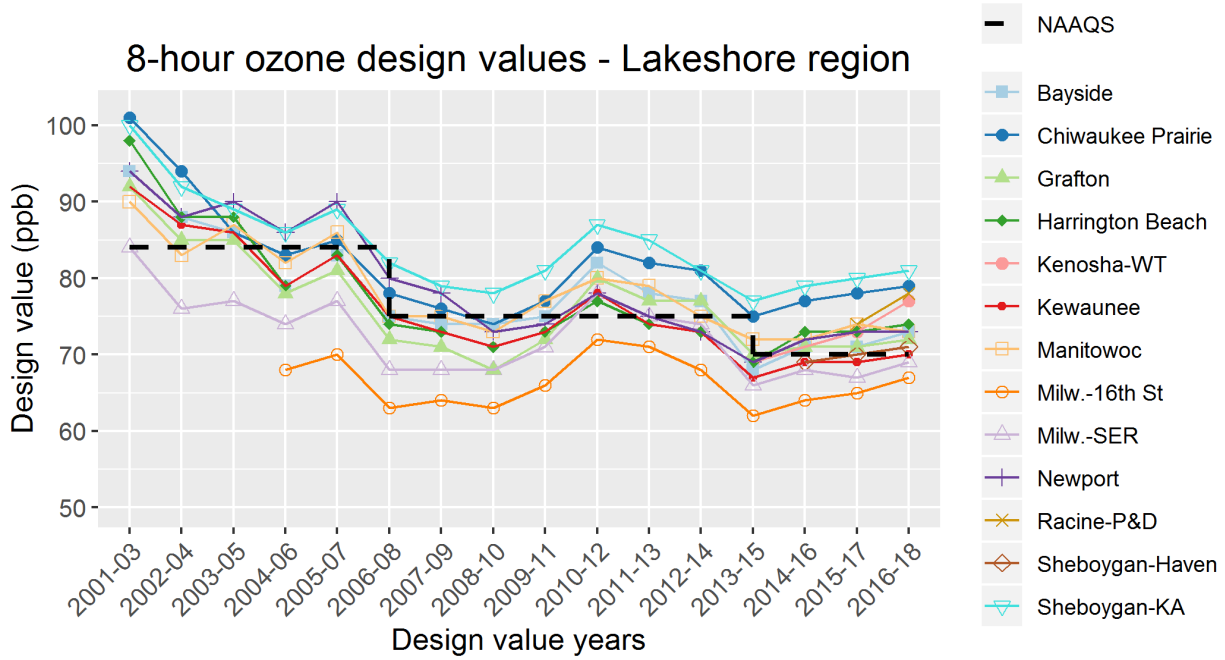

Figure 16. Trends in 8-hr ozone design values for the Lakeshore region. Note that the design value axis is truncated at 50 ppb (rather than going down to zero) to allow for a clearer view of the differences among sites.

Ozone concentrations at the Sheboygan-Kohler Andrae site have consistently been among the highest in the state (Figure 16). A special-purpose monitor was established in 2014 at the Sheboygan-Haven site, approximately three miles inland from the lakeshore Sheboygan-Kohler Andrae site, to help determine the ozone gradient in Sheboygan County. The 2016-2018 design value at the Sheboygan-Haven site was 71 ppb, which was 10 ppb lower than the value at Sheboygan-Kohler Andrae for the same period. The lowest design values in the Lakeshore region were observed at the Milwaukee 16th St. site, which had ozone concentrations consistently below the NAAQS.

Collectively, the design values in the Lakeshore region demonstrated an overall downward trend over the length of monitoring period shown in Figure 16. There was a 21 percent average reduction in design

values in this region from 2001-2003 to 2016-2018 among sites with data available for the full period, including a 20 percent reduction in design values at the Sheboygan-Kohler Andrae site (Appendix B, Table B1).

Inland region

Figure 17 shows trends in ozone design values for the Inland region. No design value in this region exceeded either the 2008 or the 2015 NAAQS between 2001-2003 and 2016-2018. Design values for each of the monitoring sites in the Inland region generally decreased over time. There was a 17 percent average reduction in design values in this region from 2001-2003 to 2016-2018 among sites with data available for the full period (Appendix B, Table B1).

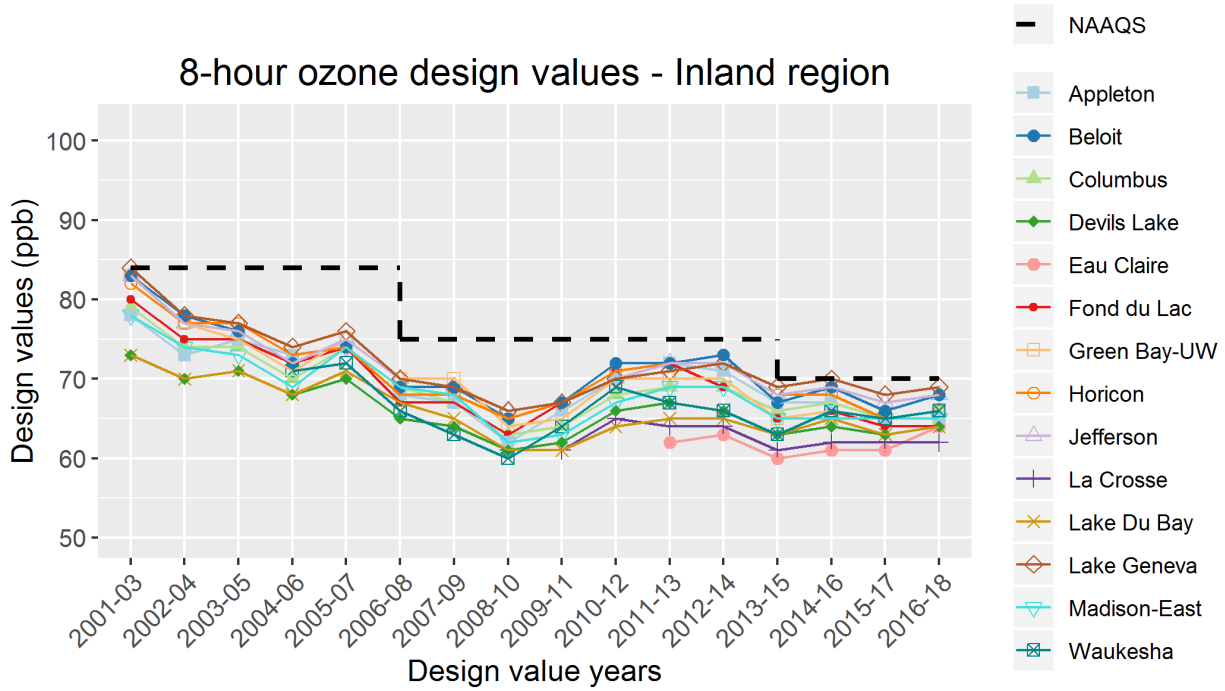

Figure 17. Trends in 8-hr ozone design values for the Inland region. Note that the design value axis is truncated at 50 ppb (rather than going down to zero) to allow for a clearer view of the differences among sites.

Overall, the design values in the Inland region were more similar among sites within the region than were those in the Lakeshore region. This suggests that while ozone concentrations are subject to variation at local scales in the Lakeshore region due to the impact of the lake breeze effect, Inland region concentrations are buffered from this effect because they are farther from the shoreline. Since onshore ozone transport is less of a factor at inland locations, the ozone concentrations at the Inland sites were both more uniform throughout the region and generally lower than concentrations at the Lakeshore sites. In addition to having generally lower ozone concentrations, sites in the Inland region showed a smaller average reduction in design value compared to the Lakeshore sites (17 percent vs 21 percent) over the time period examined (Appendix B, Table B1).

Far North region

Figure 18 shows trends in ozone design values for the Far North region. All sites were consistently below the NAAQS and had the lowest concentrations of ozone in the state.

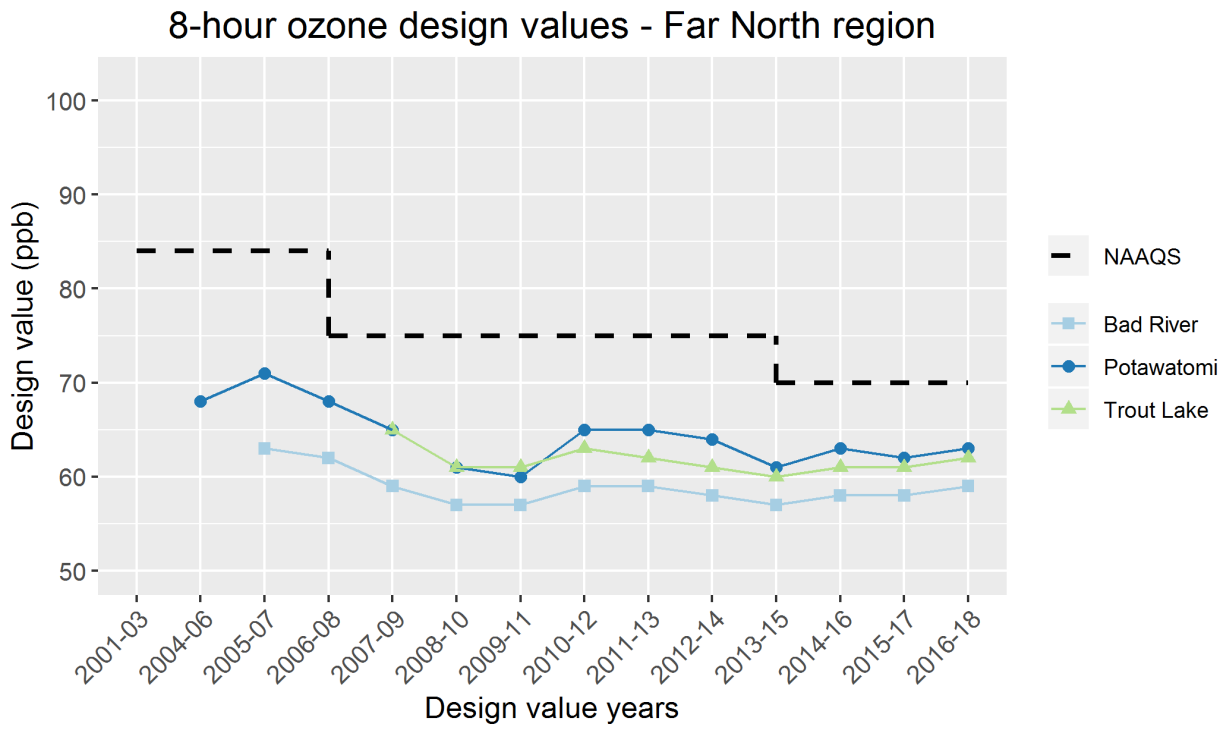

Figure 18. Trends in 8-hr ozone design values for Far North region. Note that the design value axis is truncated at 50 ppb (rather than going down to zero) to allow for a clearer view of the differences among sites

Fine particles ($PM_{2.5}$)

The DNR maintains a robust network of $PM_{2.5}$ monitoring sites throughout the state, monitoring fine particles using a combination of filter-based and continuous methods. In 2018, changes were made to modernize the network, which include, moving from filter-based to continuous samplers as the primary sampling system in the network, and updating the method used for continuous $PM_{2.5}$ sampling.

Fine particles may be transported long distances and are considered a regional pollutant. Ambient concentrations of fine particles are strongly influenced by weather and local topography. Specifically, low-lying areas may exhibit elevated concentration levels during periods of localized air stagnation.

To highlight geographic trends in fine particle concentrations, design values are grouped by the following regions (as shown in Figs 19 and 20):

1) Southeast
2) Inland
3) Far North

Note that $PM_{2.5}$ monitoring began in 2017 at the Milwaukee-College Avenue Near Road site, so this location does not have a valid $PM_{2.5}$ design value for either the 2015-2017 or 2016-2018 periods.

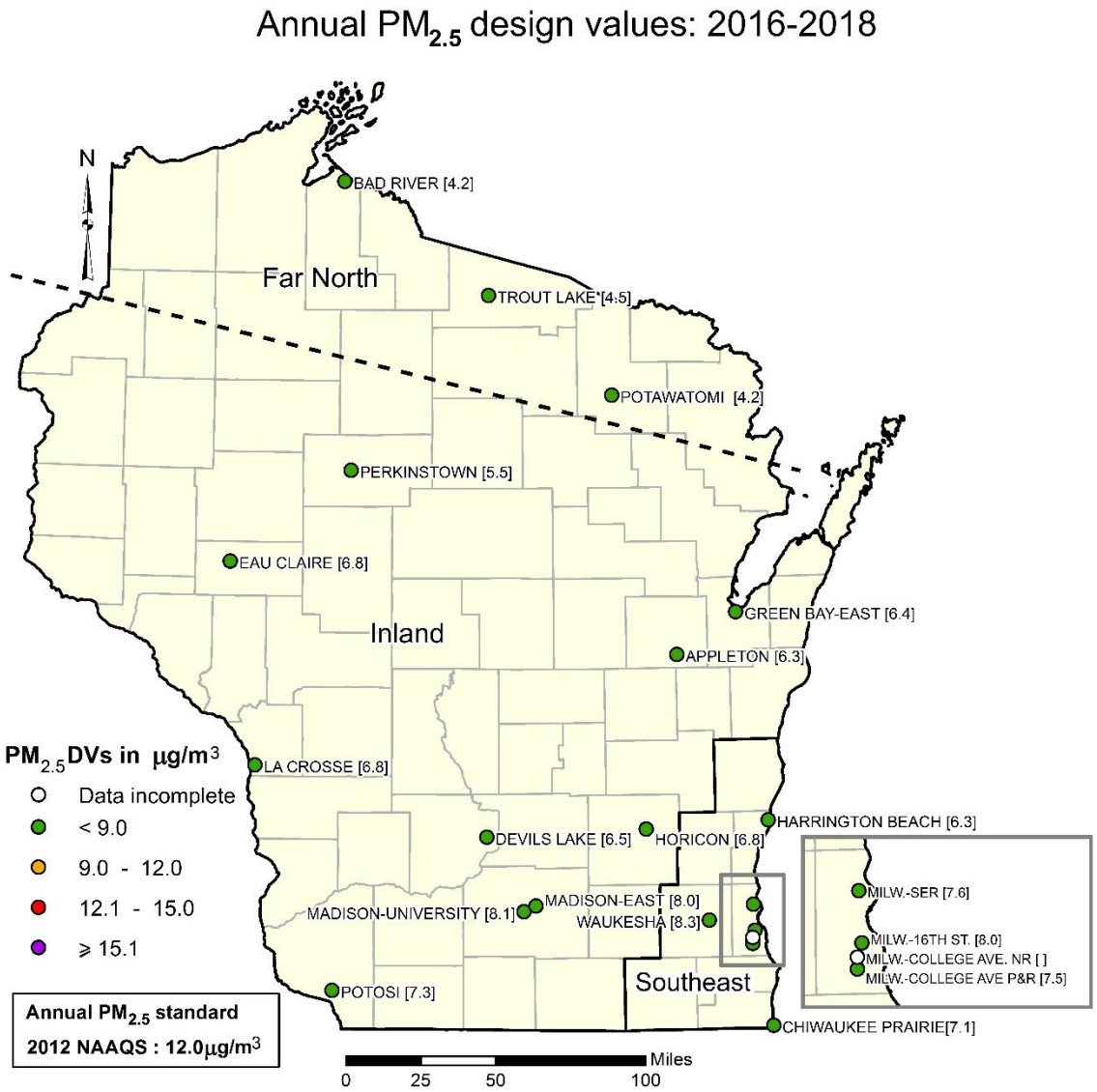

Figure 19. The annual $PM_{2.5}$ design values for each monitoring site for 2016-2018. Note that the Far North region includes the three sites shown, but its boundaries are not clearly defined.

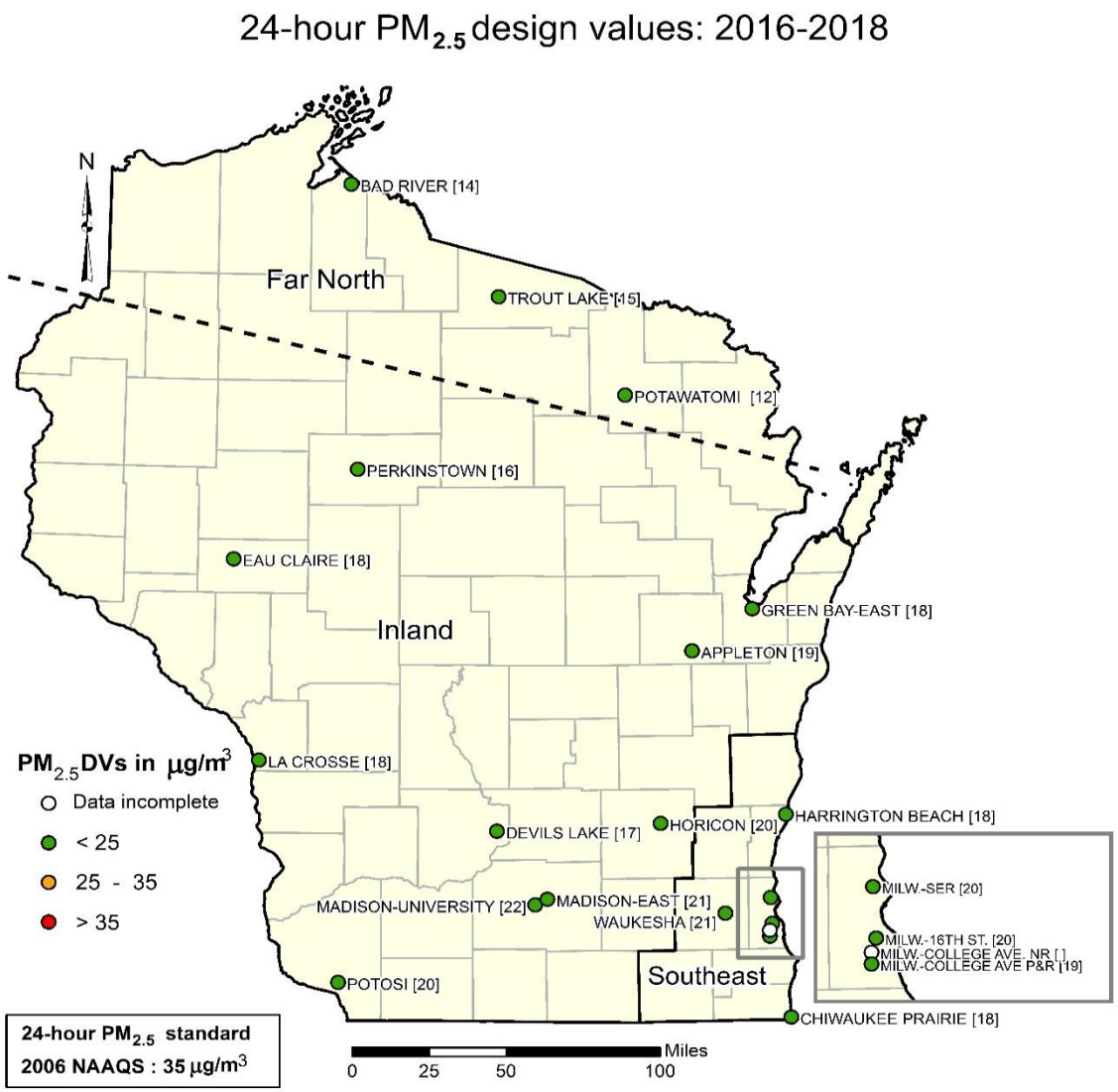

Figure 20. The 24-hr $PM_{2.5}$ design values for each monitoring site for 2016-2018. Note that the Far North region includes the three sites shown, but its boundaries are not clearly defined.

Southeast region

Figures 21 and 22 show trends in annual and 24-hr $PM_{2.5}$ design values for the Southeast region. The relationships between design values at different sites were relatively consistent for both the annual and 24-hr design values. For both metrics, monitoring sites generally measured a steady decrease in concentrations over the past 12 design value periods, reaching the lowest overall concentrations in 2016-2018.

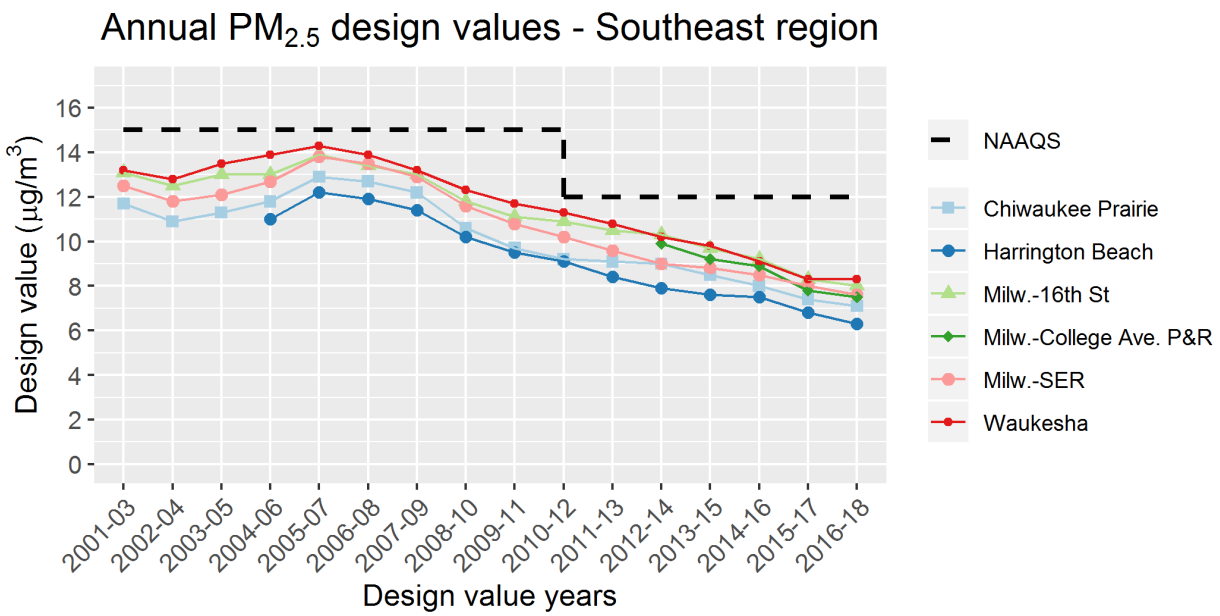

Figure 21. Trends in annual $PM_{2.5}$ design values in the Southeast region.

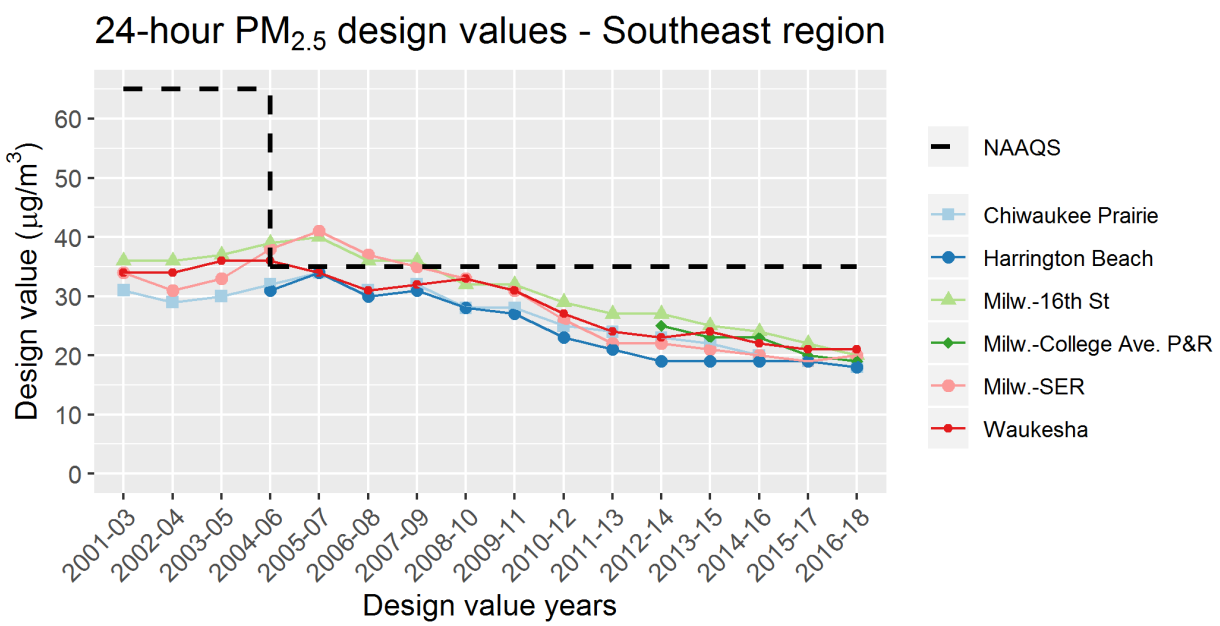

Figure 22. Trends in 24-hr $PM_{2.5}$ design values in the Southeast region.

While none of the fine-particle monitoring sites in the Southeast region has measured an annual design value exceeding the relevant NAAQS (the 2006 annual standard of 15.0 µg/m^3 or the 2012 annual standard of 12.0 µg/m^3), the decrease in the 24-hr standard from 65 to 35 µg/m^3 in 2006 resulted in design values at some sites exceeding the standard during subsequent years. Nonetheless, 24-hr design

values for all sites in the region have been below the 2006 NAAQS since 2008-2010. Fine particle design values decreased around 40 percent on average for the region between 2001-2003 and 2016-2018 among sites with data available for the full period (Appendix B, Tables B2-B3).

Inland region

Figures 23 and 24 show trends in annual and 24-hr $PM_{2.5}$ design values for the Inland region. Similar to the Southeast region, the relationship between annual design values at different sites in the Inland region were generally consistent over time. The annual design values decreased consistently at all sites after 2006-2008.

The 24-hr design values have generally decreased since 2008-2010. Inland region design values decreased almost 40 percent on average for the region between 2001-2003 and 2016-2018 among sites with data available for the full period, similar to the decreases observed in the Southeast region over the same time period (Appendix B, Tables B2-B3).

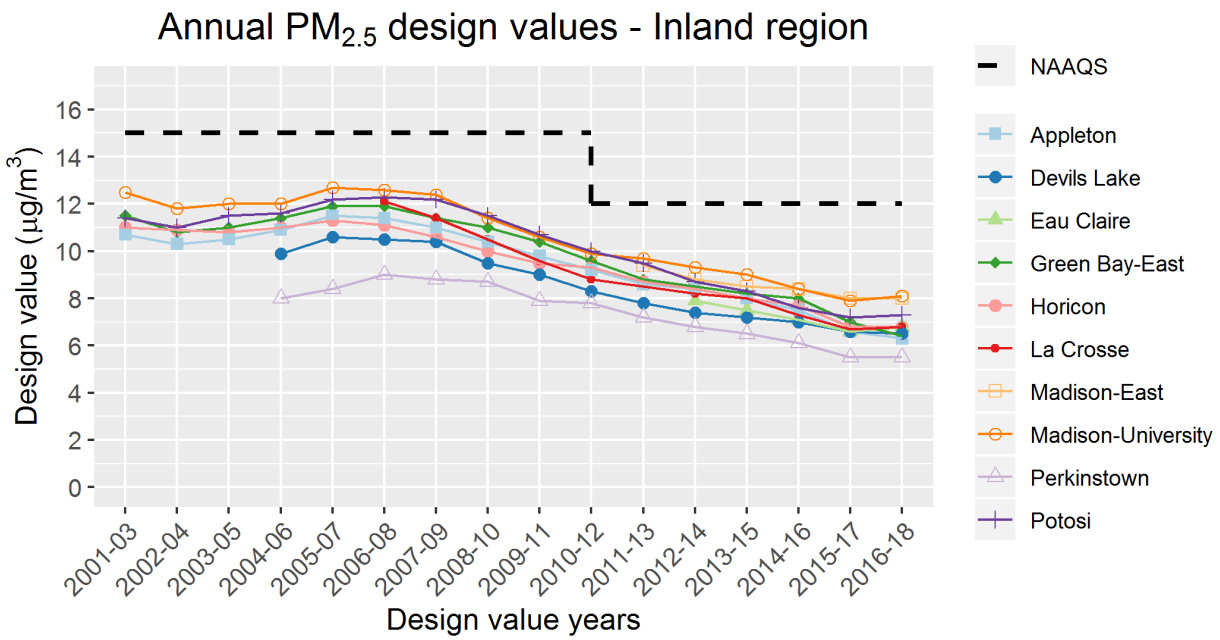

Figure 23. Trends in annual $PM_{2.5}$ design values in the Inland region.

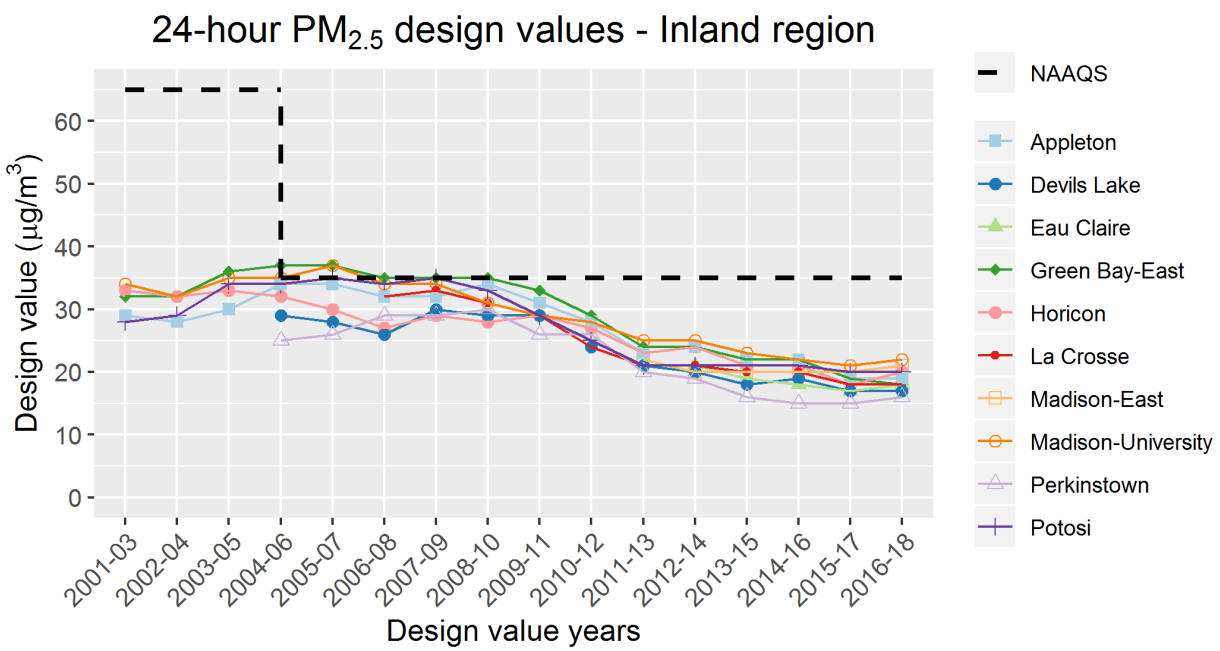

Figure 24. Trends in 24-hr $PM_{2.5}$ design values in the Inland region.

Far North region

Figures 25 and 26 show trends in annual and 24-hr $PM_{2.5}$ design values for the Far North region. Sites in this region showed the lowest concentrations of fine particles in the state. The annual design values decreased consistently after 2006-2008. Values were more similar among sites for the annual design values than the 24-hr values.

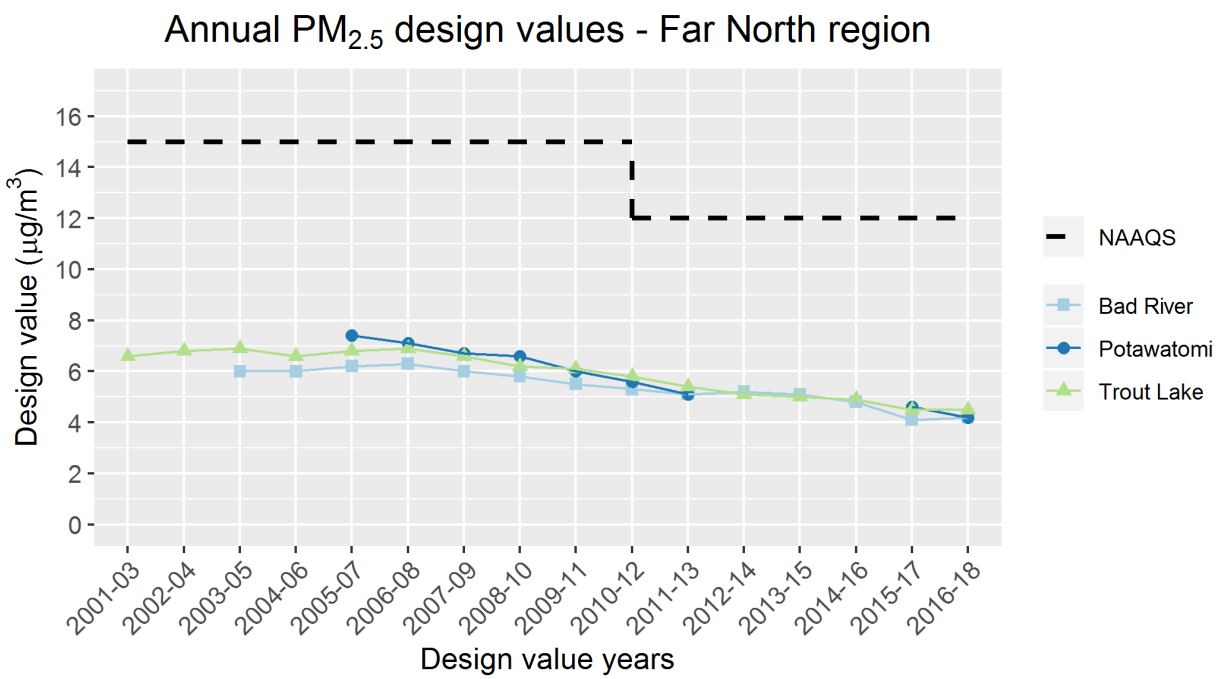

Figure 25. Trends in annual $PM_{2.5}$ design values in the Far North region.

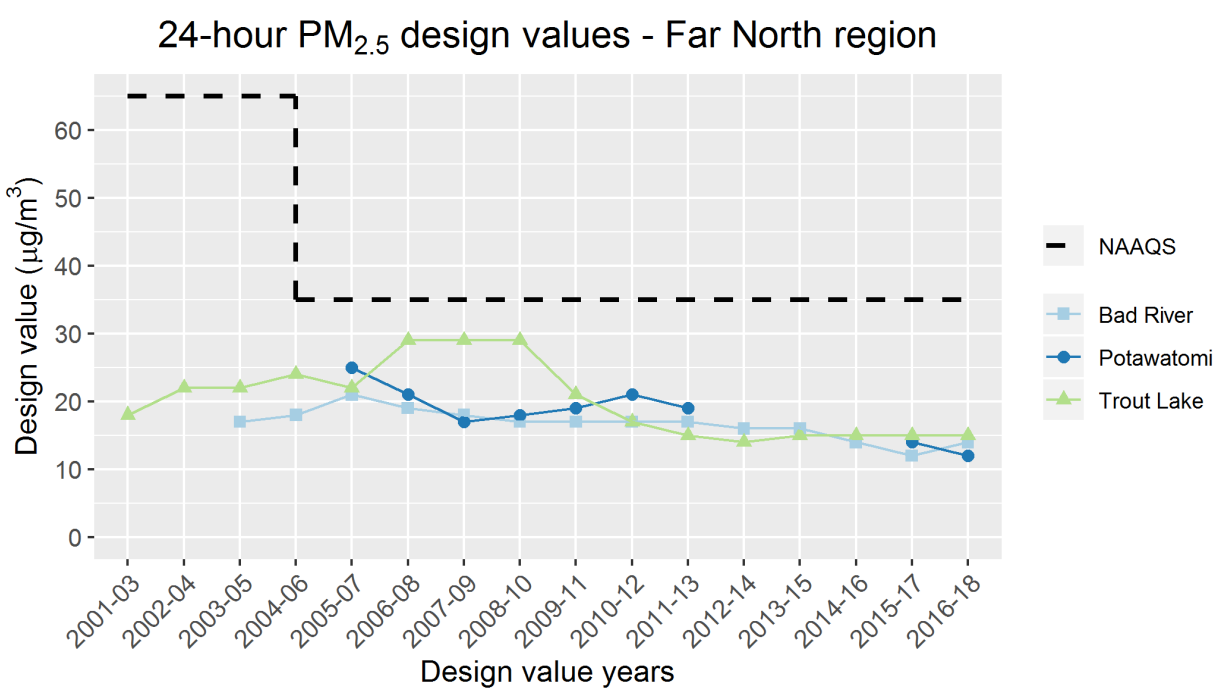

Figure 26. Trends in 24-hr $PM_{2.5}$ design values in the Far North region.

Inhalable particles (PM_{10})

Inhalable particles (PM_{10}) are monitored at eight sites in the state network (Fig. 27), using a combination of filter-based and continuous monitors. As with the $PM_{2.5}$ network, changes were made to modernize the PM_{10} network in 2018, which included increasing reliance on continuous versus filter-based methods and updating the method used for continuous PM_{10} sampling.

Values shown in the map below are the 3-yr maximum 24-hr (calendar-day) averages measured from 2016-2018. These averages contribute to the determination of the PM_{10} design value. The highest PM_{10} concentrations are generally measured in urban areas.

PM_{10} measurement was started at the Milwaukee – College Avenue Near Road site in July of 2018. While this site is included in Figure 27, it does not yet have a valid 3-yr maximum value because it has not operated long enough to generate a design value.

Some industrial sources in Wisconsin have a requirement in their air permits to monitor for inhalable particles. The majority of these sources are industrial sand facilities monitoring for PM_{10}. The DNR quality assures these data and posts them quarterly on a webpage for viewing (http://dnr.wi.gov/topic/Mines/AQSandMap.html).

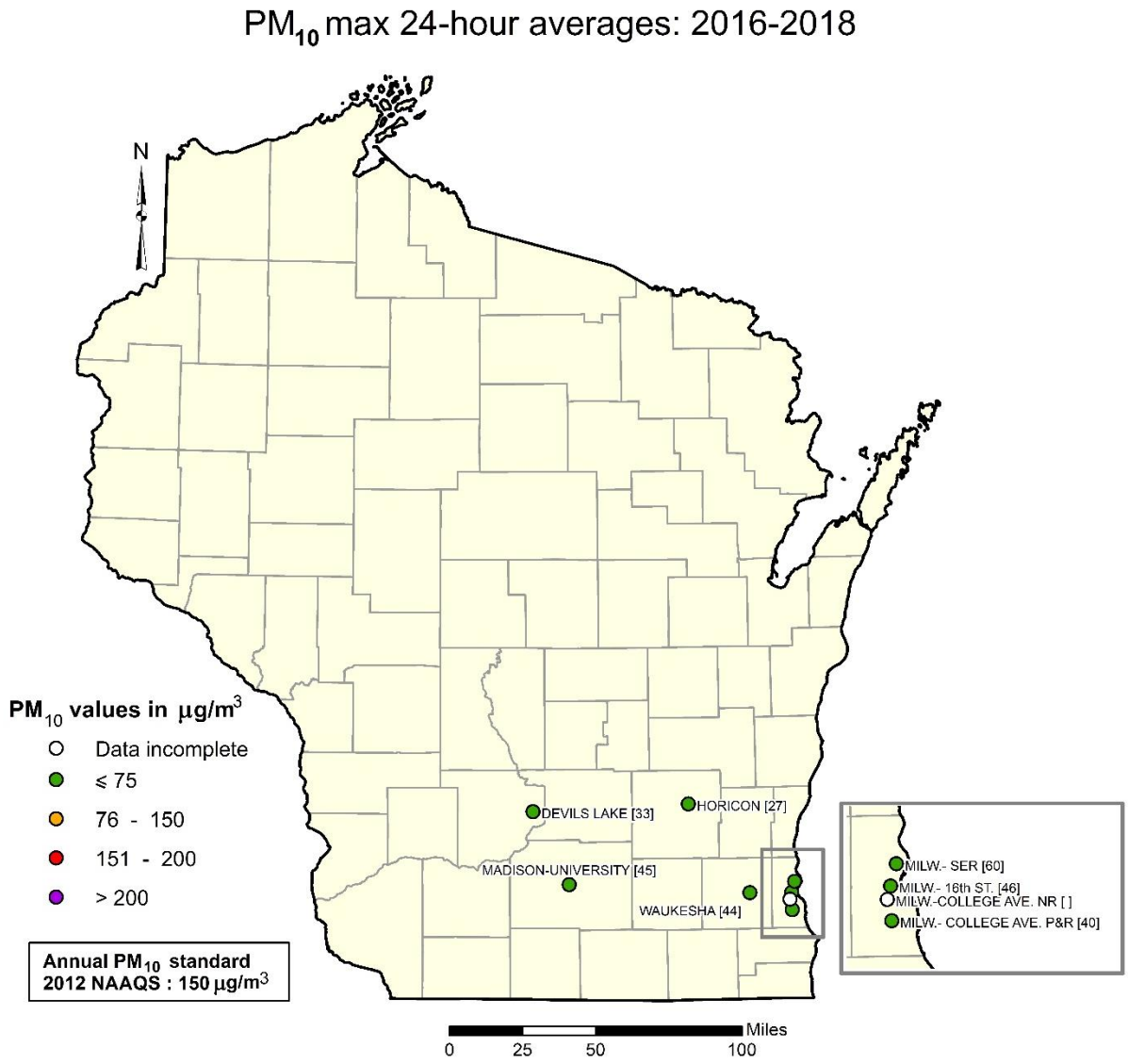

Figure 27. The maximum 24-hr averages of PM_{10} for 2016-2018.

Figure 28 shows trends in 3-yr maximum 24-hr PM_{10} averages for each PM_{10} monitoring site. If the 24-hr average PM_{10} values exceed the standard (150 µg/m^3) more than once per year on average over three years, the standard is violated.

The three-year 24-hr maximum values for all sites are well below the NAAQS. In addition, concentrations of PM_{10} generally decreased over time. Three-year 24-hr maximum values decreased between 20 percent (Devils Lake) and 56 percent (Horicon) between the start of monitoring and the most recent (2016-2018) values, except at the Milwaukee-SER and Milwaukee-16th St. sites where values have remained fairly steady (Appendix B, Table B4).

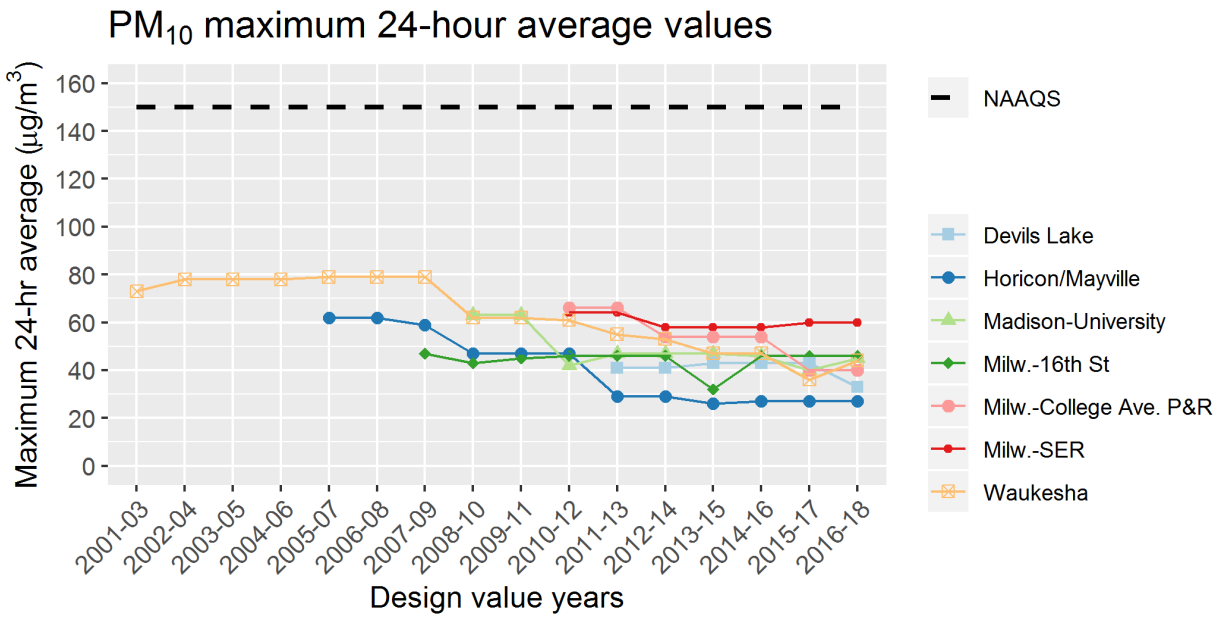

Figure 28. Trends in maximum 24-hr averages of PM_{10} over each 3-yr period.

Sulfur dioxide

Figure 29 shows SO_2 monitoring sites in the state network and the most recent 1-hr design values. These data are compared against the 2010 1-hr NAAQS of 75 ppb.

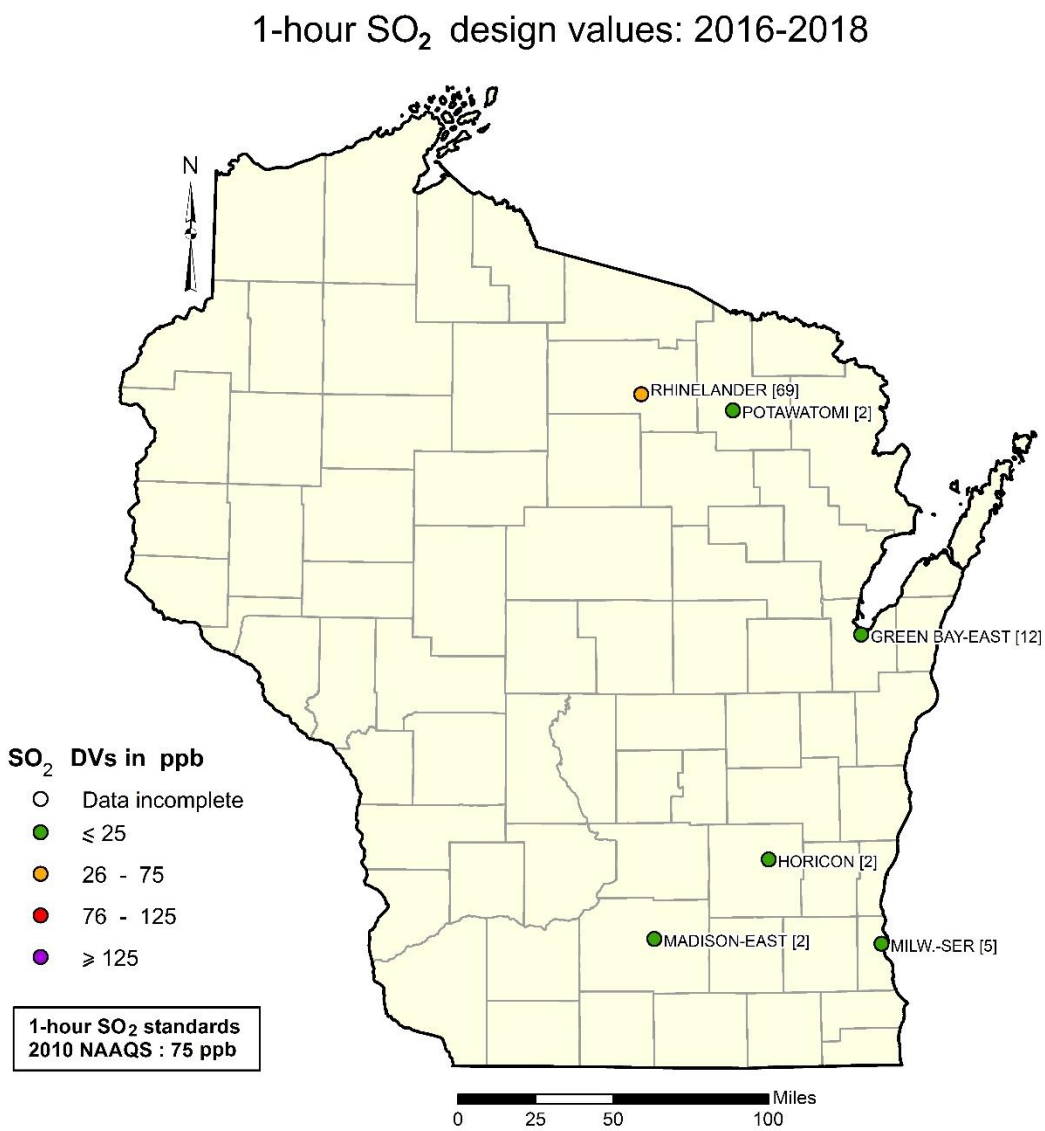

Figure 29. The 1-hr SO_2 design values for each monitoring site for 2016-2018.

Figure 30 shows trends in 1-hr SO_2 design values. Note that SO_2 monitoring was not conducted at the Milwaukee-SER site from 2007 through 2010, so no design values are available for 2005-2007 through 2010-2012.

As mentioned previously, the annual and 24-hr SO_2 standards were replaced with a 1-hr standard in 2010. To provide a clearer picture of trends in SO_2 concentrations over time, 1-hr design values were calculated for years prior to 2010.

Very low concentrations of SO_2 were observed at the Horicon, Madison-East, and Potawatomi sites. Low concentrations were also seen at the Milwaukee-SER site starting in 2011-2013. Design values from the Green Bay-East site have decreased substantially since 2014-2016 and are now well below the NAAQS. Design values at the Rhinelander site have decreased substantially since 2015-2017 due to implementation of an attainment plan for that area and are now below the NAAQS for the first time since the site was established in 1981.

Compared to design values from the start of SO_2 monitoring at each site, 2016-2018 design values were nearly 75 percent lower on average at all sites. The largest reduction in SO_2 occurred at the Milwaukee-SER site, where design values decreased 93 percent since monitoring at the site began (Appendix B, Table B5).

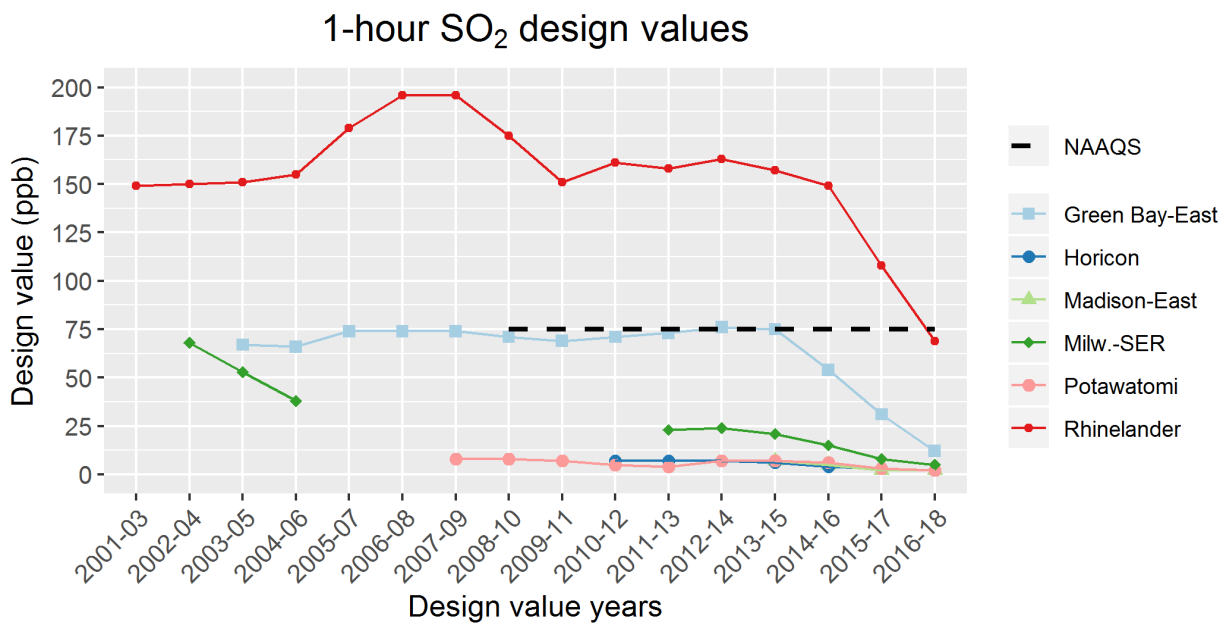

Figure 30. Trends in 1-hr SO_2 design values. Note that the 75 ppb 1-hr NAAQS was established in 2010, replacing the annual and 24-hr standards.

Nitrogen dioxide

Figures 31 and 32 show annual and 1-hr design values for the two sites in the DNR network that measure NO_2 year round.

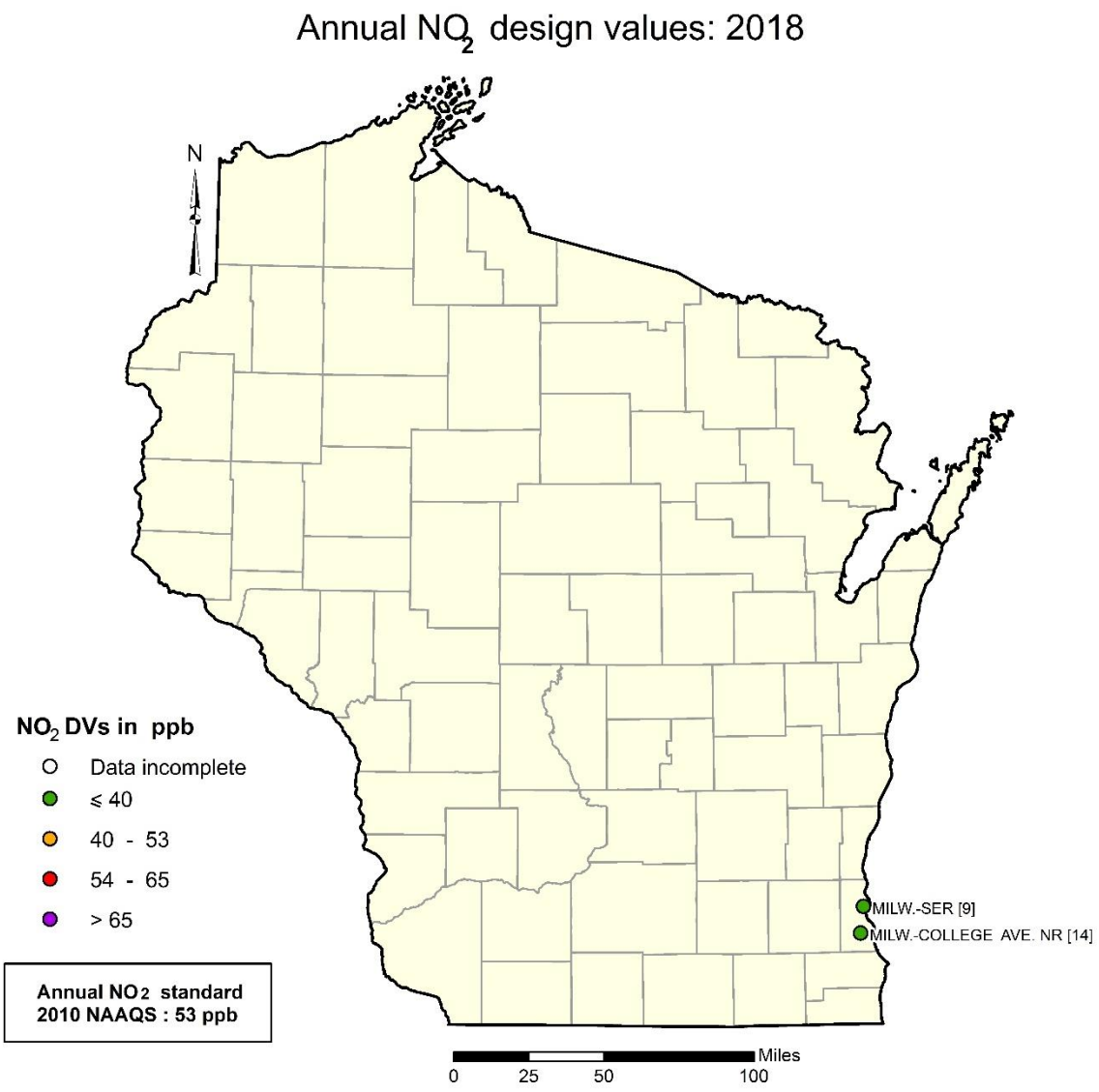

Figure 31. The annual NO_2 design values for each monitoring site for 2018.

The DNR monitors NO_2 at the Manitowoc site during the summer months (June-August). This monitoring is focused on understanding concentrations of NO_2, an ozone precursor, during peak ozone season. Due to the shorter monitoring period at Manitowoc, NO_2 values from the site cannot be used to determine compliance with the NAAQS and are not included in this report.

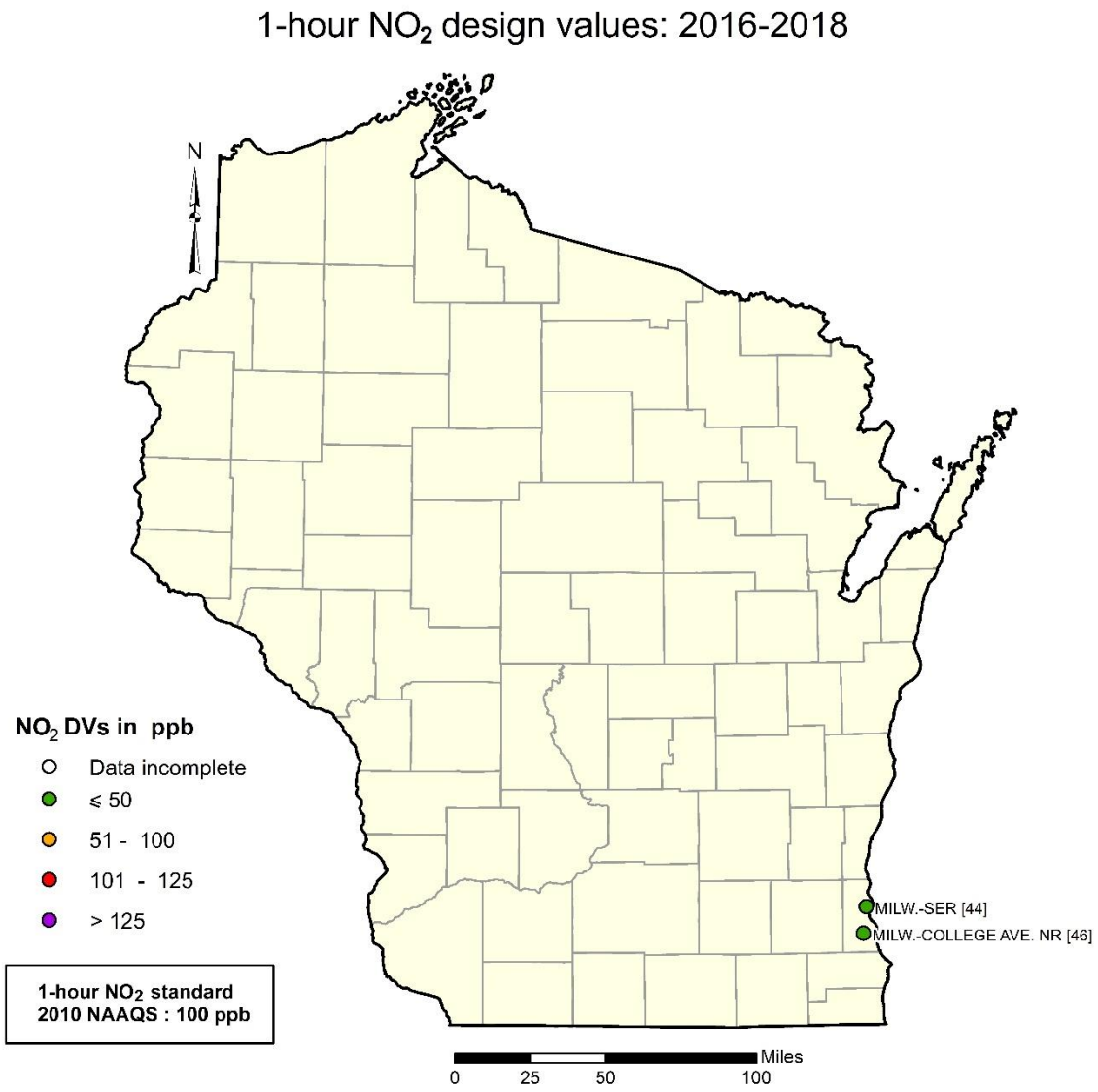

Figure 32. The 1-hr NO_2 design values for each monitoring site for 2016- 2018.

Figures 33 and 34 show trends in annual and 1-hr NO_2 design values. Overall, monitored levels of NO_2 were very low and are decreasing at both locations. Because monitoring for NO_2 has begun only recently at the Milwaukee-College Avenue Near Road site, however, long-term trends in the 1-hr design value are not yet apparent.

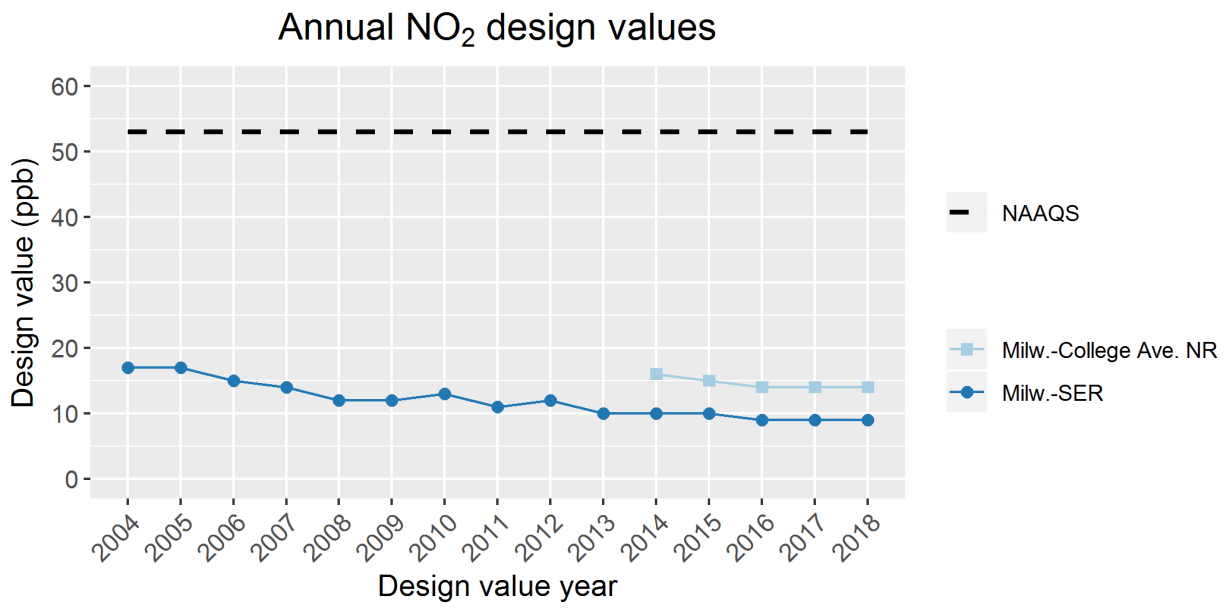

Figure 33. Trends in annual NO_2 design values.

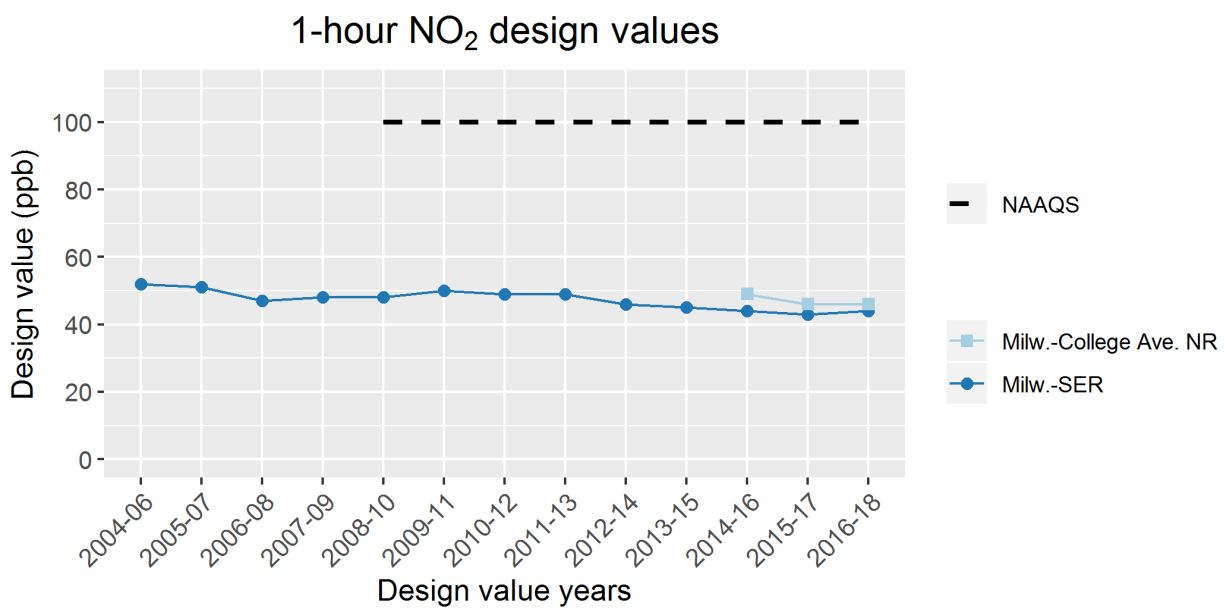

Figure 34. Trends in 1-hr NO_2 design values.

Nitrogen dioxide satellite observations

Satellites can be used to observe the total amount of NO_2 in the atmospheric column (i.e., the column of air between the satellite and the ground). While these estimates of NO_2 concentration are not directly comparable to the NAAQS, satellites can map NO_2 on the landscape between monitors, providing information about the spatial distribution of this pollutant in the atmosphere. Changes in the column density of NO_2 as mapped by satellites support DNR's observations from ground-based monitors and further illustrate that NO_2 concentrations have decreased over time over a wide geographic area.

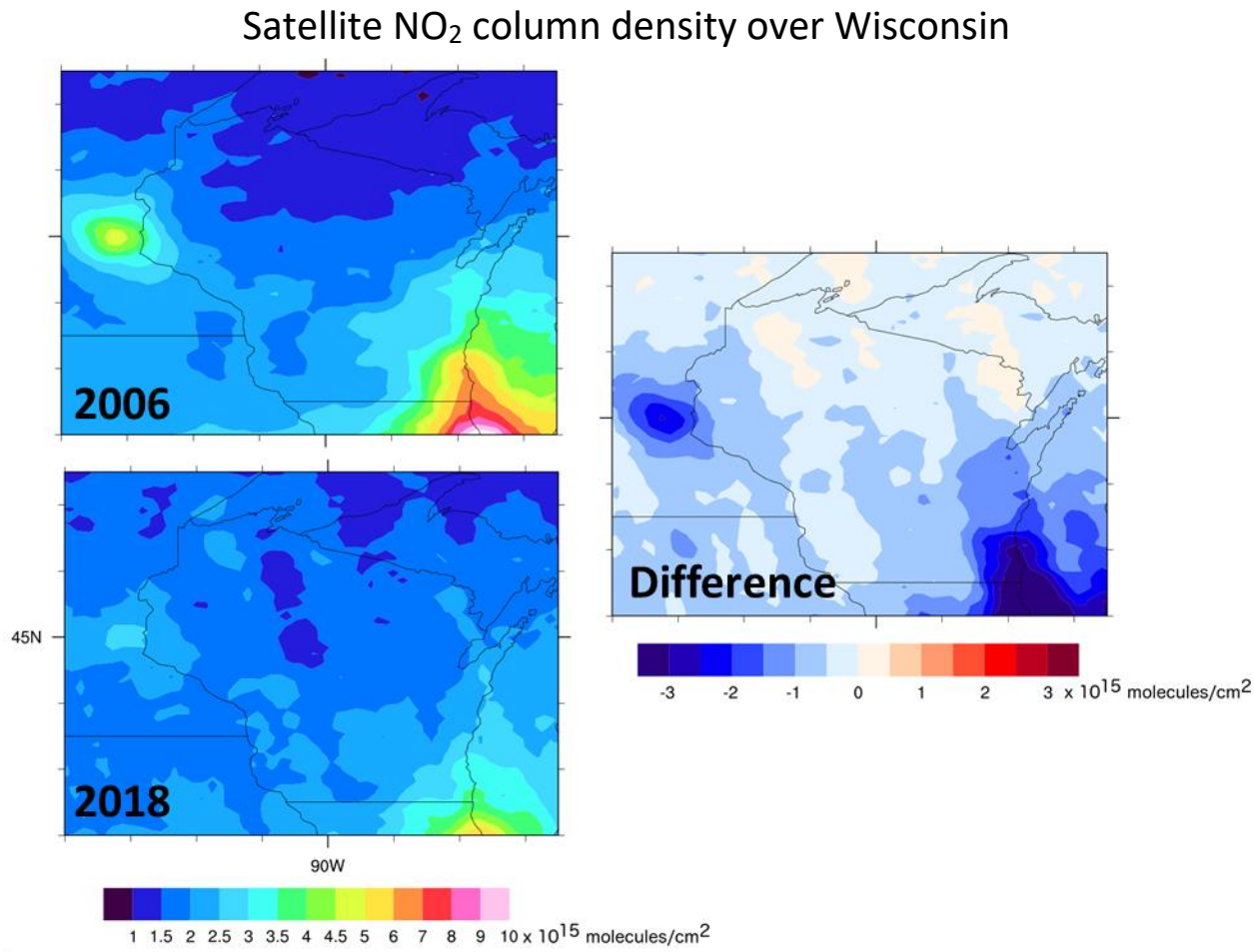

Figure 35. Maps of average annual NO_2 column density from the Ozone Monitoring Instrument (OMI) satellite. The map on the right shows the difference in NO_2 column density between 2006 and 2018. Figure courtesy of Drs. Monica Harkey and Tracey Holloway at UW-Madison.

Figure 35 shows the annual average NO_2 column densities for Wisconsin and surrounding areas in 2006 and 2018, along with the difference between these two years, based on data from the Ozone Monitoring Instrument (OMI) on the NASA Aura satellite.[16] These maps show that the greatest NO_2 column densities occurred in the Chicago area, and the lowest column densities occurred in

[16] NO_2 column density maps were prepared by Drs. Monica Harkey and Tracey Holloway at the University of Wisconsin – Madison. Methodology available upon request. For more information about satellite NO_2 measurements, see https://airquality.gsfc.nasa.gov/no2.

northwestern Wisconsin. Additionally, the satellite observed very large reductions in the estimated column density of NO_2 in almost all of the state over this time period, with the greatest reductions found in the Milwaukee and Chicago areas. These satellite data are consistent with the decreases in NO_2 observed by the state's ground-based monitors and indicates that the reduction of this ozone-forming pollutant is widespread.

Lead

Lead is measured for comparison to the NAAQS at a monitoring site in the town of Kohler in Sheboygan County (Fig. 36) using two filter-based monitors operating at frequencies of 1-in-6 days and 1-in-12 days. The design value at the Kohler site has never exceeded the lead NAAQS.

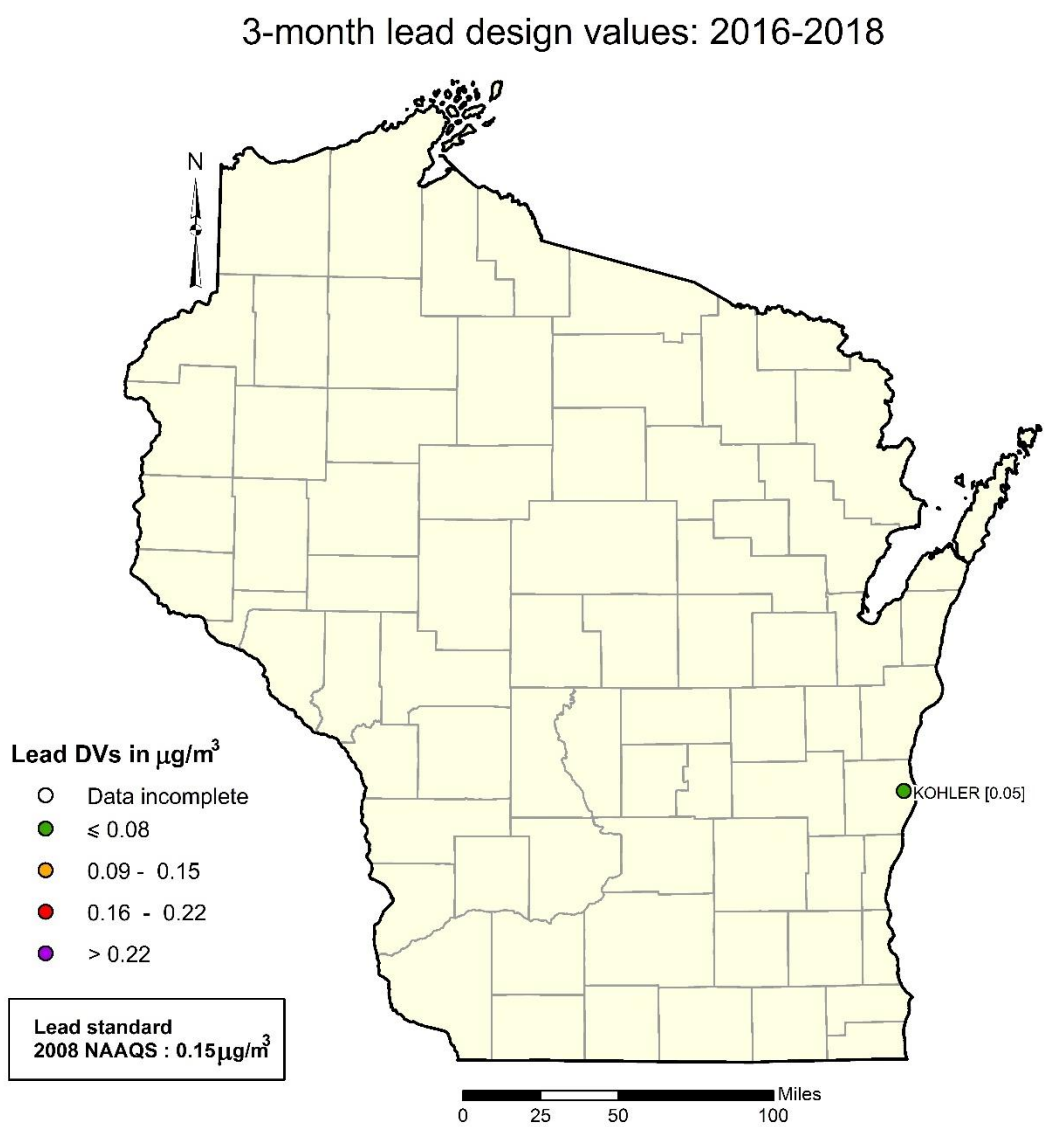

Figure 36. The 3-mo lead design values for 2016-2018.

The DNR also monitors lead at the Horicon and Milwaukee-16th St. sites as part of the National Air Toxics Trends Stations network and Urban Air Toxics program, respectively. The fraction of particles monitored for lead at these sites (i.e., PM_{10}), however, differs from that required for lead criteria pollutant monitoring (i.e., TSP). As a result of this difference, the lead monitoring data from the Horicon and Milwaukee-16th St. sites cannot be used to determine compliance with the NAAQS and are not included in this report.

Figure 37 shows the trend in 3-mo lead design values. Lead was monitored at the Kohler site prior to 2012; however, previous design values were not valid and therefore are not shown. Lead design values at the Kohler site have been decreasing. The most recent 3-mo design value at the site (2016-2018) was 55 percent lower than the first valid design value determined in 2012-2014 (Appendix B, Table B8). On March 22, 2019, EPA approved the discontinuation of monitoring at this site based on data that demonstrated that the site met the federal monitor shutdown requirements.

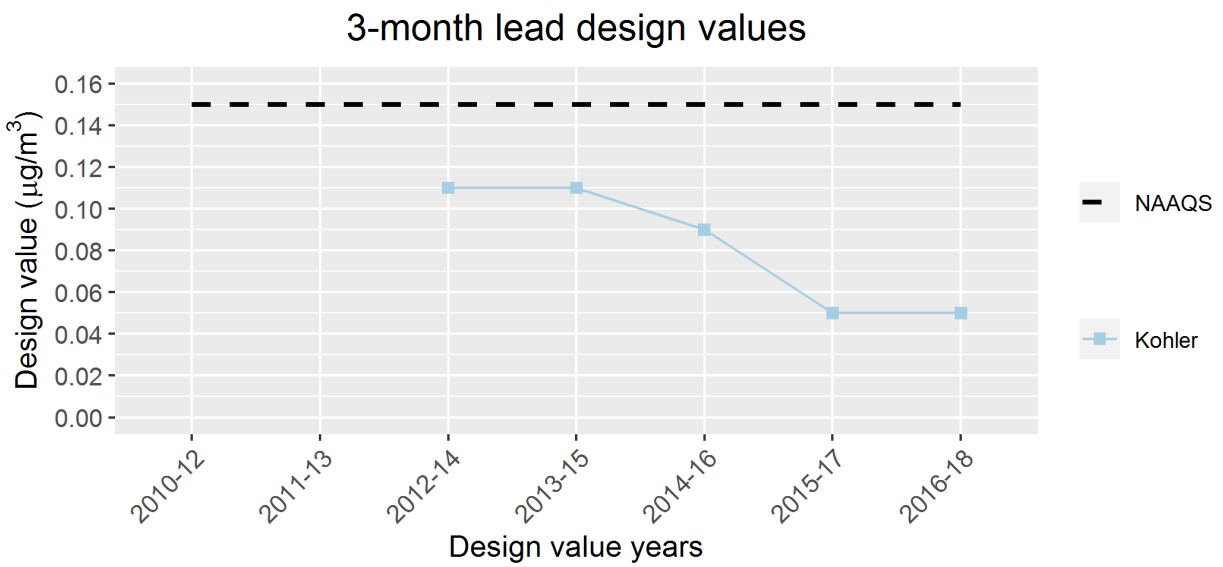

Figure 37. Trends in 3-mo lead design values.

Carbon monoxide

Carbon monoxide is monitored at two sites in the DNR network. Design values are compared against an 8-hr and a 1-hr NAAQS (Figs 38 and 39, respectively). Both design values are based on one year of data.

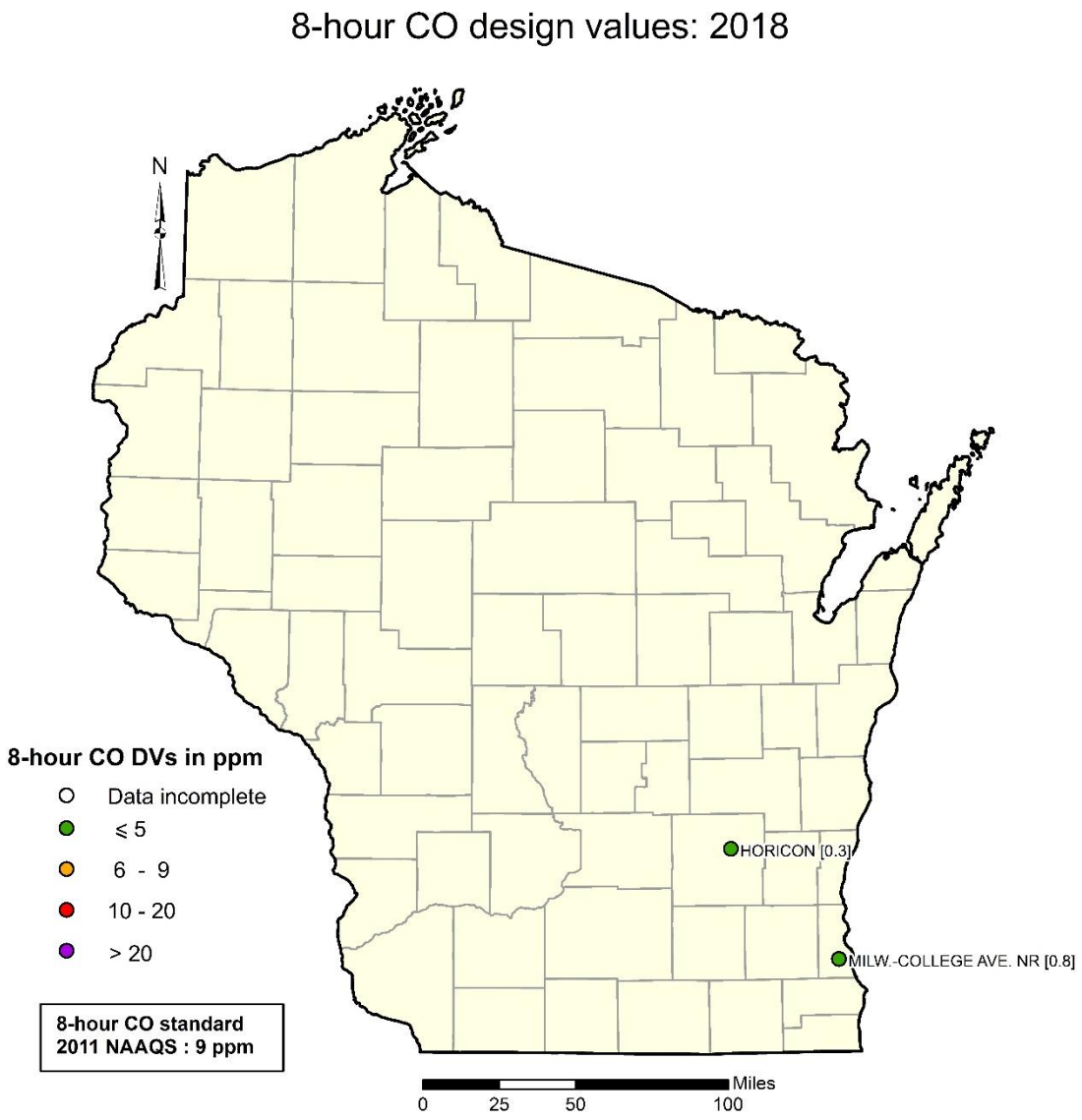

Figure 38. The 8-hr CO design values for each monitoring site for 2018.

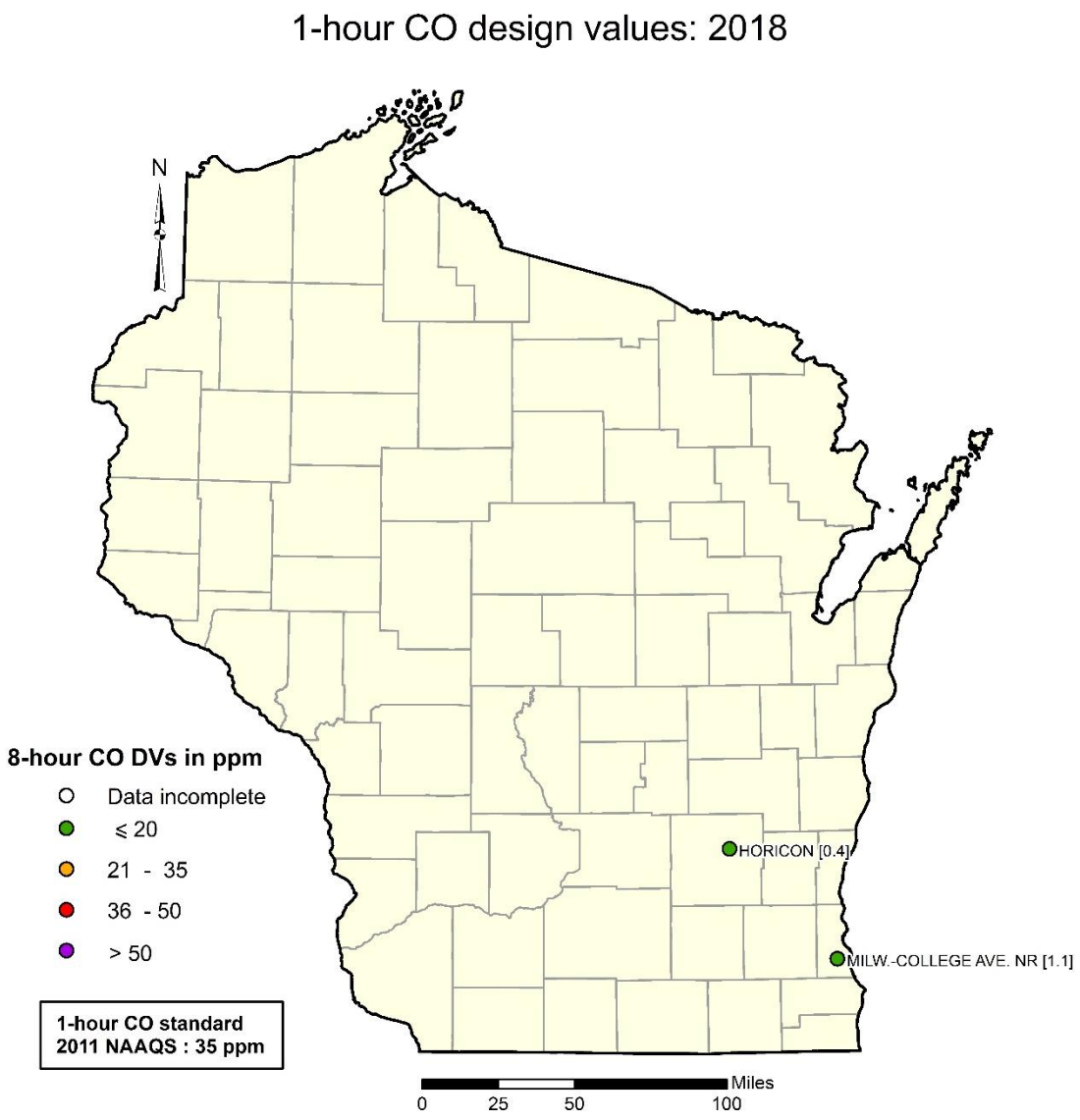

Figure 39. The 1-hr CO design values for each monitoring site for 2018.

Figures 40 and 41 show trends in 8-hr and 1-hr CO design values, which were extremely low at both sites (Appendix B, Table B9).

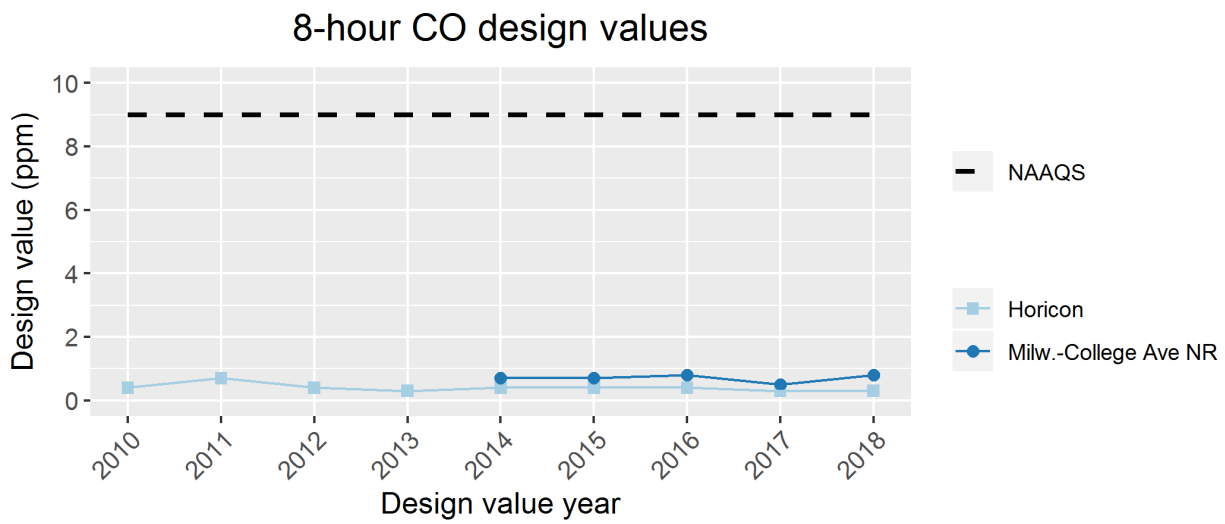

Figure 40. Trends in 8-hr CO design values.

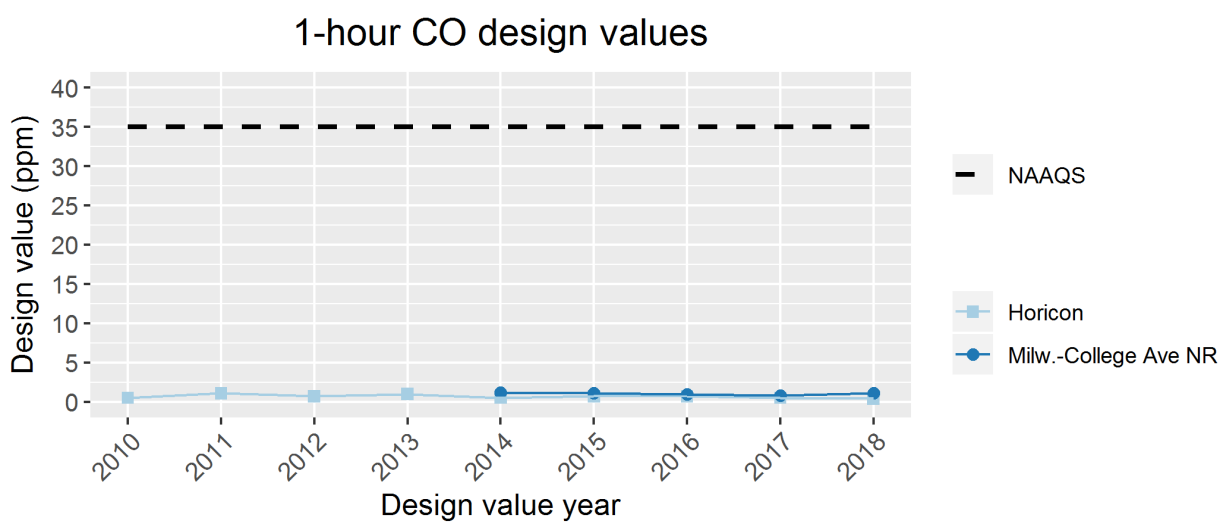

Figure 41. Trends in 1-hr CO design values.

Real-time air quality data

The air quality data presented in the figures above include data that has been through a rigorous quality assurance process. For readers interested in real-time air quality, DNR maintains an interactive website (https://airquality.wi.gov/home/map) containing the most recently available monitoring data. It is important to note that these real-time data have not been quality assured and have the potential to be corrected or excluded. The DNR's Air Quality Monitoring Data Information page (https://airquality.wi.gov/home/text/5) provides important information about interpreting these interactive maps. In addition to this real-time data, regularly updated air quality forecasts for Wisconsin are available at https://airquality.wi.gov/home/text/6.

Appendix A. – Air quality by county

County-level air quality maps can be found online. Please visit https://dnr.wi.gov/topic/AirQuality/Trends.html and navigate to the link for Wisconsin Air Quality Trends by County to find information about station location and single-pollutant trends maps on a county-by-county basis.

Appendix B. – Design value changes

TABLE B1. Change in 8-hr design values for ozone between 2001-2003 and 2016-2018. Only monitors with valid design values for both beginning and ending periods are included. Note that none of the Far North monitors operated in 2001-2003.

Site name	County	Site ID	8-hr design values^ (ppb)		Change (2001-03 to 2016-18)	
			2001-2003	2016-2018	ppb	%
Appleton	Outagamie	55-087-0009	78	65	-13	-17%
Bayside	Milwaukee	55-079-0085	94	73	-21	-22%
Beloit*	Rock	55-105-0030	83	68	-15	-18%
Chiwaukee Prairie	Kenosha	55-059-0019	101	79	-22	-22%
Columbus	Columbia	55-021-0015	79	66	-13	-16%
Devils Lake	Sauk	55-111-0007	73	64	-9	-12%
Fond du Lac	Fond du Lac	55-039-0006	80	64	-16	-20%
Grafton	Ozaukee	55-089-0008	92	72	-20	-22%
Green Bay-UW	Brown	55-009-0026	83	65	-18	-22%
Harrington Beach	Ozaukee	55-089-0009	98	74	-24	-24%
Horicon*	Dodge	55-027-0001	82	66	-16	-20%
Jefferson*	Jefferson	55-055-0009	83	68	-15	-18%
Kewaunee	Kewaunee	55-06-10002	92	70	-22	-24%
Lake Du Bay	Marathon	55-07-30012	73	64	-9	-12%
Lake Geneva	Walworth	55-127-0005	84	69	-15	-18%
Madison-East	Dane	55-025-0041	78	65	-13	-17%
Manitowoc	Manitowoc	55-07-10007	90	73	-17	-19%
Milw.-SER	Milwaukee	55-079-0026	84	69	-15	-18%
Newport	Door	55-029-0004	94	73	-21	-22%
Sheboygan-KA	Sheboygan	55-117-0006	100	81	-19	-19%
Lakeshore region** average					-20	-21%
Inland region** average					-14	-17%

^The 2001-2003 design values would be compared against the 1997 8-hour ozone NAAQS of 84 ppb; the 2016-2018 design values would be compared against both of the 8-hr ozone NAAQS in effect in 2018: 75 ppb for the 2008 standard and 70 ppb for the 2015 standard.

*The "Beloit" monitor combines records from the Beloit-Cunningham monitor (55-105-0024), which shut down in 2013, and the Beloit-Converse monitor, which replaced it. The "Horicon" monitor combines records from the Mayville monitor (55-027-0007), which shut down after 2009, and Horicon, which replaced it. The "Jefferson" monitor combines records from the Jefferson H.S. monitor (55-055-0002), which shut down after 2012, and the Jefferson-Laatsch monitor, which replaced it.

**See Figure 15 and associated text for definition of these regions.

TABLE B2. Change in annual design values for $PM_{2.5}$ between 2001-2003 and 2016-2018. Only monitors with valid design values for both beginning and ending periods are included.

Site name	County	Site ID	Annual design values^ (µg/m³)		Change (2001-03 to 2016-18)	
			2001-2003	2016-2018	(µg/m³)	%
Appleton	Outagamie	55-087-0009	10.7	6.3	-4.4	-41%
Chiwaukee Prairie	Kenosha	55-059-0019	11.7	7.1	-4.6	-39%
Green Bay-East	Brown	55-009-0005	11.5	6.4	-5.1	-44%
Horicon*	Dodge	55-027-0001	11.0	6.8	-4.2	-38%
Madison-University	Dane	55-025-0047	12.5	8.1	-4.4	-35%
Milw.-16th St.	Milwaukee	55-079-0010	13.1	8.0	-5.1	-39%
Milw.-SER	Milwaukee	55-079-0026	12.5	7.6	-4.9	-39%
Potosi	Grant	55-043-0009	11.4	7.3	-4.1	-36%
Trout Lake**	Vilas	55-125-0001	6.6	4.5	-2.1	-32%
Waukesha	Waukesha	55-133-0027	13.2	8.3	-4.9	-37%
Southeast region† average					-4.9	-39%
Inland region† average					-4.4	-39%

^The 2001-2003 design values would be compared against the 1997 annual $PM_{2.5}$ NAAQS of 15.0 µg/m³; the 2016-2018 design values would be compared against the 2012 annual $PM_{2.5}$ NAAQS of 12.0 µg/m³.

*The "Horicon" monitor combines records from the Mayville monitor (55-027-0007), which shut down after 2009, and Horicon, which replaced it.

**The only Far North monitor operating in 2001-03 was Trout Lake, so no average is shown.

†See Figure 19 and associated text for definition of these regions.

TABLE B3. Change in 24-hr design values for $PM_{2.5}$ between 2001-2003 and 2016-2018. Only monitors with valid design values for both beginning and ending periods are included.

Site name	County	Site ID	24-hr design values^ (µg/m³)		Change (2001-03 to 2016-18)	
			2001-2003	2016-2018	(µg/m³)	%
Appleton	Outagamie	55-087-0009	29	19	-10	-34%
Chiwaukee Prairie	Kenosha	55-059-0019	31	18	-13	-42%
Green Bay-East	Brown	55-009-0005	32	18	-14	-44%
Horicon*	Dodge	55-027-0001	33	20	-13	-39%
Madison-University	Dane	55-025-0047	34	22	-12	-35%
Milw.-16th St.	Milwaukee	55-079-0010	36	20	-16	-44%
Milw.-SER	Milwaukee	55-079-0026	34	20	-14	-41%
Potosi	Grant	55-043-0009	28	20	-8	-29%
Trout Lake**	Vilas	55-125-0001	18	15	-3	-17%
Waukesha	Waukesha	55-133-0027	34	21	-13	-38%
Southeast region† average					-14.0	-41%
Inland region† average					-11.4	-36%

^The 2001-2003 design values would be compared against the 1997 24-hour $PM_{2.5}$ NAAQS of 65 µg/m³; the 2016-2018 design values would be compared against the 2006 24-hour $PM_{2.5}$ NAAQS of 35 µg/m³.

*The "Horicon" monitor combines records from the Mayville monitor (55-027-0007), which shut down after 2009, and Horicon, which replaced it.

**The only Far North monitor operating in 2001-03 was Trout Lake, so no average is shown.

†See Figure 20 and associated text for definition of these regions.

TABLE B4. Change in 3-yr maximum 24-hr averages for PM_{10} between the start of monitoring (date variable) and 2016-2018. Annual maximum values over three years contribute to the determination of the PM_{10} design value.

Site name**	County	Site ID	First years of data	3-yr maximum 24-hr average^ (ppb)		Change (first years to 2016-18)	
				First years	2016-2018	ppb	%
Devils Lake	Sauk	55-111-0007	2012-14	41	33	-8	-20%
Horicon*	Dodge	55-027-0001	2005-07	62	27	-35	-56%
Madison-University	Dane	55-025-0047	2008-10	63	45	-18	-29%
Milw.-16th St.	Milwaukee	550-790-010	2007-09	47	46	-1	-2%
Milw.-College Ave. P&R	Milwaukee	55-079-0058	2010-12	66	40	-26	-39%
Milw.-SER	Milwaukee	55-079-0026	2010-12	64	60	-4	-6%
Waukesha	Waukesha	55-133-0027	2001-03	73	44	-29	-40%

**Milwaukee – College Ave. NR began PM_{10} measurements in 2018 but is not included in this table because data were not sufficiently complete to calculate a 3-yr maximum.

^All design values would be compared against the 1987 24-hour PM_{10} NAAQS of 150 µg/m^3, which is not to be exceeded more than once per year on average over 3 yr.

*The "Horicon" monitor combines records from the Mayville monitor (55-027-0007), which shut down after 2009, and Horicon, which replaced it.

TABLE B5. Change in 1-hr design values for SO_2 between the start of monitoring (date variable) and 2016-2018. Only one monitor (Rhinelander) had valid design values for the entire 2001-2003 to 2016-2018 period.

Site name	County	Site ID	First years of data	1-hr design values^ (ppb)		Change (first years to 2016-18)	
				First years	2016-2018	ppb	%
Green Bay-East	Brown	55-009-0005	2003-05	67	12	-55	-82%
Horicon	Dodge	55-027-0001	2010-12	7	2	-5	-71%
Madison-East	Dane	55-025-0041	2013-15	7	2	-5	-71%
Milw.-SER	Milwaukee	55-079-0026	2002-04	68	5	-63	-93%
Potawatomi	Forest	55-041-0007	2007-09	8	2	-6	-75%
Rhinelander	Oneida	55-085-0996	2001-03	149	69	-80	-54%

^Design values from 2010-2012 to 2016-2018 would be compared against the 2010 1-hour SO_2 NAAQS of 75 ppb. There was not a 1-hr standard in effect prior to 2010; rather there were annual and 24-hr standards of 30 ppb and 140 ppb, respectively.

TABLE B6. Change in annual design values for NO_2 between the start of monitoring (date variable) and 2018.

Site name	County	Site ID	First year of data	Annual design values^ (ppb)		Change (first year to 2018)	
				First year	2018	ppb	%
Milw.-College Ave. NR	Milwaukee	55-079-0056	2014	16	14	-2	-13%
Milw.-SER	Milwaukee	55-079-0026	2004	17	9	-8	-47%

^All design values would be compared against the annual NO_2 NAAQS of 53 ppb which EPA has retained since 1971.

TABLE B7. Change in 1-hr design values for NO_2 between the start of monitoring (date variable) and 2016-2018.

Site name	County	Site ID	First years of data	1-hr design values^ (ppb)		Change (first years to 2016-18)	
				First years	2016-2018	ppb	%
Milw.-College Ave. NR	Milwaukee	55-079-0056	2014-16	49	46	-3	-6%
Milw.-SER	Milwaukee	55-079-0026	2004-06	52	44	-8	-15%

^Design values from 2016-2018 would be compared against the 2010 1-hour NO_2 NAAQS of 100 ppb. There was not a 1-hr standard in effect prior to 2010; rather values would be compared to the 1971 annual standard of 53 ppb.

TABLE B8. Change in 3-mo design values for lead between 2012-2014 and 2016-2018.

Site name	County	Site ID	3-mo design values^ ($\mu g/m^3$)		Change (2012-2014 to 2016-18)	
			2012-2014	2016-2018	$\mu g/m^3$	%
Kohler	Sheboygan	55-117-0008	0.11	0.05	-0.06	-55%

^All design values would be compared against the 2008 3-mo lead NAAQS of 0.15 $\mu g/m^3$.

TABLE B9. Change in 8-hr and 1-hr design values for CO between the start of monitoring (date variable) and 2018.

Site name	County	Site ID	First year of data	8-hr design values^ (ppm)		1-hr design values^ (ppm)	
				First year	2018	First year	2018
Horicon	Dodge	55-027-0001	2010	0.4	0.3	0.5	0.4
Milw.-College Ave. NR	Milwaukee	55-079-0056	2014	0.7	0.8	1.2	1.1

^All 8-hr design values would be compared against the 1971 8-hour CO NAAQS of 9 ppm, and all 1-hr design values would be compared against the 1971 1-hour NAAQS of 35 ppm.

Appendix C. – Full site names

TABLE C1. Full site names corresponding to shorter names used in the text, tables, and figures.

Site Name	County	Site ID	Full site name
Appleton	Outagamie	55-087-0009	Appleton - AAL
Bad River	Ashland	55-003-0010	Bad River Tribal School - Odanah
Bayside	Milwaukee	55-079-0085	Bayside
Beloit*	Rock	55-105-0030	Beloit - Converse
Chiwaukee Prairie	Kenosha	55-059-0019	Chiwaukee Prairie Stateline
Columbus	Columbia	55-021-0015	Columbus
Devils Lake	Sauk	55-111-0007	Devils Lake Park
Eau Claire	Eau Claire	55-035-0014	Eau Claire - DOT Sign Shop
Fond du Lac	Fond du Lac	55-039-0006	Fond du Lac
Grafton	Ozaukee	55-089-0008	Grafton
Green Bay-East	Brown	55-009-0005	Green Bay - East High
Green Bay-UW	Brown	55-009-0026	Green Bay - UW
Harrington Beach	Ozaukee	55-089-0009	Harrington Beach Park
Horicon*	Dodge	55-027-0001	Horicon Wildlife Area
Jefferson*	Jefferson	55-055-0009	Jefferson - Laatsch
Kenosha-WT	Kenosha	55-059-0025	Kenosha-Water Tower
Kewaunee	Kewaunee	55-061-0002	Kewaunee
Kohler	Sheboygan	55-117-0008	Kohler
La Crosse	La Crosse	55-063-0012	Lacrosse - DOT Building
Lake Du Bay	Marathon	55-073-0012	Lake Du Bay
Lake Geneva	Walworth	55-127-0005	Lake Geneva
Madison-East	Dane	55-025-0041	Madison - East
Madison-University	Dane	55-025-0047	Madison – University Ave. Well #6
Manitowoc	Manitowoc	55-071-0007	Manitowoc - Wdlnd Dunes
Milw.-16th St.	Milwaukee	55-079-0010	Milwaukee - Sixteenth St. Health Center
Milw.-College Ave. NR	Milwaukee	55-079-0056	Milwaukee – College Ave. Near Road
Milw.-College Ave. P&R	Milwaukee	55-079-0058	Milwaukee – College Ave. Park & Ride
Milw.-SER	Milwaukee	55-079-0026	Milwaukee - SER DNR Hdqrs.
Newport	Door	55-029-0004	Newport Park
Perkinstown	Taylor	55-119-8001	Perkinstown
Potawatomi	Forest	55-041-0007	Potawatomi
Potosi	Grant	55-043-0009	Potosi
Racine-Payne & Dolan	Racine	55-101-0020	Racine-Payne & Dolan
Rhinelander	Oneida	55-085-0996	Rhinelander Tower
Sheboygan-Haven	Sheboygan	55-117-0009	Sheboygan - Haven
Sheboygan - KA	Sheboygan	55-117-0006	Sheboygan - Kohler Andrae
Trout Lake	Vilas	55-125-0001	Trout Lake
Waukesha	Waukesha	55-133-0027	Waukesha - Cleveland Ave.

* The "Beloit" monitor combines records from the Beloit-Cunningham monitor (55-105-0024), which shut down in 2013, and the Beloit-Converse monitor, which replaced it. The "Horicon" monitor combines records from the Mayville monitor (55-027-0007), which shut down after 2009, and Horicon, which replaced it. The "Jefferson" monitor combines records from the Jefferson H.S. monitor (55-055-0002), which shut down after 2012, and the Jefferson-Laatsch monitor, which replaced it.