Overview of Carbon Monoxide (CO) Air Quality in the United States

Updated: June 29, 2023

1. Introduction

The overall purpose of this document is to maintain an up-to-date graphical summary of air quality information that supports the review of the National Ambient Air Quality Standards (NAAQS) for carbon monoxide (CO). In previous reviews of the CO NAAQS, this type of information has generally been included in atmospheric sections of the Integrated Science Assessment (ISA) and Policy Assessment (PA) for carbon monoxide. This stand-alone document will either replace or complement the air quality emissions and monitoring data in the atmospheric sections of future CO NAAQS review supporting documents and will be updated at regular intervals as new data becomes available.

The content of past NAAQS documents' atmospheric sections has included major sections on emissions and concentration trends utilizing maps and data from the Environmental Protection Agency's (EPA's) National Emissions Inventory (NEI) and the EPA's Air Quality System (AQS) database. In past NAAQS reviews, this often involved adaptation of figures and tables prepared for other reports or development of new figures and tables using data analysis and mapping software. Additionally, the release of updated emission inventories and ambient air monitoring data may not coincide with the schedule for the development of NAAQS review supporting documents. As a result, data access and resources can limit the availability of the most recent information for inclusion in NAAQS review supporting documents.

This stand-alone document allows the content to be updated as soon as new data becomes available, rather than relying on information that is available at the time of development of the NAAQS review supporting documents. It also ensures that the public will have access to a consistent set of maps and figures for each NAAQS pollutant that are updated on a routine basis, rather than separated by several years because of the disparate schedules of the various NAAQS reviews for each pollutant. Moreover, a stand-alone document can be expanded to include new air quality analyses as they are completed, rather than following the timeline for the public release of the NAAQS review supporting documents. Finally, this document takes advantage of a more flexible digital format for the routinely prepared maps and trends figures with an end product that more strongly emphasizes visual presentation of data and reduces the amount of text, while also creating a more interactive presentation of the information through the use of external links.

This document follows an organizational structure similar to that of the atmospheric sections of past CO NAAQS review supporting documents. The subsequent sections are as follows: 2. Atmospheric Chemistry; 3. Sources and Emissions of CO; 4. Ambient Air Monitoring Requirements and Monitoring Networks; 5. Data Handling Conventions and Computations for Determining Whether the Standards are Met; and 6. CO Concentrations Measured at Ambient Air Monitoring Sites Across the U.S. These sections are broad enough in scope to communicate relevant information about CO air quality, including scientific advances, but specific enough that the information needed to develop NAAQS review supporting documents can be quickly and readily retrieved.

2. Atmospheric Chemistry

CO is formed primarily by incomplete combustion of carbon-containing fuels and photochemical reactions in the atmosphere. In general, any increase in fuel O_2 content, burn temperature, or mixing time in the combustion zone will tend to decrease production of CO relative to CO_2. CO emissions from large fossil-fueled power plants are typically very low since the boilers at these plants are tuned for highly efficient combustion with the lowest possible fuel consumption. In contrast, internal combustion engines used in many mobile sources have widely varying operating conditions. Therefore, higher and more varying CO formation results from the operation of these mobile sources.

Oxidation of anthropogenic and biogenic volatile organic compounds (VOCs) constitute important secondary sources of CO. Secondary CO production occurs by photooxidation of methane (CH_4) and other VOCs, including nonmethane hydrocarbons (NMHCs) in the atmosphere and organic molecules in surface waters and soils. Photolysis of formaldehyde (CH_2O) proceeds by two pathways. The first produces molecular hydrogen (H_2) and CO with a reaction yield of 55% in conditions of clear skies and low zenith angles; the second yields a hydrogen radical (H) and the formyl radical (HCO). HCO then reacts with O_2 to form hydroperoxy radical (HO_2; OH and HO_2 together are termed HO_X) and CO. Reaction of methyl

peroxy radical (CH_3O_2) with HO_2 radicals to form methyl hydroperoxide (CH_3OOH) is also operative, especially in low oxides of nitrogen (NO_X) conditions. Heterogeneous removal of the partially water-soluble intermediate products, such as CH_3OOH and CH_2O, will decrease CO yields from CH_4 oxidation.

While oxidation of CH_2O nearly always produces CO and some small quantities of formic acid (CH_2O_2) in the reaction of CH_2O with HO_2, oxidation of acetaldehyde (CH_3CHO) does not always yield two CO molecules. Reaction of CH_3CHO with OH can yield acetyl radicals (CH_3CO) which then will participate with O_2 in a termolecular recombination reaction to form peroxyacyl radicals, which then can react with nitric oxide (NO) to form CH_3 and CO_2. The peroxyacyl radicals may also react with NO_2 to form peroxyacetyl nitrate (PAN), $CH_3CO_3NO_2$. In this way, one carbon atom is oxidized directly to CO_2 without passing through CO. The yield of CO from these pathways depends on the OH concentration and the photolysis rate of CH_3CHO, as well as on the abundance of NO, since peroxyacyl radicals also will react with other odd hydrogen radicals like HO_2.

Estimating the CO yield from oxidation of hydrocarbons (HCs) larger than CH_4 requires computing the yields of CH_2O, CH_3CHO, CH_3CO, and analogous radicals from oxidation of the parent molecules. Moreover, the extent of heterogeneous removal of soluble intermediate products also affects oxidation of more complex HCs. However, the detailed gas-phase kinetics for many HCs with more than a few carbons is still unknown. This is especially the case for several important classes of VOCs, including the aromatics, biogenic HCs including isoprene, and their intermediate oxidation products like epoxides, nitrates, and carbonyls. Mass-balance analyses performed on irradiated smog chamber mixtures of aromatic HCs indicate that only about one-half of the carbon is in the form of compounds that can be identified. In addition, reactions like the oxidation of terpenes that produce condensable products are also significant because these reactions produce secondary organic aerosols, thereby reducing the potential yield of CO.

The major pathway for removal of CO from the atmosphere is reaction with OH to produce CO_2 and H radicals that rapidly combine with O_2 to form HO_2 radicals. The mean tropospheric photochemical lifetime of CO in the northern hemisphere is estimated to be about 57 days. Owing to variation in atmospheric water vapor, OH concentration, and insolation, shorter photochemical lifetimes are found nearer the tropics and longer ones at higher latitudes. During winter at high latitudes, CO has nearly no photochemical reactivity on urban and regional scales. Because the CO lifetime is shorter than the roughly one year characteristic time scale for mixing between the hemispheres and because northern hemisphere CO emissions are higher due to anthropogenic activity, a large gradient in concentrations exists between the hemispheres. In addition, the CO lifetime at high latitudes is long enough to result in much smaller gradients between 30° latitude and the pole of either hemisphere. The typical residence time of CO in urban areas when assuming a diel-average OH concentration of $3{\times}10^6/cm^3$ in urban areas is about 16 days, so CO will not typically be destroyed in urban areas where it is emitted and will likely be mixed on continental and larger scales. OH concentrations are orders of magnitude lower in indoor environments, and so CO will generally not be affected by indoor air reactions.

3. Sources and Emissions of CO

Mobile sources are the largest anthropogenic source of CO emissions in the U.S., comprising 39% of total CO emissions in 2020 (Figure 1). CO emissions from internal combustion engines vary substantially with ambient temperature and operating conditions. Substantial light-duty gasoline vehicle CO emissions occur during the cold start before the catalyst is warmed up. Lower ambient temperatures result in increased CO emissions because ignition engines are required to run richer air:fuel ratios for longer periods of time. Increased vehicle CO emissions can also occur under conditions such as high rates of acceleration, rapid speed fluctuations, heavy-vehicle load demands (such as those that occur while pulling a trailer or going up a steep hill), and use of air-conditioning. Moreover, the gasoline-powered spark ignition engines that predominate in light-duty on-road vehicles have higher uncontrolled CO emission rates than other combustion sources because they typically operate closer to the stoichiometric air-to-fuel ratio, have relatively short residence times at peak combustion temperatures, and have very rapid cooling of cylinder exhaust gases. By contrast, the diesel-powered engines that predominate in heavy-duty onroad vehicles and in off-road and non-road fixed combustion sources have much lower engine-out CO emissions than do the spark-ignition engines because the diesels typically operate at very high air-to-fuel ratios, which promote mixing oxygen and fuel, thus improving carbon burn.

Another important source of CO emissions is fires, which consists of wildfires, agricultural field burning to control the growth of unwanted plants on crop and pasture land, and prescribed burns to manage forest resources. Wildfires are typically treated as natural emissions in emissions inventories, while agricultural and prescribed fires are treated as anthropogenic. Fires made up 43% of total U.S. CO emissions in 2020, though wildfires especially tend to exhibit large interannual variability mostly due to fluctuations in meteorological conditions. Other important sources of CO emissions include stationary fuel combustion, which includes emissions from coal-, gas-, and oil-fired power plants and industrial, commercial, and institutional sources, as well as residential heaters (e.g., wood-burning stoves) and boilers; industrial processes, which include chemical production, petroleum refining and metals production, and natural emissions from plants and soil (biogenics).

The National Emissions Inventory (NEI) is a comprehensive and detailed estimate of air emissions of criteria pollutants, precursors to criteria pollutants, and hazardous air pollutants from air emissions sources. The NEI is released every three years based primarily upon data provided by State, Local, and Tribal air agencies for sources in their jurisdictions and supplemented by data developed by the EPA. The NEI is built using the EPA's Emissions Inventory System (EIS) first to collect the data from State, Local, and Tribal air agencies and then to blend that data with other data sources.

Accuracy in an emissions inventory reflects the extent to which the inventory represents the actual emissions that occurred. Anthropogenic emissions of air pollutants result from a variety of sources such as power plants, industrial sources, motor vehicles and agriculture. The emissions from any individual source typically vary in both time and space. For the thousands of sources that make up the NEI, there is uncertainty in one or both of these factors. For some sources, such as power plants, direct emission measurements enable the emission factors derived from them to be more certain than sources without such direct measurements. However, it is not practically possible to directly monitor each of the emission sources individually and, therefore, emission inventories necessarily contain assumptions, interpolation and extrapolation from a limited set of sample data.
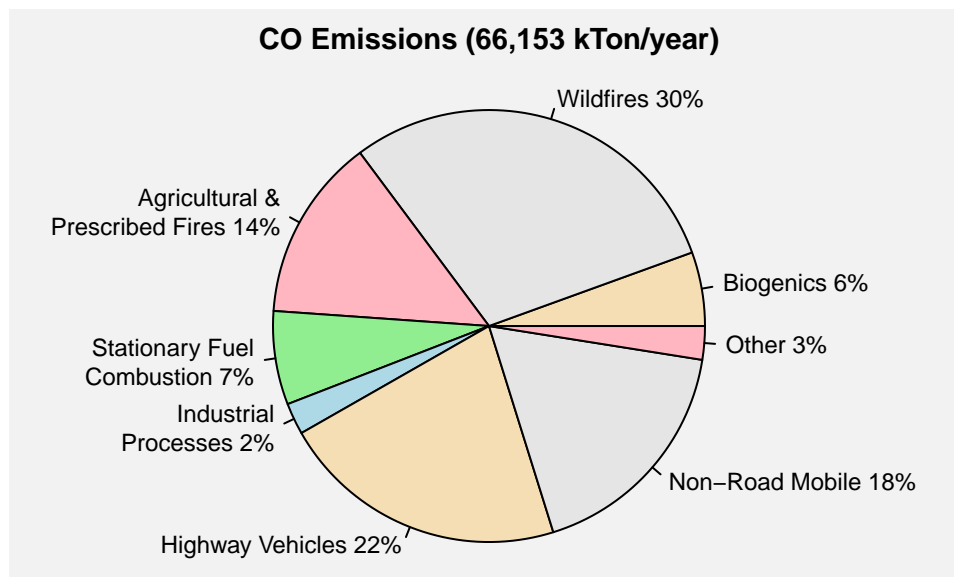

Figure 1. U.S. CO emissions by sector. **Source:** 2020 NEI.

Figure 2 shows the CO emissions density in tons/mi^2/year for each U.S. county based on the 2020 NEI. The majority of CO emissions tend to be located near urban areas, which tend to have the most vehicle traffic and industrial sources. However, there are also some counties in rural areas with higher CO emissions due to fires or the presence of large stationary sources such as power plants. Figure 3 shows the national trend in U.S. anthropogenic CO emissions by sector from 2002 to 2022.[1] Nationally, CO emissions have decreased by 37% since 2002, mostly due to reductions in mobile source emissions.

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[1] Data for Figure 2 come from the EPA's Air Pollutant Emissions Trends Data. Note that emissions for some sectors are interpolated between inventory years, and the emissions for some sectors are held constant beyond the most recent inventory year (for details, see the "Development of Data" table in the national emissions trends data file. For the purposes of this document, wildfires are considered to be natural emissions and thus are not included in Figure 2.
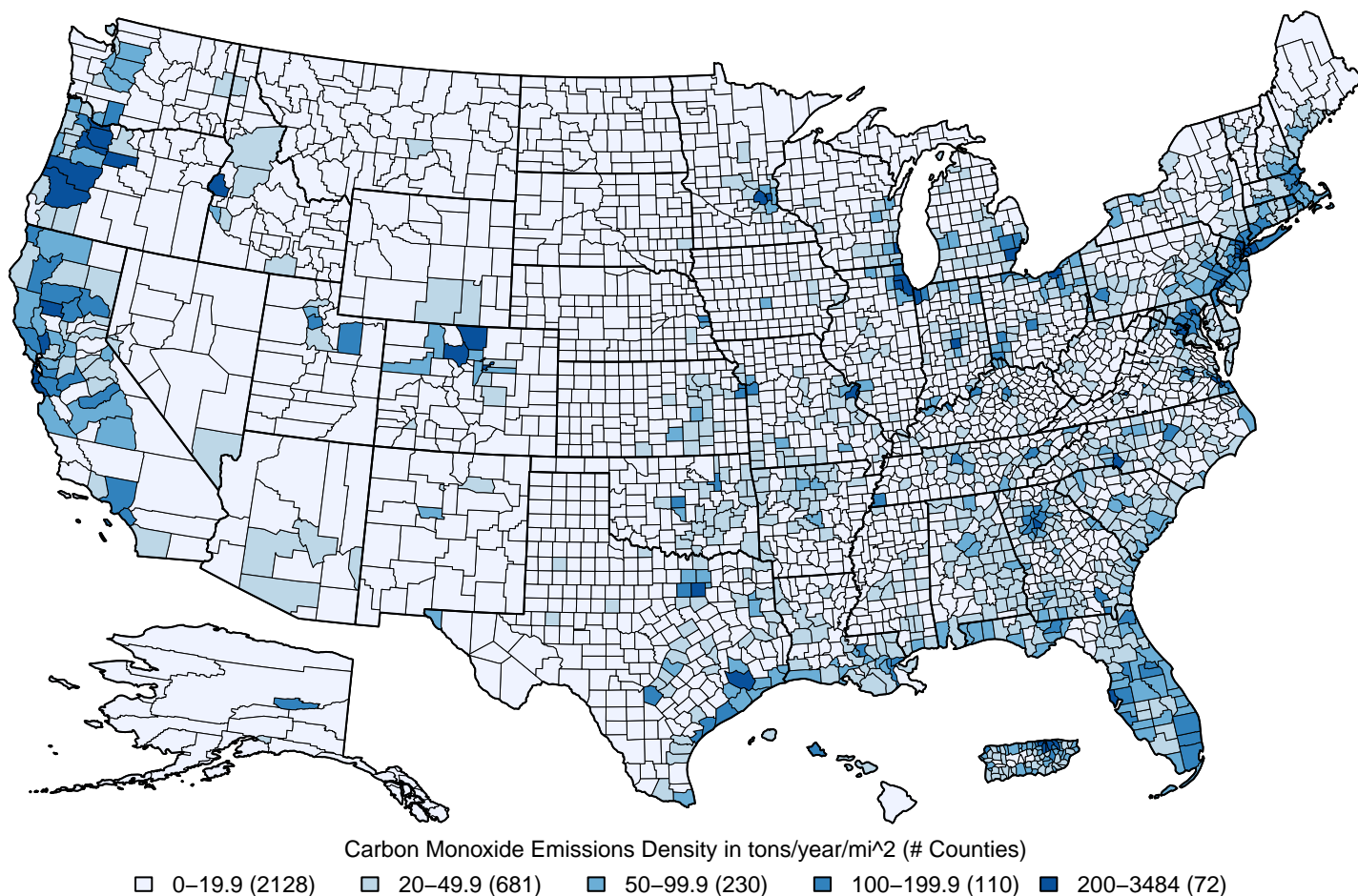
**Figure 2.** U.S. county-level CO emissions density estimates in tons/year/mi^2. **Source:** 2020 NEI
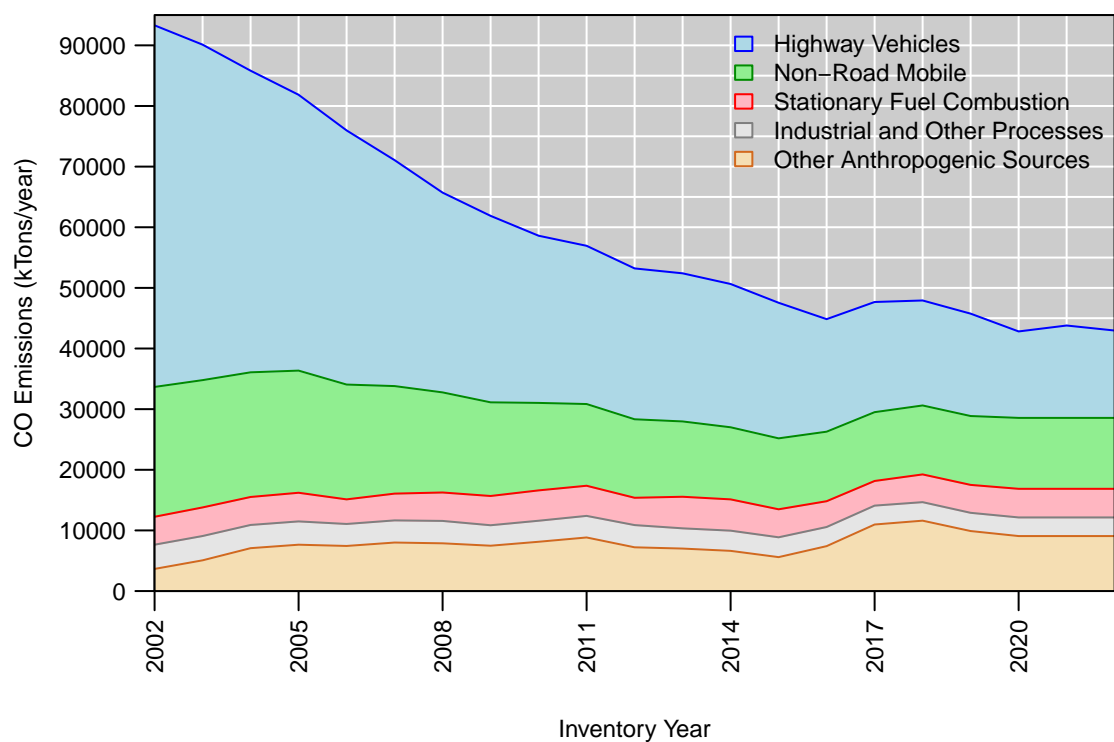
Figure 3. U.S. anthropogenic CO emissions trend, 2002-2022. **Source:** EPA's Air Pollutant Emissions Trends Data

4. Ambient Air Monitoring Requirements and Monitoring Networks

The EPA and its partners at State, Local and Tribal monitoring agencies manage and operate the nation's ambient air monitoring networks. The EPA provides monitoring requirements for CO and other pollutants in 40 CFR Part 58. Monitoring agencies carry out and perform ambient air monitoring in accordance with the EPA's requirements and guidance. Federal Reference Methods (FRMs) and Federal Equivalent Methods (FEMs) are monitoring methods that have been approved for use by States and other monitoring organizations to assess NAAQS compliance and implementation. Prior to 2006, CO monitoring instruments typically had a lower detection limit (LDL) of 0.5 ppm. This is sufficient for the purpose of determining compliance with the CO NAAQS, but with many areas routinely measuring CO levels below 1 ppm, a large percentage of the measurements from these monitors were below the LDL of these instruments, which contributed to greater measurement uncertainties. Since 2005, the older instruments have slowly been replaced with a new generation of 'trace-level' instruments, which have LDLs on the order of 0.02 to 0.04 ppm. As of 2022, about half of the CO monitoring network consists of measurements from these newer trace-level instruments.

There were 274 monitoring sites reporting hourly CO concentration data to the EPA during the 2020-2022 period. The locations of these monitoring sites are shown in Figure 4. The main network providing ambient data for use in comparison to the NAAQS is the State and Local Air Monitoring Stations (SLAMS) network, which consists of nearly 90% of all CO monitoring sites in the U.S. Currently there are no minimum monitoring requirements for the number of CO monitoring sites, except as part of the NCore and near-road networks as discussed below. However, continued operation of existing SLAMS sites is required unless discontinuation is approved by the EPA Regional Administrator. Further, in areas where SLAMS CO monitoring is ongoing, at least one site must be a maximum concentration site for the area.

SLAMS (114)   NCORE (76)   NEAR ROAD (57)   SPM/OTHER (27)
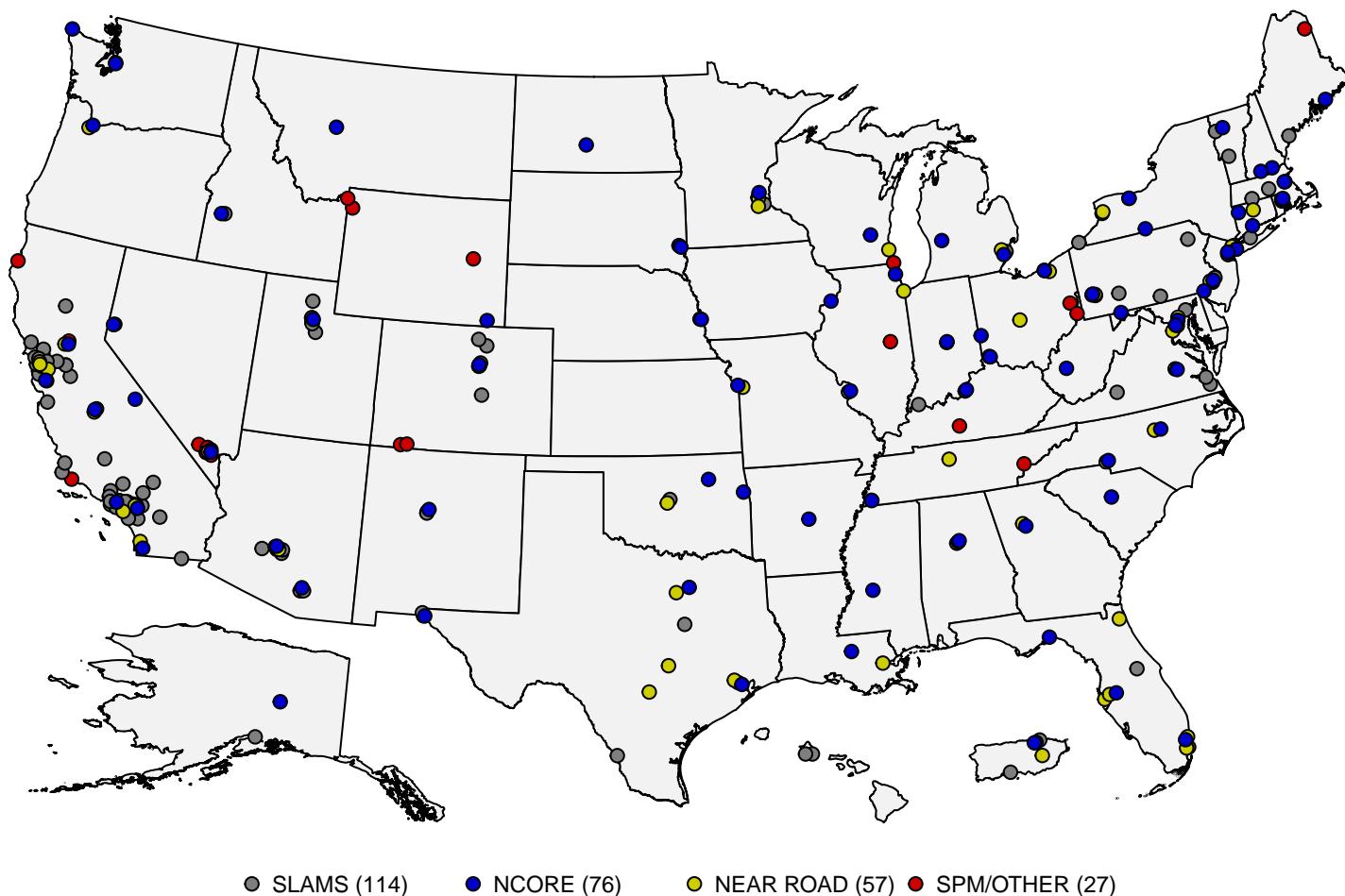
Figure 4: Map of U.S. CO monitoring sites reporting data to the EPA during the 2020-2022 period. **Source:** AQS.

Two important subsets of SLAMS sites are the National Core (NCore) multi-pollutant monitoring network and the near-road network. The NCore network, designed to collect consistent measurements of criteria pollutants for trends and NAAQS compliance purposes, was fully implemented in 2011 and consists of approximately 60 urban monitoring stations and 20 rural monitoring stations. Each State is required to have at least one NCore station. The near-road monitoring network, which began operating in 2014, requires sites to operate near major roadways in each metropolitan statistical area (MSA) with a population of 1,000,000 or greater. There were 57 near-road monitors collecting CO measurements during the

2020-2022 period.

Finally, there are also a number of Special Purpose Monitors (SPMs), which are not required but are often operated by air agencies for short periods of time (i.e., less than 3 years) to collect data for human health and welfare studies, as well as other types of monitoring sites, including monitors operated by tribes and industrial sources. The SPMs are typically not used to assess compliance with the NAAQS.

To provide an assessment of data quality, monitoring agencies must perform quality assurance (QA) checks at least once every two weeks to derive estimates of precision and bias for CO and the other gaseous criteria pollutant measurements using calibration gas. For CO monitors, the data quality goal for precision and bias is 15 percent. Ambient air quality data and associated QA data are reported to the EPA via the Air Quality System (AQS).[2] Data are reported quarterly and must be submitted to AQS within 90 days after the end of each calendar quarter (i.e. Jan/Feb/Mar, Apr/May/Jun, Jul/Aug/Sep, Oct/Nov/Dec). Additionally, each monitoring agency is required to certify all FRM/FEM data that is submitted to AQS annually, taking into consideration any QA findings, and a data certification letter must be sent to the EPA Regional Administrator by May 1st of the following year.

5. Data Handling Conventions and Computations for Determining Whether the Standards are Met

To assess whether a monitoring site or geographic area (usually a county or urban area) meets or exceeds a NAAQS, the monitoring data are analyzed consistent with the established regulatory requirements for the handling of monitoring data for the purposes of deriving a design value. A design value summarizes ambient air concentrations for an area in terms of the indicator, averaging time and form for a given standard such that its comparison to the level of the standard indicates whether the area meets or exceeds the standard. There are currently two primary CO NAAQS in effect: the 1-hour NAAQS of 35 ppm and the 8-hour NAAQS of 9 ppm, neither to be exceeded more than once per year.[3]

Hourly CO measurement data collected at an ambient air monitoring site using FRMs or FEMs, meeting all applicable requirements in 40 CFR Part 58, and reported to AQS in parts per million (ppm) with decimal digits after the first decimal place truncated are used in design value calculations. The design value for the 1-hour and 8-hour CO NAAQS are evaluated for each monitor based on hourly concentration data collected over two consecutive calendar years. For the 1-hour CO NAAQS, the 2nd highest hourly concentration in each year is determined, and the design value is the higher of these two annual 2nd maximum values, rounded to the nearest ppm. The 1-hour NAAQS is met when the design value is less than or equal to 35 ppm.

For the 8-hour NAAQS, rolling 8-hour averages are computed from the hourly concentration data for each 8-hour period over the 2 years. The 8-hour averages are stored in the last hour of each 8-hour period (e.g., for the 8-hour period from 8:00 AM to 3:59 PM, the 8-hour average is stored in the 3:00 PM hour). Each 8-hour average is considered valid if hourly concentrations are available for at least 6 of the 8 hours in the 8-hour period. For each of the 2 years, the 2nd highest non-overlapping 8-hour average concentration is determined, and the design value is the higher of these two annual 2nd maximum values, rounded to the nearest ppm. The 8-hour NAAQS is met when the design value is less than or equal to 9 ppm. Unlike the other pollutants, there are no minimum data completeness requirements for determining valid 1-hour and 8-hour CO design values.

6. CO Concentrations Measured at Ambient Air Monitoring Sites Across the U.S.

Table 1 below presents summary statistics based on three daily CO metrics, the daily maximum 1-hour (MDA1) metric, the daily maximum 8-hour (MDA8) metric, and the daily 24-hour average (DA24) metric. These statistics are presented for year-round and each season (winter=Dec/Jan/Feb, spring=Mar/Apr/May, summer=Jun/Jul/Aug, autumn=Sep/Oct/Nov) for monitors that have complete data (defined as having at least 75% data completeness) in AQS for 2020-2022. Table 2 presents the same set of summary statistics for the three daily CO metrics based on three types of sites: near-road sites, urban NCore sites, and rural sites, which includes rural NCore sites plus a few sites operated by the National Park Service. It is apparent from Table 1 that CO concentrations tend to be slightly higher in the fall and winter months than in the spring and summer. In Table 2, it is apparent that the near-road sites typically measure slightly higher CO concentrations than other urban sites, while CO concentrations are typically much lower in rural areas than in urban areas.

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[2]Quality assurance requirements for monitors used in evaluations of the NAAQS are provided in Appendix A to 40 CFR Part 58. Annual summary reports of precision and bias can be obtained for each monitoring site at the EPA's Air Data website.
[3]The procedures for calculating design values for the CO NAAQS are documented in 40 CFR §50.8 and (Laxton, 1990).

Table 1. National distribution of CO concentrations in ppm by season for 2020-2022.[4] **Source:** AQS.

metric	season	N.sites	N.obs	mean	SD	min	p1	p5	p10	p25	p50	p75	p90	p95	p98	p99	max	max.site
MDA1	all	221	233,245	0.49	0.39	-0.40	0.00	0.10	0.16	0.23	0.40	0.60	0.92	1.20	1.50	1.80	29.00	720210010
MDA1	winter	219	57,340	0.60	0.44	-0.40	0.07	0.14	0.19	0.30	0.50	0.80	1.20	1.45	1.80	2.10	6.70	060531003
MDA1	spring	220	59,126	0.41	0.32	-0.40	0.00	0.10	0.15	0.21	0.34	0.50	0.78	0.90	1.20	1.36	29.00	720210010
MDA1	summer	219	58,230	0.38	0.27	-0.30	0.00	0.10	0.13	0.20	0.31	0.50	0.70	0.83	1.10	1.27	9.52	150030010
MDA1	autumn	214	56,285	0.56	0.44	-0.40	0.00	0.12	0.17	0.29	0.46	0.70	1.08	1.30	1.60	1.90	15.31	410510080
MDA8	all	221	233,176	0.38	0.28	-0.40	0.00	0.10	0.10	0.20	0.30	0.50	0.70	0.90	1.10	1.30	14.30	410670005
MDA8	winter	219	57,336	0.46	0.32	-0.40	0.00	0.10	0.20	0.20	0.40	0.60	0.90	1.10	1.30	1.60	3.70	060371302
MDA8	spring	220	59,117	0.32	0.21	-0.40	0.00	0.10	0.10	0.20	0.30	0.40	0.60	0.70	0.80	0.90	4.30	420031376
MDA8	summer	219	58,220	0.30	0.20	-0.40	0.00	0.10	0.10	0.20	0.30	0.40	0.50	0.70	0.80	1.00	3.40	420031376
MDA8	autumn	214	56,249	0.43	0.33	-0.40	0.00	0.10	0.10	0.20	0.40	0.60	0.80	1.00	1.20	1.40	14.30	410670005
DA24	all	221	233,245	0.28	0.19	-0.40	-0.02	0.06	0.11	0.16	0.24	0.35	0.50	0.61	0.75	0.86	10.46	410670005
DA24	winter	219	57,340	0.32	0.20	-0.40	0.00	0.10	0.13	0.19	0.28	0.42	0.58	0.70	0.84	0.96	2.47	020200018
DA24	spring	220	59,126	0.24	0.15	-0.40	-0.05	0.06	0.10	0.15	0.22	0.31	0.42	0.50	0.61	0.68	3.18	350010029
DA24	summer	219	58,230	0.24	0.16	-0.38	-0.08	0.03	0.08	0.14	0.21	0.31	0.43	0.52	0.64	0.74	2.58	720210010
DA24	autumn	214	56,285	0.30	0.22	-0.40	0.00	0.08	0.11	0.17	0.26	0.40	0.55	0.66	0.82	0.95	10.46	410670005

N.sites = number of sites; N.obs = number of observations; SD = standard deviation; min = minimum; p1, p5, p10, p25, p50, p90, p95, p98, p99 = 1st, 5th, 10th, 25th, 50th, 90th, 95th, 98th, 99th percentiles; max = maximum; max.site = AQS ID number for the monitoring site corresponding to the observation in the max column. winter = December/January/February; spring = March/April/May; summer = June/July/August; autumn = September/October/November.

Table 2. National distribution of CO concentrations in ppb by site type for 2020-2022.[4] **Source:** AQS.

metric	site.type	N.sites	N.obs	mean	SD	min	p1	p5	p10	p25	p50	p75	p90	p95	p98	p99	max	max.site
MDA1	All Sites	221	233,245	0.49	0.39	-0.40	0.00	0.10	0.16	0.23	0.40	0.60	0.92	1.20	1.50	1.80	29.0	720210010
MDA1	Near Road	48	51,082	0.63	0.38	-0.10	0.13	0.22	0.30	0.40	0.56	0.80	1.10	1.30	1.54	1.80	14.7	410670005
MDA1	Urban NCore	58	60,510	0.43	0.37	-0.40	0.05	0.14	0.17	0.22	0.32	0.51	0.82	1.07	1.38	1.61	29.0	720210010
MDA1	Rural	19	19,766	0.21	0.21	-0.20	0.00	0.07	0.10	0.13	0.16	0.21	0.31	0.50	0.80	1.10	5.5	090050005
MDA8	All Sites	221	233,176	0.38	0.28	-0.40	0.00	0.10	0.10	0.20	0.30	0.50	0.70	0.90	1.10	1.30	14.3	410670005
MDA8	Near Road	48	51,050	0.50	0.28	-0.10	0.10	0.20	0.20	0.30	0.40	0.60	0.80	1.00	1.20	1.30	14.3	410670005
MDA8	Urban NCore	58	60,479	0.33	0.26	-0.40	0.00	0.10	0.10	0.20	0.30	0.40	0.60	0.80	1.00	1.20	14.2	410510080
MDA8	Rural	19	19,743	0.17	0.13	-0.20	0.00	0.10	0.10	0.10	0.10	0.20	0.30	0.40	0.60	0.70	2.9	350010029
DA24	All Sites	221	233,245	0.28	0.19	-0.40	-0.02	0.06	0.11	0.16	0.24	0.35	0.50	0.61	0.75	0.86	10.5	410670005
DA24	Near Road	48	51,082	0.37	0.19	-0.14	0.06	0.15	0.18	0.25	0.34	0.46	0.60	0.71	0.83	0.94	10.5	410670005
DA24	Urban NCore	58	60,510	0.23	0.16	-0.40	0.00	0.08	0.11	0.15	0.20	0.27	0.40	0.50	0.65	0.75	10.2	410510080
DA24	Rural	19	19,766	0.15	0.10	-0.20	-0.01	0.04	0.07	0.10	0.13	0.16	0.22	0.31	0.43	0.52	3.2	350010029

N.sites = number of sites; N.obs = number of observations; SD = standard deviation; min = minimum; p1, p5, p10, p25, p50, p90, p95, p98, p99 = 1st, 5th, 10th, 25th, 50th, 90th, 95th, 98th, 99th percentiles; max = maximum; max.site = AQS ID number for the monitoring site corresponding to the observation in the max column.

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[4]Negative concentration values may appear in AQS datasets down to the negative of the LDL to allow for normal instrument variability at very low concentrations. Data that exceed the negative of the LDL is typically indicative of a malfunction or another issue that affects the data defensibility.

Figure 5 below shows a map of the 8-hour CO design values and Figure 6 shows a map of the 1-hour CO design values at U.S. ambient air monitoring sites based on data from the 2021-2022 period. There were two sites in Puerto Rico that exceeded the 8-hour CO NAAQS in 2022 and one of those sites also exceeded the 1-hour CO NAAQS. It is unclear what caused these high concentrations. Nearly all other sites in the U.S. were well below the NAAQS, with design values generally below 3 ppm for the 8-hour CO NAAQS and below 5 ppm for the 1-hour CO NAAQS.

● 0.2 – 3 ppm (258 sites)   ● 3.1 – 6 ppm (3 sites)   ● 15.1 – 29.7 ppm (2 sites)
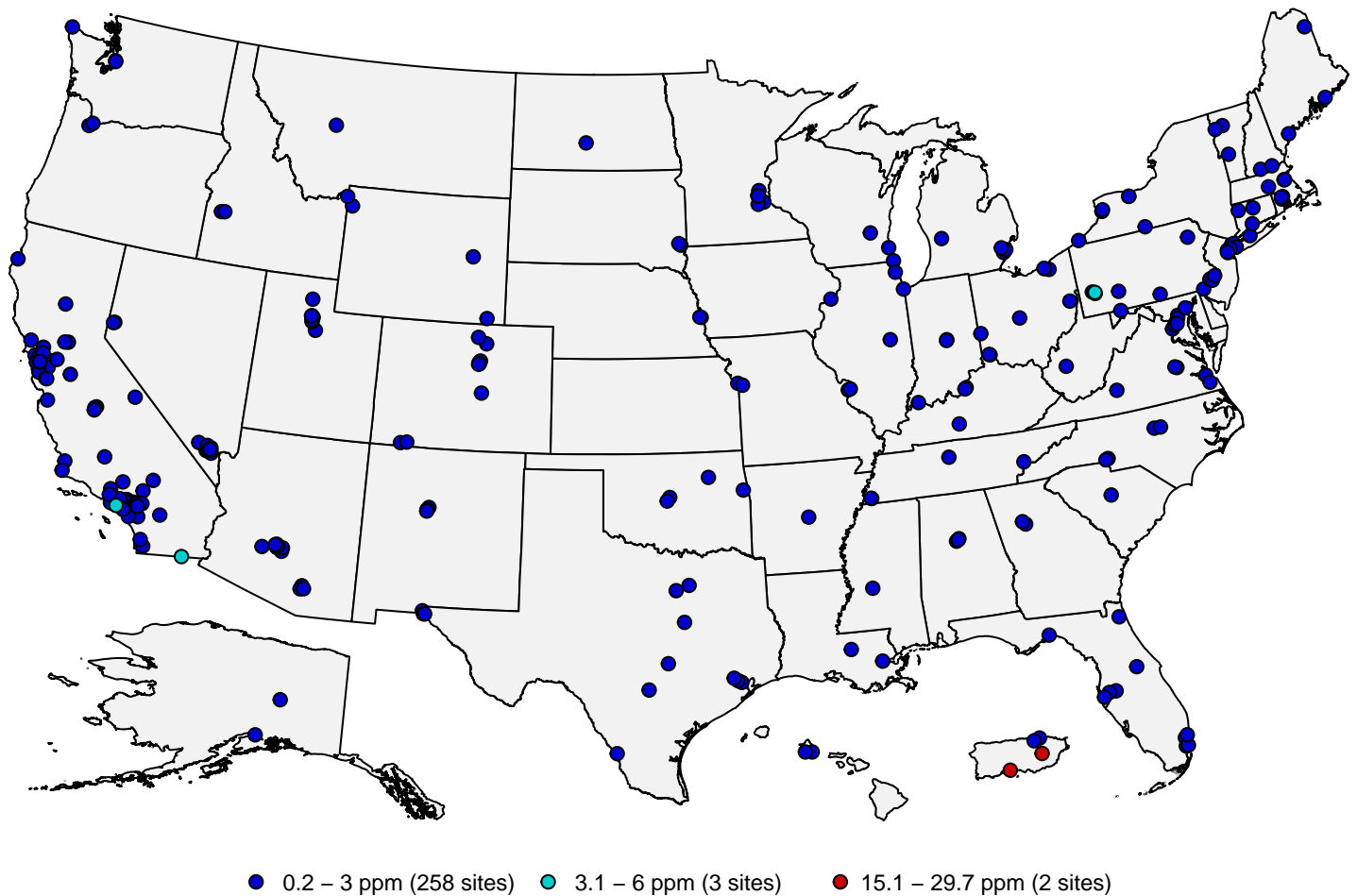
**Figure 5:** 8-hour CO design values in ppm for the 2021-2022 period. **Source:** AQS.
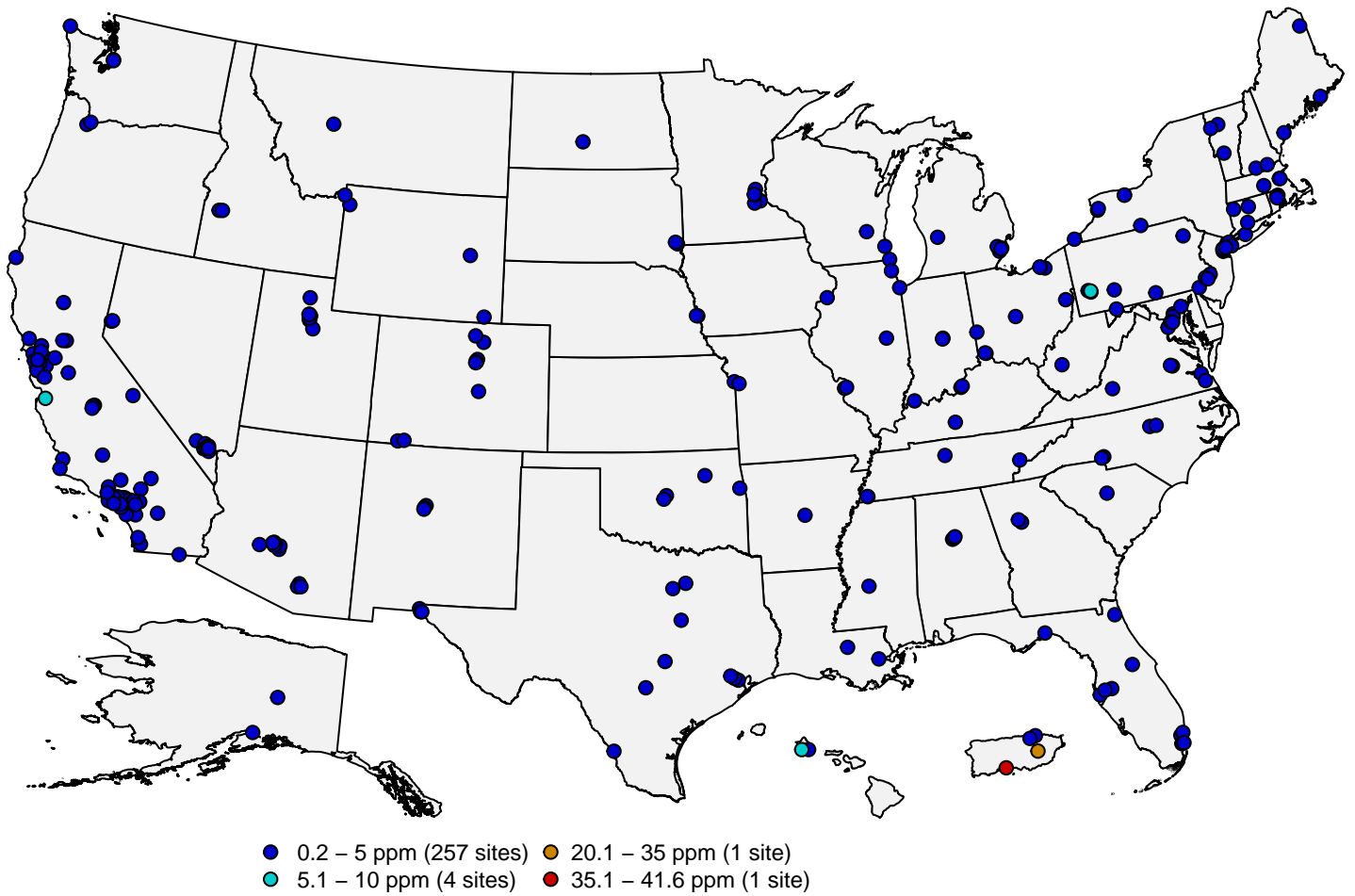
Figure 6: 1-hour CO design values in ppm for the 2021-2022 period. **Source:** AQS.

Figure 7 below shows a map of the site-level trends in the 8-hour CO design values and Figure 8 shows a map of the site-level trends in the 1-hour CO design values at U.S. monitoring sites having valid design values in at least 18 years from 2000 through 2022. The trends were computed using the Thiel-Sen estimator, and tests for significance (p-value < 0.05) were computed using the Mann-Kendall test. From these figures it is apparent that CO concentrations have been decreasing at nearly all sites in the U.S.


▼ Decreasing > 0.1 ppm/yr (61 sites)   ○ No Significant Trend (12 sites)
▽ Decreasing < 0.1 ppm/yr (74 sites)
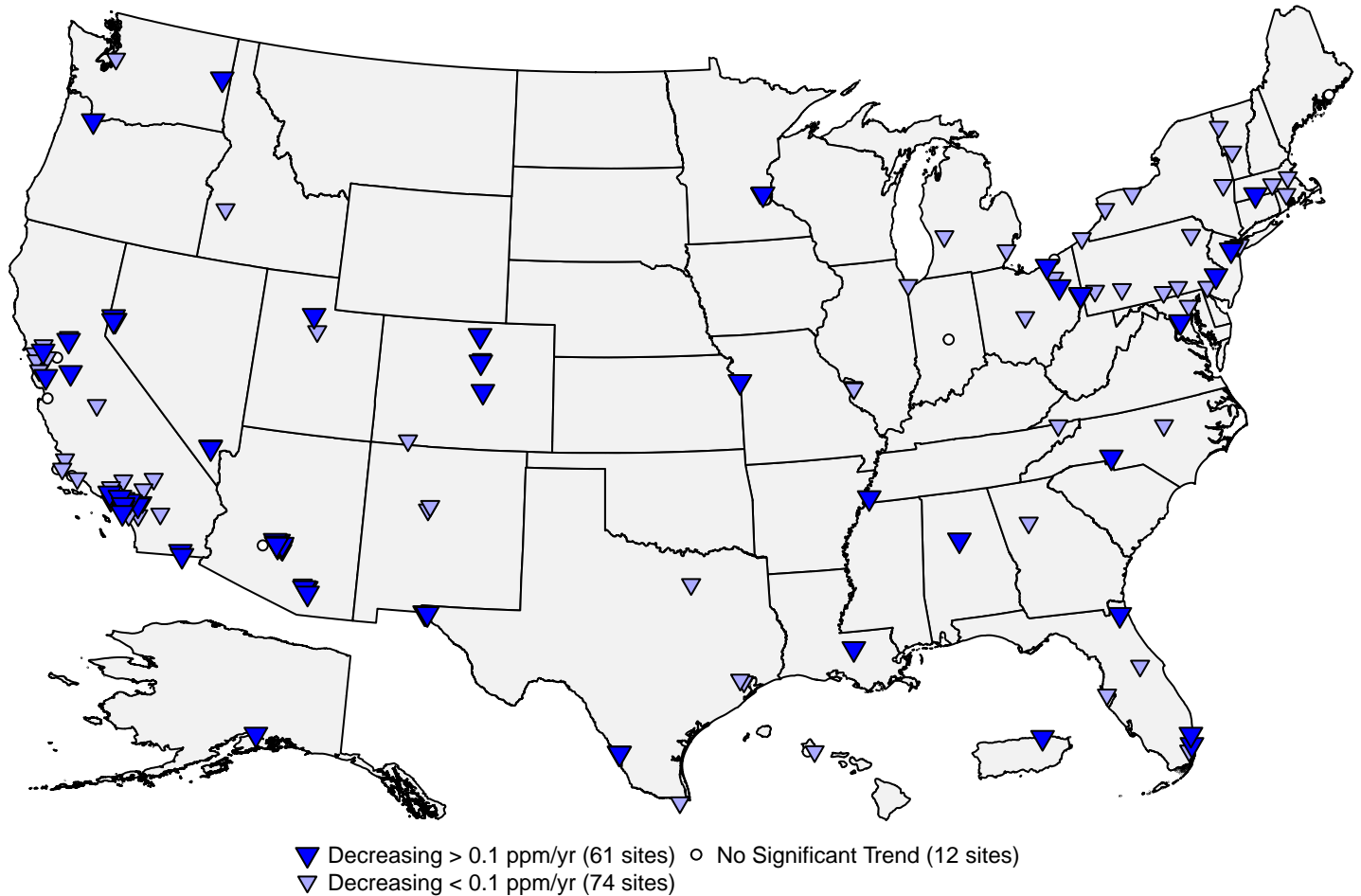
Figure 7: Site-level trends in 8-hour CO design values based on data from 2000 through 2022. **Source:** AQS, trends computed using R statistical software.
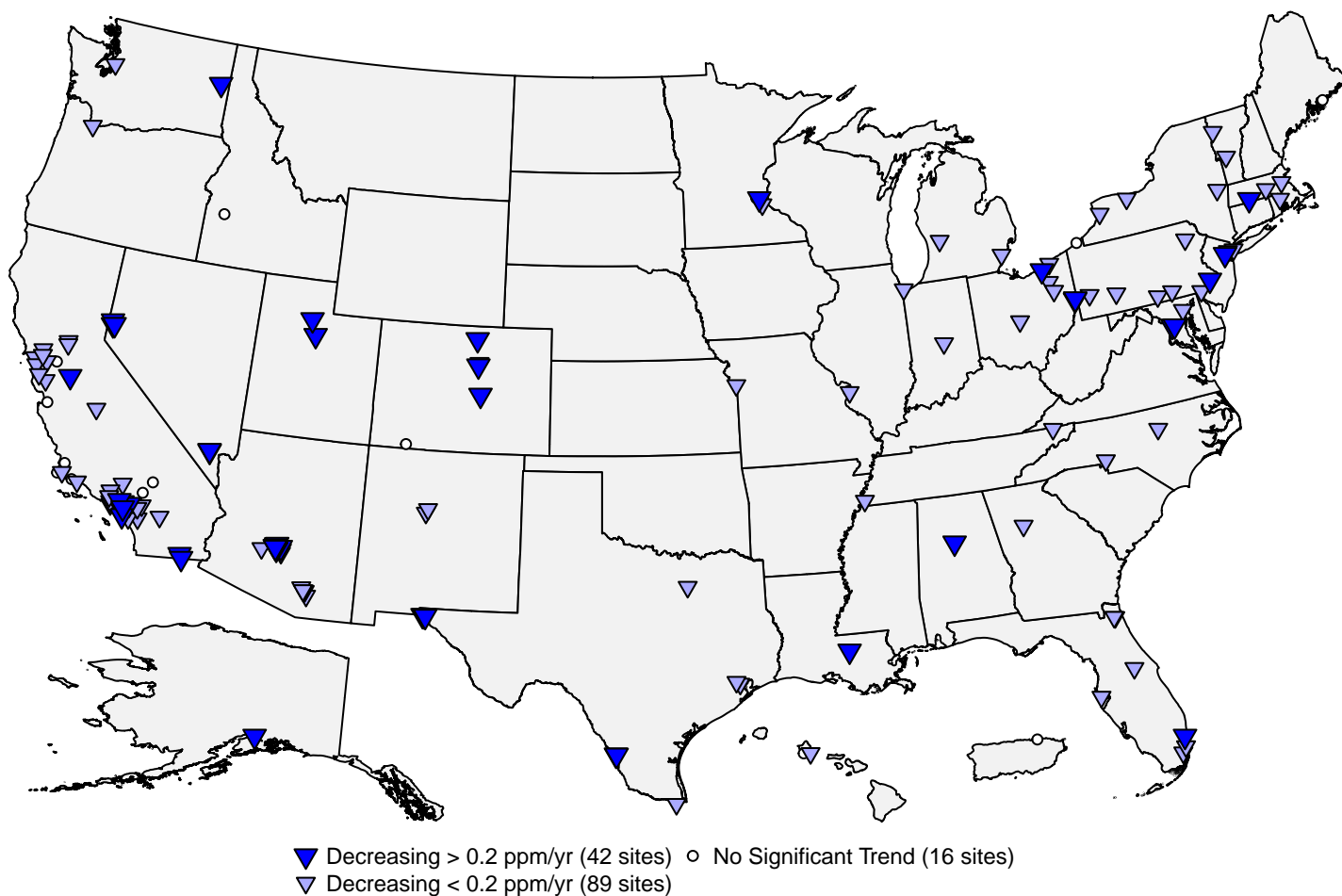
Figure 8: Site-level trends in 1-hour CO design values based on data from 2000 through 2022. **Source:** AQS, trends computed using R statistical software

Figure 9 below shows the national trends in the 8-hour and 1-hour CO design values based on the 147 sites shown in Figure 7 and Figure 8, respectively. The national median of the 8-hour design values has decreased by 70% from about 3.7 ppm in 2000 to about 1.1 ppm in 2022. The national median of the 1-hour design values has decreased by 72% from about 5.7 ppm in 2000 to about 2 ppm in 2022.
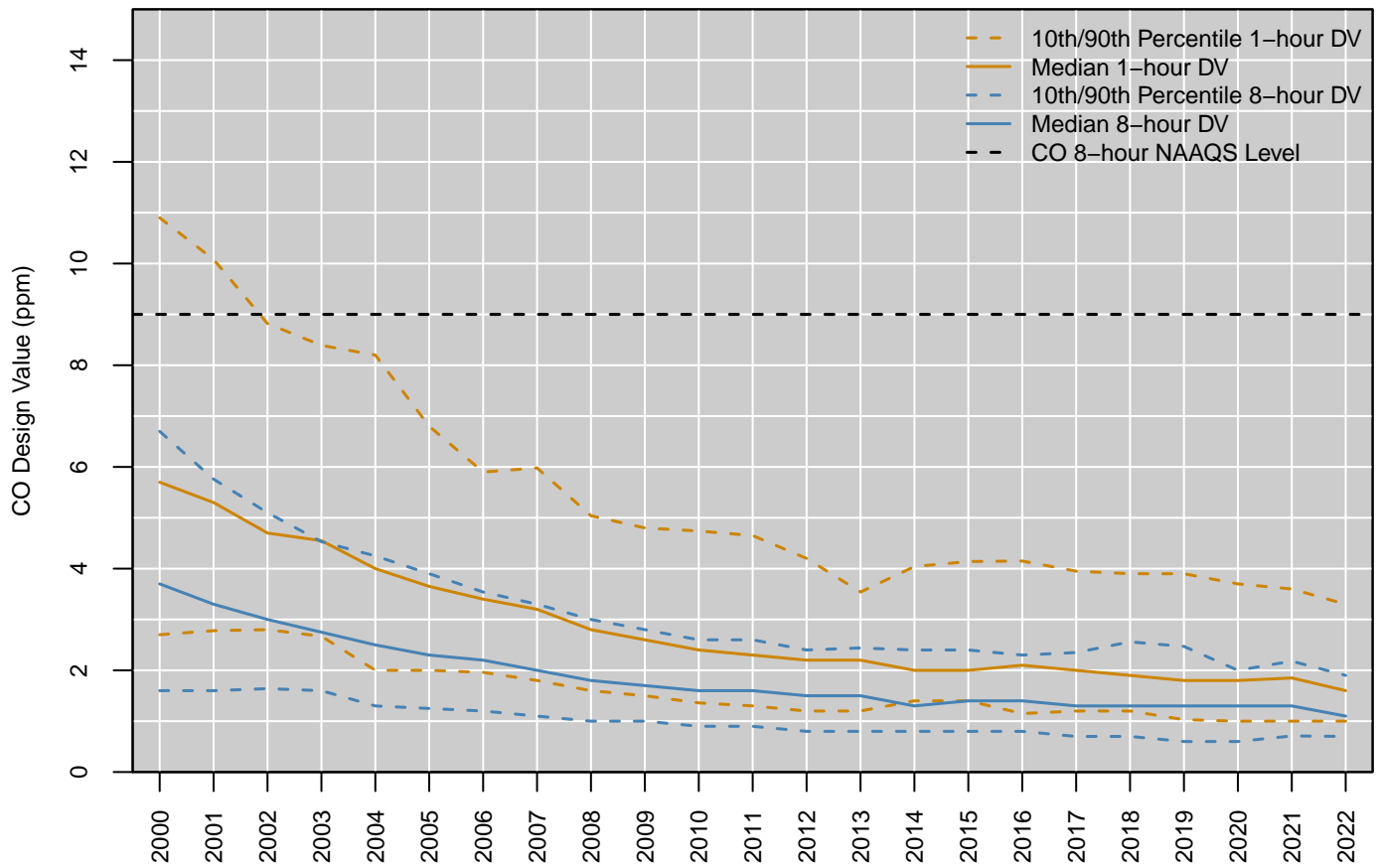

Figure 9: National trends in CO design values in ppm, 2000 to 2022. **Source:** AQS.

Figure 10 below shows the national distribution of the annual 2nd highest 8-hour CO concentrations reported in each year from 1980 to 2022, while Figure 11 shows the national distribution of the annual 2nd highest 1-hour CO concentrations reported to EPA during the same period.[5] The red line shows the number of sites included in the boxplot for each year. These figures show that CO concentrations have decreased steadily over the past 40 years as older cars were replaced with newer models with lower CO emissions, and power plants and other industrial sources transitioned to cleaner burning fuels. The median 8-hour concentration decreased by 87%, from 7.8 ppm in 1980 to 1 ppm in 2022. Similarly, the median 1-hour concentration decreased by 89%, from 13.9 ppm in 1980 to 1.5 ppm in 2022. Over the past decade, annual 2nd maximum 8-hour and 1-hour CO concentrations have been relatively constant at levels well below the NAAQS. The size of the CO monitoring network increased from 1980 through the mid-1990's, reaching a peak of nearly 500 sites in 1995. Since then, the CO monitoring network has gradually decreased in size to fewer than 250 sites, as most sites are now measuring very low concentrations and many States' air monitoring priorities have shifted to other pollutants. However, required CO monitoring as part of the NCore and near-road networks will ensure that long-term CO measurements continue to be collected.
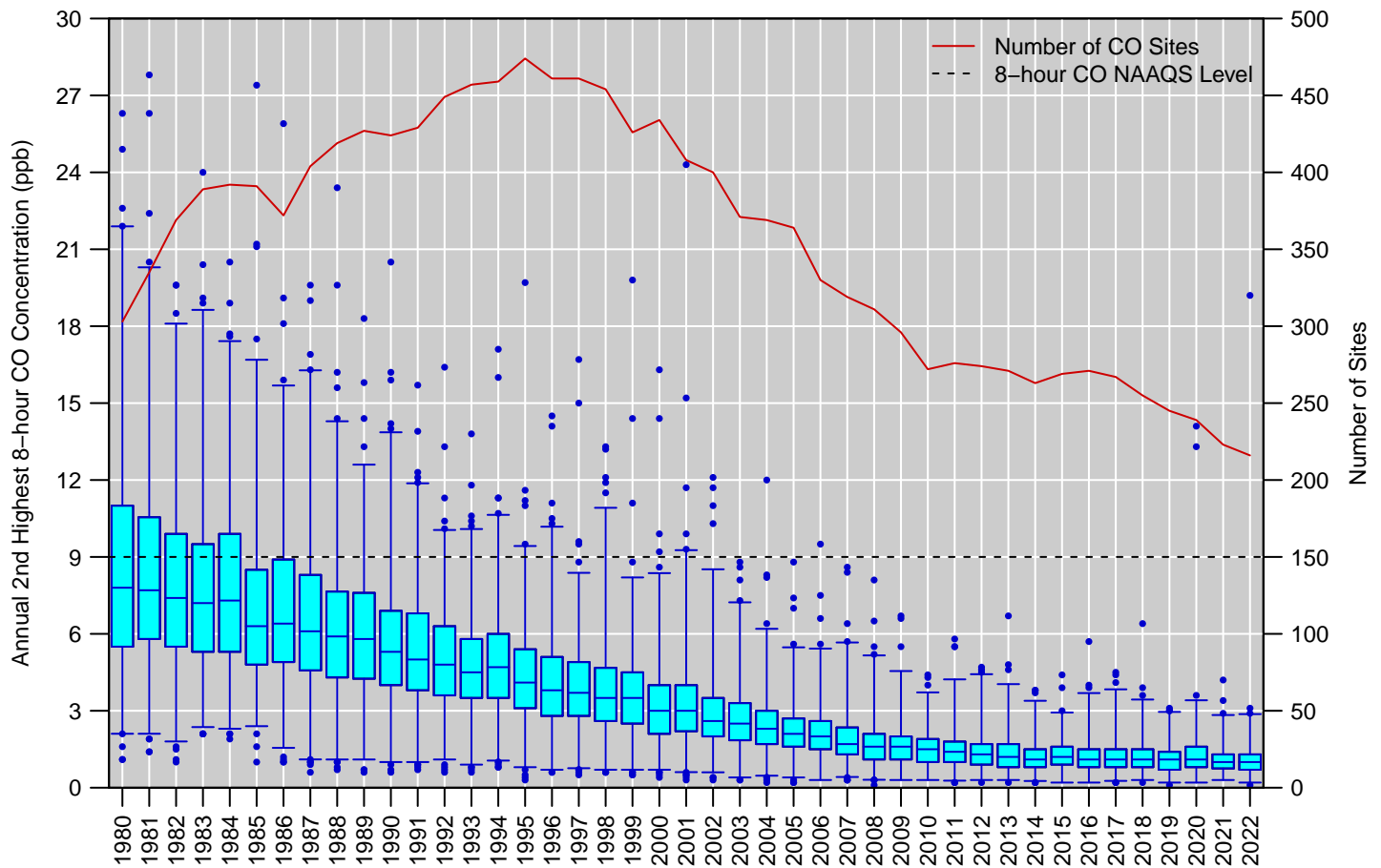
Figure 10: Distribution of annual 2nd highest 8-hour CO concentrations measured at U.S. monitoring sites, 1980 to 2022. Boxes represent the median and interquartile range, whiskers extend to the 1st and 99th percentiles, and values outside this range are shown as circles. The red line shows the number of CO monitoring sites reporting data to EPA in each year. **Source:** AQS.

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[5]For this analysis, the annual 2nd highest non-overlapping 8-hour and 1-hour CO concentrations were retrieved from AQS for all U.S. sites for years that had at least 75% annual data completeness.
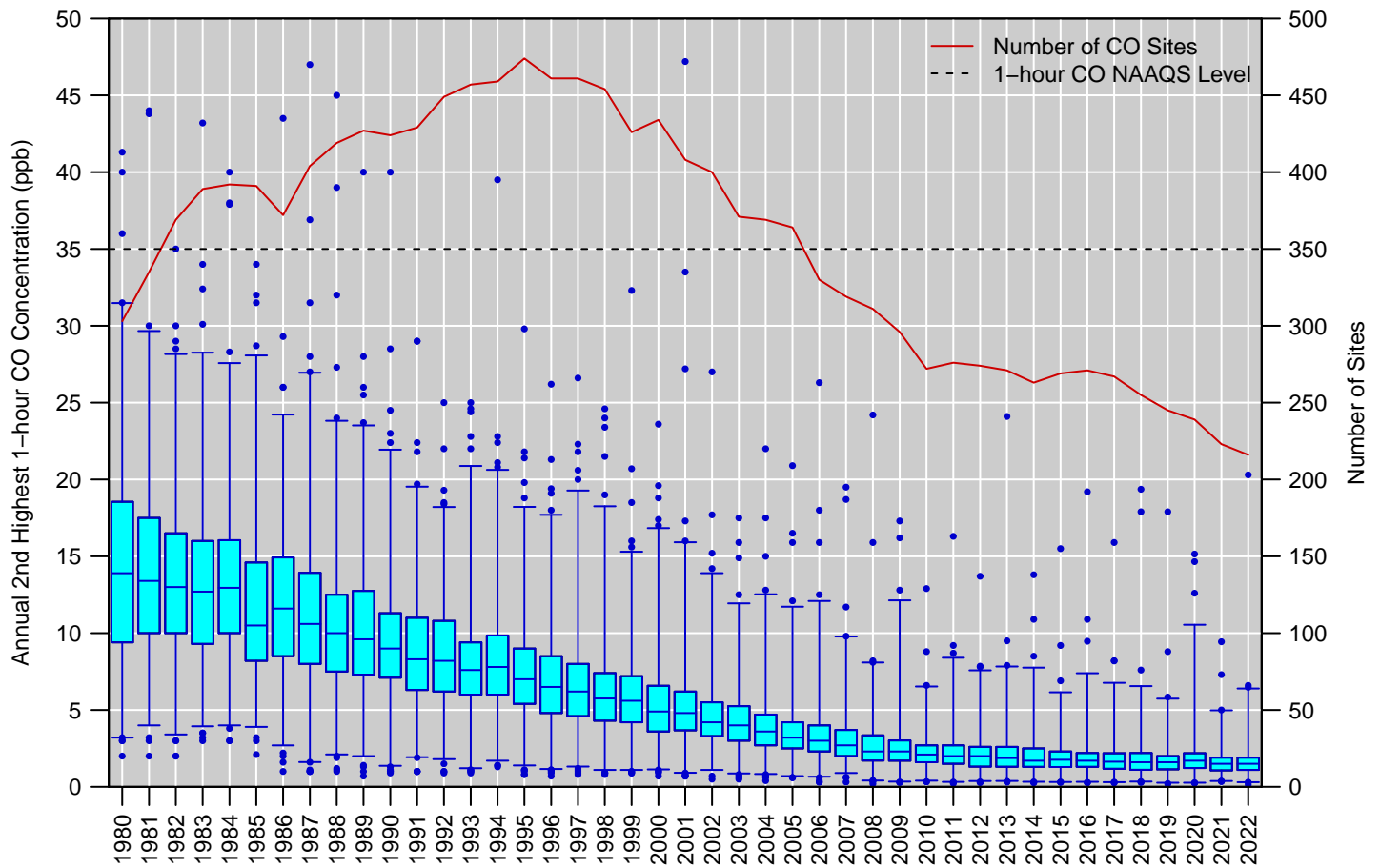
Figure 11: Distribution of annual 2nd highest 1-hour CO concentrations measured at U.S. monitoring sites, 1980 to 2022. Boxes represent the median and interquartile range, whiskers extend to the 1st and 99th percentiles, and values outside this range are shown as circles. The red line shows the number of CO monitoring sites reporting data to EPA in each year. **Source:** AQS.

References

U.S. EPA. Integrated Science Assessment for Carbon Monoxide (Final Report, January 2010). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/019F, 2010.

U.S. EPA. Policy Assessment for the Review of the Carbon Monoxide NAAQS (Final Report, October 2010). U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA 452/R-10-007, 2010.

Additional Resources

- Carbon Monoxide (CO) Pollution

- Carbon Monoxide (CO) Air Quality Standards

- National Emissions Inventory (NEI)

- Ambient Monitoring Technology Information Center (AMTIC)

- Air Quality Design Values

- National Air Quality: Status and Trends of Key Air Pollutants

- Air Data: Air Quality Data Collected at Outdoor Monitors Across the U.S.