

Criteria Pollutants — National Trends

<http://www.epa.gov/oar/aqtrnd98/chapter2.pdf>

This chapter presents national and regional trends for each of the pollutants for which the United States Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards (NAAQS). NAAQS are in place for the following six criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO₂), ozone (O₃), particulate matter (PM), and sulfur dioxide (SO₂). Table 2-1 lists the NAAQS for each pollutant in terms of the level and averaging time of the standard used to evaluate compliance.

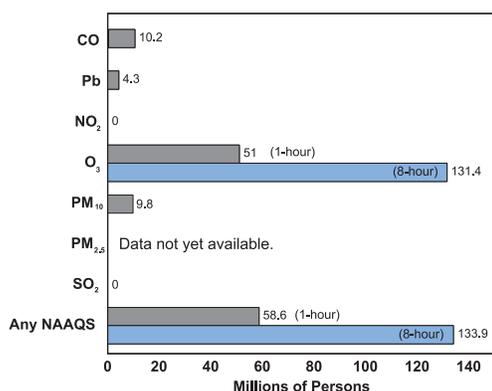
There are two types of standards: primary and secondary. Primary standards protect against adverse human health effects, whereas secondary standards protect against welfare effects such as damage to crops, ecosystems, vegetation, buildings, and decreased visibility. There are primary standards for all of the criteria pollutants, and some pollutants (PM and SO₂) have primary standards for both long-term (annual average) and short-term (24 hours or less) averaging times. Short-term standards most directly protect people from adverse health effects associated with peak short-term exposures to air pollution, while long-term standards can protect people from adverse health effects associated with short- and long-term exposures to air pollution. Second-

Table 2-1. NAAQS in effect as of December 1999.

Pollutant	Primary Standard (Health Related)		Secondary Standard (Welfare Related)	
	Type of Average	Standard Level Concentration ^c	Type of Average	Standard Level Concentration ^a
CO	8-hour ^b	9 ppm (10 µg/m ³)	No Secondary Standard	
	1-hour ^b	35 ppm (40 µg/m ³)	No Secondary Standard	
Pb	Maximum Quarterly Average	1.5 µg/m ³	Same as Primary Standard	
NO ₂	Annual Arithmetic Mean	0.053 ppm (100 µg/m ³)	Same as Primary Standard	
O ₃	Maximum Daily 1-hour Average ^c	0.12 ppm (235 µg/m ³)	Same as Primary Standard	
	4th Maximum Daily 8-hour Average ^d	0.08 ppm (157 µg/m ³)	Same as Primary Standard	
PM ₁₀	Annual Arithmetic Mean	50 µg/m ³	Same as Primary Standard	
PM _{2.5}	24-hour ^b	150 µg/m ³	Same as Primary Standard	
	Annual Arithmetic Mean ^e	15 µg/m ³	Same as Primary Standard	
SO ₂	24-hour ^f	65 µg/m ³	Same as Primary Standard	
	Annual Arithmetic Mean	0.03 ppm (80 µg/m ³)	3-hour ^b	0.50 ppm (1,300 µg/m ³)
	24-hour ^b	0.14 ppm (365 µg/m ³)		

^a Parenthetical value is an approximately equivalent concentration. (See 40 CFR Part 50).
^b Not to be exceeded more than once per year.
^c The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than one, as determined according to Appendix H of the Ozone NAAQS.
^d Three-year average of the annual 4th highest daily maximum 8-hour average concentration.
^e Spatially averaged over designated monitors.
^f The form is the 98th percentile.

ary standards have been established for each criteria pollutant except CO. Secondary standards are identical to the primary standards, with the exception of SO₂. Approximately 134 million people in the United States reside in counties that did not meet the primary standard for at least one of the criteria pollutants for the single year 1998.



Number of people living in counties with air quality concentrations above the level of NAAQS in 1998.

On July 18, 1997, EPA revised the ozone and PM NAAQS. The averaging time of the ozone standard changed from a 1-hour average to an 8-hour average to protect against longer exposure periods that are of concern for both human health and welfare. The primary PM standards were revised to change the form of the PM₁₀ standards and to add two new PM_{2.5} standards to protect against fine particles.

In May 1999, however, the U.S. Court of Appeals for the D.C. Circuit issued an opinion affecting these revised standards. In particular, the court remanded the ozone standard back to EPA for further consideration. The court also vacated the revised PM₁₀ standard and remanded the PM_{2.5} standards back to EPA for further consideration. Following the

denial of a petition for a rehearing by the D.C. Circuit, the Justice Department has filed a petition for review before the Supreme Court. Refer to <http://www.epa.gov/airlinks> for up-to-date information concerning actions surrounding the revised standards.

The trends information presented in this chapter is based on two types of data: ambient concentrations and emissions estimates. Ambient concentrations are measurements of pollutant concentrations in the ambient air from monitoring sites across the country. This year's report contains trends data accumulated from 1989 to 1998 on the criteria pollutants at thousands of monitoring stations located throughout the United States. The trends presented here are derived from the composite average of these direct measurements. The averaging times and air quality statistics used in the trends calculations relate directly to the NAAQS.

The second type of data presented in this chapter are national emissions estimates. These are based largely on engineering calculations of the amounts and kinds of pollutants emitted by automobiles, factories, and other sources over a given period. In addition, some emissions estimates are based on measurements from continuous emissions monitors (CEMs) that have recently been installed at major electric utilities to measure actual emissions. This report incorporates data from CEMs collected between 1994 and 1998 for NO_x and SO₂ emissions at major electric utilities. The emissions data summarized in this chapter and in Appendix A were obtained from the *National Air Pollutant Emission Trends Report, 1900–1998*, which can be

found at <http://www.epa.gov/ttn/chief/trends98/emtrnd.html>.

Changes in ambient concentrations do not always track changes in emissions estimates. There are four known reasons for this. First, because most monitors are positioned in urban, population-oriented locales, air quality trends are more likely to track changes in urban emissions rather than changes in total national emissions. Urban emissions are generally dominated by mobile sources, while total emissions in rural areas may be dominated by large stationary sources such as power plants and smelters.

Second, emissions for some pollutants are calculated or measured in a different form than the primary air pollutant. For example, concentrations of ozone are caused by VOC emissions as well as NO_x emissions.

Third, the amount of some pollutants measured at monitoring locations depends on what chemical reactions, if any, occur in the atmosphere during the time it takes the pollutant to travel from its source to the monitoring station.

Finally, meteorological conditions often control the formation and buildup of pollutants in the ambient air. For example, peak ozone concentrations typically occur during hot, dry, stagnant summertime conditions; CO is predominately a cold weather problem; also, the amount of rainfall can affect particulate matter levels and the frequency of forest fires.

For a more detailed discussion of the methodology used to compute the trend statistics in this chapter, please refer to Appendix B.

Carbon Monoxide

Air Quality Concentrations		
1989–98	39%	decrease
1997–98	3%	decrease
Emissions		
1989–98	16%	decrease
1997–98	5%	decrease

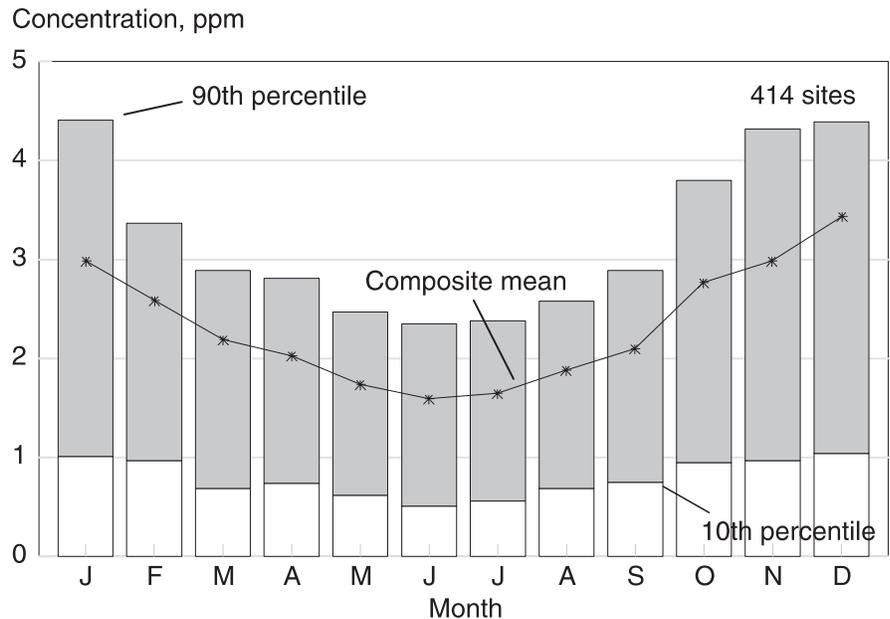
Nature and Sources

CO is a colorless, odorless, (and at much higher levels) poisonous gas, formed when carbon in fuels is not burned completely. It is a product of motor vehicle exhaust, which contributes about 60 percent of all CO emissions nationwide. High concentrations of CO generally occur in areas with heavy traffic congestion. In cities, as much as 95 percent of all CO emissions may emanate from automobile exhaust. Other sources of CO emissions include industrial processes, non-transportation fuel combustion, and natural sources such as wildfires. Woodstoves, cooking, cigarette smoke, and space heating are sources of CO in indoor environments. Peak CO concentrations typically occur during the colder months of the year when CO automotive emissions are greater and nighttime inversion conditions are more frequent. Figure 2-1 shows this seasonal pattern in average daily maximum 1-hour CO concentrations at 414 sites reporting complete data in 1998.

Health Effects

Carbon monoxide enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. The health threat from lower levels of CO is most serious for those who suffer from cardiovascular disease, such as angina

Figure 2-1. Average daily maximum 1-hour CO concentrations by month, 1998.



pectoris. At much higher levels of exposure, CO can be poisonous, and healthy individuals may also be affected. Visual impairment, reduced work capacity, reduced manual dexterity, poor learning ability, and difficulty in performing complex tasks are all associated with exposure to elevated CO levels.

Primary Standards

There are two primary NAAQS for ambient CO—a 1-hour average of 35 ppm, and an 8-hour average of 9 ppm. These concentrations are not to be exceeded more than once per year. There currently are no secondary standards for CO.

National 10-Year Trends

The 10-year trend in ambient CO concentrations is shown in Figure 2-2. Nationally, CO concentrations decreased 39 percent during the past 10 years as measured by the composite average of the annual second highest 8-hour concentration (referred to as

the second maximum non-overlapping 8-hour concentration). Year-to-year reductions in peak 8-hour CO concentrations have continued since the upturn in 1994. Between 1997 and 1998, CO concentrations decreased 3 percent on average and are the lowest level recorded during the past 10 years. Exceedances of the 8-hour CO NAAQS (which are simply a count of the number of times the level of the standard is exceeded) have declined 98 percent since 1989.

Long-term reductions in ambient CO concentrations have been measured across all monitoring environments—rural, suburban, and urban sites. Figure 2-3 shows that on average, urban monitoring sites record higher CO concentrations than suburban sites, with the lowest levels found at 12 rural CO sites. During the past 10 years, the composite mean CO 8-hour concentration decreased 36 percent at 12 rural monitoring sites, 37 percent at 148 suburban sites, and 41 percent at 200 urban sites.

Emissions Trends

Figure 2-4 shows that national total CO emissions have decreased 16 percent since 1989. Emissions from all transportation sources have decreased 16 percent during the past 10 years. Despite a 23-percent increase in vehicle miles traveled (VMT), emissions from on-road vehicles decreased 24 percent during the past 10 years as a result of automotive emissions control programs. Total CO emissions decreased 5 percent since 1997, while CO emissions from on-road vehicles recorded a 2-percent decline. Figure 2-5 shows that the transportation category, composed of on-road and off-road sources, accounts for 79 percent of the nation's total CO emissions in 1998.

Table 2-2 lists some of the major milestones in the control of emissions from automobiles starting with the Clean Air Act (CAA) of 1970. At the national level, these measures, which have led to reductions in emissions of CO as well as other pollutants, include establishing national standards for tailpipe emissions, new vehicle technologies, and clean fuels programs. State and local emissions reduction measures include inspection and maintenance (I/M) programs and transportation management programs.

Figure 2-2. Trend in 2nd maximum non-overlapping 8-hour average CO concentrations, 1989–1998.

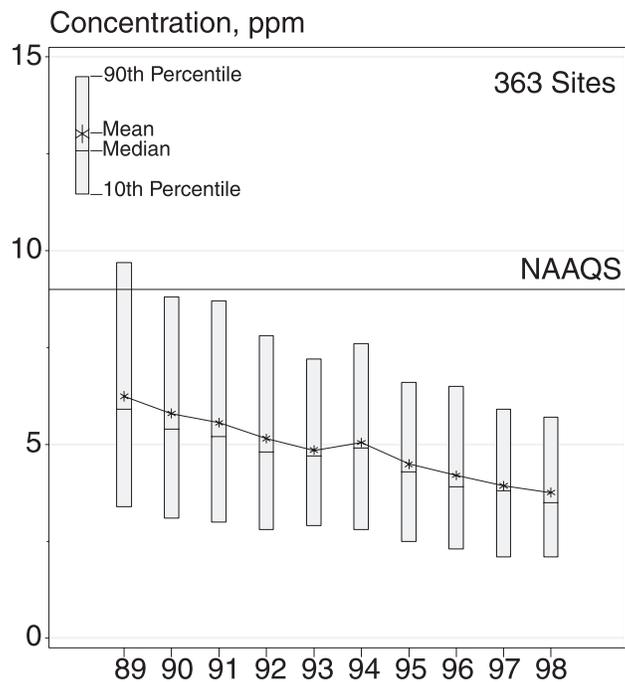


Figure 2-3. Trend in 2nd maximum non-overlapping 8-hour average CO concentrations by type of location, 1989–1998.

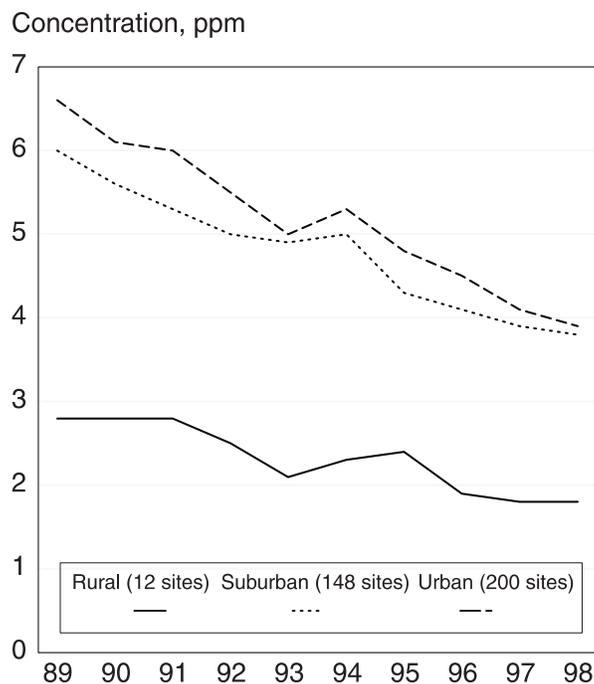


Figure 2-4. Trend in national total CO emissions, 1989–1998.

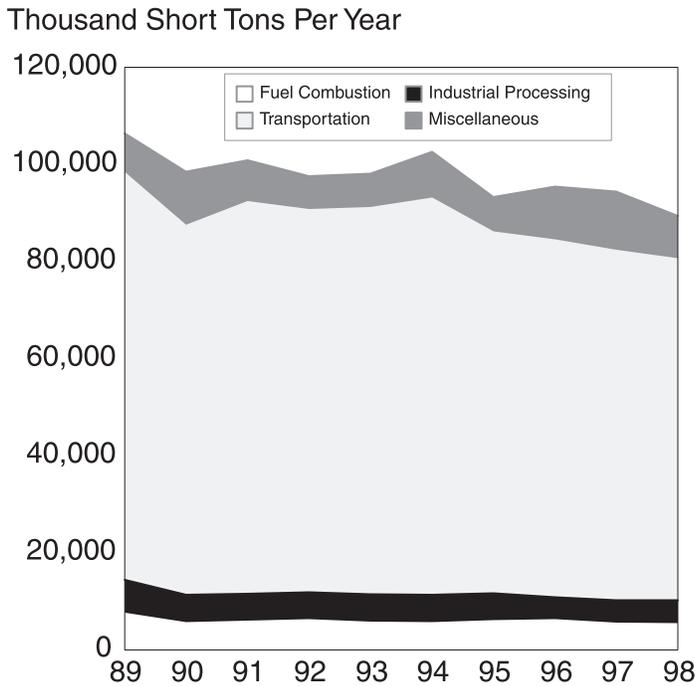


Figure 2-5. CO emissions by source category, 1998.

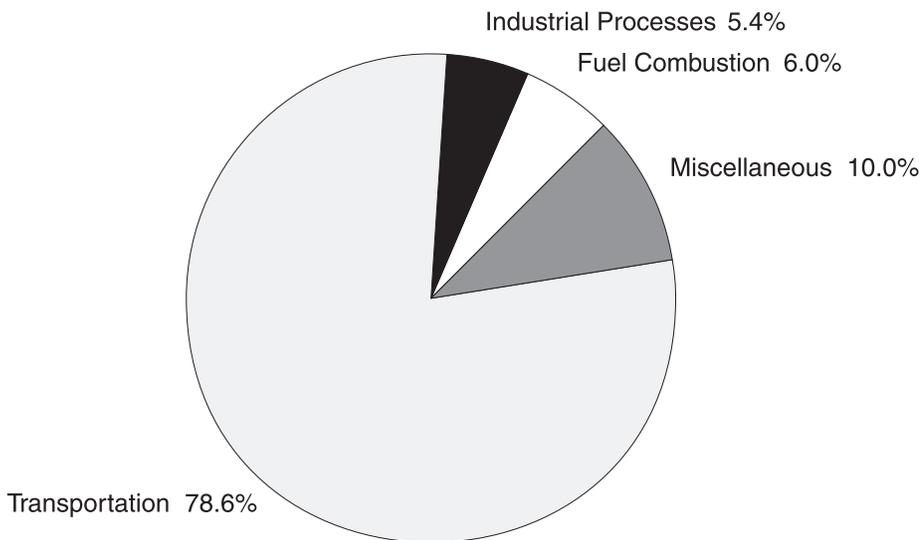


Table 2-2. Milestones in Motor Vehicle Emissions Control

1970	New Clean Air Act sets auto emissions standards.
1971	Charcoal canisters appear to meet evaporative standards.
1972	EGR valves appear to meet NO _x standards.
1974	Fuel economy standards are set.
1975	The first catalytic converters appear for hydrocarbon, CO. Unleaded gas appears for use in catalyst equipped cars.
1981	3-way catalysts with on-board computers and O ₂ sensors appear.
1983	I/M programs are established in 64 cities.
1989	Fuel volatility limits are set for RVP.
1990	CAAA set new tailpipe standards.
1992	Oxy-fuel introduced in cities with high CO levels.
1993	Limits set on sulfur content of diesel fuel.
1994	Phase-in begins of new vehicle standards and technologies.
1995	On-board diagnostic systems in 1996 model year cars.
1998	Sales of 1999 model year California emissions equipped vehicles begin in the Northeast.

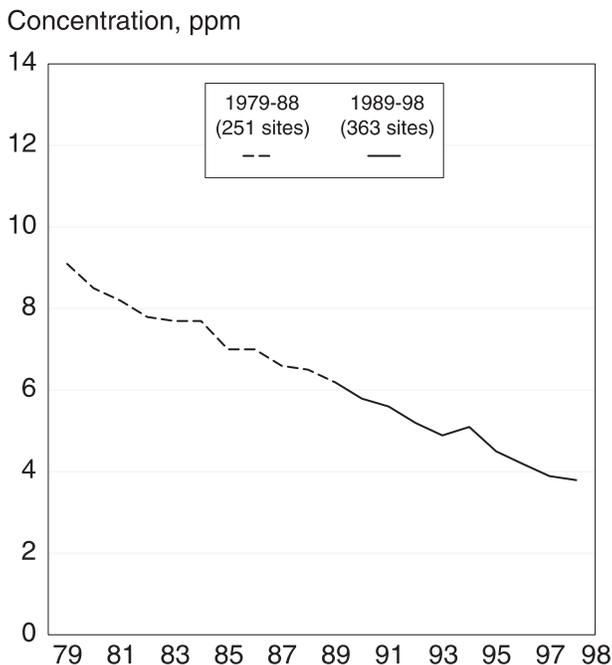
In the area of clean fuels, the 1990 Clean Air Act Amendments (CAAA) require oxygenated gasoline programs in several regions of the country during the winter months. Under the program regulations, a minimum oxygen content (2.7 percent by weight) is required in gasoline to ensure more complete fuel combustion.^{1,2} Of the 36 CO nonattainment areas that initially implemented the program in 1992, 25 areas participated in the program during January and February 1998, while 17 areas continued to use oxygenated fuels during November and December 1998. An analysis of the oxygenated

fuels program in several cities with winter oxygenated gasoline programs showed reductions in ambient CO concentrations of about 10 percent.³ Other studies estimated that the oxy-fuel effect was an average total reduction in ambient CO concentrations of 7 to 14 percent overall for the eight winter seasons from 1986 through 1994.^{4,5}

Blue Ribbon Panel on Oxygenates in Gasoline

In November 1998, in response to the public concern regarding the detection of MTBE (methyl tertiary butyl ether—one of two fuel oxygenates used in reformulated gasoline to help improve air quality) in water, EPA Administrator Carol M. Browner announced the creation of a blue ribbon panel of leading experts from the public health and scientific communities, automotive fuels industry, water utilities, and local and state governments to review the important issues posed by the use of MTBE and other oxygenates in gasoline. The Panel's final report stated that "the Wintertime Oxyfuel Program continues to provide a means for some areas of the country to come into, or maintain, compliance with the carbon monoxide standard. Only a few metropolitan areas continue to use MTBE in this program. In most areas today, ethanol can, and is, meeting these wintertime needs for oxygen without raising fuel volatility concerns given the season of the year. The Panel recommends that the Wintertime Oxyfuel program be continued (a) for as long as it provides a useful compliance and/or maintenance tool for the affected states and metropolitan areas, and (b) assuming that the clarification of state and federal authority described above is enacted to enable

Figure 2-6. Long-term trend in 2nd maximum non-overlapping 8-hour average CO concentrations, 1979–1998.



states, where necessary, to regulate and/or eliminate the use of gasoline additives that threaten drinking water supplies.”⁶ The Panel’s Executive Summary and final report entitled *Achieving Clean Air and Clean Water: The Report of the Blue Ribbon Panel on Oxygenates in Gasoline* can be found on the Panel’s homepage at: <http://www.epa.gov/oms/consumer/fuels/oxypanel/blueribb.htm>.

National 20-Year Trends

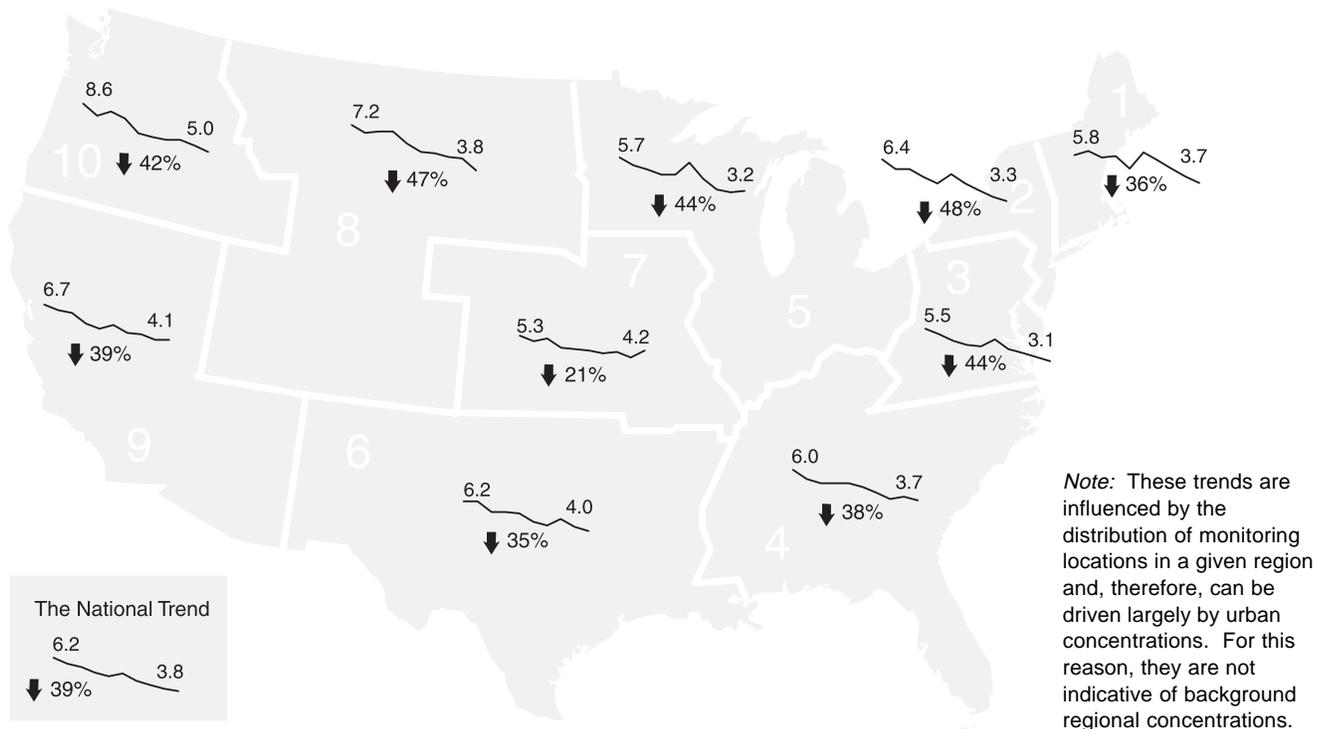
Because of the annual loss and replacement of ambient monitoring sites (e.g., redevelopment, new leases, etc.), too few sites are able to meet a 20-year trends data completeness criteria. Thus, long-term trends are assessed by piecing together two separate 10-year trends databases. Although there are differences in the mix of trend sites for the two periods (251 vs. 363 sites), Figure 2-6 shows a

consistent decline in CO concentrations during the past 20 years. Nationally, the 1998 composite average ambient concentration is 58 percent lower than 1979, and is the lowest level recorded during the past 20 years of monitoring.

Regional Trends

The map in Figure 2-7 shows the regional trends in ambient CO concentrations during the past 10 years, 1989–1998. All 10 EPA Regions recorded 10-year declines in CO levels as measured by the regional composite mean concentrations. The largest 10-year concentration reductions are in the Northcentral, Rocky Mountain and Northwest states. Smaller reductions can be seen in the New England, West, South and Midwest regions. Two regions (Region 5 and Region 7) saw increases in the composite mean CO concentration be-

Figure 2-7. Trend in CO 2nd maximum non-overlapping 8-hour concentrations by EPA Region, 1989–1998.



Alaska is in EPA Region 10; Hawaii, EPA Region 9; and Puerto Rico, EPA Region 2. Concentrations are ppm.

tween 1997 and 1998 (increases of 3 percent and 14 percent, respectively).

1998 Air Quality Status

The map in Figure 2-8 shows the variations in CO concentrations across the country in 1998. The air quality indicator is the largest annual second maximum 8-hour CO concentration measured at any site in each county. The bar chart to the left of the map displays the number of people living in counties within each concentration range. The colors on the map and bar chart correspond to the colors of the concentration ranges displayed in the map legend. Only seven of the 526 monitoring sites reporting ambient CO data to the Aerometric Information Retrieval

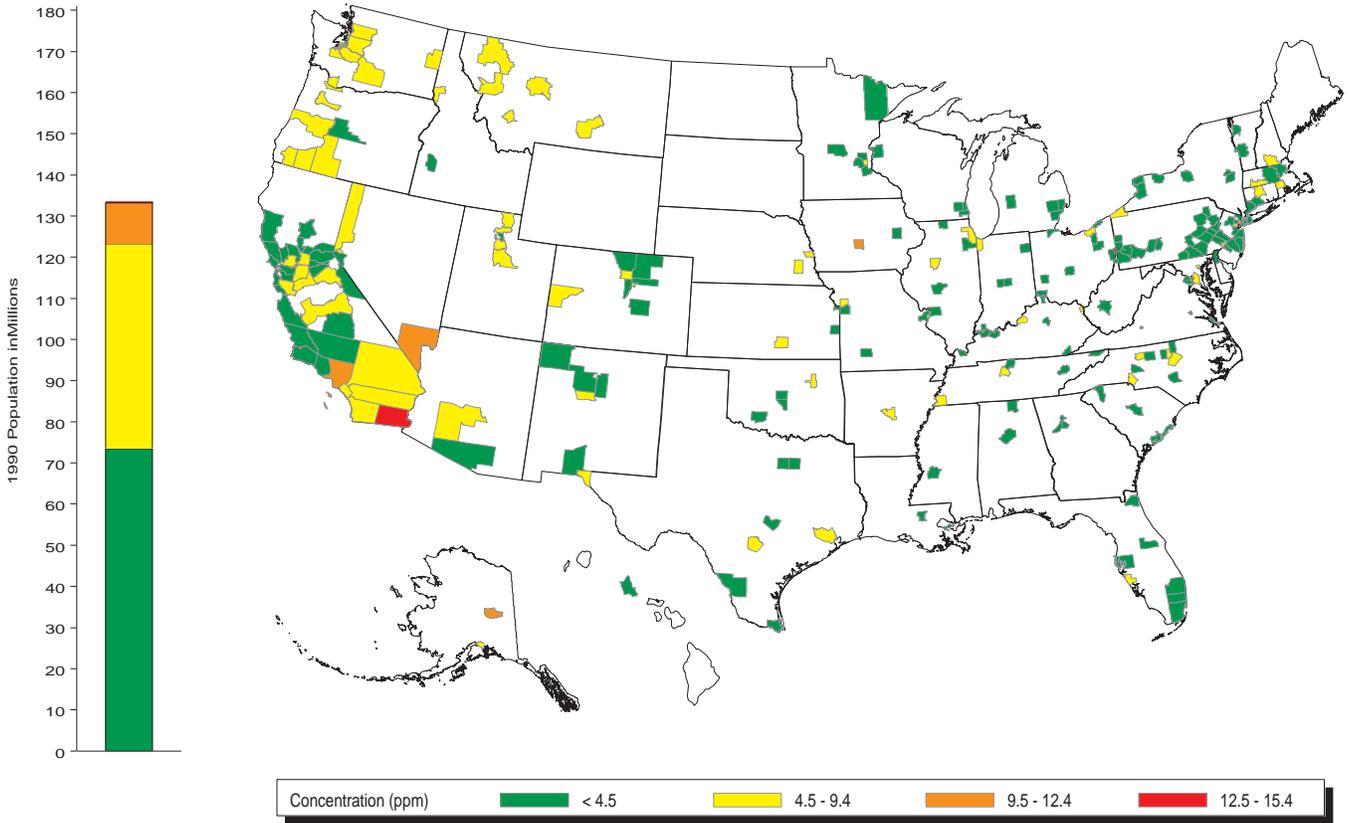
System (AIRS) failed to meet the CO NAAQS in 1998. These seven sites were located in six counties—Los Angeles County, CA; Fairbanks Borough, AK; Clarke County, NV (Las Vegas, NV); Polk County, IA (Des Moines, IA); Hancock County, WV (Weirton, WV); and Imperial County, CA (Calexico, CA). The two sites in this latter area are located just north of the border crossing with Mexicali, Mexico. There are 10 million people living in these six counties, compared to the 1997 count of three counties with a total population of 9 million people.

Data Sources

The CO ambient trends plotting points and emissions totals, by

source category, are listed in Tables A-1 and A-2. The plotting points for the 20-year trend charts are listed in Table A-9. The 1998 county maximum second-highest non-overlapping 8-hour CO concentrations are listed in Table A-11.

Figure 2-8. Highest 2nd maximum non-overlapping 8-hour average CO concentration by county, 1998.



Lead

Air Quality Concentrations		
1989–98	56%	decrease
1997–98		no change
Emissions		
1989–98	27%	decrease
1997–98	1%	increase

Nature and Sources

Twenty years ago, automotive sources were the major contributor of lead emissions to the atmosphere. As a result of EPA's regulatory efforts to reduce the content of lead in gasoline, the contribution from the transportation sector has declined. Today, metals processing is the major source of lead emissions to the atmosphere. The highest ambient air concentrations of lead are found in the vicinity of ferrous and nonferrous smelters, battery manufacturers, and other stationary sources of lead emissions.

Health and Environmental Effects

Exposure to lead occurs mainly through inhalation and through ingestion of lead in food, water, soil, or dust. It accumulates in the blood, bones, and soft tissues. Lead can also adversely affect the kidneys, liver, nervous system, and other organs. Excessive exposure to lead may cause neurological impairments such as seizures, mental retardation, and/or behavioral disorders. Even at low doses, lead exposure is associated with changes in fundamental enzymatic, energy transfer, and homeostatic mechanisms in the body. At low doses, fetuses and children may suffer from central nervous system damage. Recent studies show that lead may be a factor in high blood

pressure and subsequent heart disease. Recent studies also indicate that neurobehavioral changes may result from lead exposure during the child's first years of life.

Airborne lead can also have adverse impacts on the environment. Wild and domestic grazing animals may ingest lead that has deposited on plant or soil surfaces or that has been absorbed by plants through leaves or roots. Animals, however, do not appear to be more susceptible or more sensitive to adverse effects from lead than humans. For this reason, the secondary standard for lead is identical to the primary standard.

At relatively low concentrations (2–10 $\mu\text{g}/\text{m}^3$), lead can inhibit plant growth and result in a shift to more tolerant plant species growing near roadsides and stationary source emissions. In spite of the fact that the majority of soil lead becomes bound so that it is insoluble, immobile, and biologically unavailable, elevated soil lead concentrations have been observed to cause shifts in the microbial community (fungi and bacteria), reduced numbers of invertebrates, reduced decomposition and nitrification rates, and altered other soil parameters. Because lead remains in the soil, soil concentrations continue to build over time, even when deposition rates are low. Thus, another concern is that acid precipitation may be increasing the mobility and bioavailability of soil lead in some places.

Lead enters water systems mainly through urban runoff and sewage and industrial effluents. Most of this lead is readily complexed and bound in the sediment. However, water lead concentrations can reach levels that are associated with increased mortality and impaired reproduction

in aquatic invertebrates and blood and neurological changes in fish. Given the above effects, there continue to be implications for the long-term impact of lead on ecosystem function and stability. (See also the Toxics chapter and the *December 1990 OAQPS Staff Paper* (EPA-450/2-89-022)).

Primary and Secondary Standards

The primary and secondary NAAQS for lead is a quarterly average concentration not to exceed 1.5 $\mu\text{g}/\text{m}^3$.

National 10-Year Trends

The statistic used to track ambient lead air quality is the maximum quarterly mean concentration of each year. A total of 189 ambient lead monitors met the trends data completeness criteria for the 10-year period 1989–1998. Point-source oriented monitoring data were excluded from all ambient trends analyses presented in this section to avoid masking the underlying urban trends. Figure 2-9 indicates that between 1989 and 1998, maximum quarterly average lead concentrations decreased 56 percent at population-oriented monitors. Between 1997 and 1998, national average lead concentrations (approaching the minimum detectable level) remained unchanged. Figure 2-10 looks at urban, rural, and suburban 10-year trends separately. The figure shows that background levels of lead are similar in the three demographic regions.

Emissions Trends

Figure 2-11 shows that total lead emissions decreased 27 percent between 1989 and 1998. The large ambient and emissions reductions are a waning result of the phase-out of

leaded gasoline. Table A-3, which lists lead emissions by major source category, shows that on-road vehicles accounted for 64 percent of the 10-year emissions decline. Between 1997 and 1998, lead emissions estimates did not change substantially. Figure 2-12 shows that industrial processes were the major source of lead emissions in 1998, accounting for 74 percent of the total. The transportation sector (on-road and non-road sources) now accounts for only 13 percent of total 1998 lead emissions, with most of that coming from aircraft.

National 20-Year Trends

The effect of the conversion to unleaded gasoline usage on ambient lead concentrations is most impressive when viewed over a longer period, such as illustrated in Figure 2-13. Between 1979 and 1998, ambient concentrations of lead declined 96 percent. This large decline tracks well with overall lead emissions, which declined 98 percent between 1979 and 1998.

Regional Trends

Figure 2-14 segregates the ambient trend analysis by EPA Region. Although most regions showed large concentration reductions between 1989 and 1998, there were some intermittent upturns. Many of the “bumps” in the graphs can be attributed to the inherent variability associated with data reported near the minimum detectable level.

1998 Air Quality Status

The large reductions in long-term lead emissions from transportation sources have changed the nature of the ambient lead problem in the United States. Because industrial pro-

Figure 2-9. Trend in maximum quarterly average Pb concentrations (excluding source-oriented sites), 1989–1998.

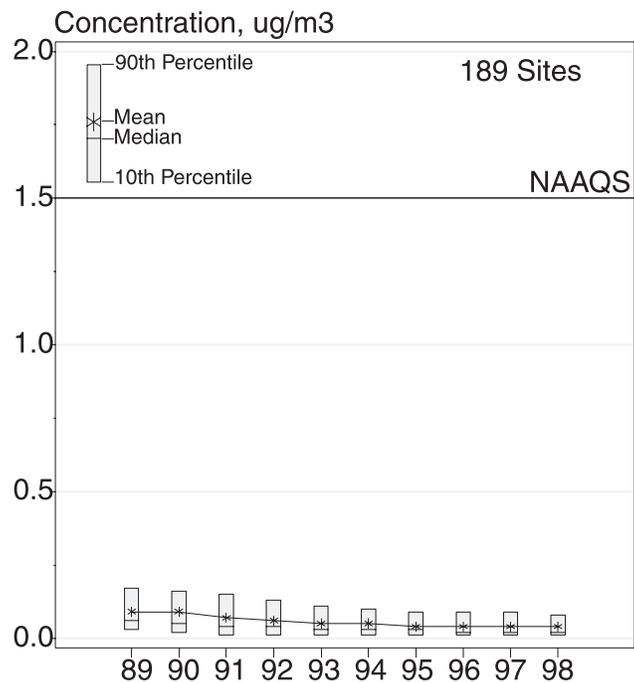


Figure 2-10. Pb maximum quarterly mean concentration trends by location (excluding point-source-oriented sites), 1989–1998.

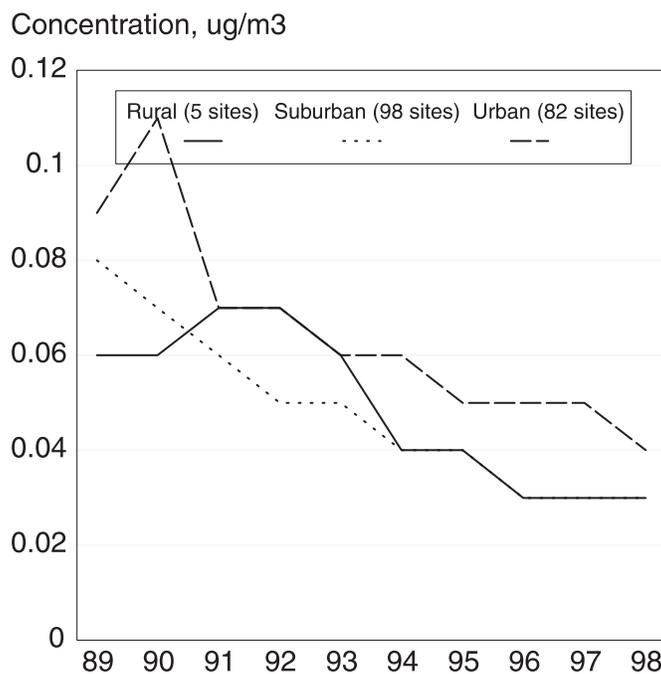


Figure 2-11. National total Pb emissions trend, 1989–1998.

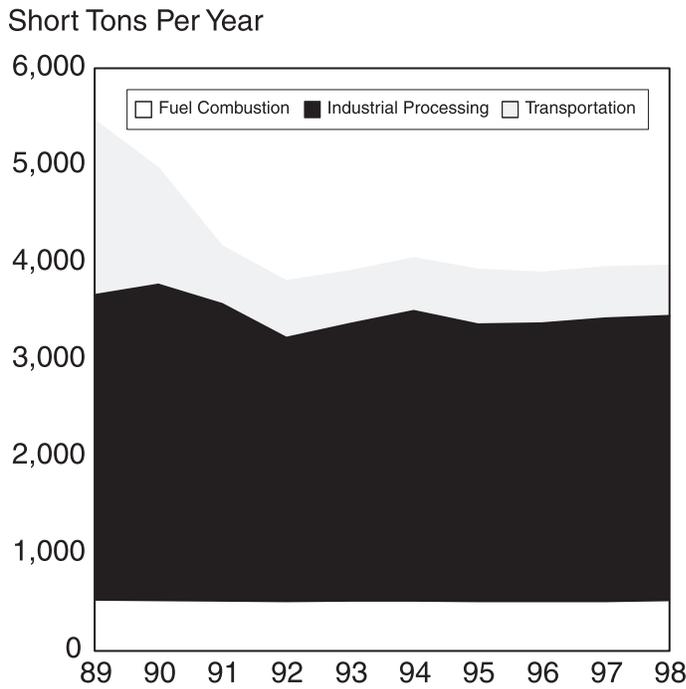
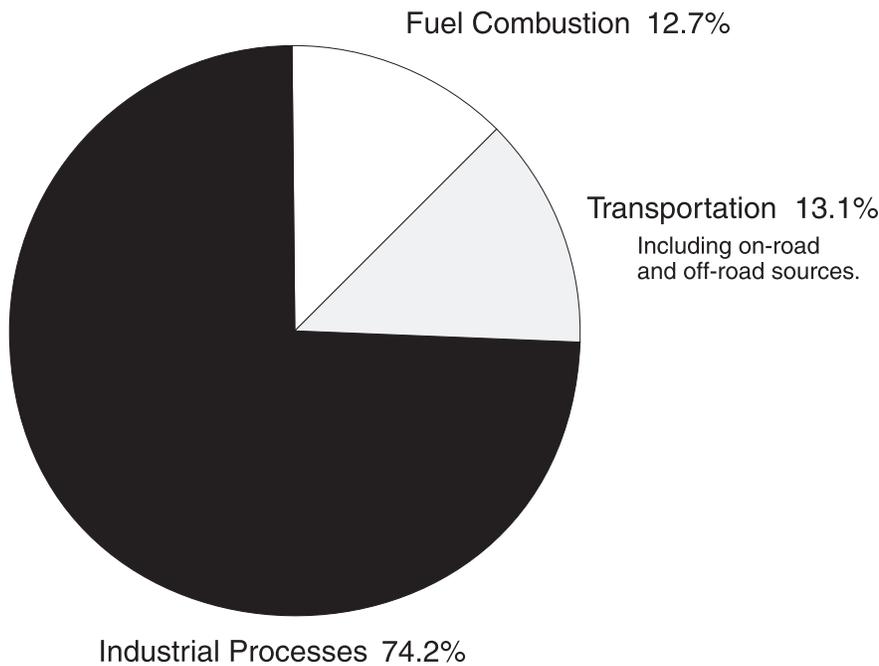


Figure 2-12. Pb emissions by source category, 1998.



cesses are now responsible for all violations of the lead standard, the lead monitoring strategy now focuses on emissions from these point sources. The map in Figure 2-15 shows the lead monitors located in the vicinity of major sources of lead emissions. In 1998, five lead point sources had one or more source-oriented monitors that violated the NAAQS. These five sources are ranked in Figure 2-15 according to the site with the greatest maximum quarterly mean. Various enforcement and regulatory actions are being actively pursued by EPA and the states for these sources.

The map in Figure 2-16 shows the highest quarterly mean lead concentration by county in 1998. Five counties, with a total population of 4.3 million and containing the point sources identified in Figure 2-15, did not meet the lead NAAQS in 1998.

Monitoring Status

Because of the shift in ambient air monitoring focus from mobile-source emissions to stationary point sources of lead air pollution, EPA revised the lead air monitoring regulations by publishing a new rule on January 20, 1999. This action was taken at the direct request of numerous state and local agencies whose on-road mobile-source oriented lead monitors have been reporting peak lead air pollution values that are many times less than the quarterly lead NAAQS of 1.5 µg/m³ for a number of consecutive years.

The previous regulation required that each urbanized area with a population of 500,000 or more operate at least two lead National Air Monitoring Stations (NAMS). The new rule allows state and local agencies more flexibility. The rule substantially reduces the requirements

for measuring lead air pollutant concentrations near major highways, thus shifting the focus to point sources and their impact on neighboring populations. The regulation allows states to reduce the number of NAMS from approximately 85 to approximately 15. This reduction will still allow EPA to confirm that lead air pollution in populated areas remains well below the NAAQS, but it refocuses available monitoring resources into areas with industrial sources.

Figure 2-13. Long-term ambient Pb trend, 1979–1998.

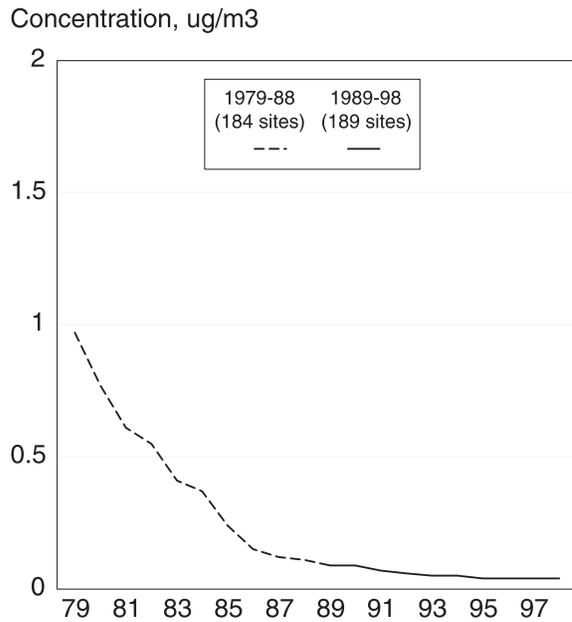
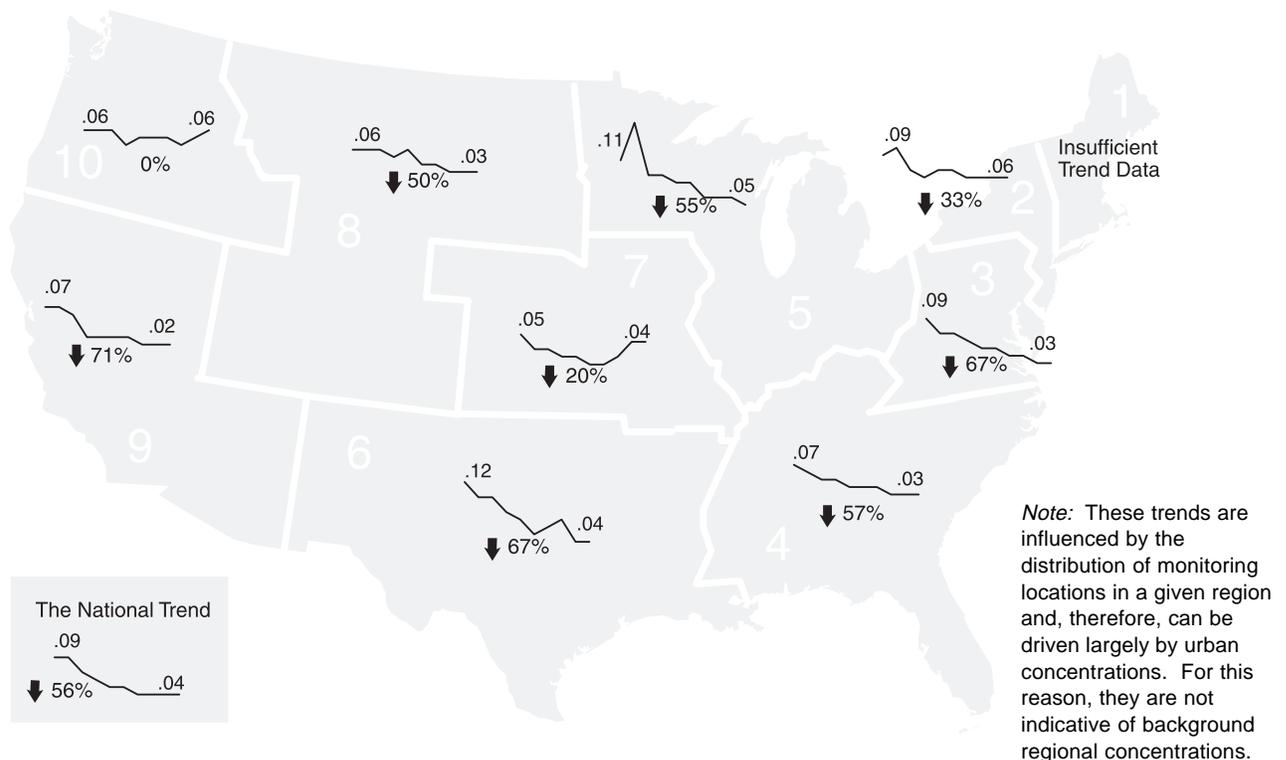


Figure 2-14. Trend in Pb maximum quarterly mean concentration by EPA Region, 1989–1998.



Alaska is in EPA Region 10; Hawaii, EPA Region 9; and Puerto Rico, EPA Region 2. Concentrations are µg/m³.

Figure 2-15. Pb maximum quarterly concentration in the vicinity of Pb point sources, 1998.

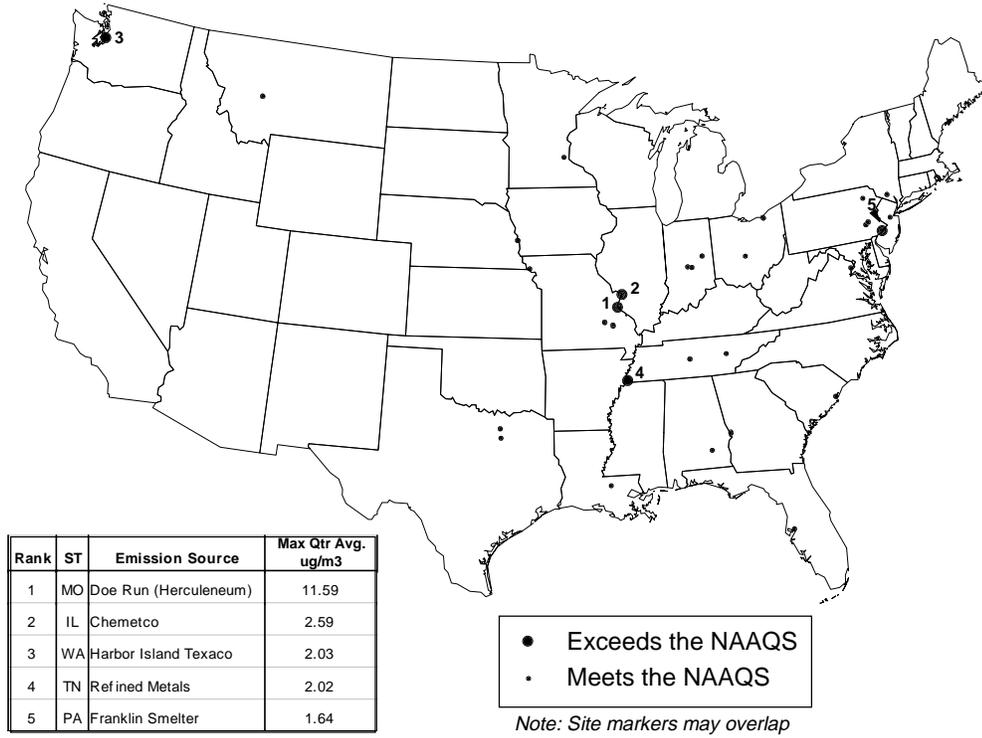
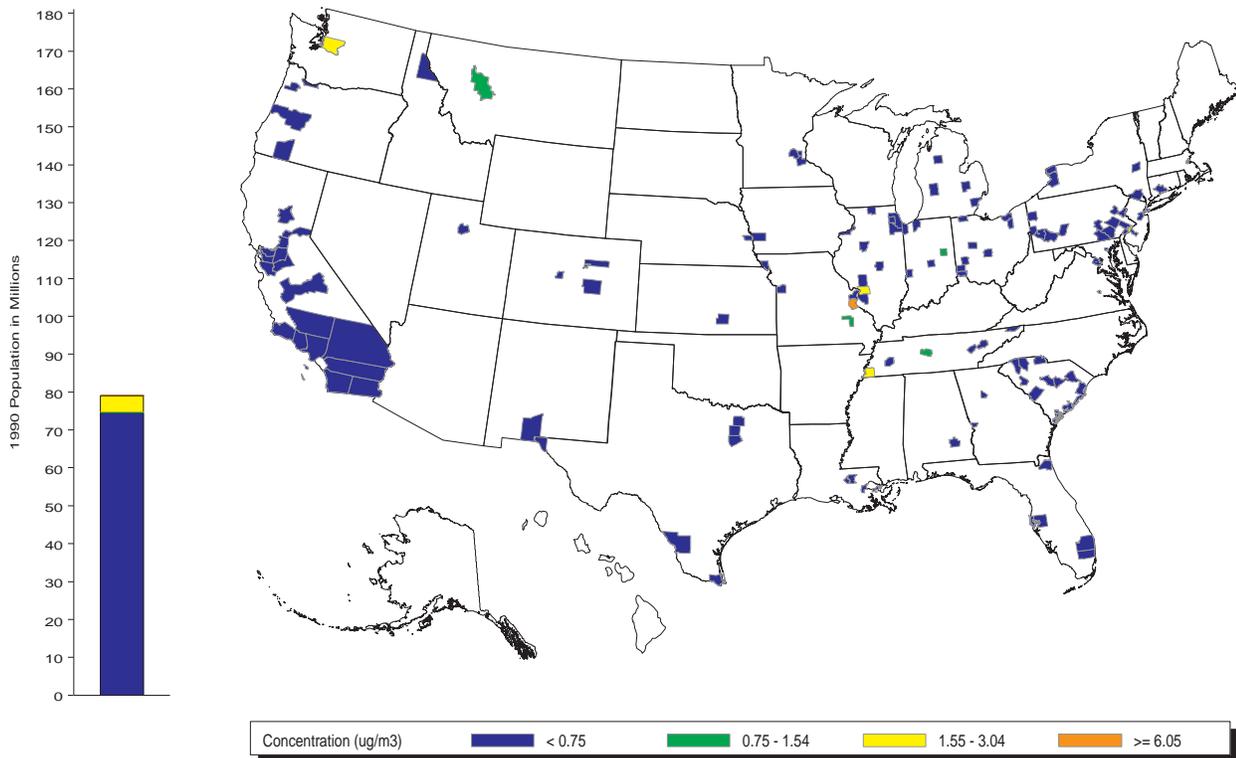


Figure 2-16. Highest Pb maximum quarterly mean by county, 1998.



Nitrogen Dioxide

Air Quality Concentrations		
1989–98	14%	decrease
1997–98		no change
Emissions		
1989–98	2%	increase
1997–98	1%	decrease

Nature and Sources

Nitrogen dioxide (NO₂) is a reddish brown, highly reactive gas that is formed in the ambient air through the oxidation of nitric oxide (NO). Nitrogen oxides (NO_x), the term used to describe the sum of NO, NO₂ and other oxides of nitrogen, play a major role in the formation of ozone in the atmosphere through a complex series of reactions with volatile organic compounds (VOCs). A variety of NO_x compounds and their transformation products occur both naturally and as a result of human activities. Anthropogenic (i.e., man-made) emissions of NO_x account for a large majority of all nitrogen inputs to the environment. The major sources of anthropogenic NO_x emissions are high-temperature combustion processes, such as those occurring in automobiles and power plants. Most of NO_x from combustion sources (about 95 percent) is emitted as NO; the remainder is largely NO₂. Because NO is readily converted to NO₂ in the environment, the emissions estimates reported here assume nitrogen oxides are in the NO₂ form. Natural sources of NO_x are lightning, biological and abiological processes in soil, and stratospheric intrusion. Ammonia and other nitrogen compounds produced naturally are important in the cycling of nitrogen through the ecosystem. Home heat-

ers and gas stoves also produce substantial amounts of NO₂ in indoor settings.

Health and Environmental Effects

Nitrogen dioxide is the most widespread and commonly found nitrogen oxide and is a matter of public health concern. The health effects of most concern associated with short-term exposures (i.e., less than three hours) to NO₂ at or near the ambient NO₂ concentrations seen in the United States, include changes in airway responsiveness and pulmonary function in individuals with preexisting respiratory illnesses, as well as increases in respiratory illnesses in children 5–12 years old.^{7,8}

Evidence suggests that long-term exposures to NO₂ may lead to increased susceptibility to respiratory infection and may cause alterations in the lungs. Atmospheric transformation of NO_x can lead to the formation of ozone and nitrogen-bearing particles (e.g., nitrates and nitric acid). As discussed in the ozone and PM sections of this report, exposure to both PM and ozone is associated with adverse health effects.

Nitrogen oxides contribute to a wide range of effects on public welfare and the environment, including global warming and stratospheric ozone depletion. Deposition of nitrogen can lead to fertilization, eutrophication, or acidification of terrestrial, wetland and aquatic (e.g., fresh water bodies, estuaries, and coastal water) systems. These effects can alter competition between existing species, leading to changes in the number and type of species (composition) within a community. For example, eutrophic conditions in aquatic systems can produce explosive algae

growth leading to a depletion of oxygen in the water and/or an increase in levels of toxins harmful to fish and other aquatic life. Nitrogen oxides are also important precursors or components of ozone, particulate matter and visibility impairment. (See sections on ozone, particulate matter, and sulfur dioxide, as well as chapters on visibility and atmospheric deposition).

Primary and Secondary Standards

The level for both the primary and secondary national ambient air quality standards (NAAQS) for NO₂ is 0.053 ppm annual arithmetic average, not to be exceeded.

National 10-Year Trends

The annual mean NO₂ concentration is the statistic used to track ambient NO₂ air quality trends. A total of 225 ambient NO₂ monitoring sites met the trends data completeness criteria for the 10-year period 1989–1998. Figure 2-17 shows that the national composite annual mean NO₂ concentration in 1998 is 14 percent lower than the composite mean recorded in 1989, and is unchanged from the 1997 level. Except for 1994, annual mean NO₂ concentrations have decreased, or remained unchanged, each year since 1989. Figure 2-18 shows how the trends in annual mean NO₂ concentrations vary among rural, suburban and urban monitoring locations. The highest annual mean NO₂ concentrations are typically found in urban areas, with significantly lower annual mean concentrations recorded at rural sites. The 1998 composite mean at 80 urban sites is 12 percent lower than the 1989 level, compared to an 18-percent reduction at 104 suburban sites. At 39 rural sites, the

Figure 2-17. Trend in annual NO₂ mean concentrations, 1989–1998.

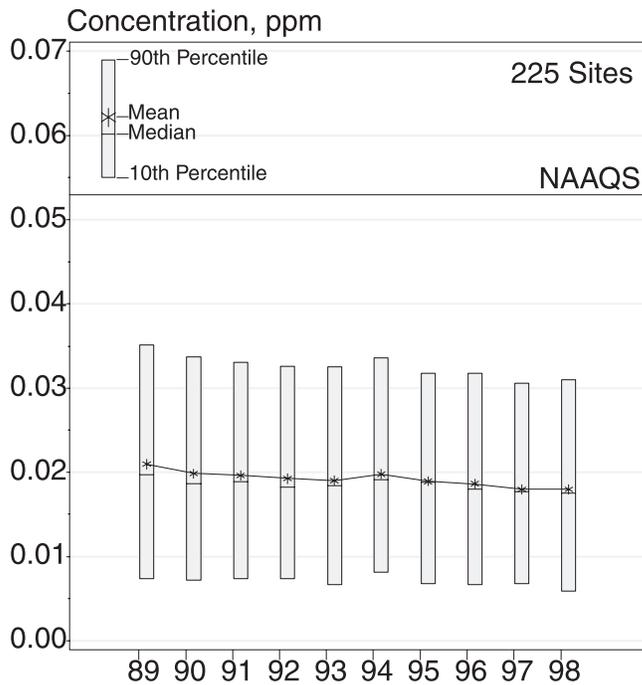
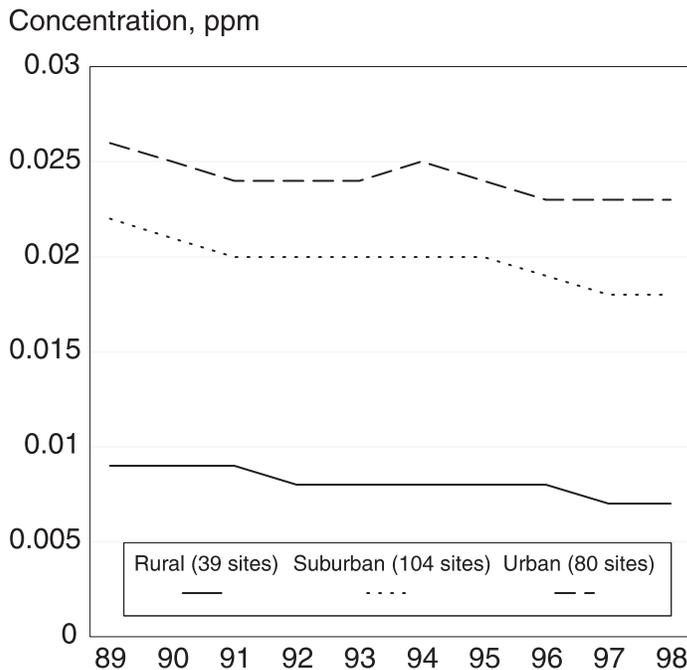


Figure 2-18. Trend in annual mean NO₂ concentrations by type of location, 1989–1998.



composite mean NO₂ concentration decreased 22 percent from the 1989 concentration level. (See Figure B-3 in Appendix B for a map of the NO₂ monitoring site locations.)

Atmospheric concentrations of NO₂ are determined by indirect photomultiplier measurement of the luminescence produced by a critical reaction of NO with ozone. The measurement of NO₂ is based first on the conversion of NO₂ to NO, and then subsequent detection of NO using this well characterized chemiluminescence technique. This conversion is not specific for NO₂, hence chemiluminescence analyzers are subject to interferences produced by response to other nitrogen containing compounds (e.g., peroxyacetyl nitrate [PAN]) that can be converted to NO. The chemiluminescence technique has been reported to overestimate NO₂ due to these interferences. This is not an issue for compliance since there are no violations of the NO₂ NAAQS. In addition, the interferences are believed to be relatively small in urban areas.⁹ The national and regional air quality trends depicted are based primarily on data from monitoring sites in urban locations, and are expected to be reasonable representations of urban NO₂ trends. That is not the case in rural and remote areas, however, where air mass aging could foster greater relative levels of PAN and nitric acid and interfere significantly with the interpretation of NO₂ monitoring data.

Emissions Trends

Figure 2-19 shows the 10-year trend in NO_x emissions. National total NO_x emissions in 1998 are 2 percent higher than the 1989 total, although changes in data availability and methodology between 1989 and 1990

(in the other combustion category) introduce uncertainty in this comparison. Emissions from electric utility fuel combustion sources in 1998 are 7 percent lower than the 1989 level, while emissions from on-road sources have increased 1 percent during the past 10 years. Figure 2-20 shows that the two primary sources of NO_x emissions are fuel combustion and transportation. Together, these two sources comprise 95 percent of 1998 total NO_x emissions. Title IV (Acid Deposition Control) of the CAA required EPA to establish NO_x annual average emission limits for coal-fired electric utility units in two phases. NO_x reductions are approximately 400,000 tons per year during Phase I (1996–1999) and two million tons per year in Phase II (year 2000 and subsequent years).¹⁰ In 1998, 265 Phase I coal-fired utility units were subject to the Title IV emission limitations. For these 265 affected utility units, total NO_x emissions in 1998 were 29 percent lower than in 1990, but 3 percent higher than in 1997.¹⁰ While this is the second year that NO_x emissions from these sources have increased, the ascent can be attributed in part to greater electrical production compared to 1996.¹⁰

National 20-Year Trends

As discussed in previous sections of this report, long-term national ambient air quality trends are difficult to assess because few monitoring sites have operated continuously in the same location for 20 years. Figure 2-21 presents 20-year trends in ambient NO₂ concentrations by combining two separate 10-year trends databases, 1979–1988 (127 sites) and 1989–1998 (225 sites). Nationally, annual mean NO₂ concentrations have decreased approximately 25 percent

Figure 2-19. Trend in national total NO_x emissions, 1989–1998.

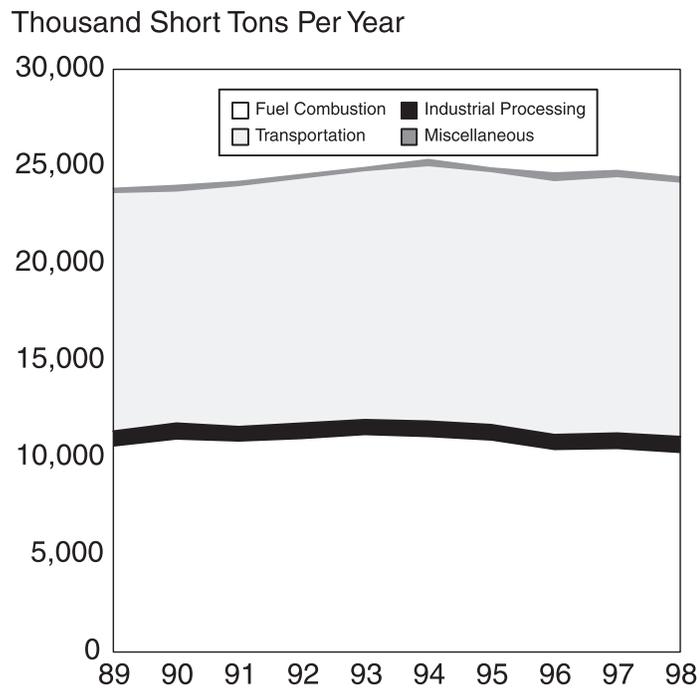


Figure 2-20. NO_x emissions by source category, 1998.

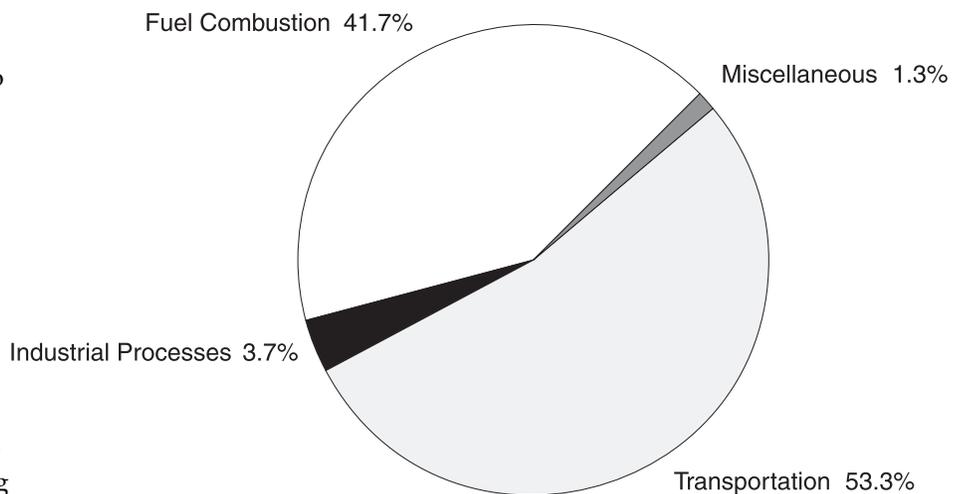
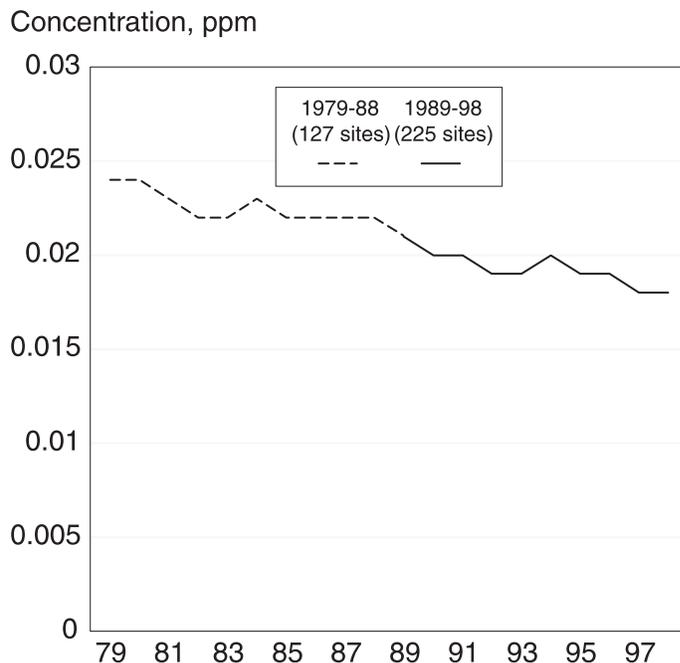


Figure 2-21. Long-term trend in annual mean NO₂ concentrations, 1979–1998.

since 1979. Annual mean NO₂ concentrations declined in the early 1980s, were relatively unchanged during the mid-to-late 1980s, and resumed their decline in the 1990s. Because most NO₂ monitoring sites are mobile-source oriented sites in urban areas, the 20-year decline in NO₂ concentrations more closely tracks the 19-percent reduction in NO_x emissions from on-road vehicles since 1980.

Regional Trends

The map in Figure 2-22 shows regional trends in NO₂ concentrations during the past 10 years, 1989–1998 (except Region 10 which does not have any NO₂ trend sites). The trends statistic is the regional composite mean of the NO₂ annual mean concentrations across all sites with at

least 8 years of ambient measurements. Figure 2-22 shows that the largest reductions in composite annual mean NO₂ concentrations occurred in the South Coast of California, followed by the New England states, and the northeastern states, New York and New Jersey. Smaller reductions in mean NO₂ concentrations were recorded in mid-Atlantic, southeast, southwest and Rocky Mountain states. The 1989 and 1998 composite mean NO₂ concentrations were the same level in both the North Central and Midwest states.

1998 Air Quality Status

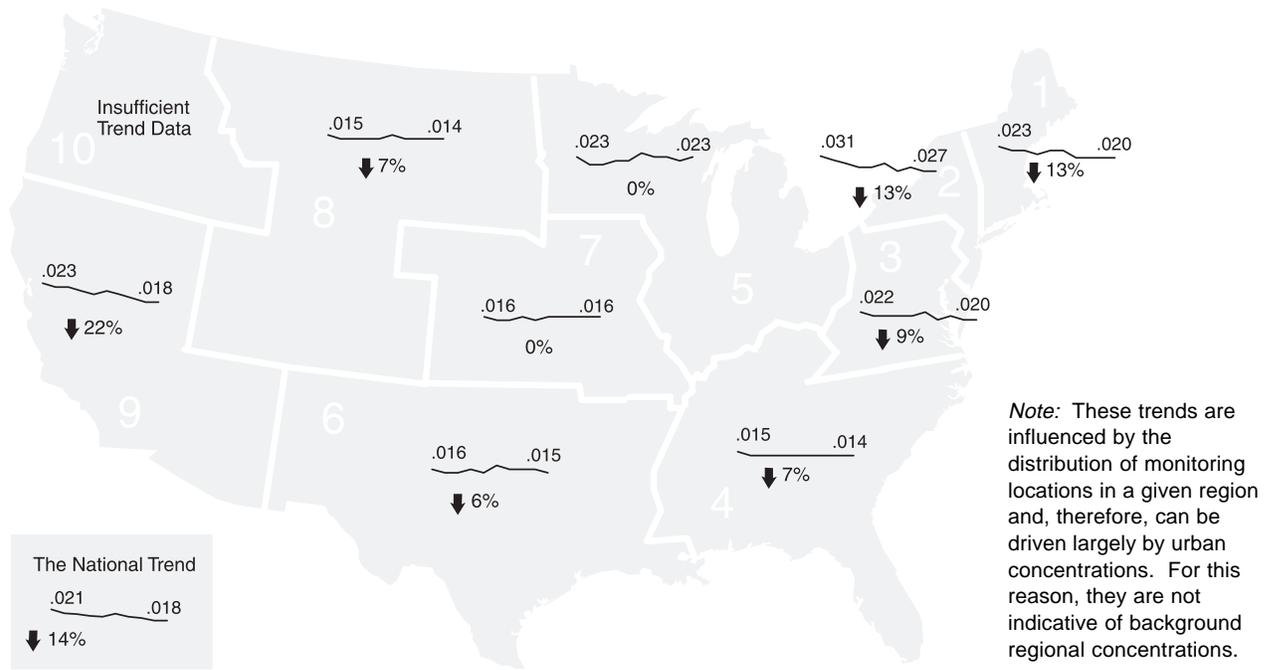
All monitoring locations across the nation, including Los Angeles, met the NO₂ NAAQS in 1998. This is reflected on the map in Figure 2-23 that displays the highest annual

mean NO₂ concentration measured in each county. In July 1998, EPA announced the redesignation of the South Coast Air Basin (the last remaining nonattainment area for NO₂) to attainment for the NO₂ NAAQS.¹¹

Data Sources

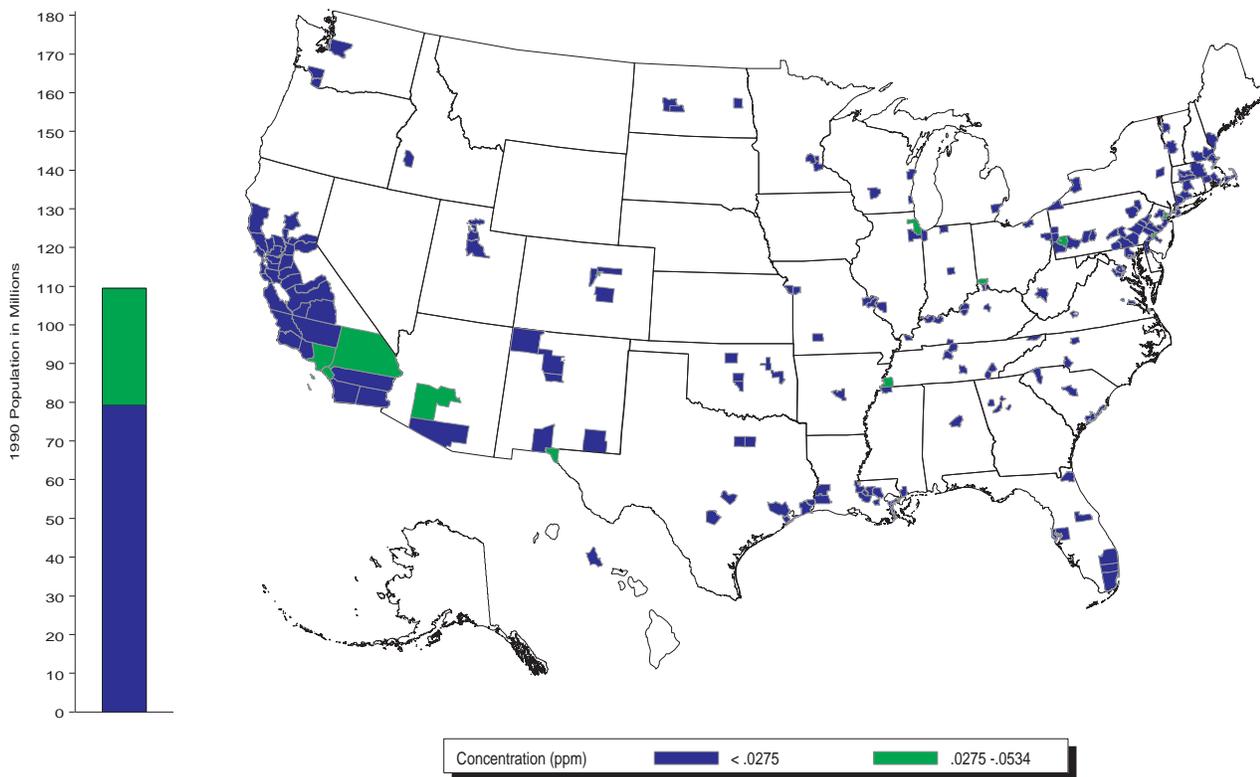
The NO₂ ambient trends plotting points and emissions totals by source category are listed in Tables A-1 and A-4, respectively. The plotting points for the 20-year trend charts are listed in Table A-9. Table A-11 contains the highest annual mean NO₂ concentration by county in 1998.

Figure 2-22. Trend in NO₂ maximum quarterly mean concentration by EPA Region, 1989–1998.



Alaska is in EPA Region 10; Hawaii, EPA Region 9; and Puerto Rico, EPA Region 2. Concentrations are ppm.

Figure 2-23. Highest NO₂ annual mean concentration by county, 1998.



Ozone

Air Quality Concentrations	
1989–98	4% decrease (1-hr) no change (8-hr)
1997–98	5% increase (1-hr) 4% increase (8-hr)
Emissions (Anthropogenic VOCs)	
1989–98	20% decrease
1997–98	5% decrease

Nature and Sources

Ground level ozone remains a pervasive pollution problem in the United States. Ozone is readily formed in the atmosphere by the reaction of VOCs and NO_x in the presence of heat and sunlight, which are most abundant in the summer. VOCs are emitted from a variety of sources including: motor vehicles, chemical plants, refineries, factories, consumer and commercial products, other industries, and natural (biogenic) sources. Nitrogen oxides are emitted from motor vehicles, power plants, and other sources of combustion, and natural sources including lightning and biological processes in soil. Changing weather patterns contribute to yearly differences in ozone concentrations. Ozone and the precursor pollutants that cause ozone also can be transported into an area from pollution sources located hundreds of miles upwind.

Health and Environmental Effects

Ozone occurs naturally in the stratosphere and provides a protective layer high above the Earth. However, at ground level, it is the prime ingredient of smog. Short-term (1–3 hours) and prolonged (6–8 hours) exposures to ambient ozone concentrations have been linked to a number of health effects of concern. For

example, increased hospital admissions and emergency room visits for respiratory causes have been associated with ambient ozone exposures.

Exposures to ozone may make people more susceptible to respiratory infection, result in lung inflammation, and aggravate preexisting respiratory diseases such as asthma. Other health effects attributed to short-term and prolonged exposures to ozone, generally while individuals are engaged in moderate or heavy exertion, include significant decreases in lung function and increased respiratory symptoms such as chest pain and cough. Children active outdoors during the summer when ozone levels are at their highest are most at risk of experiencing such effects. Other at-risk groups include adults who are active outdoors, such as outdoor workers, and individuals with preexisting respiratory disorders such as asthma and chronic obstructive lung disease. Within each of these groups are individuals who are unusually sensitive to ozone. In addition, repeated long-term exposure to ozone presents the possibility of irreversible changes in the lungs which could lead to premature aging of the lungs and/or chronic respiratory illnesses.

Ozone also affects sensitive vegetation and ecosystems. Specifically, ozone can lead to reductions in agricultural and commercial forest yields, reduced survivability of sensitive tree seedlings, and increased plant susceptibility to disease, pests, and other environmental stresses such as harsh weather. In long-lived species, these effects may become evident only after several years or even decades. As these species are out-competed by others, long-term effects on forest ecosystems and habitat quality for wildlife and endangered species

occurs. Furthermore, ozone injury to the foliage of trees and other plants can decrease the aesthetic value of ornamental species as well as the natural beauty of our national parks and recreation areas.

Primary and Secondary 1-hour Ozone Standards

In 1979, EPA established 1-hour primary and secondary standards for ozone. The level of the 1-hour primary and secondary ozone NAAQS is 0.12 ppm daily maximum 1-hour concentration that is not to be exceeded more than once per year on average. To encourage an orderly transition to the revised ozone standards (promulgated in 1997; see following section for more information), EPA initiated a policy in which the 1-hour standards would no longer apply once an area experienced air quality data meeting the 1-hour standards. In 1998 and early 1999, EPA revoked the 1-hour ozone NAAQS in 2,942 counties in the United States, leaving 201 counties where the 1-hour standard still applies.^{12,13,14} However, due to unresolved legal challenges, the Agency is unable to enforce and effectively implement the 8-hour standard. As a result, many areas are without applicable air quality standards adequate to ensure public health and welfare. Therefore, at the time of publication of this report, EPA has proposed to reinstate the 1-hour standard nationwide to alleviate this unanticipated policy outcome and provide protection of public health and welfare.¹⁵

Primary and Secondary 8-hour Ozone Standards

On July 18, 1997, EPA established an 8-hour primary ozone standard to protect against longer exposure peri-

ods that are of concern for both human health and environmental welfare.¹⁶ The level of the national 8-hour primary and secondary ambient air quality standards for ozone is 0.08 ppm, daily maximum 8-hour average over 3 years. The standards are met when the 3-year average of the annual fourth-highest daily maximum 8-hour ozone concentration is less than or equal to 0.08 ppm.¹⁶ In May 1999, however, the U.S. Court of Appeals for the D.C. Circuit issued an opinion concerning the revised ozone standard. The court remanded the case back to EPA for further consideration. Following the denial of a petition for rehearing by the D.C. Circuit, the Justice Department has filed a petition for review before the Supreme Court.

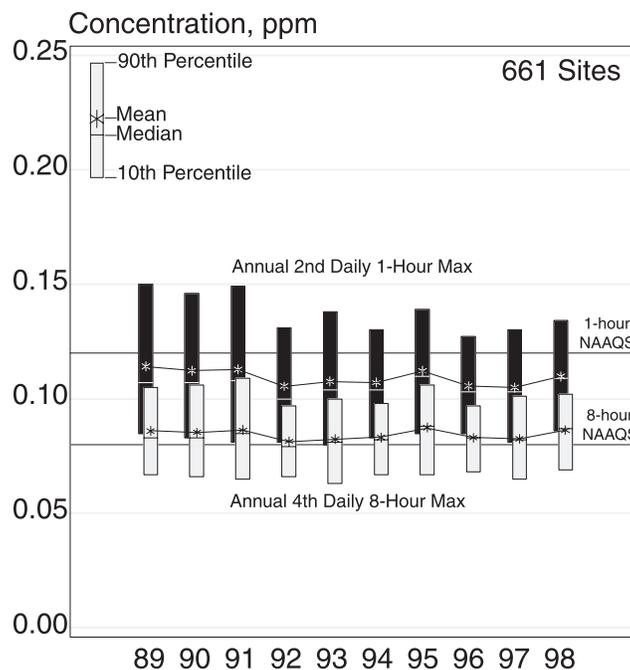
Air Quality Trends

Because the 1-hour and 8-hour NAAQS have different averaging times and forms, two different statistics are used in this report to track ambient ozone air quality trends. For the 1-hour O₃ NAAQS, this report uses the composite mean of the annual second-highest daily maximum 1-hour O₃ concentration as the statistic to evaluate trends. For the 8-hour ozone NAAQS, the report relies on the annual fourth-highest 8-hour daily maximum O₃ concentration as the statistic of interest to assess trends.

National 10-Year Trends

As shown in Figure 2-24, peak 1-hour O₃ concentrations at 661 monitoring sites across the country have declined 4 percent over the past 10 years. The variability among monitoring locations across the country for this measure is represented by the 90th percentile, median, composite mean, and 10th percentile values. During

Figure 2-24. Trend in annual 2nd-highest daily maximum 1-hour, and 4th-highest daily 8-hour O₃ concentrations, 1989–1998.

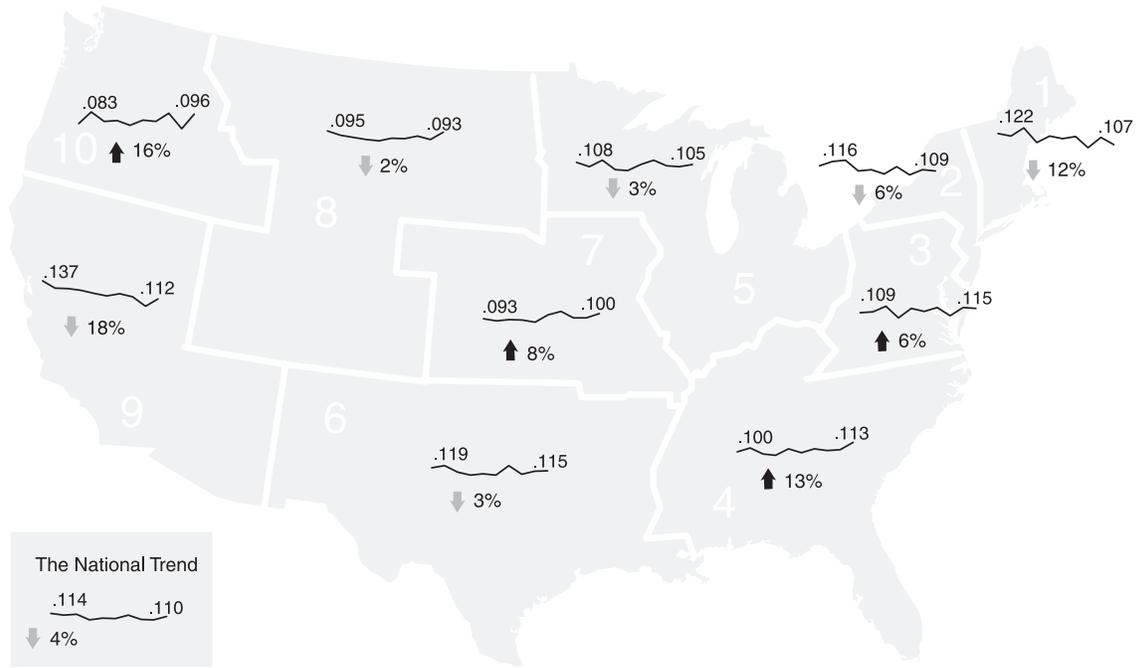


the past 10 years, values at the sites with the highest concentrations of the second daily maximum ozone level values have continued to decline more substantially than those at the sites with average levels of this measure. While the concentrations at the more typical sites (composite mean) are only 4 percent lower in 1998 than in 1989, the 1-hour ozone levels at higher concentration sites (the 90th percentile) declined by 11 percent during the same period. Although not shown in a figure, the national exceedance rate (i.e., the average number of days when the daily maximum 1-hour average concentration exceeds the level of the 1-hour NAAQS) has declined 62 percent compared to the rate in 1989. As noted in previous reports, this statistic, which is simply a count of the number of times the level of the NAAQS has been exceeded, can vary significantly from year to year. Fig-

ure 2-24 also shows the national trend in 8-hour ozone concentrations across the same 661 sites. The 8-hour concentration at typical sites is the same level in 1998 as observed in 1989. However, the 8-hour ozone values at the higher concentration sites (as shown by the 90th percentile) have decreased by 3 percent since 1989. The trend in the 8-hour ozone statistic is similar to the trend in the 1-hour values, although the concentration range is smaller.

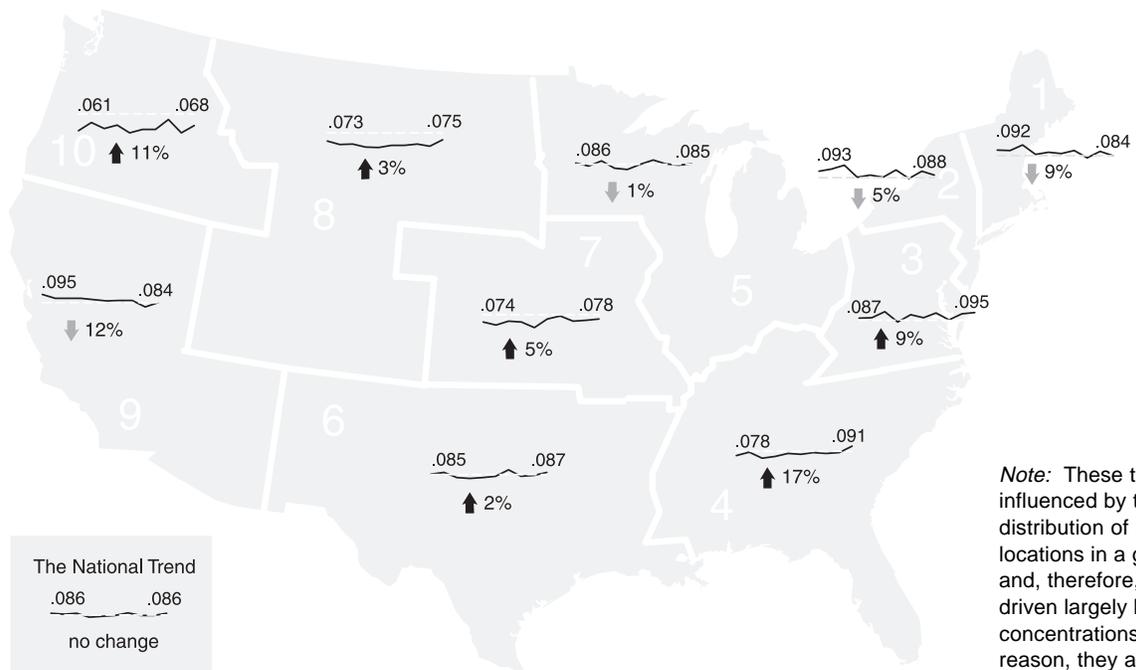
The maps in Figures 2-25 and 2-26 examine the trend in 1-hour and 8-hour ozone concentrations during the past 10 years, by geographic region of the country. For both the 1-hour and 8-hour ozone measurements, trends in the Mid-Atlantic, Southeast, Central, and Northwest increased from 1989 to 1998. In addition, the Southwest region also experienced an increase over the same 10-year period for the 8-hour ozone

Figure 2-25. Trend in 2nd highest daily 1-hour O₃ concentration by EPA Region, 1989–1998.



Alaska is in EPA Region 10; Hawaii, EPA Region 9; and Puerto Rico, EPA Region 2. Concentrations are ppm.

Figure 2-26. Trend in 4th highest daily 8-hour O₃ concentration by EPA Region, 1989–1998.



Note: These trends are influenced by the distribution of monitoring locations in a given region and, therefore, can be driven largely by urban concentrations. For this reason, they are not indicative of background regional concentrations.

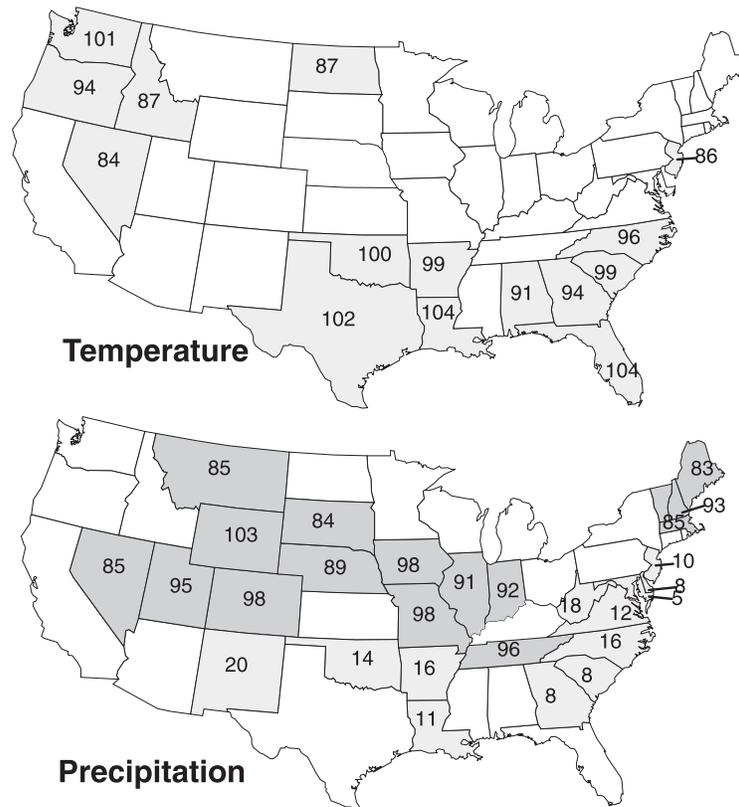
Alaska is in EPA Region 10; Hawaii, EPA Region 9; and Puerto Rico, EPA Region 2. Concentrations are ppm.

measurement only. The ozone levels in all other areas followed declining trends similar to that of the national observations. These patterns are generally consistent with, and partially explained by, the meteorological conditions experienced during the 1998 summer in these areas. The summer of 1998 was among the 10 hottest seasons (of the last 100) for many states within the Southeast, Southwest and Northwest regions of the country, and was among the 20 driest summers in the Southeast. Statewide temperature and precipitation ranks for the summer of 1998 are shown in Figure 2-27 based on preliminary meteorological data available from National Oceanic and Atmospheric Administration (NOAA).¹⁸

In Figure 2-28, the national 1-hour ozone trend is deconstructed to show the 10-year change in ambient ozone concentrations among rural, suburban, and urban monitoring sites. The highest ambient ozone concentrations are typically found at suburban sites, consistent with the downwind transport of emissions from the urban center. During the past 10 years, ozone concentrations decreased by 3 percent at 304 suburban sites, and 9 percent at 117 urban sites. However, at 222 rural sites, 1-hour ozone levels for 1998 are only 1 percent lower than the 1989 level and, for the first time, are greater than the level observed for urban sites.

Figure 2-29 presents the trend in 8-hour ozone concentrations for 34 Clean Air Status and Trends Network (CASTNet) sites from 1989–1998.^{18a} The 8-hour ozone concentrations at these eastern CASTNet sites, which were the highest during the hot and dry summers of 1991 and 1998, have increased 6 percent over the last 10-

Figure 2-27. Summer 1998 statewide ranks for temperature and precipitation.



Note: For each individual state, the last 104 summers were ranked warmest to coldest and wettest to driest. A rank of 104 corresponds to the warmest or wettest, while a rank of 1 corresponds to the coldest or driest. Light gray states are in the warmest or wettest 20 percent of the last 104 years and dark gray states are in the driest 20 percent. There were no states having ranks in the coldest 20 percent in 1998.

Figure 2-28. Trend in annual 2nd-highest daily maximum 1-hour O₃ concentrations by location, 1989–1998.

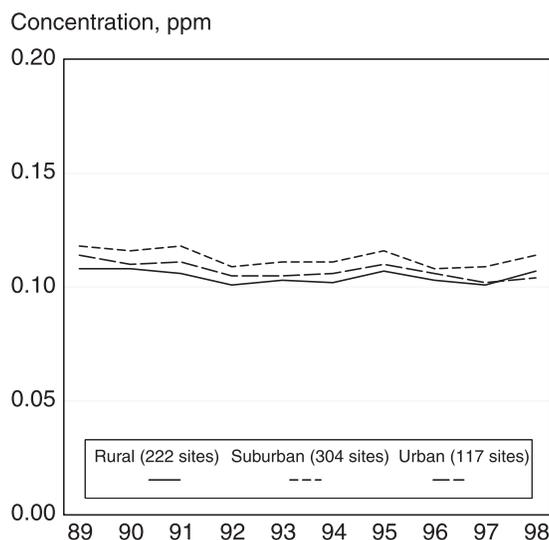
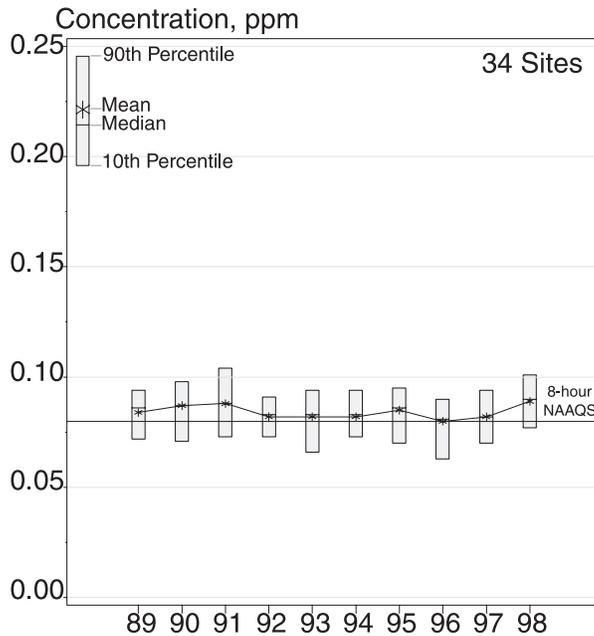


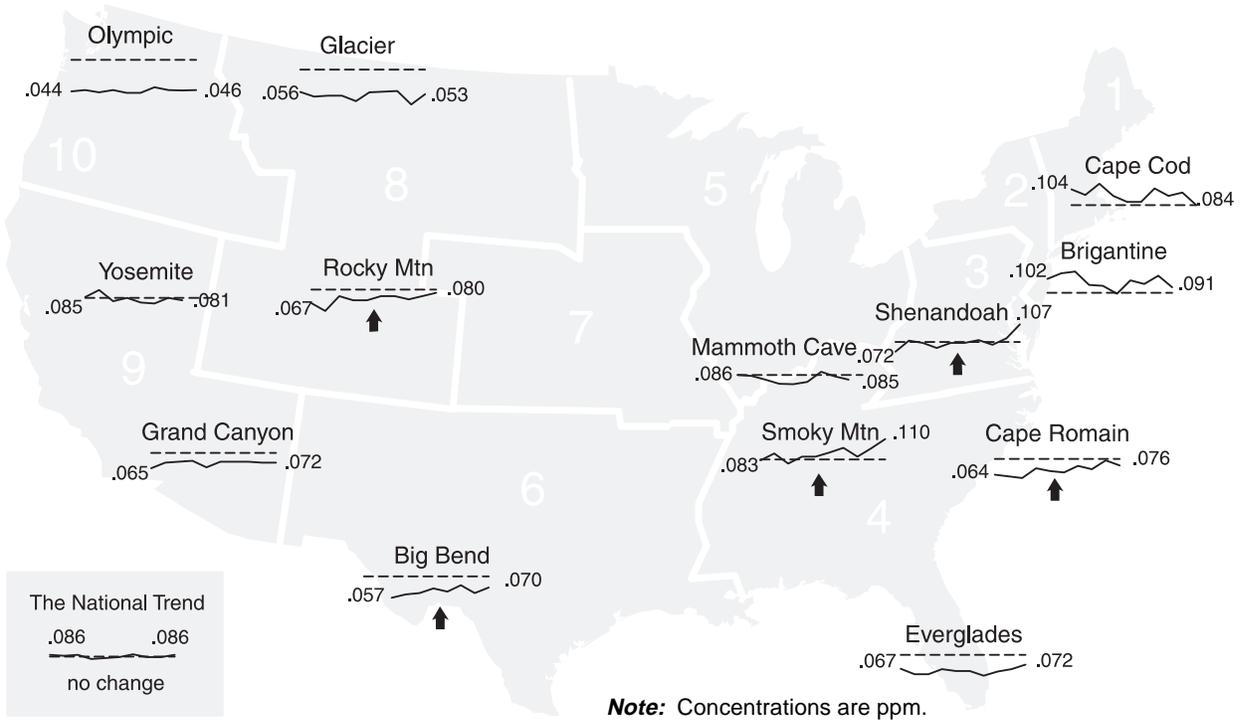
Figure 2-29. Trend in 4th-highest daily 8-hour O₃ based on 34 CASTNet sites in the rural eastern United States, 1989–1998.



year period and 8 percent from 1997–1998. The CASTNet data complement the larger ozone data sets gathered by the State and Local Monitoring (SLAMS) and National Air Monitoring (NAMS) networks with additional rural coverage.

Figure 2-30 further examines patterns in ozone levels by presenting the 10-year trend in the 8-hour ozone concentrations across 24 National Park Service (NPS) sites as well as specific trends in ambient ozone levels for each individual site.¹⁹ These sites are located in Class I areas, a special subset of rural environments (all national parks and wilderness areas exceeding 5,000 acres) accorded a higher degree of protection under the CAA provisions for the prevention of significant dete-

Figure 2-30. Trend in annual 4th-highest daily maximum 8-hour O₃ concentrations in National Parks, 1989–1998.



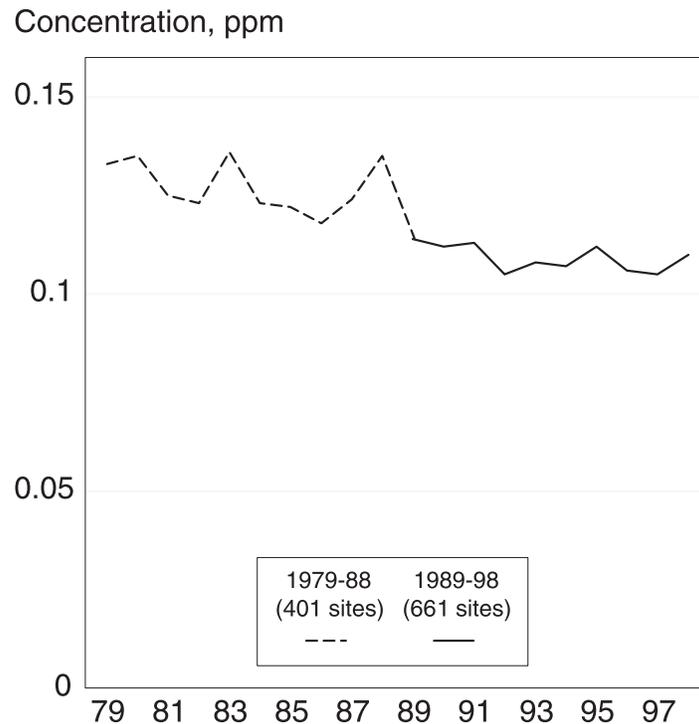
↑ Indicates a statistically significant upward trend. Otherwise the trend was not statistically significant.

rioration. There are more than 24 NPS sites nationally; however, this analysis focuses on the specific sites with sufficient data to evaluate 10-year trends. Although the composite mean ozone concentration for 1998 across all 24 sites was unchanged from the level in 1989, nine of the NPS sites experienced statistically significant upward trends in 8-hour ozone levels. Figure 2-30 highlights five such sites: two in the Great Smoky Mountains National Park, one in Big Bend National Park, one in the Rocky Mountain National Park, and one in Cape Romain National Wildlife Refuge. Although not statistically significant, the 8-hour ozone levels at eight of the remaining 15 sites increased between 1989 and 1998, while only three showed downward slopes, and four sites showed no change. The 1998 levels were particularly high at the Shenandoah National Park and the Great Smoky Mountains National Park. Ozone levels at these sites were the highest in a decade and 30–40 percent higher than the 8-hour ozone standard. Table A-18 provides data on 10-year trends in air quality at all 24 NPS sites.

National 20-Year Trends

Since 1979, 1-hour O_3 concentrations have declined 17 percent nationally. Figure 2-31 clearly shows the peak ozone years of 1980, 1983, 1988 and 1995. Because only a few sites have monitored continuously for two decades, the 20-year trends line in Figure 2-31 is composed of two segments—401 sites with complete data during the first 10 years (1979–1987) and 661 sites meeting the data completeness criteria in the most recent 10 years (1989–1998). It is important to interpret such long-

Figure 2-31. Trend in annual 2nd-highest daily maximum 1-hour O_3 concentrations, 1979–1998.



term, quantitative ambient ozone trends carefully given changes in network design, siting criteria, spatial coverage and monitoring instrument calibration procedures during the past two decades.

Change Since Last Year

A comparison of the change in 1-hour ozone concentrations for the two most recent years of data reveals a 5-percent increase between 1997 and 1998. Similarly, the national 8-hour ozone concentrations increased 4 percent between 1997 and 1998 (Figure 2-24). Ambient ozone trends are influenced by year-to-year changes in meteorological conditions, population growth, changes in emissions levels from ongoing control measures as well as the relative levels of ozone precursors VOC and NO_x .

As discussed in previous *Trends Reports*, EPA uses a statistical model to adjust data on the annual rate of change in ozone from individual metropolitan areas to account for meteorological impacts, including surface temperature and wind speed.²⁰ Figure 2-32 presents the composite meteorologically-adjusted trend in 1-hour average daily maximum ozone concentrations for 40 metropolitan areas between 1986 and 1998. As seen in this figure, even after adjusting for meteorological conditions, 1-hour ozone levels in these selected areas increased slightly more than 1 percent between 1997 and 1998. This modest one year increase is within the range of uncertainty of this analysis and its significance should not be over interpreted. However, this increase combined with a similar rise in adjusted ozone levels

Figure 2-32. Comparison of actual and meteorologically adjusted 1-hour O₃ trends, 1989–1998.

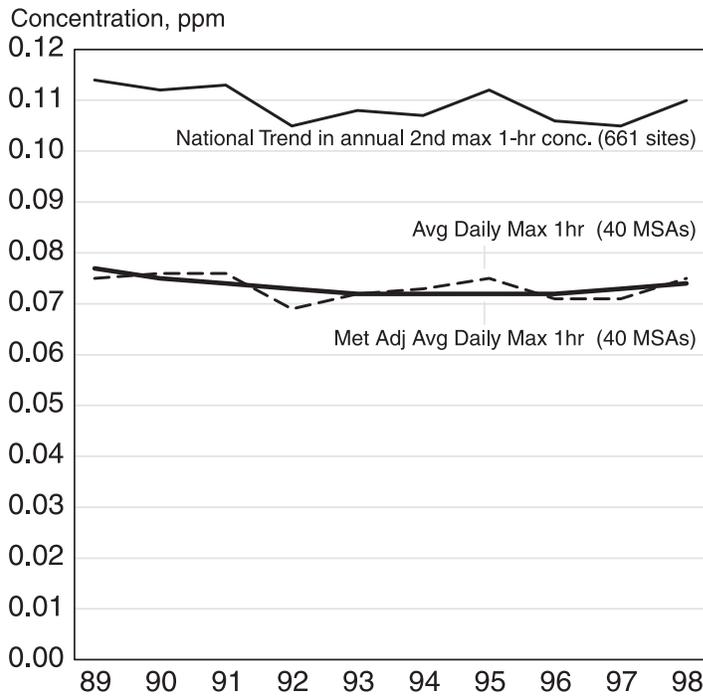
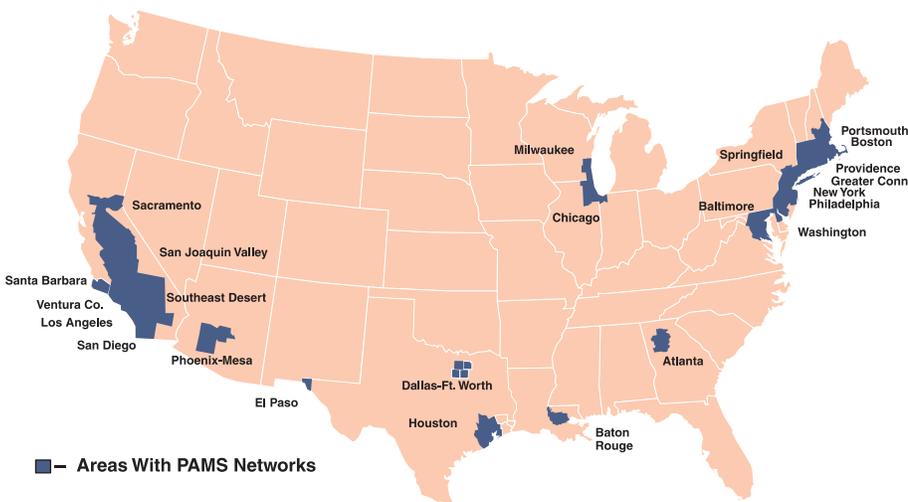


Figure 2-33. Areas with PAMS networks.



between 1996 and 1997 (slightly greater than 1 percent) for these same areas suggests the beginnings of a possible upward trend in the adjusted statistic which will continue to be monitored and evaluated in future analyses and *Trends Reports*.

The 1-hour ozone concentrations in urban areas with the most severe and persistent ozone problems (i.e., those classified as extreme, severe, and serious ozone nonattainment areas) also increased between 1997 and 1998. This 2-percent increase, based on data from sites in the areas required to operate the Photochemical Assessment Monitoring Stations (PAMS) network, is consistent with, but less pronounced than, the 5-percent increase seen nationwide (at the 661 10-year trend sites). Currently, 22 of the nation’s remaining 32 non-attainment areas for the 1-hour ozone NAAQS are required to operate PAMS sites.²¹ In addition, although recently reclassified to attainment for the 1-hour standard, Boston and Providence still maintain PAMS sites. Areas with PAMS networks are shown in Figure 2-33. Each PAMS network consists of as many as five monitoring stations, depending on the area’s population. These stations are carefully located according to meteorology, topography, and relative proximity to emissions sources of VOC and NO_x. As of October 1999, there were 83 active designated PAMS sites.

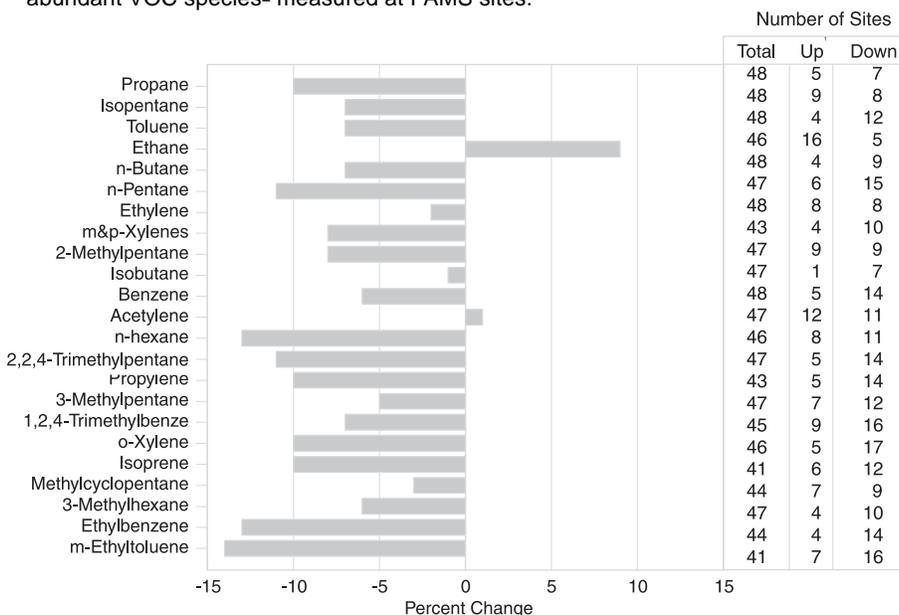
In addition to measuring ozone levels, PAMS sites include measurements of NO_x, total non-methane organic compounds (TNMOC), a target list of VOC species including several carbonyls, plus surface and upper air meteorology during summer months when weather conditions are most conducive to ozone

formation. Table 2-3 shows changes in summer 6:00–9:00 a.m. VOC and NO_x concentrations for selected PAMS sites.²² Morning periods for NO_x and VOCs are used because those time frames are generally thought to be an appropriate indicator of anthropogenic emissions. Morning NO_x concentrations showed a median decline of 3 percent between 1997 and 1998 across 60 PAMS sites. Summer morning VOC concentrations registered a median decline of 7 percent across 45 PAMS sites. Figure 2-34 presents the median changes in summer morning concentrations of the most abundant VOC species measured at PAMS sites. These 23 VOC species are the focus of this analysis because they account for more than 75 percent (by volume) of the VOCs concentrated on in the PAMS program. Twenty-one of the 23 compounds included showed declines in median values between 1997 and 1998.²³

Emissions Trends

Figure 2-35 shows that national total VOC emissions (which contribute to ozone formation) from anthropogenic (man-made) sources decreased 20 percent between 1989 and 1998. National total NO_x emissions (the other major precursor to ozone formation) increased 2 percent over the same 10-year period, although changes in data availability and methodology between 1989 and 1990 (in the other combustion category) introduce uncertainty in this comparison. Nationally, the two major sources of VOC emissions are industrial processes (47 percent) and transportation sources (44 percent) as shown in Figure 2-36. Solvent use comprises 62 percent of the industrial process emissions category and 29 percent of total VOC

Figure 2-34. The median changes in summer morning concentrations of the most abundant VOC species² measured at PAMS sites.



Notes: 1. The numbers shown in the “Up” and “Down” columns refer to the number of sites in which the change in summer 6–9 a.m. mean concentrations between 1997 and 1998 is statistically significant (as determined by a t-test with a significance level of .05). The total number of sites (“Total”) may not equal the sum of the corresponding “Up” and “Down” categories.

2. Results for Formaldehyde and Acetaldehyde (both carbonyl compounds) were not included in this analysis. EPA is continuing to assess carbonyl sampling issues to compare these measurements.

Table 2-3. Summary of 1997–1998 Changes in Summer 6–9 a.m. Mean Concentrations of NO_x and TNMOC at PAMS Sites

	Total	Number of Sites		Median Change
		Up	Down	
NO _x	60	6	13	-3%
TNMOC	45	6	11	-7%

Note: The numbers shown in the “Up” and “Down” columns refer to the number of sites in which the change in summer 6–9 a.m. mean concentrations between 1997 and 1998 is statistically significant. The total number of sites (“Total”) may not equal the sum of the corresponding “Up” and “Down” categories.

emissions. The emissions totals by source category and year can be found in Table A-5. Recent control measures to reduce emissions include regulations to lower fuel volatility and to reduce NO_x and VOC emissions from tailpipes.²⁴ The effectiveness of these control measures is

reflected in the 20-percent decrease in VOC emissions from transportation sources. VOC emissions from highway vehicles have declined 26 percent since 1989, while highway vehicle NO_x emissions have increased 1 percent over the same period.

Figure 2-35. Trend in national total anthropogenic VOC emissions, 1989–1998.

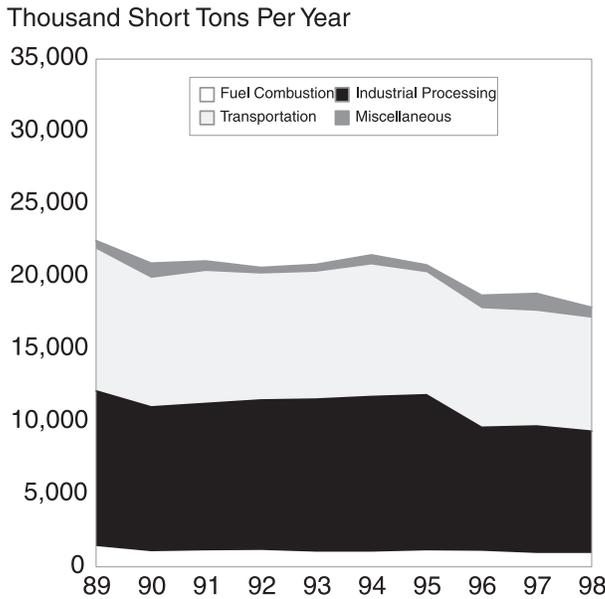


Figure 2-36. Anthropogenic VOC emissions by source category.

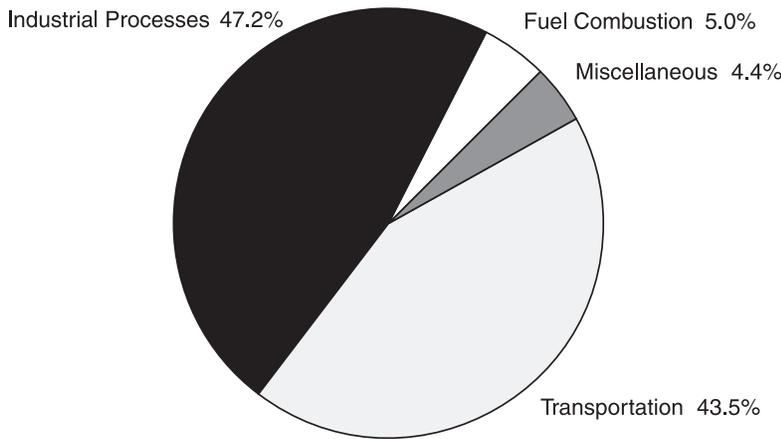


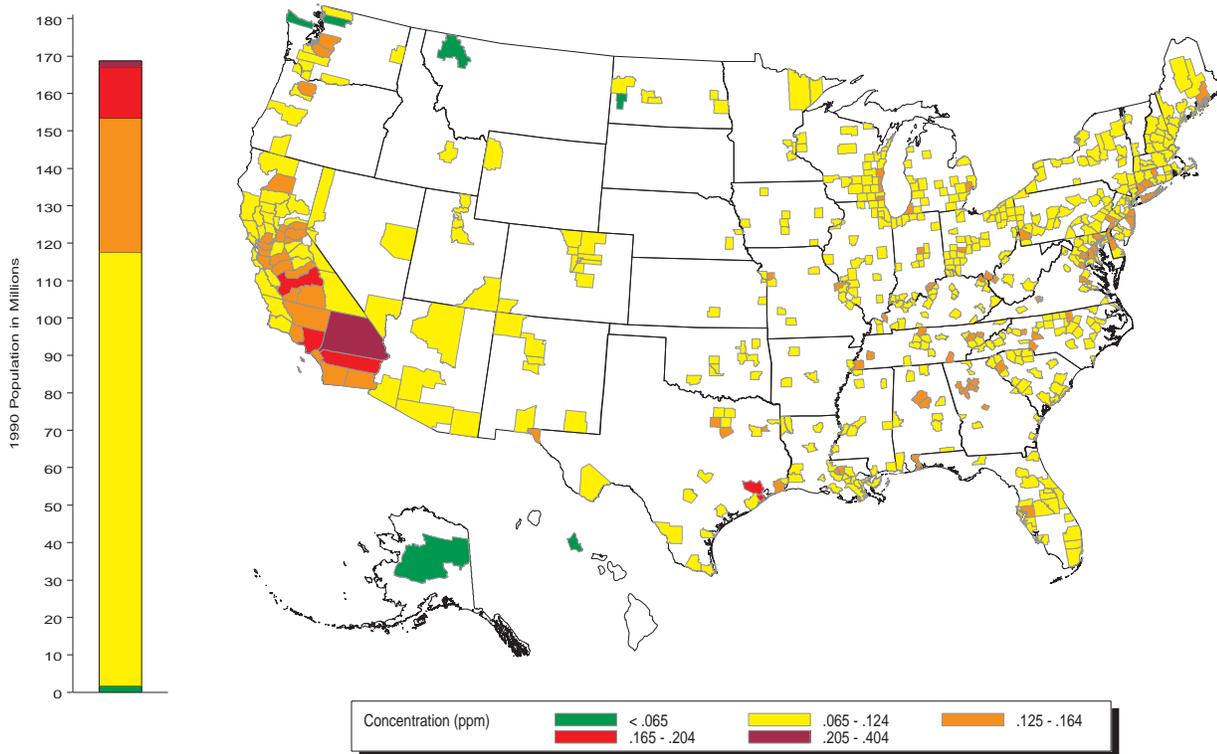
Table 2-4. Biogenic sources of VOC emissions by region.

Region	VOC	Source
Southwestern United States	Isoprene	Oak (mostly), citrus, eucalyptus
	Monoterpenes	Pine, citrus, eucalyptus
Northeastern United States	Isoprene	Oak (mostly), spruce
	Monoterpenes	Maple, hickory, pine, spruce, fir, cottonwood

As required by the CAA, the Federal Reformulated Gasoline Program (RFG) implemented in 1995 has resulted in emissions reductions that exceed those required by law.^{25, 26} However, the discovery of MTBE (one of two fuel oxygenates used in reformulated gasoline to help improve air quality) in the water supplies around the country has required examination of the approach used in this program. As previously described in the carbon monoxide section of this report, in November 1998, EPA Administrator Carol M. Browner announced the creation of a blue ribbon panel of leading experts from the public health and scientific communities, automotive fuels industry, water utilities, and local and state government to review the important issues posed by the use of MTBE and other oxygenates in gasoline. The Panel concluded that RFG provides considerable air quality improvements and benefits for millions of U.S. citizens. However, due to MTBE's persistence and mobility in water, and its likelihood to contaminate ground and surface water, the Panel recommended that its use in gasoline be substantially reduced.²⁷

In addition to anthropogenic sources of VOCs and NO_x, there are natural or biogenic sources of these compounds as well. Table 2-4 shows the different predominant plant species responsible for VOC emissions in different parts of the country for two major biogenic species of concern, isoprene and monoterpenes. Though it is not possible to control the level of these natural emissions, when developing ozone control strategies, their presence is an important factor to consider. Biogenic NO_x emissions are associated with lightning and biological processes in soil.

Figure 2-37. Highest second daily maximum 1-hour O₃ concentration by county, 1998.



On a regional basis, biogenic VOC emissions can be greater than anthropogenic VOC emissions. Biogenic NO_x emissions, on the other hand, are less than 10 percent of total NO_x emissions.²⁸

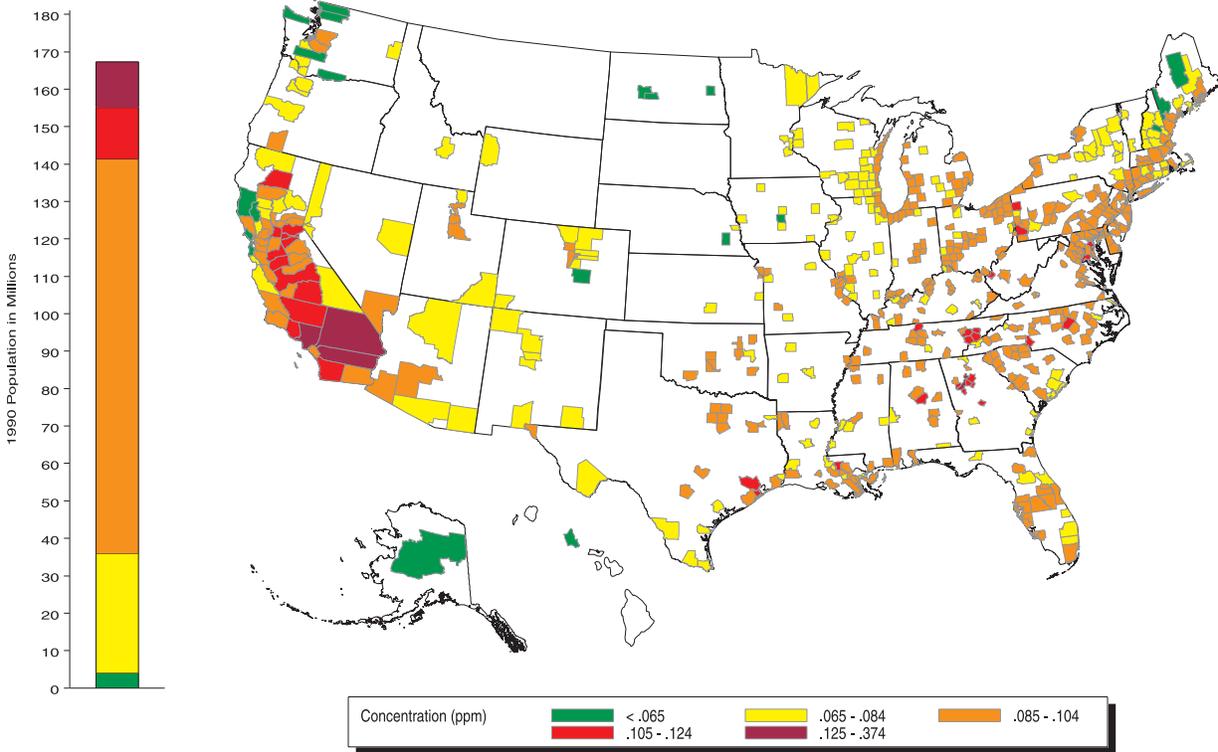
1998 Air Quality Status

The map in Figure 2-37 presents second highest daily maximum 1-hour ozone concentrations by county in 1998. The accompanying bar chart to the left of the map reveals that in 1998 approximately 51 million people lived in 92 counties where ozone concentrations were above the level of the 1-hour ozone NAAQS. These numbers represent an slight increase

from the totals reported last year (49 million people living in 77 counties) with ozone concentrations above the level of the ozone NAAQS in 1997. As noted previously, meteorological conditions in some regions of the country were more conducive to peak ozone formation in 1998, than in 1997. The map in Figure 2-37 shows large spatial differences, with higher ozone concentrations typically found in Southern California, the Gulf Coast, and the Northeast and North Central states. Historically, the highest 1-hour concentrations have been found in Los Angeles and this is again the case in 1998.

Figure 2-38 presents a map of fourth highest daily maximum 8-hour ozone values by county in 1998 and an accompanying bar chart of the number of people in counties corresponding to various air quality ranges. The map reveals widespread areas with high 8-hour ozone concentrations (i.e., greater than 0.084 ppm) in much of the eastern half of the country and in California as well as isolated counties in the West. The corresponding bar chart indicates that roughly 130 million people live in counties where fourth highest daily maximum 8-hour ozone concentrations were greater than 0.084 ppm.

Figure 2-38. Highest fourth daily maximum 8-hour O₃ concentration by county, 1998.



Air Quality Impact of Major Wildfires

Biomass burning has been recognized as having the potential for significantly impacting visibility as well as contributing to elevated ambient concentrations of ozone and particulate matter.^{1,2} Two severe wildfire incidents occurred during 1998 that affected ambient concentrations of ozone and particulate matter in specific areas of the United States. The first incident occurred late April to early June in Mexico and Central America, when thousands of fires of unusual intensity resulted in elevated air pollution levels. Figures 2-39 and 2-40 show NASA's images of the widespread area affected by smoke plumes that caused elevated pollution levels mainly for the central section of the United States. These images show levels of absorbing aerosol particles (airborne microscopic dust/smoke) from NASA's Total Ozone Mapping Spectrometer (TOMS) instrument. The TOMS data images have been used increasingly to understand the behavior of this material within the atmosphere. The TOMS is the first instrument to allow observation of aerosols as the particles cross the land/sea boundary. Using these data, it is possible to observe a wide range of phenomena such as desert dust storms, forest fires and biomass burning. In Figure 2-41, the smoke plumes almost two weeks later have diminished significantly from their earlier impacts on the United States. Guidance was issued by the Agency to assure that monitoring data was properly flagged and effects on air quality are adequately documented.³

Figure 2-39. Smoke/dust over North America for May 15, 1998.

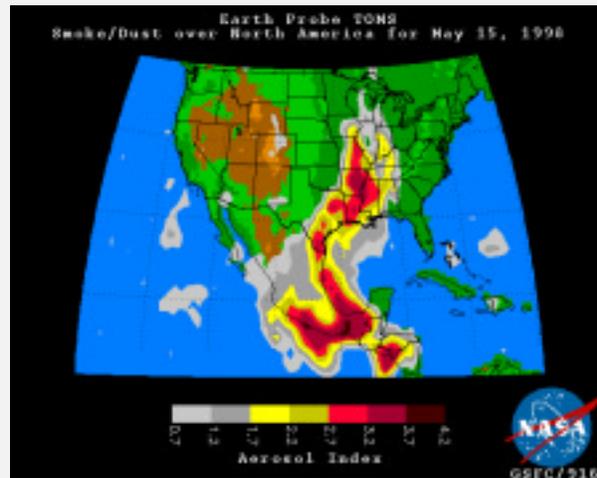


Figure 2-40. Smoke/dust over North America for May 16, 1998.

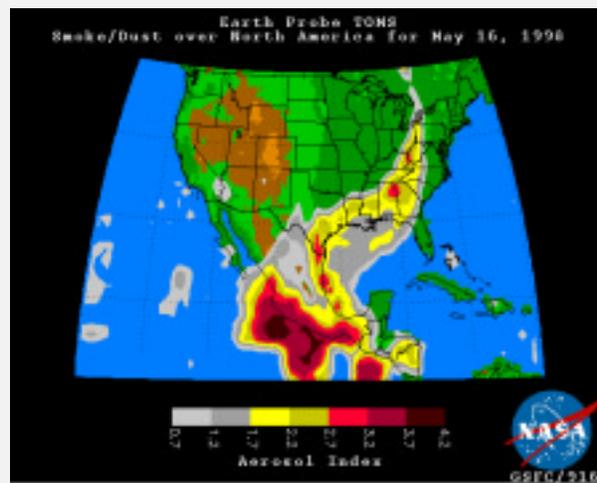


Figure 2-41. Smoke/dust over North America for May 28, 1998.

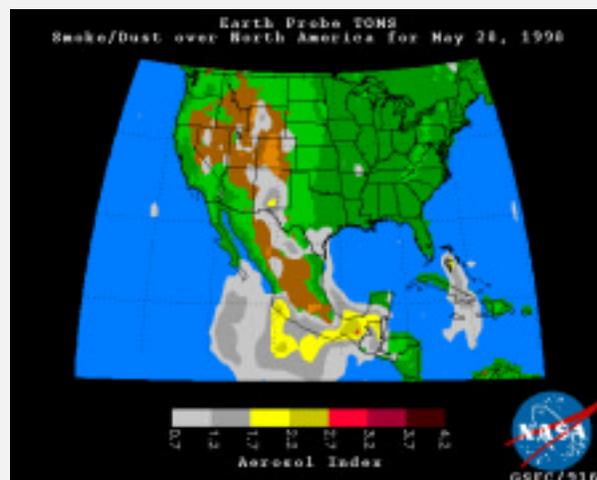
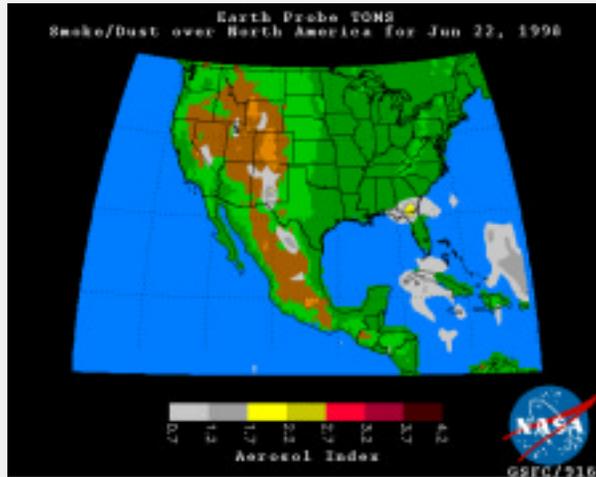
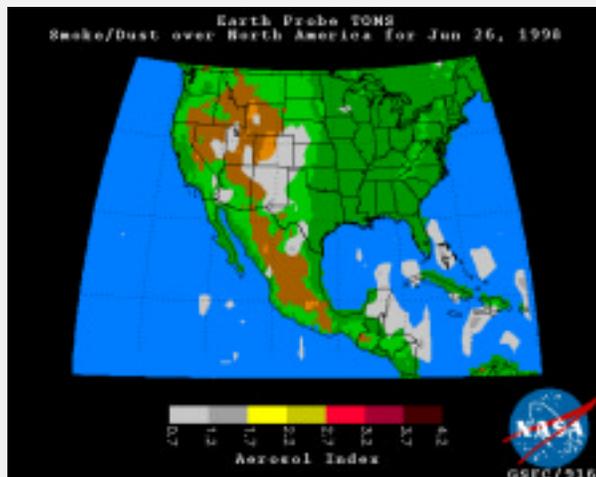


Figure 2-42. Smoke/dust over North America for June 22, 1998.**Figure 2-43.** Smoke/dust over North America for June 26, 1998.

In late June, a second significant wildfire incident occurred in Central Florida and also caused elevated air pollution levels. Figure 2-42 shows the areas of Florida affected by the smoke plumes. These plumes a week later, as shown in Figure 2-43, were over the Atlantic Ocean. The State of Florida worked closely with EPA regional offices, and the public was alerted to potential health concerns. The ambient monitoring data affected by these fires were also properly flagged and effects on air quality are adequately documented.

Ambient concentration data resulting from exceptional events, such as these, are excluded from the trends analyses and tables in this report because they are not indicative of typical air quality levels.

1. Mauzerall, D.L., et al, "Photochemistry in biomass burning plumes and implications for tropospheric ozone over the tropical South Atlantic," *Journal of Geophysical Research*, Vol. 103, Number. D7, 1998.
2. Andreae, M.O., et al, "Biomass-Burning Emissions and Associated Haze Layers Over Amazonia," *Journal of Geophysical Research*, Vol. 93, Number. D2, 1988.
3. Memorandum on "Guidance on Assessing the Impacts of May 1998 Mexican Fires on Ozone Levels in the United States" from John S. Seitz to all Regional Office Directors, 1998.

Particulate Matter

Air Quality Concentrations (PM ₁₀)		
1989–98	25%	decrease
1997–98		no change
Emissions (PM ₁₀)		
1989–98	19%	decrease
1997–98		no change

Nature and Sources

Particulate matter (PM) is the general term used for a mixture of solid particles and liquid droplets found in the air. These particles, which come in a wide range of sizes and shapes, originate from many different stationary and mobile sources, as well as from natural sources. They may be emitted directly by a source (direct emissions) or formed in the atmosphere by the transformation of gaseous precursor emissions such as SO₂ and NO_x (secondary particles). Their chemical and physical compositions vary depending on location, time of year, and meteorology.

Health and Environmental Effects

Scientific studies show a link between inhalable PM (alone, or combined with other pollutants in the air) and a series of significant health effects. Inhalable PM includes both fine and coarse particles. Fine particles are those that are less than 2.5 micrometers in diameter. Those between 2.5 and 10 micrometers are known as coarse particles. Both coarse and fine particles can accumulate in the respiratory system and are associated with numerous adverse health effects. Exposure to coarse particles is primarily associated with the aggravation of respiratory conditions such as asthma. Fine particles

are most closely associated with adverse health effects including decreased lung function, increased hospital admissions and emergency room visits, increased respiratory symptoms and disease, and premature death. Sensitive groups that appear to be at greatest risk to such PM effects include the elderly, individuals with cardiopulmonary disease such as asthma, and children.

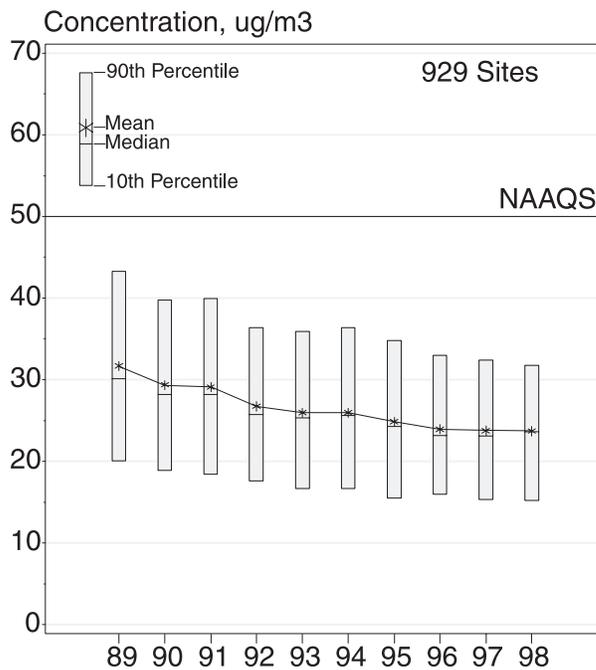
Particulate matter also can also cause adverse impacts to the environment. Fine PM is the major cause of reduced visibility in parts of the United States, including many of our national parks. Other environmental impacts occur when particles deposit onto soils, plants, water, or materials. For example, particles containing nitrogen and sulfur that deposit onto land or water bodies may change the nutrient balance and acidity of those environments so that species composition and buffering capacity change. An ecosystem condition known as “nitrogen saturation,” where additions of nitrogen to soil over time exceed the capacity of the plants and microorganisms to utilize and retain the nitrogen, has already occurred in some areas of the United States.

Particles that are deposited directly onto the leaves of plants can, depending on their chemical composition, corrode leaf surfaces or interfere with plant metabolism. When deposited in sufficient quantities, such as near unpaved roads, tilled fields, or quarries, particles block sunlight from reaching the leaves, stressing or killing the plant. Finally, PM causes soiling and erosion damage to materials, including culturally important objects such as carved monuments and statues.

Primary and Secondary PM Standards

The original standards for PM, established in 1971, were for total suspended particulate matter (TSP). In 1987, EPA replaced the TSP standards with PM₁₀ standards to focus on smaller particles of aerodynamic diameter less than or equal to 10 micrometers. These smaller particles cause greater health concern than TSP because of their ability to penetrate into sensitive regions of the respiratory tract. The standards for PM₁₀ include both short- and long-term NAAQS. The short-term (24-hour) standard of 150 µg/m³ is not to be exceeded more than once per year on average over three years. The long-term standard specifies an expected annual arithmetic mean not to exceed 50 µg/m³ averaged over three years. These are the primary, or health-based, PM₁₀ standards. The secondary, or welfare-based, standards for PM₁₀ are identical to the primary standards.

The most recent review of the PM standards concluded that still more protection from adverse health effects was needed. In July 1997, the primary (health-based) PM standards were revised to add two new PM_{2.5} standards, for protection from fine particles, and to change the form of the PM₁₀ standards. The new PM_{2.5} standards were set at 15 µg/m³ and 65 µg/m³, respectively, for the annual and 24-hour standards.²⁹ The secondary (welfare-based) PM_{2.5} standards were made identical to the primary standards, and will be implemented in conjunction with a revised visibility protection program to address regional haze in mandatory federal Class I areas (certain large national parks and wilderness areas).

Figure 2-44. Trend in annual mean PM₁₀ concentrations, 1989–1998.

In May 1999, however, the U.S. Court of Appeals for the D.C. Circuit issued an opinion concerning the revised particulate matter standards. The court vacated the revised PM₁₀ standard and remanded the PM_{2.5} standards back to EPA for further consideration. Following the denial of a petition for rehearing by the D.C. Circuit, the Justice Department has filed a petition for review before the Supreme Court.

National 10-Year Trends

The first complete year of PM₁₀ trends data for most monitors is 1988. Therefore, this is only the second time that the *Trends Report* has been able to present a full 10-year air quality trend for PM₁₀. Figure 2-44 shows a 25-percent decrease in the average of annual mean PM₁₀ concentrations measured at 929 monitoring sites across the country between 1989 and

1998. The downward trend in PM₁₀ annual means is apparent, with a leveling off of the trend occurring in the later years. The final year (1997–1998) shows no change. This same general trend can be seen if the sites are grouped as rural, suburban, and urban, as in Figure 2-45. The highest values are generally found at the urban sites, followed closely by the suburban sites. The PM₁₀ composite annual mean is significantly lower at the rural sites, which are generally located away from local sources of PM₁₀.

Several factors have played a role in reducing PM₁₀ concentrations. Where appropriate, states required emissions from industrial sources and construction activities to be reduced to meet the PM₁₀ standards. Measures were also adopted to reduce street dust emissions, including the use of clean anti-skid materials

like washed sand, better control of the amount of material used, and removal of the material from the street as soon as the ice and snow melt. Cleaner burning fuels like natural gas and fuel oil have replaced wood and coal as fuels for residential heating, industrial furnaces, and electric utility and industrial boilers.

Emissions Trends

Nationally, PM₁₀ direct emissions decreased 19 percent between 1989 and 1998 (see Figure 2-45). Direct PM₁₀ emissions are generally examined in two separate groups. First there are the more traditionally inventoried sources, shown in Figures 2-46 and 2-47. These include fuel combustion, industrial processes, and transportation. Of these, the fuel combustion category saw the largest decrease over the 10-year period (21 percent), with most of the decline attributable to a decrease in emissions from residential wood burning. Local control programs to curtail the use of residential wood heaters during times when the air was stagnant and to replace old woodstoves with new, cleaner-burning models are responsible for the decrease in residential wood burning, along with lower natural gas and fuel oil prices. Emissions from the industrial processes category decreased 20 percent, and emissions from the transportation category decreased 15 percent.

The second group of direct PM₁₀ emissions is a combination of miscellaneous and natural sources including agriculture and forestry, wildfires and managed burning, fugitive dust from paved and unpaved roads, and wind erosion. As Figure 2-48 shows, these miscellaneous and natural sources actually account for a large percentage of the total direct PM₁₀

emissions nationwide, although they can be difficult to quantify compared to the traditionally inventoried sources. The trend of emissions in the miscellaneous/natural group may be more uncertain from one year to the next or over several years because these emissions tend to fluctuate a great deal from year to year.

Table A-6 lists PM₁₀ emissions estimates for the traditionally inventoried sources for 1989–1998. Miscellaneous and natural source PM₁₀ emissions estimates are provided in Table A-7.

Regional Trends

Figure 2-49 is a map of regional trends for the PM₁₀ annual mean from 1989–1998. All 10 EPA regions show decreasing trends over the 10-year period, ranging from 18–38 percent declines. The largest decreases are generally seen in the western part of the United States. This is significant since the two westernmost regions, 9 and 10, started at the highest annual mean concentrations back in 1989. In the western states, programs such as those with residential wood heaters and agricultural practices have helped reduce emissions of PM₁₀. Soil moisture levels have also been higher (from more rainfall) in many western states in recent years. In the eastern United States, the Title IV Acid Rain Program has certainly contributed to the decrease in PM₁₀ emissions. The program has reduced SO₂ and NO_x emissions, both precursors of particulate matter in the atmosphere (see Chapter 7 on Atmospheric Deposition and the SO₂ section in this chapter for more information on the Acid Rain Program).

Figure 2-45. PM₁₀ annual mean concentration trends by location, 1989–1998.

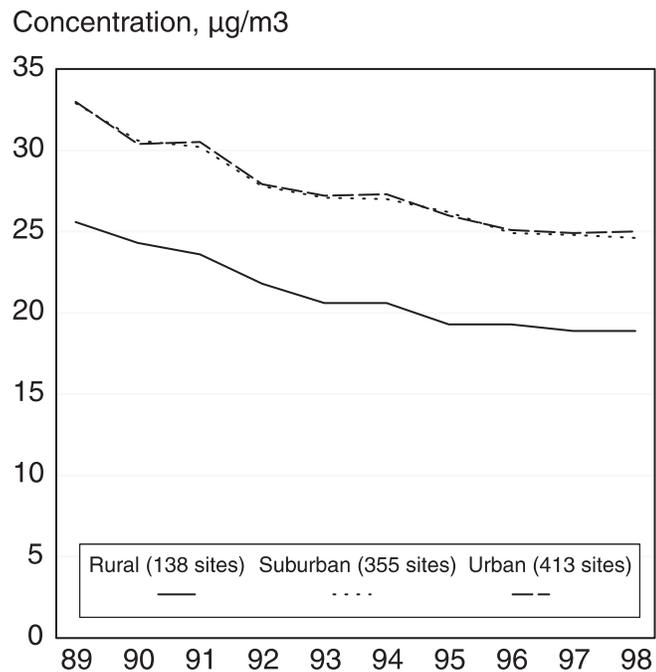


Figure 2-46. National PM₁₀ emissions trend, 1989–1998 (traditionally inventoried sources only).

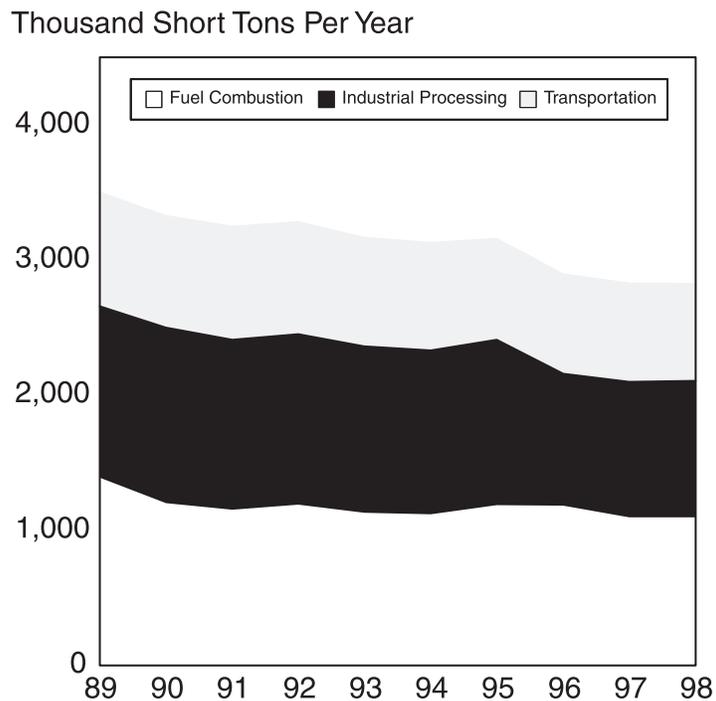
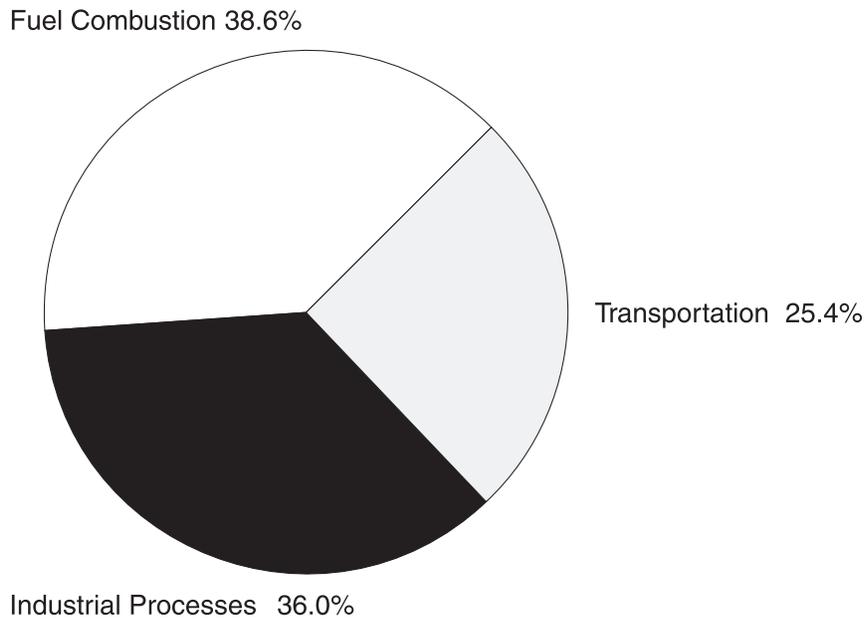


Figure 2-47. PM₁₀ emissions from traditionally inventoried source categories, 1998.



1998 Air Quality Status

The map in Figure 2-50 displays the highest second maximum 24-hour PM₁₀ concentration in each county for 1998. The largest of these was recorded in Inyo County, California, caused by wind blown dust from a dry lake bed. The bar chart which accompanies the national map shows the number of people living in counties within each concentration range. The colors on the map and bar chart correspond to the colors of the concentration ranges displayed in the map legend. In 1998, approximately 4 million people lived in 9 counties where the highest second maximum 24-hour PM₁₀ concentration was above the level of the 24-hour PM₁₀ NAAQS. When both the annual and 24-hour PM₁₀ standards are considered, there were 10 million people living in 13 counties with PM₁₀ concentrations above the NAAQS in 1998.

Figure 2-48. Total PM₁₀ emissions by source category, 1998.

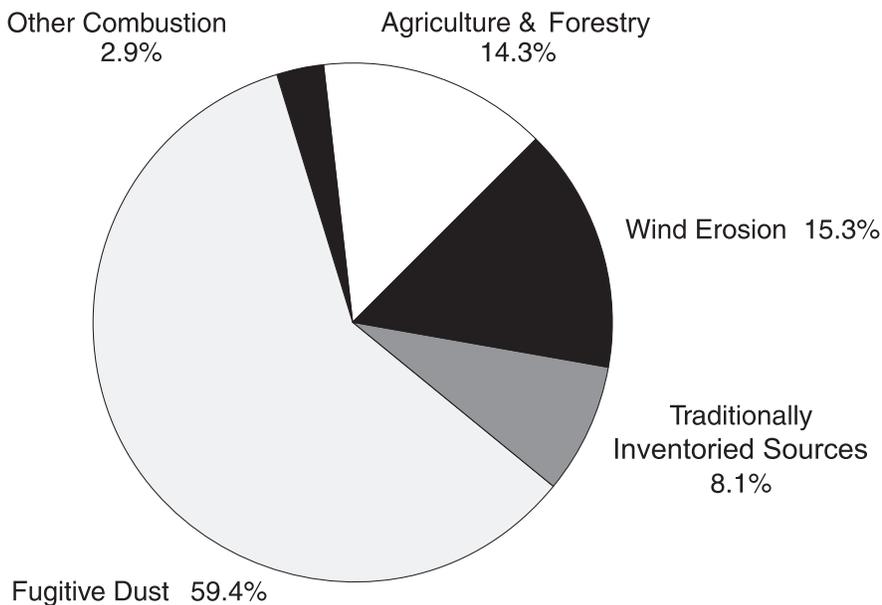


Figure 2-49. Trend in PM₁₀ annual mean concentration by EPA Region, 1989–1998.

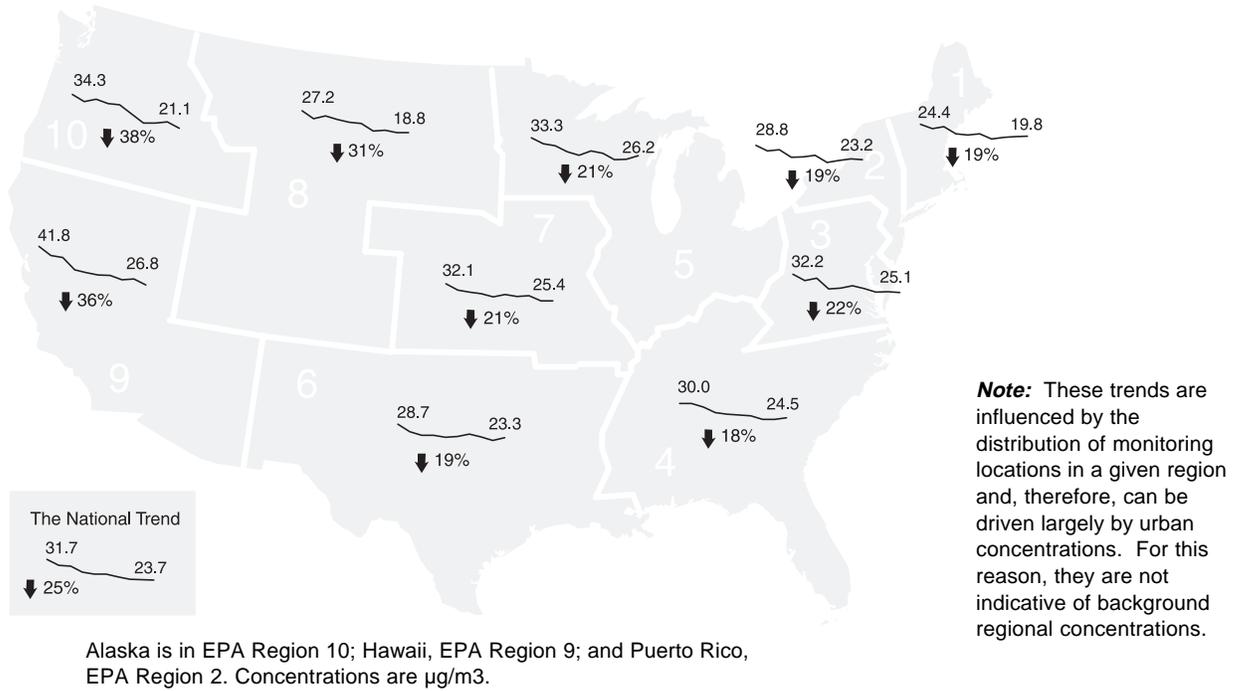
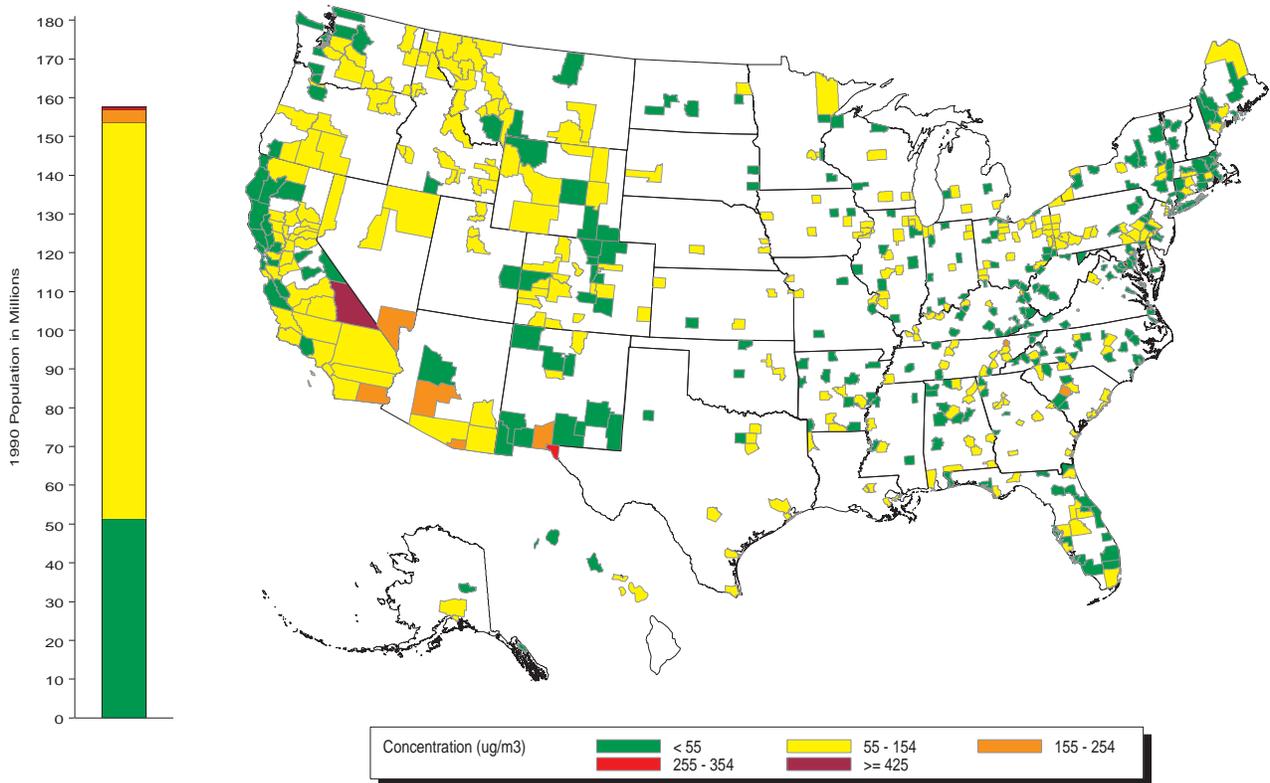


Figure 2-50. Highest 2nd maximum 24-hour PM₁₀ concentration by county, 1998.



Fine Particulate Matter (PM_{2.5})

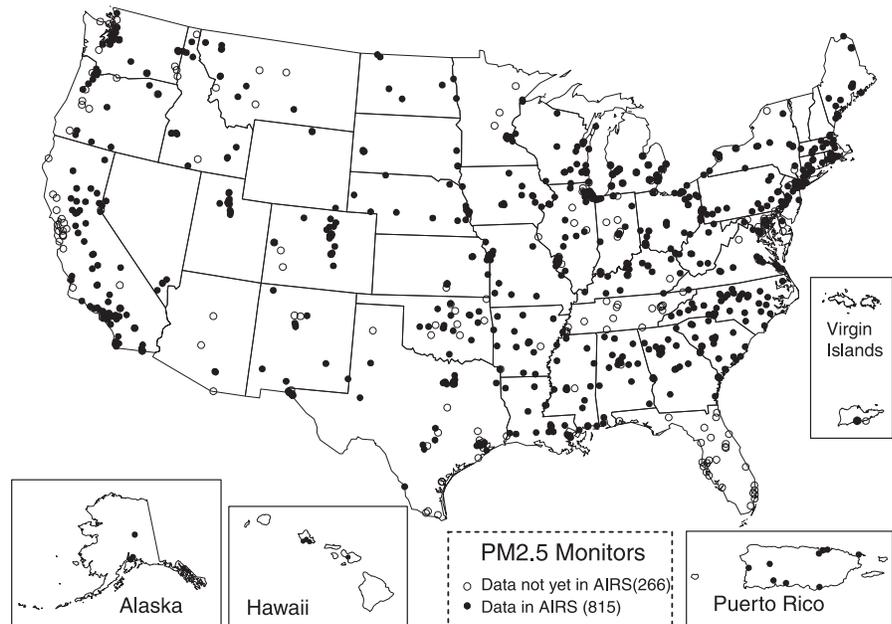
Characterizing PM_{2.5} Trends

A new monitoring network designed to assess fine PM data with respect to the new PM_{2.5} standards began deployment in early 1999. The status of this network is shown in Figure 2-51. As of February 2000, approximately 94 percent of the Federal Reference Method (FRM) monitoring sites were operating and 815 of them had already reported data to EPA's Aerometric Information Retrieval System (AIRS). Once deployment is completed in December 2000, the network will consist of approximately 1,700 monitors at over 1,100 sites. These monitors include the mass monitors (the FRMs), speciation sites, continuous monitoring sites, and additional Interagency Monitoring of Protected Visual Environments (IMPROVE) sites.

Since this monitoring network started in 1999, data from another network, the IMPROVE network of predominately rural sites, were used to assess ambient PM_{2.5} concentrations in this report. Since the monitors in the IMPROVE network are non-FRM, the data cannot be used for compliance purposes (i.e., to tell whether or not an area meets the PM_{2.5} standard). They do, however, provide a good indication of PM_{2.5} concentrations and compositions over broad regions of the country.

The IMPROVE network was established in 1987 to track visibility impairment in the nation's most pristine areas, like national parks and wilderness areas. (The IMPROVE network is discussed in further detail in Chapter 6: Visibility Trends.) For this reason, the data primarily represent rural areas. There is, however, one

Figure 2-51. Status of new PM_{2.5} Monitor Deployment, based on AIRS February, 2000.



urban site (Washington, D.C.) in the network with adequate trend data. Data from this site and other sites meeting data completeness criteria described in Appendix B, are presented in this section. Figure 2-52 shows the location of these sites by region.

1998 Rural PM_{2.5} Concentrations and Composition

Rural PM_{2.5} concentrations vary regionally. Sites in the east typically have higher annual mean concentrations. Figure 2-53 shows annual mean concentrations for 1998 and reveals the natural break that forms between the eastern and western halves of the country. Some comparisons can be made between the two regions. Of the 12 eastern sites, 10 have higher annual averages of measured PM_{2.5} than any sites in the west. In fact, most sites in the west are roughly less than half of those in the east. This difference is mainly

due to higher sulfate concentrations in the east. Sulfate concentrations in the eastern sites are 4–5 times greater than those in the western sites. Electric utilities account for 71 percent of the SO₂ emissions in the eastern United States. The trend in ambient sulfates and sulfur dioxides both appear to generally correspond to the change in annual sulfur dioxide emissions from electric utilities in the eastern United States. In the most recent year (1997–1998), sulfate concentrations increased 10 percent in the East (as shown later in Figure 2-54). (Atmospheric deposition of sulfur and nitrogen compounds is discussed in further detail in Chapter 7).

The chemical composition of PM_{2.5} also varies regionally. Sulfate and organic carbon account for most of the PM_{2.5} concentrations in the east and the west. Sites in the east on average have a higher percentage of sulfate concentrations (56 percent)

Figure 2-52. Class I Areas in the IMPROVE Network meeting the data completeness criteria in Appendix B.



Figure 2-53. Annual average 1998 PM_{2.5} concentrations (in µg/m³) at IMPROVE sites and contribution by individual constituents. Pie chart sizes are scaled by annual average PM_{2.5} concentrations.

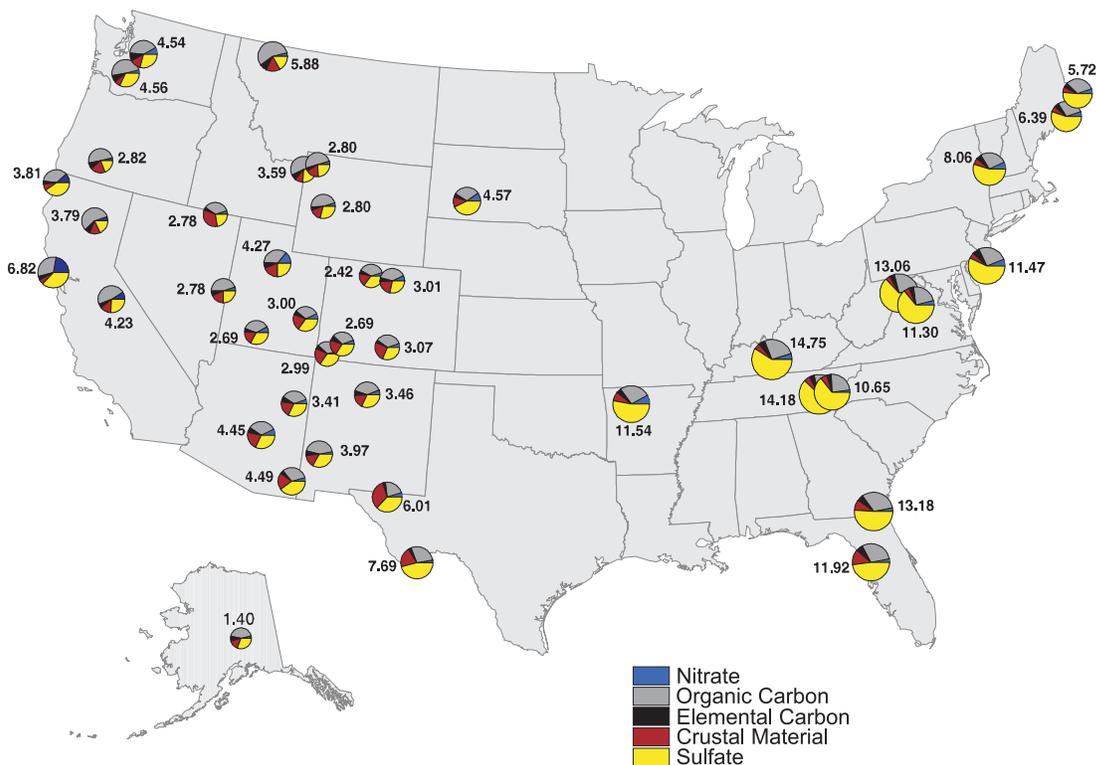


Figure 2-54. PM_{2.5} Concentrations, 1989–1998 at eastern IMPROVE sites meeting trends criteria.

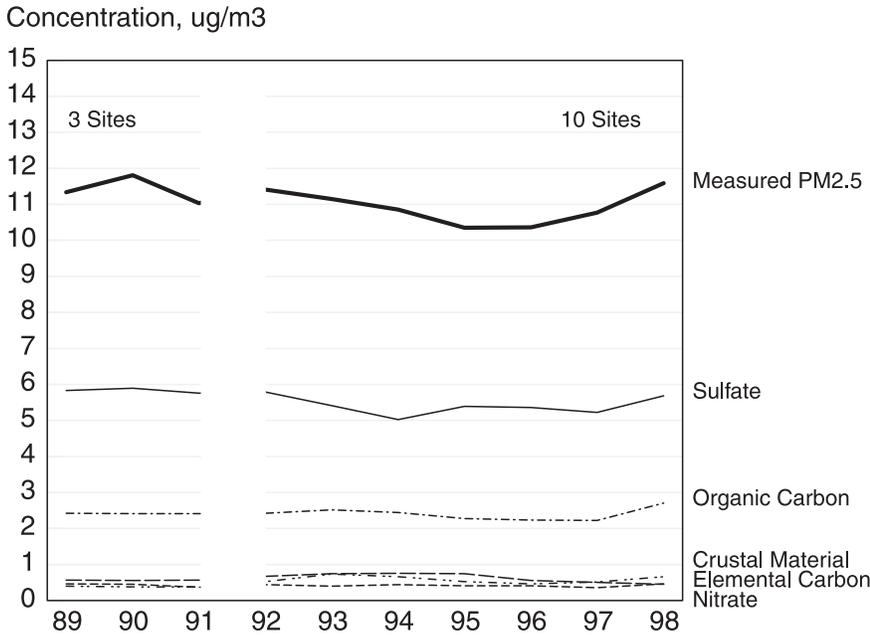
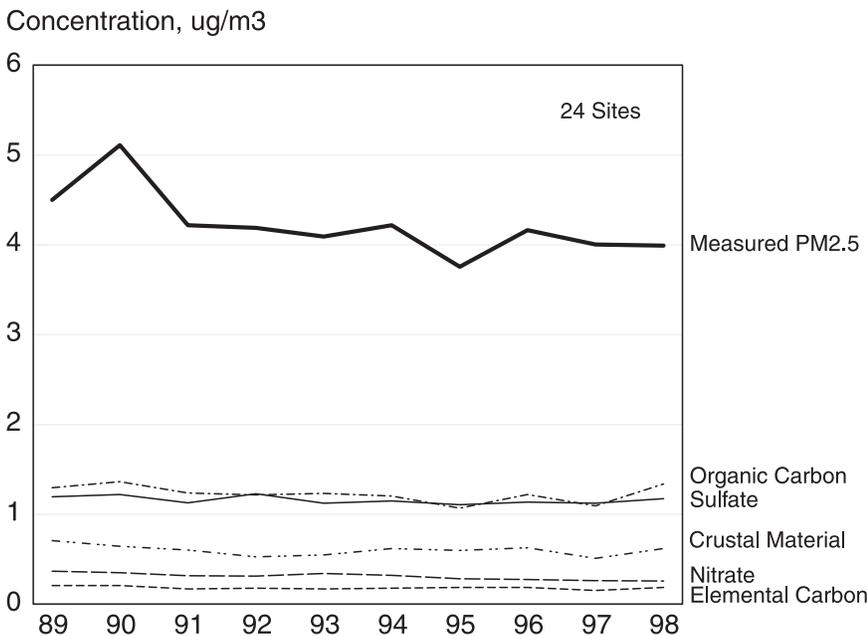


Figure 2-55. PM_{2.5} Concentrations, 1989–1998 at western IMPROVE sites meeting trends criteria.



relative to those in the west (33 percent). Table 2-5 shows the difference in percent contribution of each species for the eastern versus western regions of the United States.

Table 2-5. Percent Contribution to PM_{2.5} by Component, 1998

	East	West
Sulfate	56	33
Elemental Carbon	5	6
Organic Carbon	27	36
Nitrate	5	8
Crustal Material	7	17

10-Year Trends

Rural

Because of the significant regional variations in rural PM_{2.5} concentrations, trends are aggregated by eastern and western regions as shown in Figures 2-54 and 2-55. Based on the 10 sites with trend data in the East, measured PM_{2.5} concentrations decreased 9 percent between 1992 and 1995, then increased 12 percent from 1995 to 1998. The net change between 1992 and 1998 is a 2 percent increase. Trends in the West, though, decreased 5 percent during the 1992 to 1998 period and decreased 11 percent over the longer, 10-year period from 1989 to 1998.

Measured mass represents the direct mass measurement from the filter. The individual concentrations do not equal this value because they do not account for all measured mass. For more information on the IMPROVE network, visit http://alta_vista.cira.colostate.edu/.

Urban

The Washington, D.C. site is not grouped with the other eastern sites because it has much higher concentrations. Figure 2-56 shows that

PM_{2.5} concentrations decreased 5 percent between 1989 and 1997. Data for this site was incomplete for 1998. The available, incomplete data indicate that the trend might have increased slightly 1997–1998 consistent with the eastern rural sites. The elevated levels from 1991 to 1994 are primarily due to changes in sulfate concentrations.

Seasonal Trends

Figure 2-57 shows the 1998 seasonal patterns for PM_{2.5} at eastern and western IMPROVE sites. These sites were selected to represent typical patterns across the two regions. Each square, or tile, represents one day of the year. The color of each tile corresponds to the daily PM_{2.5} concentration level. Higher levels are yellow and orange. The chronological arrangement of daily concentrations over the course of the year reveals that summer months typically experience higher PM_{2.5} concentrations. Daily concentrations at some sites are more variable throughout the year and do not necessarily follow this pattern as closely. Most western sites experience few, if any, days with concentrations above 15 µg/m³, while most eastern sites regularly exceed this value in the summertime. In fact, daily levels at the highest annual mean site in the west (Big Bend) are comparable to the second lowest annual mean site in the east (Acadia). Both sites had six days with concentrations above 15 µg/m³ in 1998.

Figure 2-56. PM_{2.5} Concentrations, 1989-1998, at the Washington, D.C. IMPROVE site.

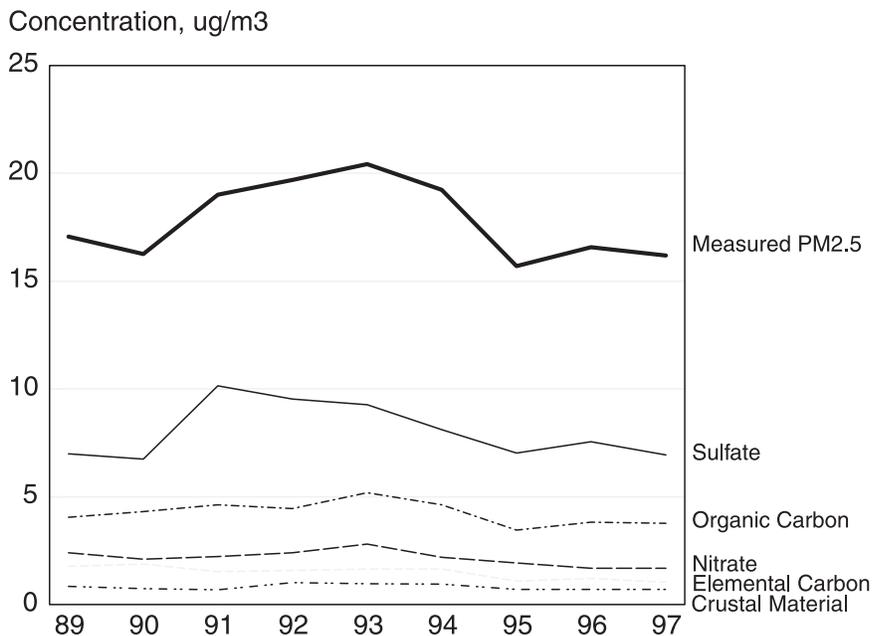
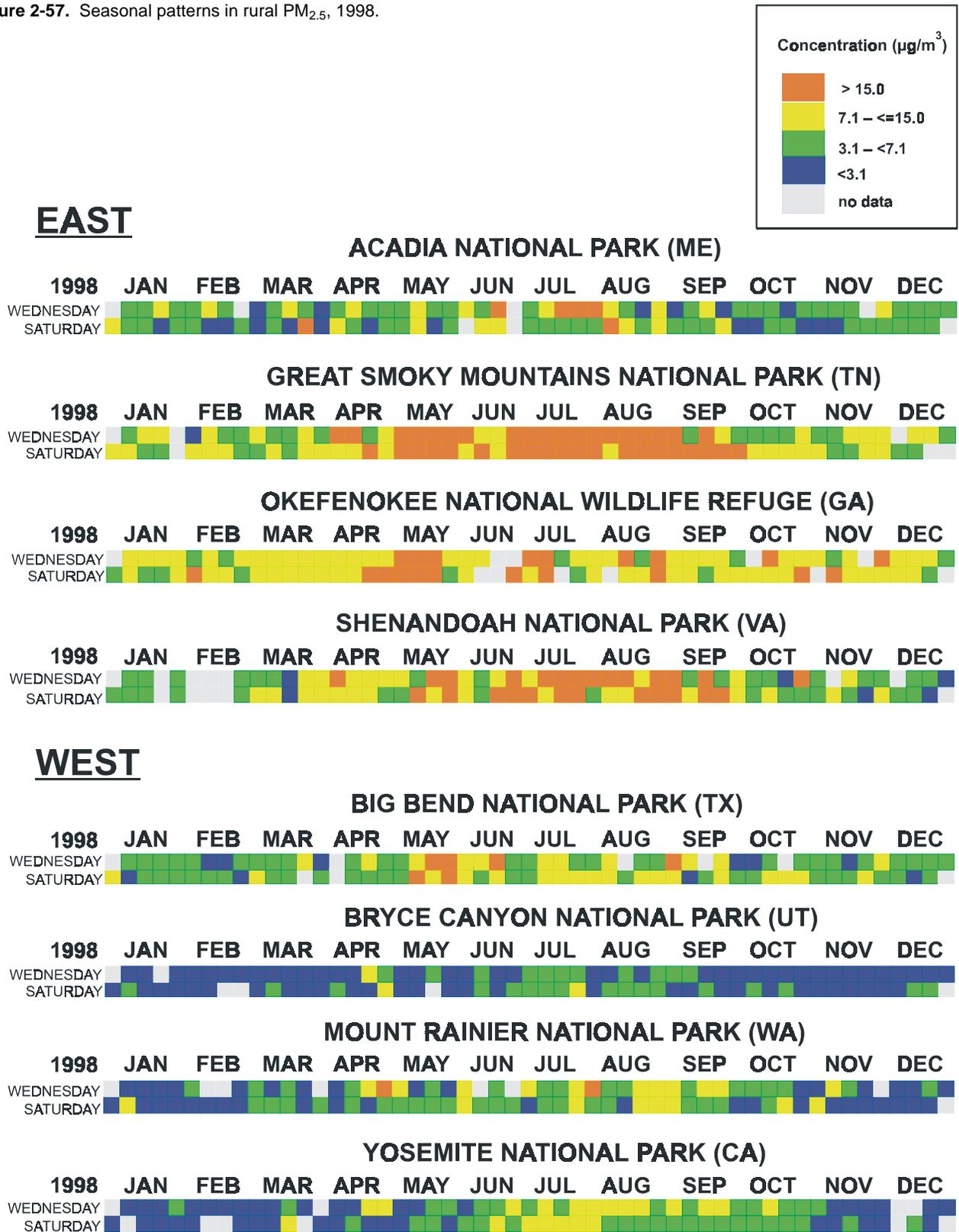


Figure 2-57. Seasonal patterns in rural PM_{2.5}, 1998.



Sulfur Dioxide

Air Quality Concentrations		
1989–98	39%	decrease
1997–98	2%	decrease
Emissions		
1989–98	16%	decrease
1997–98		no change

Nature and Sources

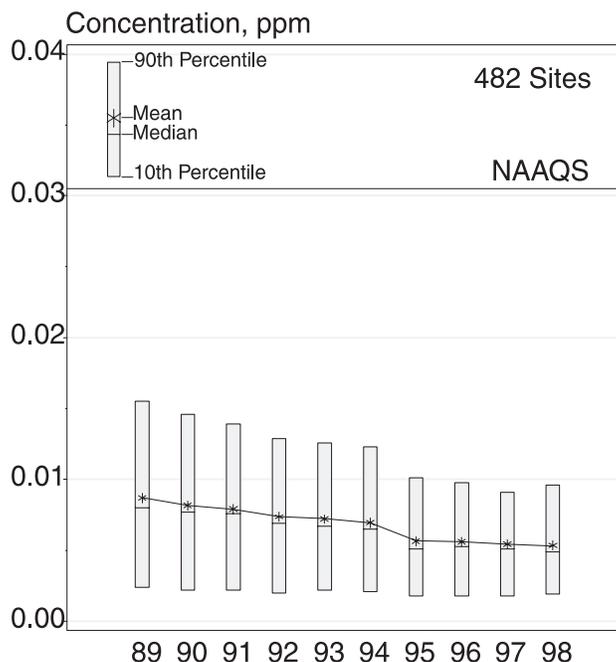
Sulfur dioxide (SO₂) belongs to the family of sulfur oxide (SO_x) gases. These gases are formed when fuel containing sulfur (mainly coal and oil) is burned, and during metal smelting and other industrial processes. The highest monitored concentrations of SO₂ have been recorded in the vicinity of large industrial facilities.

Health and Environmental Effects

High concentrations of SO₂ can result in temporary breathing impairment for asthmatic children and adults who are active outdoors. Short-term exposures of asthmatic individuals to elevated SO₂ levels while at moderate exertion may result in reduced lung function that may be accompanied by symptoms such as wheezing, chest tightness, or shortness of breath. Other effects that have been associated with longer-term exposures to high concentrations of SO₂, in conjunction with high levels of PM, include respiratory illness, alterations in the lungs' defenses, and aggravation of existing cardiovascular disease. The subgroups of the population that may be affected under these conditions include individuals with cardiovascular disease or chronic lung disease, as well as children and the elderly.

Additionally, there are a variety of environmental concerns associated

Figure 2-58. Trend in annual mean SO₂ concentrations, 1989–1998.



with high concentrations of SO₂. Because SO₂, along with NO_x, is a major precursor to acidic deposition (acid rain), it contributes to the acidification of soils, lakes and streams and the associated adverse impacts on ecosystems (see Chapter 7, Atmospheric Deposition of Sulfur and Nitrogen Compounds). Sulfur dioxide exposure to vegetation can increase foliar injury, decrease plant growth and yield, and decrease the number and variety of plant species in a given community. Sulfur dioxide also is a major precursor to PM_{2.5}, which is of significant concern to human health (as discussed in the particulate matter section of this chapter), as well as a main pollutant that impairs visibility (see Chapter 6, Visibility Trends). Finally, SO₂ can accelerate the corrosion of natural and man-made materials (e.g., concrete and limestone) which are used in buildings and monuments, as well as paper, iron-containing metals, zinc and other protective coatings.

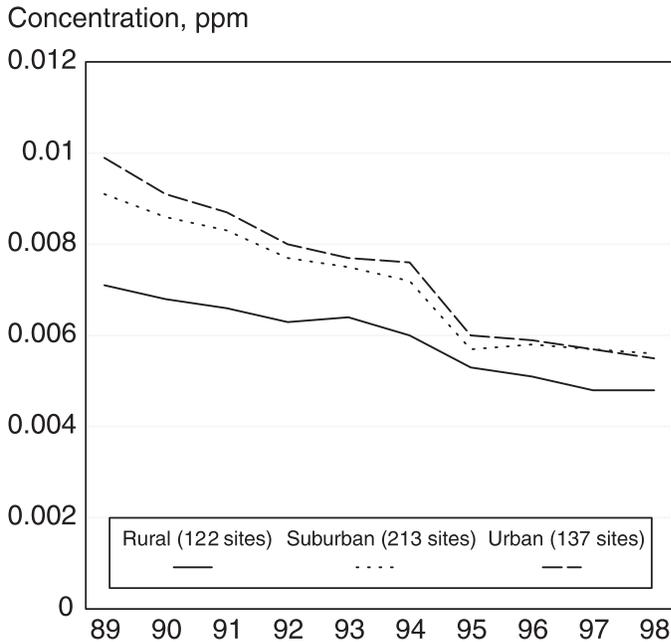
Primary and Secondary Standards

There are both short- and long-term primary NAAQS for SO₂. The short-term (24-hour) standard of 0.14 ppm (365 µg/m³) is not to be exceeded more than once per year. The long-term standard specifies an annual arithmetic mean not to exceed 0.030 ppm (80 µg/m³). The secondary NAAQS (3-hour) of 0.50 ppm (1,300 µg/m³) is not to be exceeded more than once per year.

National 10-Year Trends

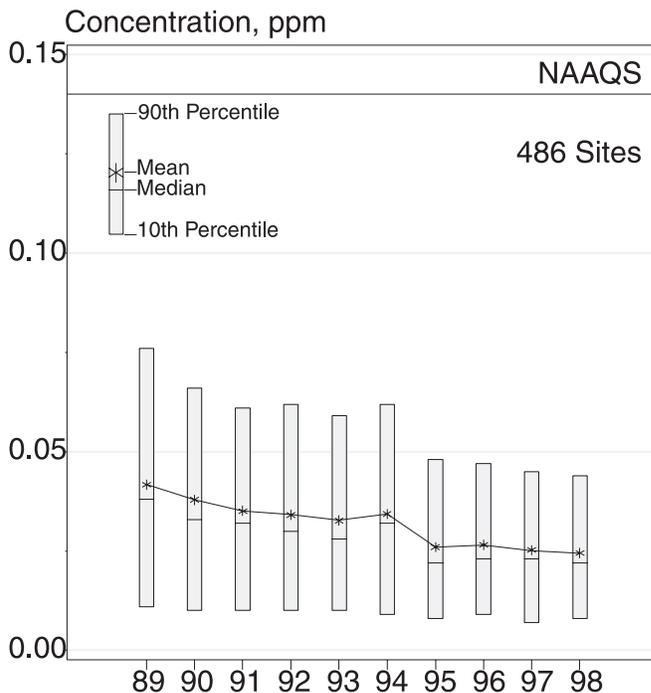
The national composite average of SO₂ annual mean concentrations decreased 39 percent between 1989 and 1998 as shown in Figure 2-58, with the largest single-year reduction (16 percent) occurring between 1994 and 1995.³⁰ The trend has since leveled off, declining only 2 percent from 1997–1998. This same general trend is seen in Figure 2-59, which plots the ambient concentrations grouped by rural, suburban, and urban

Figure 2-59. Annual mean SO₂ concentration by trend location, 1989–1998.



It shows that the mean concentrations at the urban and suburban sites are consistently higher than those at the rural sites. However, the 1994–1995 reduction in the concentrations at non-rural sites does narrow the gap between the trends. The greater reduction seen in the non-rural sites reflects the fact that the proportion of non-rural sites is greater in the eastern United States, which is where most of the 1994–1995 emissions reductions at electric utilities occurred.³¹ The national composite second maximum 24-hour SO₂ annual mean concentrations decreased 42 percent between 1989 and 1998, as shown in Figure 2-60, with the largest single-year reduction (25 percent) occurring between 1994 and 1995. See also Chapter 7, Atmospheric Deposition of Sulfur and Nitrogen Compounds.

Figure 2-60. Trend in 2nd max 24-hour average SO₂ concentrations, 1989–1998.



Emissions Trends

National SO₂ emissions decreased 16 percent between 1989 and 1998, with a sharp decline between 1994 and 1995, similar to the decline in the ambient concentrations. Unlike the air quality trend, however, the emissions trend begins to climb again from 1995–1998, as shown in Figure 2-61. This dramatic reduction and subsequent increase is driven by the yearly changes in emissions from the electric utility industry. Much of the increase was caused by units not yet affected by the acid rain program. These units will be in the program and subject to a national emissions cap beginning in 2000. The electric utility industry accounts for most of the fuel combustion category in Figure 2-62. In particular, the coal-burning power plants have consistently been the largest contributor to SO₂ emissions, as documented in Table A-8 in Appendix A. See also Chapter

7, Atmospheric Deposition of Sulfur and Nitrogen Compounds.

The Acid Rain Program

The national reductions from 1994–1995 in emissions and ambient concentrations of SO₂ are due mainly to Phase I implementation of the Acid Rain Program. Established by EPA under Title IV of the CAA, the Acid Rain Program’s principal goal is to achieve significant reductions in SO₂ and NO_x emissions. Phase I compliance for SO₂ began in 1995 and significantly reduced emissions from the participating utilities.³² Table 2-6 shows this reduction in terms of Table 1 units (units required to participate in Phase I) and Non-Table I and other units. The 1994–1995 decrease in total SO₂ emissions from electric utilities is due largely to the Phase I emissions reduction.

Since 1995, however, total SO₂ emissions from electric utilities have increased. Again, Table 2-6 explains this increase in terms of Table I units and Non-Table I units. Most Phase I plants over-complied in 1995, banking their emission allowances for use in Phase II, which begins in 2000. As a result, SO₂ emissions have increased slightly at some Phase I sources since the initial 1995 reduction. However, Table I units account for only 18 percent of the total 1995 to 1998 increase. The majority of the increase is attributed to those units not yet participating in the Acid Rain Program. Most of these units will be included in Phase II of the Program. When fully implemented, total SO₂ emissions from electric utilities will be capped at 8.95 million tons per year. For more information on the Acid Rain Program, visit <http://www.epa.gov/airmarkets>. See also

Table 2-6. Total SO₂ Emissions from Table I units and Non-Table I units, 1994–1998 (thousand short tons).

	1994	1995	1996	1997	1998	Percent Change	
						1994–95	1995–98
Phase I units³³	7,379	4,455	4,760	4,766	4,660	-40	+5
Non-Phase I units	7,510	7,625	7,871	8,324	8,557	+2	+12
All Electric Utility units	14,889	12,080	12,631	13,090	13,217	-19	+9

Figure 2-61. National total SO₂ emissions trend, 1989–1998.

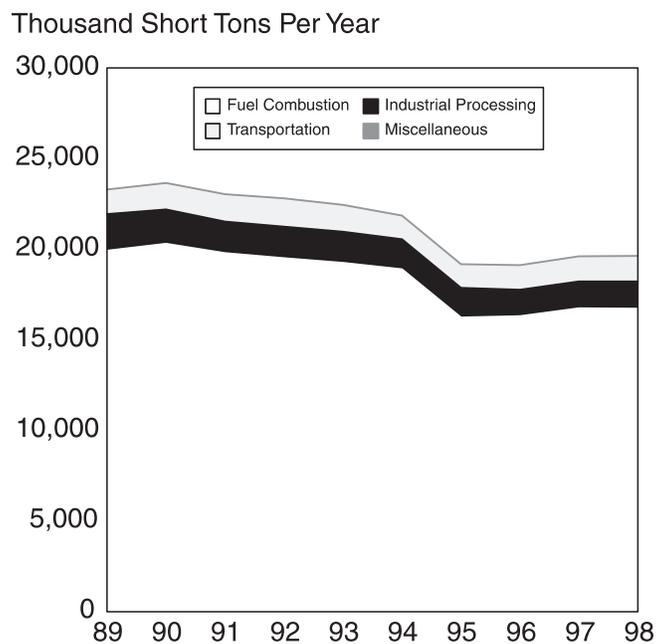


Figure 2-62. SO₂ emissions by source category, 1998.

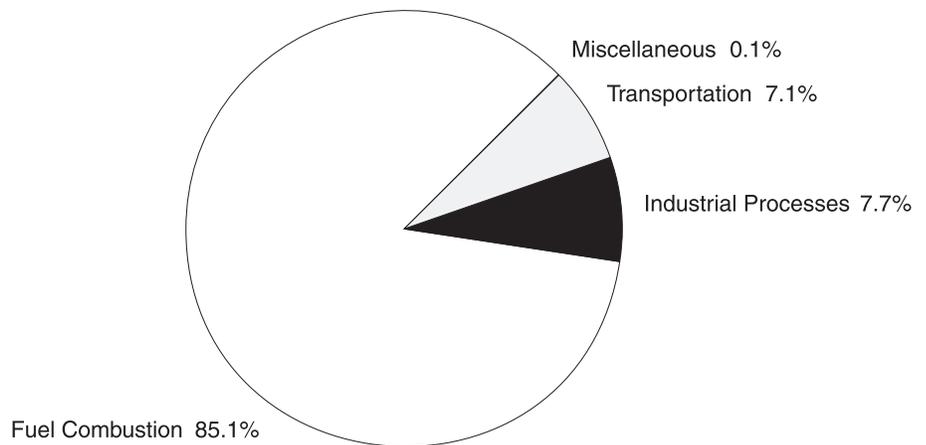
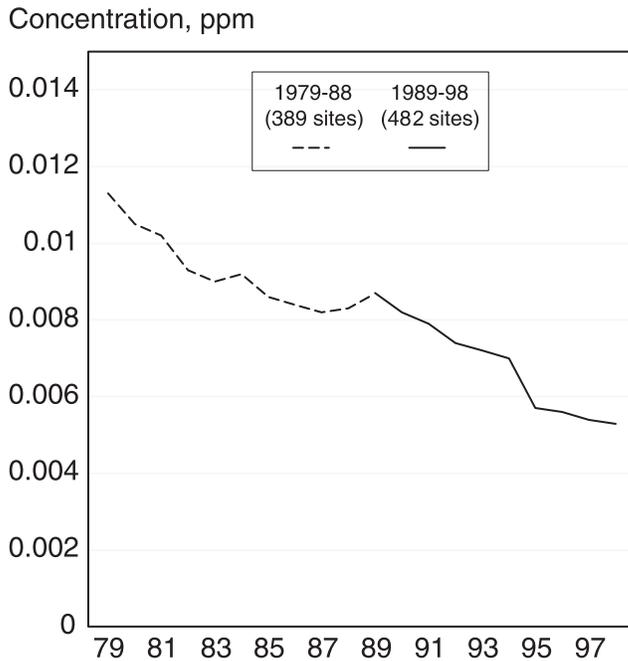


Figure 2-63. Long-term ambient SO₂ trend, 1979–1998.

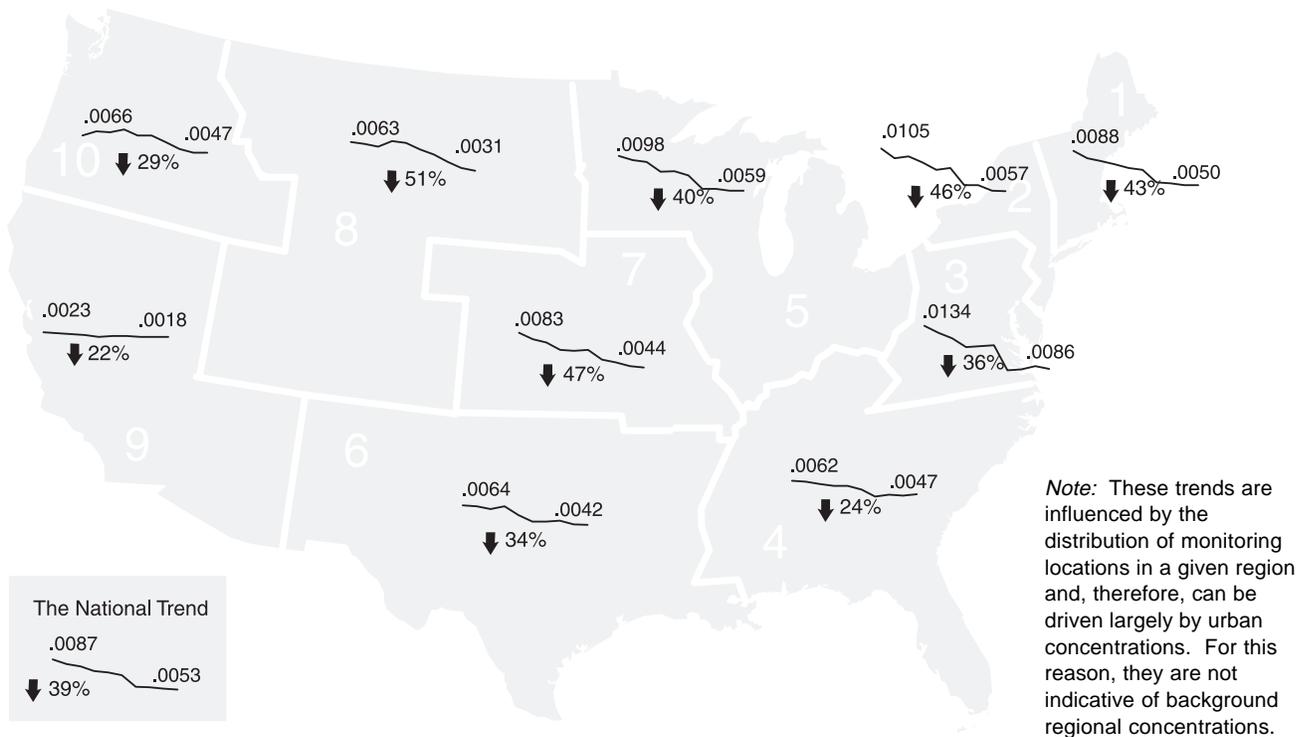


Chapter 7, Atmospheric Deposition of Sulfur and Nitrogen Compounds.

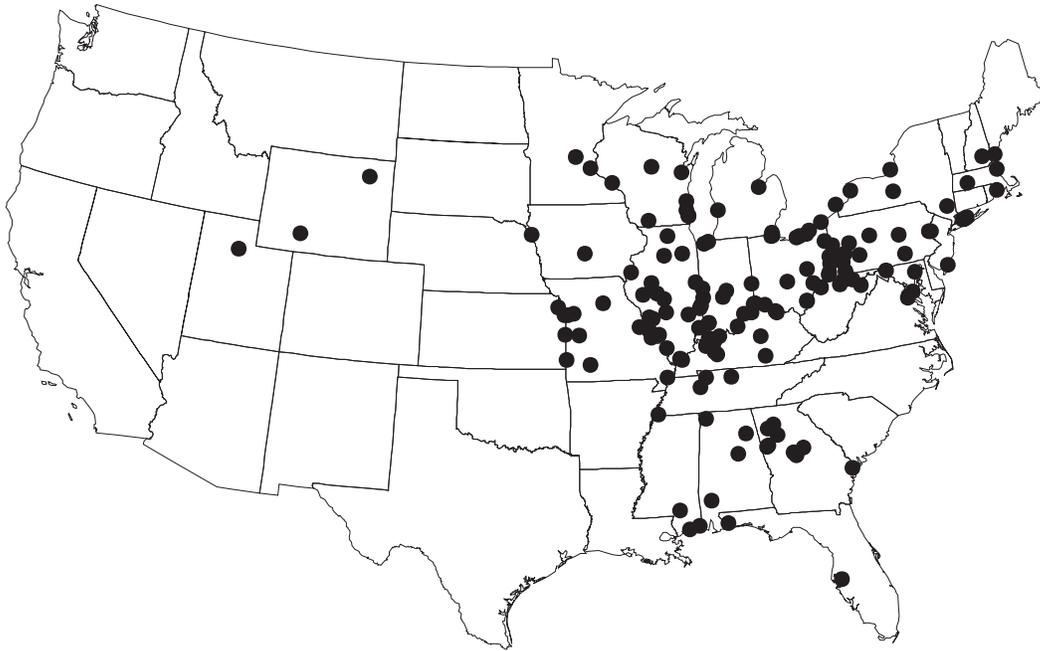
National 20-Year Trends

The progress in reducing ambient SO₂ concentrations during the past 20 years is shown in Figure 2-63. While there is a slight disconnect in the trend line between 1988 and 1989 due to the mix of trend sites in each 10-year period, an overall downward trend is evident. The national 1998 composite average SO₂ annual mean concentration is 53 percent lower than 1979. In addition to the previously mentioned effects of the Acid Rain Program, these steady reductions over time were accomplished by installing flue-gas control equipment at coal-fired generating plants, reducing emissions from industrial

Figure 2-64. Trend in SO₂ annual arithmetic mean concentration by EPA Region, 1989–1998.



Alaska is in EPA Region 10; Hawaii, EPA Region 9; and Puerto Rico, EPA Region 2. Concentrations are ppm.

Figure 2-65. Plants affected by Phase I of the Acid Rain Program.

processing facilities such as smelters and sulfuric acid manufacturing plants, reducing the average sulfur content of fuels burned, and using cleaner fuels in residential and commercial burners.

Regional Trends

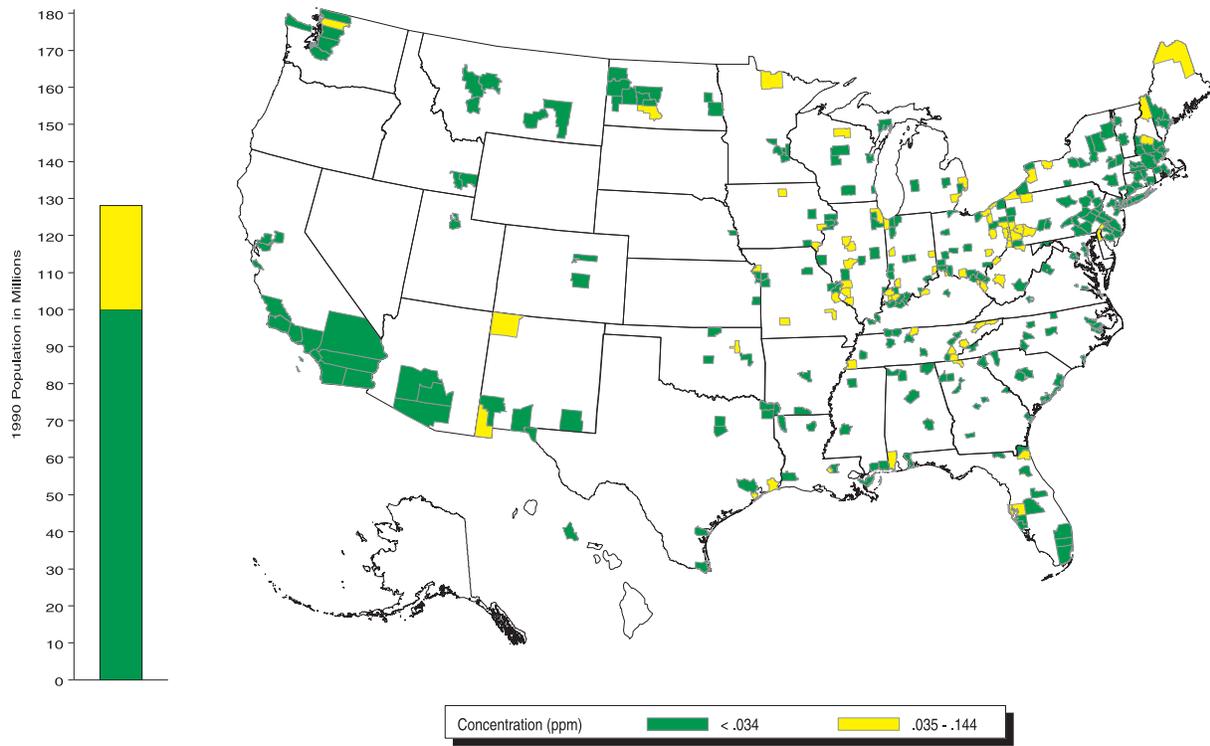
The map of regional trends in Figure 2-64 shows that ambient SO_2 concentrations are generally higher in the northeastern United States. The effects of Phase I of the Acid Rain Program are seen most vividly in the

northeast. In particular, concentrations fell 20–25 percent between 1994 and 1995 in EPA Regions 1, 2, 3, and 5. These broad regional trends are not surprising since most of the units affected by Phase I of the Acid Rain Program also are located in the east as shown in Figure 2-65. This figure also shows that ambient concentrations have increased slightly between 1995 and 1997 in Regions 3 and 4 where many of the electric utility units not yet affected by the Acid Rain Program are located.

1998 Air Quality Status

The most recent year of ambient data shows that all counties did meet the primary SO_2 short-term standard, according to Figure 2-66.

Figure 2-66. Highest 2nd maximum 24-hour SO₂ concentration by county, 1998.



References

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2. *Guidelines for Oxygenated Gasoline Credit Programs and Guidelines on Establishment of Control Periods Under Section 211(m) of the Clean Air Act as Amended*, 57 FR 47853 (October 20, 1992).
3. *Interagency Assessment of Oxygenated Fuels*, National Science and Technology Council, Executive Office of the President, Washington, D.C., June 1997.
4. G. Whitten, J. Cohen, and A. Kuklin, *Regression Modeling of Oxyfuel Effects on Ambient CO Concentrations: Final Report*, SYSAPP-96/78, prepared for the Renewable Fuels Association and Oxygenated Fuels Association by System Applications International, Inc., San Rafael, CA, January 1997.
5. Cook, J. R., P. Enns, and M. S. Sklar, *Regression Analysis of Ambient CO Data from Oxyfuel and Nonoxyfuel Areas*, Paper No. 97-RP139.02, Air and Waste Management Association 90th Annual Meeting, Toronto, Ontario, June 1997.
6. *Achieving Clean Air and Water: The Report of the Blue Ribbon Panel on Oxygenates in Gasoline*, EPA-420-R-99-021, U.S. Environmental Protection Agency, Office of Mobile Sources, Washington, D.C., September 15, 1999 Proposed Rule," *Federal Register*, 62 FR 60317, Washington, D.C., November 7, 1997.
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8. "Review of the National Ambient Air Quality Standards for Nitrogen Oxides: Assessment of Scientific and Technical Information," EPA-452/R-95-005, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1995.
9. J. H. Seinfeld and S. N. Pandis, *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, John Wiley & Sons, Inc., New York, NY, 1998.
10. "1998 Compliance Report," U.S. Environmental Protection Agency, Acid Rain Program, Washington, D.C., August 1999.
11. "Approval and Promulgation of State Implementation Plans and Redesignation of the South Coast Air Basin in California to Attainment for Nitrogen Dioxide; Direct Final Rule," *Federal Register*, 63 FR 39747, Washington, D.C., July 24, 1998.
12. "Identification of Ozone Areas Attaining the 1-hour Standard and to Which the 1-hour Standard is No Longer Applicable; Final Rule," *Federal Register*, 63 FR 2804, Washington, D.C., June 5, 1998.
13. "Identification of Additional Ozone Areas Attaining the 1-hour Standard and to Which the 1-hour Standard is No Longer Applicable; Final Rule," *Federal Register*, 63 FR 39431, Washington, D.C., July 22, 1998.
14. "Identification of Additional Ozone Areas Attaining the 1-hour Standard and to Which the 1-hour Standard is No Longer Applicable; Final Rule," *Federal Register*, 64 FR 30911, Washington, D.C., June 9, 1999.
15. "Rescinding Findings that the 1-hour Ozone Standard No Longer Applies in Certain Areas," *Federal Register*, 64 FR 57424, Washington, D.C., November 5, 1999.
16. "National Ambient Air Quality Standards for Ozone; Final Rule," *Federal Register*, 62 FR 38856, Washington, D.C., July 18, 1997.
17. "Re-Issue of Early Planning Guidance for the Revised Ozone and Particulate Matter (PM) National Ambient Air Quality Standards (NAAQS)," memorandum from S. Shaver, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 17, 1998.
18. "Climate Variations Bulletin: August 1997," *Historical Climatology Series* 4-7, Volume 9, Number 8, National Climatic Data Center, NOAA, Asheville, NC, September 1997.
- 18a. CASTNet is considered the nation's primary source for atmospheric data to estimate dry acidic deposition and to provide data on rural ozone levels. Established in 1987, CASTNet now comprises 79 monitoring stations across the United States. The longest data records are primarily at eastern sites. The majority of the monitoring stations are operated by EPA's Office of Air and Radiation; however, 27 stations are operated by the National Park Service (NPS) in cooperation with EPA. A more detailed treatment of CASTNet's atmospheric deposition role and data are provided in Chapter 7: Atmospheric Deposition of Sulfur and Nitrogen Compounds.
19. This analysis utilizes a non-parametric procedure to assess statistical significance. A description of this non-parametric regression procedure is provided in Chapter 3: Criteria Pollutants—Metropolitan Area Trends.
20. W. M. Cox and S. H. Chu, "Meteorologically Adjusted Ozone Trends in Urban Areas: A Probabilistic Approach," *Atmospheric Environment*, Vol. 27B, No. 4, Pergamon Press, Great Britain, 1993.
21. "Ambient Air Quality Surveillance: Final Rule," *Federal Register*, 58 FR 8452, Washington, D.C., February 12, 1993.
22. "Selected PAMS sites" refers to the inclusion of only those sites with measurements of NO_x or VOC in both years were used *Median changes* (in summer site 6-9 a.m. means) are highlighted for NO_x and VOC since that indicator minimizes the greater variability seen in concentrations of those parameters in this smaller data set.
23. Although among the top 25 VOC species (by volume) of the PAMS program formaldehyde and acetaldehyde (both carbonyl compounds) were not included in this analysis due to lack of definitive analytic results. Further,

EPA has evaluating carbonyl sampling over the past several years and improved measurement protocols will be issued soon.

24. "Volatility Regulations for Gasoline and Alcohol Blends Sold in Calendar Years 1989 and Beyond," *Federal Register*, 54 FR 11868, Washington, D.C., March 22, 1989.

25. "Reformulated Gasoline: A Major Step Toward Cleaner Air," EPA-420-B-94-004, U.S. Environmental Protection Agency, Office of Air and Radiation, Washington, D.C., September 1994.

26. The Clean Air Act requires that RFG contain 2 percent oxygen by weight. "Requirements for Reformulated Gasoline," *Federal Register*, 59 FR 7716, Washington, D.C., February 16, 1994.

27. The Panel's Executive Summary and final report entitled "*Achieving Clean Air and Clean Water: The Report of the Blue Ribbon Panel on Oxygenates in Gasoline*" can be found on the Panel's homepage at: <http://www.epa.gov/oms/consumer/fuels/oxypanel/blueribb.htm>

28. *National Air Pollutant Emission Trends, 1900-1996*, EPA-454/R-97-011, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1997.

29. *National Ambient Air Quality Standards for Particulate Matter: Final Rule, July 18, 1997*. (62 FR 38652), <http://www.epa.gov/ttn/oarpg/rules.html>.

30. The annual mean is used to show trends in national SO₂ air quality because it is a more stable statistic than the 24-hour statistic.

31. *National Air Pollutant Emissions Trends Report*, EPA-454/R-97-011, US EPA, Research Triangle Park, NC 27711, December 1997.

32. *1997 Compliance Report: Acid Rain Program*, EPA-430-R-98-012, U.S. Environmental Protection Agency, Office of Air and Radiation, Washington, D.C., August 1998.

33. These data were obtained from the 1998 Emission Scorecard found at <http://www.epa.gov/acidrain/score98/es1998.htm>.

