

## Chapter 2

# Air Quality Trends

THIS CHAPTER PRESENTS national air quality trends for each of the pollutants for which EPA has established NAAQS. NAAQS are in place for the following six criteria pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter whose aerodynamic size is less than or equal to 10 microns, and sulfur dioxide. Table 2-1 lists the NAAQS for each pollutant in terms of the level of the standard, the associated averaging time, and the form of the statistic used to evaluate compliance. **Just recently, the NAAQS for ozone and for particulate matter were revised. Since these revisions did not take place until 1997, they were not included in Table 2-1, which covers the NAAQS in effect in 1996. The revised standards, however, are discussed in detail within this chapter in special sections entitled “The New Ozone Standards” and “The New Particulate Matter Standards.”**

There are two types of standards: primary and secondary. Primary standards protect against adverse health effects, whereas secondary standards protect against welfare effects such as damage to crops, vegetation, buildings, and decreased visibility. There are primary standards for all of the criteria pollutants, and some pollutants (PM<sub>10</sub> and SO<sub>2</sub>) 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 any adverse health effects associated with peak short-term exposures to air pollution, while long-term standards can protect

**Table 2-1.** NAAQS in Effect in 1996

Pollutant	Primary (Health Related)		Secondary (Welfare Related)	
	Type of Average	Standard Level Concentration <sup>a</sup>	Type of Average	Standard Level Concentration
CO	8-hour <sup>b</sup>	9 ppm (10 µg/m <sup>3</sup> )	No Secondary Standard	
	1-hour <sup>b</sup>	35 ppm (40 µg/m <sup>3</sup> )	No Secondary Standard	
Pb	Maximum Quarterly Average	1.5 µg/m <sup>3</sup>	Same as Primary Standard	
NO <sub>2</sub>	Annual Arithmetic Mean	0.053 ppm (100 µg/m <sup>3</sup> )	Same as Primary Standard	
O <sub>3</sub>	Maximum Daily 1-hour Average <sup>c</sup>	0.12 ppm (235 µg/m <sup>3</sup> )	Same as Primary Standard	
PM <sub>10</sub>	Annual Arithmetic Mean <sup>d</sup>	50 µg/m <sup>3</sup>	Same as Primary Standard	
	24-hour <sup>d</sup>	150 µg/m <sup>3</sup>	Same as Primary Standard	
SO <sub>2</sub>	Annual Arithmetic Mean	0.03 ppm (80 µg/m <sup>3</sup> )	3-hour <sup>b</sup>	0.50 ppm (1,300 µg/m <sup>3</sup> )
	24-hour <sup>b</sup>	0.14 ppm (365 µg/m <sup>3</sup> )		

<sup>a</sup> Parenthetical value is an approximately equivalent concentration.

<sup>b</sup> Not to be exceeded more than once per year.

<sup>c</sup> 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.

<sup>d</sup> Particulate standards use PM<sub>10</sub> as the indicator pollutant. The annual standard is attained when the expected annual arithmetic mean concentration is less than or equal to 50 µg/m<sup>3</sup>; the 24-hour standard is attained when the expected number of days per calendar year above 150 µg/m<sup>3</sup> is equal to or less than one, as determined according to Appendix K of the PM NAAQS.

people from adverse health effects associated with short- and long-term exposures to air pollution. There are secondary standards for each criteria pollutant except CO. Secondary standards are identical to the primary standard with the exception of SO<sub>2</sub>.

This chapter emphasizes the most recent 10 years of air pollution trends, from 1987 to 1996. Trends over a 15- or 20-year time frame are presented when possible; however, the limited amount of data available in the earliest years of monitoring make them suitable only for examining the general behavior of ambient concentrations. In addition, one-year changes in ambient concentrations are presented. These must also be interpreted with a bit of caution, as they can be heavily influenced by meteorological conditions.

Most of 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 data accumulated on the criteria pollutants between 1987 and 1996 at 4,858 monitoring stations located in urban,

suburban, and some rural areas. The trends presented here are derived from the composite average of these direct measurements (see Table A-10). 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 report is emissions estimates. These are based on engineering calculations of the amounts and kinds of pollutants emitted by automobiles, factories, and other sources over a given period. There are also monitors known as 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 1996 for NO<sub>x</sub> and SO<sub>2</sub> emissions at major electric utilities.

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 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 VOCs emissions of as well as NO<sub>x</sub> 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; and 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 trends estimates in this chapter, please refer to Appendix B.

## Carbon Monoxide

- Air Quality Concentrations**

1987-96	37% decrease
1995-96	7% decrease

- Emissions**

1987-96	18% decrease
1995-96	1% decrease

### Nature and Sources

Carbon monoxide is a colorless, odorless, and at higher levels, a 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. 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.

### 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 CO is most serious for those who suffer from cardiovascular disease. At higher levels of exposure, healthy individuals are also 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 parts per million (ppm) and an 8-hour average of 9 ppm. These concentrations are not to be exceeded more than once per year. Secondary standards have not been established for CO.

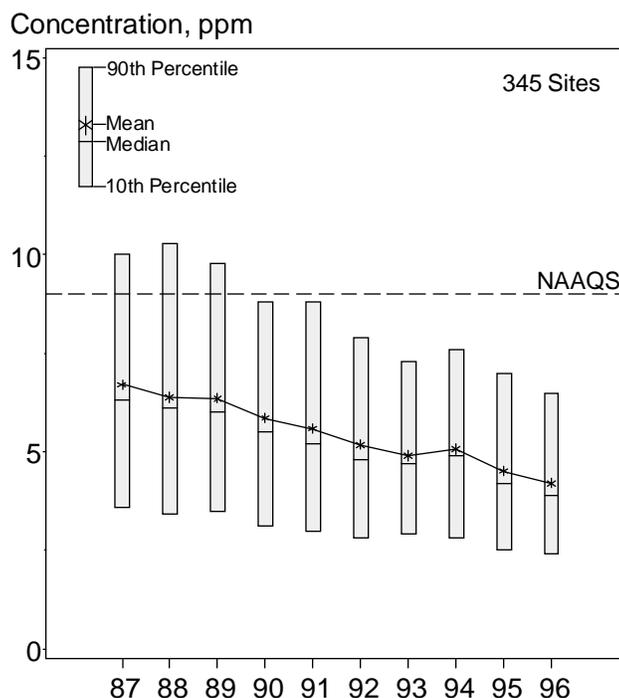
### Trends

The consistent downward trend in concentrations and emissions of CO is clear, with long-term improvements continuing between 1987 and 1996. Figure 2-1 shows that national average CO concentrations decreased 37 percent during the past 10 years as measured by the composite average of the annual second highest 8-hour concentration. These reductions in ambient CO levels occurred despite a 28-percent increase in VMT. Nationally, the composite average of exceedances of the CO NAAQS declined 92 percent since

1987. The large difference between the rate of change in concentrations and the percentage change in exceedances is due to the nature of the exceedance statistic (which is simply a count of a pass/fail indicator). There are only a few monitoring sites currently recording exceedances of the level of the standard.

National total CO emissions have decreased 18 percent since 1987 as illustrated in Figure 2-2. As expected, the national CO air quality decrease of 37 percent from the urban CO monitoring network, which is primarily mobile-source oriented, more closely tracks the estimated 26 percent reduction in highway vehicle emissions. Figure 2-3 shows that transportation sources now account for 79 percent of the nation's total CO emissions.

The CO air quality improvement occurred across all monitoring environments—urban, suburban and rural



**Figure 2-1.** Trend in second maximum non-overlapping 8-hour average CO concentrations, 1987-1996.

monitoring sites. As expected, Figure 2-4 shows, that urban monitoring sites record higher CO concentrations on average, than suburban sites, with the lowest levels found at 10 rural CO sites. During the past 10 years, composite mean CO 8-hour concentrations decreased 37 percent at 190 urban sites, 37 percent at 142 suburban locations, and 48 percent at the 10 rural monitoring sites.

Between 1995 and 1996, national composite average CO concentrations decreased 7 percent. Eight of the 10 EPA Regions located throughout the country experienced declines in composite mean ambient CO levels between 1995 and 1996, while monitoring sites in Regions 6 and 10 recorded small increases in composite average concentrations. Nationally, the 1996 composite average ambient concentration is the lowest level recorded during the past 20 years of monitoring. Total CO emissions decreased 1 percent since 1995, with CO emissions from highway vehicles recording a 2-percent decline since last year. These improvements in highway vehicle emissions occurred despite the 2-percent increase in VMT since last year.

To reduce tail pipe emissions of CO and to help attain the national standard for CO, the 1990 Clean Air Act Amendments (CAAA) require oxygenated gasoline programs in several regions 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.<sup>1,2</sup> Of the 36 nonattainment areas that initially implemented the program in 1992, 25 areas continue to use oxygenated fuels. The White House Office of Science and Technology Policy (OSTP) review of the oxygenated fuels program, *Inter-agency Assessment of Oxygenated Fuels*,<sup>3</sup>

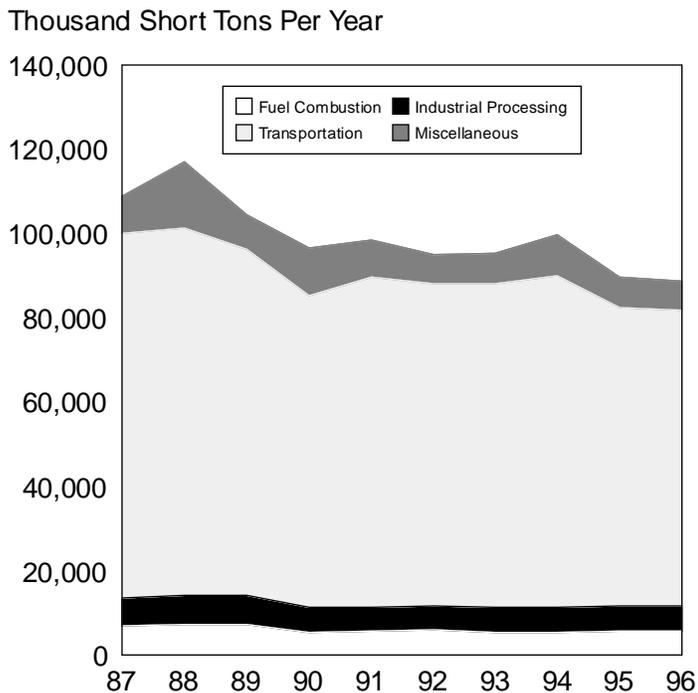


Figure 2-2. National total CO emissions trend, 1987-1996.

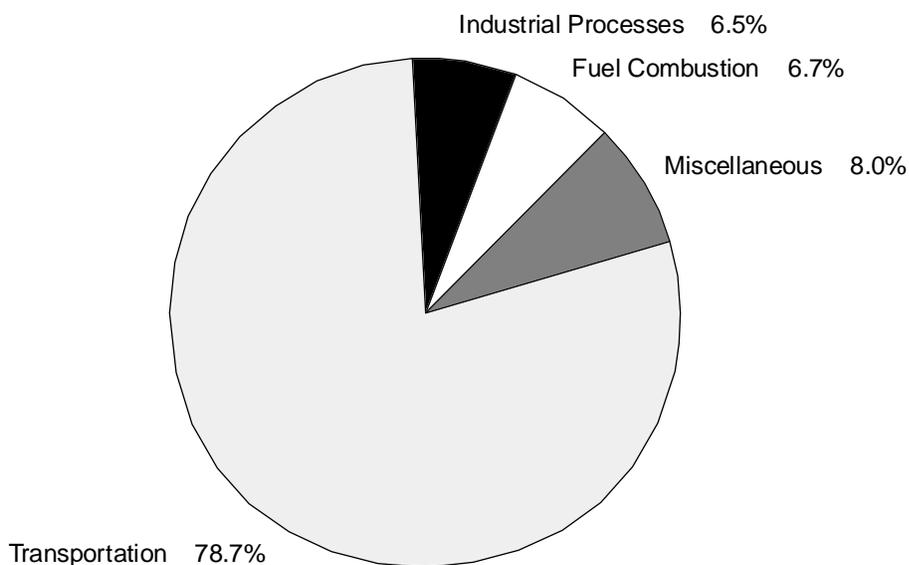


Figure 2-3. CO emissions by source category, 1996.

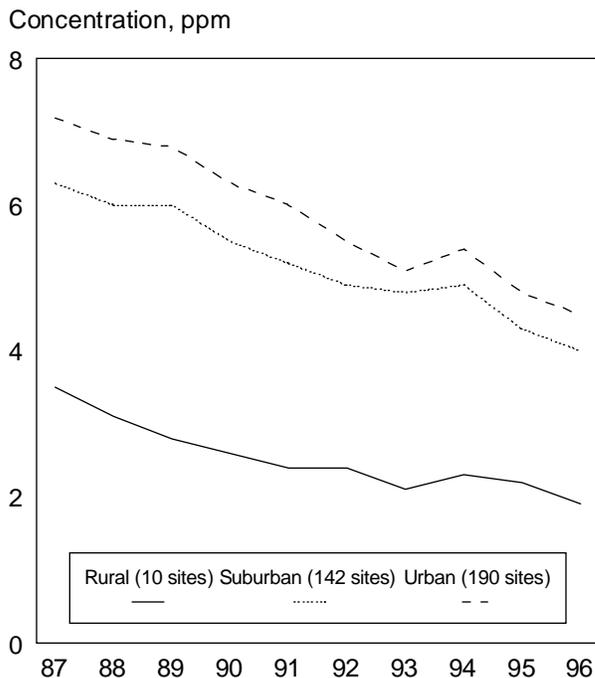


Figure 2-4. CO second maximum 8-hour concentration trends by location, 1987–1996.

stated that analyses of ambient CO measurements in some cities with winter oxygenated gasoline programs showed reductions of about 10 percent. In a regression analysis that expanded on a recent EPA study, the estimated oxyfuel effect was an average total reduction in ambient CO concentrations of 14 percent overall for the eight winter seasons from 1986 through 1994.<sup>4,5</sup>

The map in Figure 2-5 shows the variations in CO concentrations across the country in 1996. The air quality indicator is the highest annual second maximum 8-hour concentration measured 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. In 1996, seven counties (with a total population

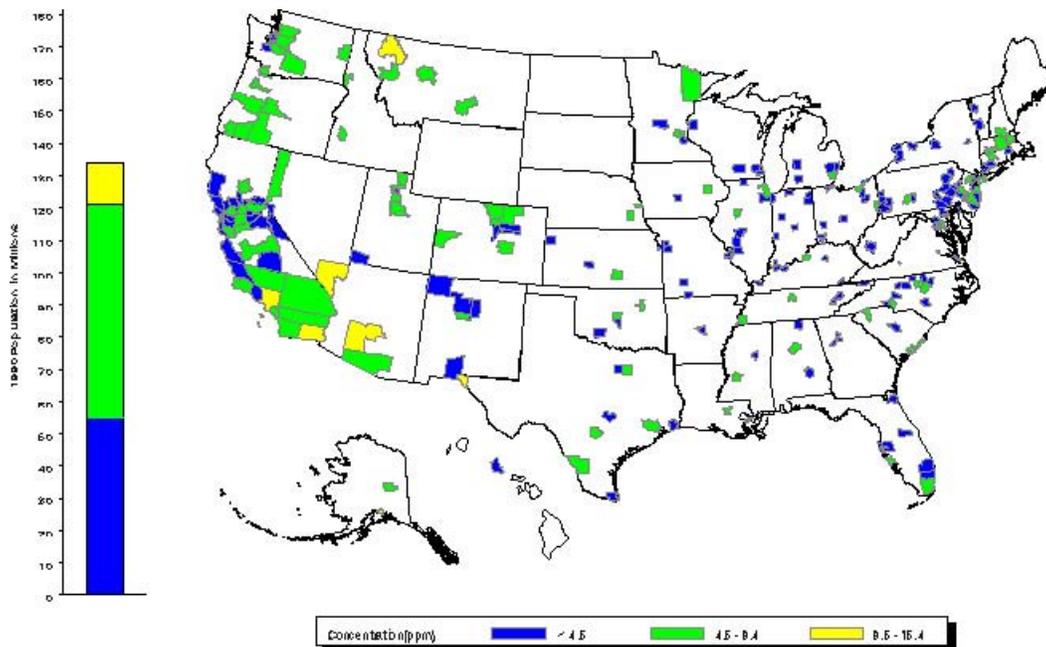


Figure 2-5. Highest CO second maximum 8-hour concentration by county, 1996.

of approximately 13 million people) had second maximum 8-hour concentrations greater than 9 ppm. These totals are up slightly from 1995 totals of six counties and 12 million people.

Figure 2-6 illustrates the improvement in ambient CO air quality during the past 20 years. Although there are differences in the mix of trend sites for the two periods (168 vs. 345 sites), there is evidence of a consistent decline in CO concentrations during the past 20 years.

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.

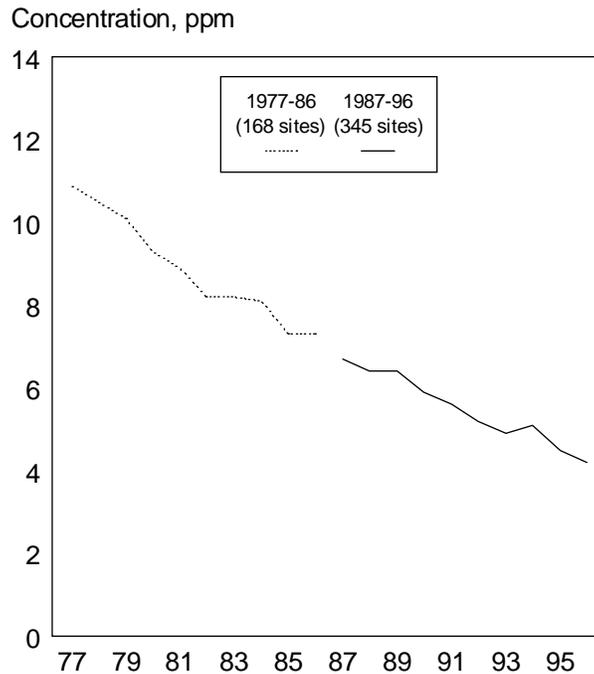


Figure 2-6. Long-term ambient CO trend, 1977-1996.

## Lead

• <b>Air Quality Concentrations</b>		
1987-96	75%	decrease
1995-96	no	change
• <b>Emissions</b>		
1987-96	50%	decrease
1995-96	2%	decrease

### Nature and Sources

In the past, 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 over the past decade. Today, metals processing is the major source of lead emissions to the atmosphere. The highest concentrations of lead are found in the vicinity of nonferrous and ferrous smelters, battery manufacturers, and other stationary sources of lead emissions.

### Health and Other Effects

Exposure to lead occurs mainly through the inhalation of air and the ingestion of lead in food, water, soil, or dust. It accumulates in the blood, bones, and soft tissues. Because it is not readily excreted, 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 often suffer from central nervous system damage. Recent studies also show that lead may be a factor in high blood pressure and subsequent heart disease. Lead can also be deposited

on the leaves of plants, presenting a hazard to grazing animals. Animals do not appear to be more susceptible to adverse effects from lead than humans however, nor do adverse effects in animals occur at lower levels of exposure than comparable effects in humans. For these reasons, the secondary standard for lead is identical to the primary standard.

### Primary and Secondary Standards

The primary and secondary NAAQS for lead is a quarterly average concentration not to exceed 1.5 µg/m<sup>3</sup>.

### Trends

Figure 2-7 indicates that between 1987 and 1996 maximum quarterly average lead concentrations decreased 75 percent at population-oriented monitors. Figure 2-8 shows that total lead emissions decreased 50 percent. These reductions are a direct 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 95 percent of the 10-year lead emissions decline. Note that previously published lead emissions estimates have been recently revised significantly downwards for the on-road vehicle category.

Air quality trends segregated by location (rural, suburban, and urban) are provided in Figure 2-9. All three location types show similar declines over the past 10 years.

The effect of the conversion to unleaded gasoline usage on ambient lead concentrations is even more impressive when viewed over a longer period, as illustrated in Figure 2-10. Between 1977 and 1996, ambient concentrations of lead declined 97 percent. This large decline tracks well with the emissions trend, which shows a decline of 98 percent between 1970 and 1996. Between

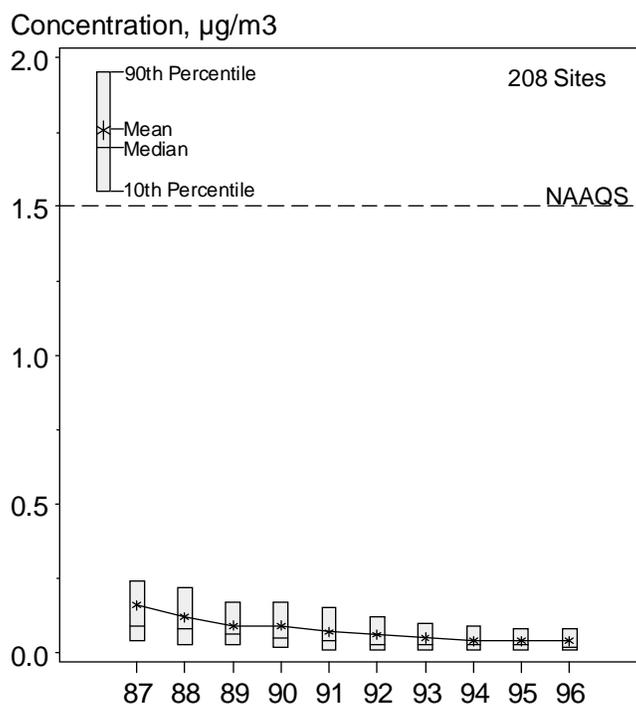


Figure 2-7. Trend in maximum quarterly average Pb concentrations (excluding source-oriented sites), 1987-1996.

1995 and 1996, national average lead concentrations (approaching the minimum detectable level) remained unchanged, while lead emissions estimates showed a 2-percent decline.

The large reductions in long-term lead emissions from transportation sources has changed the nature of the ambient lead problem in the United States. As Figure 2-11 shows, industrial processes were the major source of lead emissions in 1996, accounting for 73 percent of the total. The transportation sector (on-road and non-road sources) now accounts for only 15 percent of total 1996 lead emissions; on-road vehicles account for less than one half of a percent. Because industrial processes are now responsible for all violations of the lead standard, the lead monitoring strategy now focuses on these emissions point sources. The map in Figure 2-12 shows the lead monitors oriented in the vicinity of major sources of lead emissions. In 1996, eight lead point sources had one or more source-oriented monitors that exceeded the NAAQS. These eight sources are ranked in Figure 2-12 according to the site with 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 2-13 shows the highest quarterly mean lead concentration by county in 1996. Eight counties, with a total population of 4.7 million and containing the point sources identified in Figure 2-12, did not meet the lead NAAQS in 1996. Note that the point-source oriented monitoring data were excluded from trends analyses presented in Figures 2-7 and 2-9 so as not to mask the underlying urban trends.

In an effort to reduce unnecessary monitoring requirements and allow

Short Tons Per Year

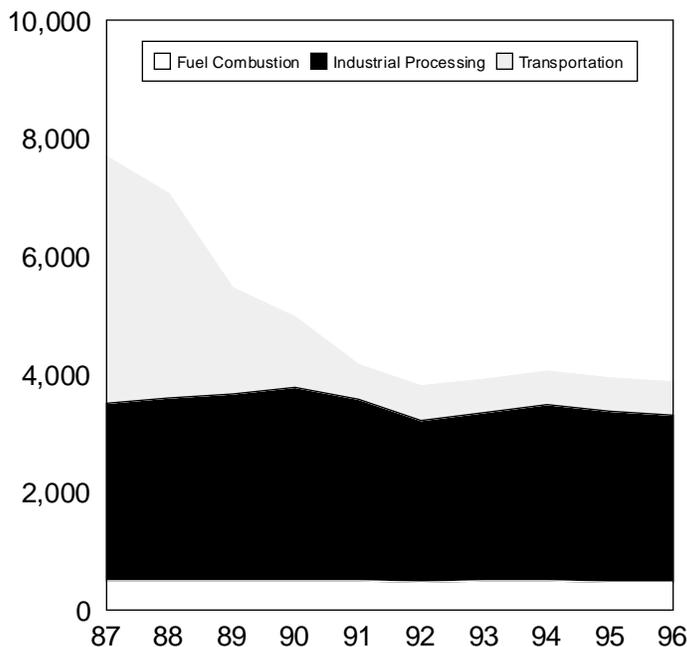


Figure 2-8. National total Pb emissions trend, 1987-1996.

Concentration,  $\mu\text{g}/\text{m}^3$

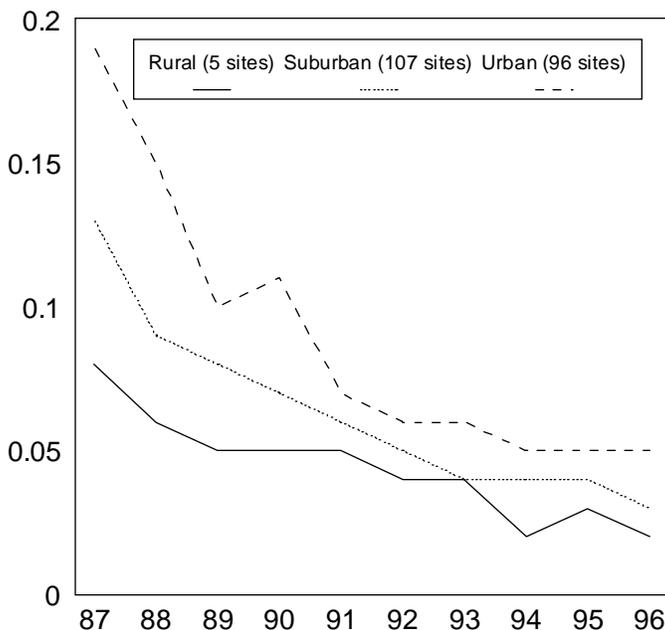


Figure 2-9. Pb maximum quarterly mean concentration trends by location (excluding source-oriented sites), 1987-1996.

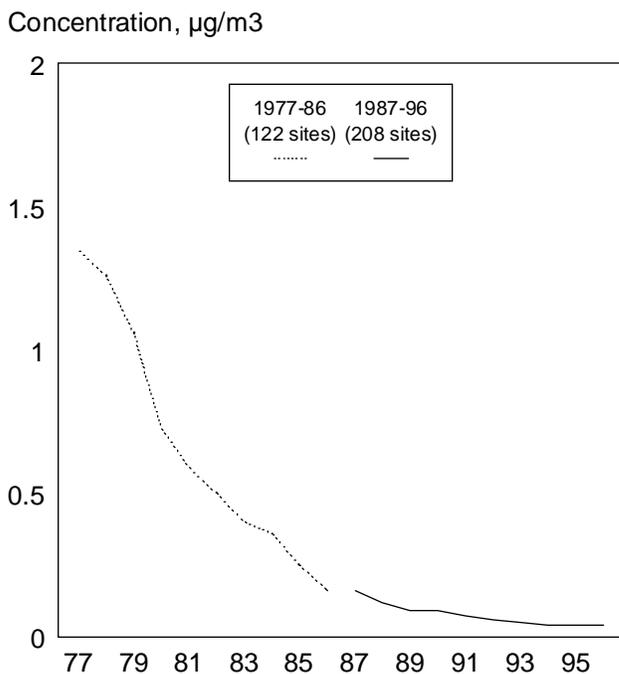


Figure 2-10. Long-term ambient Pb trend, 1977-1996.

diverted savings to be utilized for new monitoring requirements, EPA has decided to significantly reduce the mobile-source oriented lead monitoring requirement. Previously, regulations required that each urbanized area with a population of 500,000 or more operate at least two lead National Air Monitoring Stations (NAMS); there are approximately 85 NAMS in operation and reporting data for 1996. With the new lead monitoring rule proposed in September 1997, NAMS monitoring will only be required in the largest metropolitan area in each of the 10 EPA Regions, and also in each populated area (either a MSA/CMSA, town, or county) where lead violations have been measured.

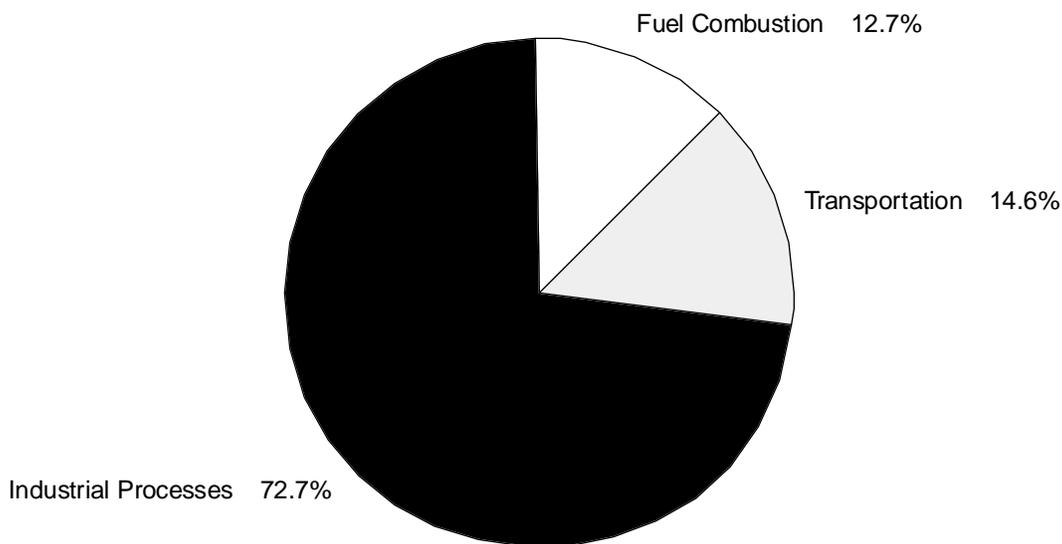


Figure 2-11. Pb emissions by source category, 1996.

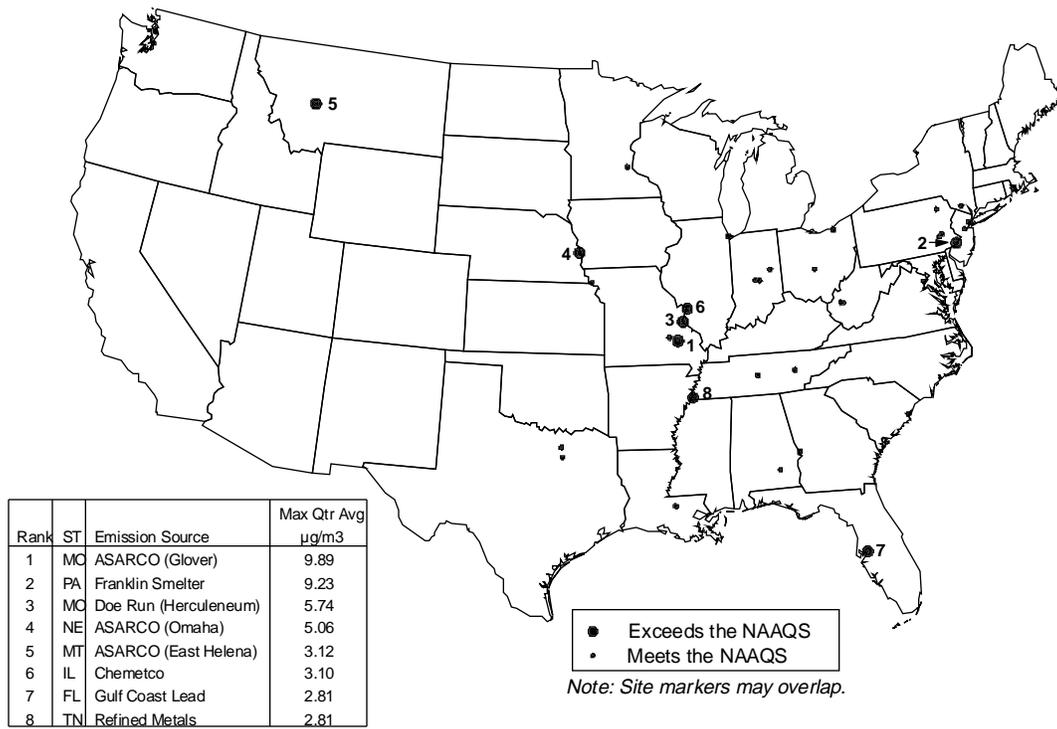


Figure 2-12. Pb maximum quarterly concentration in the vicinity of Pb point sources, 1996.

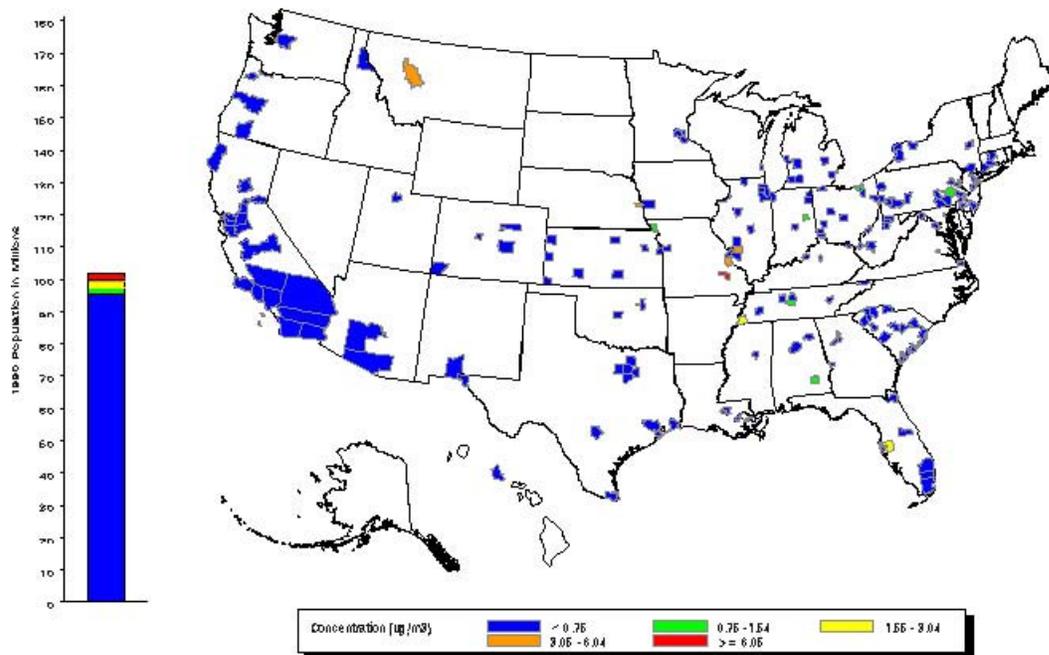


Figure 2-13. Highest Pb maximum quarterly mean by county, 1996.

## Nitrogen Dioxide

• Air Quality Concentrations		
1987-96	10%	decrease
1995-96		no change
• Emissions		
1987-96	3%	increase
1995-96	2%	decrease

### Nature and Sources

Nitrogen dioxide is a light brown gas that can become an important component of urban haze. Nitrogen oxides usually enter the air as the result of high-temperature combustion processes, such as those occurring in automobiles and power plants. NO<sub>2</sub> plays an important role in the atmospheric reactions that generate ozone. Home heaters and gas stoves also produce substantial amounts of NO<sub>2</sub>.

### Health and Other Effects

Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infections such as influenza. The effects of short-term exposure are still unclear, but continued or frequent exposure to concentrations higher than those normally found in the ambient air may cause increased incidence of acute respiratory disease in children.

Nitrogen oxides are an important precursor to both ozone and acidic precipitation (acid rain) and can affect both terrestrial and aquatic ecosystems. The regional transport and deposition of nitrogenous compounds arising from emissions of NO<sub>x</sub> is a potentially significant contributor to such environmental effects as the growth of algae and subsequent unhealthy or toxic conditions for fish in the Chesapeake Bay and other estuaries. In some parts of the western United States, NO<sub>x</sub> have a

significant impact on particulate matter concentrations.

### Primary and Secondary Standards

The ambient NO<sub>2</sub> primary and secondary NAAQS are an annual mean concentration not to exceed 0.053 ppm.

### Trends

The trend in annual mean NO<sub>2</sub> concentrations measured at 214 sites across the country between 1987 and 1996 is shown in Figure 2-14. The trend shows a 10-percent decrease in the national composite mean. However, the trend in total NO<sub>x</sub> emissions during the same period shows a 3-percent increase, as shown in Figure 2-15. Since most NO<sub>2</sub> monitors are located in urban, population-oriented areas, the trend in ambient concentrations is more representative of the highway vehicle NO<sub>x</sub> emissions,

which decreased 6 percent between 1987 and 1996.

The increase in total NO<sub>x</sub> emissions is due, in large part, to emissions from coal-fired electric utilities. NO<sub>x</sub> emissions from these utilities account for roughly one quarter of all NO<sub>x</sub> emissions. Between 1987 and 1996, emissions from these sources rose 3 percent. In October 1997, EPA proposed a rule that will reduce regional emissions of NO<sub>x</sub>. Utilities and large utility point sources are the most likely sources for these emissions reductions. See the ozone section, beginning on page 27, for more information concerning this rule.

The two primary sources of NO<sub>x</sub> emissions are fuel combustion and transportation. Together these two sources made up 95 percent of 1996 total NO<sub>x</sub> emissions. Table A-4 provides a listing of NO<sub>x</sub> emissions by major source category.

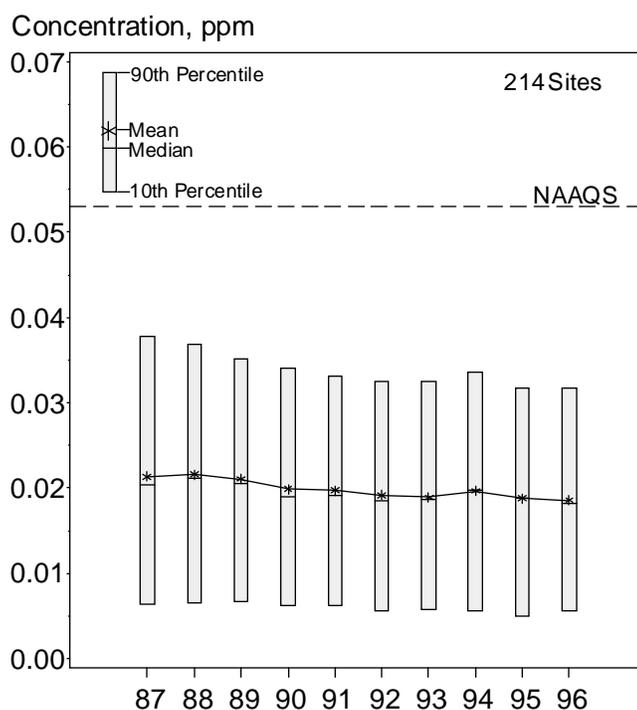


Figure 2-14. Trend in annual NO<sub>2</sub> concentrations, 1987-1996.

Title IV (Acid Deposition Control) of the CAA specifies that between 1980 and 2010, total annual NO<sub>x</sub> emissions will be reduced by approximately 10 percent (2 million tons). In 1996, NO<sub>x</sub> emissions were reduced 33 percent from 1990 levels at participating utilities. It is important to note, however, that these participating utilities made up only three percent of total national NO<sub>x</sub> emissions in 1996. Further, emissions from these participating utilities only made 12 percent of NO<sub>x</sub> emissions from electric utilities in 1996. EPA's rule to reduce the regional transport of ozone will help to achieve important additional reductions in emissions of NO<sub>x</sub>.

Although higher ambient NO<sub>2</sub> levels are typically observed in urban areas, Figure 2-17 shows that the ambient NO<sub>2</sub> air quality trends are similar across monitoring locations. Additionally, 1996 is the fifth consecutive year that all monitoring locations across the nation, including Los Angeles, met the national NO<sub>2</sub> air quality standard (see Figure 2-18). Twenty-year trends in ambient NO<sub>2</sub> concentrations show an overall decrease of approximately 27 percent (see Figure 2-19).

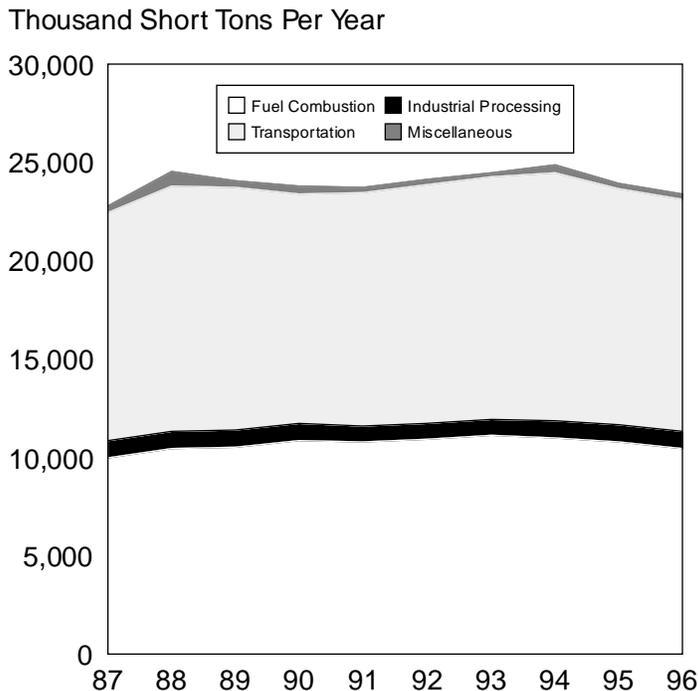


Figure 2-15. National total NO<sub>x</sub> emissions trend, 1987-1996.

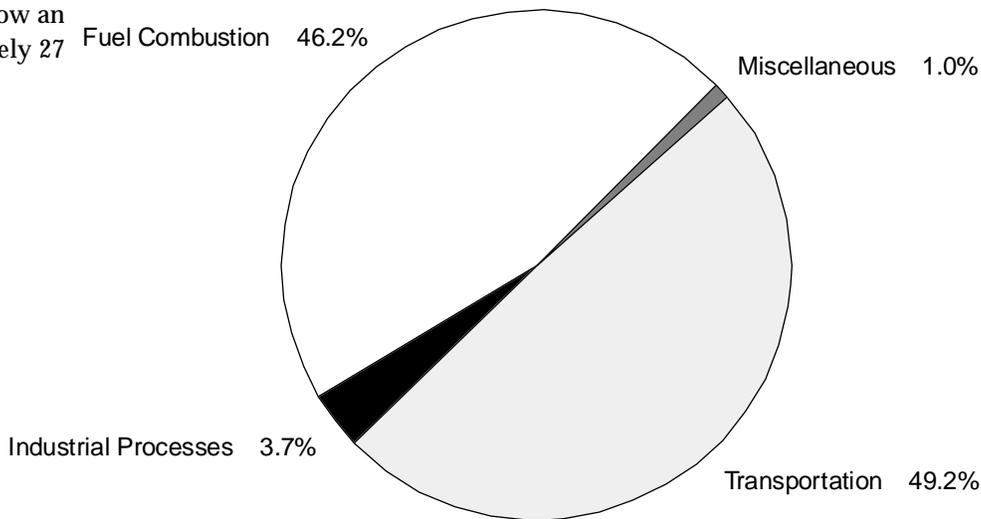


Figure 2-16. NO<sub>x</sub> emissions by source category, 1996.

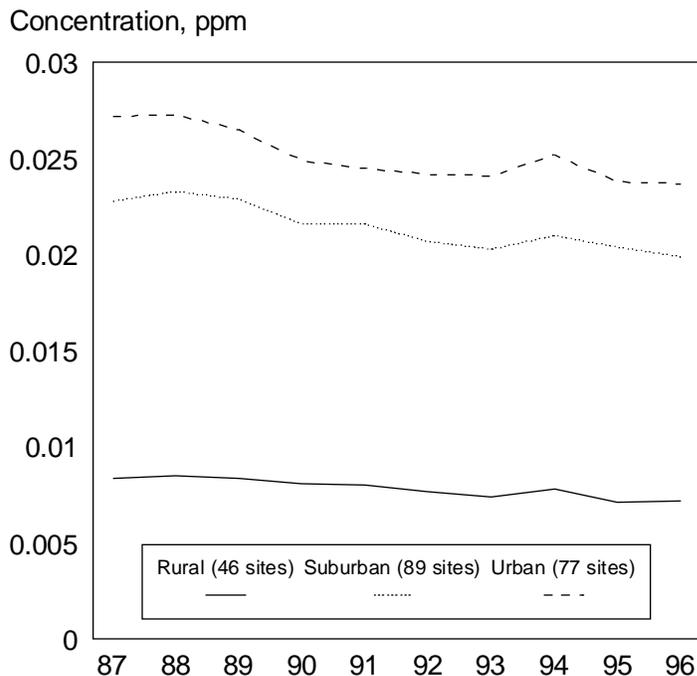


Figure 2-17. NO<sub>2</sub> annual mean concentration trend by location, 1987–1996.

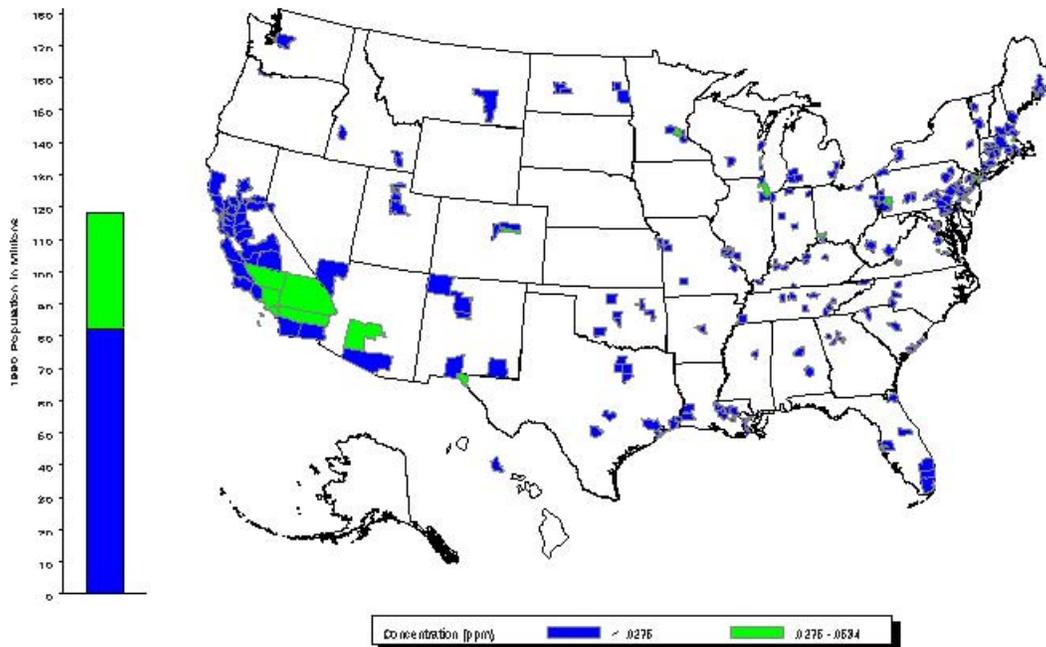
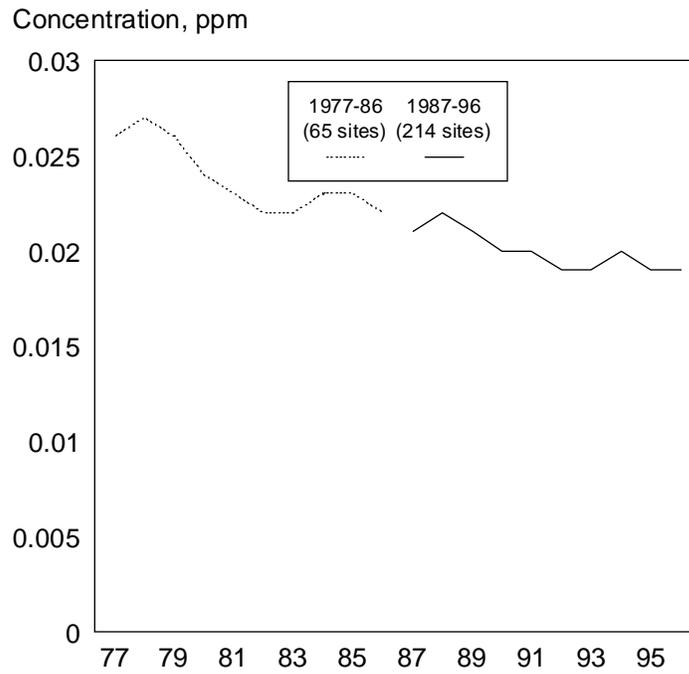


Figure 2-18. Highest NO<sub>2</sub> annual mean concentration by county, 1996.



**Figure 2-19.** Long-term ambient NO<sub>2</sub> trend, 1977–1996.

## Ozone

- **Air Quality Concentrations (1 hour)**

1987-96	15% decrease
1995-96	6% decrease
- **Emissions**

1987-96	18% decrease
1995-96	7% decrease

### **Nature and Sources**

Ground level ozone (the primary constituent of smog) has remained a pervasive pollution problem throughout the United States. Ozone is not emitted directly into the air but is formed by the reaction of VOCs and NO<sub>x</sub> in the presence of heat and sunlight. Ground-level ozone forms readily in the atmosphere, usually during hot summer weather. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. NO<sub>x</sub> is emitted from motor vehicles, power plants, and other sources of combustion. Changing weather patterns contribute to yearly differences in ozone concentrations from city to city. Ozone and the precursor pollutants that cause ozone also can be transported into an area from pollution sources found hundreds of miles upwind.

### **Health and Other Effects**

Ozone occurs naturally in the stratosphere and provides a protective layer high above the earth. At ground-level, however, it is the prime ingredient of smog. Short-term exposures (1 to 3 hours) to ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory causes. Repeated exposures to ozone can make people more susceptible to respiratory infection and lung inflammation, and

can aggravate preexisting respiratory diseases such as asthma. Other health effects attributed to short-term 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 outdoor workers, individuals with preexisting respiratory disease such as asthma and chronic obstructive lung disease, and individuals who are unusually responsive to ozone. Recent studies have attributed these same health effects to prolonged exposures (6 to 8 hours) to relatively low ozone levels during periods of moderate exertion. In addition, long-term exposures to ozone present the possibility of irreversible changes in the lungs which could lead to premature aging of the lungs and/or chronic respiratory illnesses.

The recently completed review of the ozone standard also highlighted concerns associated with ozone effects on vegetation for which the 1-hour ozone standard did not provide adequate protection. These effects include reduction in agricultural and commercial forest yields, reduced growth and decreased survivability of tree seedlings, increased tree and plant susceptibility to disease, pests, and other environmental stresses, and potential long-term effects on forests and ecosystems. Because ground-level ozone interferes with the ability of the plant to produce and store food, plants become more susceptible to disease, insect attack, harsh weather and other environmental stresses. In long-lived species, these effects may only become evident after several years or even decades.

Ozone also damages the foliage of trees and other plants, decreasing the natural beauty of our national parks and recreation areas, and reducing the quality of the habitat for wildlife, including endangered species.

### **The Ozone Transport Assessment Group**

Through a 2-year effort known as the Ozone Transport Assessment Group (OTAG), EPA worked in partnership with state and local government agencies in the 37 easternmost states, industry, and academia to address ozone transport. Based on OTAG's extensive analysis of ozone transport, on October 10, 1997 EPA proposed a rule to reduce the regional transport of ozone. This rule sets a budget for emissions of NO<sub>x</sub> for 22 states east of the Mississippi and the District of Columbia and will significantly reduce the transport of NO<sub>x</sub> and ozone. EPA plans to finalize the rule in September 1998. More detailed information on the OTAG process and details on information generated by the OTAG workgroups are available on the OTAG web page at <http://www.epa.gov/ttn/otag>.

### **Primary and Secondary 1-hour Standards**

In 1979, EPA established 1-hour primary and secondary standards for ozone. The level of the 1-hour primary NAAQS is 0.12 ppm daily maximum 1-hour ozone concentration that is not to be exceeded more than once per year on average. The secondary standard was set identical to the primary standard.

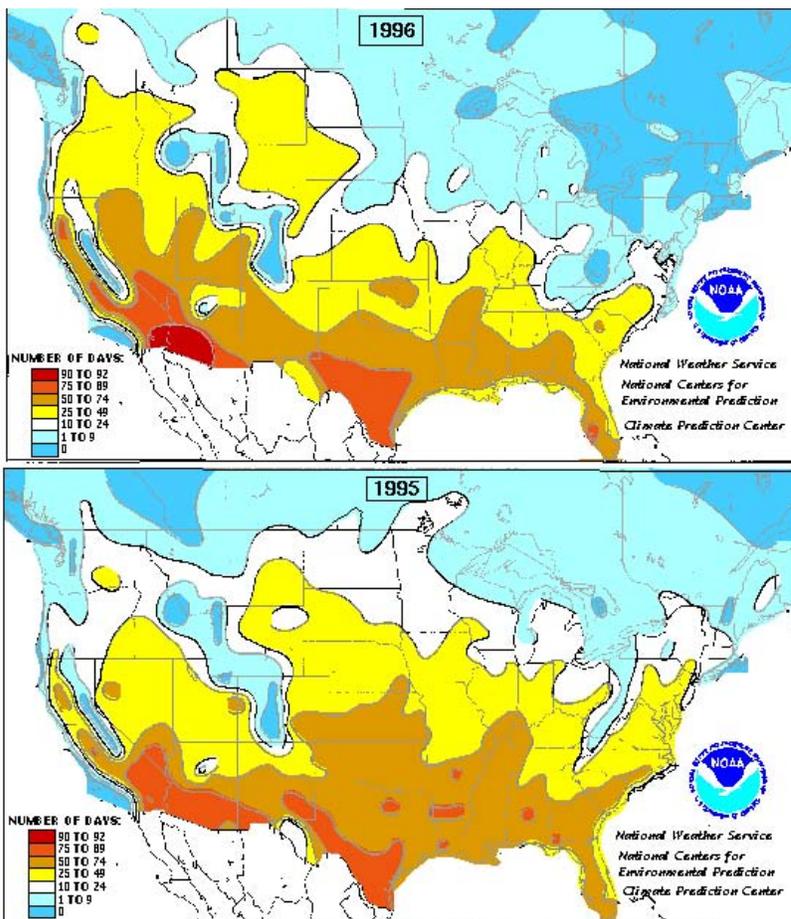
### **The New Primary and Secondary 8-hour Ozone Standards**

On July 18, 1997, EPA replaced the previous 1-hour primary standard (health-based) with a new 8-hour standard to

protect against longer exposure periods that are of concern at ozone concentrations below the level of the previous 1-hour standard.<sup>6</sup> The secondary standard (welfare-based) was set identical to the 8-hour primary standard. EPA also announced that it will expand the rural ozone monitoring network to focus on ozone-related vegetation research. Although the following trends discussion focuses on the 1-hour NAAQS in place in 1996, a description of the new 8-hour ozone NAAQS and some preliminary 8-hour trends results immediately follows. Subsequent reports will feature trends and status for daily maximum 8-hour concentrations.

**Trends**

Ambient ozone trends are influenced by year-to-year changes in meteorological conditions, population growth, VOC to NO<sub>x</sub> ratios, and by changes in emissions from ongoing control measures. Unlike the hot, dry meteorological conditions in 1995 that were highly conducive to peak ozone formation, the summer of 1996 in most of the central and eastern United States was wet and cool, while excessive heat, and minimal precipitation affected the west.<sup>7</sup> As shown in Figure 2-20, frequent cloudiness and precipitation often kept highs below 90°F across areas to the north and east of the central Great Plains, in dramatic contrast to the excessive heat that periodically covered these regions during the summer of 1995. Figure 2-21 reveals that the 1996 composite national average daily maximum 1-hour ozone concentration is 15 percent lower than the 1987 level. Nationally, the 1996 composite mean concentration is 6 percent lower than 1995 and tied with 1992 as the lowest composite mean during this 10-year period. The highest national composite mean level was recorded in 1988. Since



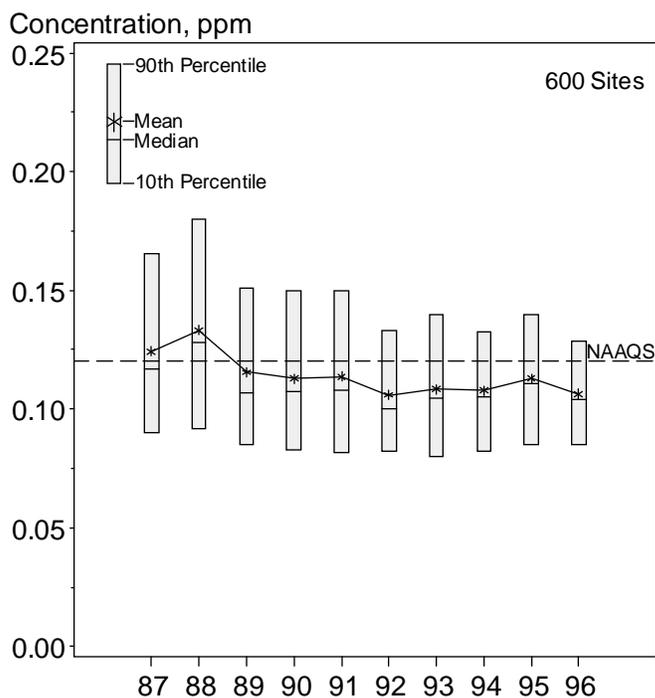
**FIGURE 1.** The number of days during Summer (June–August) with highs  $\geq 90^{\circ}\text{F}$ , 1996 (top) vs. 1995 (bottom). Only stations with reports for at least 31 days during the 92-day period were included in the analyses. Sharp gradients near major coastlines and in regions of irregular terrain may be under-represented. Mexican areas were not analyzed due to the sparseness of reliable data. This summer, hot days were unusually frequent in western North America while few instances of  $90^{\circ}\text{F}+$  heat occurred across the northeastern quarter of the United States and southeastern Canada. These conditions are nearly the opposite of those observed during Summer 1995, when heat and humidity were commonplace in the East and cooler than normal conditions dominated the West.

**Figure 2-20.** Number of summer days, June–August with temperatures  $\geq 90^{\circ}$ , 1995 vs. 1996.

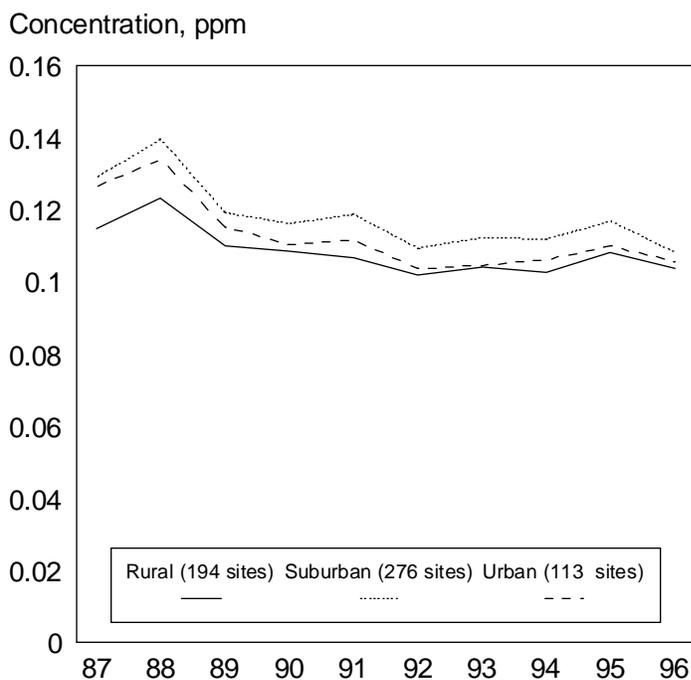
1987, the composite mean of the number of exceedances of the ozone NAAQS has declined 73 percent. Nationally, the composite average estimated exceedance rate declined 37 percent between 1995 and 1996. Significant reductions in ozone concentrations were seen in the Northeast, North Central, Southwest and the California coastal regions.

The reductions in ozone levels described above, however, do not affect all environments equally. Although the

general pattern of ozone trends across rural, suburban, and urban environments are similar, the magnitudes of the reductions differ. Figure 2-22 shows the trends in composite mean second daily maximum 1-hour concentrations for all three monitor settings. The highest concentration levels are typically found at suburban sites. During the past 10 years, the composite mean at 276 suburban sites and at 113 urban sites recorded the same 16 percent reduction in ozone composite mean con-



**Figure 2-21.** Trend in annual second daily maximum 1-hour O<sub>3</sub> concentrations, 1987–1996.



**Figure 2-22.** O<sub>3</sub> second daily maximum 1-hour concentration trends by location, 1987–1996.

centrations. Since 1987, ozone levels declined 10 percent at 194 sites in rural locations.

As noted in a study by the National Academy of Science, and in previous *Trends Reports*, ozone trends are affected by changing meteorological conditions that are conducive to ozone formation.<sup>8,9</sup> EPA has developed a statistical model that attempts to account for meteorological effects and helps to normalize the resulting trend estimates across years.<sup>10</sup> The model, based on the Weibull probability distribution, includes a trend component that adjusts the annual rate of change in ozone for concurrent impacts of meteorological conditions, including surface temperature and wind speed. Figure 2-23 shows the results from application of the model in 41 major urban areas. While the raw data trends reflect the year-to-year variability in ozone conducive conditions, the meteorologically adjusted ozone composite trend provides a better indicator of ozone trends due to emissions trends. For these 41 metropolitan areas, the adjusted trend shows continued improvement with an average decrease of about 1 percent per year since 1987.

The map in Figure 2-24 presents the highest second daily maximum 1-hour concentration by county in 1996. The accompanying bar chart to the left of the map reveals that in 1996 approximately 39 million people lived in 52 counties where the second daily maximum 1-hour concentration was above the level of the ozone NAAQS. These numbers represent a significant improvement from the 70 million people (living in 108 counties) with ozone concentrations above the level of the ozone NAAQS in 1995. As noted previously, differences in meteorological conditions between 1995 and 1996, are likely responsible for much of this decline.

The population totals for 1996 are similar to those recorded in 1994. Nationally, peak 1-hour ozone levels show large spatial differences. Los Angeles has the highest number of exceedances of the ozone NAAQS, followed by Houston and metropolitan areas in California and the northeast United States.

Long-term, quantitative ambient ozone trends are difficult to estimate due to changes in network design, siting criteria, spatial coverage and monitoring instrument calibration procedures over the past two decades. For example, in Figure 2-25, the shaded area in the late 1970s shows the period corresponding to the old calibration procedure where concentration levels are less certain. Figure 2-25 contrasts the 1977–1986 composite trend line based on 238 sites with the current 1987–1996 composite trend

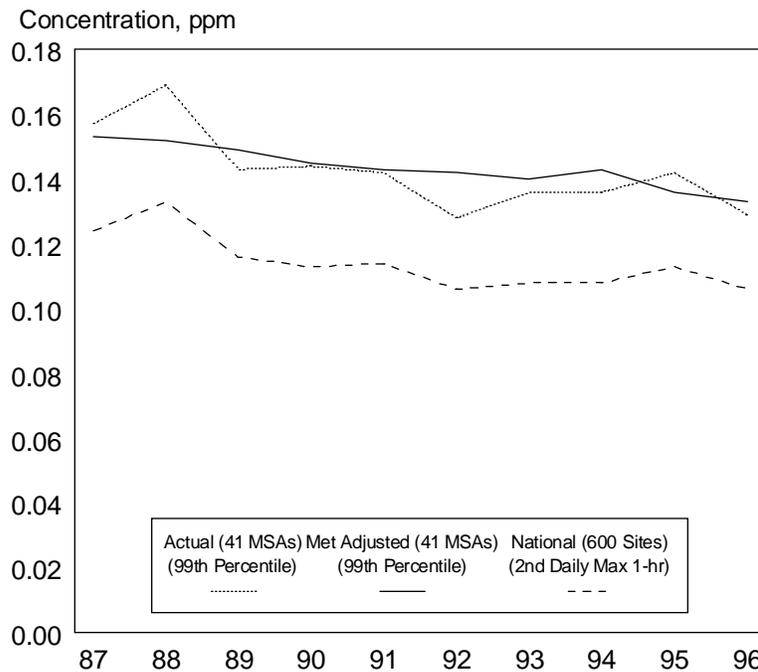


Figure 2-23. Comparison of actual and meteorologically adjusted ozone trends, 1987–1996 (composite average of 99th percentile 1-hr daily max concentration).

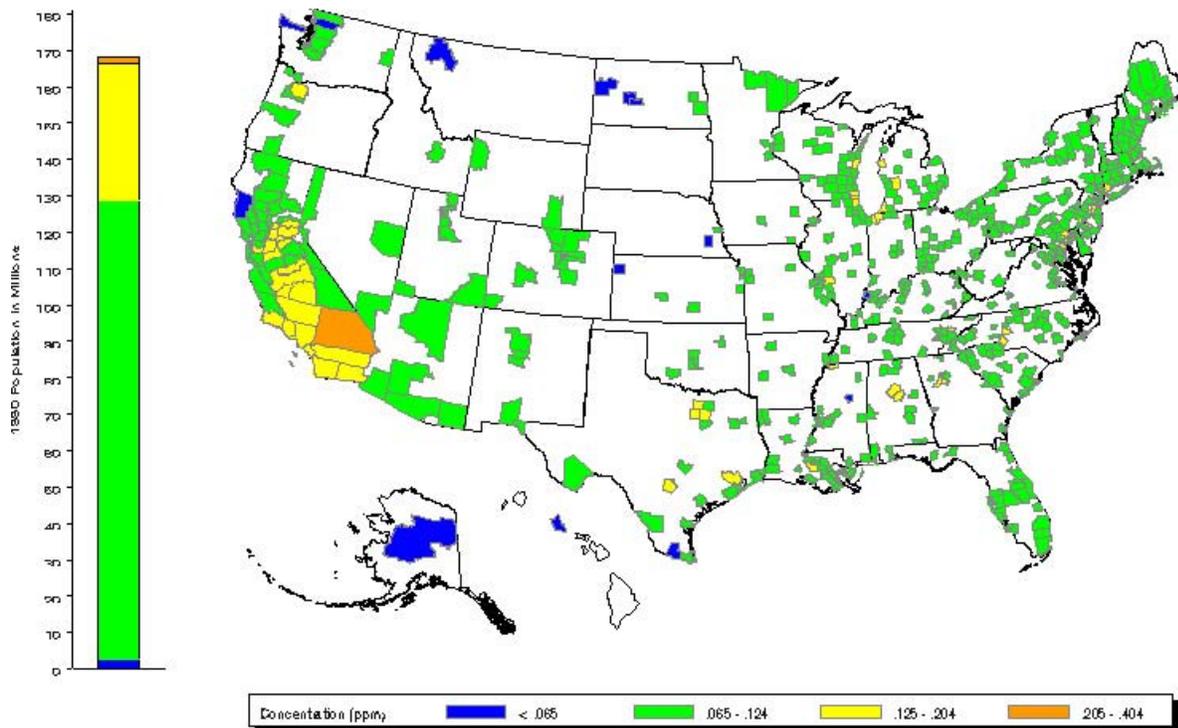
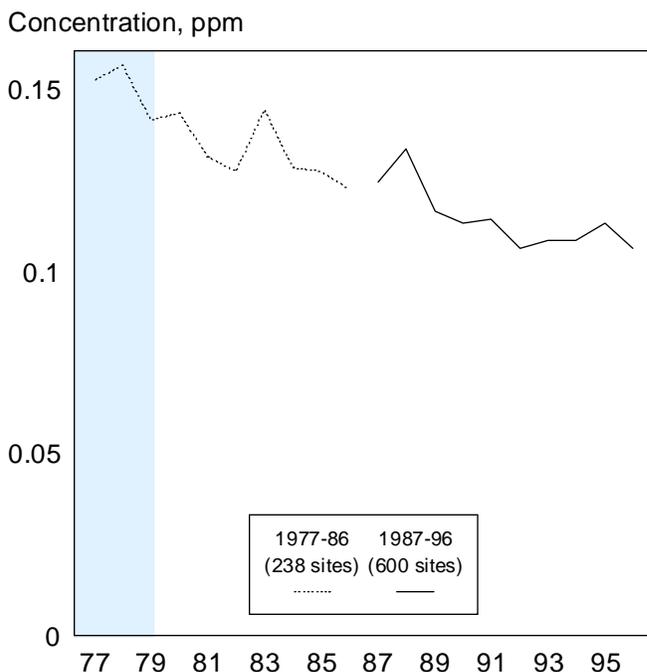
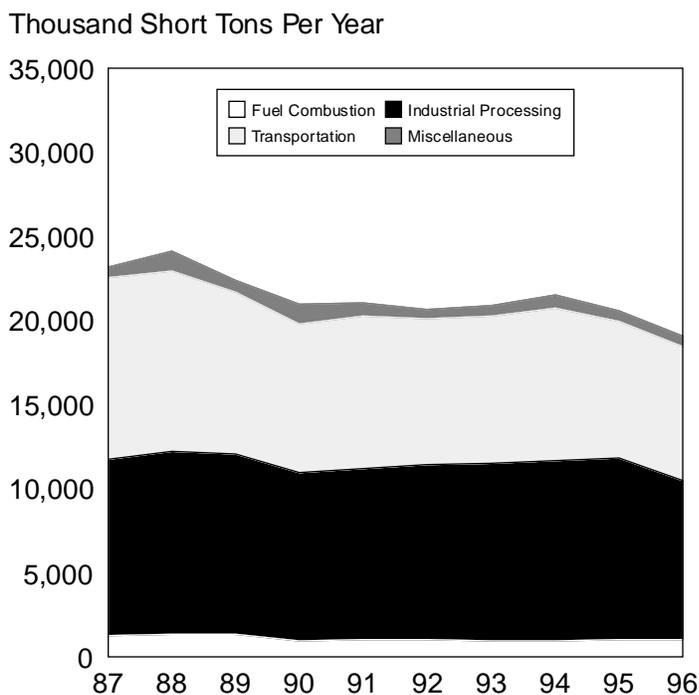


Figure 2-24. Highest O<sub>3</sub> second daily maximum concentration by county, 1996.



**Figure 2-25.** Long-term trend in second daily maximum 1-hour O<sub>3</sub> concentrations, 1977–1996.



**Figure 2-26.** National total VOC emissions trend, 1987–1996.

line for the 600 trend sites, revealing about a 30-percent decline in ozone concentrations during the past 20 years. Although the overall trend is downward, short-term upturns corresponding to ozone-conducive meteorology are evident.

Figure 2-26 shows that national total VOC emissions (which contribute to ozone formation) decreased 18 percent between 1987 and 1996. National total NO<sub>x</sub> emissions (the other major precursor to ozone formation) increased 5 percent between 1987 and 1996. Recent control measures to reduce emissions include regulations to lower fuel volatility and to reduce NO<sub>x</sub> and VOC emissions from tailpipes.<sup>11</sup> The effectiveness of these control measures is reflected in the 26-percent decrease in VOC emissions from transportation sources. VOC emissions from highway vehicles have declined 35 percent since 1987, while highway vehicle NO<sub>x</sub> emissions have declined 7 percent since their peak level in 1994. Nationally, the two major sources of VOC emissions are industrial processes (50 percent) and transportation sources (42 percent) as shown in Figure 2-27 and in Table A-5. Solvent use comprises 66 percent of the industrial process emissions category and 33 percent of total VOC emissions.

To further understand the air quality problems in metropolitan areas, the CAA called for improved monitoring of ozone and its precursors (VOC and NO<sub>x</sub>). PAMS are found in all ozone nonattainment areas classified as serious, severe, or extreme. The 21 affected areas collect measurements of ozone, NO<sub>x</sub> (NO, NO<sub>2</sub>, and total NO<sub>x</sub>), and many VOCs, as well as surface and upper air meteorological data. Between 1995 and 1996, a majority of the PAMS sites showed decreases in the concentrations of key ozone-forming VOCs.

For a more detailed discussion of the PAMS program and VOC reductions, see Chapter 4, “PAMS: Enhanced Ozone and Precursor Monitoring.”

As required by the CAA, a cleaner burning fuel known as reformulated gasoline has been sold since January 1, 1995 in those areas of the country with the worst ozone or smog problems. RFG is formulated to reduce automotive emissions of ozone-forming pollutants and toxic chemicals—it is estimated to reduce both VOC and toxic emissions by more than 15 percent. RFG sold during the summer ozone season has lower volatility than most conventional gasoline.<sup>12</sup> The RFG program is mandated year-round in 10 areas of the country (Los Angeles, San Diego, Hartford, New York, Philadelphia, Chicago, Baltimore, Houston, Milwaukee, and Sacramento). Besides these required areas, several other parts of the country exceeding the ozone standard have voluntarily entered the RFG program.<sup>13</sup> For a more detailed discussion of the VOC reductions that have been achieved since the start of the RFG program, see Chapter 4.

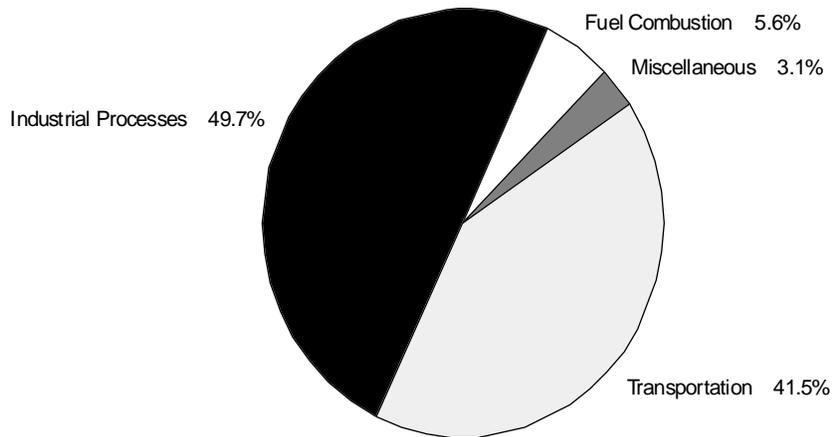


Figure 2-27. VOC emissions by source category, 1996.

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## The New 8-hour Ozone Standards

ON JULY 18, 1997, EPA announced revisions to the NAAQS for ground-level ozone, the primary constituent of smog. After a lengthy scientific review process, including extensive external scientific review, and public review and comment, the EPA Administrator determined that the previous 1-hour ozone standard should be replaced with a new 8-hour standard to protect both public health and the environment. Many new health studies show that health effects occur at levels lower than the previous standard and that exposure times longer than one hour (as reflected in the previous standard) are of concern.

The ozone primary and secondary standards, when last revised in 1979, were set at 0.12 ppm for one hour and was expressed as a "one-expected-exceedance" form. As the Clean Air Scientific Advisory Committee (CASAC) unanimously recommended, EPA changed the ozone standard averaging time to eight hours. EPA also changed the form of the primary standard, consistent with CASAC recommendations, from an expected-exceedance form to a concentration-based form because it relates more directly to ozone concentrations associated with health effects. It also avoids exceedances, regardless of magnitude, from being counted equally in the attainment tests. The new 8-hour primary standard was set at 0.08 ppm for the 3-year average of the annual 4th-highest daily maximum 8-hour ozone concentrations. The previous secondary standard (to protect the environment, i.e., agricultural crops, national parks, and forests) was

replaced with a standard identical to the new primary standard.

Based on the most recent health studies, prolonged exposures (6 to 8 hours) to relatively low ozone levels during periods of moderate exertion can result in significant decreases in lung function, increased respiratory symptoms such as chest pain and cough, increased susceptibility to respiratory infection and lung inflammation, and aggravation of preexisting respiratory diseases such as asthma. Exposures to ambient ozone concentrations have also been linked to increased hospital admissions and emergency room visits for respiratory causes. Children active outdoors during the summertime when ozone levels are at their highest are most at risk of experiencing such effects. Other at-risk groups include outdoor workers, individuals with preexisting respiratory disease such as asthma and chronic obstructive lung disease, and individuals who are unusually responsive to ozone. In addition, long-term exposures to ozone present the possibility of irreversible changes in the lungs which could lead to premature aging of the lungs and/or chronic respiratory illness.

In setting the 8-hour standard at 0.08 ppm, the EPA Administrator recognized that since there is no discernible threshold below which no adverse health effects occur, no level would eliminate all risk. Thus, a zero-risk standard is not possible, nor is it required by the Clean Air Act. The selected 0.08 ppm level is based on the judgment that at this level, public health will be protected with an adequate margin of safety.

The scientific review also highlighted concerns associated with ozone effects on vegetation for which the previous ozone standard did not provide adequate protection. These effects include reduction in agricultural and commercial forest yields; reduced growth and decreased survivability of tree seedlings; increased tree and plant susceptibility to disease, pests, and other environmental stresses; and potential long-term effects on forests and ecosystems. Many studies suggested that the degree of ozone damage to plants depends as much on the total seasonal cumulative ozone dose the plant receives as it does on the magnitude of any one particular acute ozone episode. Thus, during this current ozone NAAQS review, discussions on possible forms for a new secondary standard included a seasonal, cumulative index. Although a separate seasonal secondary standard was not set at this time, EPA believes attainment of the new 8-hour primary standard will substantially protect vegetation. EPA is committed to enhancing rural ozone monitoring, working in conjunction with other federal agencies, and considering long-term cumulative effects of ozone on plants as additional information becomes available.

The averaging times and air quality statistics used to track national air quality trends relate directly to the form of the respective national ambient air quality standard. For the 1-hour ozone standard, the solid line in Figure 2-28 shows the trend in the composite average of the annual second daily maximum 1-hour ozone concentrations. For the new 8-hour ozone standard, the

dashed line shows the trend in the composite average of the annual fourth highest daily maximum 8-hour ozone concentrations. Between 1987 and 1996, the composite average of the 1-hour daily maximum ozone concentrations declined 15 percent, while the composite average of 8-hour fourth highest daily maximum concentrations decreased by 11 percent. The 1997 *Trends Report* will mark the transition to the 8-hour standard for tracking air quality status and trends.

The new 8-hour standard became effective on September 16, 1997, while the 1-hour standard will remain in effect in an area until EPA determines that the area has met the 1-hour standard.

A copy of the Federal Register Notice (62FR 38856) for the new standard can be downloaded from EPA's homepage on the Internet. The address is: <http://www.epa.gov/ttn/oarpg/rules.html>.

## Determining Compliance with the New 8-hour Ozone Standards

### The Standards

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. The 8-hour air quality standards are met at an ambient air quality monitoring site when the average of the annual fourth-highest daily maximum 8-hour average ozone concentration is less than or equal to 0.08 ppm. (Computational details are specified in Appendix I to Part 50.10 of Title 40 of the *Code of Federal Regulations*.)

### The Attainment Test

As shown in Example 1, the primary and secondary standards are met at this monitoring site because the 3-year average of the annual fourth-highest daily maximum 8-hour average ozone

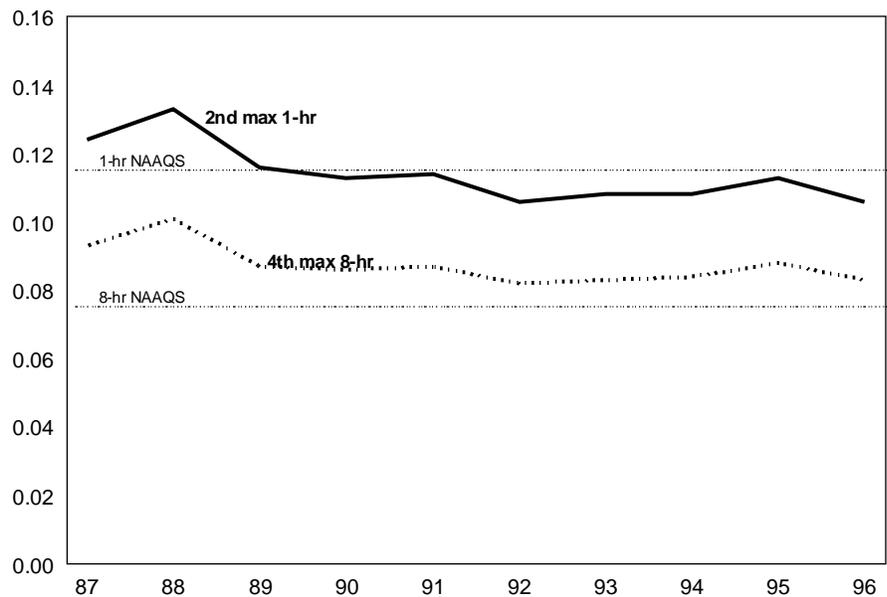


Figure 2-28. Trend in 2nd max 1-hr vs. 4th max 8-hr ozone concentrations, 1987-1996.

Example 1. Ambient monitoring site attaining the primary and secondary O<sub>3</sub> standards.

Year	Percent Valid Days	Highest Daily Max 8-hour Conc. (ppm)	2nd Highest Daily Max 8-hour Conc. (ppm)	3rd Highest Daily Max 8-hour Conc. (ppm)	4th Highest Daily Max 8-hour Conc. (ppm)
1993	100 percent	0.092	0.091	0.090	0.088
1994	96 percent	0.090	0.089	0.086	0.084
1995	98 percent	0.087	0.085	0.083	0.080
<b>Average</b>	<b>98 percent</b>				<b>0.084</b>

Example 2. Ambient monitoring site failing to meet the primary and secondary O<sub>3</sub> standards.

Year	Percent Valid Days	Highest Daily Max 8-hour Conc. (ppm)	2nd Highest Daily Max 8-hour Conc. (ppm)	3rd Highest Daily Max 8-hour Conc. (ppm)	4th Highest Daily Max 8-hour Conc. (ppm)
1993	96 percent	0.105	0.103	0.103	0.102
1994	74 percent	0.090	0.085	0.082	0.080
1995	98 percent	0.103	0.101	0.101	0.097
<b>Average</b>	<b>89 percent</b>				<b>0.093</b>

concentrations (0.084 ppm) is less than or equal to 0.08 ppm. The data completeness requirement is also met because the average percent of days with valid ambient monitoring data is greater than 90 percent, and no single year has less than 75 percent data completeness.

Example 2 shows that the primary and secondary standards are not met at this monitoring site because the 3-year average of the fourth-highest daily maximum 8-hour average ozone con-

centrations (0.093 ppm) is greater than 0.08 ppm. The ozone concentration data for 1994 is used in these computations even though the data capture is less than 75 percent, because the average fourth-highest daily maximum 8-hour average concentration is greater than 0.08 ppm.

### ***The Design Value***

The air quality design value at a monitoring site is defined as the concentration that when reduced to the level of

the standard ensures that the site meets the standard. For a concentration-based standard, the air quality design value is simply the standard-related test statistic. Thus, for the primary and secondary ozone standards, the 3-year average of the annual fourth-highest daily maximum 8-hour average ozone concentration is also the air quality design value for the site.

## Particulate Matter

- **Air Quality Concentrations (PM<sub>10</sub>)**

1988-96	25% decrease
1995-96	4% decrease
- **Emissions (PM<sub>10</sub>)**

1988-96	12% decrease
1995-96	no change

### Nature and Sources

Particulate matter 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, originate from many different stationary and mobile sources as well as from natural sources. They may be emitted directly by a source or formed in the atmosphere by the transformation of gaseous emissions. Their chemical and physical compositions vary depending on location, time of year, and meteorology.

### Health and Other Effects

Scientific studies show a link between particulate matter (alone, or combined with other pollutants in the air) and a series of significant health effects. These health effects include premature death, increased hospital admissions and emergency room visits, increased respiratory symptoms and disease, and decreased lung function, and alterations in lung tissue and structure and in respiratory tract defense mechanisms. Sensitive groups that appear to be at greater risk to such effects include the elderly, individuals with cardiopulmonary disease such as asthma, and children. In addition to health problems, particulate matter is the major cause of reduced visibility in many parts of the United States. Airborne particles also can cause soiling and damage to materials.

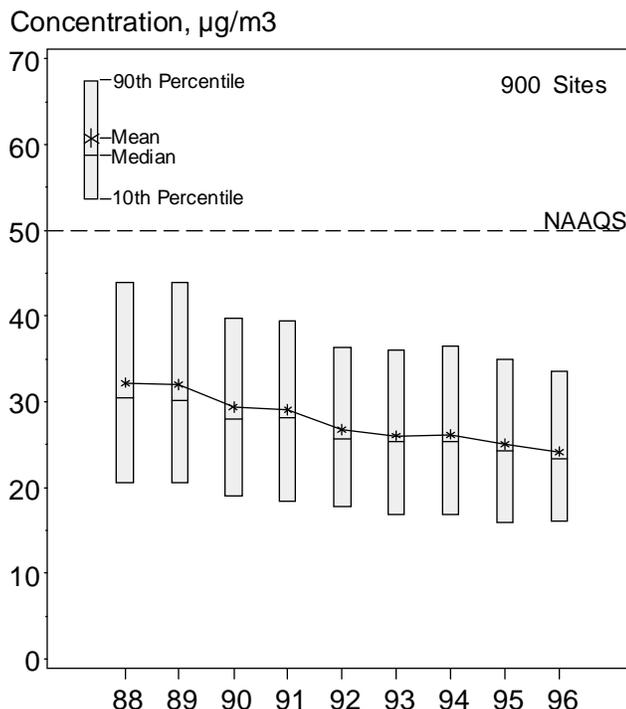


Figure 2-29. Trend in annual mean PM<sub>10</sub> concentrations, 1988-1996.

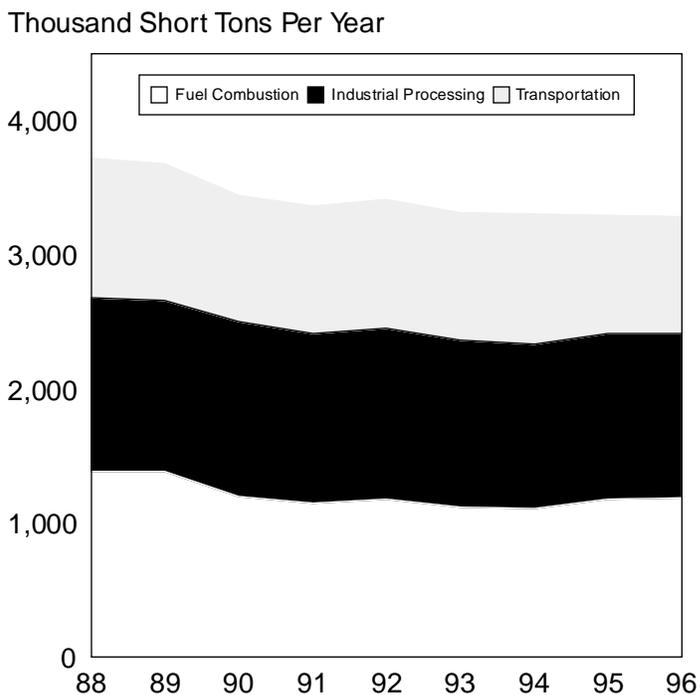
### Primary and Secondary PM<sub>10</sub> Standards

There are both short- and long-term PM<sub>10</sub> NAAQS. The long-term standard specifies an expected annual arithmetic mean not to exceed 50 µg/m<sup>3</sup> averaged over three years. The short-term (24-hour) standard of 150 µg/m<sup>3</sup> is not to be exceeded more than once per year on average over three years. Together, these make up the primary, or health-based, PM<sub>10</sub> standards. The secondary, or welfare-based, standards for PM<sub>10</sub> are identical to the primary standards.

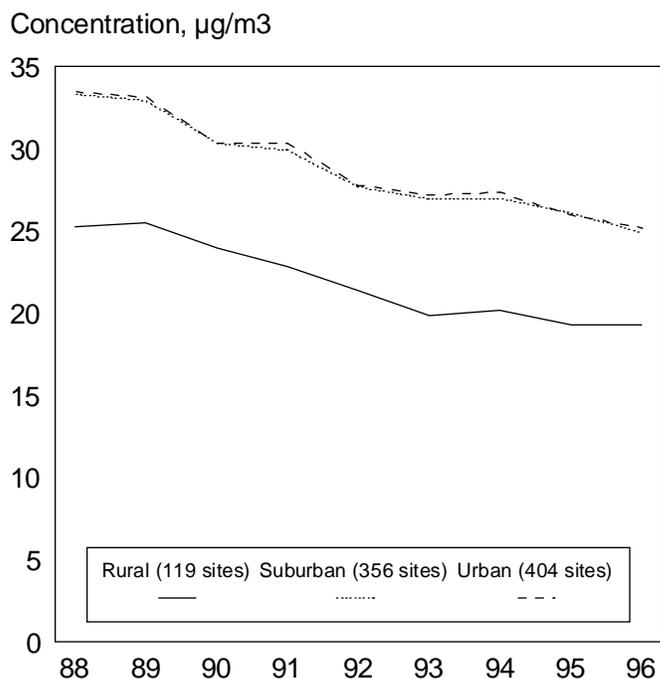
### The New PM Standards

The original standard for particulate matter was a Total Suspended Particulate (TSP) standard, established in 1971. In 1987, EPA replaced the TSP standard with a PM<sub>10</sub> standard to focus on smaller particles of aerodynamic diam-

eter less than or equal to 10 micrometers. These smaller particles caused the greatest health concern because of their ability to penetrate into sensitive regions of the respiratory tract. The most recent review of the particulate matter standards concluded that still more protection from adverse health effects was needed. On July 18, 1997 EPA revised the particulate matter standards by adding new standards for PM<sub>2.5</sub> (particles of aerodynamic diameter less than or equal to 2.5 micrometers) and by adjusting the form of the PM<sub>10</sub> 24-hour standard.<sup>14</sup> Additional details for the revised standards are provided in the next section, "The New Particulate Matter Standards." The trends discussion of this section will focus on the PM<sub>10</sub> standards that were in place when the 1987-1996 data presented in this report were collected.



**Figure 2-30.** National PM<sub>10</sub> emissions trend, 1988–1996 (traditionally inventoried sources only).



**Figure 2-31.** PM<sub>10</sub> annual mean concentration trends by location, 1988–1996.

**Trends**

The first complete year of PM<sub>10</sub> trends data for most monitors is 1988, so the trends in this section begin there. Figure 2-29 shows a 25-percent decrease in annual mean PM<sub>10</sub> concentrations measured at monitoring sites across the country between 1988 and 1996. The change in direct emissions of PM<sub>10</sub>, which are based on engineering estimates, is shown in Figure 2-30. For the same time period (1988–1996), direct emissions decreased 12 percent, while emissions of SO<sub>2</sub>, a major precursor of fine particulate matter, decreased by about the same amount. The 1-year change between 1995 and 1996 showed a 4-percent decrease in annual mean PM<sub>10</sub> concentrations, while PM<sub>10</sub> emissions remained about the same.

As shown in Figure 2-31, urban and suburban sites have similar trends and comparable average concentrations. The trends at rural sites are consistent with these urban and suburban patterns, although the composite mean level is significantly lower.

Direct PM<sub>10</sub> emissions are generally examined in two separate groups. The first is the more traditionally inventoried sources, including fuel combustion, industrial processes, and transportation, as shown in Figure 2-32. The second group 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 2-33 shows, these miscellaneous and natural sources actually account for almost 90 percent of the total direct PM<sub>10</sub> emissions nationwide, although they can be difficult to quantify compared to the traditionally inventoried sources. The emissions trend for the traditionally inventoried sources shows a 12-percent decrease since 1988. Because the emissions in

the miscellaneous/natural group tend to fluctuate a great deal from year to year, the trend from one year to the next or over several years may not be particularly meaningful. Table A-6 lists PM<sub>10</sub> emissions estimates for the traditionally inventoried sources for 1987–1996. Miscellaneous and natural source PM<sub>10</sub> emissions estimates are provided in Table A-7.

The map in Figure 2-34 displays the highest second maximum 24-hour PM<sub>10</sub> concentration by county in 1996. Three counties had a monitor with a very high 24-hour PM<sub>10</sub> second maximum concentration. The highest was recorded in Howell County, Missouri at a monitor adjacent to a charcoal kiln facility. The next highest was a monitor in Imperial County, California at a site just 1/4 mile from the border with Mexico. The third highest second maximum concentration was recorded at the Franklin Smelter in Philadelphia. The bar chart which accompanies the national map shows that in 1996, approximately 5 million people lived in 11 counties where the second highest maximum 24-hour PM<sub>10</sub> concentration was above the level of the 24-hour PM<sub>10</sub> NAAQS. When both the annual and 24-hour standards are considered, there were 7 million people living in 15 counties with PM<sub>10</sub> concentrations above the PM<sub>10</sub> NAAQS in 1996.

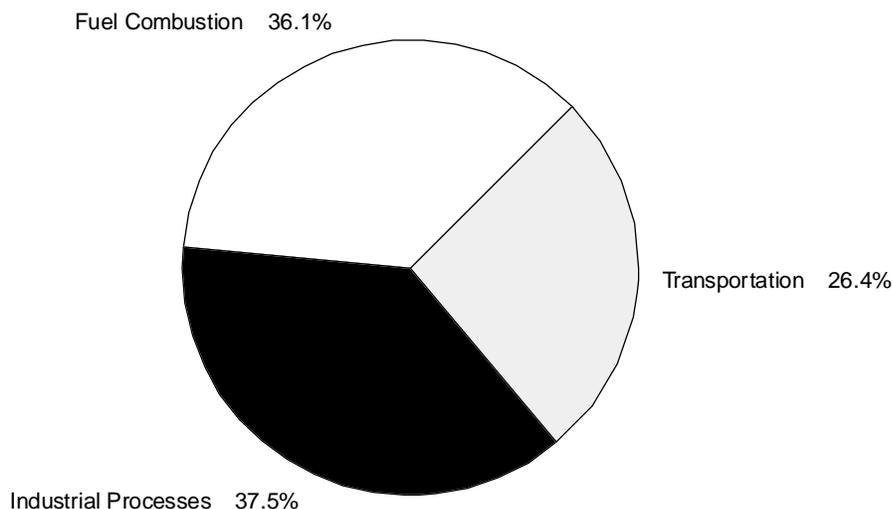


Figure 2-32. PM<sub>10</sub> emissions from traditionally inventoried source categories, 1996.

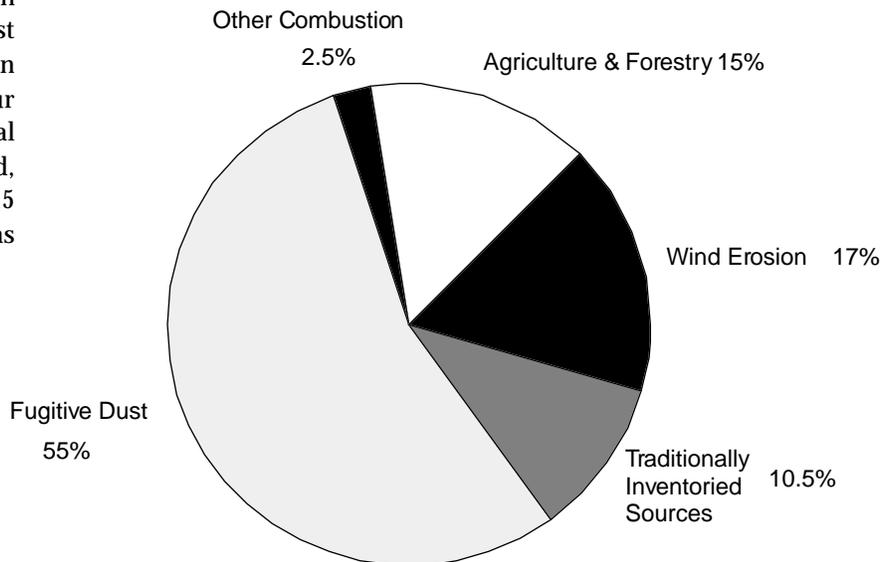


Figure 2-33. Total PM<sub>10</sub> emissions by source category, 1996.

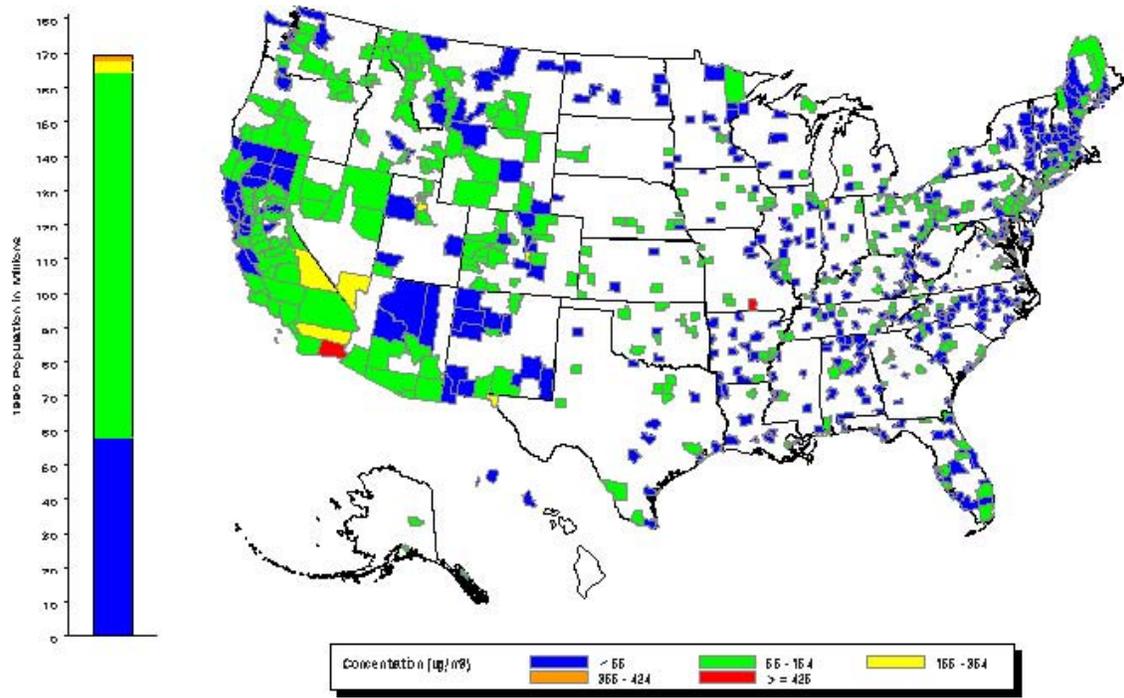


Figure 2-34. Highest second maximum 24-hour PM<sub>10</sub> concentration by county, 1996.

## The New Particulate Matter Standards

Revisions to the particulate matter standards were announced July 18, 1997. The review of hundreds of peer-reviewed scientific studies, published since the original  $PM_{10}$  standards were established, provided evidence that significant health effects are associated with exposures to ambient levels of fine particles allowed by the  $PM_{10}$  standards. Consistent with the advice given by CASAC, the EPA Administrator determined that adding new standards was necessary to protect the health of the public and the environment.

The primary (health-based) standards were revised to add two new  $PM_{2.5}$  standards, set at  $15\mu\text{g}/\text{m}^3$  and  $65\mu\text{g}/\text{m}^3$ , respectively, for the annual and 24-hour standards, and to change the form of the 24-hour  $PM_{10}$  standard. In setting these levels, the EPA Administrator recognized that since there is no discernible threshold below which no adverse health effects occur, no level would eliminate all risk. Therefore, a zero-risk standard is not possible, nor is it required by the CAA. The selected levels are based on the judgement that public health will be protected with an adequate margin of safety. The secondary (welfare-based) standards were revised by making them identical to the primary standards. In conjunction with the Regional Haze Program, the secondary standards will protect against major PM welfare effects, such as visibility impairment, soiling, and materials damage.

$PM_{2.5}$  consists of those particles that are less than 2.5 micrometers in diameter. They are also referred to as "fine" particles, while those between 2.5 and 10 micrometers are known as "coarse" particles. Fine particles result from fuel combustion from motor vehicles, power generation, and industrial facili-

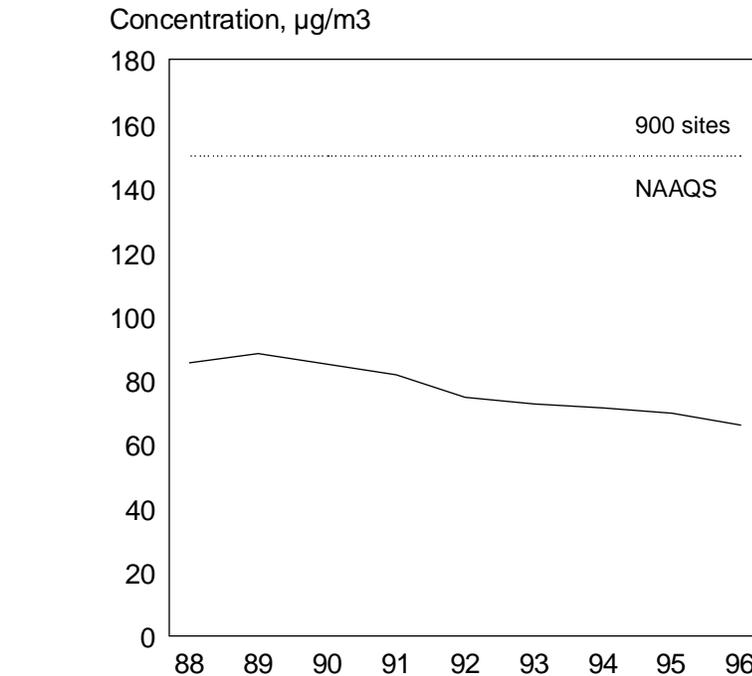


Figure 2-35.  $PM_{10}$  trend in the average 99th percentile  $PM_{10}$  concentration, 1988–1996.

ties, as well as from residential fireplaces and wood stoves. Fine particles can also be formed in the atmosphere by the transformation of gaseous emissions such as  $\text{SO}_2$ ,  $\text{NO}_x$ , and VOCs. Coarse particles are generally emitted from sources such as vehicles traveling on unpaved roads, materials handling, and crushing and grinding operations, as well as windblown dust.

Both coarse and fine particles can accumulate in the respiratory system and are associated with numerous health effects. Exposure to coarse fraction particles is primarily associated with the aggravation of respiratory conditions such as asthma. Fine particles are most closely associated with such health effects as premature death, increased hospital admissions and emergency room visits, increased respiratory symptoms and disease, and de-

creased lung function. Sensitive groups that appear to be at greatest risk to such effects include the elderly, individuals with cardiopulmonary disease such as asthma, and children.

The form of the 24-hour  $PM_{10}$  standard changed from the one-expected-exceedance form to a concentration-based 99th percentile form, averaged over three years. EPA changed the form of the 24-hour  $PM_{10}$  standard from an expected-exceedance form to a concentration-based form because the new form relates more directly to PM concentrations associated with health effects. The concentration-based form also avoids exceedances, regardless of size, from being counted equally in attainment tests. The method for computing the 99th percentile for comparison to the 24-hour standard is found in the *Code of Federal Regulations* (40 CFR Part

50, Appendix N) and is described briefly in the pages that follow.

Figure 2-35 shows a trend of the average 99th percentile for 900 sites across the country. The 99th percentile shown in the trend is computed by the Aerometric Information Retrieval System (AIRS), so it differs slightly from the data handling procedures found in the Code of Federal Regulations (CFR). The data displayed in the figure also differ from the regulatory data handling procedures in that only one year of data are presented, whereas an actual comparison to the standards is always based on an average of three years of data. The trend data show a 23-percent increase in average 99th percentile concentration between 1988 and 1996.

The form of the 24-hour  $PM_{2.5}$  standard is also a percentile form, although it is a 98th percentile. Like  $PM_{10}$ , it is averaged over three years. The form of the annual standard for  $PM_{2.5}$  is a 3-year average of the annual arithmetic mean, just as for the  $PM_{10}$  standard. However, unlike  $PM_{10}$ , compliance with the  $PM_{2.5}$  annual standard may be judged from single or multiple community-oriented monitors reflective of a community-based spatial average. A spatial average is more closely linked to the underlying health effects information. A trend of  $PM_{2.5}$  data is not presented here because there are not enough monitors in place at this time to portray an accurate national trend. The network of monitors required for the new  $PM_{2.5}$  standard will be phased in over the next three to four years.

A copy of the Federal Register Notice for the new PM standard (62FR 38652) can be downloaded from EPA's homepage on the Internet. The address is <http://www.epa.gov/ttn/oarpg/rules.html>.

## Determining Compliance With the New PM Standards

Appendix N to 40 CFR Part 50 contains the data handling regulations for the new particulate matter standards. Some of those requirements are illustrated in the examples provided here, but Appendix N includes additional details, requirements, and examples (including examples for spatial averaging and for data which do not meet data completeness requirements).

The levels, forms, and rounding conventions of the particulate matter standards can be summarized as follows:

### Annual $PM_{10}$ Standard

Level:  $50 \mu\text{g}/\text{m}^3$   
 Form: At each site, calculate the annual mean from 4 quarterly means. Average the annual means for 3 years.  
 Rounding: 50.4 rounds to 50  
 50.5 rounds to 51 (first value above the standard).

### 24-Hour $PM_{10}$ Standard

Level:  $150 \mu\text{g}/\text{m}^3$   
 Form: At each site, calculate the 99th percentile for the year. Average the 99th percentiles for 3 years.  
 Rounding: 154 rounds to 150  
 155 rounds to 160 (first value above the standard).

### Annual $PM_{2.5}$ Standard

Level:  $15.0 \mu\text{g}/\text{m}^3$   
 Form: At each site, calculate the annual mean from 4 quarterly means. If spatial averaging is used, average the annual means of the designated monitors in the area to get an annual spatial mean. Then

average the annual spatial means for 3 years.

Rounding: 15.04 rounds to 15.0  
 15.05 rounds to 15.1 (first value above the standard).

### 24-Hour $PM_{2.5}$ Standard

Level:  $65 \mu\text{g}/\text{m}^3$   
 Form: At each site, calculate the 98th percentile for the year. Average the 98th percentiles for 3 years.  
 Rounding: 65.4 rounds to 65  
 65.5 rounds to 66 (first value above the standard).

### Sample Calculation of the 3-Year Average Annual Mean for $PM_{10}$

Assume data completeness requirements have been met for this example. At each site, average all the 24-hour measurements in a quarter to find the quarterly mean. Then average the 4 quarterly means to find the annual mean. In this example, the 4 quarterly means for the first year are 43.23, 54.72, 50.96, and 60.77  $\mu\text{g}/\text{m}^3$ . Find the annual mean for the first year.

$$\frac{43.23 + 54.72 + 50.96 + 60.77}{4} = 52.42 \mu\text{g}/\text{m}^3$$

Similarly, the annual means for the second and third year are calculated to be 82.17 and 63.23  $\mu\text{g}/\text{m}^3$ . Find the 3-year average annual mean.

$$\frac{52.42 + 82.17 + 63.23}{3} = 65.94 \mu\text{g}/\text{m}^3$$

Round 65.94 to 66  $\mu\text{g}/\text{m}^3$  before comparing to the standard. *This example does not meet the  $PM_{10}$  annual standard.*

**Sample Calculation of the 3-Year Average 99th Percentile for PM<sub>10</sub>**

Assume for this example that the data completeness requirements have been met. At each site, sort all values collected in a year from lowest to highest. Number their rankings as in the following table:

Year 1	
Rank	Value (µg/m <sup>3</sup> )
1	85
2	87
3	88
—	—
108	120
109	128
110	130

Year 2	
Rank	Value (µg/m <sup>3</sup> )
1	90
2	93
3	97
—	—
96	143
97	148
98	150

Year 3	
Rank	Value (µg/m <sup>3</sup> )
1	40
2	48
3	52
—	—
98	140
99	144
100	147

In this example, the site collected 110 out of a possible 121 samples in Year 1; 98 out of 121 in Year 2; and 100 out of 121 in Year 3. Calculate the 99th percentile for each year.

$$0.99 \times 110 = 108.9$$

$$0.99 \times 98 = 97.02$$

$$0.99 \times 100 = 99$$

Take the integer part of the product and add 1 to find which ranking corresponds to the 99th percentile.

$$108 + 1 = 109$$

$$97 + 1 = 98$$

$$99 + 1 = 100$$

Find the value which corresponds to the ranking using the table above.

109 corresponds to 128 µg/m<sup>3</sup>

98 corresponds to 150 µg/m<sup>3</sup>

100 corresponds to 147 µg/m<sup>3</sup>

Find the 3-year average of the 99th percentiles.

$$\frac{128 + 150 + 147}{3} = 141.66667 \text{ µg/m}^3$$

Round 141.66667 to 140 µg/m<sup>3</sup> before comparing to the standard. *This example meets the PM<sub>10</sub> 24-hour standard.*

**Sample Calculation of the 3-Year Average of the Spatially Averaged Annual Means for PM<sub>2.5</sub>**

Assume data completeness requirements have been met for this example. Given an area designated for spatial averaging and three monitors designated for spatial averaging within the area, first average all the 24-hour measurements in each quarter at each site to find the 4 quarterly means. Then calculate the annual mean from the 4 quarterly means. If, for this example, the 4 quarterly means for first site for the first year are 11.6, 12.4, 15.1, and 12.1 µg/m<sup>3</sup>, find the annual mean for this site and year.

$$\frac{11.6 + 12.4 + 15.1 + 12.1}{4} = 12.8 \text{ µg/m}^3$$

Similarly, the annual means for the other sites and the other years can be calculated. The results appear in the following table.

	Annual Means (µg/m <sup>3</sup> )		
	Site 1	Site 2	Site 3
Year 1	12.8	14.2	13.6

Year 2	13.0	13.5	12.9
Year 3	15.2	14.8	17.1

For Year 1, find the annual spatial mean of the designated monitors in the area.

$$\frac{12.8 + 14.2 + 13.6}{3} = 13.533333 \text{ µg/m}^3$$

Similarly, the annual spatial means for Year 2 and Year 3 are calculated to be 13.13 and 15.7 µg/m<sup>3</sup>. Find the 3-year average annual spatial mean.

$$\frac{13.533333 + 13.13 + 15.7}{3} = 14.121111 \text{ µg/m}^3$$

Round 14.121111 to 14.1 µg/m<sup>3</sup> before comparing to the standard. *This example meets the PM<sub>2.5</sub> annual standard.*

**Sample Calculation of the 3-Year Average 98th Percentile for PM<sub>2.5</sub>**

Assume for this example that the data completeness requirements have been met. At each site, sort all values collected in a year from lowest to highest. Number their rankings as in the following table:

Year 1	
Rank	Value (µg/m <sup>3</sup> )
—	—
275	57.9
276	59.0
277	62.2
—	—

Year 2	
Rank	Value (µg/m <sup>3</sup> )
—	—
296	54.3
297	57.1
298	63.0
—	—

Year 3	
Rank	Value (µg/m <sup>3</sup> )
—	—
290	66.0
291	68.4

292

69.8

—

—

In this example, the site collected 281 samples out of possible 365 samples in Year 1; 304 out of 365 in Year 2; and 296 out of 365 in Year 3. Calculate the 98th percentile for each year.

$$0.98 \times 281 = 275.38$$

$$0.98 \times 304 = 297.92$$

$$0.98 \times 296 = 290.07$$

Take the integer part of the product and add 1 to find which ranking corresponds to the 98th percentile.

$$275 + 1 = 276$$

$$297 + 1 = 298$$

$$290 + 1 = 291$$

Find the value which corresponds to the ranking using the table above.

$$276 \text{ corresponds to } 59.0 \mu\text{g}/\text{m}^3$$

298 corresponds to  $63.0 \mu\text{g}/\text{m}^3$

291 corresponds to  $68.4 \mu\text{g}/\text{m}^3$

Find the 3-year average of the 98th percentiles.

$$\frac{59.0 + 63.0 + 68.4}{3} = 63.466667 \mu\text{g}/\text{m}^3$$

Round  $63.466667$  to  $63 \mu\text{g}/\text{m}^3$  before comparing to the standard. *This example meets the  $PM_{2.5}$  24-hour standard.*

## Sulfur Dioxide

- Air Quality Concentrations**

1987-96	37% decrease
1995-96	no change

- Emissions**

1987-96	14% decrease
1995-96	3% increase

### Nature and Sources

Sulfur dioxide belongs to the family of sulfur oxide gases. These gases are formed when fuel containing sulfur (mainly coal and oil) is burned, and during metal smelting and other industrial processes. Most SO<sub>2</sub> monitoring stations are located in urban areas. The highest monitored concentrations of SO<sub>2</sub> are recorded in the vicinity of large industrial facilities.

### Health and Other Effects

The major health concerns associated with exposure to high concentrations of SO<sub>2</sub> include effects on breathing, respiratory illness, alterations in the lungs' defenses, and aggravation of existing cardiovascular disease. Major subgroups of the population that are most sensitive to SO<sub>2</sub> include asthmatics and individuals with cardiovascular disease or chronic lung disease, as well as children and the elderly.

Together, SO<sub>2</sub> and NO<sub>x</sub> are the major precursors to acidic deposition (acid rain), which is associated with the acidification of lakes and streams, accelerated corrosion of buildings and monuments, and reduced visibility. SO<sub>2</sub> is a major precursor to PM<sub>2.5</sub>, which, as discussed in the previous section (beginning on page 34), is of sig-

nificant concern to health as well as a main pollutant that impairs visibility.

### Primary and Secondary Standards

There are two primary NAAQS for SO<sub>2</sub> that address these health concerns: an annual mean concentration of 0.030 ppm (80 µg/m<sup>3</sup>) not to be exceeded, and a 24-hour daily concentration of 0.14 ppm (365 µg/m<sup>3</sup>) not to be exceeded more than once per year.

The secondary SO<sub>2</sub> NAAQS is a 3-hour average concentration of 0.50 ppm (1,300 µg/m<sup>3</sup>) not to be exceeded more than once per year.

### Trends

The map in Figure 2-36 displays the highest second maximum 24-hour SO<sub>2</sub> concentration by county in 1996. Only

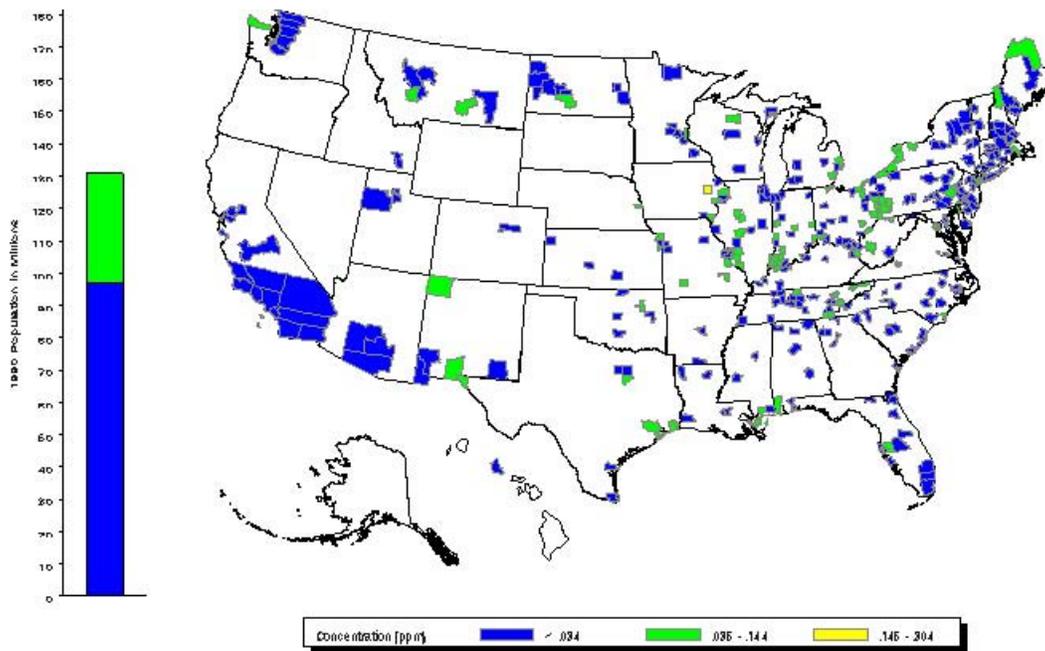


Figure 2-36. Highest second maximum 24-hour SO<sub>2</sub> concentration by county, 1996.

one county, Linn County, Iowa, containing a major SO<sub>2</sub> point source, failed to meet the ambient SO<sub>2</sub> NAAQS in 1996.

The national composite average of SO<sub>2</sub> annual mean concentrations decreased 37 percent between 1987 and 1996 (see Figure 2-37), while SO<sub>2</sub> emissions decreased 12 percent (see Figure 2-38). Between 1995 and 1996, there was no change in the national composite average of SO<sub>2</sub> annual mean concentrations, while SO<sub>2</sub> emissions increased 3 percent.

Historically, networks are positioned in population-oriented locales. As seen in Figure 2-39, eighty-eight percent of total national SO<sub>2</sub> emissions, however, result from fuel combustion sources that tend to be located in less populated areas. Thus, it is important to emphasize that current SO<sub>2</sub> problems in the United States are caused by point sources that are usually identified by modeling rather than routine ambient monitoring. Figure 2-40 reveals that composite annual mean concentrations at sites in suburban and urban locations decreased 38 and 41 percent, respectively, while ambient levels decreased 29 percent at rural sites.

The progress in reducing ambient SO<sub>2</sub> concentrations during the past 20 years is shown in Figure 2-41. This reduction was accomplished by installing flue-gas control equipment at coal-fired generating plants, reducing emissions from industrial 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.

Established by EPA under Title IV of the CAA, the Acid Rain Program's principal goal is to achieve significant reductions in SO<sub>2</sub> and NO<sub>x</sub> emissions.

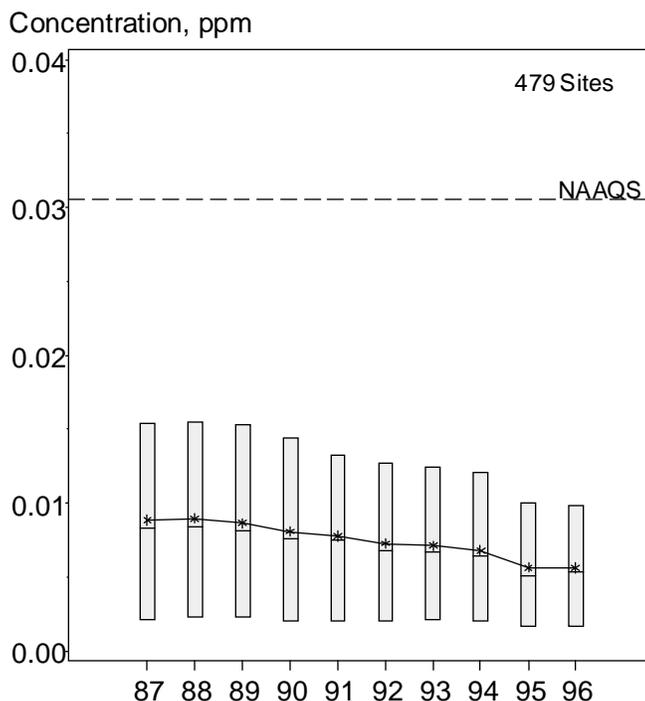


Figure 2-37. Trend in annual mean SO<sub>2</sub> concentrations, 1987-1996.

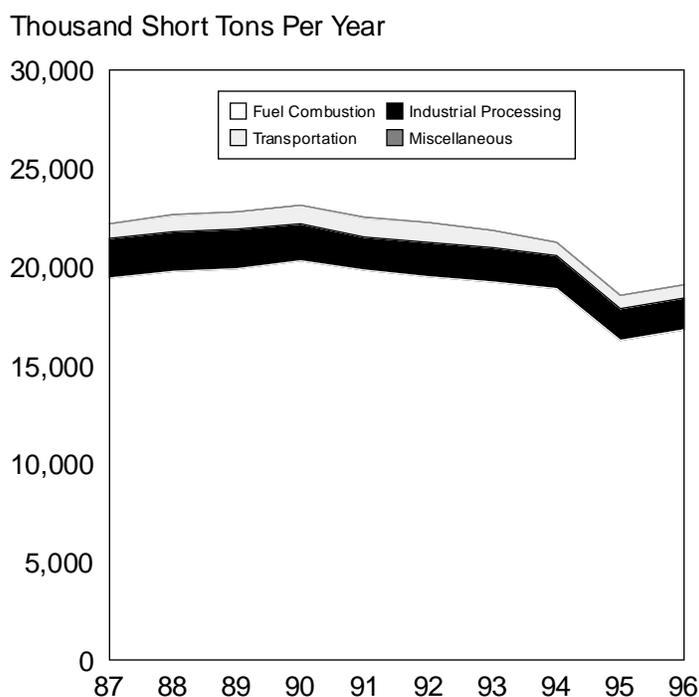


Figure 2-38. National total SO<sub>2</sub> emissions trend, 1987-1996.

Phase I of EPA's Acid Rain Program reduced SO<sub>2</sub> emissions at participating utilities from 10.9 million tons in 1980 to 5.3 million tons in 1995. This level was 39 percent below 8.7 million tons, the allowable emissions level for 1995 required by the CAAA. In 1996, SO<sub>2</sub> emissions at the participating utilities rose to 5.4 million tons, an increase of approximately 100,000 tons from 1995. This is still 35 percent below the 1996 allowable level of 8.3 million tons. Review of the largest emission increases between 1995 and 1996 reveals that increased utilization seems to be at least a contributing factor, if not the sole factor, for most of the increases. At several units, for example, the rise occurred due to increased utilization coupled with the use of higher sulfur coal in response to the market providing this coal (and allowances) less expensively. Another case reflects a utilization increase coupled with scrubber difficulties, resulting in lower removal efficiencies than in 1995. A final case where a substantial increase in emissions occurred is due solely to a utilization increase; the unit underwent an extended outage in 1995, but operated throughout 1996.<sup>15</sup> For more information, visit the Acid Rain Program Home Page at <http://www.epa.gov/acidrain>.

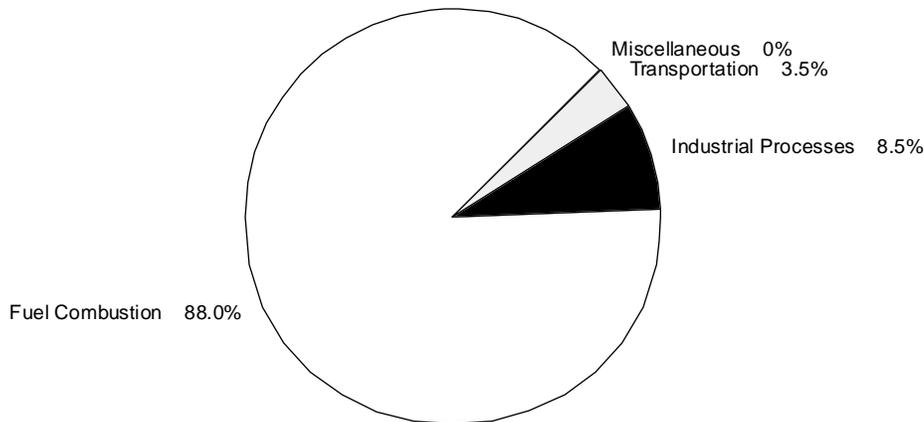


Figure 2-39. SO<sub>2</sub> emissions by source category, 1996.

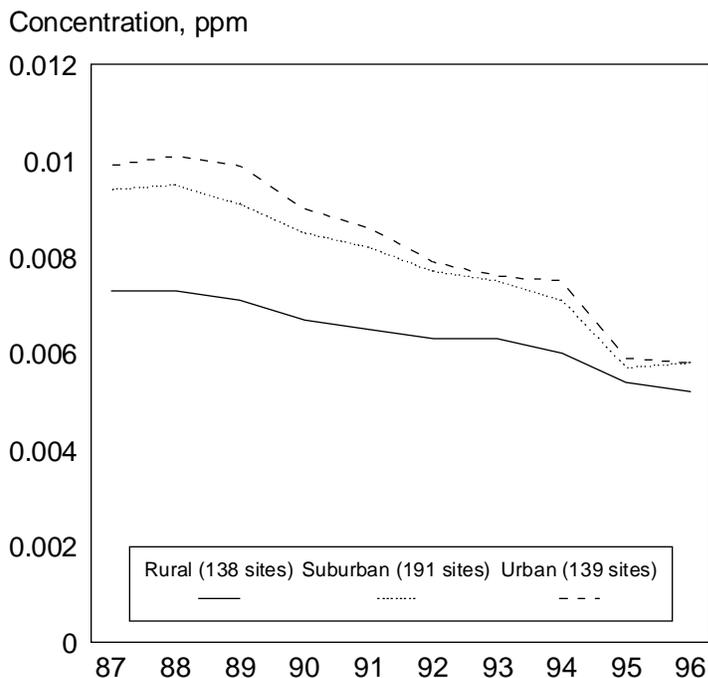
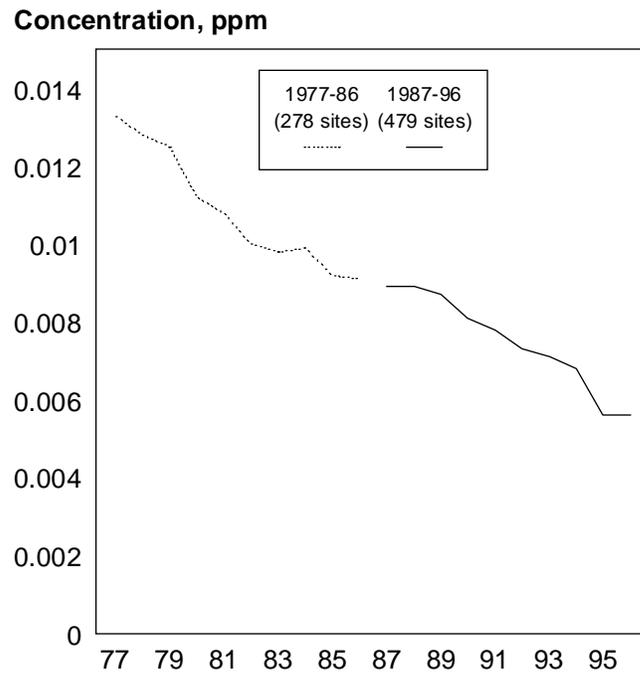


Figure 2-40. SO<sub>2</sub> annual mean concentration trend by location, 1987–1996.



**Figure 2-41.** Long-term ambient SO<sub>2</sub> trend, 1977–1996.

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