Ambient Air Quality Trends

An Analysis of Data Collected by the U.S. Environmental Protection Agency

Final Report

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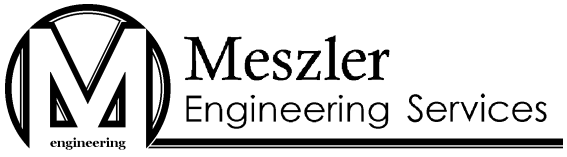

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1. Summary of Findings

Since the 1970 enactment of the Clean Air Act, ambient air quality in the United States has improved dramatically. The overwhelming majority of Americans routinely breathe air that meets National Ambient Air Quality Standards (NAAQS). Many areas that previously violated those standards are now in full compliance -- and, while portions of the U.S. continue to experience periodic violations of the NAAQS, both the frequency and severity of those violations have declined. Moreover, improvements have occurred against a backdrop of a 164 percent increase in economic output, a 42 percent increase in energy consumption, a 155 percent increase in vehicle miles of travel, and a 38 percent increase in population.[1] In short, the substantial efforts dedicated to improving air quality over the last 30-plus years have paid public health dividends and will continue to do so for the foreseeable future.

As noted above and documented in the information that follows, portions of the U.S. continue to experience NAAQS violations and efforts to bring these areas into compliance will continue. Nevertheless, air quality data collected and maintained by federal, state, and local regulators provides compelling and inarguable evidence that substantial air quality improvements have occurred over the last 25 years. In light of the common misimpression that the nation's air quality is poor and becoming poorer, this study was undertaken to provide quantitative evidence of these improvements. Although other researchers, including the U.S. Environmental Protection Agency (EPA), have reached conclusions that are entirely consistent with those presented in this report, the substantial progress observed to date is often unrecognized.[2] It is hoped that the data presented herein might serve as compelling evidence that U.S. air quality has come a long way and that American's are breathing cleaner air.

Air quality in the U.S. is monitored by the EPA through NAAQS that the agency has established for six specific pollutants. There are primary standards to protect human health (with a margin of safety) and secondary standards to protect public welfare.[3] States are responsible for ensuring attainment and maintenance of these standards once set by EPA.

Although the specific form and numerical values of the NAAQS have evolved over time, the basic pollutants monitored have remained unchanged since the early 1970s. Specifically, NAAQS have been established for ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), lead (Pb), and particulate matter (PM). All but PM are specific chemical compounds and, therefore, precisely defined. Particulate matter essentially signifies airborne particles of any composition, and these cover a rather wide size range. Since the particles of most concern from a health standpoint are those that can be deeply inhaled, PM standards have

[1] http://www.epa.gov/airtrends/sixpoll.html

[2] See for example, various materials presented on the EPA website: http://www.epa.gov/airtrends/.

[3] It is important to note that this study does not include any effort to evaluate the propriety of the air quality standards established by the EPA. The standards as set by the EPA are treated simply as compliance targets. Although there is debate regarding the propriety and attainability of some of the NAAQS, this study purposefully avoids such issues in an effort to let the air quality data "speak for itself."

been established for both PM-10 and PM-2.5. PM-10 is particulate matter with an effective aerodynamic diameter of 10 microns or less, while PM-2.5 is particulate matter with an effective aerodynamic diameter of 2.5 microns or less. The largest PM-10 and PM-2.5 is about $1/7^{th}$ and $1/30^{th}$ the diameter of a human hair respectively.

Efforts to comply with the NAAQS generally involve the implementation of regulatory programs designed to reduce contributing emissions. These efforts include approaches such as establishing specific emissions limitations for industrial and commercial facilities (through operating permits), establishing production standards for products such as motor vehicles and nonroad equipment, and operating in-use compliance programs to ensure that low emission levels are maintained. The overall approach designed by a state to attain compliance with the NAAQS is set out in a State Implementation Plan (SIP), which, under federal law, is required to be developed in any area that does not meet an air quality standard.

Of the six NAAQS pollutants, continuing violations are almost exclusively associated with ozone and PM. There are very few areas in the U.S. that are classified by the EPA as not meeting air quality standards for CO, SO_2, NO_2, and lead, and fewer still that actually experience NAAQS violations.[4] In light of this, the specific data analysis performed for this study is limited to air quality data for ozone and PM.[5] Findings for the other NAAQS pollutants are based exclusively on information extracted from previous EPA publications. It should be noted that while charts are reproduced in this section to illustrate a number of study findings, there are a large number of equally informative charts that are not reproduced here in the interest of brevity. Interested readers will find additional graphical information in the more detailed Sections 3 through 9 of this report.

Findings Related to Ozone

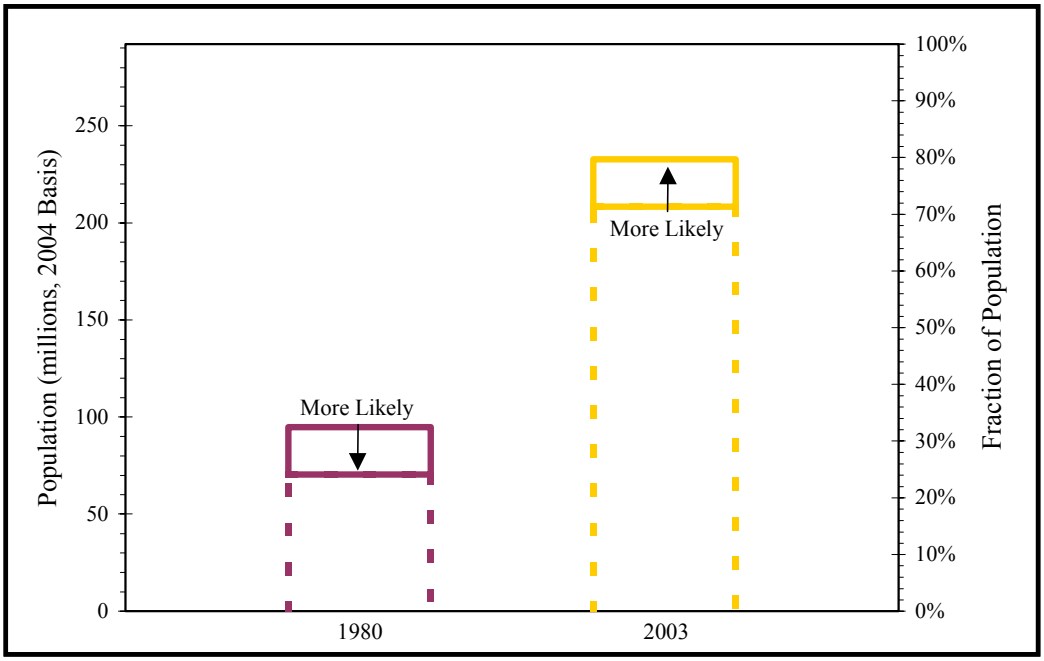
- It is estimated that over 90 percent of U.S. counties and 70-80 percent of the U.S. population live in counties that meet the 1-hour NAAQS.[6] In contrast, only 20-30 percent of the population lived in counties meeting the 1-hour NAAQS in 1980. [See Figure 1-1] *Only about 10 percent of monitored counties and 5 percent of the monitored population met the 1-hour NAAQS in 1980 -- this has increased to 90 percent of monitored counties and 70 percent of the monitored population in 2003.*

[4] Once an area is classified by the EPA as being out of compliance with an NAAQS, that area must fulfill a number of requirements *in addition to* actually meeting the standards to be reclassified as in compliance with the NAAQS. These are primarily administrative requirements designed to ensure that the area maintains its compliance status over time. Since a considerable period of time can pass between actually meeting an NAAQS and fulfilling the additional reclassification requirements, it is common for areas that have achieved compliance with numerical NAAQS requirements to continue to be classified as out of compliance for some time.

[5] The same data collected by the EPA and used to determine compliance with the NAAQS. These data are available on the EPA website at http://www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm.

[6] Precise estimates of the number of counties and population meeting the NAAQS are not possible since air quality monitors are preferentially located in counties where air quality problems are suspected. The majority of counties in the U.S. have no air quality monitoring data and, therefore, statistical estimations are required.

Figure 1-1. Population Meeting the 1-Hour Ozone Standard



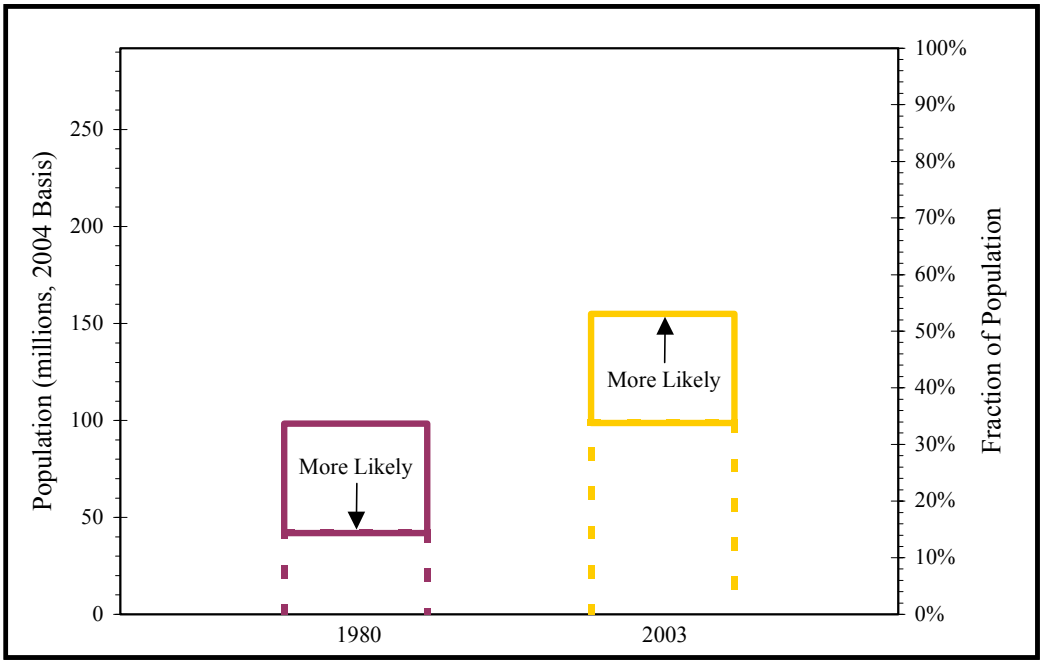
- It is estimated that up to 90 percent of U.S. counties and up to 50 percent of the U.S. population lives in counties that meet the 8-hour NAAQS. In contrast, as few as 15 percent of the population lived in counties that would have met the 8-hour NAAQS in 1980.[7] [See Figure 1-2] *Only about 10 percent of monitored counties and 5 percent of the monitored population would have met the 8-hour NAAQS in 1980 -- this has increased to 50 percent of monitored counties and 33 percent of the monitored population in 2003.*

  - Although this study treats the NAAQS as simple compliance targets and purposefully avoids any determination regarding the propriety of the standards, it is perhaps important to note that the 8-hour ozone standard represents a *very* stringent compliance target and that there is a growing body of evidence indicating that many areas of the U.S. will find it difficult, if not impossible, to attain.[8]

[7] The 8-hour NAAQS did not exist in 1980, but for trend determination purposes, existing ozone data from that period were analyzed as if the standard was in place.

[8] See for example, "*Understanding the Effectiveness of Precursor Reductions in Lowering 8-Hour Ozone Concentrations*," Journal of the Air & Waste Management Association, Vol. 53, 195-205 (2003) and "*Understanding the Effectiveness of Precursor Reductions in Lowering 8-Hr Ozone Concentrations - Part II. The Eastern United States*," Journal of the Air & Waste Management Association, In press (2005).

Figure 1-2. Population Meeting the 8-Hour Ozone Standard

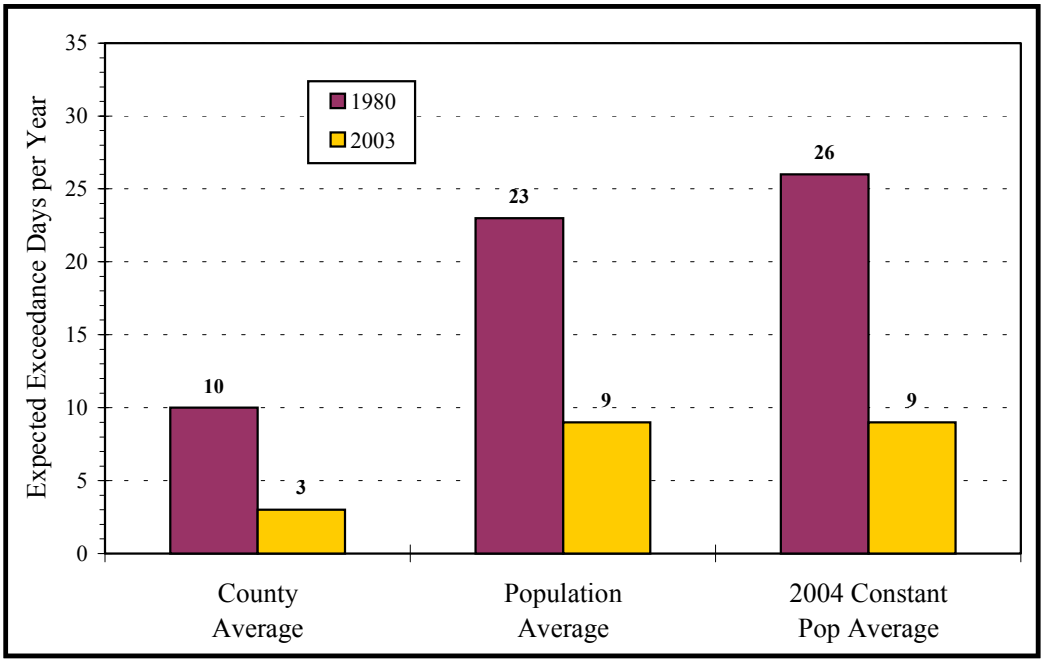


- In counties that violate the NAAQS, the number and severity of violations has been reduced dramatically.

- The number of days on which air quality exceeds the 1-hour standard in counties violating the NAAQS has been reduced by 60-70 percent since 1980 (to 3 days per year per county, or 9 days per year on a population-weighted basis). [See Figure 1-3] The number of annual exceedance hours has been reduced by an even greater 75-80 percent (to 8 hours per year per county, or 23 hours per year on a population-weighted basis). Thus, 1-hour ozone concentrations currently exceed the NAAQS for about 0.25 percent of the year *in areas violating the standard*. This means that there is one hour of air quality above the standard for every 380 hours of air quality below the standard.

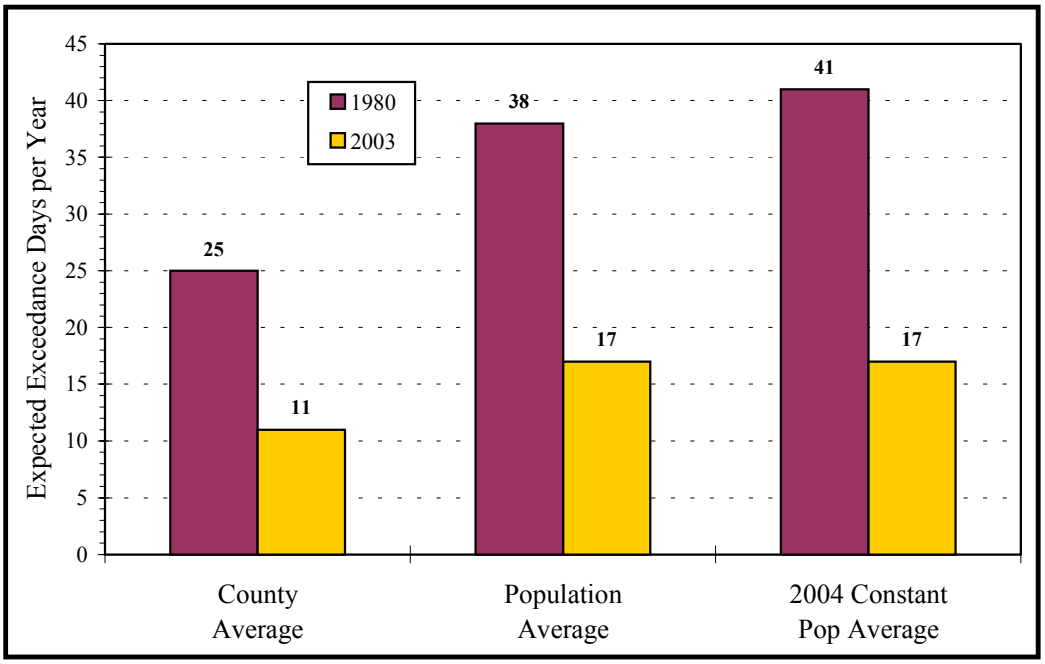
- The number of days on which air quality exceeds the 8-hour standard in counties violating the NAAQS has been reduced by about 55 percent since 1980 (to 11 days per year per county, or 17 days per year on a population-weighted basis). [See Figure 1-4] The number of annual exceedance hours has been reduced by 55-60 percent (to 58 hours per year per county, or 90 hours per year on a population-weighted basis). Thus, 8-hour ozone concentrations currently exceed the NAAQS for about 1 percent of the year *in areas violating the standard*. This means that there is one hour of air quality above the standard for every 100 hours of air quality below the standard.

Figure 1-3. Number of Days on which the 1-Hour Standard is Exceeded



Note: In Figures 1-3 and 1-4, data are based solely on counties violating the applicable NAAQS.

Figure 1-4. Number of Days on which the 8-Hour Standard in Exceeded



- On days when air quality exceeds the 1-hour standard, the degree to which the standard is exceeded has been reduced by 70-75 percent since 1980.[9] Current exceedances are about 7 percent above the standard for an average violating county, or about 17 percent above the standard on a population-weighted basis. [See Figure 1-5]

- On days when air quality exceeds the 8-hour standard, the degree to which the standard is exceeded has been reduced by about 70 percent since 1980.[10] Current exceedances are about 8 percent above the standard for an average violating county, or about 14 percent above the standard on a population-weighted basis. [See Figure 1-6]

- Thus, while additional progress will be required to bring all areas of the U.S. into compliance with the 1-hour and 8-hour NAAQS for ozone, dramatic improvement has been observed in both the number of areas meeting the standard and the frequency and severity of violations in areas not meeting the standard.

Findings Related to Particulate Matter

- Due to emission reductions prior to the availability of air quality data for PM-10 and PM-2.5, it is almost certain that air quality improvements are significantly larger than those reported in this study.[11] Nevertheless, improvement since the period of data availability is significant.

- The number of counties violating the PM-10 NAAQS has been reduced by 60 percent for the annual NAAQS and 20 percent for the daily NAAQS since 1990. On a population-weighted basis, reductions have been more dramatic, at about 70 percent for the annual NAAQS and 30-40 percent for the daily NAAQS. [See Figures 1-7 and 1-8]

- PM-10 concentrations have declined by 20-30 percent between 1990 and 2003.

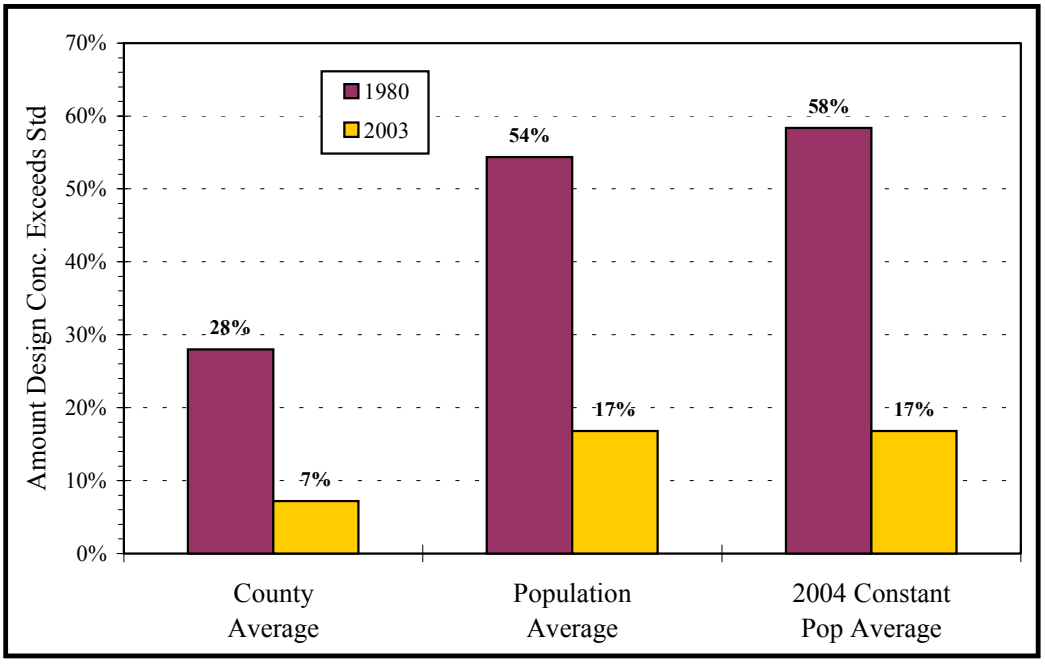
- Although PM-2.5 data are available for only a short period of time, the data do suggest a modest level of air quality improvement. The number of counties and population violating the PM-2.5 NAAQS has been reduced since 2000 by 10-15 percent for the annual NAAQS and 15-25 percent for the daily NAAQS. [See Figures 1-9 and 1-10] PM-2.5 concentrations over the period have declined by 5-10 percent.

[9] Based on the 1-hour design concentration, an indicator of the severity of ozone exceedances.

[10] Based on the 8-hour design concentration, an indicator of the severity of ozone exceedances.

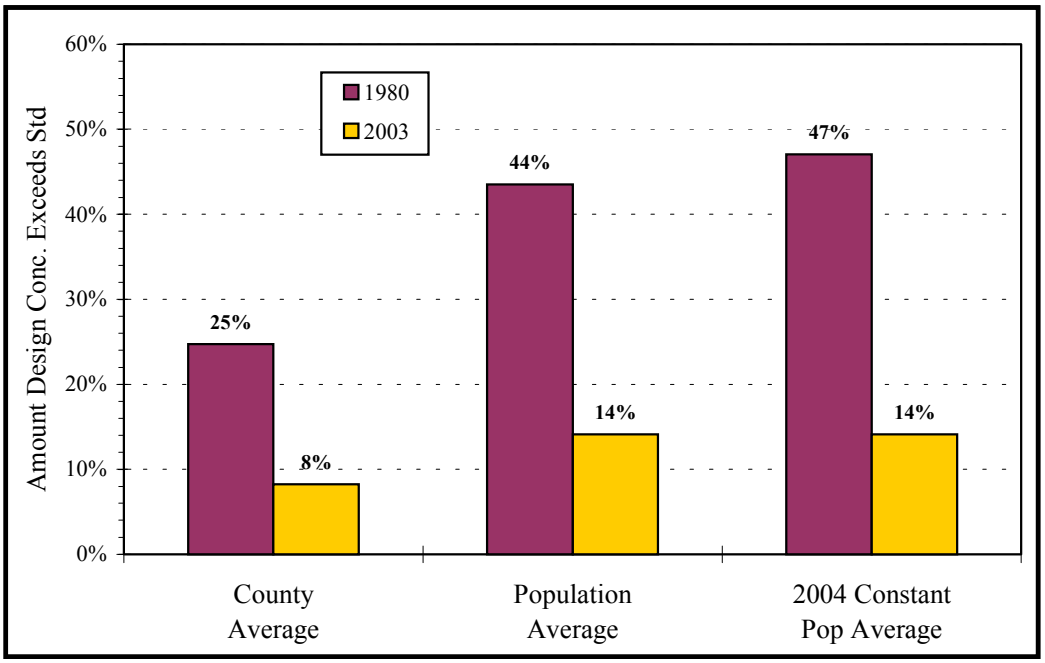
[11] Due to changes in the PM NAAQS over the years, robust data for PM-10 is only available from about 1990 and robust data for PM-2.5 is available only since 1999. However, emission reduction programs targeting PM were first implemented in the 1970s. It is not possible to estimate air quality improvement related to these earlier reductions using the air quality data analysis approach employed in this study.

Figure 1-5. Amount the 1-Hour Design Concentration Exceeds the NAAQS[12]



Note: In Figures 1-5 and 1-6, data are based solely on counties violating the applicable NAAQS.

Figure 1-6. Amount the 8-Hour Design Concentration Exceeds the NAAQS



[12] As used throughout this study, design concentration indicates the specific concentration measurement used to determine compliance with the NAAQS.

Figure 1-7. Violations of the Annual PM-10 NAAQS

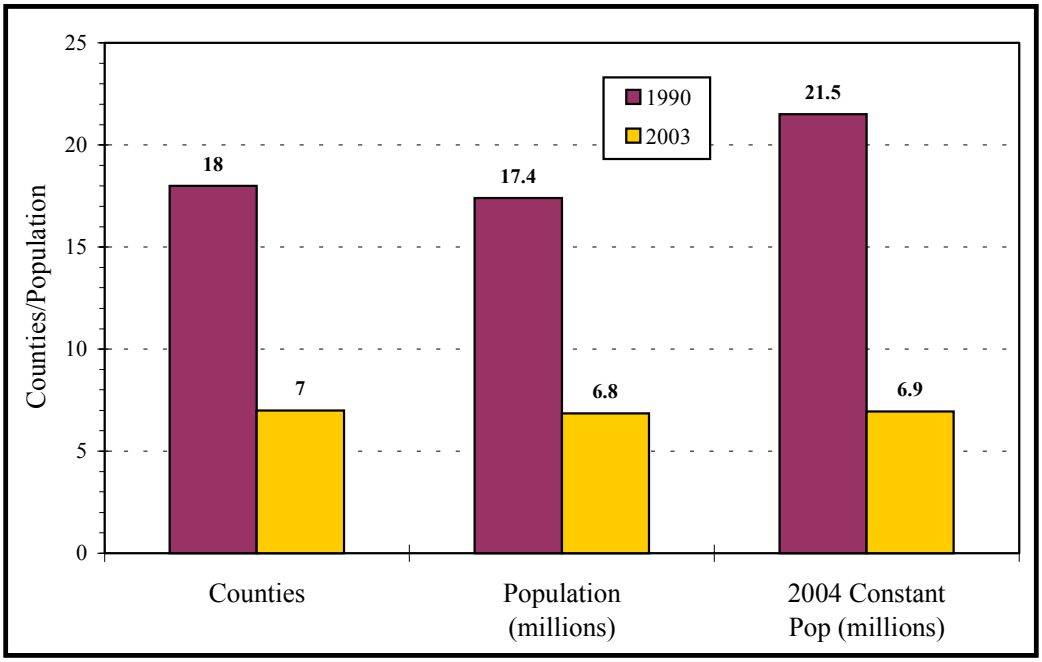


Figure 1-8. Violations of the Daily PM-10 NAAQS

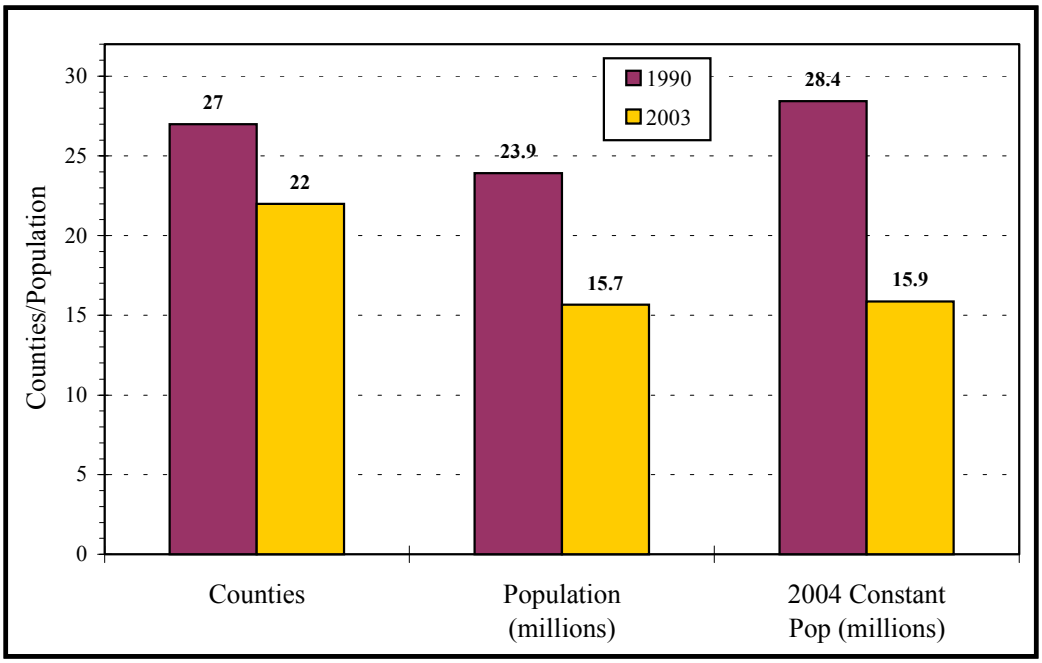


Figure 1-9. Violations of the Annual PM-2.5 NAAQS

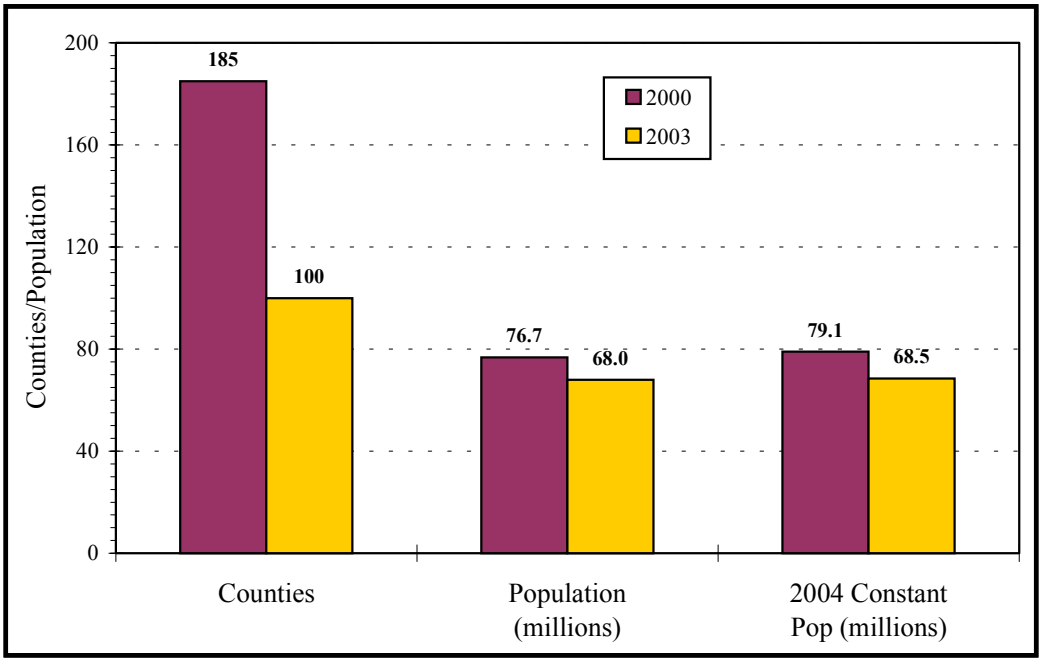
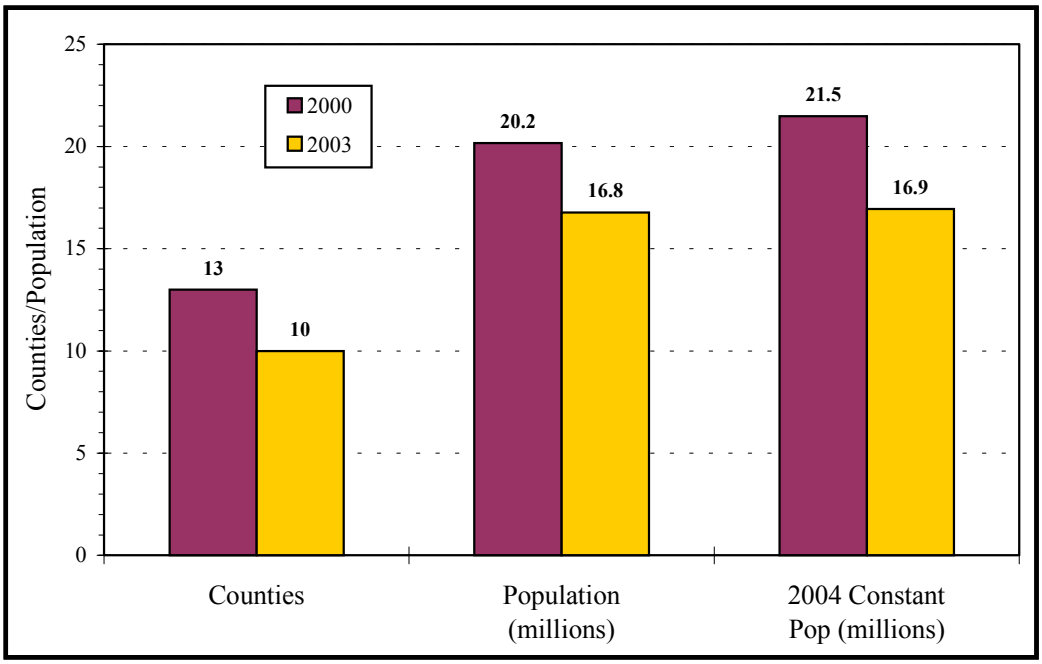


Figure 1-10. Violations of the Daily PM-2.5 NAAQS



- While improvements related to PM are less dramatic than those for ozone, it must be remembered that improvements prior to 1990 for PM-10 and prior to 2000 for PM-2.5 are not included, that improvement has occurred in an environment where most emissions control programs were targeting ozone-related reductions, and that there are currently no official PM-2.5 nonattainment designations so that efforts to reduce contributing emissions have been limited in scope. Over the last several years, several emission reduction programs specifically aimed at PM control have been adopted and are beginning to take effect. These programs will undoubtedly lead to significant continued improvement in PM-related air quality for the foreseeable future.

Findings Related to Carbon Monoxide

- Ambient carbon monoxide concentrations have declined by about 65 percent since 1983. [See Figure 1-11]

- The carbon monoxide design concentration in an average area is about one-third of the NAAQS, while nearly all areas of the U.S. exhibit design concentrations that are less than 50 percent of the NAAQS.[13] This is down from about 150 percent in 1983.

- Following the Clean Air Act amendments of 1990, 42 areas of the U.S. with a combined population of about 60 million were designated as nonattainment for carbon monoxide. All of these areas demonstrated compliance with the carbon monoxide NAAQS in 2001-2002 (the most recent period for which EPA data analysis results are available).

- Three areas not among the 42 designated nonattainment areas observed violations of the carbon monoxide NAAQS in 2001-2002. All three areas have specific localized issues, one of which has subsequently been resolved and no further violations detected. About 40,000 people live in the remaining two areas, representing about 0.01 percent of the U.S. population.

Findings Related to Lead

- Ambient concentrations of lead have declined by 94 percent since 1983. [See Figure 1-12]

- The average ambient lead concentration is approaching the limits of detectability, while nearly all areas of the U.S. exhibit design concentrations that are only about 5 percent of the NAAQS. This is down from about 70 percent in 1983.

- There are only three areas in the U.S. that violate the lead NAAQS, and each of these violations is due to emissions from a nearby metal processing industry. About 1 in 30,000 people (or 0.003 percent of the U.S. population) lives in one of these three areas.

[13] As used throughout this study, design concentration indicates the specific concentration measurement used to determine compliance with the NAAQS.

Figure 1-11. Trend in Ambient Carbon Monoxide from 1983 to 2002 (Annual 2nd Highest 8-Hour Average Concentration)[14]

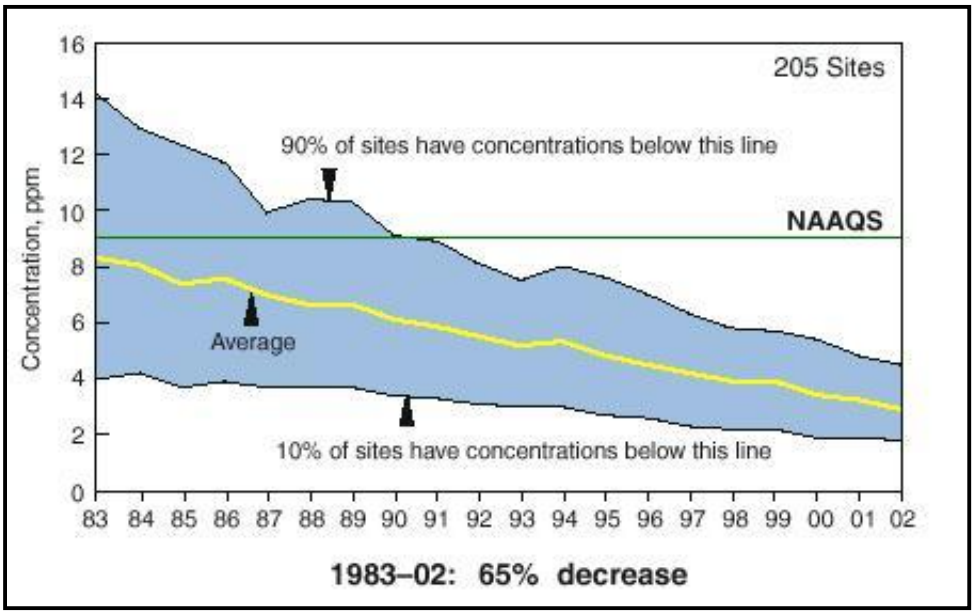
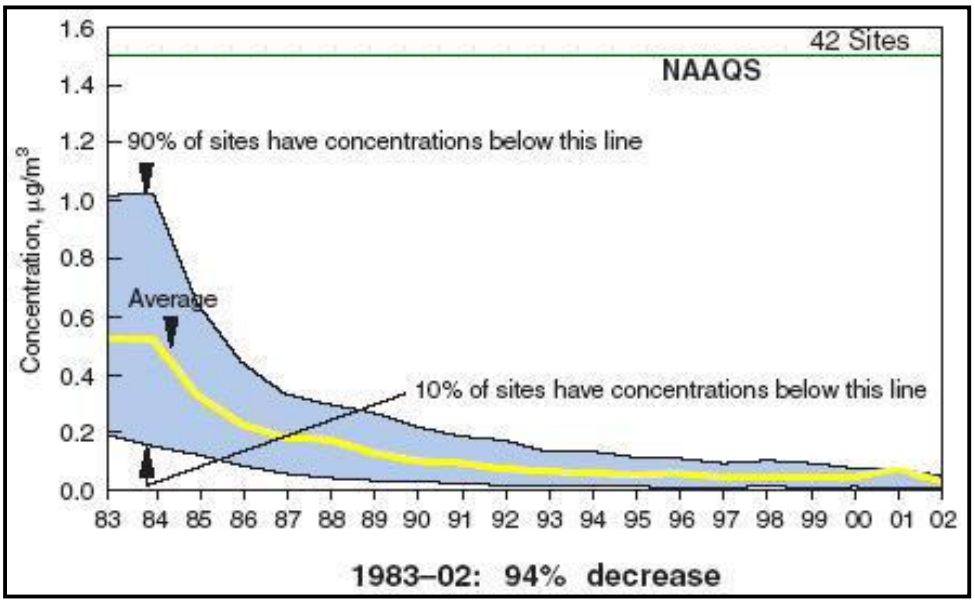


Figure 1-12. Trend in Ambient Lead from 1983 to 2002 (Maximum Quarterly Average Concentration)[15]



[14] The figure is extracted without change from U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

[15] The figure is extracted without change from http://www.epa.gov/airtrends/lead2.html

Findings Related to Nitrogen Dioxide

- Ambient nitrogen dioxide concentrations have declined by about 20 percent since 1983. [See Figure 1-13]

- The nitrogen dioxide design concentration in an average area is about 40 percent of the NAAQS, while nearly all areas of the U.S. exhibit design concentrations that are less than 60 percent of the NAAQS. This is down from about 80 percent in 1983.

- There are currently no nitrogen dioxide nonattainment areas in the U.S.

Findings Related to Sulfur Dioxide

- Ambient sulfur dioxide concentrations have declined by more than 50 percent since 1983. [See Figure 1-14]

- The sulfur dioxide design concentration in an average area is about 20 percent of the NAAQS, while nearly all areas of the U.S. exhibit design concentrations that are less than one-third of the NAAQS. This is down from about 60 percent in 1983.

- There are currently 18 areas classified as nonattainment for sulfur dioxide in the U.S., but none of these areas observed violations of the NAAQS in 2001-2002.

- Sulfur dioxide emissions have declined by about 30 percent since 1993.

Example Emission Reductions - Electrical Generating Units (EGU)[16]

- Significant EGU emission reductions have been achieved since 1985 despite a simultaneous increase of about 56 percent in electricity demand. It is expected that the demand increase will reach 90 percent (or nearly double) by 2015.

- The average NO_x emission rates (emissions per unit of electricity generated) at EGUs have been reduced by about 48 percent since 1985 and are expected to reach 80 percent shortly after 2015. [See Figure 1-15]

- The average SO_2 emission rates (emissions per unit of electricity generated) at EGUs have been reduced by about 55 percent since 1985 and are expected to reach 88 percent shortly after 2015. [See Figure 1-16]

[16] Trends for a single emission source category, electrical generating units, were investigated to provide a foundation for the observed air quality improvements. The selection of EGUs for analysis was a matter of convenience and robust data availability, it does not imply that EGUs are either more or less significant than other emission sources. It is expected that an investigation of other major emission source categories would reveal similar trends.

Figure 1-13. Trend in Ambient Nitrogen Dioxide from 1983 to 2002 (Annual Average Concentration)[17]

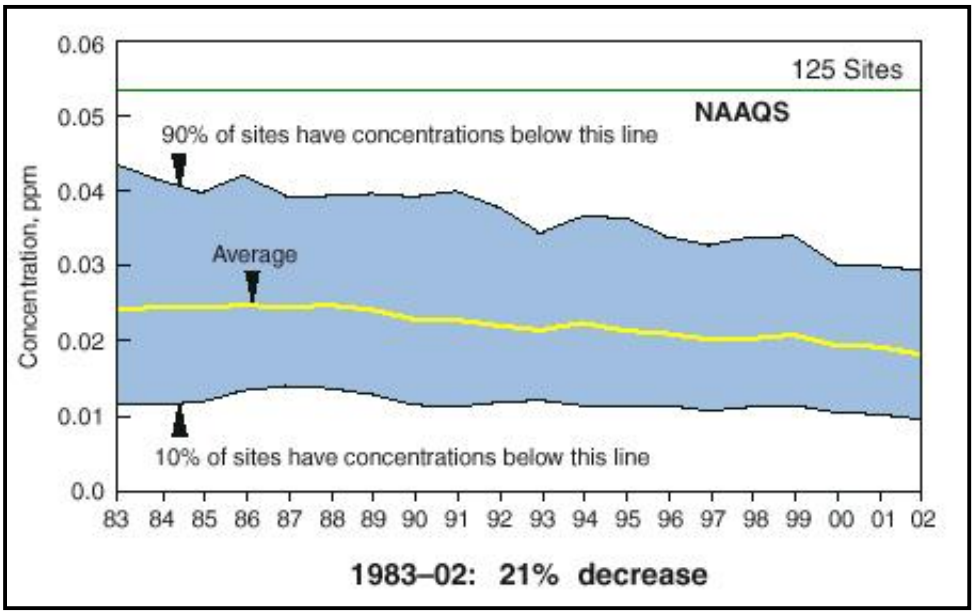
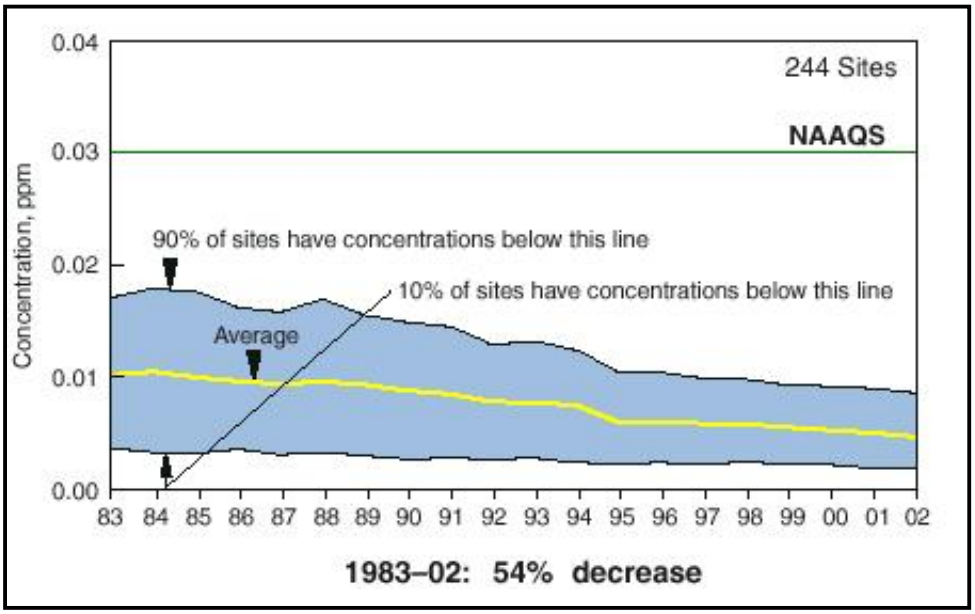


Figure 1-14. Trend in Ambient Sulfur Dioxide from 1983 to 2002 (Annual Average Concentration)[18]



[17] The figure is extracted without change from U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

[18] The figure is extracted without change from U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

Figure 1-15. Effective EGU NO_x Emission Rate (1985-2015)[19]

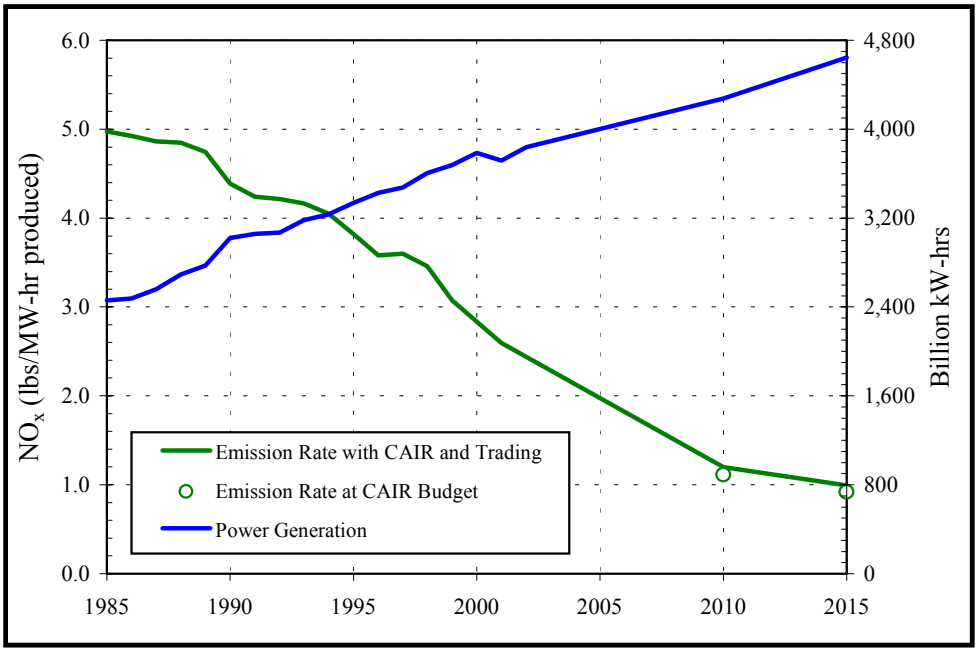
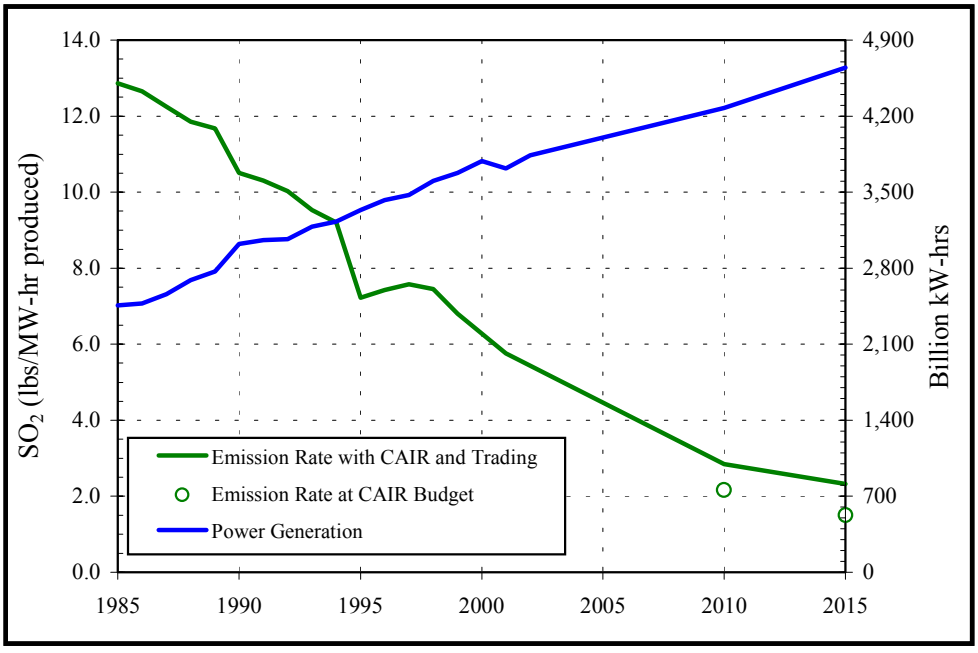


Figure 1-16. Effective EGU SO_2 Emission Rate (1985-2015)



[19] In Figures 1-15 and 1-16, CAIR indicates estimated emission rates with the Clean Air Interstate Rule as proposed by the EPA in January 2004. If the CAIR is not adopted, the decline in emission rates between now and 2015 will be lower, with 2015 emission rates of about 1.7 pounds per megawatt-hour of electricity produced for NO_x and 4.0 pounds per megawatt-hour of electricity produced for SO_2.

Conclusion

These findings, in conjunction with the more detailed support material that follows, lead to the inarguable conclusion that air quality in the U.S. is substantially improved. While continuing improvements are necessary for some areas of the U.S. to achieve full compliance with the NAAQS, air quality in the U.S. is substantially better today than at any time since data collection began in earnest in the 1970s. Despite frequent claims to the contrary, the U.S. has made, and continues to make, significant progress in providing healthful air quality for all Americans.

2. Introduction and Methodology

This study investigates and attempts to quantify the extent to which ambient air quality in the U.S. has changed since the enactment of the Clean Air Act in 1970. Various advocates present often conflicting claims on whether air quality is better or worse today than in previous years and the typical "outsider" is forced to simply accept one or the other opinion based on influences entirely divorced from the scientific record. The initial elements of a network of air quality monitors were established in the U.S. in the early 1970s and this network has grown over time to encompass virtually all of the metropolitan and many rural areas of the country. With some exceptions, data collected via this monitoring network since the late 1970s are sufficiently robust to allow for a detailed assessment of national air quality. Accordingly, there is little need to speculate about the status of current air quality relative to that of previous years -- a scientific record is in place and need only be consulted. This study attempts to do just that.

Air quality standards in the U.S. are established by the EPA. Since 1970, the agency has established National Ambient Air Quality Standards (NAAQS) for six primary pollutants. These pollutants; ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), lead (Pb), and particulate matter (PM) form the basis against which air quality in the U.S. is assessed.[20] All but PM are specific chemical compounds and, therefore, precisely defined. Particulate matter essentially signifies airborne particles of any composition, and these cover a rather wide size range. Over the years, both the form of the standard and the specific particles covered by the PM NAAQS have changed. The original PM standard was expressed as "Total Suspended Particulate (TSP)," and essentially covered airborne particles of any size. Since the particles of most concern from a health standpoint are those that can be deeply inhaled, the PM standard was revised in 1987 by replacing the TSP standard with an NAAQS based on particulate matter with an effective aerodynamic diameter of 10 microns or less (PM-10). This change effectively "restarted" the historic PM trend record since there is no way to determine with precision what fraction of historically monitored TSP was PM-10. In 1997, the PM standard was revised again. These revisions both revised the form of the PM-10 standard and added a second NAAQS for PM-2.5, particulate matter with an effective aerodynamic diameter of 2.5 microns or less. This latest revision has no impact on the historical record for PM-10, but reflects the beginning of a new historic record for PM-2.5.[21]

Due to the changes in the historic PM air monitoring record, PM trend analyses cover a substantially shorter time period than the analyses for other pollutants. The oldest PM-10 data

[20] The specific form and numerical values of several of the NAAQS have evolved over time, but the basic pollutants covered have remained, except as noted in the section on particulate matter, essentially unchanged since the early 1970s.

[21] It should be noted that the 1997 changes left the older form of the PM-10 standard in effect in certain areas of the U.S. until specific administrative requirements are met. This requirement has no effect on actual observed trends, but can influence the selection of what air quality statistics to investigate (i.e., statistics based on the older form of the NAAQS versus statistics based on the newer form of the NAAQS). For this study, PM-10 statistics are based on the newer form of the standard -- although statistics based on the older form would lead to identical conclusions.

dates back to 1985, while the PM-2.5 record spans no more than the last five years or so. As a result, observed trends will naturally be less dramatic for PM -- both because of the shorter window of observation and the shorter period of emission reduction efforts.

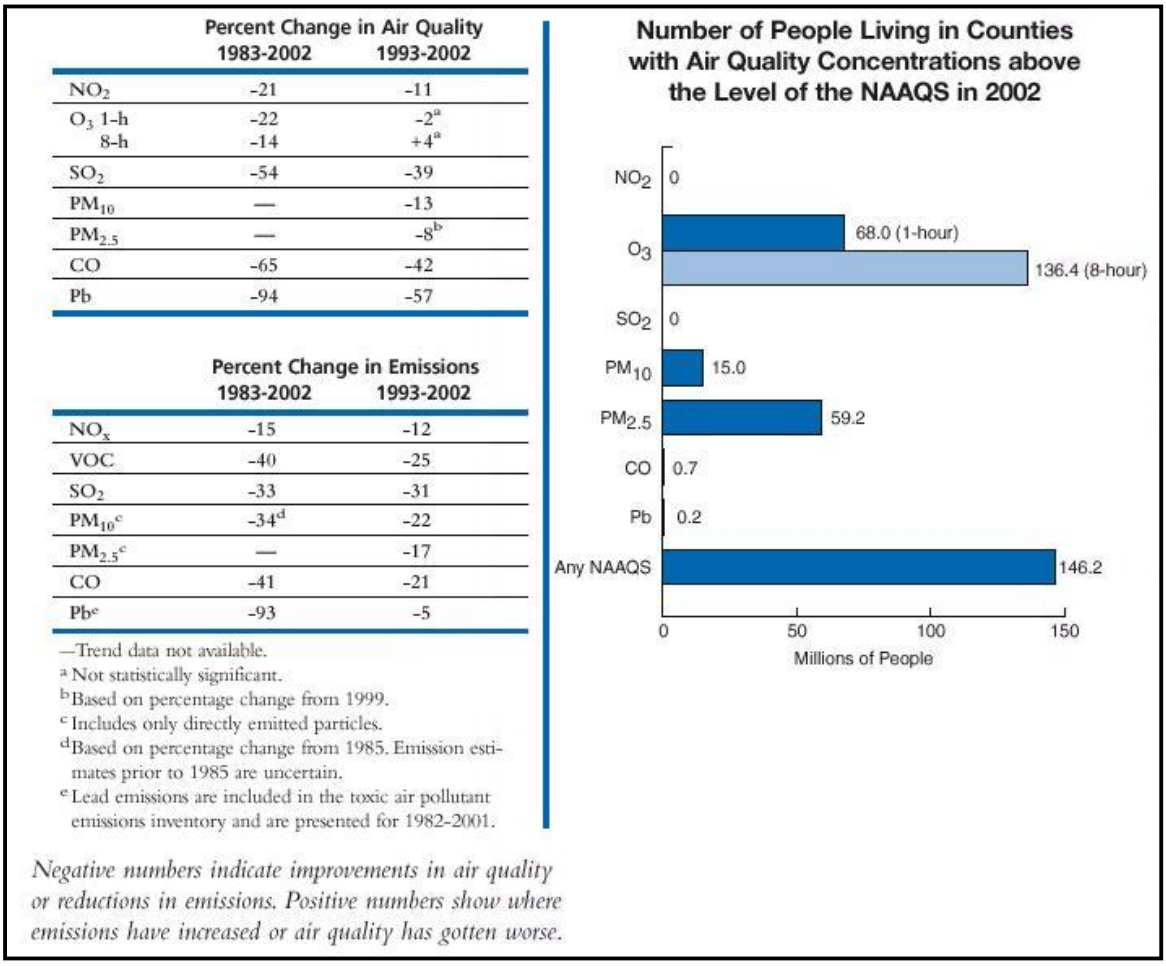
Of the six pollutants covered by the NAAQS, current violations are almost exclusively associated with ozone and PM. There continue to be a few localized violations of the CO and lead NAAQS and the EPA is working with state and local planners to eliminate these last problem areas. Each of these violations is associated with a specific and well-defined local emissions source rather than any collection of sources that might impact national air quality or be indicative of potential future influences on national trends. In the national context, these violations are minor, affecting less than 0.01 percent of the population. Of course, these conditions are not minor for local citizens subjected to the violations and reductions in the offending emissions should be sought in the most expeditious manner possible. However, given that the total population exposed to violations of the CO and lead NAAQS has declined from tens of millions in the late 1970s and early 1980s, there is no question that air quality for both is substantially improved. There are also no violations of either the NO_2 or SO_2 NAAQS and little question that air quality for both has improved over time. In light of this, this study has not investigated air quality trends for these four pollutants in detail, but instead relies exclusively on data analyses previously conducted and reported by the EPA.

Figure 2-1 presents a synopsis of the conclusions from the EPA's most recent air quality trend analysis. As indicated in the left half of the figure, the EPA finds that both significant air quality improvements and significant emission reductions have been observed since 1983 for CO, lead, NO_2, and SO_2. Moreover, the chart in the right half of the figure shows that by the EPA's estimates, only about one-third of one percent of the U.S. population resides in counties where violations of the CO, lead, NO_2, or SO_2 NAAQS are observed. In short, any lingering air quality concerns for these pollutants is localized and is being addressed in accordance with specific local conditions.

The EPA also finds that significant reductions have occurred for ozone precursor emissions (VOC and NO_x), PM, and secondary PM precursor emissions (VOC, NO_x, and SO_2) -- but generally finds lesser change in ozone and PM air quality. From the chart in the right half of Figure 2-1, it is clear that a considerable fraction of the U.S. population lives in areas that continue to experience violations of the ozone or PM NAAQS. It is no coincidence that there is considerably less consensus in the perceptions regarding air quality progress related to these pollutants. However, there are limitations in the methods that were employed by the EPA to construct the presented air quality improvement statistics. Some of these limitations are methodological, while some are artifacts of the available air quality monitoring data.

Methodological limitations primarily result from the fact that the air quality improvement statistic reported by the EPA is a single statistic that combines data for monitors that comply with the NAAQS with data for monitors that do not comply with the NAAQS. This is problematic for two reasons. First, for pollutants for which substantial emission reduction efforts have been undertaken in areas that violate the NAAQS, this combined treatment results in statistics that are biased low. For example, an ozone attainment area for which few local emission reduction measures have been implemented would be expected to demonstrate lesser

Figure 2-1. Summary of Findings from 2002 EPA Air Quality Data Analysis[22]



Percent Change in Air Quality	1983-2002	1993-2002
NO_2	-21	-11
O_3 1-h	-22	-2[a]
8-h	-14	+4[a]
SO_2	-54	-39
PM_{10}	—	-13
$PM_{2.5}$	—	-8[b]
CO	-65	-42
Pb	-94	-57

Percent Change in Emissions	1983-2002	1993-2002
NO_x	-15	-12
VOC	-40	-25
SO_2	-33	-31
PM_{10}[c]	-34[d]	-22
$PM_{2.5}$[c]	—	-17
CO	-41	-21
Pb[e]	-93	-5

—Trend data not available.
[a] Not statistically significant.
[b] Based on percentage change from 1999.
[c] Includes only directly emitted particles.
[d] Based on percentage change from 1985. Emission estimates prior to 1985 are uncertain.
[e] Lead emissions are included in the toxic air pollutant emissions inventory and are presented for 1982-2001.

Negative numbers indicate improvements in air quality or reductions in emissions. Positive numbers show where emissions have increased or air quality has gotten worse.

improvements than an ozone nonattainment area where significant local controls were in place. Looking at both together results in a statistic that overstates the degree of progress in the attainment area, while understating progress in the nonattainment area. Since progress in attainment areas is substantially less instructive (as the areas comply with the NAAQS), the net effect is that the more instructive progress in nonattainment areas is understated.

The second methodological issue is that the single air quality improvement statistic assumes that air quality improvement can proceed from the given baseline to zero with equal difficulty. In practice, however, this is not true. Background, or natural, ozone concentrations are significantly above zero due to biogenic emissions of VOC and NO_x, as are PM concentrations due to the atmospheric entrainment of geologic PM by wind and other action. Therefore, even if manmade emissions of these pollutants are reduced to zero, air quality measurements will still be above zero. As the background level of air quality is approached, continuing reductions in air quality

[22] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

concentrations will be increasingly difficult, and this difficulty will be reflected as a limitation in the air quality improvement statistic. Since only a fraction of air quality monitors actually report violations of the NAAQS, inclusion of data for all monitors in the air quality statistic results in a situation where monitors that approach the natural background level of air quality can do nothing but reduce the apparent significance of the statistic.

Finally, it must also be recognized that reporting air quality progress as a single percent reduction says nothing about whether that reduction resulted in more areas attaining compliance with the NAAQS. A ten percent reduction in a pollutant might be hugely significant if that level of reduction moved a large number of areas across the air quality levels signified by the NAAQS. Thus, a second statistic that presents the change in the number or fraction of areas complying with the NAAQS is also critical to evaluating progress. Quantifying this statistic is problematic due to limitations in the available air quality monitoring data that result from the fact that the air quality monitoring network is not static and does not cover the entire U.S. Although challenging, the statistic is necessary to truly evaluate air quality progress.

Since areas out of compliance with the CO, SO_2, NO_2, and lead NAAQS have declined to zero or near zero, the air quality analysis efforts of this study are focused on ozone and PM, pollutants for which the degree of air quality progress has been subject to continuing debate. Data for CO, SO_2, NO_2, and lead are reported, but these data are taken directly from previous statistics developed by the EPA. Air quality data for ozone and PM are analyzed in detail and statistics developed specifically for this study are reported. The specific air quality database subjected to analysis is the national database maintained by the EPA and utilized to support their air quality analyses. This database was formerly known as the Air Quality Subsystem (AQS) of the Aerometric Information Retrieval System (AIRS), but was recently migrated to an independent database processing system.[23] In effect, these are the same data that led to the EPA findings presented in Figure 2-1.

To the maximum extent possible, the air quality data were subjected to the same quality assurance procedures and related processing algorithms employed by the EPA. Strict adherence to the EPA algorithms was considered critical to ensure that results would be consistent with results that the EPA would obtain were it to conduct the same analyses. These procedures and algorithms were built into a detailed software system developed for this study, based on information reported in a series of EPA publications.[24] The development of the software processing system was a major undertaking that unfortunately was not greatly facilitated by the

[23] These data are available at http://www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm.

[24] These publications include:

- U.S. EPA, *AQS User's Guide, Volume AQ1, AQS Data Dictionary*, Version 2.0, May 13, 2004.
- U.S. EPA, *AQS User's Guide, Volume AQ2, AQS Data Coding Manual, Draft*, Version 2.0, May 14, 2004.
- U.S. EPA, *Air Quality System, Raw Data Summarization Formulas, Draft*, Version 1.1, April 12, 2004.
- U.S. EPA, *Airs User's Guide, Volume AQ1: AQS Data Dictionary*, circa 1993.
- U.S. EPA, *Data Input Formats for the Re-engineered Air Quality Subsystem*, Version 2.3, September 4, 2002.
- Various code sheets from http://www.epa.gov/ttn/airsaqs/manuals.
- 40 CFR Part 50, Appendices H, I, and N.
- 40 CFR Part 58, Appendix D (definition of Ozone Monitoring Season by State).
- 40 CFR Part 81 (definitions of Air Quality Control Regions).

condition of the air quality data publicly released by the EPA. For readers potentially interested in further investigations of these data, data processing demands should not be underestimated. There are over one hundred million data records dating back to the early 1970s that must be processed and these data are in a variety of formats depending on the particular characteristics of the individual air quality monitors.

Perhaps the greatest difficulty encountered in the processing of the publicly released air quality data results from the fact that these are the raw data originally reported to the EPA by states and local air quality agencies. As a result, they contain all the original blemishes and coding errors, so that the software system must be sufficiently robust to identify and respond to a variety of data issues that could negatively influence trend statistics. All the quality assurance algorithms developed by EPA must be replicated. Additionally, broad field checking algorithms must be developed to detect and correct or discard inconsistent data entries. For example, there are numerous records for the same monitors that report different sampling frequencies, which, if uncorrected, can significantly influence the valid data statistics for that monitor.

One additional complication is that much of the data released by the EPA are not grouped (i.e., sorted) in accordance with the information provided on the associated file formats. Data for a single monitor is interspersed with data for other monitors, which necessitates the development and implementation of dedicated sorting software. Although relatively trivial from a software development standpoint, the regrouping (i.e., sorting) of data files containing up to ten million records is not trivial from a processing resource standpoint.

In short, future analyses of the U.S. air quality database could be substantially facilitated by releasing data, not in its raw original submittal form, but rather in a form that has already been processed through the quality assurance algorithms employed by the EPA. This would ensure that independent analyses are entirely consistent with those undertaken by the EPA, allowing for the performance of progressively more detailed and mutually beneficial studies that could further a better understanding of both how far the U.S. has progressed and how much additional progress is required to attain full compliance with the NAAQS.

Finally, two specific issues related to the treatment of counties and county population data had to be addressed to conduct the air quality data analyses for this study. Unfortunately, county (and county-equivalent) definitions in the U.S. have not been constant over the period of time covered by the air quality database. Without a consistent set of county definitions, it is not possible to track progress on a consistent basis over time. Therefore, specific changes in county definitions over time were addressed in this study by creating cross-references for certain counties. The U.S. Census Bureau defined 3,141 counties or county-equivalents in 2003. Over the period since 1970, however, this number has varied by about ±10, with both new counties being created and old counties being absorbed into neighboring counties. Therefore, to ensure that data for all air quality monitors was treated as consistently as possible over time, a total to 3,132 county (or county-equivalents) were defined for this study. Census counties not explicitly included in the 3,132 study-defined counties were cross-referenced to specific study counties as described in Table 2-1.

Table 2-1. Study County (or County-Equivalent) Cross References

Census County	Study County Cross Reference	Brief Rationale for Cross Reference
Denali Borough, Alaska	Yukon-Koyukuk Census Area, Alaska	Denali Borough was created in 1990 from a portion of the Yukon-Koyukuk Census Area plus uninhabited portions of the Southeast Fairbanks Census Area.
Skagway-Hoonah-Angoon Census Area, Alaska	Skagway-Yakutat-Angoon Census Area, Alaska	Skagway-Yakutat-Angoon Census Area was divided into the Skagway-Hoonah-Angoon Census Area and Yakutat City and Borough in 1992.
Yakutat City and Borough, Alaska		
La Paz County, Arizona	Yuma County, Arizona	La Paz County was created out of a portion of Yuma County in 1983.
Broomfield County, Colorado	Boulder County, Colorado	Broomfield County was created in 2001 from portions of Boulder and three other counties (Weld, Adams, and Jefferson). The largest fraction of Broomfield County population was taken from Boulder County.
Dade County, Florida	Miami-Dade County, Florida	1997 name and coding change only.
Kalawao County, Hawaii	Maui County, Hawaii	Census population data for Kalawao County was included with that of Maui County prior to 1980.
Yellowstone National Park, Montana	Gallatin County, Montana	Yellowstone National Park was absorbed into Gallatin and Park Counties in 1997.
Cibola County, New Mexico	Valencia County, New Mexico	Cibola County was created out of a portion of Valencia County in 1981.
Clifton Forge City, Virginia	Alleghany County, Virginia	Clifton Forge City was absorbed into Alleghany County in 2001.
Manassas City, Virginia	Prince William County, Virginia	Manassas City was created from a portion of Prince William County in 1975.
Manassas Park City, Virginia	Prince William County, Virginia	Manassas Park City was created from a portion of Prince William County in 1975.
Poquoson City, Virginia	York County, Virginia	Poquoson City was created from a portion of York County in 1975.
South Boston City, Virginia	Halifax County, Virginia	South Boston City was absorbed into Halifax County in 1995.

The second issue related to the treatment of counties was the development of the specific county population data used to derive all reported population weighted statistics. U.S. Census population data at the county level were obtained for each decennial census since 1970.[25] Additionally, county level population projections were obtained for 2003. Projections for years after 2003 were only available at the state level, so 2004 county level population estimates were derived by growing 2003 county level estimates by the annual state level population change between 2000 and 2005. Data for all years between the decennial censuses and between 2000 and 2003 were estimated by interpolation. U.S. Census Bureau population estimates for the years between decennial censuses were considered and rejected since it was determined that the Census Bureau only maintains non-decennial estimates until the following decennial census is conducted. Following the next decennial census, the non-decennial estimates developed on the basis of the preceding decennial census data are archived without any adjustment for deviations relative to the newest decennial census. Thus, interpolated population estimates were considered to be more accurate since they are based on information from both bounding decennial censuses.

Since perceived changes in air quality over time can be influenced by changes in population, all population based statistics in this study are calculated on the basis of both actual annual population and constant 2004 population. Statistics based on the latter eliminate the confounding influences of population and provide a more robust picture of actual air quality changes. The potential importance of this might best be understood by considering a simple example of two jurisdictions, jurisdiction A with an air quality "level" of 1 and jurisdiction B with an air quality "level" of "2." If in year one, the two jurisdictions have equal populations then the aggregate air quality "level" in that year is 1.5 on a population-weighted basis. Over time, the populations of the two jurisdictions changes so that that of jurisdiction B is now double that of jurisdiction A. At the same time, the air quality of both areas remains unchanged. The population-weighted air quality "level" for the aggregate area is now 1.67, rather than 1.5, despite the fact that air quality in each area is unchanged. In effect, changes in population can make it look as though changes in air quality have occurred even though that is not the case. By holding population constant over time, this effect is eliminated. Both constant population (based on 2004 population data) and varying population statistics are generated in this study.

[25] All U.S. Census Bureau population data were obtained via http://www.census.gov.

3. Ozone

Tropospheric, or ground-level ozone, has been the most pervasive air quality issue in the U.S. over the last 30 years. Unlike most of the other pollutants for which NAAQS have been established, many areas of the country continue to experience violations of the ozone air quality standards. Nevertheless, substantial improvement in ozone air quality has been observed since the advent of air quality control programs in the 1970s, and continuing improvements are likely for the foreseeable future due to recently implemented emission control programs such as the Tier 2 motor vehicle standards, advanced heavy duty diesel vehicle and nonroad equipment emission standards, and the NO_x SIP call rules.

Ozone issues can be somewhat confusing since ozone is mentioned as a contributing factor in several environmental problems. For example, at ground-level, too much ozone is a problem, but higher in the atmosphere a decrease in the amount of protective ozone leads to increased solar radiation (i.e., sunlight) and an increased risk of skin cancer. Is it good or is it bad? The short answer is that it has both positive and negative health effects (i.e., its good to have around, but not good to breathe in *elevated* concentrations). A brief discussion of what ozone is may alleviate some of the potential for misconception.

Molecular oxygen, that makes up about 21 percent of the atmosphere, and sustains human existence consists of two oxygen atoms chemically joined (i.e., O_2). Ozone is simply three oxygen atoms joined chemically (i.e., O_3). At the surface level of the earth, ozone forms when a free oxygen atom (O), produced through a series of reactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOC), reacts with an oxygen molecule (O_2). Because the chemical bonding of ozone is weak, it will release the extra oxygen atom (O) to another molecule very readily. This makes ozone an excellent oxidizer (a provider of oxygen to stimulate chemical reaction) and leads directly to its potential health effects.

Because there are plenty of molecules in the lower atmosphere to accept the extra oxygen atom from ozone, its lifetime is very short and it will not persist at elevated levels. However, on hot days with intense sunlight, there is sufficient solar energy available to promote the increased formation of atomic oxygen, and the free oxygen atoms will in turn react with oxygen molecules to form ozone. If the rate of formation exceeds the rate of decomposition, ozone concentrations will rise. It is this phenomenon that leads to most of the violations of the ozone NAAQS. Since the key to the elevated levels of ozone is intense sunlight (along with available emissions of NO_x and VOC), elevated concentrations will only persist as long as the sunlight persists. Thus, almost all peak ozone concentrations occur in the early to mid afternoon when the sun is high in the sky. Ozone concentrations decrease rapidly as the sun goes down, so that exceedances of the NAAQS will generally last only a few hours.

Although not important from an NAAQS standpoint, it is important to recognize that ozone does perform a protective function as well. This is especially beneficial in the upper atmosphere, where the potential negative impacts of elevated ozone levels are not an issue. Sunlight in the ultraviolet range will break apart molecular oxygen (O_2) into its two atomic oxygen (O)

components. In promoting this reaction, the solar radiation energy is absorbed and stopped from reaching the surface of the earth, where it would otherwise be available to promote surface reactions, including skin reactions. The free atomic oxygen (O) then reacts with molecular oxygen (O_2) to form ozone (O_3). Ozone will then itself absorb additional solar radiation to dissociate back into molecular oxygen and atomic oxygen. Thus, an atomic oxygen, molecular oxygen, and ozone cycle is established and an equilibrium between the three oxygen species is attained.[26] It is estimated that up to 98 percent of incoming solar radiation is absorbed in this process so that it never reaches the surface of the earth.

Assessing the significance of continuing ozone violations is complicated by several factors. First, as indicated above, ozone formation is *very* sensitive to meteorology, with high concentrations occurring on days with high temperature, intense sunlight, and low wind speed. Thus, year to year variations in ozone reflect both actual air quality changes and variations in meteorology. Because of this, it is possible for a cool year with high ozone-forming emissions to be "cleaner" than a warm year with low-ozone forming emissions, effectively masking ozone reduction progress.

Unfortunately, there is no ideal way to isolate year to year variations in ozone from year to year variations in meteorology. While statistical methods can remove some of the meteorological variation, the resulting statistics are applicable to a "statistical year" rather than any specific year, creating some difficulty in comprehension and some suspicion of results. For these reasons, this study makes no corrections for meteorology, electing instead to view ozone data just as it has been collected. Since the study reviews data over a three decade timeframe, a considerable portion of short term meteorological variation can be observed as year to year "noise" in the longer term statistics. However, since many of the warmest years on record have occurred in the last decade, and since this will naturally serve to promote levels of ozone production that are elevated relative to a "typical" meteorological year, it is likely that actual ozone improvements are greater than implied by recent data trends.

A second important factor affecting ozone trends is the fact that the ozone air quality monitoring network is not fixed over time. Not only are monitors occasionally moved, but the overall number of monitors has increased dramatically. For example, three years of complete ozone data was available for only 70 counties in the U.S. in 1975. In 2003, complete data were available for 623 counties. Moreover, air quality monitors are not randomly located, but rather placed in areas where poor air quality is suspected. Thus, if the entire monitoring network is viewed over time, there is a selective bias towards a greater number of monitors registering air quality violations. Observed trends derived from data collected over this network must be viewed with this selective bias in mind. It is virtually certain that measured ozone concentrations overstate average concentrations throughout the U.S. In other words, ozone concentrations in the 2,428 counties not represented in the data from the current ozone monitoring network are almost certainly lower than those measured for counties in the monitoring network.

[26] Highly reactive halogens such as fluorine, chlorine, and bromine can disrupt this equilibrium by reducing the amount of oxygen available for the ozone cycle. It is these disruptive molecules that are responsible for the environmental issues related to the protective ozone layer.

It is, of course, tempting to simply assume that all counties not represented in the current monitoring network meet the ozone air quality standards. Such an assumption inherently includes, however, underlying assumptions of both unlimited monitoring resources and perfect foresight in monitor placement. Historical evidence demonstrates that neither assumption can be empirically supported.

Suppose for example, that such an assumption was made in 1980 when 2,713 counties were not represented in the monitoring network. Since that time, an additional 285 counties have been added to the ozone monitoring network. These counties would not have been added to the network if there were a high degree of certainty that they met ozone air quality standards. In fact, their addition presumes just the opposite -- a high degree of certainty that they may experience NAAQS violations. The network expansion simply reflects the dedication of additional resources to the evaluation of U.S. air quality. More importantly, ozone violations observed in these 285 counties, are <u>not</u> indicative of deteriorating air quality after 1980, as they would have to be if it were assumed that all non-monitored counties met the ozone standards in 1980. Clearly, they did not; violations in 1980 were simply not detected. Instead, the size of the monitoring network increased as resources increased and some portion of the counties not monitored in 1980 did not meet ozone air quality standards. In this same manner, it is also likely that some portion of currently unmonitored counties do not meet the ozone NAAQS.

Due to monitoring network expansion and observed ozone reductions, it is virtually certain that the fraction of unmonitored counties not meeting the ozone NAAQS today is substantially reduced relative to the fraction of such counties in 1980. However, there is no way to determine either fraction with certainty since, by definition, there is no available monitoring data. In addition, given bias in monitor placement (into areas suspected of potential violations), it is difficult to use data from monitored counties to *precisely* estimate what fraction of the unmonitored counties violate ozone air quality standards. Assuming there are not egregious errors in monitor placement, the fraction is somewhere between zero (i.e., all unmonitored counties meet the standards) and the fraction of monitored counties that do not meet the standard. The former is too low, while the latter is too high. Over time, the fraction of unmonitored counties not meeting standards can reasonably be expected to approach the zero estimate, but it is not possible to determine with *certainty* where along this path the U.S. monitoring network is currently operating. Nevertheless, by applying the assumptions indicated, bounding estimates of the number of counties and population that meet the ozone air quality standards can be derived.

In addition, definitive and precise changes in ozone air quality can also be observed through alternative statistics that show:

- How the fraction of *monitored* counties meeting (or violating) the NAAQS has changed,
- How observed ozone concentrations in monitored areas have changed, and
- How the amount of time ozone concentrations are above the NAAQS has changed.

In reviewing derived trends, it is important to consider how bias in monitor placement can mask the true degree of ozone air quality progress. For example, the fraction of monitored counties meeting the ozone standards has increased despite the fact that counties added to the monitoring network are generally areas of suspected problems. To the extent possible, this bias has been

minimized by looking at subsets of the overall data when informative (e.g., only counties in violation of the standards), but such apportionment does not always fully remove bias.

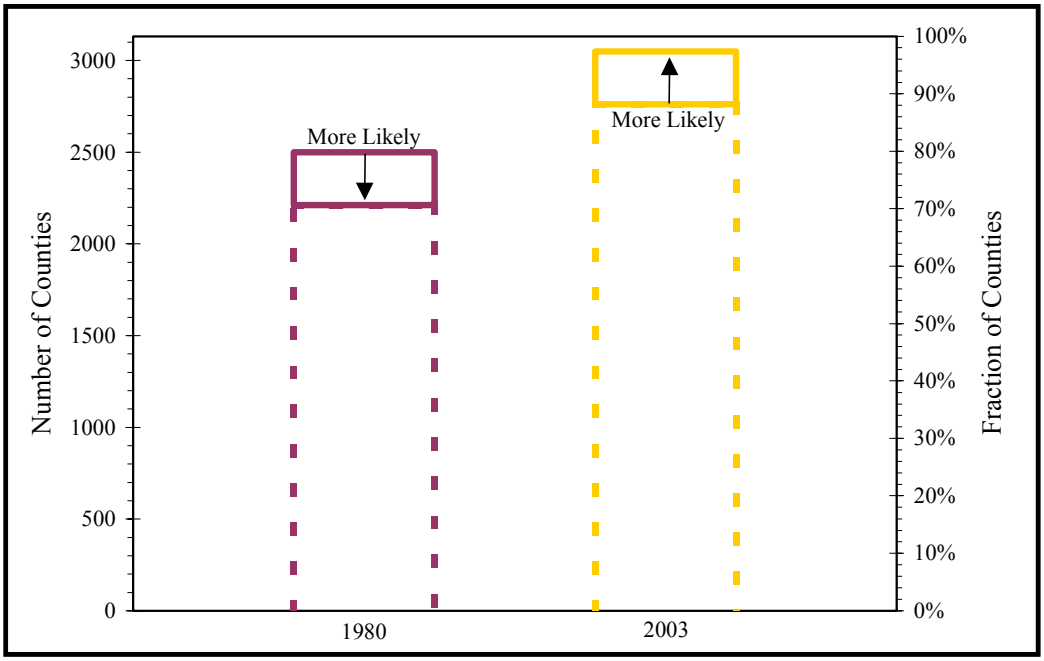
Additional depression of potential improvement trends results from the fact that counties in which multiple ozone monitors are located are treated on the basis of the single monitor with the highest measured ozone concentrations. Since, the determination of the worst performing monitor is made annually, the statistics for each multiple monitor county reflect worst case assumptions.

Other considerations include the fact that although the 8-hour ozone standard was not established until 1997, this study examines 8-hour ozone trends throughout the period of ozone data availability. Thus, even though areas were not officially classified as meeting or violating the 8-hour ozone standard during the majority of the data analysis period, they have been treated according to how they would have been classified had the 8-hour standard existed throughout the analysis period.

Despite these limitations, considerable insight into progress related to ozone air quality can be derived from existing ambient monitoring data. These insights are initially summarized in terms of simplified bar charts to enhance clarity. Detailed year-by-year trend charts used to produce the bar charts as well as additional associated discussion are presented at the conclusion of this section. All presented statistics are based on three year rolling averages. While the specific form of the NAAQS compliance demonstration varies between the 1-hour and 8-hour ozone standards, compliance (or noncompliance) with either is based on three years of measured data. For the 1-hour standard, a monitor is in compliance if there are three or less expected exceedances of the standard over the latest three data years. For the 8-hour standard, a monitor is in compliance if the average of the 4th highest measured ozone concentration in each of the latest three data years is below the standard. All statistics are generally presented in terms of both the absolute number of counties and population. The population based statistics account for the fact that the U.S. population is not evenly distributed at the county level, so that violations in one county can affect a greater or lesser population than violations in another.

Figures 3-1 through 3-4 present estimates of the number of counties and population meeting the ozone NAAQS. These estimates were derived using the methodology described above, wherein the fraction of unmonitored counties violating the NAAQS is assumed to be between zero and the fraction of *currently* monitored counties violating the NAAQS. Although the resulting estimates reflect a substantial range of uncertainty, they clearly demonstrate that ozone air quality has improved over the last 25 years. The large uncertainty results from the fact that there were and are a substantial number of counties (currently over 2,400) without ozone monitors. To estimate what fraction of these counties is likely to violate the ozone NAAQS, two bounding assumptions were employed. First, an upper bound compliance estimate assumes all of the unmonitored counties meet the ozone standards, while a lower bound estimate assumes that the unmonitored counties meet the ozone standards in the same proportion as counties with monitors *in 2003*. In fact, the lower bound estimate is truly only a lower bound for the most recent data. Since the fraction of counties violating the ozone standards was much greater historically, it is likely that the actual number of complying counties in older years is less than even the lower bound estimate. Moreover, due to selective bias in monitor placement, actual 2003 compliance

Figure 3-1. Counties Meeting the 1-Hour Ozone Standard



Note: In Figures 3-1 and 3-2, the height of each box signifies uncertainty due to counties without ozone monitors. It is expected that the actual distribution for 2003 is in the upper portion of the uncertainty box, while that for 1980 is at or below the lower portion of the uncertainty box.

Figure 3-2. Population Meeting the 1-Hour Ozone Standard

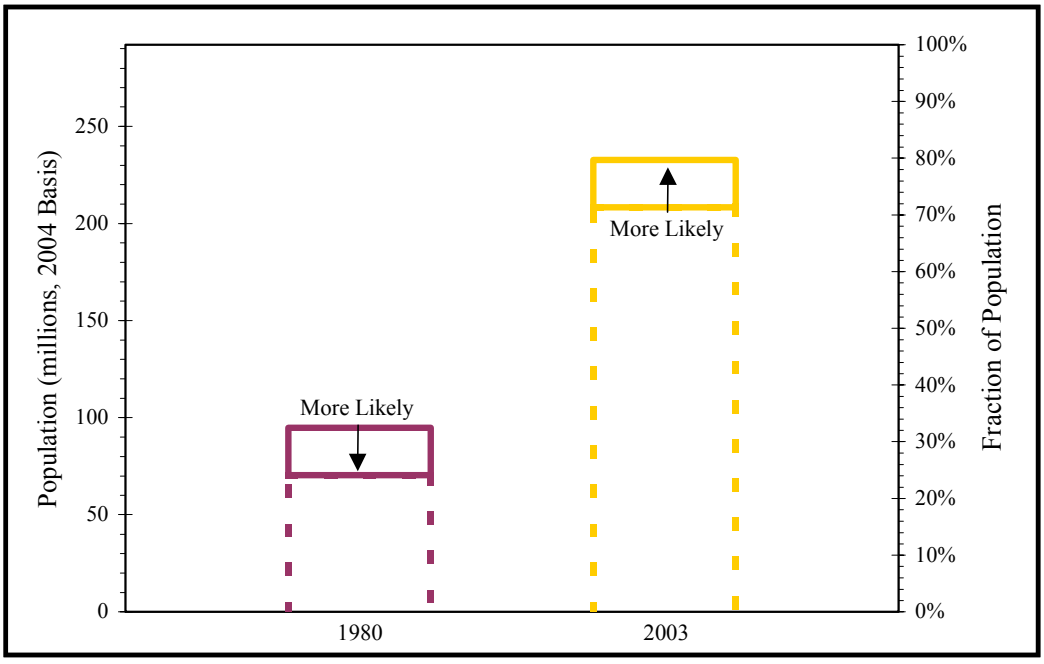
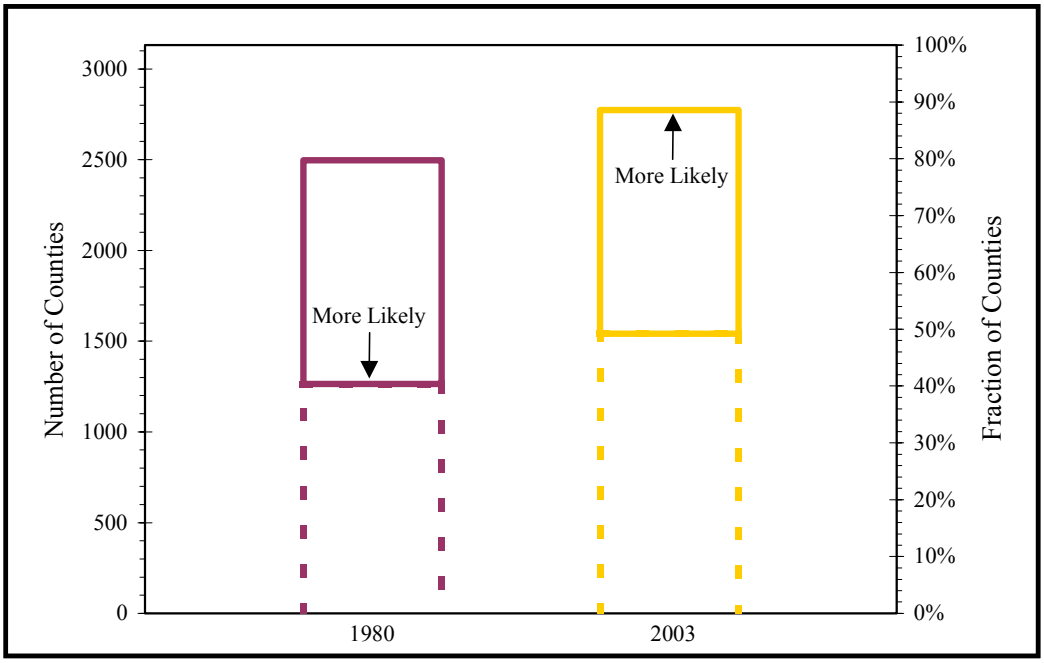
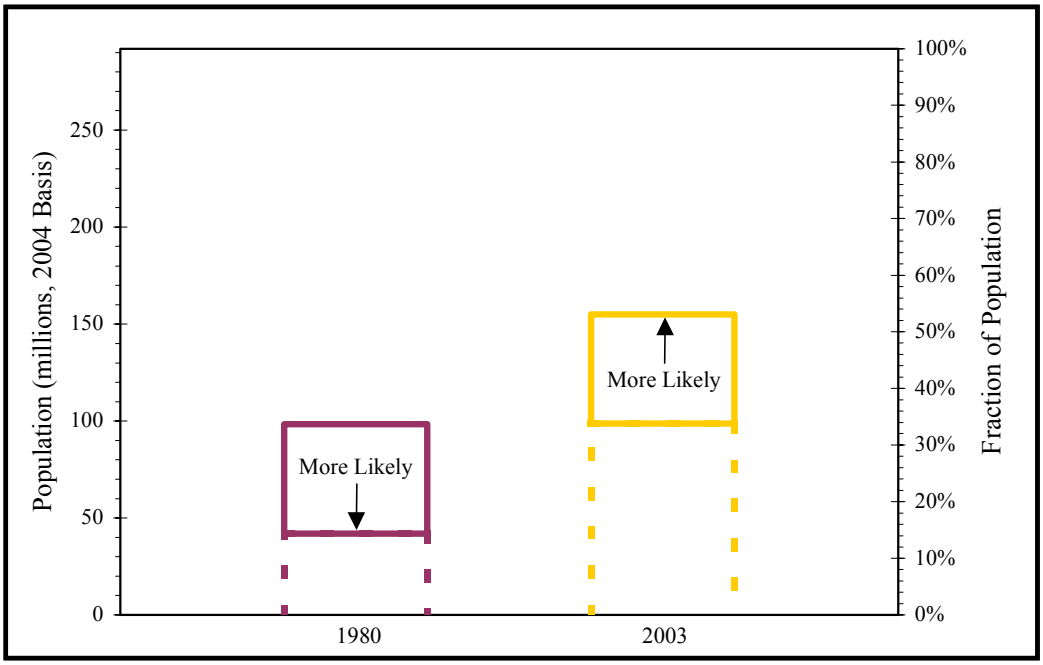


Figure 3-3. Counties Meeting the 8-Hour Ozone Standard



Note: In Figures 3-1 and 3-2, the height of each box signifies uncertainty due to counties without ozone monitors. It is expected that the actual distribution for 2003 is in the upper portion of the uncertainty box, while that for 1980 is at or below the lower portion of the uncertainty box.

Figure 3-4. Population Meeting the 8-Hour Ozone Standard



values are expected to lie closer to the upper bound compliance estimate. In short, Figures 3-1 through 3-4 almost certainly *underestimate* the degree of shift from noncompliance to compliance.

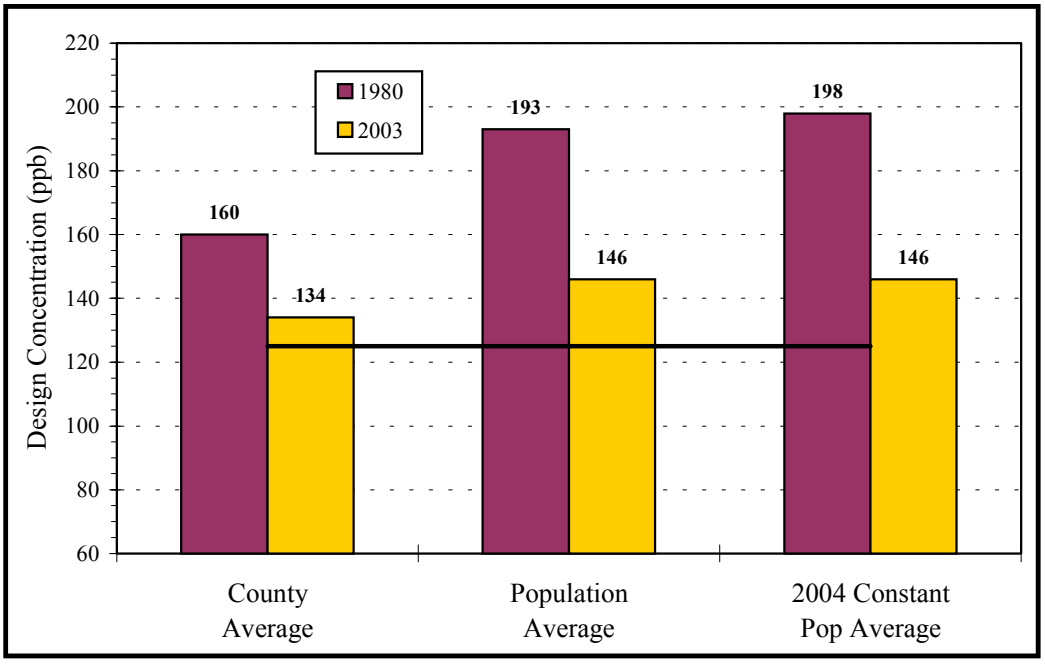
Nevertheless, it is clear from Figures 3-1 and 3-2, that an estimated 88-97 percent of U.S. counties and 71-80 percent of the U.S. population live in counties that meet the 1-hour ozone standard. This is a substantial increase from the estimates for 1980, where a maximum of 33 percent of the U.S. population lived in complying counties. Progress relative to the 8-hour ozone standard is less dramatic, but still significant. It is estimated that 49-89 percent of U.S. counties and 34-53 percent of the U.S. population currently live in counties that meet the 8-hour ozone standard. In contrast, the *maximum* population residing in such counties was 33 percent in 1980, while the actual complying county population at that time was likely to have been well below 20 percent of the U.S. total population. Therefore, although additional emission reductions will be required to bring all areas of the country into compliance, significant improvement in ozone air quality has occurred over the last 25 years.

Not only have more counties achieved compliance with the ozone NAAQS, but ozone concentrations in those counties that continue to experience violations of the NAAQS have declined substantially. As shown in Figure 3-5, the concentration triggering violation of the standard (typically denoted as the design concentration) has declined by about 25 ppb on a county average basis, or about 50 ppb on a population-weighted basis, in counties violating the 1-hour ozone standard. Figure 3-6 illustrates the fact that design concentrations, which exceeded the standard by about 30 percent on a county average basis, or about 55-60 percent on a population-weighted basis in the late 1970s, now exceed the standard by less than 10 percent on a county average basis and about 15 percent on a population-weighted basis.

Figures 3-7 and 3-8 present similar design concentration data for the 8-hour ozone standard. In counties violating the 8-hour ozone standard, the design concentration has declined by about 15 ppb on a county average basis, or 25-30 ppb on a population-weighted basis, since 1980. Whereas design concentrations exceeded the standard by about 25 percent on a county average basis, or about 45 percent on a population-weighted basis in the late 1970s, the degree of exceedance has declined to less than 10 percent on a county average basis and about 15 percent on a population-weighted basis. Thus, although both 1-hour and 8-hour ozone violations continue, the magnitude of the maximum measured concentration during exceedances of the standard has declined substantially.

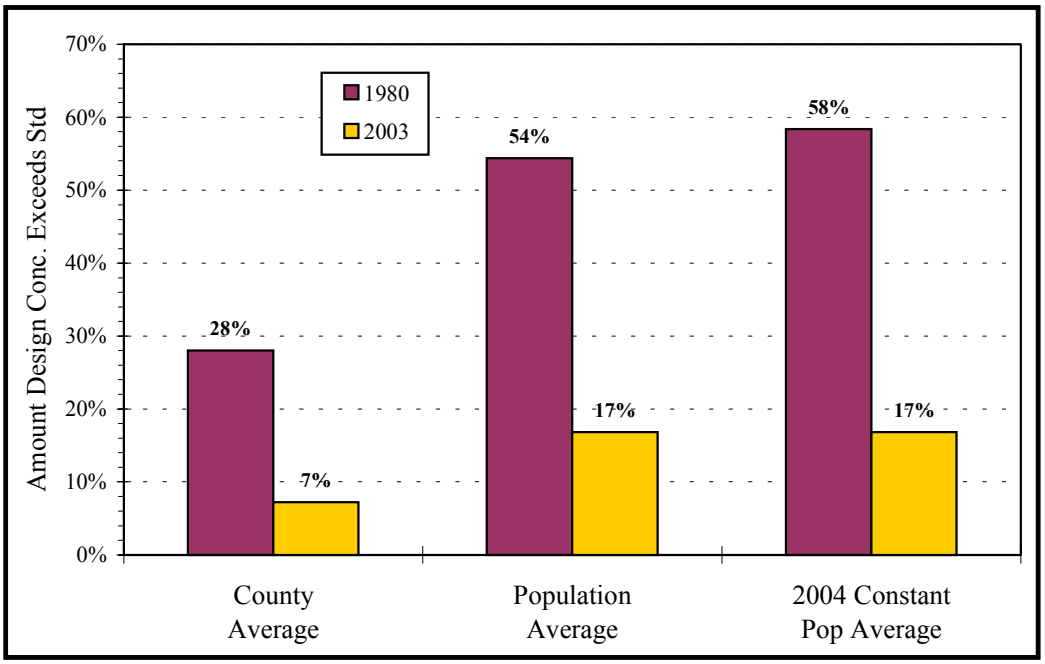
In addition to reductions in the concentrations observed during violations of the ozone NAAQS, the frequency with which such violations occur has also been substantially reduced. As shown in Figure 3-9, the number of days per year on which the standard is exceeded in counties violating the 1-hour NAAQS has declined from about 10 on a county average basis, or about 25 on a population-weighted basis in the late 1970s, to about 3 on a county average basis, or less than 10 on a population-weighted basis. Similarly, as presented in Figure 3-10, the number of exceedance hours has declined from about 35 on a county average basis, or about 100-105 on a population-weighted basis, to less than 10 on a county average basis, or about 25 on a population-weighted basis.

Figure 3-5. Design Concentration for the 1-Hour Ozone Standard[27]



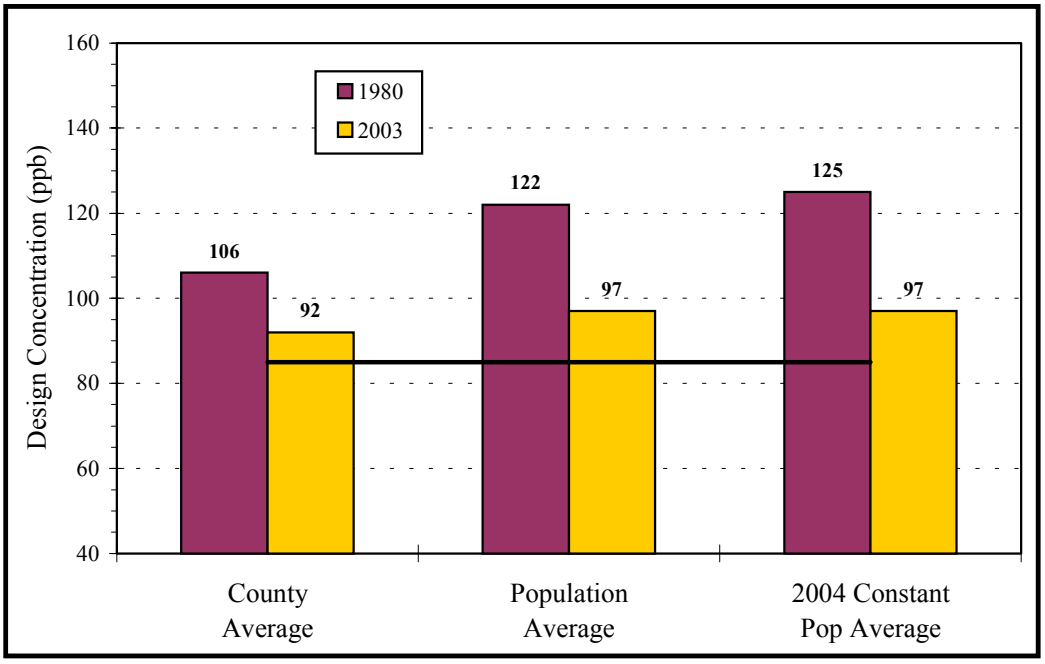
Note: In Figures 3-5 and 3-6, data are based solely on counties violating the 1-hour ozone standard.

Figure 3-6. Amount the 1-Hour Design Concentration Exceeds the NAAQS



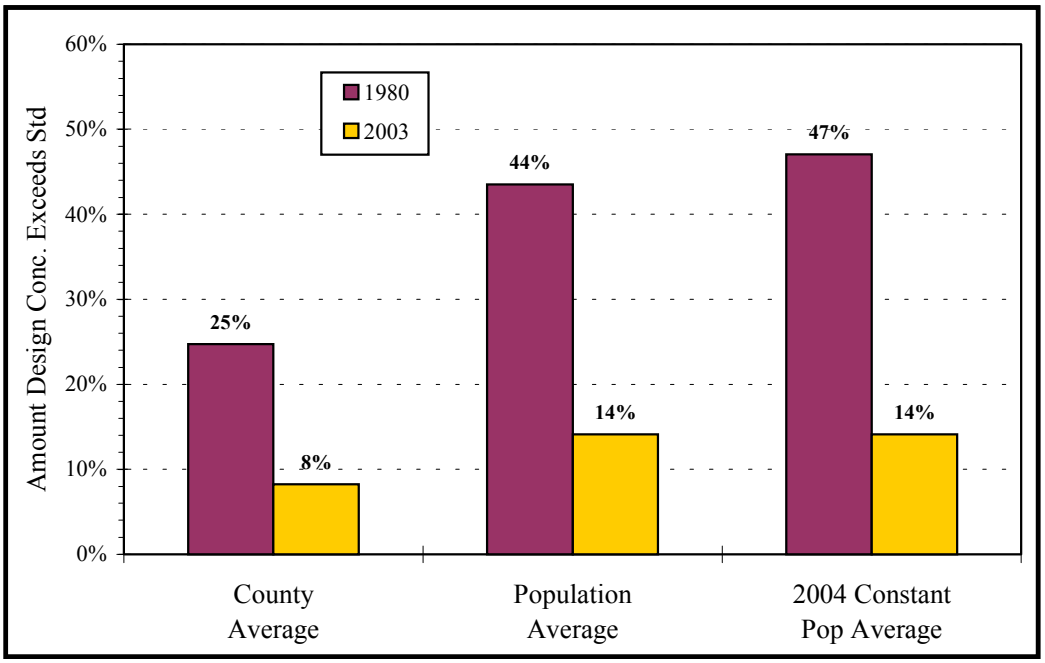
[27] As used throughout this study, design concentration indicates the specific concentration measurement used to determine compliance with the NAAQS.

Figure 3-7. Design Concentration for the 8-Hour Ozone Standard[28]



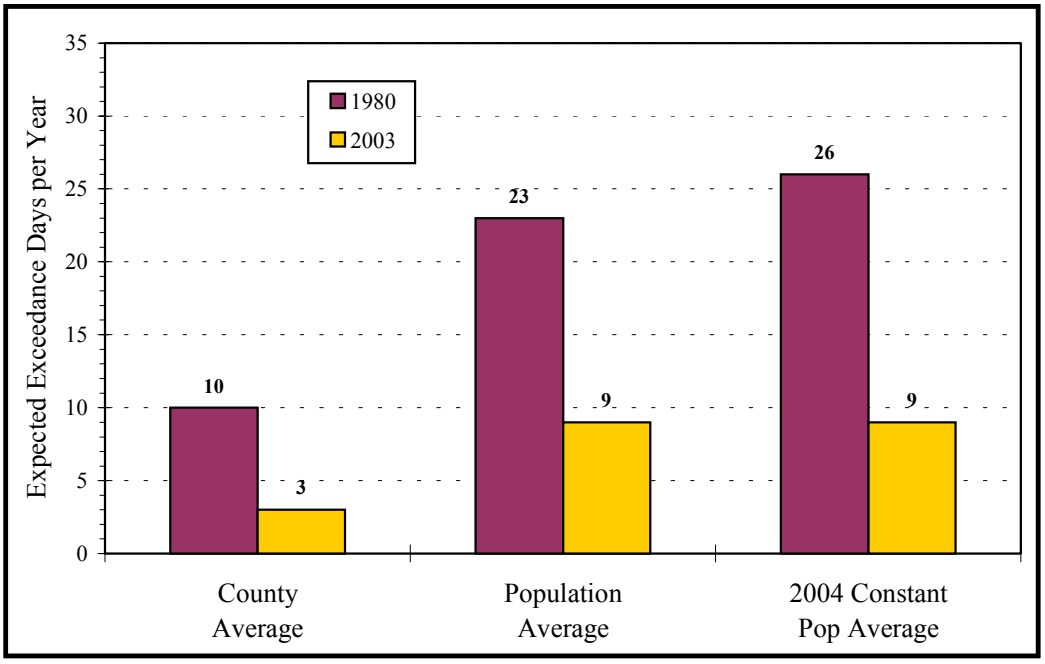
Note: In Figures 3-7 and 3-8, data are based solely on counties violating the 8-hour ozone standard.

Figure 3-8. Amount the 8-Hour Design Concentration Exceeds the NAAQS



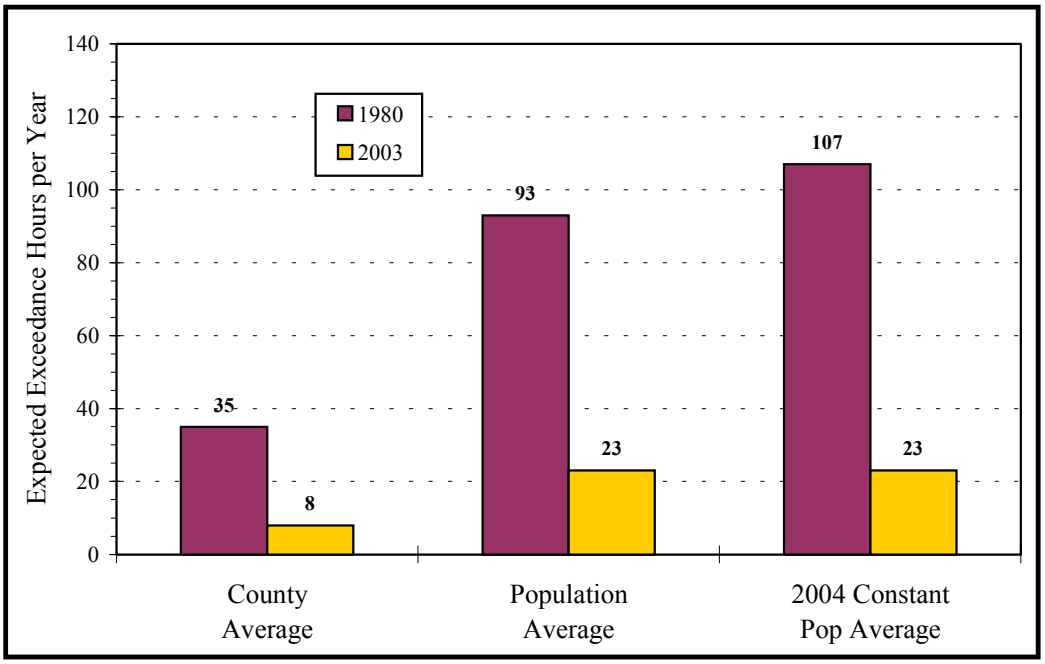
[28] As used throughout this study, design concentration indicates the specific concentration measurement used to determine compliance with the NAAQS.

Figure 3-9. Number of Days on which the 1-Hour Standard is Exceeded



Note: In Figures 3-9 and 3-10, data are based solely on counties violating the 1-hour ozone standard.

Figure 3-10. Number of Hours on which the 1-Hour Standard is Exceeded



Figures 3-11 and 3-12 present similar data for the frequency of violations of the 8-hour standard. As indicated, in counties violating the 8-hour ozone standard, the number of days per year on which the standard is exceeded has declined from about 25 on a county average basis, or about 40 on a population-weighted basis in the late 1970s, to about 10 on a county average basis, or about 15 on a population-weighted basis. Similarly, the number of exceedance hours has declined from about 135 on a county average basis, or about 240-270 on a population-weighted basis, to about 60 on a county average basis, or about 90 on a population-weighted basis.

Thus, although both 1-hour and 8-hour ozone violations continue to be observed, the amount of time that measured concentrations exceed the standard has declined by 60-80 percent. An average person living in a county that violates the ozone standard is subjected to concentrations above the 1-hour standard for a total of about 25 hours per year and concentrations above the 8-hour standard for a total of about 90 hours per year.

In summary, there is no question but that ozone air quality has improved dramatically since the 1970s. Progress to date is such that the probability of living in a county that violates the 1-hour ozone standard has declined from about 70 percent to less than 30 percent. For people living in counties that violate the standard, probable annual hours above the standard have declined by 75 percent, from 100 hours per year to 25. Moreover, the degree to which concentrations exceed the standard during those hours has declined by up to 75 percent.

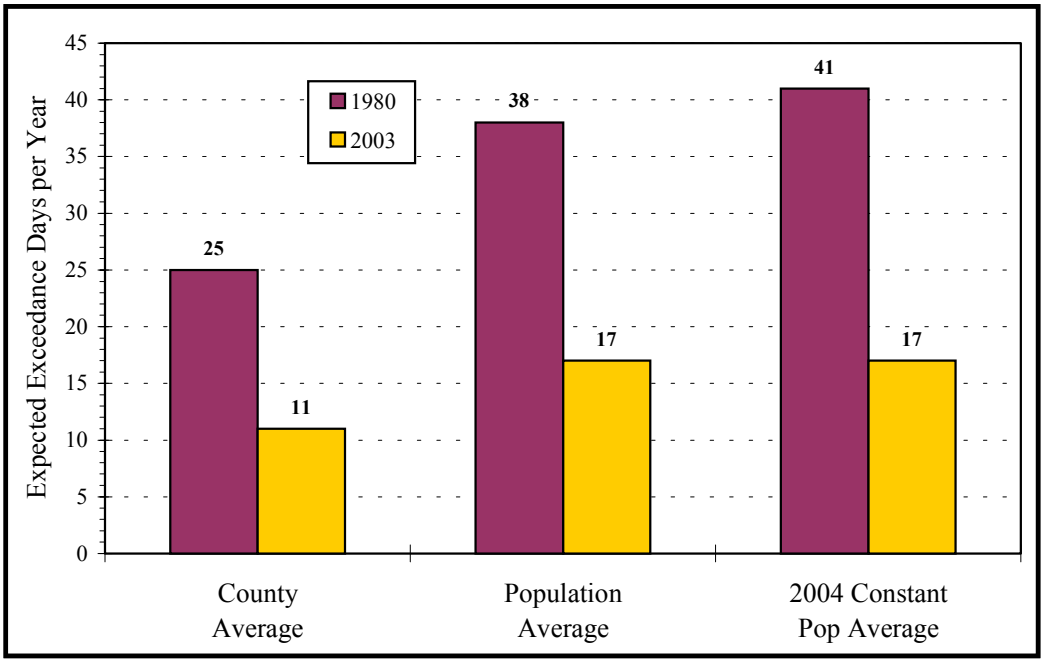
Relative to the 8-hour standard, progress has also been significant. The probability of living in an area that violates the 8-hour ozone standard has declined from about 70 percent to between 45 and 60 percent. For people living in areas that violate the standard, probable annual hours above the standard have declined by 60-65 percent, from about 250 hours per year to 90. Moreover, the degree to which concentrations exceed the standard during those hours has declined by 65-70 percent.

Clearly, progress has been substantial. Nevertheless, additional improvements are necessary to bring all areas into compliance. For the foreseeable future, continuing progress will occur through emission reductions generated by control programs such as the Tier 2 motor vehicle standards, the NO_x SIP call rules, and advanced heavy duty diesel vehicle and nonroad equipment emission standards. Each of these programs will generate significant reductions in ozone-forming NO_x emissions over the next decade and beyond. It is important to consider, however, that the 8-hour ozone standard represents a *very* stringent compliance target and that a growing body of evidence indicates that many areas of the U.S. will find it difficult, if not impossible, to attain, even with the elimination of *all* manmade emissions.[29]

The remainder of the material presented in this section consists of more detailed trend data that support the various statistics already presented. These materials are provided in the interest of allowing a more complete assessment of the analysis results generated for this study, but are not

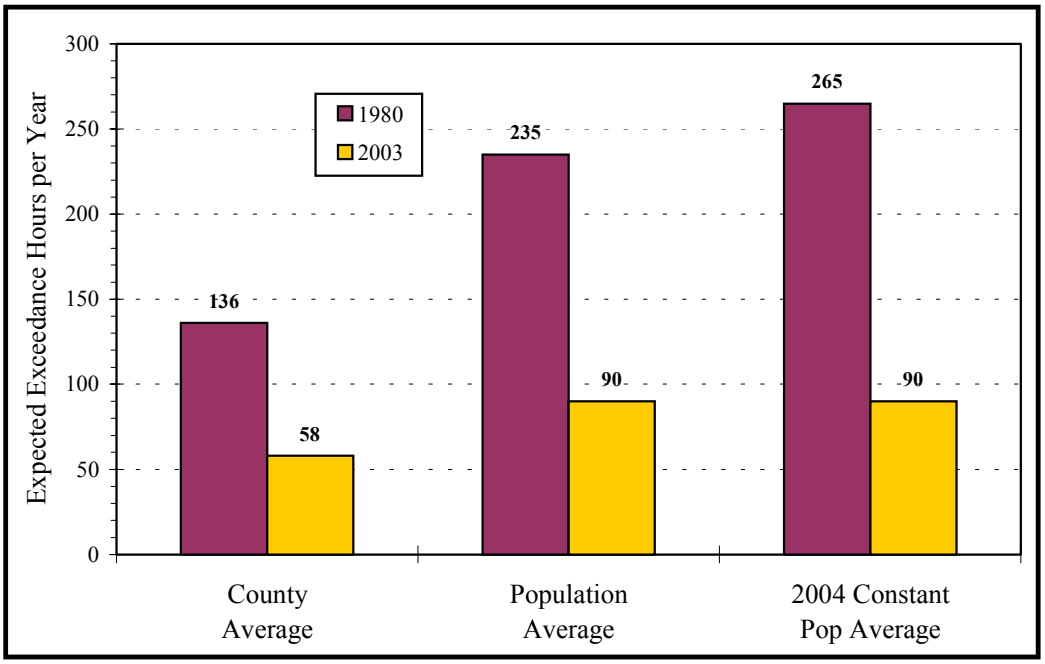
[29] See for example, "*Understanding the Effectiveness of Precursor Reductions in Lowering 8-Hour Ozone Concentrations*," Journal of the Air & Waste Management Association, Vol. 53, 195-205 (2003) and "*Understanding the Effectiveness of Precursor Reductions in Lowering 8-Hr Ozone Concentrations - Part II. The Eastern United States*," Journal of the Air & Waste Management Association, In press (2005).

Figure 3-11. Number of Days on which the 8-Hour Standard in Exceeded



Note: In Figures 3-11 and 3-12, data are based solely on counties violating the 8-hour ozone standard.

Figure 3-12. Number of Hours on which the 8-Hour Standard is Exceeded



intended to add significant additional information to the summary statistics already presented. Therefore, each of the presented charts is discussed only briefly to provide an appropriate context for review.

Figure 3-13 presents an overview of the ozone air quality monitoring network, indicating how the network has expanded over time. As indicated, ozone monitors are present in only about 30 percent of all U.S. counties, but about two-thirds of the national population resides in those counties.

Figure 3-14 illustrates that the population subjected to monitored violations of the 1-hour ozone standard has declined by about 50 percent, or 60 million, since the 1980s. The population subjected to monitored violations of the 8-hour standard has increased on a current population basis, while remaining essentially unchanged on a constant population basis. However, when considered in the context of increases in the population being monitored (the dashed curves), the changes suggest dramatic improvements in ozone air quality. For example, between 1980 and 2003, the monitoring network expanded to include about an additional 90 million people, yet the number of people subjected to 1-hour violations declined while the number subjected to 8-hour violations increased by about half of the monitored population increase. Figures 3-15 and 3-16 depict this trend more clearly.

Figure 3-15 shows that the population in monitored counties that comply with ozone standards has increased from less than 10 million in 1980 to about 140 million in 2003 for the 1-hour ozone standard and to about 70 million in 2003 for the 8-hour ozone standard. During this same period, the total monitored population increased by about 90 million. Thus, for every additional person monitored, about 1.6 people are added to complying 1-hour areas and about 0.8 people are added to complying 8-hour areas. Figure 3-16 perhaps best illustrates the dramatic improvement. In 1980, about 90-95 percent of the monitored population lived in areas violating the 1-hour and 8-hour ozone standards. By 2003, the fraction violating the 1-hour standard has declined to about 30 percent while that for the 8-hour standard has declined to about 65 percent.

Figure 3-17 shows that the ozone design value in monitored counties that violate the ozone standards has declined significantly both on a population-weighted and county-average basis, and for both the 1-hour and 8-hour standards. Design values have declined by about 15 percent since 1980 on a county-average basis and by about 20-25 percent on a population-weighted basis. In every case, the degree to which the design value exceeds the applicable standard has been reduced by about 70 percent.

Figure 3-18 shows that not only has the design value declined, but so have the number of days per year during which exceedances are observed. On a population-weighted basis, exceedance days have declined from about 25 for the 1-hour standard and 40 or more for the 8-hour standard, to less than 10 and 20 respectively. Figures 3-19 and 3-20 provide an expanded look at exceedance time trends.

Figure 3-19 shows that the number of annual hours during which exceedances are experienced in counties violating the ozone standard has also declined dramatically for both the 1-hour and 8-hour standards. On a population-weighted basis, exceedance hours have declined from about

Figure 3-13. Ozone Monitoring Network Changes Through the Study Period

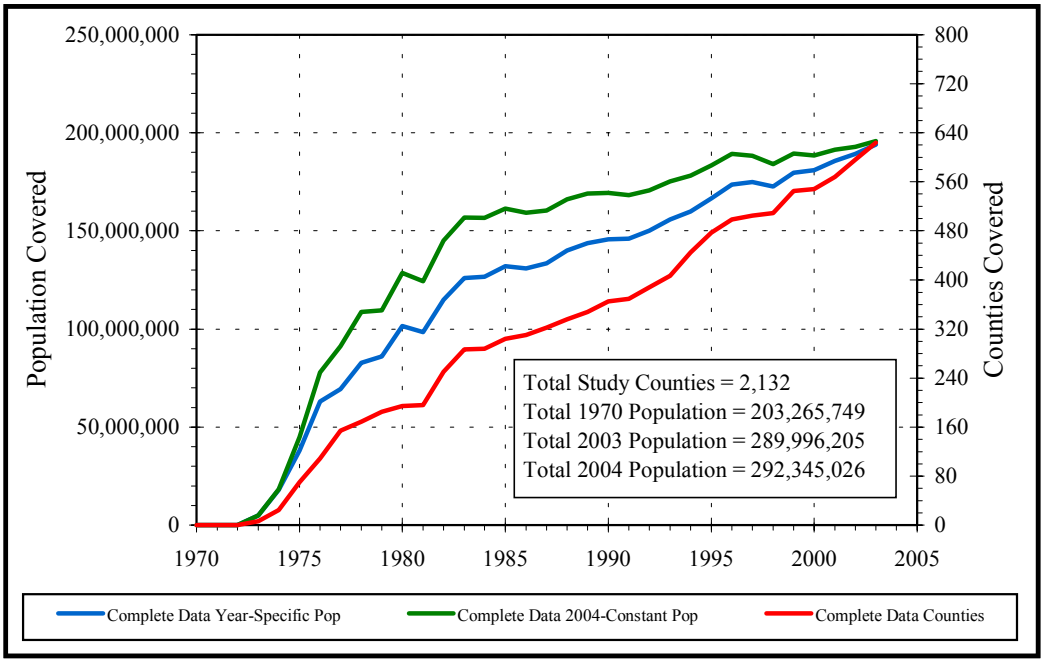


Figure 3-14. Number of Counties/Population Violating Ozone Standards

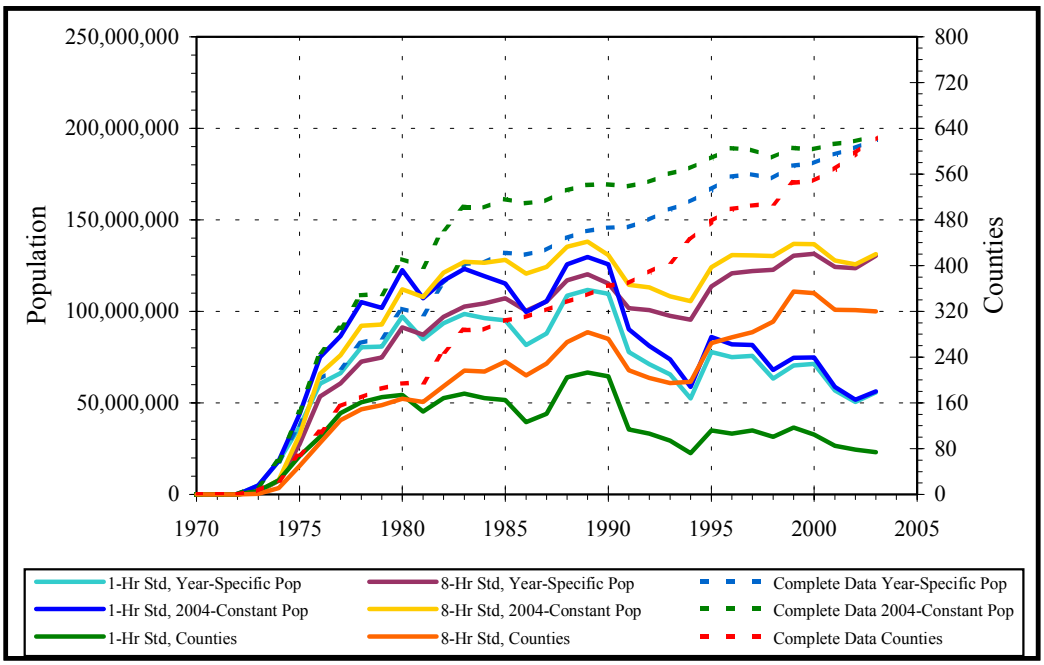


Figure 3-15. Number of Counties/Population Meeting Ozone Standards

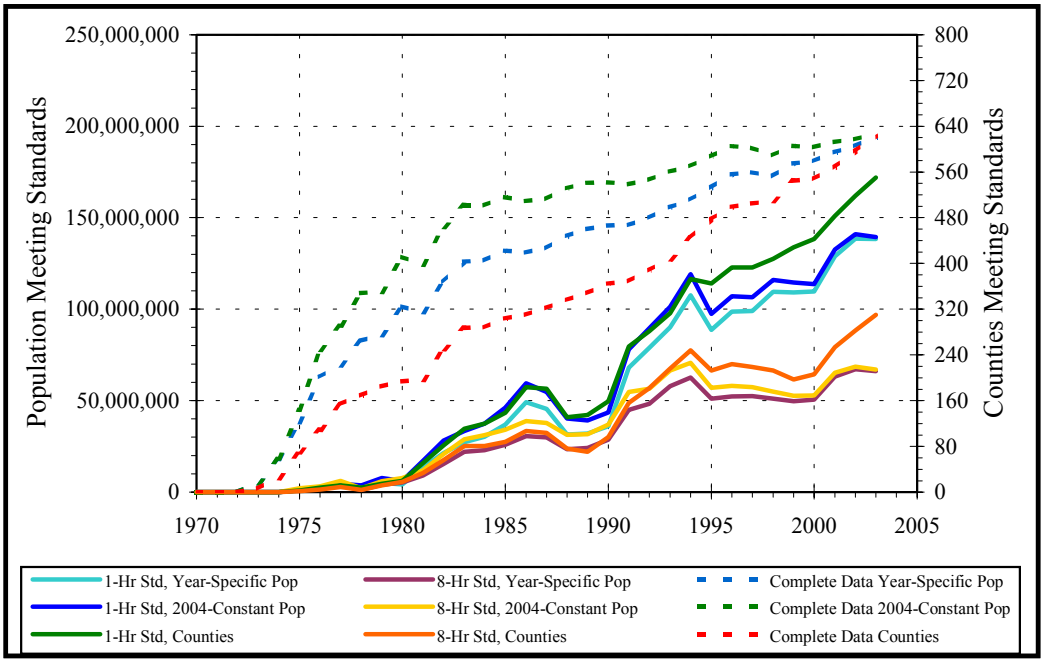


Figure 3-16. Fraction of Monitored Counties/Population Meeting Standards

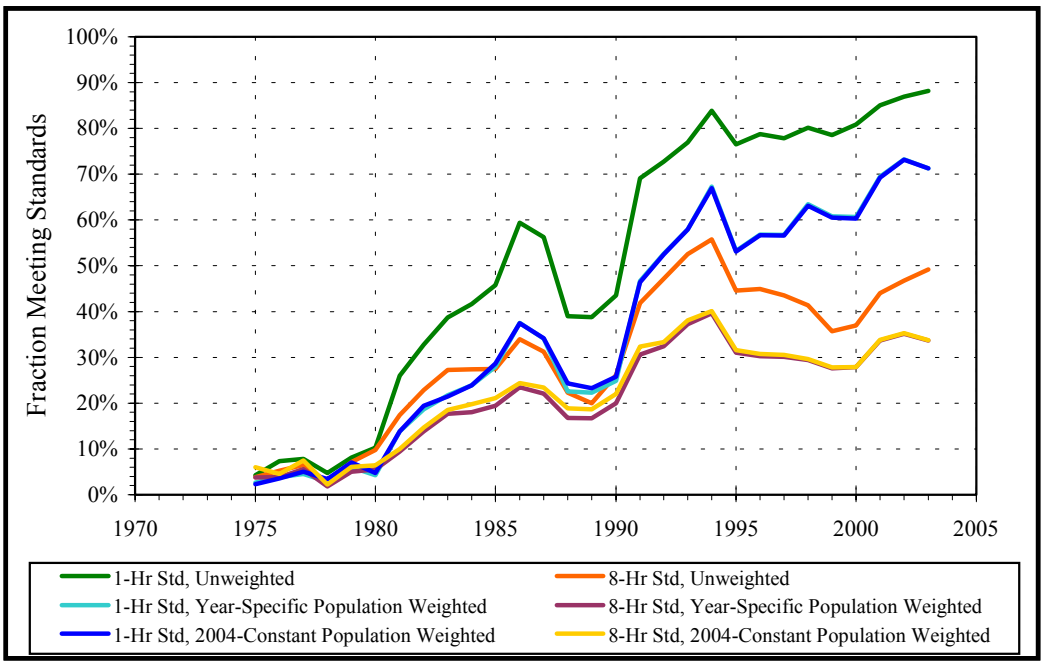


Figure 3-17. Ozone Concentration Design Values for Violating Counties

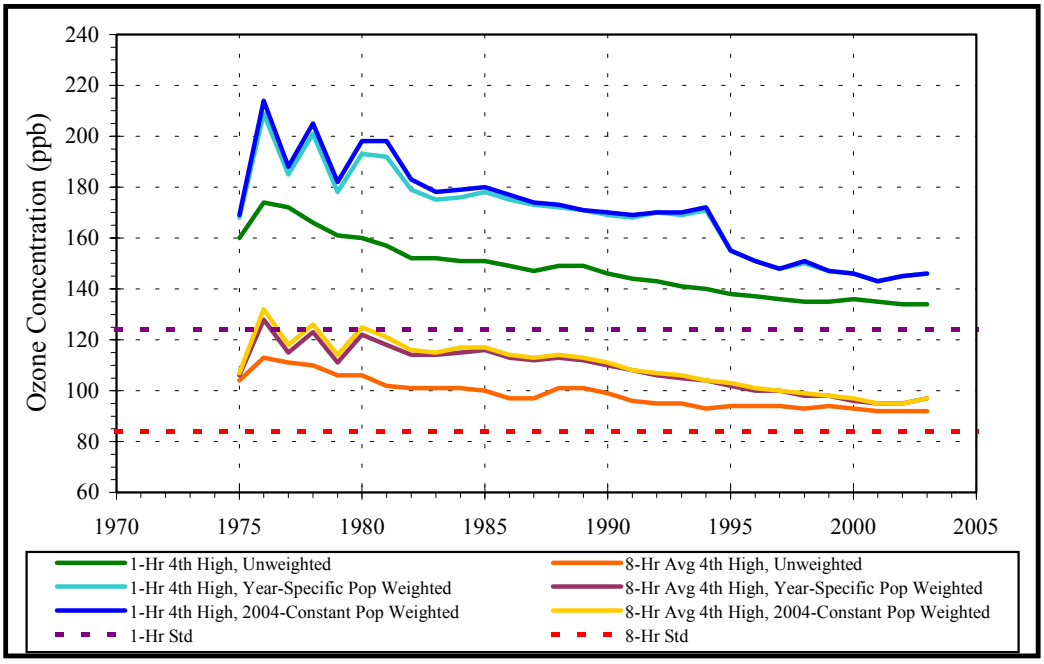


Figure 3-18. Expected Ozone Exceedance Days for Violating Counties

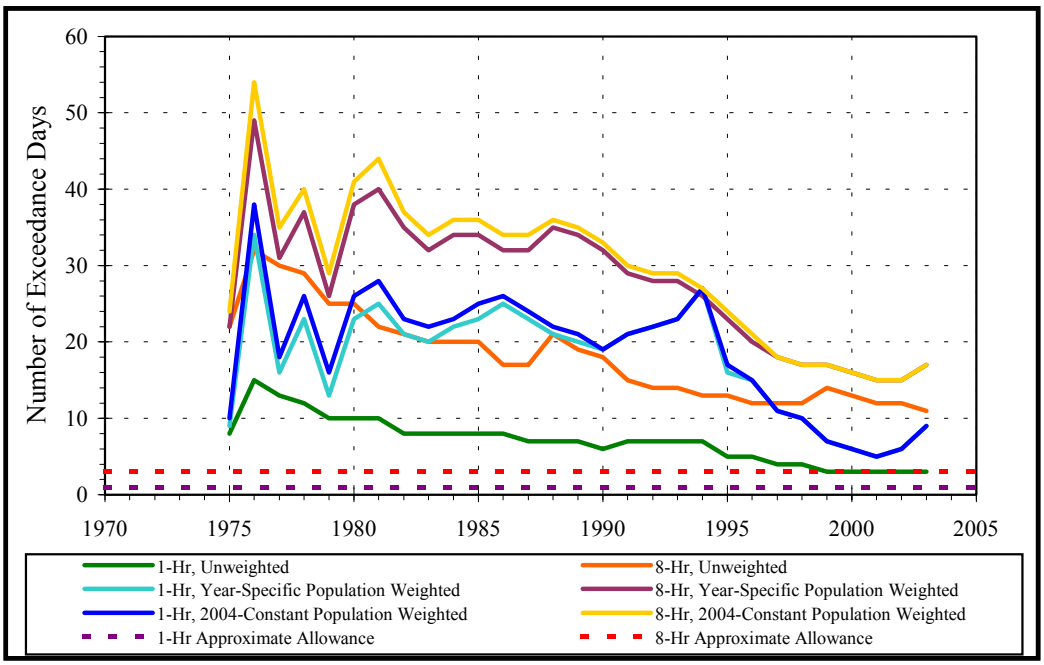


Figure 3-19. Expected Ozone Exceedance Hours for Violating Counties

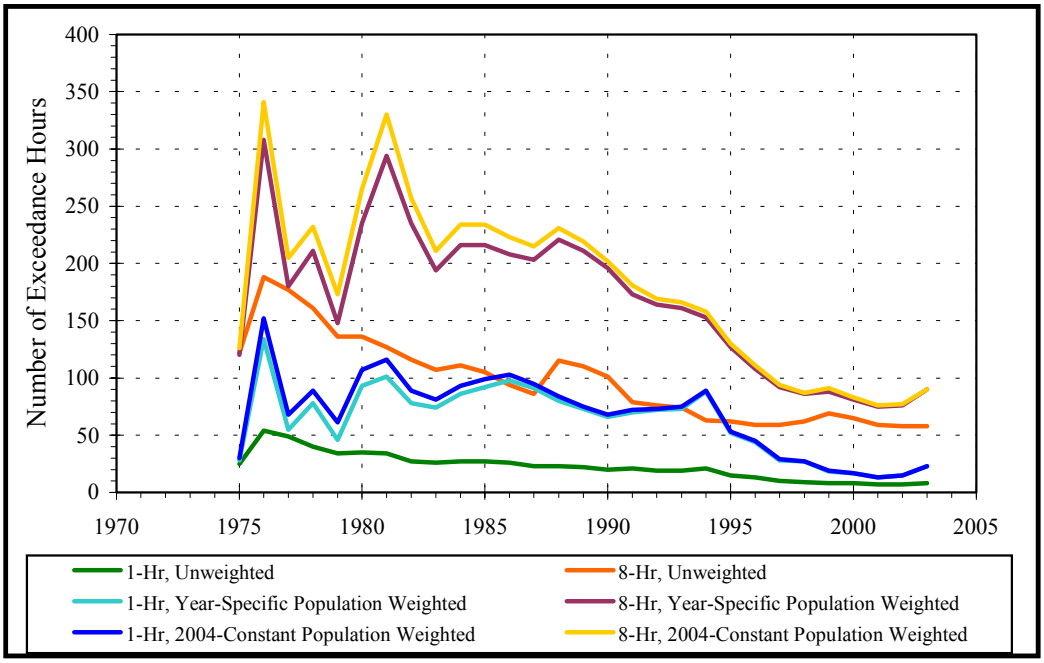
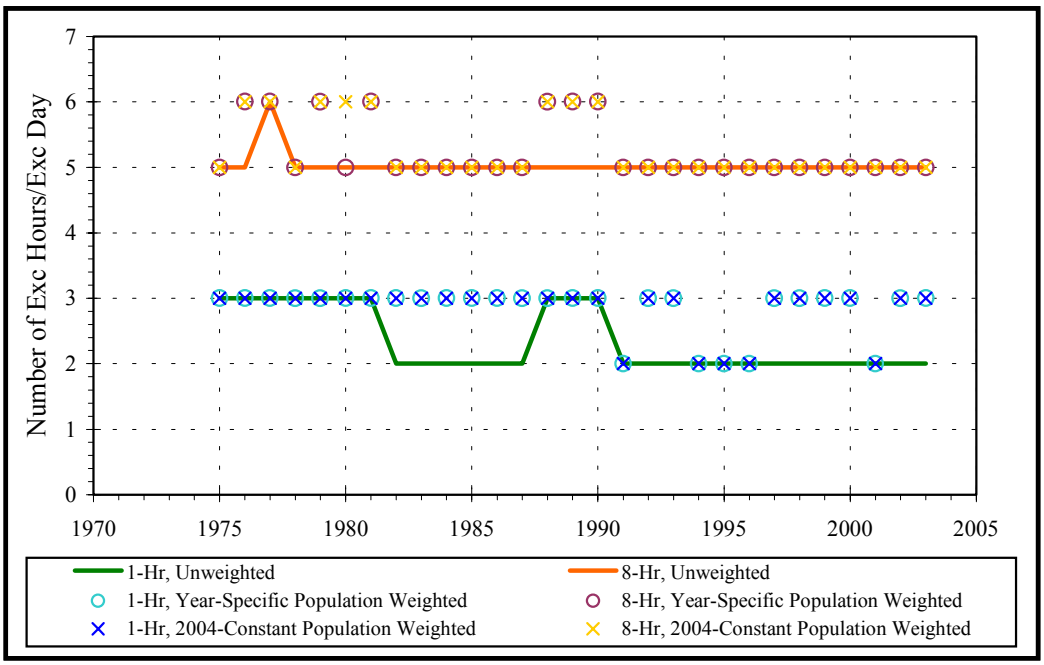


Figure 3-20. Expected Ozone Exceedance Days for Violating Counties



100 for the 1-hour standard and 250 or more for the 8-hour standard, to about 20 and 90 respectively. These represent reductions in exceedance hours of 80 percent for the 1-hour standard and 65 percent for the 8-hour standard. Although lesser absolute reductions are observed on a county-average basis, the relative changes are similar at about 75 percent for the 1-hour standard and about 60 percent for the 8-hour standard. Figure 3-20 shows that the number of exceedance hours per exceedance day has remained quite constant over time at 2-3 hours per 1-hour exceedance and 5-6 hours per 8-hour exceedance

As discussed above and as indicated in Figure 3-13, the ozone air quality monitoring network has changed considerably over time. Throughout this study it is presumed that the major influences associated with monitoring network evolution are biased towards an understatement of air quality improvement, primarily due to the bias associated with locating monitors in areas of suspected air quality problems. However, since the probability of accurately identifying such areas declines with each succeeding monitor placement, there is an influence that serves to counteract at least a portion of the understatement bias. To determine whether this counteracting influence might significantly alter study conclusions, two secondary analyses were conducted that included only monitors with complete data in all years during the analysis period. In effect, these secondary analysis are conducted over a fixed monitoring network, so that all influences associated with network evolution are eliminated.

One secondary analyses involved all monitors with complete data for every year from 1978 through 2003.[30] The 1978-2003 period allows for the generation of statistics that are exactly comparable to the statistics reported in this study for the complete ozone monitoring network. Since the statistics reported in this study represent three year average monitoring data, it is necessary to have data for 1978-1980 to generate 1980 statistics. Unfortunately, as shown in Table 3-1, only 29 ozone monitors representing a 2004 population of about 28.2 million (or about 10 percent of the U.S. population) satisfy this criteria. Therefore, another secondary analysis was performed for all monitors with complete data for every year from 1981 through 2003. As shown in Table 3-1, this results in a significantly larger dataset of 110 ozone monitors representing a 2004 population of about 71.4 million, or about 25 percent of the U.S. population. However, with this larger secondary dataset, the earliest trend year for which statistics can be quantified based on three year average data is 1983. Therefore, when comparing trends from this dataset to those reported for the complete ozone monitoring network, it should be recognized that the complete network data includes three additional years of potential air quality improvement.

Figures 3-21 through 3-28 present the results of the secondary analyses. Figures 3-21 and 3-22 illustrate the change in the fraction of monitors meeting the 1-hour standard and the fraction of monitors that would have met the 8-hour ozone standard. Figures 3-23 and 3-24 illustrate the change in ozone design concentration. Figures 3-25 and 3-26 illustrate the change in the number of expected ozone exceedance days. Finally, Figures 3-27 and 3-28 illustrate the change in the number of expected ozone exceedance hours. Table 3-2 presents statistics derived from each of these figures and compares the statistics to the corresponding statistics presented earlier in this report for the entire ozone monitoring network. As indicated, both of the secondary datasets

[30] Complete data is defined in this context as having valid 1-hour and 8-hour data for at least 75 percent of the hours between 9 a.m. and 9 p.m. DST during the ozone season applicable to the monitor (as defined by the EPA).

Table 3-1. Brief Overview of the Secondary Ozone Analysis Datasets

Parameter	1978-2003 Dataset	1981-2003 Dataset
Number of monitors	29	110
Number of counties	26	90
Number of states	13	27
States (number of counties)	Arizona (1), California (8), Colorado (1), Illinois (3), Louisiana (1), Missouri (1), New Jersey (1), New York (1), Ohio (4), Oregon (1), Virginia (2), Washington (1), Wisconsin(1)	Alabama (1), Arizona (2), Arkansas (1), California (18), Colorado (2), Connecticut (3), Florida (2), Illinois (10), Indiana (5), Kansas (1), Louisiana (5), Maine (1), Maryland (2), Michigan (5), Mississippi (1), Missouri (1), New Jersey (4), New Mexico (1), New York (5), North Carolina (1), Ohio (7), Oklahoma (2), Oregon (1), Tennessee (2), Virginia (2), Washington (1), Wisconsin(4)

Both datasets include only monitors with complete data for all of the indicated years.

exhibit air quality improvement that exceeds the improvement implied by the complete network dataset.

For the 1-hour standard, the amount of time spent above the NAAQS has declined by 90-95 percent for the secondary datasets, relative to 60-80 percent for the complete network. The average 1-hour design concentration for the secondary datasets has declined by 20-40 percent, relative to 15-25 percent for the complete network. For the 8-hour standard, the amount of time spent above the NAAQS has declined by 70-85 percent for the secondary datasets, relative to 55-65 percent for the complete network. The average 8-hour design concentration for the secondary datasets has declined by 10-30 percent, relative to 10-20 percent for the complete network. These larger improvements are even more significant than the statistics imply since the statistics for the secondary datasets include all dataset monitors, whereas those for the complete network reflect improvements for noncomplying monitors only.

In conclusion, it appears that the air quality improvement statistics derived from the complete ozone monitoring network do indeed understate the level of air quality improvement that has occurred since 1980.

Figure 3-21. Fraction of Counties/Population Meeting Standards (Counties with Complete Data Monitors for All Years from 1978-2003)

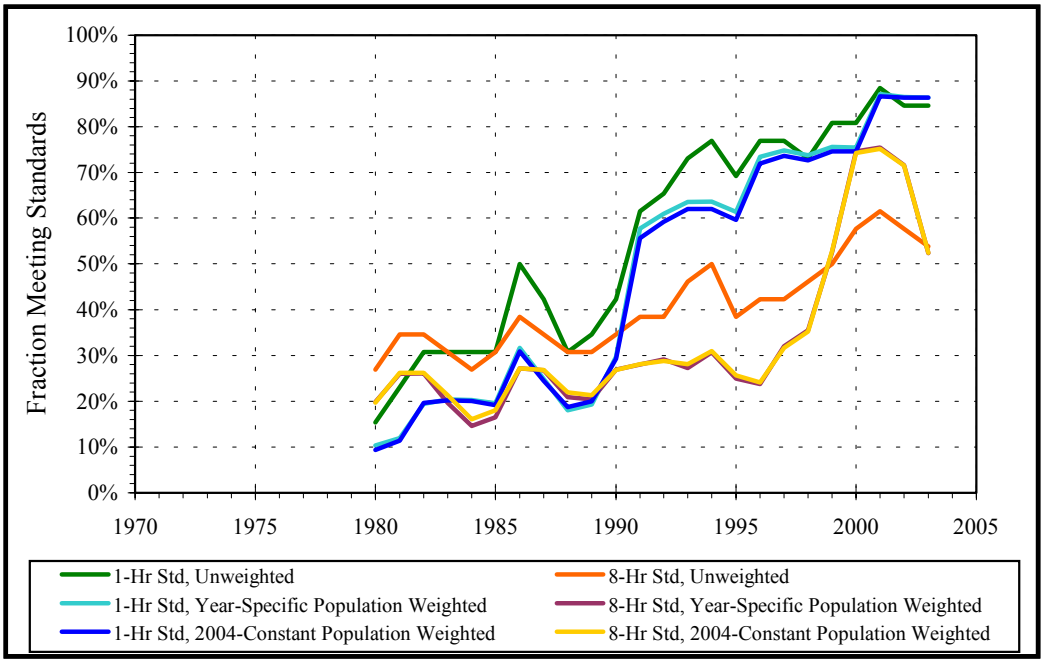


Figure 3-22. Fraction of Counties/Population Meeting Standards (Counties with Complete Data Monitors for All Years from 1981-2003)

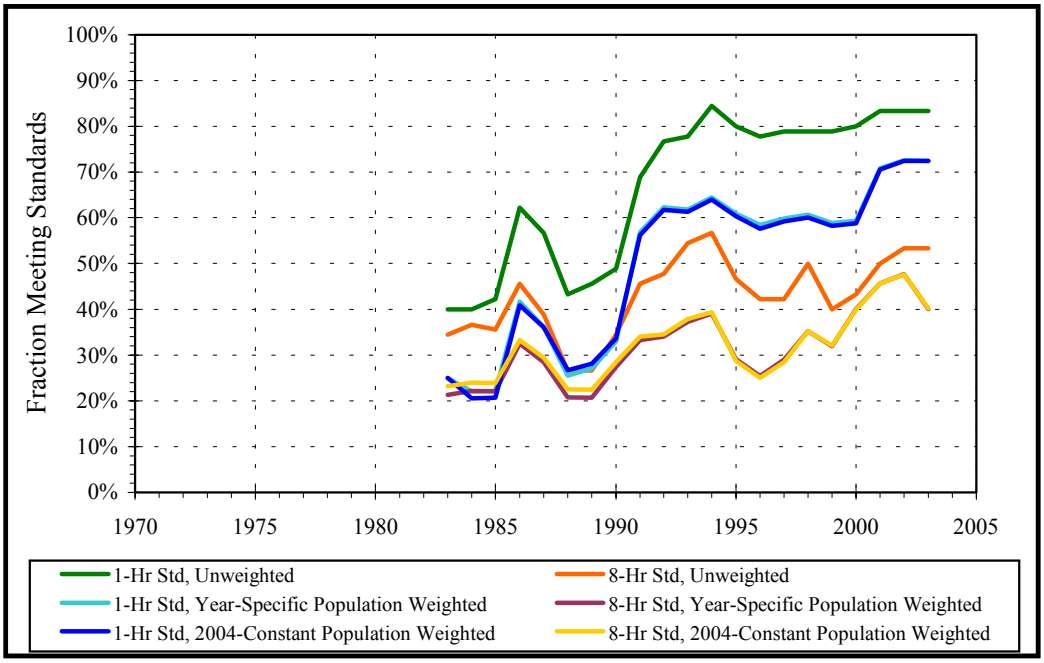


Figure 3-23. Ozone Concentration Design Values for Counties with Complete Data Monitors for All Years from 1978-2003

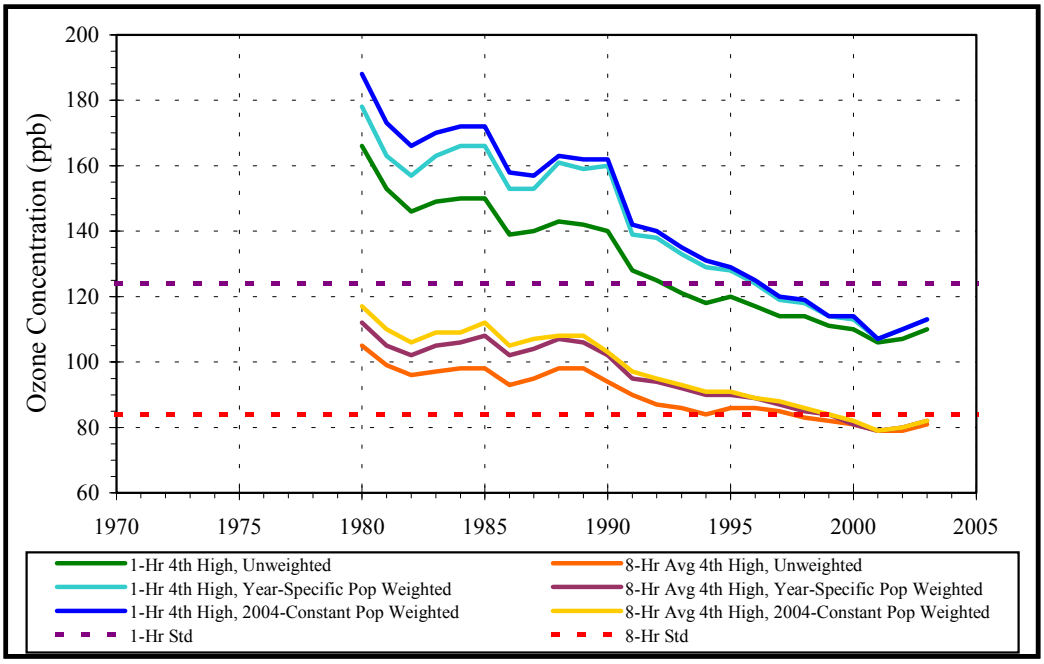


Figure 3-24. Ozone Concentration Design Values for Counties with Complete Data Monitors for All Years from 1981-2003

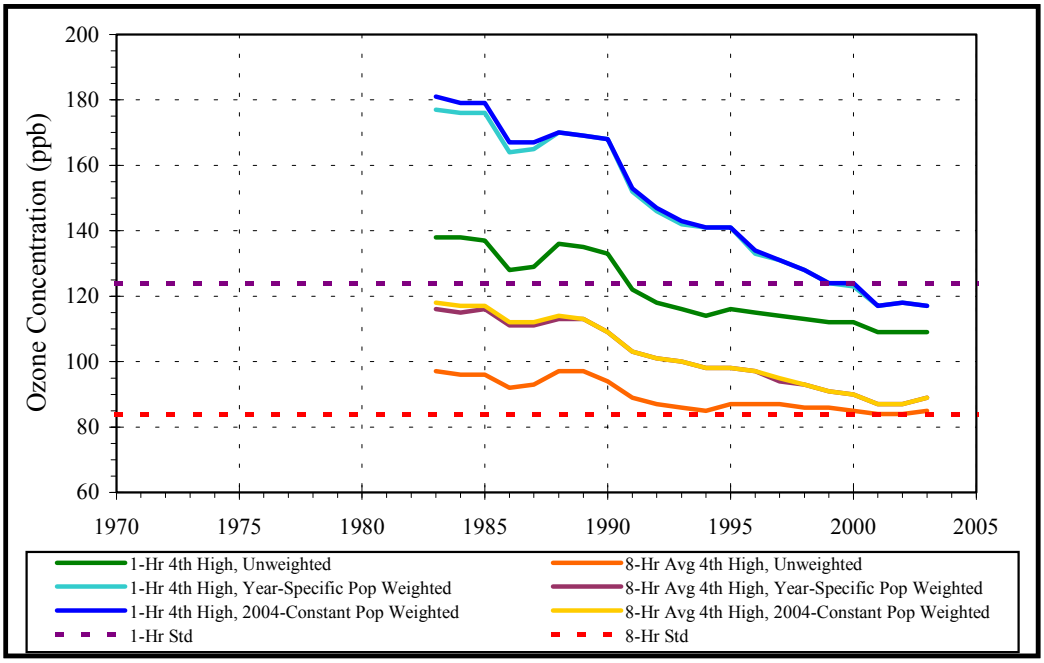


Figure 3-25. Expected Ozone Exceedance Days for Counties with Complete Data Monitors for All Years from 1978-2003

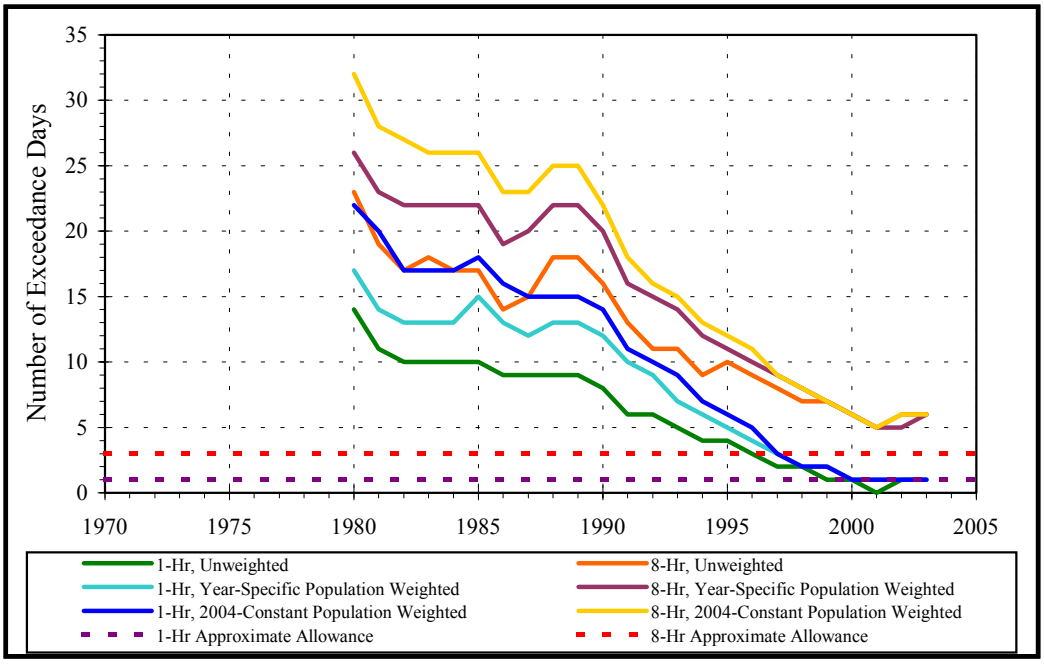


Figure 3-26. Expected Ozone Exceedance Days for Counties with Complete Data Monitors for All Years from 1981-2003

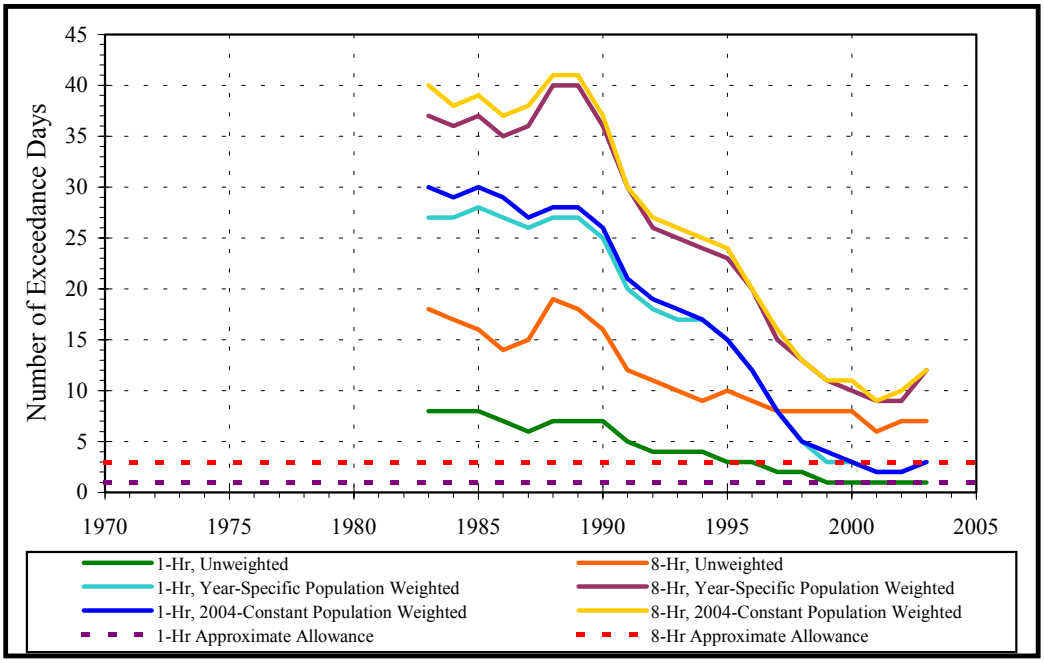


Figure 3-27. Expected Ozone Exceedance Hours for Counties with Complete Data Monitors for All Years from 1978-2003

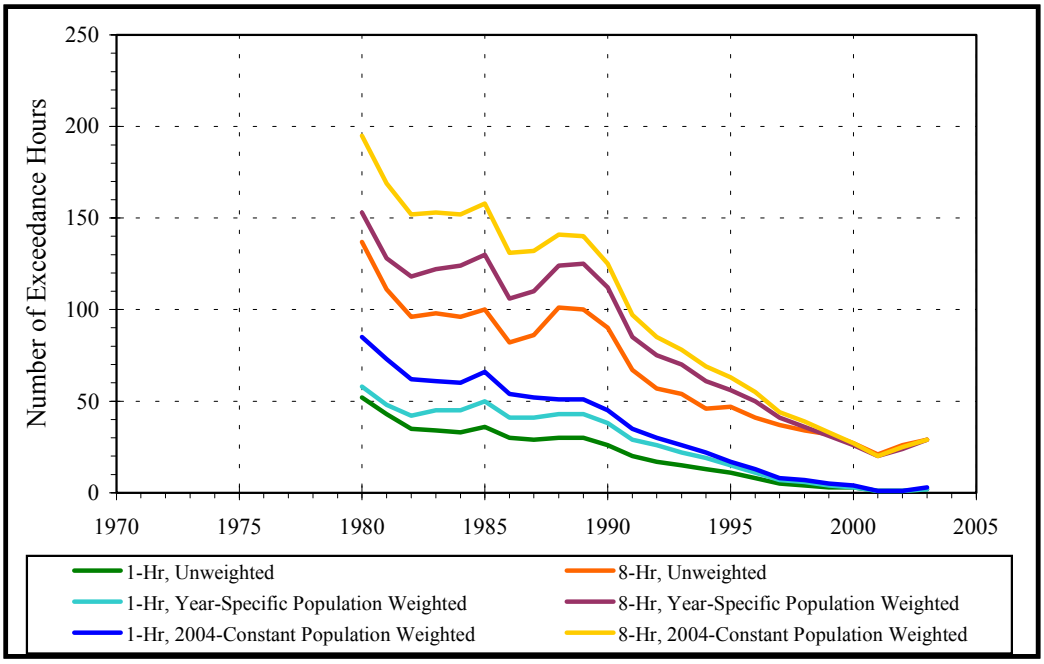


Figure 3-28. Expected Ozone Exceedance Hours for Counties with Complete Data Monitors for All Years from 1981-2003

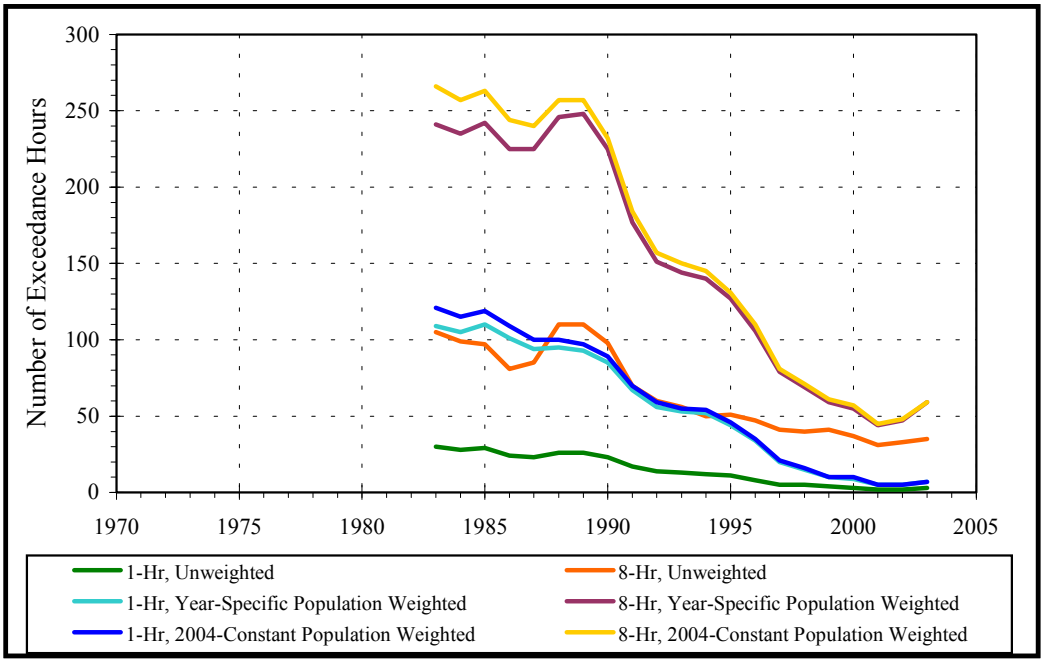


Table 3-2. Comparison of Percent Change Statistics

Analysis Parameter	County Average			Population-Weighted Average			2004 Constant Population-Wgtd. Avg.		
	Base	2003	Change	Base	2003	Change	Base	2003	Change
1-Hour Standard									
All Violating Counties with Complete Data (Base = 1980)									
Design Concentration[31]	160	134	-16%	193	146	-24%	198	146	-26%
Expected Exceedance Days	10	3	-70%	23	9	-61%	26	9	-65%
Expected Exceedance Hours	35	8	-77%	93	23	-75%	107	23	-79%
All Counties with Complete Data Monitors for all Data Years from 1978-2003 (Base = 1980)									
Design Concentration	166	110	-34%	178	113	-37%	188	113	-40%
Expected Exceedance Days	14	1	-93%	17	1	-94%	22	1	-95%
Expected Exceedance Hours	52	2	-96%	58	2	-97%	85	3	-96%
All Counties with Complete Data Monitors for all Data Years from 1981-2003 (Base = 1983)									
Design Concentration	138	109	-21%	177	117	-34%	181	117	-35%
Expected Exceedance Days	8	1	-88%	27	3	-89%	30	3	-90%
Expected Exceedance Hours	30	3	-90%	109	7	-94%	121	7	-94%
8-Hour Standard									
All Violating Counties with Complete Data (Base = 1980)									
Design Concentration	106	92	-13%	122	97	-20%	125	97	-22%
Expected Exceedance Days	25	11	-56%	38	17	-55%	41	17	-59%
Expected Exceedance Hours	136	58	-57%	235	90	-62%	265	90	-66%
All Counties with Complete Data Monitors for all Data Years from 1978-2003 (Base = 1980)									
Design Concentration	105	81	-23%	112	82	-27%	117	82	-30%
Expected Exceedance Days	23	6	-74%	26	6	-77%	32	6	-81%
Expected Exceedance Hours	137	29	-79%	153	29	-81%	195	29	-85%
All Counties with Complete Data Monitors for all Data Years from 1981-2003 (Base = 1983)									
Design Concentration	97	85	-12%	116	89	-23%	118	89	-25%
Expected Exceedance Days	18	7	-61%	37	12	-68%	40	12	-70%
Expected Exceedance Hours	105	35	-67%	241	59	-76%	266	59	-78%

Percent change values in green font indicate a larger air quality improvement than the percent change statistics for all violating counties with complete data (which are the primary presented statistics in this study). Percent change statistics in red font indicate a smaller improvement. As shown, there is only one instance where a smaller improvement is indicated, but that instance includes three fewer years of data, so that any improvement during that three year period would be in addition to the tabulated improvement. In short, all of the statistics that form the basis of the ozone air quality improvements cited in this study are almost certainly conservative.

[31] As used throughout this study, design concentration indicates the specific concentration measurement used to determine compliance with the NAAQS.

4. Particulate Matter

Particulate matter (PM) is unique among the pollutants for which the EPA has established NAAQS in that it is not a specific chemical compound, but rather is composed of airborne particles of any composition. Over the years, both the form of the PM NAAQS and the specific particles covered by the standard have changed. The original PM standard was expressed as "Total Suspended Particulate (TSP)," and essentially covered airborne particles of any size. Since the particles of most concern from a health standpoint are those that can be deeply inhaled, the PM standard was revised in 1987 by replacing the TSP standard with an NAAQS based on particulate matter with an effective aerodynamic diameter of 10 microns or less (PM-10). In 1997, the PM standard was again revised, changing the form of the PM-10 standard and adding a second NAAQS for PM-2.5, particulate matter with an effective aerodynamic diameter of 2.5 microns or less.[32]

Compared to other air pollutants, quantifying improvement in the ambient levels of PM is significantly complicated by the changes in the NAAQS that have occurred over the years. Air quality measurements for the portion of PM currently regulated, i.e., PM-10 and PM-2.5, did not begin until the mid-1980s for PM-10 and the late 1990s for PM-2.5. Prior to that time, almost all PM data was measured as TSP, which cannot be converted to either equivalent PM-10 or PM-2.5 with a degree of precision that would allow it to be compared against directly measured PM-10 and PM-2.5. As a result, the historic record for PM-10 and PM-2.5 is substantially shorter than that for other NAAQS compounds. Moreover, this record excludes a substantial period of time (from the early 1970s through the mid-1980s) when PM emissions were being reduced through control measures implemented in response to the TSP NAAQS. Although it is unclear what the precise effect of these reductions was on either PM-10 or PM-2.5, it is virtually certain that ambient concentrations of both were reduced.[33]

The EPA estimates that combustion and industrial process PM-10 emissions were reduced by about 70 percent between 1970 and 1985.[34] If EPA emission estimates for this period are corrected to include a more accurate assessment of geologic PM, which generally was not accurately estimated during the period from 1970 to 1985, then the overall reduction in PM-10 is estimated to be about 20 percent.[35] This reduction should translate into air quality improvements that will not be observed in the historic PM-10 record since the record does not begin until after

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[32] The largest PM-10 and PM-2.5 is about 1/7th and 1/30th the diameter of a human hair respectively.

[33] PM-10 and PM-2.5 are components of TSP. The only way that TSP can be reduced without reducing PM-10 or PM-2.5 is if the associated control measure is effective only on that portion of TSP larger than PM-10 or PM-2.5. Generally, there is no such "fine line" associated with implemented control measures and emissions across the full range of PM are reduced. Control efficiency may vary with PM size, but some level of control will generally be observed across the full PM size range.

[34] http://www.epa.gov/ttn/chief/trends/trends01/trends2001_aug2003.zip

[35] Geologic PM are particles of earth, dust, and rock that become airborne through the action of wind or other disturbance, such as agricultural tilling or the propelling force of motor vehicle tires. Such particulate can comprise upwards of 90 percent of PM-10 emissions.

the reductions have occurred. Thus, any improvements observed in the historic record are conservative in that they exclude prior improvements that almost certainly occurred, but cannot be quantified on the basis of air quality measurements. This same phenomenon affects the analysis of PM-2.5 data, but to an even greater extent since the PM-2.5 record does not begin until the late 1990s. In fact, the historic record for PM-2.5 is so short that the determination of ambient trends with any degree of certainty is virtually impossible.

An additional complicating factor in the analysis of national PM data is the fact that air quality problems related to PM tend to be dominated by local conditions. As a result, variations in the monitoring network over time can have a significant effect on average concentration data. Ambient PM concentrations vary by over four orders of magnitude, so the addition or removal of data for a particular monitor in the middle of an analysis period can dramatically affect implied PM trends. Contrast this with ozone data, where concentrations seldom vary my more than a single order of magnitude. Ozone trends are relatively insensitive to the inclusion or exclusion of data for a few monitors, while trends for PM can be influenced dramatically by just a single monitor.

Despite the limitations imposed by abbreviated historic records and sensitivity to local rather than regional or national conditions, several important insights on PM air quality can be derived from existing ambient data. As was the case with ozone, the insights are initially summarized in terms of simplified bar charts to enhance clarity. Detailed year-by-year trend charts used to produce the bar charts as well as additional associated discussion are presented at the conclusion of this section.

Figures 4-1 and 4-2 show the number of U.S. counties in which violations of the PM-10 NAAQS were experienced in the three year periods ending in 1990 and 2003.[36] Both figures also present the number of citizens residing in those counties. As indicated in Figure 4-1, both the number of counties and population experiencing violations of the annual PM-10 NAAQS has declined by 60-70 percent in the 1990-2003 timeframe. As shown in Figure 4-2, the decline in the number of counties and population experiencing violations of the daily PM-10 NAAQS has somewhat been less dramatic but still quite significant at about a 20 percent reduction in the number of counties and a 30-40 percent reduction in population. Moreover, these statistics almost certainly understate long term trends for two reasons. First, as described above, improvements prior to 1990 are not reflected since there is no available air quality data with which to precisely quantify such improvement. Second, the PM-10 air quality monitoring network expanded significantly in the late 1980s. Therefore, the number of counties and population for which a full three year NAAQS evaluation dataset was available in 1990 is substantially lower than in 2003. The number of counties reflected in the data increased by 110 percent, from 158 in 1990 to 332 in 2003. Monitored population increased by 81 percent on an actual population basis, from 73.7

[36] Compliance with the PM NAAQS is evaluated on the basis of three year average concentrations. It should also be noted that there are currently two forms of the PM-10 NAAQS, the older (i.e., pre-1997) form, which continues to be in effect in certain areas of the U.S. until specific administrative requirements are met, and the newer (i.e., 1997) form. This has no effect on actual observed trends, but can influence the selection of what air quality statistics to investigate (i.e., statistics based on the older form of the NAAQS versus statistics based on the newer form of the NAAQS). For this study, PM-10 statistics are based on the newer form of the standard -- although statistics based on the older form would lead to identical conclusions.

Figure 4-1. Violations of the Annual PM-10 NAAQS

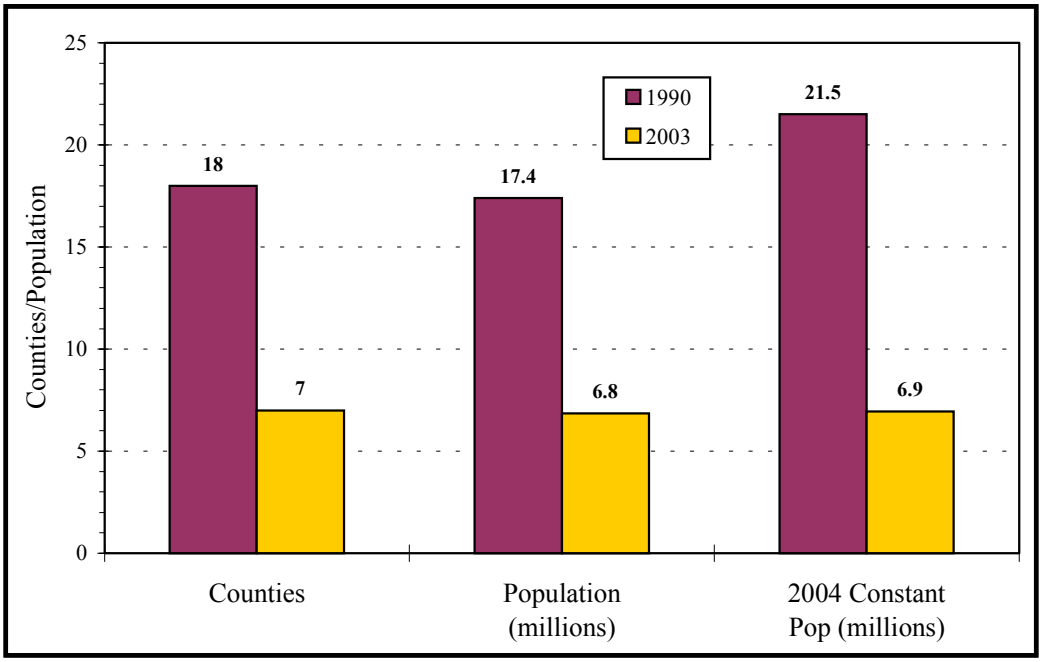
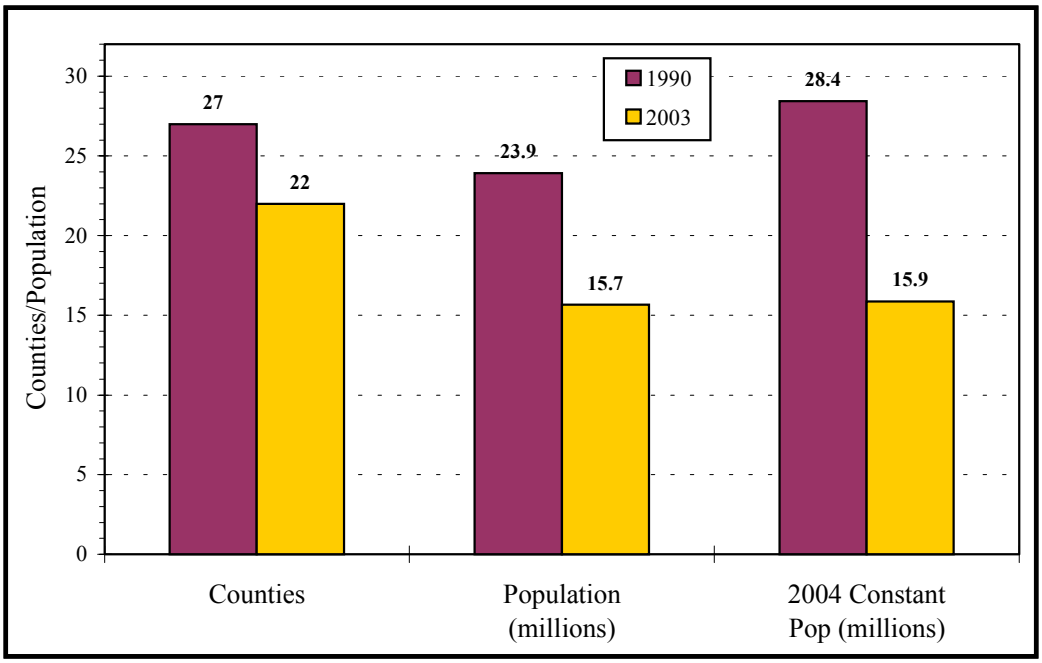


Figure 4-2. Violations of the Daily PM-10 NAAQS



million in 1990 to 133.7 million in 2003, or 60 percent on a constant 2004 population basis, from 84.1 million in 1990 to 134.9 million in 2003.[37] These substantial increases in the size of the monitoring network create a situation in which additional air quality problem areas were identified between 1990 and 2003 -- effectively reducing air quality progress statistics based on the number of counties and population violating the NAAQS. In short, actual progress is greater than the statistics imply.

The localized nature of PM-10 noncompliance is illustrated by the population statistics presented in Figures 4-1 and 4-2. The 1990 populations experiencing NAAQS violations represent about 7 percent of the total U.S. population, while the 2003 population experiencing violations has declined to about 5 percent. Violations of the PM-10 NAAQS are largely associated with areas in the southwestern U.S. where the potential for geologic PM is quite large. About 70 percent of the affected population is in California and Arizona.

Figures 4-3 and 4-4 present corresponding statistics for PM-2.5. It should be emphasized, however, that the time period for which air quality data for PM-2.5 is available is very limited, so the associated statistics cannot be considered definitive. In fact, since a robust quantity of PM-2.5 data are available only beginning in 1999, it is not possible to compare PM-2.5 statistics in any meaningful way on the basis of the three year averaging approach normally utilized for determining NAAQS compliance. Therefore, all presented PM-2.5 statistics are based on the comparison of data for two single data years, 2000 and 2003. Clearly, there is only a short period of time between the two comparison years and the resulting statistics should be considered in that context. Nevertheless, the PM-2.5 monitoring network was well established by 2000, so data for the two years should be comparable. There were 542 counties with complete PM-2.5 data in 1990, compared with 600 in 2003 -- an increase of just over 10 percent. The increase in monitored population was only about 9 percent on an actual basis, from 181.9 million in 2000 to 197.9 million in 2003 -- or only about 5 percent on a constant population basis, from 189.1 million in 2000 to 199.5 million in 2003. These modest increases in the size of the monitoring network could modestly reduce air quality progress statistics, but in general the two years are comparable.

As indicated in Figure 4-3, both the number of counties and population experiencing violations of the annual PM-2.5 NAAQS have declined between 2000 and 2003. The number of counties was nearly halved, while the decrease in associated population is much more modest, at 10-15 percent. Figure 4-4 shows that both the number of counties and population experiencing violations of the daily PM-2.5 NAAQS have declined by 15-25 percent between 2000 and 2003.

[37] As described in Section 2, two sets of population based statistics are considered in this study. The first set is based on the actual estimated population in each county in each data year. The second set is based on the assumption that the population of each county is held constant at its estimated 2004 population in each data year. This latter "constant population" statistic eliminates the confounding influence of both population increases and changing population distributions over time and allows for changes in air quality to be determined independent of changing population influences. The propriety of this can perhaps be best understood by considering what would happen in a county where air quality was unchanged, but population grew across the study period. In such a case, the population exposed to the air quality would increase and the resulting population-based trend statistics would imply a deterioration in air quality since the more recent exposed population is larger than the exposed population in earlier years, even though actual air quality during the period is unchanged. By holding population constant over time, the masking influence of population changes can be removed.

Figure 4-3. Violations of the Annual PM-2.5 NAAQS

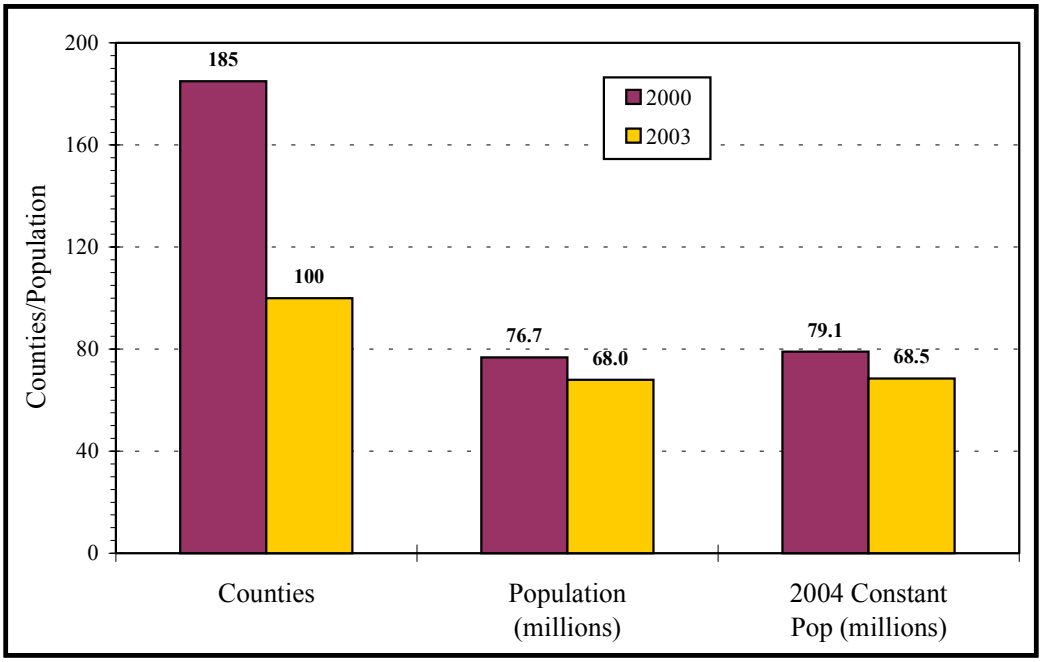
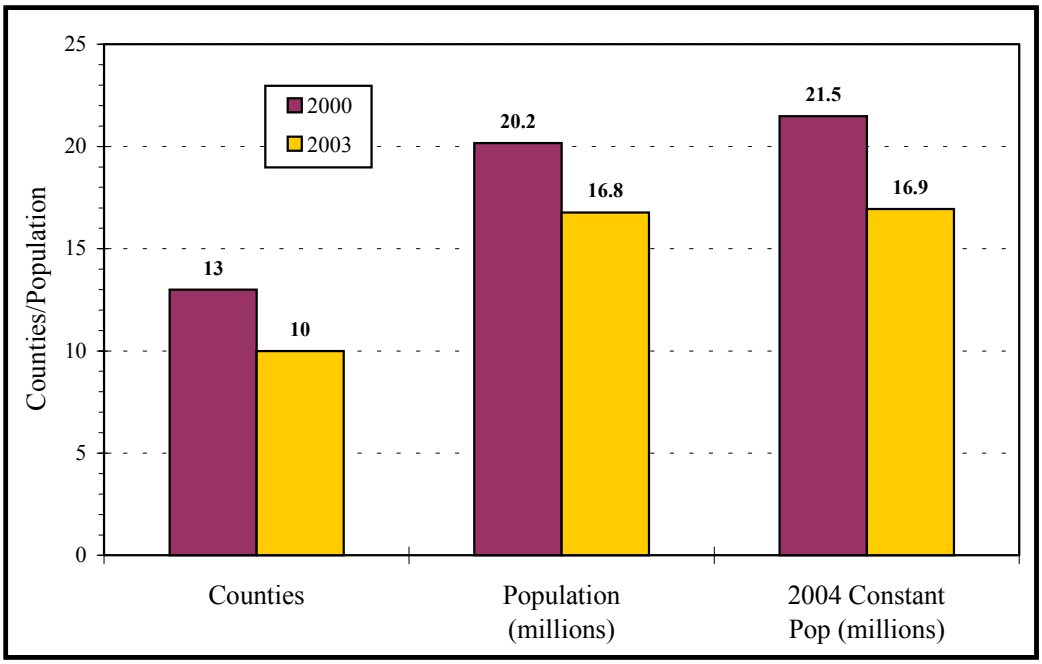


Figure 4-4. Violations of the Daily PM-2.5 NAAQS



While these improvements appear modest, it should be considered that they reflect only a three year interval for improvement, that improvement has occurred in an environment where there are yet no official PM-2.5 nonattainment designations, and that improvement prior to 2000 is not reflected in the statistics.

PM-2.5 noncompliance less sensitive to geography than is the case with PM-10. The bulk of geologic PM is larger than PM-2.5, so ambient PM-2.5 concentrations are less sensitive to the atmospheric concentrations of geologic PM. Whereas PM-10 violations were observed in portions of only 8 states in 2003, PM-2.5 violations were observed in portions of 24 states. Moreover, these states span the geography of the U.S. The county populations experiencing PM-2.5 NAAQS violations represent about 23 percent of the total U.S. population.

Figures 4-5 and 4-6 illustrate the change in three year average PM-10 concentrations since 1990. Ideally, these statistics would be generated solely for counties experiencing violations of the NAAQS (since the expected change in complying counties would naturally be less). However, the number of counties violating the standard is sufficiently low that when considered in the context of the range of variability in PM-10 across areas, results in a situation where a statistic based solely on counties violating the standard in any given year is quite unstable over time as counties move from noncompliance to compliance. Therefore, the data presented in Figures 4-5 and 4-6 are based on all counties with at least one complete data PM-10 monitor. While this approach results in a statistic that tends to underestimate improvement in counties experiencing violations of the standard, the statistic is stable as the underlying network of air quality monitors is reasonably constant.

As shown in Figure 4-5, three year annual average PM-10 concentrations have declined by about 30 percent on a county average basis, or about 25 percent on a population-weighted basis, between 1990 and 2003. Figure 4-6 presents similar data for three year average maximum daily PM-10, where concentrations have declined by about 20 percent for an average county or about 30 percent on a population-weighted basis.[38] To determine what effect changes in the underlying monitoring network might have on these statistics, a secondary analysis was conducted that included only monitors with complete data in all years between 1990 and 2003.

From the larger PM-10 air quality database, 116 such monitors were identified covering 85 counties in 29 states with a combined 2003 population of 55.6 million. Figures 4-7 and 4-8 present the associated change in three year average PM-10 concentrations since 1992 for these monitors. As shown in Figure 4-7, three year annual average PM-10 concentrations have declined by about 20 percent on both a county average and population-weighted average basis. Figure 4-8 shows almost identical improvements in three year average maximum daily PM-10.

[38] The daily NAAQS for PM-10 is actually based on the 99th percentile daily concentration, not the maximum (or 100th percentile) daily concentration, and all statistics in the study have been calculated on the basis of the 99th percentile data. The 99th percentile approach can allow as many as three daily readings per year to be excluded from the daily NAAQS statistic, but generally only one reading will be excluded for monitors collecting data less frequently than daily.

Figure 4-5. Average Annual PM-10 Concentrations

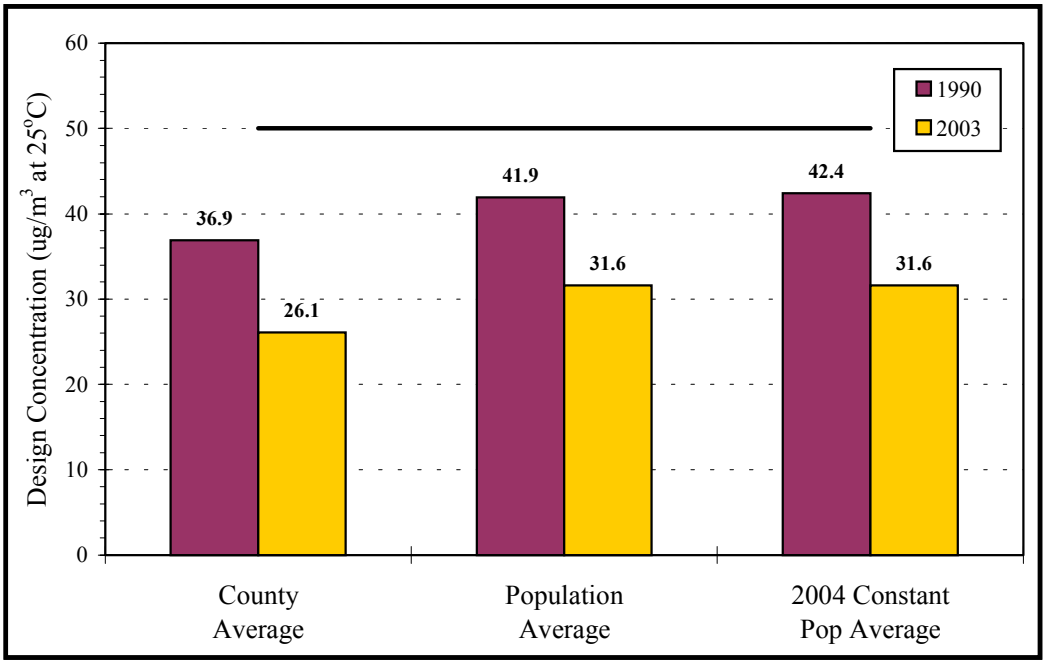


Figure 4-6. Average 99th Percentile Daily PM-10 Concentrations

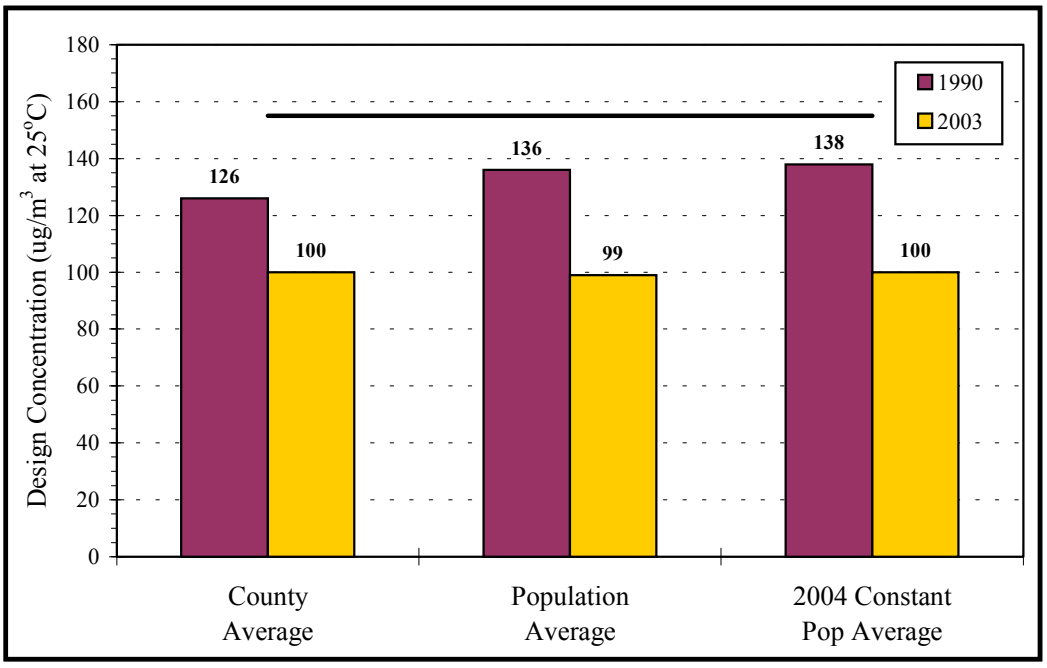


Figure 4-7. Average Annual PM-10 Concentrations for 116 Monitors with Complete Data in All Years from 1990 to 2003

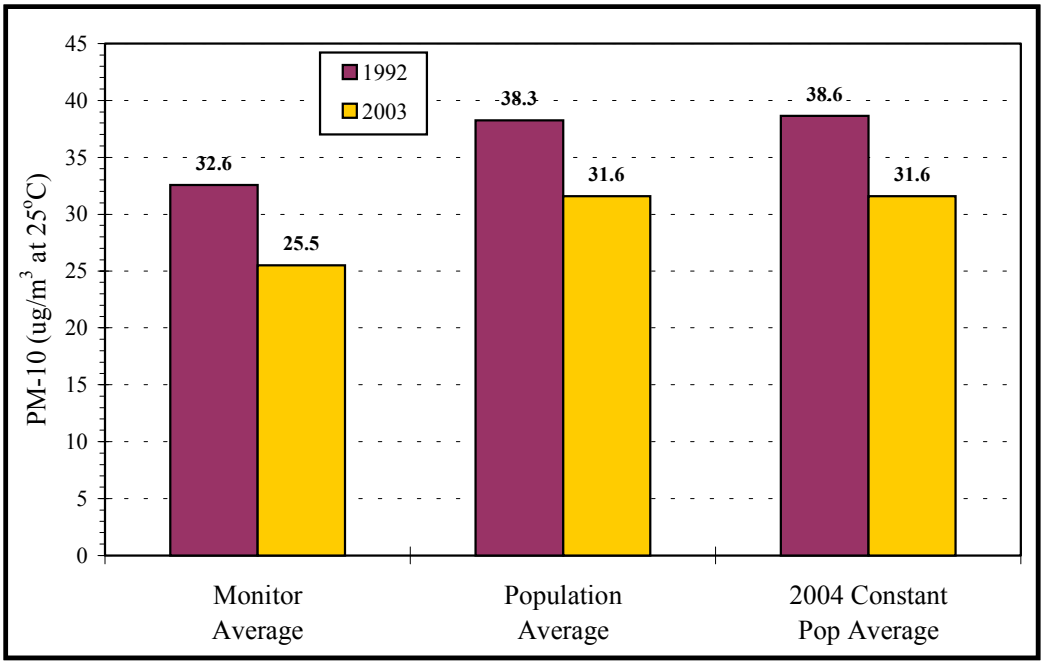
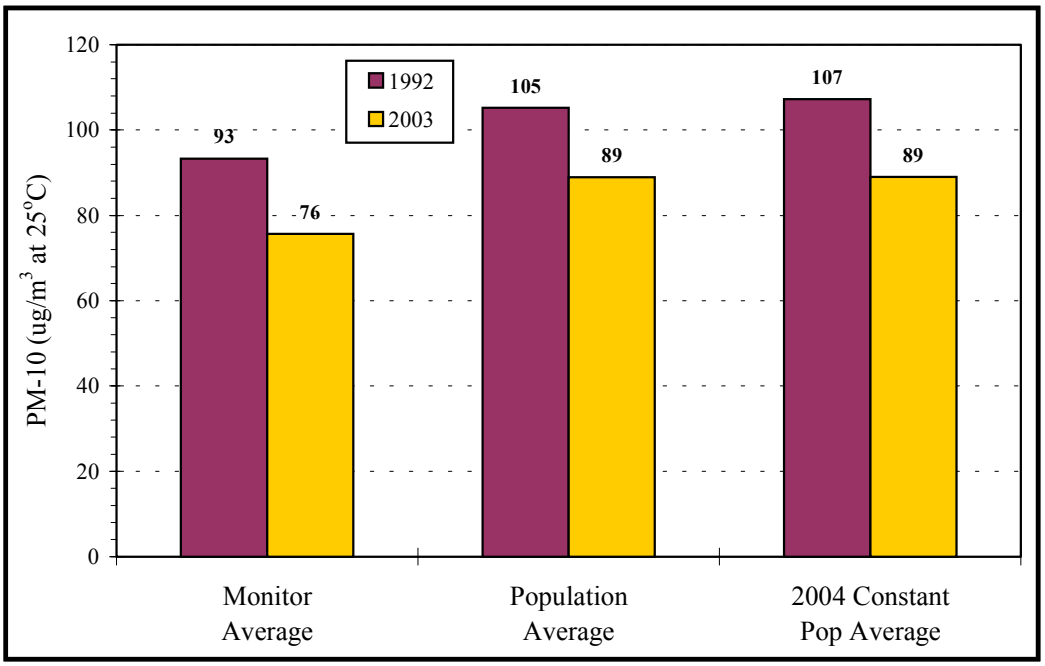


Figure 4-8. Average 99th Percentile Daily PM-10 Concentrations for 116 Monitors with Complete Data in All Years from 1990 to 2003



These results are a bit lower than those for the larger database, but are generally consistent given that the statistics are based on a 1992 baseline rather than 1990.[39]

Figures 4-9 and 4-10 illustrate the change in one year average PM-2.5 concentrations between 2000 and 2003. As discussed above, these statistics are necessarily less robust that those for PM-10 since the historic database available for analysis in limited. Nevertheless, as shown in the figures, modest improvements are indicated despite the limited analysis timeframe. Both annual average and maximum daily PM-2.5 concentrations have declined by 5-10 percent.[40] Although this level of improvement is not dramatic, it should be considered that only a three year interval is available for improvement, that improvement has occurred in an environment where there are yet no official PM-2.5 nonattainment designations, and that improvement prior to 2000 is not reflected in the statistics.

In summary, it is clear that although significant progress has been made, further improvement is required to fully attain the PM-10 NAAQS. The number of counties violating the PM-10 NAAQS has been reduced since 1990 by 60 percent for the annual NAAQS and 20 percent for the daily NAAQS. On a population-weighted basis, reductions have been more dramatic, at about 70 percent for the annual NAAQS and 30-40 percent for the daily NAAQS. PM-10 concentrations over the period have declined by 20-30 percent. PM-2.5 data are available for only a short period of time since the late 1990s, but these data do suggest a modest level of air quality improvement since that time. The number of counties and population violating the PM-2.5 NAAQS has been reduced since 2000 by 10-15 percent for the annual NAAQS and 15-25 percent for the daily NAAQS. PM-2.5 concentrations over the period have declined by 5-10 percent.

Additional, and significant, improvement in PM-10 and PM-2.5 air quality is almost certain for the foreseeable future as a substantial number of control measures targeting PM-10 and PM-2.5 emission reductions are being implemented. Among these are stringent PM or PM-related (e.g., NO_x and SO_2) reduction programs targeting motor vehicles, nonroad mobile equipment, and stationary sources such as electrical generating plants.

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[39] To confirm this, an identical analysis was conducted using a smaller dataset composed of monitors with complete data for all years between 1988 and 2003. Since this dataset begins in 1988, a three year average can be calculated for 1990 data that can be compared directly to the averages developed for the larger dataset of all complete data PM-10 monitors. This smaller dataset includes data from 44 monitors covering 36 counties in 22 states with a combined 2003 population of 18.3 million. Data for this dataset are not presented in this report in favor of the similar data for the larger 116 monitor dataset. However, the resulting three year average improvement statistics calculated for the smaller dataset were in all cases similar to, but *larger* than, those for the all monitor dataset. Therefore, the statistics for the larger dataset are appropriately representative of PM-10 trends.

[40] The daily NAAQS for PM-2.5 is actually based on the 98th percentile daily concentration, not the maximum (or 100th percentile) daily concentration, and all statistics in the study have been calculated on the basis of the 98th percentile data. The 98th percentile approach can allow as many as seven daily readings per year to be excluded from the daily NAAQS statistic, but generally only one to three readings will be excluded for monitors collecting data less frequently than daily.

Figure 4-9. Average Annual PM-2.5 Concentrations

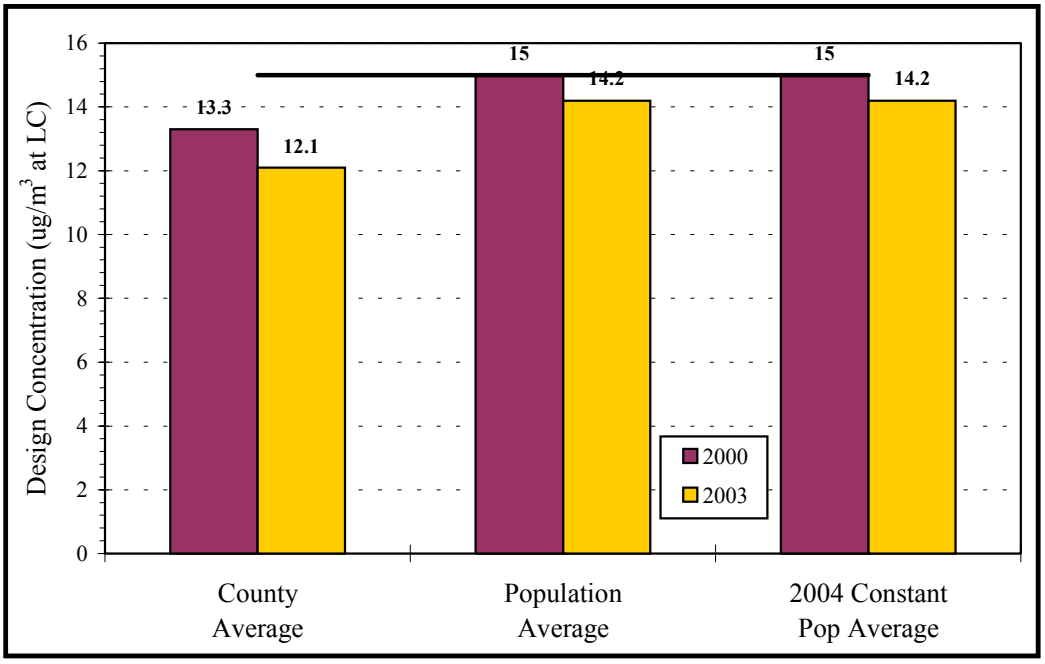
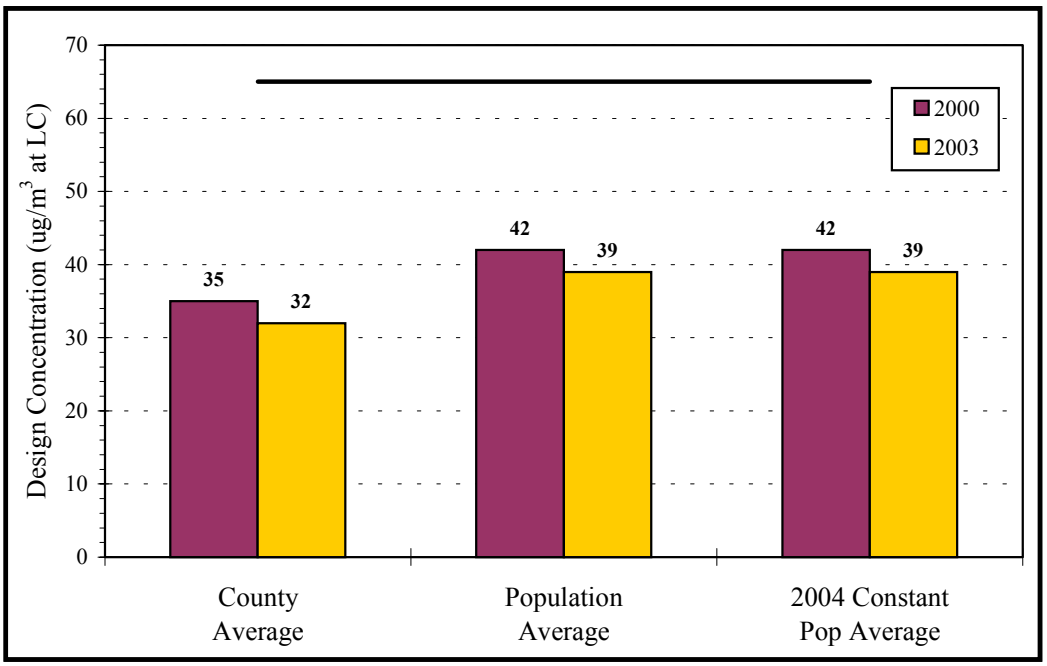


Figure 4-10. Average 98th Percentile Daily PM-2.5 Concentrations



The remainder of the material presented in this section consists of more detailed trend data that support the various statistics already presented. These materials are provided in the interest of allowing a more complete assessment of the analysis results generated for this study, but are not intended to add significant additional information to the summary statistics already presented. Therefore, each of the presented charts is discussed only briefly to provide an appropriate context for review.

Figures 4-11 and 4-12 provide an overview of the PM air quality database and the extent of its coverage. Data are presented only for monitors with complete data. As indicated, both the PM-10 and PM-2.5 monitoring networks were extensive in 2003, but data for PM-2.5 is nonexistent prior to 1998 and data for PM-10 is nonexistent prior to 1983.

Figures 4-13 and 4-14 present trend data for the number of counties and population violating the PM-10 NAAQS. These figures show that the fraction of counties experiencing violations are a small subset of the overall monitoring network (5-10 percent in 2003) and that the number of counties violating the NAAQS declined even while the overall number of air quality monitors was increasing.

Figures 4-15 and 4-16 present trend data for the number of counties and population violating the PM-2.5 NAAQS. As was the case with PM-10, these figures show that the fraction of counties experiencing violations are a relatively modest subset of the overall monitoring network and that the number of counties violating the NAAQS declined even while the overall number of air quality monitors was increasing.

Figure 4-17 presents trend data for measured PM-10 concentrations. Figure 4-18 presents similar data, but for a restricted subset of monitors with complete data in each year from 1990 to 2003. Since three years of data are required to determine NAAQS compliance, data for the restricted subset is only comparable to that presented in Figure 4-17 for data years 1992-2003. Finally, Figure 4-19 presents trend data for measured PM-2.5 concentrations. Although compliance with the PM-2.5 NAAQS is based on three years of monitored data, the data presented in Figure 4-19 reflect only single data years due to the very restricted timeframe for which PM-2.5 data are available.

Figure 4-11. PM Monitoring Network - Complete 1 Year Data Coverage

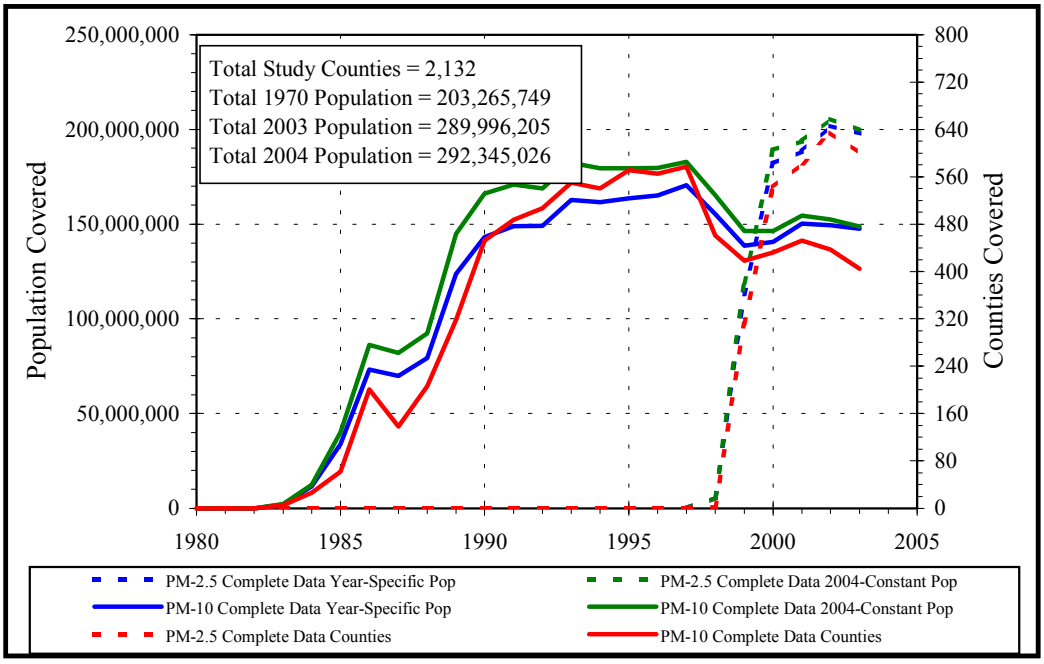


Figure 4-12. PM Monitoring Network - Complete 3 Year Data Coverage

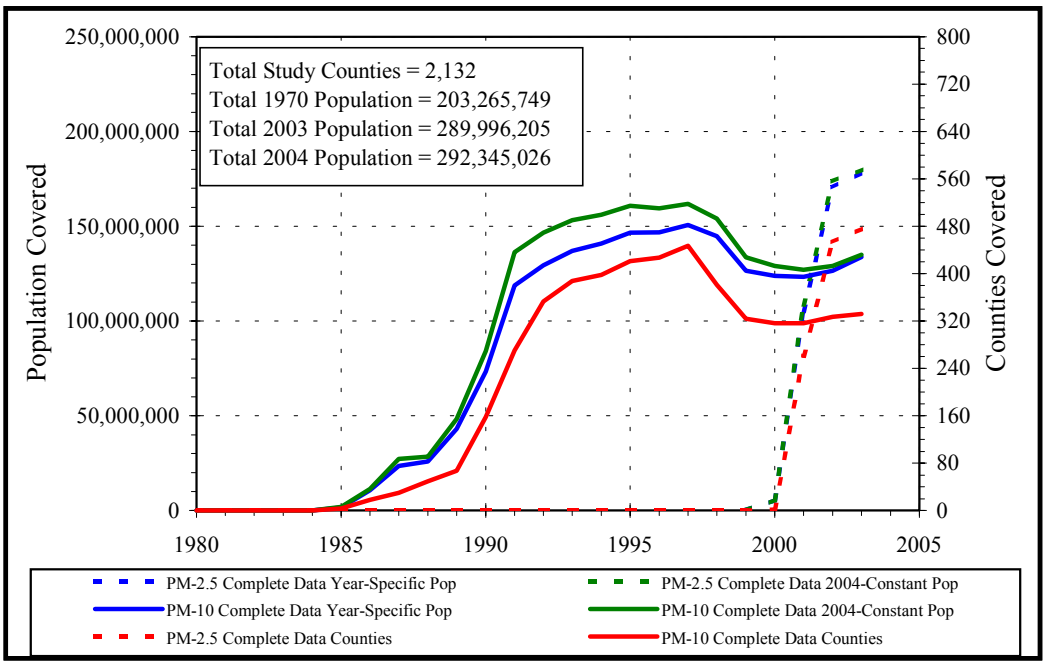


Figure 4-13. PM-10 NAAQS Violations - 3 Year Averages

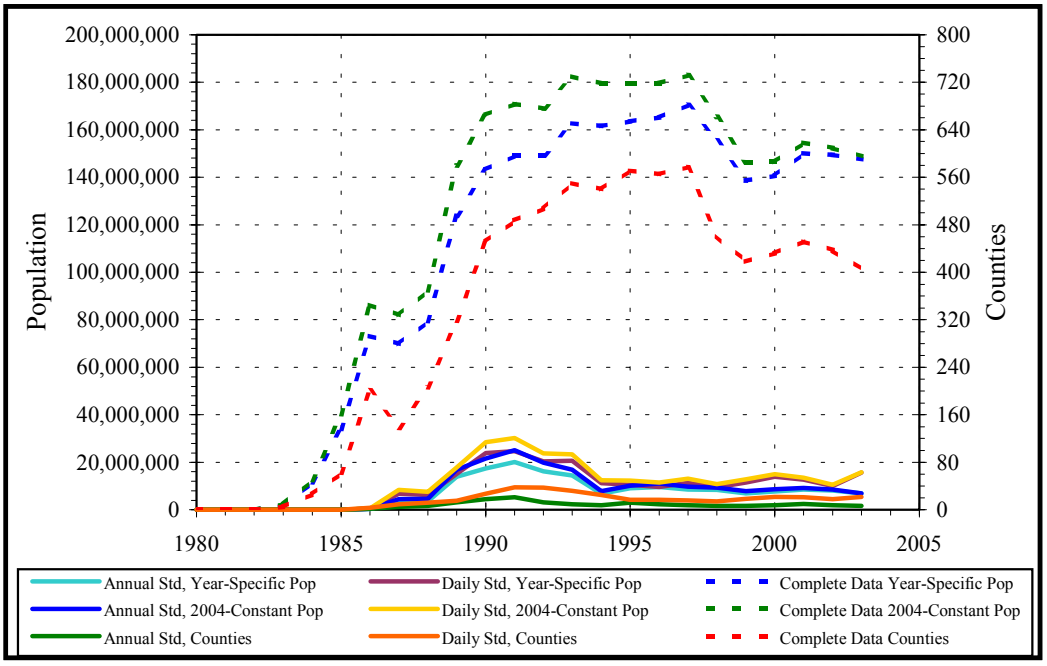


Figure 4-14. Fraction of PM-10 Data Exhibiting NAAQS Violations

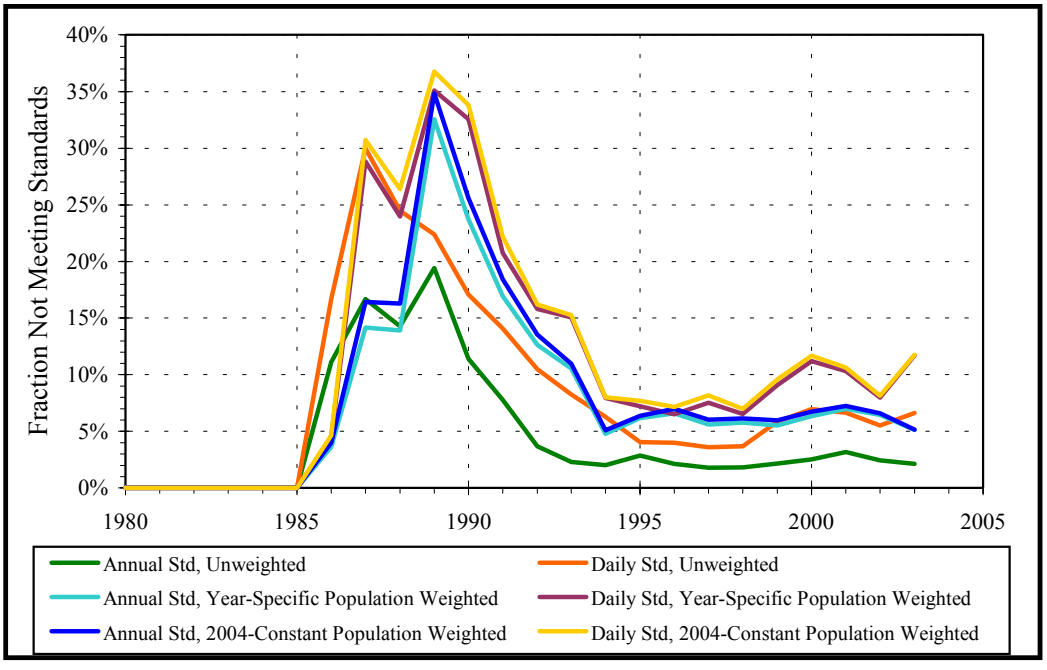


Figure 4-15. PM-2.5 NAAQS Violations - Single Year Data

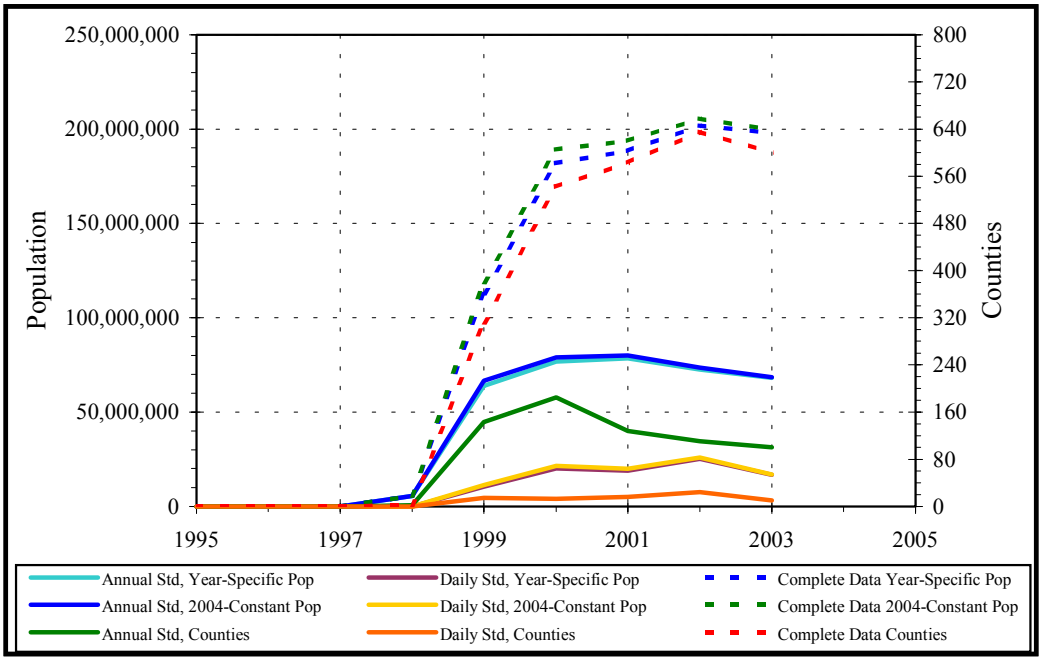


Figure 4-16. Fraction of PM-2.5 Data Exhibiting NAAQS Violations

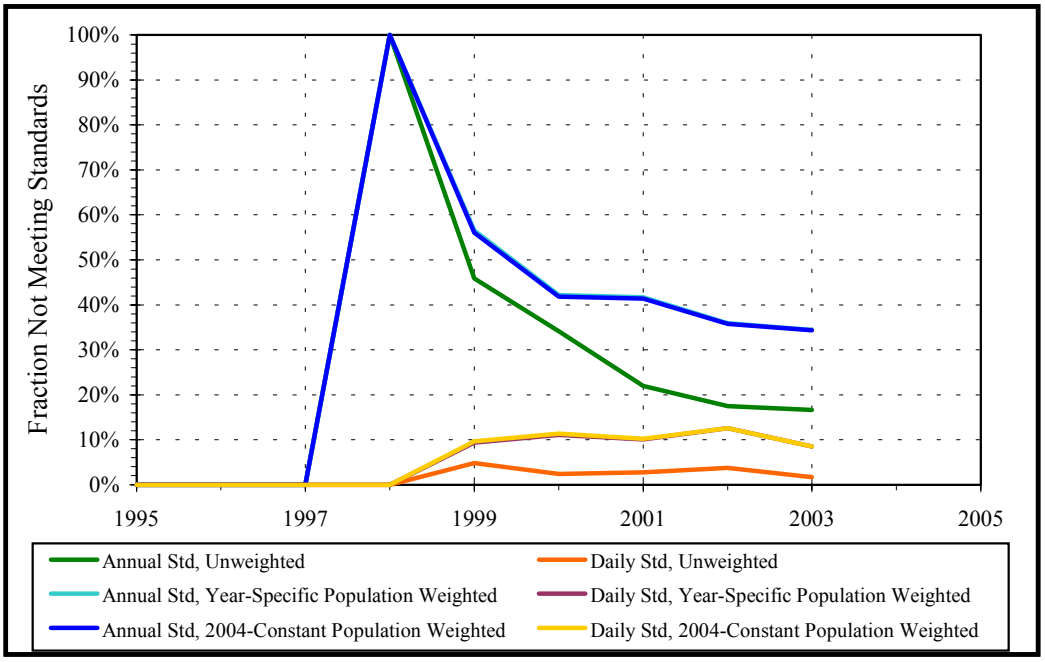


Figure 4-17. PM-10 Concentrations - Three Year Averages

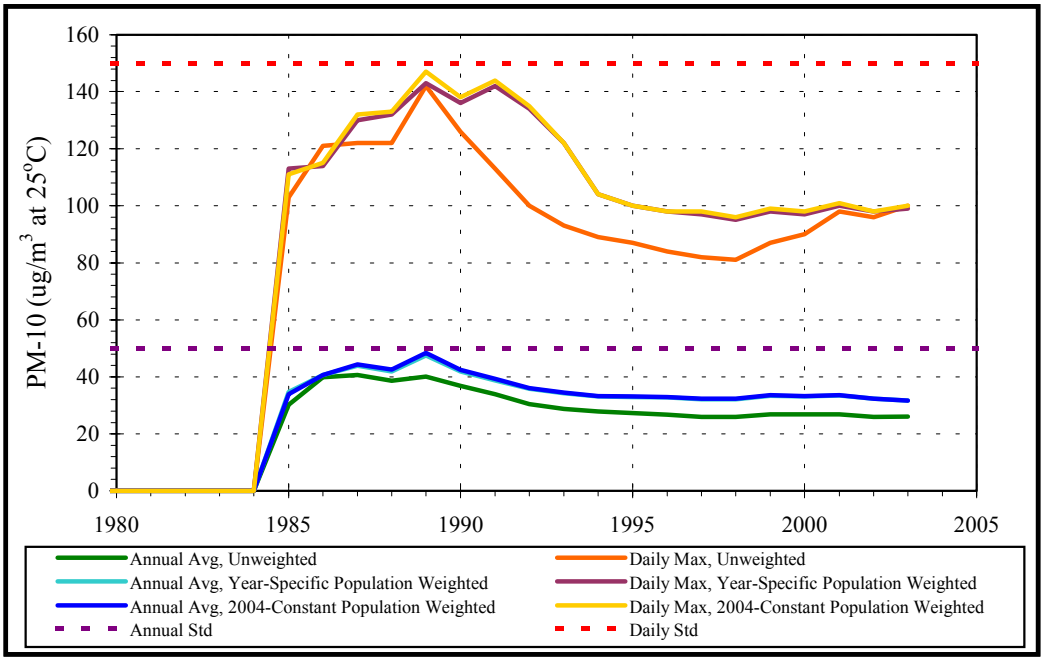


Figure 4-18. PM-10 Concentrations for 116 Monitors with Complete Data in All Years from 1990 to 2003

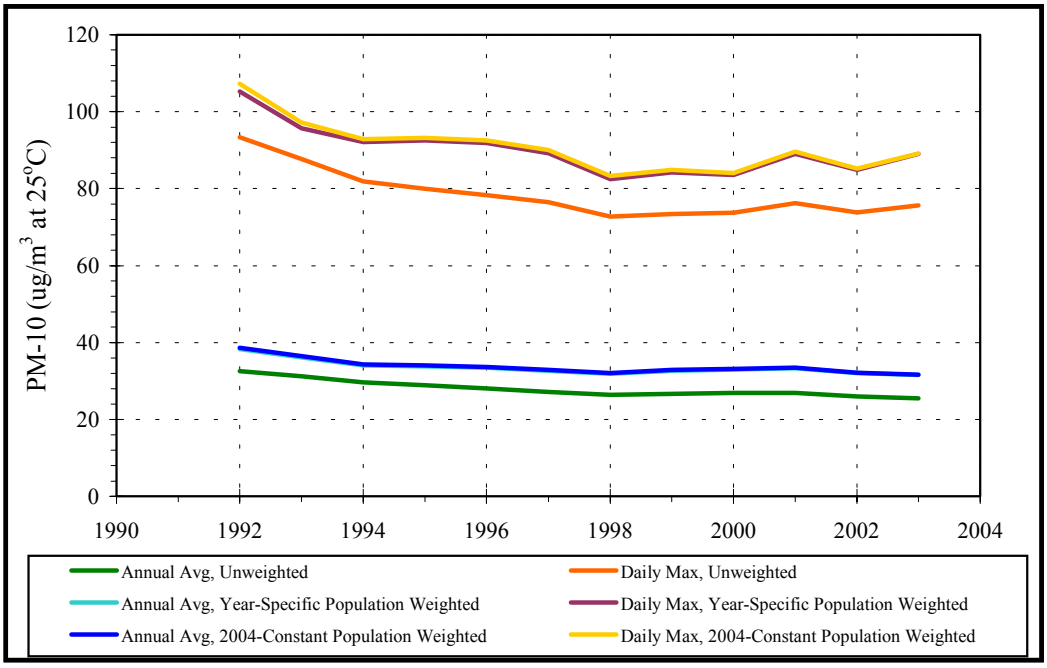
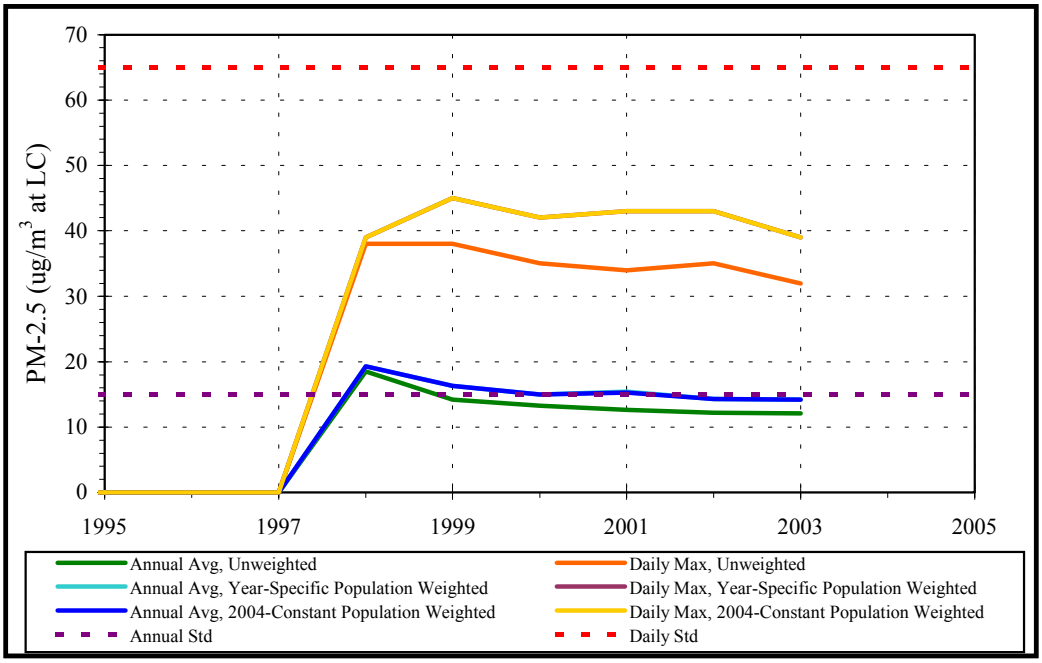


Figure 4-19. PM-2.5 Concentrations - Single Year Data



5. Lead

Excluding a very small number of areas with localized emissions issues, atmospheric emissions of lead have been virtually eliminated. Through the mid-1980s, motor vehicles were the main emitters of atmospheric lead. Prior to the introduction of catalytic converters to control motor vehicle emissions of hydrocarbons and carbon monoxide in the mid-1970s, tetraethyl lead was commonly used to increase the octane value of gasoline. Because lead degrades the performance of catalytic systems, unleaded gasoline was introduced concurrent with the introduction of motor vehicle catalytic conversion technology. Over a 20 year period that culminated in the mid-1990s, the quantity of leaded gasoline sold in the U.S. declined from an approximate 100 percent market share to zero. At the same time that unleaded gasoline was becoming the dominant market commodity, the lead content of leaded gasoline was also reduced dramatically. Commensurate with this phase-out, lead concentrations in the ambient air have declined dramatically.

Transportation sources are now only minor contributors to atmospheric lead emissions. The largest sources of lead emissions currently are metal processing industries such as smelters and battery manufacturers. At this time, there are only three areas in the U.S. that experience violations of the lead NAAQS, and these violations are very localized around industrial sources. Portions of two counties in Missouri (Iron and Jefferson Counties) and portions of one county in Montana (Lewis and Clark County) constitute the only areas of the U.S. currently classified as nonattainment for the lead NAAQS.[41] The total population exposed to these violations is estimated by the EPA to be about 10,000[42] -- about 0.003 percent of the total U.S. population, or approximately 1 out of every 30,000 citizens.

Figure 5-1 illustrates the dramatic improvement in ambient lead concentrations in the U.S. since 1983.[43] Although even more dramatic reductions have occurred since the first introduction of unleaded gasoline in the mid-1970s, ambient lead concentrations have declined by 94 percent on average since 1983. Moreover, average ambient concentrations now approach the limits of detectability. As indicated in Figure 5-1, the maximum design concentration measured at almost all ambient monitors is less than 5 percent of the allowable NAAQS -- down from about 70 percent of the allowable NAAQS in 1983.[44] Independent confirmatory evidence of these dramatic improvements is offered in medical surveys taken between 1976 and 1991, which found a nearly 80 percent reduction in lead levels in the bloodstreams of tested subjects.[45] This period spans the time from the initial imposition of the NAAQS and widespread reductions in lead emissions and the use of lead for purposes such as soldering.

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[41] http://www.epa.gov/oar/oaqps/greenbk/lncs.html

[42] http://www.epa.gov/oar/oaqps/greenbk/lnsum.html

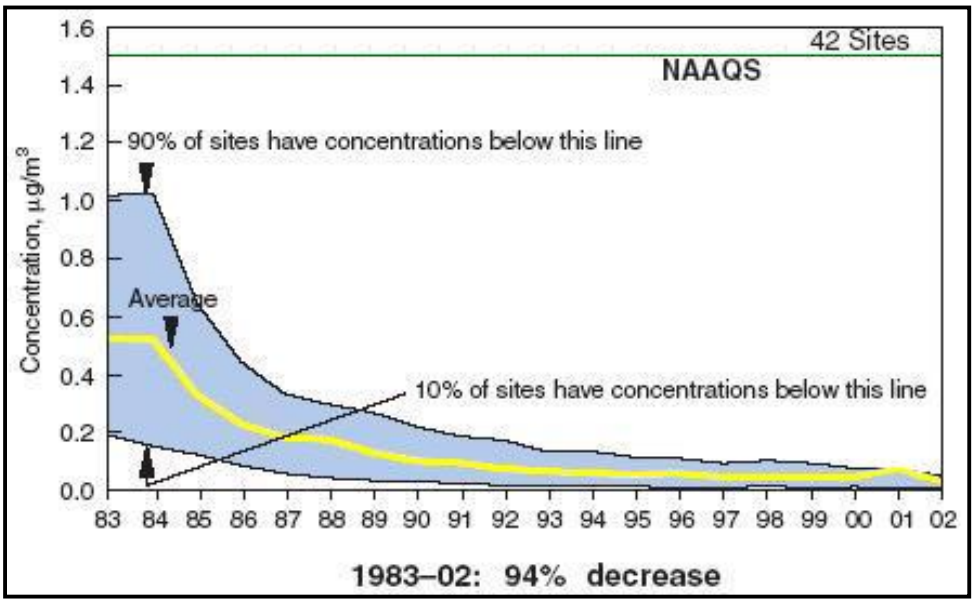
[43] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

[44] As used throughout this study, design concentration indicates the specific concentration measurement used to determine compliance with the NAAQS.

[45] http://www.epa.gov/oar/oaqps/greenbk/o3co.html

Even though industrial sources now constitute the primary emissions sources of ambient lead, the level of emission reductions from these sources should also not be underestimated. EPA estimates that emissions of lead from lead smelters declined by approximately 91 percent from 1970 to 1993.[46] During the same period, emissions associated with solid waste disposal declined by about 76 percent. Nevertheless, because of even more dramatic emission reductions in the transportation sector, industrial sources now constitute about 80 percent of total ambient lead emissions. In light of this fact, and more specifically in response to the localized NAAQS violations previously discussed, the EPA is continuing to work with affected states to bring all areas of the U.S. into compliance. As a result of these efforts, ambient lead concentrations continue to decline, with reductions since 1993 approaching 60 percent. While progress with localized issues is likely to continue for the foreseeable future, the overwhelming majority of Americans breathe air that is not only in compliance with the lead NAAQS, but which contains lead at levels that approach minimum detectability limits.

Figure 5-1. Trend in Ambient Lead from 1983 to 2002 (Maximum Quarterly Average Concentration)[47]



[46] http://www.epa.gov/oar/oaqps/greenbk/o3co.html

[47] The figure is extracted without change from http://www.epa.gov/airtrends/lead2.html

6. Carbon Monoxide

CO emissions result from the incomplete combustion of carbon-based fuels such as gasoline, diesel fuel, home heating oil, natural gas, coal, and wood. The largest emissions of CO result from transportation-related fuel combustion, but the overall level of emissions from these sources has declined dramatically since the advent of emission standards for motor vehicles and, more recently, nonroad equipment. Despite dramatic increases in miles of travel, the EPA estimates that CO emissions from transportation sources have declined by over 40 percent since 1983.[48]

The highest levels of ambient CO generally occur during colder months, when typical meteorological conditions (i.e., temperature inversions[49]) reduce the volume of air available for diluting emissions. Since maximum inversions occur during the hours after midnight, the highest ambient CO concentrations typically occur during the very early morning hours when human exposure is reduced. Elevated levels of CO can also occur in localized areas, or "hot spots," such as alongside congested roadways or intersections.

Following the passage of the Clean Air Act amendments of 1990, the EPA reviewed and reclassified areas on the basis of measured ambient CO data. Through that process, a total of 42 areas with a combined population of over 60 million were identified as not meeting the CO NAAQS.[50] Although nine of these areas continue to be classified as not meeting the NAAQS, *none* experienced violations of the standard during the 2001-2002 data period.[51] However, three areas not among the 42 classified nonattainment areas did experience violations during the same period. In each case, however, violations were due to localized conditions that have already been, or are being addressed. A considerable number of violations were experienced in Birmingham, Alabama in 2001 and early 2002. According to the EPA, these violations were associated with specific stationary source permitting issues that were resolved at the end of May 2002.[52] No subsequent violations have been observed. Several violations of the NAAQS were also observed in Weirton, West Virginia in 2002. The EPA indicates that all of the violations are attributable to a single stationary source. Finally, violations of the CO NAAQS were also

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[48] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

[49] A temperature inversion is a condition where a layer of warm air acts as a barrier (or "lid") against the movement of colder air below it. As inversion height decreases, the amount of air available to absorb emissions decreases and ambient concentrations increase.

[50] http://www.epa.gov/oar/oaqps/greenbk/cnsum.html

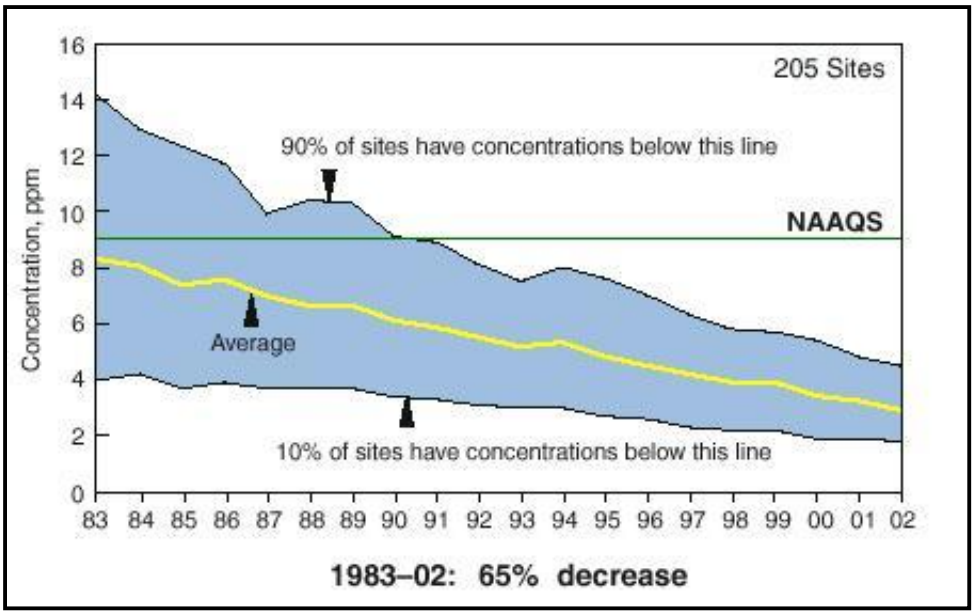
[51] To be reclassified to attainment of an NAAQS, an area previously classified as nonattainment must fulfill a number of requirements *in addition to* actually meeting the standards. These are primarily administrative requirements designed to ensure that the area maintains its attainment status over time. Since a considerable period of time can pass between actually meeting an NAAQS and fulfilling the additional reclassification requirements, it is common for areas that have achieved compliance with numerical NAAQS requirements to continue to be classified as nonattainment for some time.

[52] U.S. EPA, Air Quality Trends and Analysis Group, *Air Quality Data Update, 2001-2002 Carbon Monoxide*, September 9, 2003.

experienced in Calexico, California in 2001 and 2002. This is a Mexican border city, located directly opposite Mexicali, Mexico, for which trans-border issues present unique challenges. The combined metropolitan population of these three areas is about 300,000 people, but only about 40,000 in the two areas where violations have not yet been definitively resolved. While the population actually exposed to the localized problems is only a subset of either, the full population estimate for the two potentially continuing areas of violation (i.e., 40,000) represents about 0.01 percent of the total U.S. population -- or approximately 1 out of every 7,000 citizens.

Figure 6-1 illustrates the dramatic improvement in ambient CO concentrations in the U.S. since 1983.[53] Although even more dramatic reductions have occurred since the first introduction of CO emission standards for motor vehicles in the mid-1970s, ambient CO concentrations have declined by 65 percent on average since 1983. Moreover, average ambient design concentrations are now only about one-third of the NAAQS. As indicated in Figure 6-1, the maximum concentration measured at almost all ambient monitors is about 50 percent of the allowable NAAQS -- down from about 100 percent of the allowable NAAQS in 1990 and over 150 percent

Figure 6-1. Trend in Ambient Carbon Monoxide from 1983 to 2002 (Annual 2nd Highest 8-Hour Average Concentration)[54]



[53] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

[54] The figure is extracted without change from U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

of the NAAQS in 1983.[55] While progress with localized issues (as discussed above) is likely to continue for the foreseeable future, the overwhelming majority of Americans breathe air that is in compliance with the CO NAAQS.

[55] There are actually two NAAQS for carbon monoxide, one based on concentrations measured over one hour and one based on concentrations measured over eight hours. However, NAAQS violations are exclusively violations of the eight hour standard, so that the presented statistics and numerical relations are specific to the eight hour standard. It should also be recognized that a violation of the CO NAAQS occurs only on the *second* exceedance of the numerical standard in a given year. Therefore, statistics are generally based on the second highest measured concentration and the term maximum concentration as used here, actually signifies the second highest measured concentration.

7. Nitrogen Dioxide

A small fraction of NO_2 is emitted directly as a byproduct of combustion, but most NO_2 forms in the atmosphere from the more common combustion byproduct nitrogen oxide (NO).[56] In addition to the direct health effects of NO_2, both NO and NO_2 are highly reactive compounds that play significant roles in the formation of ozone (see Section 3), particulate matter (see Section 4), acid rain, and visibility impairment. The deposition of atmospheric nitrogen compounds into marine environments can contribute to excessive algae growth and oxygen depletion, conditions that can threaten marine life. Reduction in the ambient concentration of NO_2 lessens both direct and indirect impacts.

About 55 percent of national NO and NO_2 emissions are associated with fuel combustion in transportation sources, including both motor vehicles and nonroad equipment.[57] Another 40 percent results from fuel combustion in stationary sources, primarily at electrical generating units (i.e., power plants), but also in residential and commercial heating units. The remaining 5 percent is emitted as a byproduct of industrial processes. Since the control of nitrogen emissions has been targeted as a key mechanism in the improvement of a wide range of environmental issues, substantial emission reductions in both the transportation and stationary source sectors are expected for the foreseeable future. Strict emission standards for both motor vehicles and nonroad engines take effect in the latter half of this decade, while electrical generating units have already been subject to significant reductions under federal Acid Rain Program provisions and are targeted for additional reductions under the EPA's "NO_x SIP Call" rule aimed at reducing ambient ozone and particulate matter concentrations.

There are currently no areas of the U.S. in violation of the NO_2 NAAQS. Historically, the only area to violate the NAAQS was the Los Angeles metropolitan area, but that area was redesignated to attainment in 1998. Nevertheless, as illustrated in Figure 7-1, significant reductions in ambient NO_2 concentrations in the U.S. have occurred since 1983.[58] These reductions, estimated at just over 20 percent by the EPA, have served to increase the margin by which all areas of the U.S. comply with the NAAQS. Average ambient concentrations are now less than 40 percent of the NAAQS and, as indicated in Figure 7-1, the design concentration

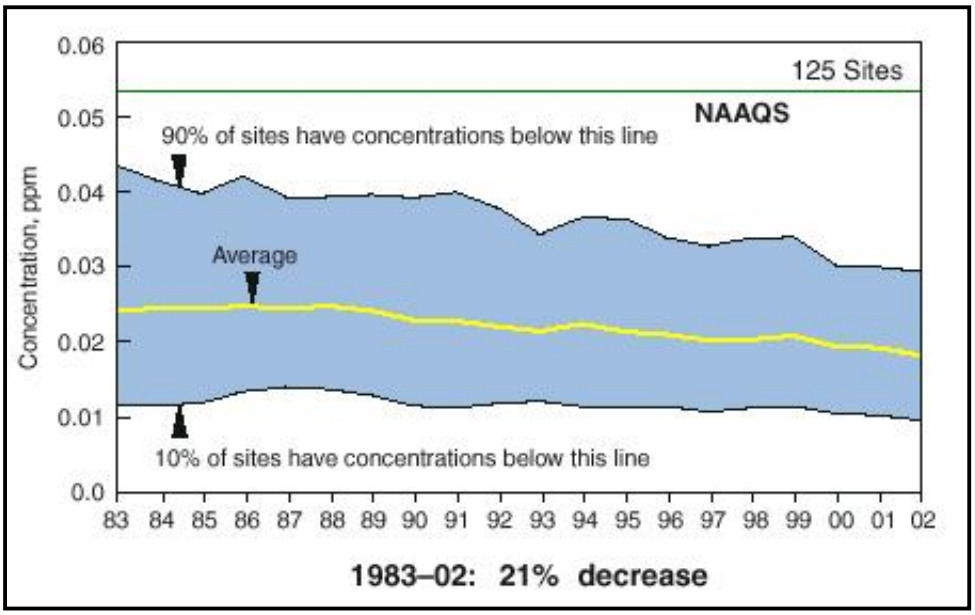
[56] Both NO and NO_2, typically referred to in combination as oxides of nitrogen (NO_x), are formed through the reaction of atmospheric nitrogen and oxygen. Although molecular nitrogen and oxygen are stable at atmospheric conditions, they will react in the high temperature and high pressure environments typically associated with fuel combustion. As an intermediate reaction product requiring less oxygen, NO formation is typically much greater than NO_2 formation during the initial reaction process. However, once emitted, most NO undergoes additional oxidation in the atmosphere to form NO_2. As a result, emissions are generally characterized in terms of NO_x rather than NO_2, as NO_x is a better indicator of the atmospheric NO_2 significance of those emissions. Nitrogen present as an impurity in fuel can also contribute to NO_x formation, but even nitrogen-free fuels produce NO_x through the influence of combustion on ambient air. Since both the nitrogen and oxygen that produce NO_x are primarily derived from the air, the type fuel being combusted is generally of lesser influence on NO_x formation than the combustion process itself.

[57] http://www.epa.gov/airtrends/nitrogen2.html

[58] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

measured at almost all ambient monitors is less than 60 percent of the NAAQS -- down from about 80 percent of the NAAQS in 1983.[59] Given that currently adopted regulations will further reduce NO_2 emissions from both transportation and stationary sources over the next decade and beyond, it is virtually certain that all Americans will continue to breathe air that is in compliance with the NO_2 NAAQS for the foreseeable future.

Figure 7-1. Trend in Ambient Nitrogen Dioxide from 1983 to 2002 (Annual Average Concentration)[60]



[59] As used throughout this study, design concentration indicates the specific concentration measurement used to determine compliance with the NAAQS.

[60] The figure is extracted without change from U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

8. Sulfur Dioxide

The overwhelming majority of SO_2 emissions are associated with stationary source fuel combustion.[61] The EPA estimates that such sources are responsible for over 85 percent of all emitted SO_2, with electrical generating units (i.e., power plants) constituting the largest single source type.[62] About 10 percent of SO_2 emissions result from industrial processes, with transportation sources contributing most of the remainder. Substantial SO_2 emission reductions have occurred over the last ten years, driven in large part by federal Acid Rain Program provisions. The EPA estimates that total SO_2 emissions have declined by over 30 percent since 1993.[63]

There are currently 18 areas of the U.S. that are classified as violating the SO_2 NAAQS. These areas are estimated by the EPA to have a combined population of about 3 million.[64] However, recent EPA data indicates that there were no violations of the SO_2 NAAQS in either 2001 or 2002.[65,66] As a result, all Americans are breathing air that is in compliance with the SO_2 NAAQS. As illustrated in Figure 8-1, the EPA estimates that ambient SO_2 concentrations in the U.S. have declined by over 50 percent since 1983.[67] These reductions have served to increase the margin by which all areas of the U.S. comply with the NAAQS. As indicated in Figure 8-1, average ambient concentrations are now less than 20 percent of the NAAQS and the annual average SO_2 concentration at almost all ambient monitors is less than about one-third of the NAAQS -- down from about 60 percent of the NAAQS in 1983. Given expected additional reductions in SO_2 emissions, it is almost certain that universal compliance with the SO_2 NAAQS will continue for the foreseeable future.

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[61] Unlike NO_2 emissions, which are relatively insensitive to the specific fuel being combusted (see Section 7), SO_2 emissions primarily result from sulfur contained within the combustion fuel. Therefore, SO_2 emissions are highly sensitive to fuel sulfur content. The sulfur content of coal and heavier oils tends to be substantially higher than that of lighter fuels derived from petroleum and other hydrocarbons, so the primary SO_2 emitters are coal and heavy oil burning combustion sources.

[62] http://www.epa.gov/airtrends/sulfur2.html

[63] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

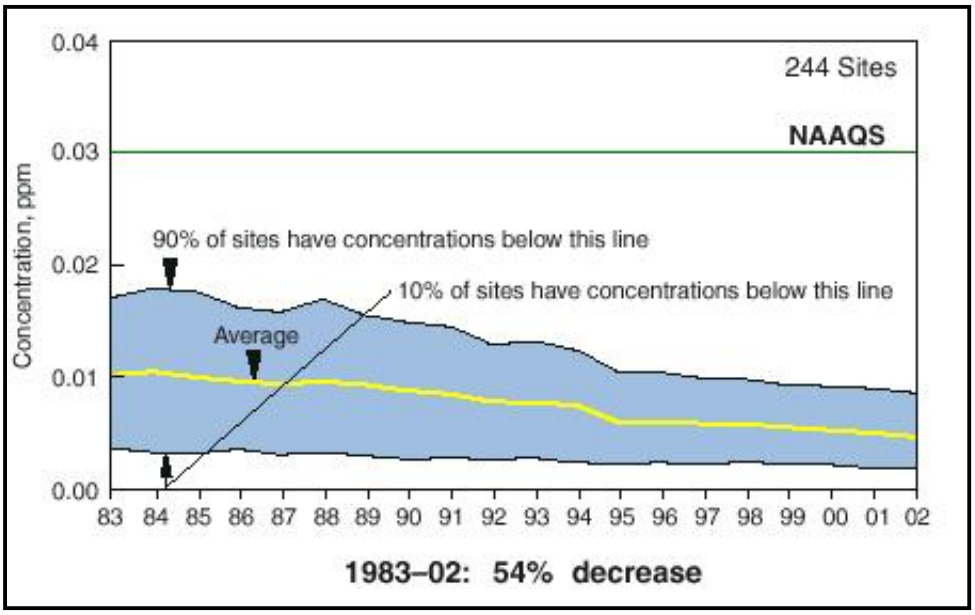
[64] http://www.epa.gov/oar/oaqps/greenbk/snsum.html

[65] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003 and http://www.epa.gov/airtrends/sulfur2.html.

[66] To be reclassified to attainment of an NAAQS, an area previously classified as nonattainment must fulfill a number of requirements *in addition to* actually meeting the standards. These are primarily administrative requirements designed to ensure that the area maintains its attainment status over time. Since a considerable period of time can pass between actually meeting an NAAQS and fulfilling the additional reclassification requirements, it is common for areas that have achieved compliance with numerical NAAQS requirements to continue to be classified as nonattainment for some time.

[67] U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

Figure 8-1. Trend in Ambient Sulfur Dioxide from 1983 to 2002 (Annual Average Concentration)[68]



[68] The figure is extracted without change from U.S. EPA, *Latest Findings on National Air Quality, 2002 Status and Trends*, EPA 454/K-03-001, August 2003.

9. EGU Emissions

Electric generating units (EGUs)[69] represent only one of several categories of sources that contribute significantly to atmospheric emissions in the U.S. Other such sources include industrial and commercial fuel combustion, industrial processing and manufacturing operations, motor vehicle and nonroad equipment operation, agricultural activity, and natural occurrences such as fires and wind-driven erosion. While the main focus of this study is an analysis of air quality monitoring data and not a detailed investigation of the specific sources contributing to that data, a brief overview of emissions trends for one major source category may help to validate the improvement trends revealed in the air quality data. If air quality is improving, then the emissions that contribute to potential air quality concerns should be declining. While the indicated improvement in air quality should serve as prima facie evidence that atmospheric emissions are declining, a focused look at one example source may help to more firmly establish the foundation for the observed air quality progress.

Selecting EGUs as the focus of the emissions overview is <u>not</u> intended to imply that such sources bear an uncommon responsibility for air quality concerns. As indicated above, there are a variety of contributing sources. EGUs simply represent a convenient source for two reasons. First, they are relatively well understood compared to other sources, since both emission rates and operating characteristics are subject to considerable regulation and oversight. Second, their emission species of primary significance are fewer in number than many of the other source types -- with NO_x and SO_2 emissions dominating all other species. In short, associated emissions data is both well documented and focused.

Like most sources, EGUs do emit the full range of air pollutants that can lead to violations of the NAAQS. EGUs are major sources of NO_x, estimated in a recent EPA analysis to contribute between 20 and 25 percent of total atmospheric NO_x.[70] NO_x emissions are the sole determinant of nitrogen dioxide air quality and one of the two main emissions determinants of ozone air quality. EGUs are relatively insignificant sources of the other major ozone emissions determinant, volatile organic compounds (VOC) -- estimated in the same EPA emissions analysis to be responsible for less than one-half of one percent of VOC emissions. EGUs are also insignificant contributors to carbon monoxide (CO) air quality, with the same EPA analysis indicating an EGU CO emissions share that is also less than one-half of one percent. EGUs are, however, the largest contributor to atmospheric sulfur dioxide (SO_2) emissions, the sole determinant of SO_2 air quality. The contribution of EGUs to particulate air quality is also relatively minor, but that contribution is dominated by the sulfates and nitrates that form from emissions of NO_x and SO_2. As a result, EGU NO_x and SO_2 trends serve as reasonable surrogates

[69] In non-technical terms, EGUs can be generally thought of as power plants. However, in recent years, electricity production has become considerably more diverse, with a substantial number of independent power producers delivering electricity to the U.S. market through the operation of smaller gas turbines and internal combustion engines. In recognition of this, the more expansive term EGU has come into common use.

[70] http://www.epa.gov/ttn/chief/trends/trends01/trends2001_aug2003.zip

for EGU PM trends. It is therefore possible to get a nearly complete overview of EGU emission impacts by focusing solely on emissions of NO_x and SO_2.

Like most emissions sources, EGUs have also been the target of substantial regulatory activity over the last 30-plus years. Through the permitting and major modification provisions of the Clean Air Act, EGUs have been subject to progressively more stringent emission standards since 1970. In more recent years, as the influence of NO_x on ambient ozone concentrations and the significance of ambient particulate on air quality, acid rain, and visibility have become better understood, a series of additional regulatory programs targeting EGU emissions have been instituted. The EPA's Acid Rain Program instituted significant controls on both NO_x and SO_2 emissions from EGUs -- through an initial (Phase I) set of controls that began in 1995 for SO_2 and 1996 for NO_x and a second (Phase II) set of controls that began in 2000. An aggressive set of ozone season NO_x controls is currently being implemented in 22 eastern states and the District of Columbia through the EPA's NO_x SIP Call Rule. By 2007, this rule is expected to reduce annual ozone season NO_x emissions from EGUs by about 1 million tons. Finally, in January of this year, EPA proposed the Clean Air Interstate Rule (CAIR), which (if adopted) will require additional EGU NO_x and SO_2 reductions through 2015 and beyond in 29 middle and eastern states and the District of Columbia. When fully implemented, additional annual emission reductions of 5.5 million tons of SO_2 and 1.8 million tons of NO_x will be required.

Before presenting specific emission estimates, it is important to recognize that emission reductions from EGUs must be accomplished concurrent with increasing demands for electricity. Figure 9-1 illustrates the substantial increase in electricity demand observed between 1985 and 2002, and the additional demand expected between 2002 and 2015.[71] As indicated, demand has increased by about 56 percent since 1985, and is expected to have increased by nearly 90 percent by 2015. Emissions must be reduced by an amount sufficient to offset this entire growth in demand *before* EGU emissions can be reduced by even a single pound from 1985 levels.[72]

Figures 9-2 and 9-3 present estimated NO_x and SO_2 emissions from EGU for the period 1985 through 2015. Historic emission levels and emissions expected between now and 2015 are indicated by the green trend line. As depicted, NO_x emissions have currently been reduced from 1985 levels by about 21 percent, and are expected to be reduced by about 62 percent from 1985 levels by 2015.[73] The red trend line indicates where emissions would have been in each year in the absence of emission reduction technology instituted in the EGU sector since 1985. This line

[71] Data for the 48 continental U.S. states and the District of Columbia are included in all of the figures and statistics presented in this section. Data for Alaska and Hawaii are not included. The EPA emission estimates that are used as the basis for the data presented in this section are only available for the continental U.S. To ensure consistency, data for Alaska and Hawaii were removed from the electricity generation data. The impact of this exclusion is insignificant as Alaska and Hawaii together are responsible for only about 0.2 percent of total U.S. electricity production.

[72] Because of significant changes in the methodology employed by the EPA to estimate emissions from many sources, including EGU, 1985 is used as the base year for all comparative statistics in this section.

[73] The estimated 2015 emission levels assume that the Clean Air Interstate Rule is adopted as proposed. This assumption underlies all emission forecasts in this section. If the CAIR is not adopted, or does not require reductions similar to those proposed, future emission reductions could be substantially lower than forecasted in this study.

Figure 9-1. EGU Electricity Production (1985-2015)[74]

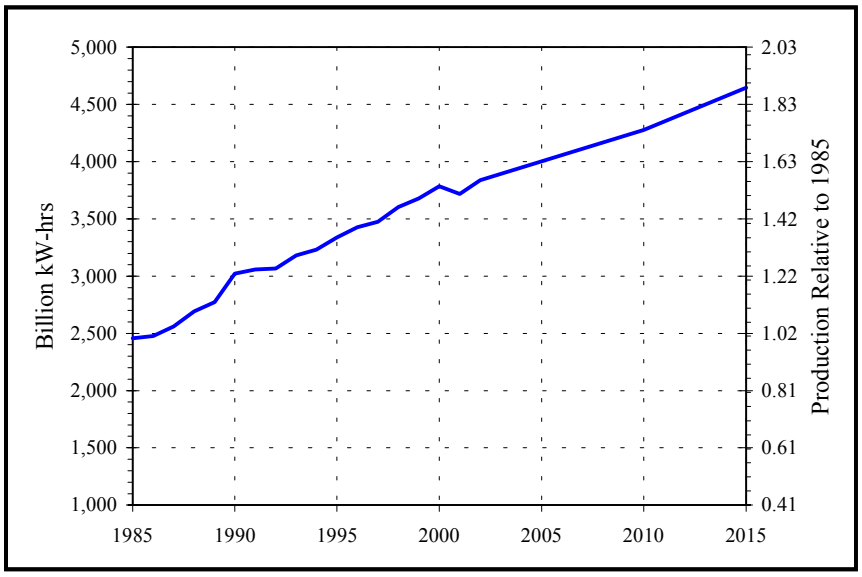
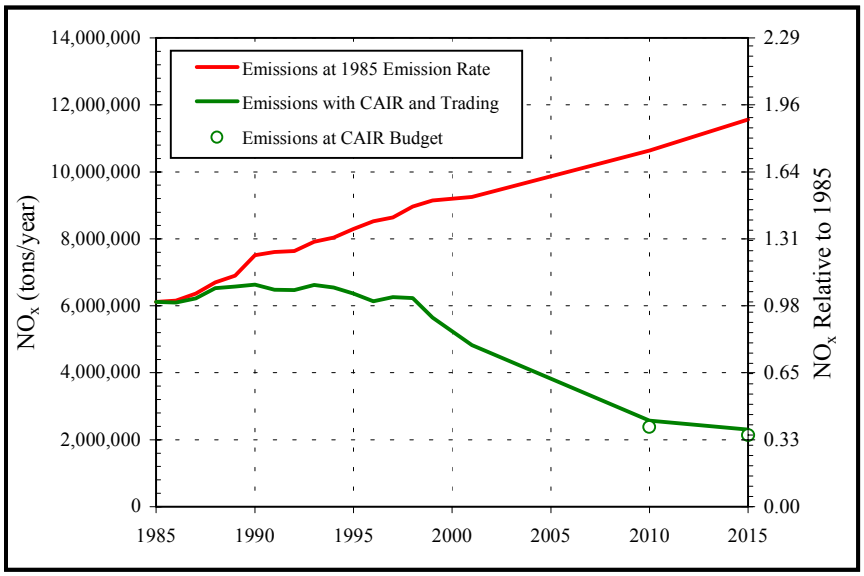


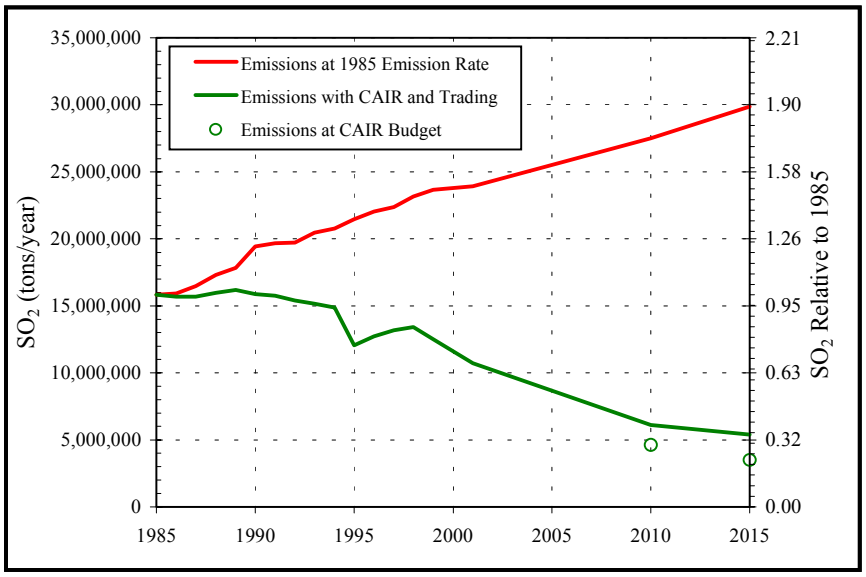
Figure 9-2. EGU NO_x Emissions (1985-2015)[75]



[74] 1985-2002 data from Energy Information Administration Forms EIA-759 and EIA-906. Post-2000 projections from EPA Integrated Planning Model analyses performed for the proposed Clean Air Interstate Rule. See http://www.epa.gov/airmarkets/epa-ipm/iaqr.html, http://www.eia.doe.gov/cneaf/electricity/page/eia906u.html, and http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html.

[75] 1985-1999 data from EPA AirData website. Post-1999 projections from EPA Integrated Planning Model analyses performed for the proposed Clean Air Interstate Rule. See http://www.epa.gov/air/data/ and http://www.epa.gov/airmarkets/epa-ipm/iaqr.html. Clean Air Interstate Rule emission budgets are from the EPA proposed rule at 69FR4619-4620 (January 24, 2004 Federal Register).

Figure 9-3. EGU SO_x Emissions (1985-2015)[76]



indicates the emissions that would have occurred due to growth in demand since 1985, if offsetting emission reduction measures had not been implemented. The difference between these two trend lines indicates that actual NO_x reductions to date are about 48 percent, and NO_x reductions expected through 2015 are about 80 percent.

Based on the data presented in Figure 9-3, the emission reductions for SO_2 are even more dramatic. SO_2 emissions have currently been reduced from 1985 levels by about 32 percent, and are expected to be reduced by about 66 percent from 1985 levels by 2015. Relative to the emissions levels that would have been observed in the absence of measures to offset growth in electricity demand, SO_2 reductions to date are about 55 percent, and SO_2 reductions expected through 2015 are about 82 percent.

The green circular markers in Figures 9-2 and 9-3 (labeled emissions at CAIR budget) indicate the actual level of emission reductions that ultimately must be achieved under the CAIR. If an emissions trading system is implemented as proposed, actual forecasted emissions in 2015 will be somewhat greater than the budget level of emissions (as reflected in the green trend line). While the budget level of emission reductions must ultimately be achieved, the target date is extended beyond 2015 under the CAIR trading program in return for earlier emission reductions prior to 2015. Therefore, while the budget level of emissions is depicted in Figures 9-2 and 9-3 as being "attained" in a two-step process in 2010 and 2015, actual attainment of the indicated

[76] 1985-1999 data from EPA AirData website. Post-1999 projections from EPA Integrated Planning Model analyses performed for the proposed Clean Air Interstate Rule. See http://www.epa.gov/air/data/ and http://www.epa.gov/airmarkets/epa-ipm/iaqr.html. Clean Air Interstate Rule emission budgets are from the EPA proposed rule at 69FR4619-4620 (January 24, 2004 Federal Register).

budget-level reductions will occur sometime after the target dates. This additional compliance time is more than offset by reductions achieved earlier than 2010 and 2015 under the emissions reduction trading program. For NO_x, the difference between expected and budget level emissions is marginal, while the difference for SO_2 is reasonably significant as indicated by the wider range of SO_2 emission reductions expected in 2015 under the Clean Air Interstate Rule.

When the budget level of emission reductions is attained, NO_x will be reduced by about 65 percent from 1985 levels, or about 82 percent relative to the levels that would have been observed in the absence of measures to offset growth in electricity demand. SO_2 will be reduced by about 78 percent from 1985 levels, or about 88 percent relative to the levels that would have been observed in the absence of measures to offset growth in electricity demand.

Figures 9-4 and 9-5 present an alternative method of viewing the substantial emission reductions achieved in the EGU sector by presenting observed EGU emission rates per unit of electricity generated. For reference, the absolute level of electricity generation is also presented. As indicated in Figure 9-4, current unit-specific NO_x emissions have declined by about 48 percent, from 5.0 pounds per megawatt-hour generated to 2.6 pounds per megawatt-hour generated. Unit-specific NO_x emissions are expected to decline to between 0.9 and 1.0 pounds per megawatt-hour generated by 2015, a total reduction of 80-82 percent relative to 1985 unit-specific emissions.

As indicated in Figure 9-5, current unit-specific SO_2 emissions have declined by about 55 percent, from 12.9 pounds per megawatt-hour generated to 5.8 pounds per megawatt-hour generated. Unit-specific SO_2 emissions are expected to decline to between 1.5 and 2.3 pounds per megawatt-hour generated by 2015, a total reduction of 82-88 percent relative to 1985 unit-specific emissions.

Clearly, substantial reductions in EGU NO_x and SO_2 emissions have been achieved in the last 20 years. Moreover, additional reductions are expected throughout the next decade and beyond. These reductions have enabled, and will continue to enable, improvements in U.S. air quality, during a period when the EGU sector has simultaneously delivered a 56 percent increase in electricity generation. The emission reductions expected over the next decade will be achieved despite a significant additional increase in electricity generation. EGUs have achieved this remarkable success through a combination of improved fuel combustion efficiency, lower emissions combustion technology, and effective post-combustion emissions control -- all enabled by innovative technology development. Similar successes can be observed across a wide range of non-EGU emission sources -- and it is the cumulative emission reductions from all these sources that have brought about the substantial air quality improvements observed to date *and* that will drive continuing air quality improvements for the foreseeable future.

Continuing improvements in air quality are necessary for some areas of the U.S. to achieve full compliance with the NAAQS. However, despite frequent claims to the contrary, air quality in the U.S. is substantially better today than at any time since data collection began in earnest in the 1970s. The U.S. has made, and continues to make, significant progress in providing healthful air quality for all Americans.

Figure 9-4. Effective EGU NO_x Emission Rate (1985-2015)[77]

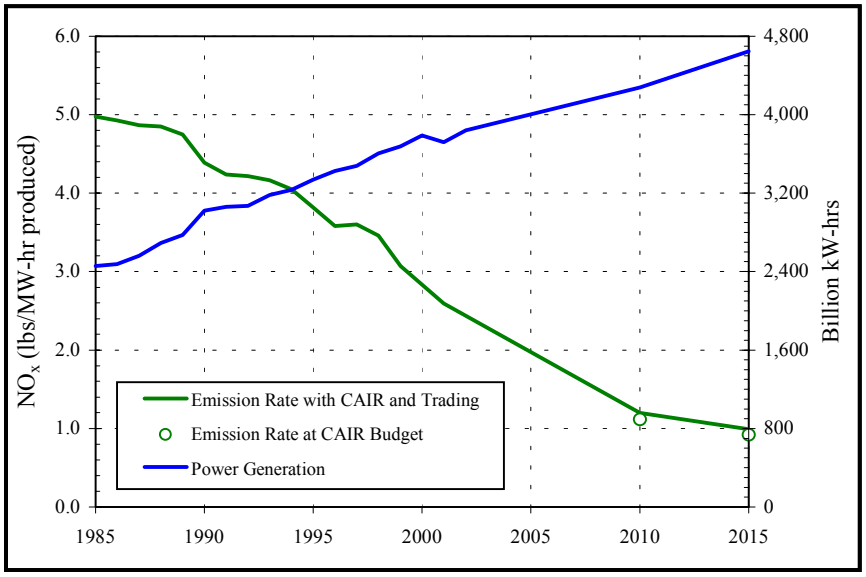
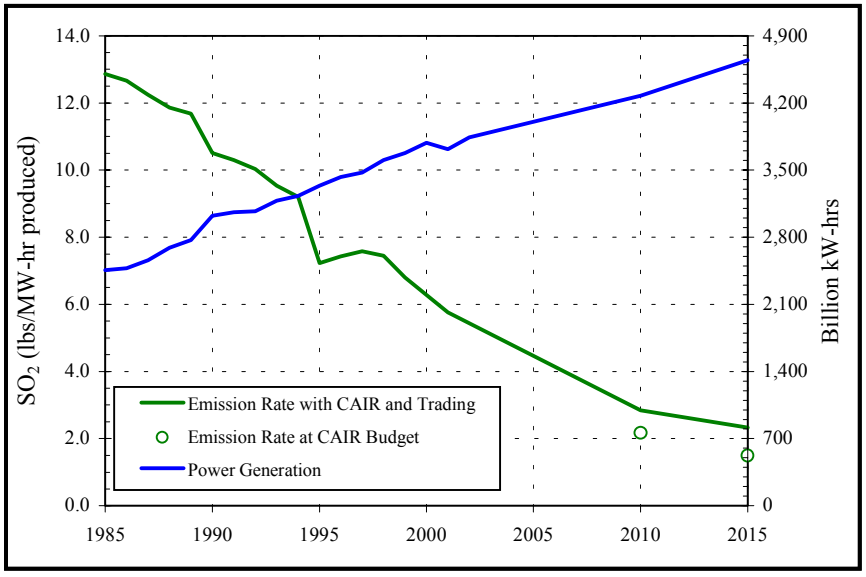


Figure 9-5. Effective EGU SO_2 Emission Rate (1985-2015)[78]



[77] Derived from data presented in Figures 9-1 and 9-2.

[78] Derived from data presented in Figures 9-1 and 9-3.