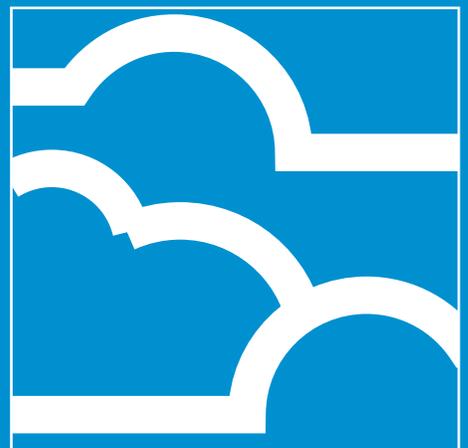


Chapter 1: Cleaner Air



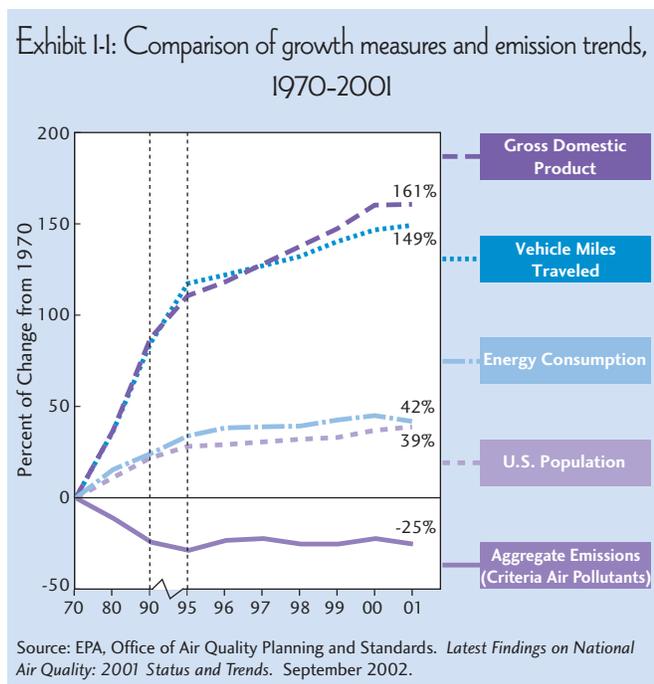
Indicators that were selected and included in this chapter were assigned to one of two categories:

- **Category 1** –The indicator has been peer reviewed and is supported by national level data coverage for more than one time period. The supporting data are comparable across the nation and are characterized by sound collection methodologies, data management systems, and quality assurance procedures.
- **Category 2** –The indicator has been peer reviewed, but the supporting data are available only for part of the nation (e.g., multi-state regions or ecoregions), or the indicator has not been measured for more than one time period, or not all the parameters of the indicator have been measured (e.g., data has been collected for birds, but not for plants or insects). The supporting data are comparable across the areas covered, and are characterized by sound collection methodologies, data management systems, and quality assurance procedures.

1.0 Introduction

In 1970, Congress responded to concern over visible air pollution, irritating smog, and associated health and ecological effects by enacting the federal Clean Air Act (CAA). As a result, total national emissions of the six criteria air pollutants decreased by 25 percent between 1970 and 2001. Emissions of air toxics have declined as well, dropping 24 percent between 1990 and 1993 (the baseline period) and 1996. One of the major components of acid rain, wet sulfate deposition, has also decreased substantially (EPA, OAQPS, September 2002).

These improvements occurred during a time of significant growth in the nation's population and economy: from 1970 to 2001, the Gross Domestic Product (GDP) increased by 161 percent, the number of people increased from about 203 million to more than 280 million, energy consumption increased by 42 percent, and vehicle miles traveled increased by 149 percent (Exhibit 1-1) (EPA, OAQPS, September 2002).



Despite progress toward cleaner air, in 2001 more than 133 million people lived in counties where monitored air quality was unhealthy at times because of high levels of at least one criteria air pollutant (EPA, OAQPS, September 2002). Even after decades of regulation and emissions control, certain air quality problems persist. In particular, ozone and particulate matter are the criteria pollutants most often found at levels above national health-based standards.

Outdoor air is not the nation's only air quality concern. The levels of pollutants in the air inside homes, schools, and other buildings can be higher than in the outdoor air. Uncertainty remains about levels of indoor air pollutants, such as radon and environmental tobacco smoke.

Changes to stratospheric ozone levels are also concerns. The stratospheric ozone layer has become substantially thinner in recent decades, although scientists generally believe it will recover over the next several decades as a result of international controls (Scientific Assessment Panel, 2003).

This chapter summarizes the current status and trends in air quality, the pressures affecting air quality, and information regarding human health and ecological effects. It poses fundamental questions about air quality, contributors to pollution, and health and ecological effects, and it uses indicators drawn from well-reviewed data sources to help answer those questions. Exhibit 1-2 lists these questions and indicators, as well as the number of the chapter section where each indicator is presented.

The chapter is divided into six main sections:

- Section 1.1 discusses the quality of outdoor air.
- Section 1.2 provides information about acid deposition.
- Section 1.3 examines the quality of air inside homes, schools, and other buildings.
- Section 1.4 focuses on stratospheric ozone.
- Section 1.5 briefly addresses climate change research plans.
- Section 1.6 reviews the challenges and data gaps that remain in assessing the nation's air quality.

Exhibit I-2: Air – Questions and Indicators

Outdoor Air Quality

Question	Indicator Name	Category	Section
What is the quality of outdoor air in the United States? (See also following four questions)	Number and percentage of days that metropolitan statistical areas (MSAs) have Air Quality Index (AQI) values greater than 100	2	1.1.1
– How many people are living in areas with particulate matter and ozone levels above the National Ambient Air Quality Standards (NAAQS)?	Number of people living in areas with air quality levels above the NAAQS for particulate matter (PM) and ozone	1	1.1.1.a
– What are the concentrations of some criteria air pollutants: PM _{2.5} , PM ₁₀ , ozone, and lead?	Ambient concentrations of particulate matter: PM _{2.5} and PM ₁₀	1	1.1.1.b
	Ambient concentrations of ozone: 8-hour and 1-hour	1	1.1.1.b
	Ambient concentrations of lead	1	1.1.1.b
– What are the impacts of air pollution on visibility in national parks and other protected lands?	Visibility	1	1.1.1.c
– What are the concentrations of toxic air pollutants in ambient air?	Ambient concentrations of selected air toxics	2	1.1.1.d
What contributes to outdoor air pollution? (See also following three questions)	See emissions indicators		1.1.2
– What are contributors to particulate matter, ozone, and lead in ambient air?	Emissions: particulate matter (PM _{2.5} and PM ₁₀) sulfur dioxide, nitrogen oxides, and volatile organic compounds	2	1.1.2.a
	Lead emissions	2	1.1.2.a
– What are contributors to toxic air pollutants in ambient air?	Air toxics emissions	2	1.1.2.b
– To what extent is U.S. air quality the result of pollution from other countries, and to what extent does U.S. air pollution affect other countries?	No Category 1 or 2 indicators identified		1.1.2.c
What human health effects are associated with outdoor air pollution?	No Category 1 or 2 indicators identified Also see Human Health chapter		1.1.3
What ecological effects are associated with outdoor air pollution?	No Category 1 or 2 indicators identified Also see Ecological Condition chapter		1.1.4

Acid Deposition

Question	Indicator Name	Category	Section
What are the deposition rates of pollutants that cause acid rain?	Deposition: wet sulfate and wet nitrogen	2	1.2.1
What are the emissions of pollutants that form acid rain?	Emissions (utility): sulfur dioxide and nitrogen oxides	2	1.2.2
What ecological effects are associated with acid deposition?	No Category 1 or 2 indicators identified Also see Ecological Condition chapter		1.2.3

Indoor Air Quality

Question	Indicator Name	Category	Section
What is the quality of the air in buildings in the United States?	U.S. homes above EPA's radon action levels	2	1.3.1
	Percentage of homes where young children are exposed to environmental tobacco smoke	2	1.3.1
What contributes to indoor air pollution?	No Category 1 or 2 indicators identified Also see Human Health chapter		1.3.2
What human health effects are associated with indoor air pollution?	No Category 1 or 2 indicators identified Also see Human Health chapter		1.3.3

Stratospheric Ozone

Question	Indicator Name	Category	Section
What are the trends in the Earth's ozone layer?	Ozone levels over North America	1	1.4.1
What is causing changes to the ozone layer?	Worldwide and U.S. production of ozone-depleting substances (ODSs)	2	1.4.2
	Concentrations of ozone-depleting substances (effective equivalent chlorine)	2	1.4.2
What human health effects are associated with stratospheric ozone depletion?	No Category 1 or 2 indicators identified		1.4.3
What ecological effects are associated with stratospheric ozone depletion?	No Category 1 or 2 indicators identified		1.4.4

1.1 Outdoor Air Quality

Among the pollutants affecting outdoor air quality are:

- Criteria pollutants—ozone (O₃), particulate matter (PM), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), and lead.
- Air toxics—pollutants such as mercury and benzene.

Under the Clean Air Act, EPA and states collect data on the six criteria air pollutants to measure compliance with National Ambient Air Quality Standards (NAAQS) (Exhibit 1-3). “Primary” NAAQS are set to protect public health with an adequate margin of safety, and “secondary” NAAQS protect against adverse welfare effects (e.g., effects on vegetation, ecosystems, visibility, manmade materials) (42 U.S.C. 7408 and 7409). After initially adopting NAAQS for each of the criteria air pollutants in the 1970s, EPA has periodically reviewed and sometimes revised the standards. EPA recently revised the health-based standard for ozone and added a new standard for fine PM_{2.5} based on new health studies (EPA, 2003; EPA, 1997).

Criteria air pollutants are monitored through the National Air Monitoring Stations/State or Local Air Monitoring Stations network. This network consists of more than 5,000 monitors operating at 3,000 sites across the country, mostly in urban areas (EPA, OAQPS, September 2002). Measurements are taken on both a daily and

continuous basis to assess both peak concentrations and overall trends, and are reported in the Air Quality Subsystem (AQS) database. In addition to other uses, EPA analyzes these air quality measurements to designate areas as either attainment or nonattainment for specific criteria air pollutants (i.e., determines if air quality levels in an area violate the NAAQS).

While air quality data on criteria air pollutants are ample, national data on air toxics concentrations are limited. Several metropolitan areas measure ambient air toxics concentrations, but there are few standards by which to evaluate levels of concern. In addition, cumulative or synergistic impacts of various air pollutants are not well understood.

Visibility is another outdoor air concern. Some data on this aspect of air quality are available from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network, which collects data to characterize visibility at national parks and other protected areas.

This section addresses the following specific questions about outdoor air quality:

- What is the quality of outdoor air in the United States? (Section 1.1.1)
 - ▲ How many people are living in areas with particulate matter and ozone levels above the NAAQS?

Exhibit 1-3: National Ambient Air Quality Standards (NAAQS) in effect as of February 2003

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

a Parenthetical value is an approximately equivalent concentration. (See 40 CFR Part 50).
 b Not to be exceeded more than once per year.
 c The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than one, as determined according to Appendix H of the Ozone NAAQS.

d Three-year average of the annual 4th highest daily maximum 8-hour concentration.
 e The short-term (24-hour) standard of 150 µg/m³ is not to be exceeded more than once per year on average over three years.
 f Spatially averaged over designated monitors.
 g The form is the 98th percentile.

Source: Based on EPA, Office of Air Quality Planning and Standards. *National Air Quality and Emissions Trends Report*, 1999. March 2001.

- ▲ What are the concentrations of some criteria air pollutants: PM_{2.5}, PM₁₀, ozone, and lead?
- ▲ What are the impacts of air pollution on visibility in national parks and other protected lands?
- ▲ What are the concentrations of toxic air pollutants in ambient air?
- What contributes to outdoor air pollution? (Section 1.1.2)
 - ▲ What are contributors to particulate matter, ozone, and lead in ambient air?
 - ▲ What are contributors to toxic air pollutants in ambient air?
 - ▲ To what extent is U.S. air quality the result of pollution from other countries, and to what extent does U.S. air pollution affect other countries?
- What human health effects are associated with outdoor air pollution? (Section 1.1.3)
- What ecological effects are associated with outdoor air pollution? (Section 1.1.4)

1.1.1 What is the quality of outdoor air in the United States?

Indicator

Number and percentage of days that metropolitan statistical areas (MSAs) have Air Quality Index (AQI) values greater than 100

The nation's air quality has generally improved, as indicated by trends derived by averaging the direct measurements from the nation's criteria air pollutant monitoring stations on a yearly basis. In general, air pollution concentrations are declining, and overall air quality is improving (EPA, OAQPS, September 2002).

Most areas of the U.S. now have concentrations of NO₂, SO₂, CO, and lead that are below the level of the NAAQS (EPA, OAQPS, September 2002). However, ozone levels are above the level of the standard in many heavily populated areas, including many of the urban areas in the eastern half of the U.S. and in most of the urban areas in California (EPA, OAQPS, March 2001). Concentrations of PM_{2.5}—particles less than or equal to 2.5 micrometers in diameter—are above the level of the standard in much of the eastern U.S. and parts of California (EPA, OAQPS, September 2002).

It is important to recognize that while the national trend is toward cleaner air, regional and local conditions can vary quite greatly. This report focuses on national status and trends, but regional and local conditions should be evaluated as well, with the goal of understanding regional air quality conditions and trends and improving air quality in those areas where air quality does not meet the standards.

A number of indicators, described on the following pages, help to answer the questions posed in this section about outdoor air quality:

- Number and percentage of days that Metropolitan Statistical Areas (MSAs) have Air Quality Index (AQI) values greater than 100
- Number of people living in areas with air quality levels above the NAAQS for particulate matter and ozone
- Ambient concentrations of particulate matter: PM_{2.5} and PM₁₀
- Ambient concentrations of ozone: 8-hour and 1-hour
- Ambient concentrations of lead
- Visibility
- Ambient concentrations of selected air toxics
- Emissions of particulate matter (PM_{2.5} and PM₁₀), sulfur dioxide, nitrogen oxides, and volatile organic compounds
- Lead emissions
- Air toxics emissions

Indicator

Number and percentage of days that metropolitan statistical areas (MSAs) have Air Quality Index (AQI) values greater than 100 - Category 2

One measure of outdoor air quality is the daily AQI, which is based on concentrations of five of the criteria air pollutants: ozone, PM, CO, SO₂, and NO₂. The AQI indicates how clean or polluted the air is and the associated health concerns. It focuses on the health effects that can occur within a few hours or days after breathing polluted air. AQI data are compiled by state and local agencies and must be reported in metropolitan statistical areas (MSAs) with populations of more than 350,000 (EPA, OAQPS, March 2001).

AQI values range from 0 to 500, with higher numbers indicating more air pollution and more potential risk to public health. An AQI value of 100 generally corresponds to the short-term public health standard set by EPA for a particular pollutant. Values below 100 are generally thought of as satisfactory. However, unusually sensitive individuals may experience health effects when AQI values are between 50 and 100. Values above 100 suggest increasingly unhealthy air; sensitive population groups, such as children, the elderly, and those with respiratory illnesses, are likely to be among the first affected as the values increase.

The AQI scale is divided into six categories, each color-coded to correspond to a different level of health concern. For example,

- The color green is associated with “good” air quality or an AQI from 0 to 50.
- Yellow or “moderate”—51 to 100.
- Orange or “unhealthy for sensitive groups”—101 to 150.
- Red or “unhealthy”—151 to 200.
- Purple or “very unhealthy”—201 to 300.
- Maroon or “hazardous”—301 to 500. AQI values over 300 would trigger health warnings of emergency conditions for the entire population (EPA, OAQPS, March 2001).

The highest AQI value for an individual pollutant becomes the AQI value for that area for that particular day. For example, if on a day a certain area had AQI values of 150 for ozone and 120 for PM, the AQI value would be 150 for the pollutant ozone on that day. However, for all pollutants above 100, the appropriate sensitive groups would be cautioned. Ozone levels most often drive the AQI, but experts anticipate that PM_{2.5} will also be a key driver of the AQI in coming years.

The AQI is useful in communicating to the public the air quality in a specific area on a given day and the potential health effects and

actions to avoid exposure and reduce harmful impacts. Nationally, the number and percentage of days with AQI values of more than 100 gives a sense of the number of days that are potentially unhealthy for sensitive populations.

What the Data Show

This indicator is the annual sum of the number of days, and percentage of days, with AQI values above 100 across all MSAs with a population greater than 500,000. To assess trends, the number of days is adjusted to reflect changes in air quality standards or criteria for the number of MSAs reporting.

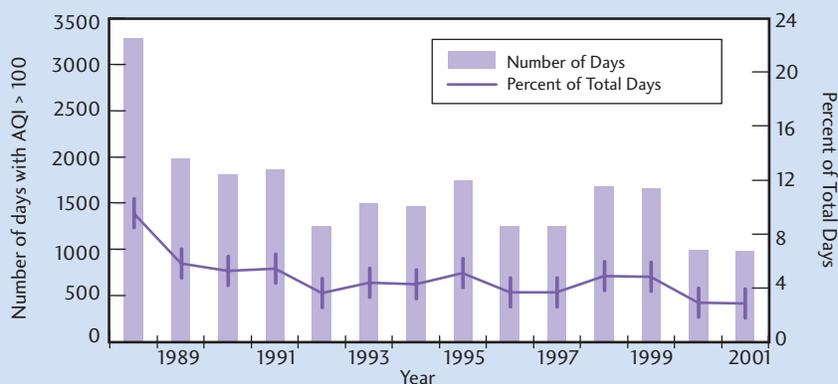
Between 1988 and 2001, the number of days with an AQI of 100 or greater decreased from approximately 3,300 days to approximately 1,000 days. In 1989 and after, the number of days with an AQI of 100 or greater ranged between 1,000 and 2,000. Based on EPA AQI data, the percentage of days across the country with AQI values above 100 dropped from almost 10 percent in 1988 to 3 percent in 2001 (Exhibit 1-4) (EPA, OAQPS, December 1998; EPA, OAQPS, 2001).

Indicator Gaps and Limitations

Limitations of this indicator include the following:

- The data for this indicator are associated with large MSAs only (500,000 people or more); therefore, the data tend to reflect urban air quality.

Exhibit 1-4: Number and percentage of days with Air Quality Index (AQI) greater than 100, 1988-2001



Note: Data are for MSAs > 500,000
 Source: Data used to create graphic are drawn from EPA, Office of Air Quality Planning and Standards. *National Air Quality and Emissions Trends Report*, 1997. Table A-15. December, 1998; EPA, Office of Air Quality Planning and Standards. *Air trends: Metropolitan area trends*, Table A-17, 2001. (February 25, 2003; <http://www.epa.gov/airtrends/metro.html>).

Indicator

Number and percentage of days that metropolitan statistical areas (MSAs) have Air Quality Index (AQI) values greater than 100 - Category 2 (continued)

- This composite AQI indicator does not identify the pollutants of concern—that is, it does not show which pollutant(s) are causing the days with an AQI of more than 100, or which ones have decreased and are responsible for an improvement in the AQI.
- This composite AQI indicator does not show which areas, or how many areas, have problems—a specific number of days could reflect a few areas with persistent problems or many areas with occasional problems.

Data Source

The data sources for this indicator were “Air Trends: Metropolitan area trends,” Table A-17, EPA, 2001, and *National Air Quality and Emissions Trends Report, 1997*, Table A-15, EPA, 1998. (See Appendix B, page B-2, for more information.)

1.1.1.a How many people are living in areas with particulate matter and ozone levels above the National Ambient Air Quality Standards (NAAQS)?

In 2001, more than 133 million Americans (of a total population of 281 million) lived in counties where monitored outdoor air quality was unhealthy at times because of high levels (levels above the NAAQS) of at least one criteria air pollutant (EPA, OAQPS, September 2002). Ozone and PM remain the most persistent criteria pollutants.

Indicator

Number of people living in areas with air quality levels above the NAAQS for particulate matter (PM) and ozone

Indicator

Number of people living in areas with air quality levels above the NAAQS for particulate matter (PM) and ozone - Category I

The number of people living in areas above the level of the health-based NAAQS gives some indication of the number of people potentially exposed to unhealthy air.

What the Data Show

Despite trends of decreasing concentrations of criteria pollutants, many people still live in areas with air quality levels above the health-based standards for ozone and PM. In 2001, 11.1 million people lived in counties with air quality concentrations that at times were above the NAAQS for PM₁₀, and 72.7 million people lived in counties with air quality concentrations above the standard for PM_{2.5}. Some 40.2 million people lived in counties with

concentrations that at times were above the 1-hour ozone standard, and 110.3 million people lived in counties with concentrations above the 8-hour ozone standard (Exhibit 1-5) (EPA, OAQPS, September 2002).

Indicator Gaps and Limitations

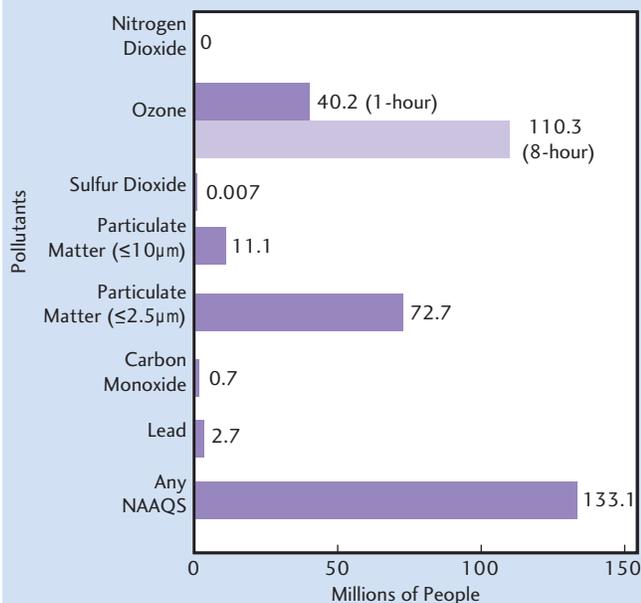
Limitations of this indicator include the following:

- The indicator helps in understanding the number of people potentially affected by air quality problems, but it does not tell the actual number of people exposed to unhealthy air. Not all counties have complete monitoring data, so some areas may be excluded. However, the areas of most concern are likely covered.

Indicator

Number of people living in areas with air quality levels above the NAAQS for particulate matter (PM) and ozone - Category I (continued)

Exhibit I-5: People living in areas with air quality above the National Ambient Air Quality Standards (NAAQS) in 2001



Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

■ The indicator does not tell the amount or extent to which different areas exceed the standards, and so does not provide any specific exposure data.

Data Sources

The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-3, for more information.)

1.1.1.b What are the concentrations of some criteria air pollutants: PM_{2.5}, PM₁₀, ozone, and lead?

Indicators

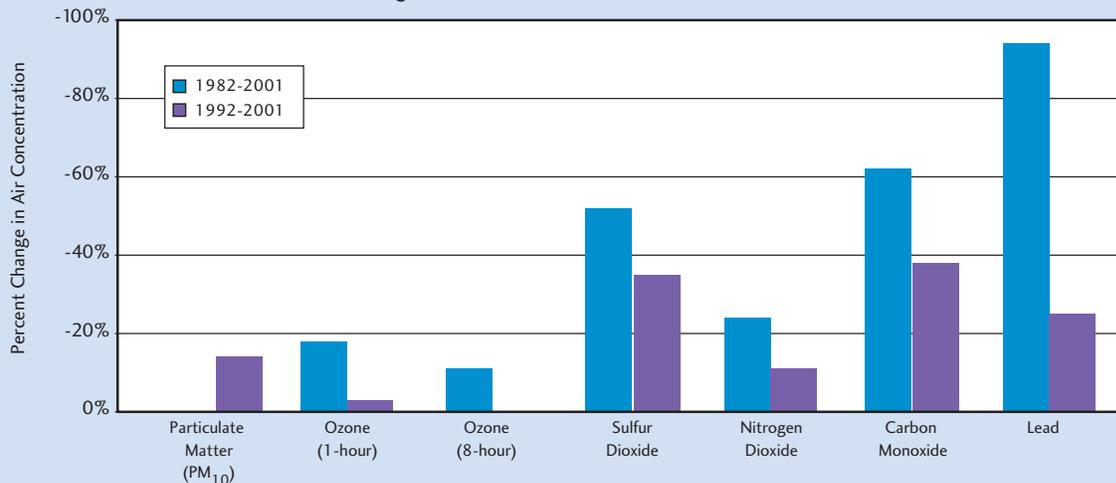
Ambient concentrations of particulate matter: PM_{2.5} and PM₁₀
 Ambient concentrations of ozone: 8-hour and 1-hour
 Ambient concentrations of lead

Three indicators, presented on the following pages, are available to help answer this question: ambient concentrations of particulate matter, ambient concentrations of ozone (8-hour and 1-hour), and ambient concentrations of lead. Concentrations of the criteria air pollutants have decreased over the past 2 decades, with substantial

reductions in SO₂, CO, and lead levels (Exhibit 1-6) (EPA, OAQPS, September 2002). However, PM_{2.5} and ozone concentrations are above the NAAQS in many areas, potentially exposing a significant percentage of the U.S. population to unhealthy air (EPA, OAQPS, September 2002).

The data for national levels of criteria pollutants tell only part of the story. Although significant improvements have been occurring nationally and regionally, some areas still have chronic air quality problems. The Northeast, for example, experiences frequent and widespread violations of the ozone health-based standard (Northeast States for Coordinated Air Use Management, 2002).

Exhibit I-6: Percent reduction in concentration of six criteria air pollutants regulated under the Clean Air Act, 1982-2001



Note: Trend data for PM_{2.5} are not available. Trend data for PM₁₀ are only available for 1992-2001. Between 1992-2001, ozone (8-hour) concentrations remained level.

Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Indicator

Ambient concentrations of particulate matter: PM_{2.5} and PM₁₀- Category I

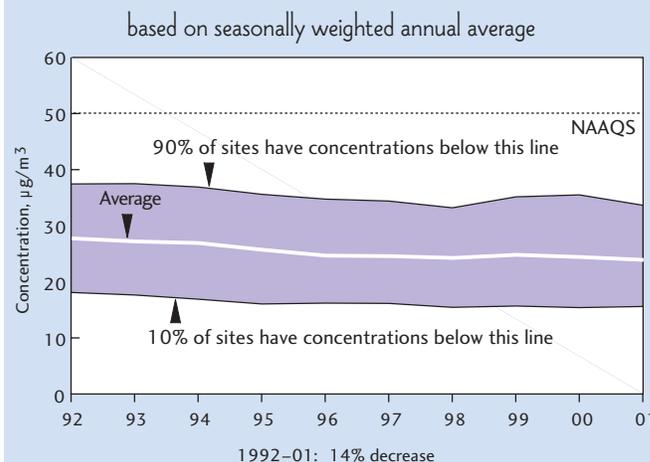
Particulate matter concentrations are a good indication of air quality health effects, because of concerns about associated respiratory effects. This indicator is based on the annual average concentrations, in micrograms per cubic meter (µg/m³) of PM_{2.5} and PM₁₀. PM₁₀ refers to particles 10 micrometers or less in diameter, and PM_{2.5} refers to particles less than or equal to 2.5 micrometers in diameter.

Trends in PM₁₀ are presented from 1992 to 2001, and comparable PM_{2.5} data have been collected since 1999 (EPA, OAQPS, September 2002).

What the Data Show

Concentrations of PM₁₀ decreased by 14 percent between 1992 and 2001 (Exhibit I-7), and are below the NAAQS standard concentration in most areas. Concentrations of PM_{2.5} are above the level of the annual standard in much of the eastern U.S. and parts of California (Exhibit I-8) (EPA, OAQPS, September 2002). Annual average PM_{2.5} concentrations are generally higher in the eastern U.S. than in the West, mostly because sulfate concentrations are four to five times higher in the eastern U.S. (largely due to coal-fired power plants) (EPA, OAQPS, September 2001).

Exhibit I-7: Particulate matter (PM₁₀) air quality, 1992-2001



Coverage: 770 monitoring sites nationwide with sufficient data to assess trends.

Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Indicator

Ambient concentrations of particulate matter: $PM_{2.5}$ and PM_{10} - Category I (continued)

Indicator Gaps and Limitations

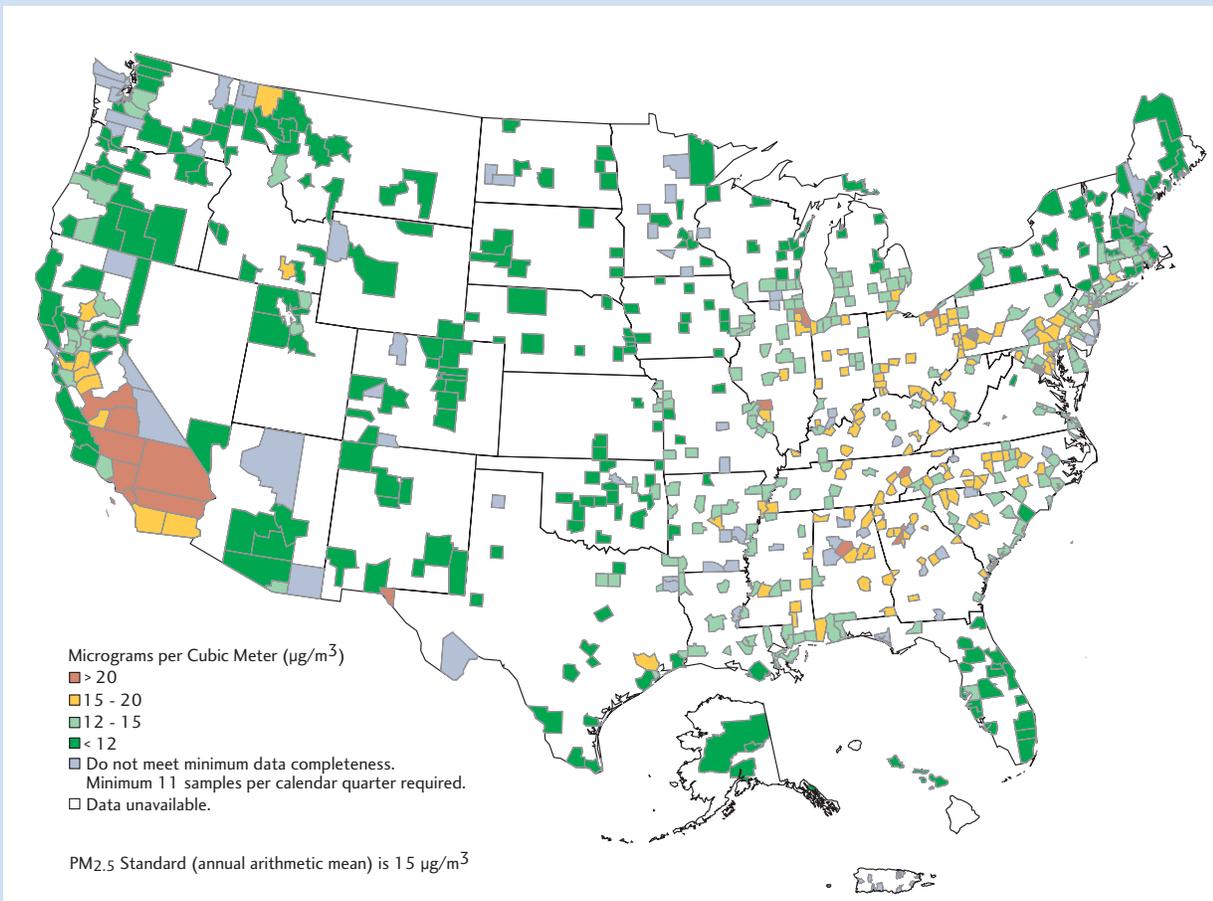
Limitations of this indicator include the following (EPA, OAQPS, September 2002):

- Ten-year trend data for PM_{10} are not available before 1990, because total suspended particulates, which include particle sizes larger than PM_{10} , were monitored until 1990.
- The monitoring is conducted mostly in urban areas, although the $PM_{2.5}$ data from the IMPROVE network support assessments of rural trends from 1992 to 1999.

Data Source

The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-3, for more information.)

Exhibit I-8: 2001 annual average particulate matter ($PM_{2.5}$) concentrations



Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Indicator

Ambient concentrations of ozone: 8-hour and 1-hour - Category I

Ozone is one of six criteria pollutants regularly monitored under the CAA to determine compliance with health-based standards. This indicator reflects ambient concentrations in parts per million (ppm) of ground-level ozone from 1982 to 2001, based on 1-hour and 8-hour measurements to gauge shorter-term and longer-term levels.

The 1-hour standard is useful in measuring potential effects during short-term "spikes" in concentrations. The longer 8-hour standard is used in evaluating exposures occurring over a more sustained period of time (e.g., an outdoor worker's exposure over the course of a work day).

What the Data Show

Although ozone concentrations are generally decreasing, they are higher than the NAAQS in many areas. Ground-level ozone concentrations fell by 11 percent between 1982 and 2001, based on the annual fourth highest daily maximum 8-hour average (Exhibit 1-9). Ozone levels based on the annual second highest daily maximum 1-hour standard fell by 18 percent during the same time (Exhibit 1-10). All regions experienced some improvement in 8-hour ozone levels during the past 20 years except the north central region (EPA Region 7), which showed little change (Exhibit 1-11) (EPA, OAQPS, September 2002).

Indicator Gaps and Limitations

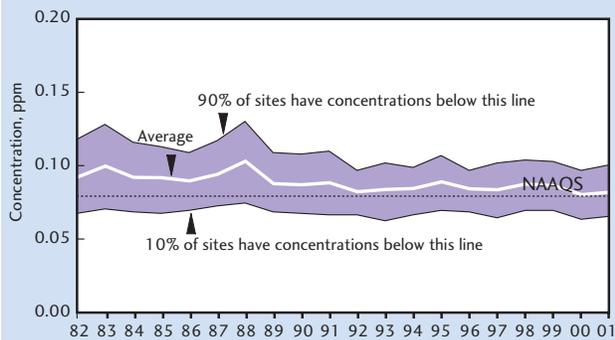
Limitations of this indicator include the following:

- Ground-level ozone is not emitted directly into the air, but is formed by the reaction of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of heat and sunlight, particularly in hot summer weather. To assess ozone trends, VOC and NO_x emissions and meteorological information are also evaluated.
- The monitoring is conducted mostly in urban areas; therefore, data may not accurately encompass rural impacts from ozone transport.

Data Source

The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-3, for more information.)

Exhibit 1-9: Ozone air quality, 1982-2001 based on annual 4th maximum 8-hour average

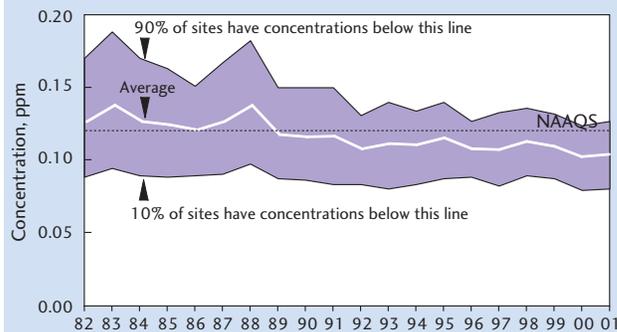


1982-01: 11% decrease
1992-01: 0% change

Coverage: 379 monitoring sites nationwide with sufficient data to assess trends.

Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Exhibit 1-10: Ozone air quality, 1982-2001 based on annual 2nd maximum 1-hour average



1982-01: 18% decrease
1992-01: 3% decrease

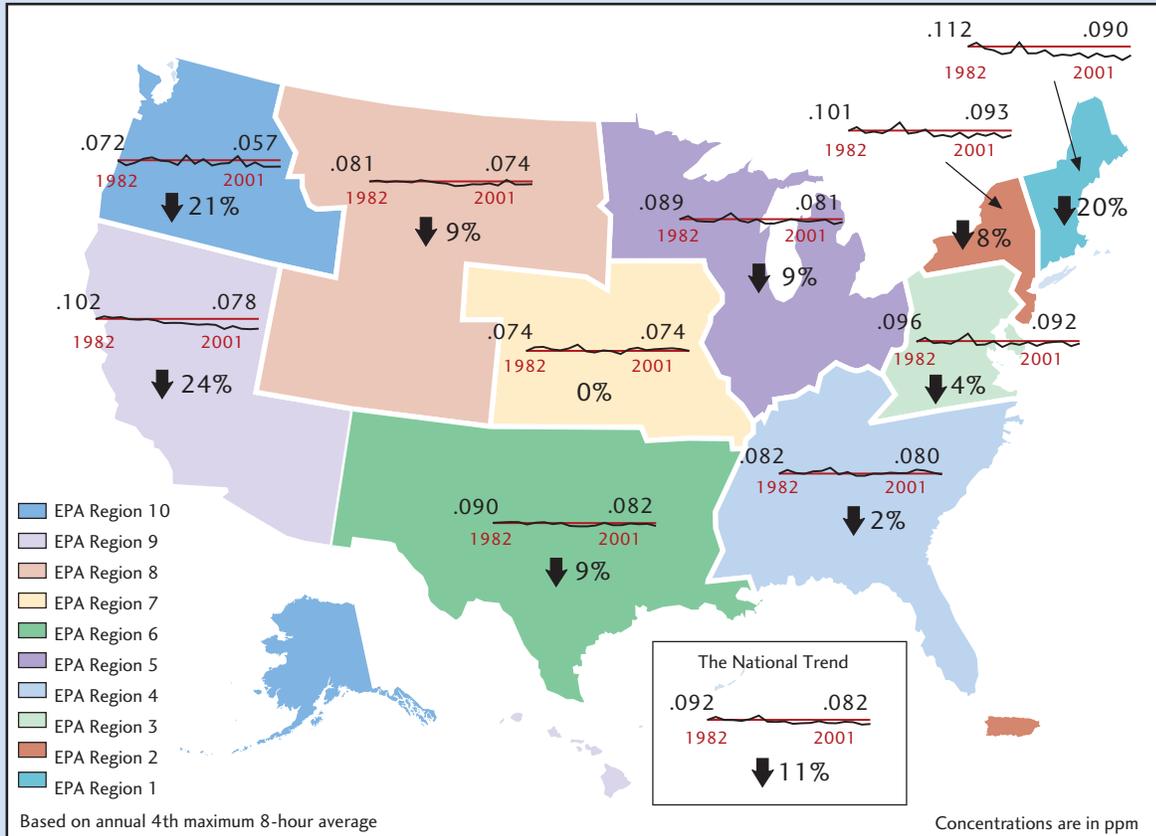
Coverage: 379 monitoring sites nationwide with sufficient data to assess trends.

Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Indicator

Ambient concentrations of ozone: 8-hour and 1-hour - Category I (continued)

Exhibit I-II: Trends in ozone levels (8-hour), 1982-2001, averaged across EPA regions



Note: Alaska levels are included in EPA region 10 averages; Hawaii levels are included in EPA region 9 averages; and Puerto Rico levels are included in EPA region 2 averages.

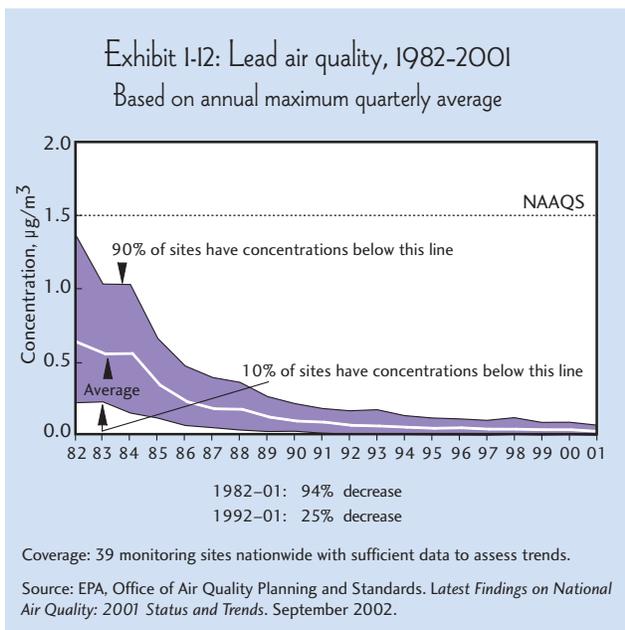
Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Indicator Ambient concentrations of lead - Category I

Lead is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been motor vehicles and industrial sources. Due to the phase-out of leaded gasoline, metals processing is the major source of lead emissions to the air today. The highest air concentrations of lead are usually found in the vicinity of smelters and battery manufacturers. Lead is a criteria and toxic air pollutant with significant health effects, as described in Chapter 4, Human Health.

What the Data Show

This indicator shows ambient lead concentrations measured in $\mu\text{g}/\text{m}^3$ per year from 1982 to 2001. Lead levels decreased by 94 percent in those years, largely because of regulations reducing the lead content in gasoline (Exhibit 1-12) (EPA, OAQPS, September 2002). The most significant decline in ambient lead levels began in the late 1970s and continued through the early 1980s. Outdoor lead levels are below the NAAQS for most areas of the U.S. (EPA, OAQPS, September 2002).



Indicator Gaps and Limitations

Limitations of this indicator include the following:

- Ambient lead monitoring is conducted mostly in urban areas, so it may not accurately encompass rural concentrations.
- This indicator would be very useful in conjunction with indicators of lead concentration in indoor air, drinking water, and soil to portray a broad picture of potential sources of lead exposure.

Data Source

The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-4, for more information.)

1.1.1.c What are the impacts of air pollution on visibility in national parks and other protected lands?

Indicator

Visibility

Visibility is a measure of aesthetic value and the ability to enjoy scenic vistas, but it also can be an indicator of general air quality. PM is

the major contributor to reduced visibility, and high humidity levels worsen the effects of pollution on visibility. The Interagency Monitoring of Protected Visual Environments (IMPROVE) network collects data to characterize visibility in protected lands. IMPROVE was established in 1987 to:

- Determine the type of pollutants primarily responsible for reduced visibility in protected areas.
- Assess progress toward the Clean Air Act's national goal of remedying existing and preventing future visibility impairment.

The indicator below presents data from the IMPROVE network on visibility trends for national parks and other protected lands.

Indicator Visibility - Category I

This indicator presents visibility trends for U.S. national parks and wilderness areas in the eastern and western U.S. by mean visual range, as measured in km for 1992 to 1999 and 1990 to 1999, respectively, by worst, mid-range, and best visibility. Under the Clean Air Act, a Class I area is one in which visibility is protected more stringently than under the NAAQS, including national parks, wilderness areas, monuments, and other areas of special national and cultural significance.

What the Data Show

Data collected by the IMPROVE network show that visibility for the worst visibility days in the West is similar to days with the best visibility in the East (Exhibit 1-13). In 1999, the mean visual range for the worst days in the East was only 24 km (14.9 miles) compared to 84 km (52.2 miles) for the best visibility. In the West, visibility impairment for the worst days remained relatively unchanged over the 1990s, with the mean visual range for 1999 (80 km or 49.7 miles) nearly the same as the 1990 level (86 km or 53.4 miles). Without the effects of pollution, a natural visual range in the U.S. is approximately 75 to 150 km (47 to 93 miles) in the East and 200 to 300 km (124 to 186 miles) in the West (EPA, OAQPS, September 2002).

Indicator Gaps and Limitations

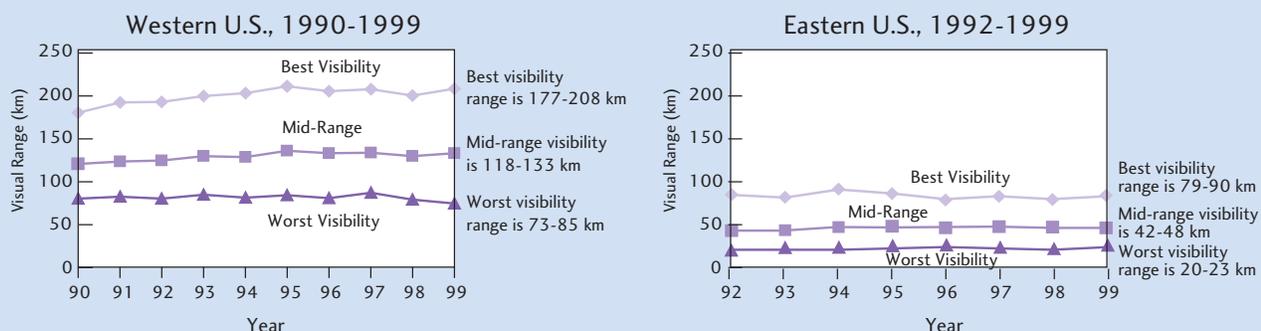
Limitations of this indicator include the following:

- The indicator compares trends within visibility range categories, but it would also be useful to indicate how often visibility falls into each range during a year.
- The data represent only a sampling of national park and wilderness areas; nevertheless, this indicator provides a good picture of the impact of air pollution on the nation's parks and protected areas. As of 2001, the network monitored 110 sites.

Data Source

The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-4, for more information.)

Exhibit 1-13: Visibility trends for U.S. Class I areas



Note: Under the Clean Air Act, a Class I area is one in which visibility is protected more stringently than under the National Air Quality Standards (NAAQS), including national parks, wilderness areas, monuments, and other areas of special national and cultural significance.

Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

1.1.1.d What are the concentrations of toxic air pollutants in ambient air?

Indicator

Ambient concentrations of selected air toxics

Air toxics, also known as hazardous air pollutants, are pollutants that may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects. The Clean Air Act identifies 188 air toxics; some common ones are perchloroethylene (from dry cleaners), mercury (from coal combustion), methylene chloride (from consumer products such as paint strippers), and benzene and 1,3-butadiene (from gasoline). EPA does not set health-based standards for these pollutants; instead, the Clean Air Act mandates a two-phased approach. In the first phase, EPA establishes standards for source categories (major sources, area sources, and mobile sources). In the second phase, EPA

assesses how well the standards are reducing health and environmental risks, and based on these assessments, determines what further actions are necessary to address any significant remaining, or residual, health or environmental risks.

No formal monitoring network for air toxics currently exists, but several metropolitan areas do maintain monitoring programs. Data from these areas provide the basis for an air toxics indicator. Metropolitan areas with air toxics data generally show downward trends (EPA, OAQPS, September 2002). However, although data and tools for assessing risks from air toxics are limited, available evidence suggests that emissions of air toxics may still pose significant health risks in many areas throughout the U.S. (EPA, OAR, September 2002). In addition to ambient concentrations of air toxics, an issue of particular concern is the deposition of toxic air pollutants to surface waterbodies. A pollutant of particular concern is mercury, which accumulates in fish tissue and in humans after they ingest contaminated fish (see Chapter 2, Purer Water; and Chapter 5, Ecological Condition).

Indicator

Ambient concentrations of selected air toxics - Category 2

This indicator reflects data about annual average ambient concentrations of four selected air toxics, in $\mu\text{g}/\text{m}^3$, derived from monitoring sites with sufficient trend data from 1994 to 1999. Selected air toxics are benzene, 1,3-butadiene, total suspended lead, and perchloroethylene (EPA, OAQPS, March 2001).

What the Data Show

Ambient concentrations of the selected air toxics—benzene, 1,3-butadiene, total suspended lead, and perchlorethylene—generally declined between 1994 and 1999, based on the annual average from the reporting sites (EPA, OAQPS, March 2001). The lead concentration level is well below the NAAQS standard (see Section 1.1.1.b in this chapter). Benzene levels, measured at 95 urban monitoring sites, decreased 47 percent from 1994 to 2000 (Exhibit 1-14) (EPA, OAQPS, September 2002).

Indicator Gaps and Limitations

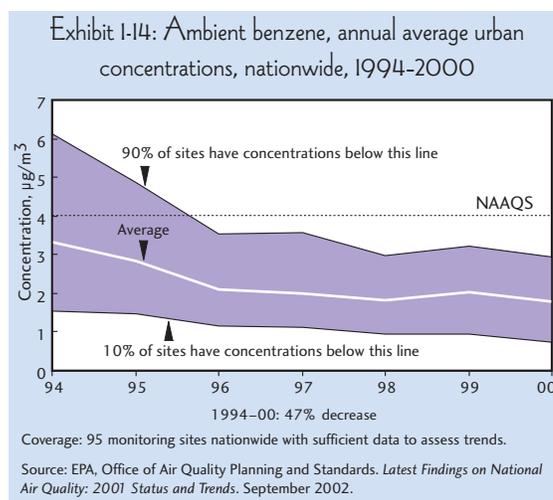
Limitations of this indicator include the following:

- Information is limited because no formal network is currently in place for monitoring ambient concentrations of air toxics; however, EPA and states are working to establish a national toxics monitoring network.
- The indicator reflects trends for selected air toxics, but not for all 188 toxic air pollutants identified under the CAA.
- More information is available for lead than for the other three

selected air toxics. Monitoring stations with sufficient trend data for the other three compounds tend to be concentrated in California, the Great Lakes, southern Texas, and the Northeast.

Data Sources

The data sources for this indicator were *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002, and *National Air Quality and Emissions Trends Report, 1999*, EPA, 2001. (See Appendix B, page B-4, for more information.)



1.1.2 What contributes to outdoor air pollution?

Anthropogenic sources of air pollution range from “stationary sources” such as factories, power plants, agricultural facilities, and smelters, to smaller “area sources” such as dry cleaners and degreasing operations, to “mobile sources” such as cars, buses, planes, trucks, trains, construction equipment, and lawn mowers. Naturally occurring sources such as wind-blown dust, volcanoes, and wildfires add to the total air pollution burden and may be significant on local and regional scales.

Most of the six criteria air pollutants show declining emissions since 1982. But as reported in *Latest Findings on National Air Quality: 2001 Status and Trends*, emissions of NO_x , a contributor to ozone, PM, and acid rain formation, increased by nine percent between 1982 and 2001, with a slight decrease (three percent) between 1992 and 2001 (EPA, OAQPS, September 2002). A significant amount of that increase is attributed to growth in emissions from non-road engines, including construction and recreation equipment and diesel vehicles. EPA continuously reviews and improves estimates of pollutant emissions. Emissions estimates for criteria pollutants are currently under such evaluation and may be updated.

1.1.2.a What are contributors to particulate matter, ozone, and lead in ambient air?

Indicators

Emissions: particulate matter ($\text{PM}_{2.5}$ and PM_{10}), sulfur dioxide, nitrogen oxides, and volatile organic compounds
Lead emissions

Two indicators are available to help answer this question:

- Emissions of particulate matter, sulfur dioxide, nitrogen oxide, and volatile organic compounds.
- Emissions of lead.

Particulate matter can be emitted directly or formed in the atmosphere. “Primary” particles, such as dust from roads and elemental carbon (soot) from wood combustion, are emitted directly into the atmosphere. “Secondary” particles are formed in the atmosphere from primary gaseous emissions. Examples include sulfates, formed from SO_2 emissions from power plants and industrial facilities, and nitrates, formed from NO_x emissions from power plants, automobiles, and other types of combustion sources. The chemical composition of particles depends on factors such as location, time of year, and weather.

The VOCs contributing to ozone formation are emitted from motor vehicles, chemical plants, refineries, factories, consumer and commercial products such as paints and strippers, and other industrial sources. Nitrogen oxides, also an ozone precursor, are emitted primarily from vehicles, power plants, and other combustion sources. Smelters and battery manufacturers are the largest sources of lead in outdoor air.

Indicator

Emissions: particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide, nitrogen oxides, and volatile organic compounds - Category 2

This indicator includes the following data:

- Direct PM emissions are measured in thousands of short tons per year. PM_{10} emissions are presented from 1985 to 2001; emissions of $PM_{2.5}$ from 1992 to 2001.
- Emissions of NO_x and SO_2 presented from 1982 to 2001. Emissions of NO_x contribute to nitrogen loading on land and in water directly and as runoff from land. NO_x is also a precursor of ground-level ozone. Sulfates and nitrates, formed by emissions of SO_2 and NO_x , contribute to acid deposition, which can have significant impacts on aquatic life (see Chapter 2, Purer Water).
- Emissions of VOCs, also precursors of ground-level ozone. These emissions, presented from 1982 to 2001, are measured in thousands of short tons per year.

What the Data Show

Direct emissions of PM_{10} fell by 13 percent between 1992 and 2001 (Exhibit 1-15). Emissions of direct $PM_{2.5}$ also fell, decreasing by 10 percent between 1992 and 2001 (Exhibit 1-16). Sulfur dioxide emissions also decreased by 25 percent between 1982 and 2001 and by 24 percent between 1992 and 2001 (Exhibit 1-17). However, emissions of NO_x increased by 9 percent between 1982 and 2001 and decreased by 3 percent between 1992 and 2001 (Exhibit 1-18) (EPA, OAQPS, September 2002). VOC emissions decreased by 16 percent from 1982 to 2001 and by 8 percent from 1992 to 2001 (Exhibit 1-19) (EPA, OAQPS, September 2002).

Indicator Gaps and Limitations

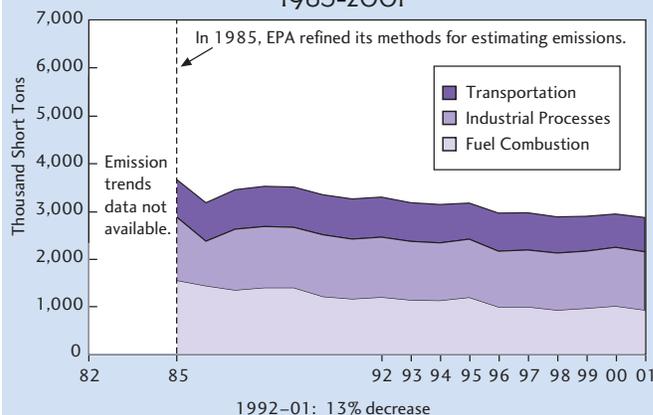
Limitations of this indicator include the following:

- The emissions indicators are estimates; however, consistent estimation methods can provide useful trend data.
- The methodology for estimating emissions is continually reviewed and is subject to revision. EPA is currently conducting such an evaluation of emissions data, and emissions estimates may be updated. Trend data prior to these revisions must be considered in the context of those changes.

Data Source

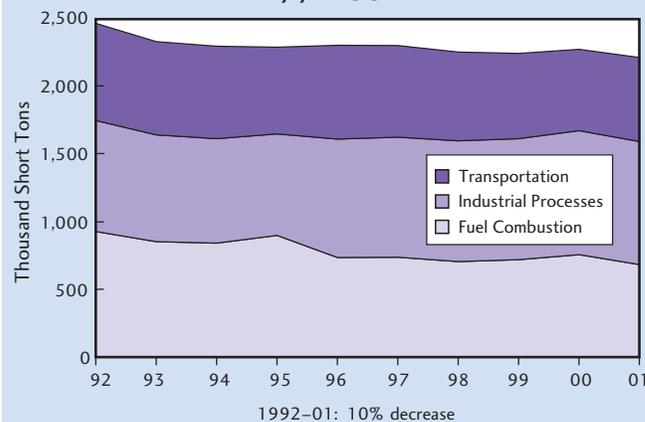
The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-5 for more information.)

Exhibit 1-15: Direct particulate matter (PM_{10}) emissions, 1985-2001



Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Exhibit 1-16: Direct particulate matter ($PM_{2.5}$) emissions, 1992-2001

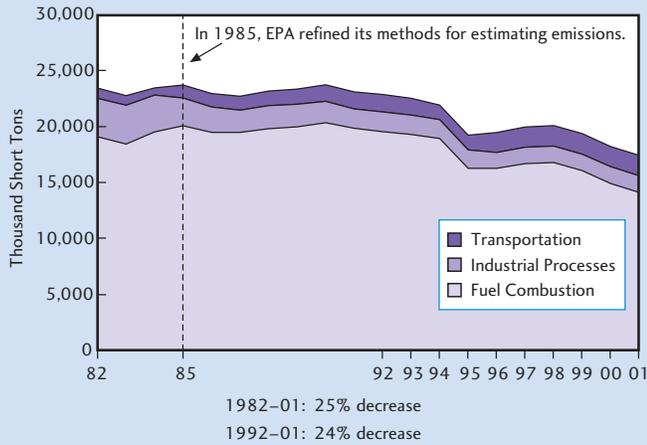


Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Indicator

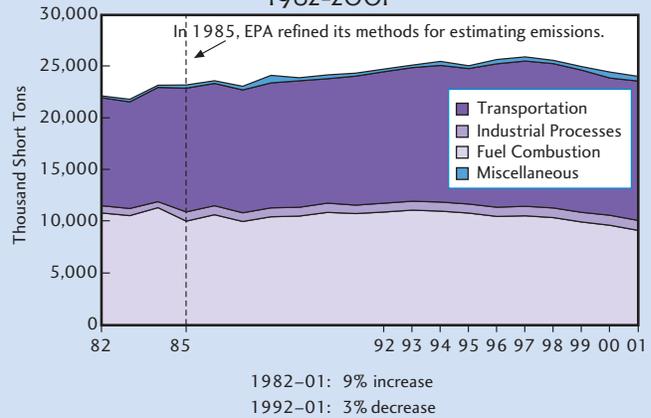
Emissions: particulate matter (PM_{2.5} and PM₁₀), sulfur dioxide, nitrogen oxides, and volatile organic compounds - Category 2 (continued)

Exhibit I-17: Sulfur dioxide (SO₂) emissions, 1982-2001



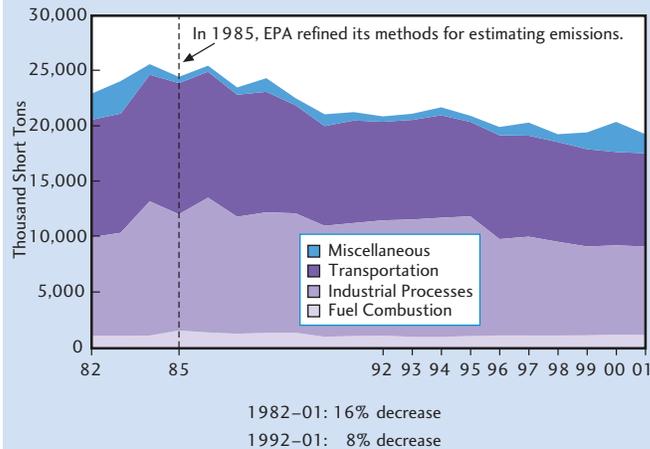
Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Exhibit I-18: Nitrogen oxides (NO_x) emissions, 1982-2001



Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Exhibit I-19: Volatile organic compounds (VOCs) emissions, 1982-2001



Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

Indicator

Lead Emissions - Category 2

This indicator is lead emissions from 1982 to 2001, measured in short tons per year.

What the Data Show

Lead emissions decreased by 93 percent from 1982 to 2001 and by 5 percent from 1992 to 2001 (Exhibit 1-20) (EPA, OAQPS, September 2002). The transportation sector, particularly automotive sources, used to be the major source of lead emissions. The phase-out of lead in gasoline resulted in great declines in lead emissions from the transportation sector over the past 2 decades. Today, industrial processes, primarily metals processing, are the major source of lead emissions to the atmosphere.

Indicator Gaps and Limitations

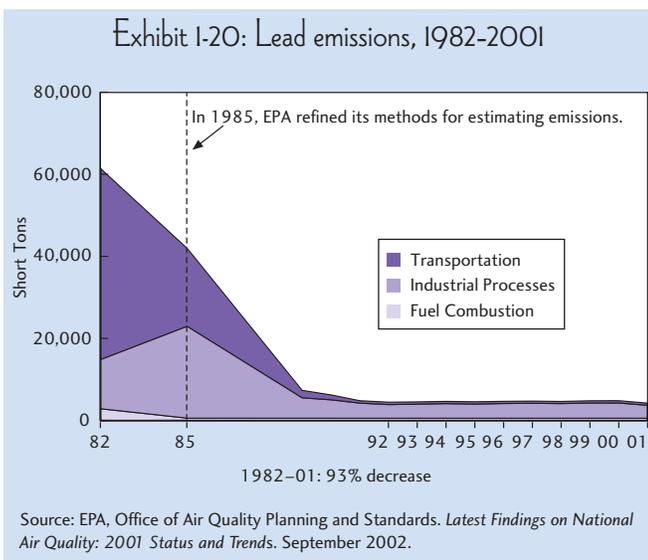
Limitations of this indicator include the following:

- The indicator does not present actual emissions data; thus, it has the inherent limitations of estimates. However, consistent estimation methods can provide useful trend data.

- Estimation is necessary for mobile sources and several area-wide sources.
- The methodology for estimating emissions is continually reviewed and is subject to revision. Trend data for years prior to revisions must be considered in the context of those changes.

Data Source

The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-5, for more information.)



1.1.2.b What are contributors to toxic air pollutants in ambient air?

Indicator

Air toxics emissions

An indicator for air toxics emissions is available to help address this question. The Clean Air Act identifies 188 air toxics. EPA estimates that more than 50 percent of air toxics emissions come from vehicles

and other mobile sources such as aircraft, locomotives, and construction equipment (EPA, OAQPS, September 2002). Other major sources include industrial facilities and area sources such as small dry cleaners and gas stations. Emissions of benzene, come from cars, trucks, oil refineries, and chemical processes. Mercury emissions come from coal combustion and waste incineration and can travel thousands of miles before being deposited in water or on land (see Chapter 2, Purer Water). Some air toxics are also released from natural sources such as volcanic eruptions and forest fires.

Indicator

Air toxics emissions - Category 2

This indicator is national air toxics emissions, in million of tons per year, between the 1990-1993 baseline period and 1996. EPA compiles an air toxics inventory as part of the National Emissions Inventory, which focuses on four sectors—large industrial sources, smaller industrial and natural sources, on-road mobile sources, and non-road mobile sources.

What the Data Show

Estimates show a 24 percent reduction in nationwide air toxics emissions between the baseline period (1990-1993) and 1996—a reduction from 6.11 million to 4.67 million tons per year (Exhibit 1-21) (EPA, OAQPS, September 2002).

Indicator Gaps and Limitations

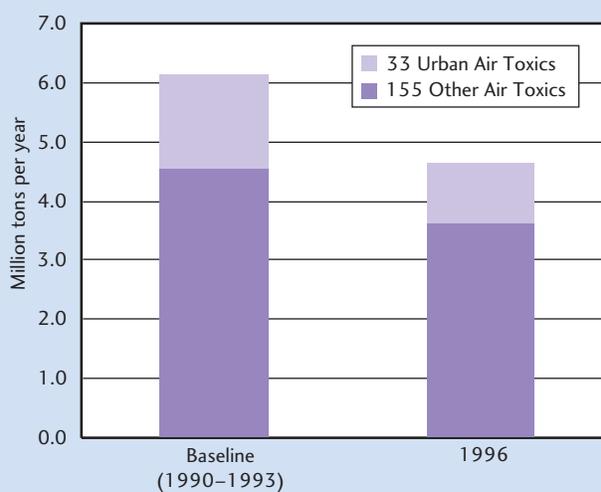
Limitations of this indicator include the following:

- Air toxics emissions estimates are currently available for only 1990 to 1993 (a mix of years depending on data availability on various source types) and 1996.
- The emissions data are based on estimates that are not available on an annual basis.
- The indicator is an aggregate number; actual changes vary among the toxic air pollutants and also vary from one part of the country to another.

Data Source

The data source for this indicator was *Latest Findings on National Air Quality: 2001 Status and Trends*, EPA, 2002. (See Appendix B, page B-6, for more information.)

Exhibit 1-21: National air toxics emissions, 1990-1993, 1996 (total for 188 toxic air pollutants)



Source: EPA, Office of Air Quality Planning and Standards. *Latest Findings on National Air Quality: 2001 Status and Trends*. September 2002.

1.1.2.c To what extent is U.S. air quality the result of pollution from other countries, and to what extent does U.S. air pollution affect other countries?

Air pollution does not recognize political boundaries: ozone and PM, for example, can be transported hundreds or thousands of miles, depending on weather conditions, including wind speeds. Canada and the U.S. have jointly studied ground-level ozone occurrence and transport in eastern North America. Eight-hour ozone measurements for 1988 and 1995 from eastern Canada and the eastern U.S. demonstrate how ozone travels in both directions across the U.S.-Canadian border. The data suggested that ozone was being transported from urban to non-urban areas.

The U.S.-Canada Air Quality Committee studied the relative contribution of sources in each country to the ozone precursors—NO_x and VOCs. According to the report, “anthropogenic sources of NO_x emissions in the U.S. are ten times larger, and VOC emissions are 7 times larger in magnitude than in Canada, paralleling the relative population ratio between the 2 countries.” The study also showed that wind speed can significantly affect ozone transport between the two countries. At low wind speed (<3 meters per second), ozone concentrations were high over major metropolitan areas or close to the sources. At intermediate wind speeds (3 to 6 meters per second), overall concentrations were lower and ozone was transported up to 500 km downwind. At higher wind speeds, higher concentrations were in downwind corners up to 1,000 km away (U.S.-Canada Air Quality Committee, March 1999).

Transboundary air pollution issues are not limited to North America, as demonstrated in the discussion of stratospheric ozone depletion (see Section 1.4 in this chapter). More recently, the U.N. Environment Programme suggested that the so-called Asian Brown Cloud, a 2-mile-thick blanket of pollution over part of South Asia, could travel halfway around the globe in a week (CNN, 2002).

No specific indicators have been identified at this time to address the issue of transboundary air pollution.

1.1.3 What human health effects are associated with outdoor air pollution?

Outdoor air pollution can cause a variety of adverse health effects. Exposure to air pollution can result in short-term health effects and can also contribute to or aggravate chronic conditions. One such

condition is asthma, the leading chronic illness of children in the U.S. and a leading cause of school absenteeism. In 2000, asthma caused 465,000 hospitalizations and about 4,500 deaths in the U.S. (CDC, 2003). Other chronic conditions to which air pollution can contribute include lung cancer, asthma, respiratory disease, and cardiovascular disease.

Some of the criteria pollutants, including ozone, NO₂, and SO₂, are associated primarily with respiratory-related effects, including aggravation of asthma and other respiratory diseases and irritation of the lung and respiratory symptoms (e.g., cough, chest pain, difficulty breathing) (EPA, ORD, 1982, 1986, August 1993, 1994). Carbon monoxide, on the other hand, primarily affects people with cardiovascular disease by reducing oxygen in the blood, leading to aggravation of angina (EPA, ORD, NCEA, 2000).

Short-term exposure to ozone has been linked to lung inflammation and increased hospital admissions and emergency room visits (EPA, ORD, NCEA, July 1996). Repeated short-term exposures to ozone may damage children's developing lungs and may lead to reduced lung function later in life; long-term exposures to high ozone levels are a possible cause of increased incidence of asthma in children engaged in outdoor sports (McConnell, et al., 2002). Efforts to control automobile traffic in Atlanta during the 1996 Summer Olympic Games were associated with a 28 percent reduction in peak daily ozone concentrations during the Games and a significantly lower rate of childhood asthma events (Friedman, et al., 2001).

When EPA introduced a new 8-hour ozone ambient standard in 1997, it estimated that meeting the standard would reduce the risk of significant decreases in children's lung functions (such as difficulty in breathing or shortness of breath) by about 1 million incidences per year and would result in thousands of fewer hospital admissions and visits for people with asthma (EPA, OAQPS, July 1997).

Exposure to airborne particulate matter is associated with a broader range of health problems, including respiratory-related and cardiovascular effects. For example, short-term exposures to PM may aggravate asthma and bronchitis and have been associated with heartbeat irregularities and heart attacks. PM exposures have been linked to increased school absences and lost work days, hospital admissions and emergency room visits, and even death from heart and lung diseases (EPA, ORD, NCEA, April 1996). Long-term exposures have also been linked to deaths from heart and lung diseases, including lung cancer (EPA, ORD, NCEA, 2002; Pope, et al., 2002).

When EPA established new PM_{2.5} standards in 1997, it estimated that meeting the standard would save about 15,000 lives each year, especially among the elderly and those with existing heart and lung diseases. The Agency said the new standard would reduce hospital admissions by thousands each year; reduce risk of symptoms associated with chronic bronchitis by tens of thousands each year; and avoid hundreds of thousands of incidences of asthma each year (EPA, OAQPS, July 1997).

Lead, both a criteria pollutant and a toxic air pollutant, has significant health effects. Elevated blood lead levels are associated with behavioral problems, neurological effects, and lowered IQ (EPA, OAQPS, September 2002). The decrease in the average level of lead in children's blood reflects declines in ambient lead levels by 93 percent from 1982 to 2001—largely the result of regulations reducing lead content in gasoline (EPA, OAQPS, September 2002).

Toxic or hazardous air pollutants may cause many other less common but potentially hazardous health effects, including cancer and damage to the immune system, and neurological, reproductive, and developmental problems. Acute exposure to some air toxics can cause immediate death. Many of these pollutants can cause serious health damages even at relatively low concentrations. National emission standards have been established for eight of the 188 listed hazardous air pollutants: asbestos, mercury, beryllium, benzene, vinyl chloride, arsenic, radionuclides, and coke oven emissions.

The National-Scale Air Toxics Assessment, a nationwide analysis of air toxics, develops health risk estimates for 33 toxic air pollutants using computer modeling of the 1996 National Emissions Inventory air toxics data. Based on the assessment, chromium, benzene, and formaldehyde appear to pose the greatest nationwide carcinogenic risk (EPA, OAR, September 2002). Benzene exposure has been linked to increases in the risk of leukemia and multiple myeloma (EPA, OAQPS, July 1995).

No specific indicators have been identified at this time to address the health effects associated with outdoor air pollution. For additional discussion of air pollution and associated health effects, see Chapter 4, Human Health.

1.1.4 What ecological effects are associated with outdoor air pollution?

Outdoor air not only has the potential to affect human health, but also transports pollutants and deposits them onto soils or surface waters. There, the pollutants can cause ecological effects and damage to property. Ground-level ozone damages plants and crops. It interferes with the ability of plants to produce and store food, reducing overall plant health and the ability to grow and reproduce. The weakened plants are more susceptible to harsh weather, disease, and pests. Through its effects on plants, ozone also can pose risks to ecological functions such as water movement, mineral nutrient cycling, and habitats for various animal and plant species (see Chapter 5, Ecological Condition).

Airborne nitrogen species (including the criteria pollutants NO₂ and particulate nitrate) can contribute to excess nitrogen levels in ecosystems. These excess nitrogen levels can result in:

- Changes in plant and soil community species diversity.
- Altered community structure.
- Eutrophication in surface and coastal waters.
- Acidified soils and waters (see Chapter 2, Purer Water).

Airborne sulfur species (including the criteria pollutants SO₂ and particulate sulfate) can also contribute excess sulfur to ecosystems, which can lead to acidification of the soils and related effects. When deposited together, airborne nitrogen and sulfur species are known as acid deposition. (See the discussion of acid deposition in Section 1.2 of this chapter.)

Land and water can be contaminated by deposition of air toxics, leading to contamination of plants and animals and, eventually, of humans further up the food chain. Airborne mercury from incineration, for example, can settle in water and contaminate fish (see Chapter 2, Purer Water). People who eat fish are then exposed to mercury, which is known to be harmful to the nervous system.

No specific indicators have been identified at this time to address the ecological effects associated with outdoor air pollution. Additional discussion of the ecological effects associated with outdoor air pollution is found in Chapter 5, Ecological Condition.

1.2 Acid Deposition

Sulfur dioxide and NO_x emissions in the atmosphere react with water, oxygen, and oxidants to form acidic components, also referred to as acid deposition or "acid rain." Air contaminants can be deposited on land or water through precipitation (wet deposition) or directly by dry deposition. Wet acid deposition is monitored by the National Atmospheric Deposition Program/National Trends Network, a cooperative program of federal and state agencies, universities, electric utilities, and other industries. Dry deposition is measured by the Clean Air Status and Trends Network (CASTNET), operated by EPA and the National Park Service.

The acidity in precipitation in the eastern U.S. is at least twice as high as in pre-industrial times (EPA, ORD, January 2003). To reduce emissions of SO_2 and NO_x , EPA established the Acid Rain Program under the Clean Air Act. This program focuses on the largest and highest-emitting coal-fired power plants, which are significant contributors to acid deposition.

This section addresses the following questions:

- What are the deposition rates of pollutants that cause acid rain? (Section 1.2.1)
- What are the emissions of pollutants that form acid rain? (Section 1.2.2)
- What ecological effects are associated with acid deposition? (Section 1.2.3)

1.2.1 What are the deposition rates of pollutants that cause acid rain?

Indicators

Deposition: wet sulfate and wet nitrogen

Efforts to reduce sulfur dioxide and nitrogen oxides emissions from power plants have helped to significantly reduce wet sulfate deposition and to contain increases in nitrogen deposition. Wet sulfate deposition levels for 1999 to 2001 showed reductions of 20 to 30 percent compared to levels for 1989 to 1991 over widespread areas in the Midwest and the Northeast, where acid rain has had its greatest impact. Nitrogen deposition levels showed no major changes. Although NO_x emissions from power plants decreased, nitrogen emissions from sources other than power plants (e.g., motor vehicles, non-road vehicles, and agricultural activities) increased between 1990 and 2001 (EPA, OAR, November 2002).

Deposition of wet sulfate and wet nitrogen is the indicator used to address this question.

Indicator Deposition: wet sulfate and wet nitrogen - Category 2

Measures of wet sulfate and wet nitrogen deposition in kilograms per hectare (kg/ha), are a key indicator of acid deposition.

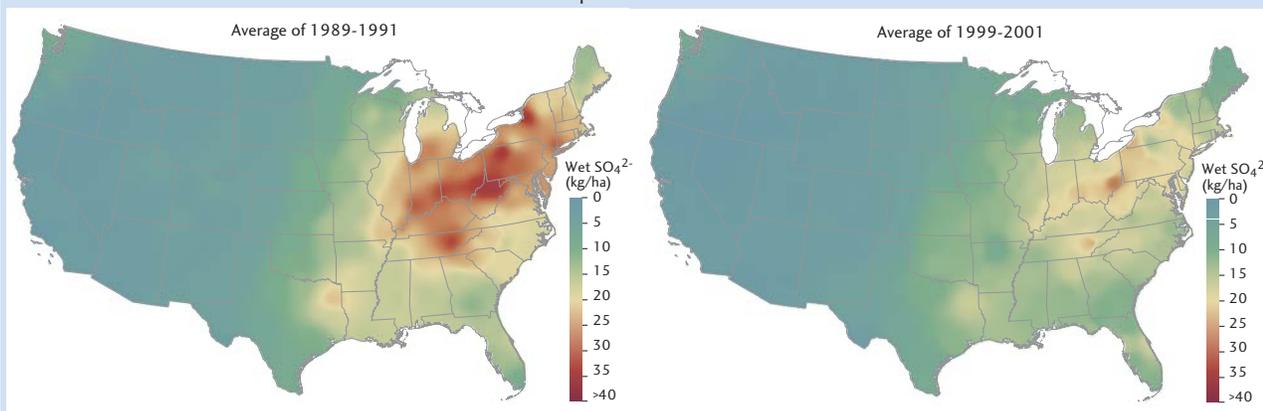
What the Data Show

Wet sulfate decreased substantially throughout the Midwest and Northeast between 1989-1991 and 1999-2001 (Exhibit 1-22). By 2001, wet sulfate deposition had decreased more than 8 kilograms per hectare (kg/ha) from 30-40 kg/ha/year in 1990 in much of the Ohio River Valley and northeastern U.S. The greatest

reductions occurred in the mid-Appalachian region (EPA, OAR, November 2002).

There were no dramatic regional changes in wet nitrogen deposition between 1989-1991 and 1999-2001 (Exhibit 1-23). Since 1990, nitrogen deposition decreased slightly in areas of the eastern U.S., while increases occurred in some areas with significant agricultural activity (e.g., the Plains and coastal North Carolina) or substantial mobile source emissions (e.g., southern California). (EPA, OAR, November 2002).

Exhibit I-22: Wet sulfate deposition, 1989-1991 vs. 1999-2001

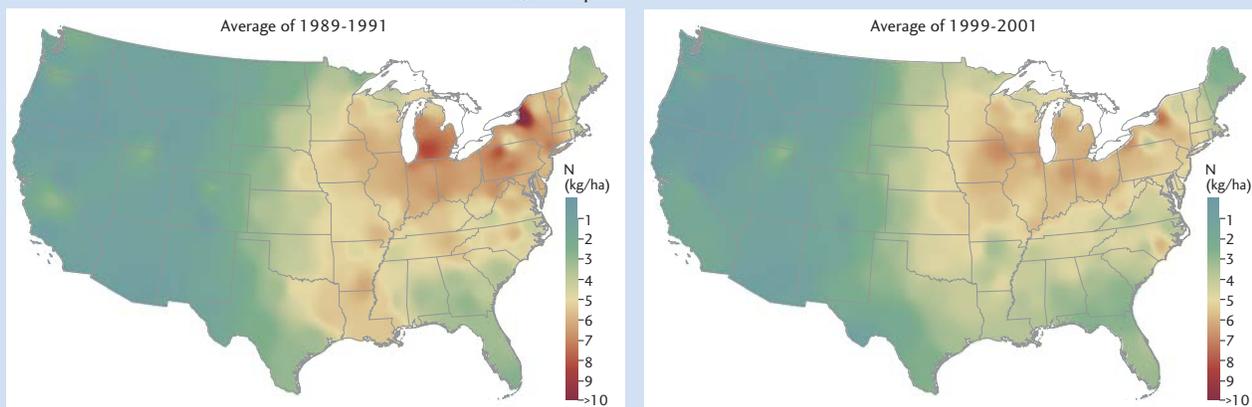


Coverage : 250 National Atmospheric Deposition Program National Trends Network (NADP/NTN) monitoring stations located throughout the lower 48 states.

Note: Map colors represent relative concentrations and do not imply ecological or human health status

Source: EPA, Office of Air and Radiation, Clean Air Markets Program. EPA Acid Rain Program: 2001 Progress Report. November 2002.

Exhibit I-23: Wet nitrogen deposition, 1989-1991 vs. 1999-2001



Coverage : 250 National Atmospheric Deposition Program National Trends Network (NADP/NTN) monitoring stations located throughout the lower 48 states.

Note: Map colors represent relative concentrations and do not imply ecological or human health status

Source: EPA, Office of Air and Radiation, Clean Air Markets Program. EPA Acid Rain Program: 2001 Progress Report. November 2002.

Indicator

Deposition: wet sulfate and wet nitrogen - Category 2 (continued)

Wet and dry sulfur deposition make up roughly the same percentages of total sulfur deposition in the Midwest, whereas, in most other areas, wet deposition makes up a greater percentage of the total. Wet deposition also makes up most of the total nitrogen deposition load at the majority of the monitoring sites in the eastern U.S. In southern California, dry deposition makes up a greater percentage of the total (Exhibit 1-24).

Using National Atmospheric Deposition Program data, a U.S. Department of Agriculture (USDA) report on sustainable forests observed that annual wet sulfate deposition decreased significantly between 1994 and 2000, especially in the North and South Resource Planning Act regions, where deposition was the highest. Nitrate deposition rates were lowest in the Pacific and Rocky Mountain regions, where approximately 84 percent of the regions experienced deposition rates of less than 4.2 pounds per acre (4.8kg/ha) per year. Only 2 percent of the sites in the eastern U.S. received less than that amount (USDA, FS, 2002).

monitoring sites for both in coastal areas in the Southeast would support improved measurement of nitrogen deposition to estuaries. Additional dry deposition monitoring would provide a better understanding of acid deposition in the Ohio Valley and Central and Rocky Mountain areas.

- Measurement techniques for dry deposition have improved substantially, but still lag behind operational wet deposition techniques.

Data Source

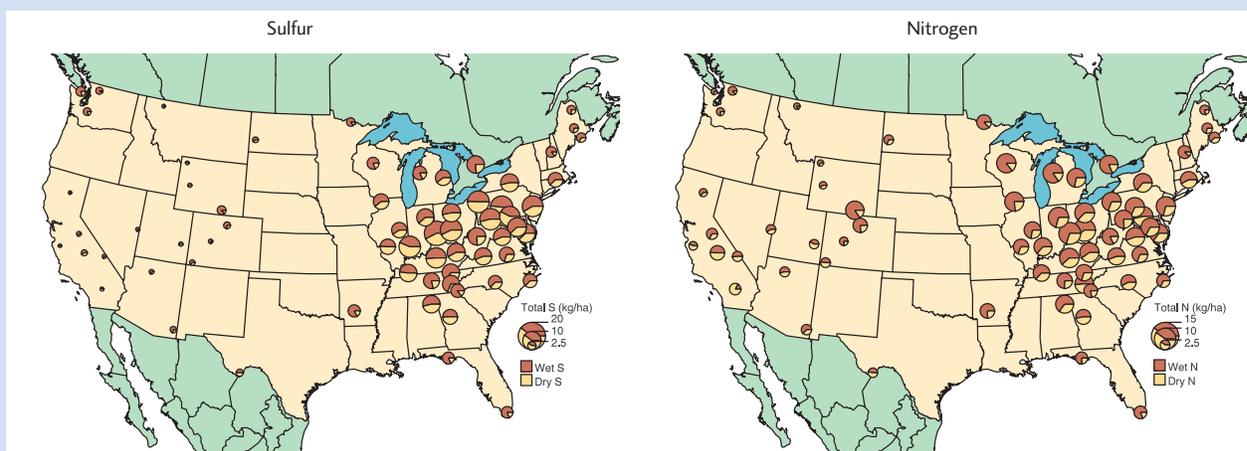
The data source for this indicator was *EPA Acid Rain Program: 2001 Progress Report*, EPA, 2002. (See Appendix B, page B-6, for more information.)

Indicator Gaps and Limitations

Limitations of this indicator include the following:

- Geographic coverage is limited for measuring wet deposition and even more so for measuring dry deposition. Additional

Exhibit 1-24: Total sulfur and total nitrogen deposition, 2001



Coverage: 70 Clean Air Status and Trends Network (CASTNet) monitoring stations concentrated in the eastern half of the lower 48 states.

Note: The size of the "pies" indicates the total magnitude of deposition; the colors indicate the percentage of wet and dry deposition.

Source: EPA, Office of Air and Radiation, Clean Air Markets Program. *EPA Acid Rain Program: 2001 Progress Report*. November 2002.

1.2.2 What are the emissions of pollutants that form acid rain?

Indicators

Emissions (utility): sulfur dioxide and nitrogen oxides

Acid deposition occurs when emissions of SO₂ and NO_x in the atmosphere react with water, oxygen, and oxidants to form acidic

compounds. Electric utility plants that burn fossil fuels are a significant source of SO₂ and NO_x and monitor their emissions continuously. NO_x is also emitted from other high-temperature combustion sources, including automobiles.

The indicator used to address this question is emissions of sulfur dioxide and nitrogen oxides from utilities.

Indicator

Emissions (utility): sulfur dioxide and nitrogen oxides - Category 2

This indicator is millions of tons of NO_x and SO₂ emissions from sources covered under the Acid Rain Program from 1990 to 2001 and 1980 to 2001, respectively. These emissions data are an important component of a market-based trading program to reduce emissions and consequent impacts on the environment.

What the Data Show

SO₂ emissions from sources covered under the Acid Rain Program were 10.6 million tons in 2001, compared to 15.7 million tons in 1990. Emissions of NO_x from these sources declined from 6.7 million tons in 1990 to 4.7 million tons in 2001 (Exhibit 1-25) (EPA, OAR, June 2002).

Indicator Gaps and Limitations

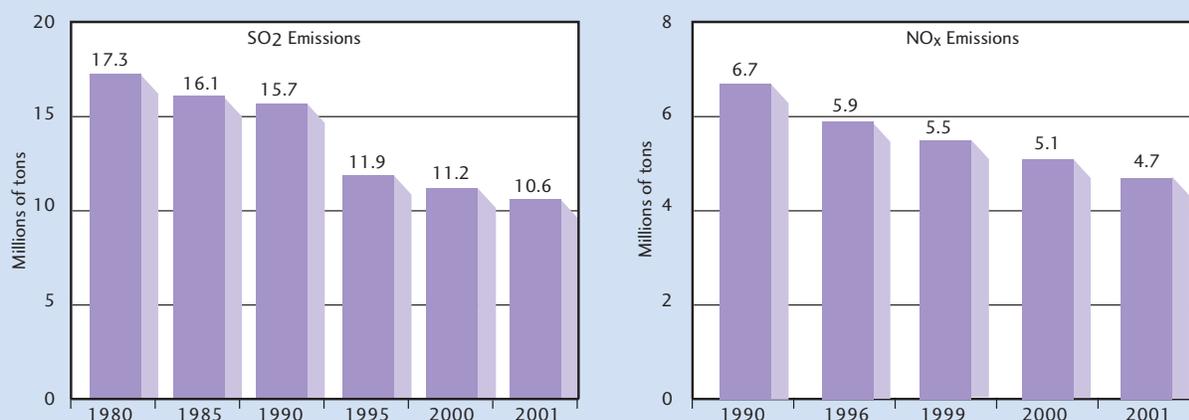
Limitations of this indicator include the following:

- Although electric utilities and large boilers are key sources of SO₂ and NO_x, they are not the only sources. It is estimated that about 64 percent of annual SO₂ emissions and 26 percent of NO_x emissions are produced by electric utility plants that burn fossil fuels (EPA, OAQPS, September 2002).
- Information on mobile source emissions is particularly useful for completing the picture of NO_x contributions to acid deposition.

Data Source

The data source for this indicator was *EPA Acid Rain Program: 2001 Progress Report*, Appendices A and B1, EPA, 2002. (See Appendix B, page B-6, for more information.)

Exhibit 1-25: Power plant sulfur dioxide (SO₂), 1980-2001, and nitrogen oxides (NO_x), 1990-2001, emissions



Source: EPA, Office of Air and Radiation, Clean Air Markets Program. *EPA Acid Rain Program: 2001 Progress Report*. November 2002. Appendix A: Acid Rain Program - Year 2001 SO₂ Allowance Holdings and Deductions. (April 8, 2003; <http://www.epa.gov/airmarkets/cmrprt/arp01/appendix.pdf>) and Appendix B1: 2001 Compliance Results for NO_x Affected Units. (April 8, 2003; <http://www.epa.gov/airmarkets/cmrprt/arp01/appendixb1.pdf>).

1.2.3 What ecological effects are associated with acid deposition?

Increased acid levels damage soils, lakes, and streams, rendering some waterbodies unfit for certain fish and wildlife species. Indirect effects of acid deposition are also responsible for damage to forest ecosystems (see Chapter 5, Ecological Condition). Acidic ions in the soil displace calcium and other nutrients from plant roots, inhibiting growth. Acidic deposition can also mobilize toxic amounts of aluminum, increasing its availability for uptake by plants and by fish and other aquatic life (EPA, OAR, November 2002).

The nitrogen in acid rain adds to the total loading of nitrogen in waterbodies. As coastal ecosystems become overly rich in nitrogen, conditions favor more frequent and more severe emergence of algal blooms, which deplete oxygen, harming fish and reducing plant and animal diversity (see Chapter 2, Purer Water).

A recent report assessing deposition-related changes in surface water chemistry in the northern and eastern U.S. found that the Clean Air Act has resulted in a large and widespread decrease in the deposition of sulfur by approximately 40 percent in the 1990s. In the same period, surface water sulfate concentrations declined in all regions except the Ridge and Blue Ridge provinces (Virginia). Acid neutralizing capacity (ANC), a key indicator of recovery, increased in three of the regions (Adirondacks, Northern Appalachian Plateau and Upper Midwest) and was unchanged in the New England and the Ridge/Blue Ridge region. Modest increases in ANC have reduced the number of acidic lakes and stream segments in some regions:

- In the Adirondacks, 8.1 percent of lakes (150 lakes) were acidic in 2000. In the early 1990s, 13 percent (240 lakes) were acidic.
- In the Upper Midwest, an estimated 80 of 250 lakes that were acidic in the mid-1980s are no longer acidic.
- In the Northern Appalachian Plateau region in 2000, there were an estimated 3,393 kilometers (2,104 miles) of acidic streams in the region, or 7.9 percent of the total population; this compares to 5,014 kilometers (3,109 miles) of acidic streams (12 percent) in 1993-94.
- There was no evidence of recovery in New England, or in the Ridge and Blue Ridge Provinces; the latter region is not expected to recover immediately, due to the nature of forest soils in the province.
- In the three regions showing recovery, approximately one-third of formerly acidic surface waters are no longer acidic, although still subject to episodes of acidification.
- Nitrogen deposition levels changed little between 1989 and 2001, and surface water nitrate concentrations are largely unchanged as well. Nitrogen deposition remains a concern, because future increases in surface water nitrate concentrations could retard surface water recovery (EPA, ORD, January 2003).

No specific indicators have been identified at this time to address the ecological effects associated with acid deposition.

1.3 Indoor Air Quality

People in the U.S. spend 90 percent of their time indoors, and indoor air pollutant levels may exceed those allowable outside. Radon and environmental tobacco smoke (ETS) are the two indoor air pollutants of greatest concern from a health perspective (EPA, ORD, December 1992; NRC, 1988).

Although methods to monitor and measure indoor air quality (IAQ) exist, there is no practical way to assess the general quality of indoor air nationwide. There are millions of residences, thousands of workplaces, and more than a hundred thousand schools in the U.S., and representative samples are not practical because of cost and access issues. This section, therefore, presents indoor air quality data from limited studies, not from ongoing monitoring efforts.

This section addresses the following questions:

- What is the quality of the air in buildings in the United States? (Section 1.3.1)
- What contributes to indoor air pollution? (Section 1.3.2)
- What human health effects are associated with indoor air pollution? (Section 1.3.3)

1.3.1 What is the quality of the air in buildings in the United States?

Indicators

U.S. homes above EPA's radon action levels
Percentage of homes where young children are exposed to environmental tobacco smoke

While it is difficult to make general statements about the quality of indoor air nationwide, two studies—the National Residential Radon Survey and an analysis of ETS exposure based on data from the National Health Interview Survey—offer important insights. These studies provide data about residential levels of radon and ETS, presented in the description of two indicators on the following pages.

In addition, several studies have attempted to characterize environmental issues inside office buildings and schools. The Building Assessment Survey and Evaluation (BASE) study, conducted from 1994 to 1998, is a study of office IAQ. The study was designed with input from more than 40 national IAQ experts and reviewed by the EPA Science Advisory Board. The consensus of these national experts was that a sample of 100 to 200 office buildings would be sufficient to characterize the central tendency of IAQ in office buildings nationwide.

Limited information about IAQ in schools is available from a 1999 survey of about 900 public schools by the National Center for Education Statistics. This survey addressed concerns related to

environmental conditions, defined as lighting, heating, ventilation, IAQ, acoustics or noise control, and physical security of buildings. In all, 43 percent of schools responded that at least one environmental condition was unsatisfactory. Ventilation was the most often cited environmental issue of concern (DOE, NCES, 2000).

In addition to the indoor pollutants discussed above, pesticides also may pose IAQ concerns. Approximately three-quarters of U.S. households use at least one pesticide product indoors during the course of a year. Products used most often are insecticides and disinfectants. The EPA Nonoccupational Pesticide Exposure Study (NOPES), published in 1990, assessed exposure to airborne pesticides in Jacksonville, Florida, and in Springfield and Chicopee, Massachusetts. Indoor sources accounted for 90 percent or more of the total airborne exposure to most of these pesticides. NOPES found that tested households had at least 5 pesticides in indoor air, at levels often 10 times greater than levels measured in outdoor air (EPA, AREAL, January 1990). Some of the pesticides had been banned or otherwise regulated by EPA (e.g., aldrin, dieldrin, heptachlor, and chlordane), but continued to be found in the homes. Since these pesticides previously were widely used to prevent termites, they are believed to have entered the homes via diffusion of soil gas into basements, similar to the way radon enters homes. Another pesticide, DDT, banned for nearly 20 years, was found in house dust in five out of eight homes (EPA, AREAL, January 1990). Later studies, including measurements in soil just outside

the home, suggested that DDT and other long-lasting pesticides can be tracked in from soil clinging to shoes.

No comprehensive nationwide information is available on the amount of pesticides used in the nation's 11,000 public schools. The federal government has not collected such data, and only one state, Louisiana, requires its school districts to specifically report the amount of pesticides used (GAO, 1999).

This report uses two indicators, discussed below, to address the question, "What is the quality of air in the buildings in the United States?":

- U.S. homes above EPA radon action levels.
- Percentage of homes where young children are exposed to ETS.

Indicator

U.S. homes above EPA's radon action levels - Category 2

Naturally occurring radon gas is formed by the decay of uranium in rock, soil, and water. Radon enters a home by moving up from rock and soil and into the building through cracks or other holes in the foundation.

The amount of radon gas in the air is measured in picocuries per liter of air or pCi/L. EPA has set a recommended "action level" of four pCi/L for homes and schools to reduce the risk of lung cancer.

What the Data Show

A 1991 representative survey of all housing units in the United States estimated that six percent of U.S. homes (5.8 million in 1990) had an annual average radon level of more than four picocuries per liter (pCi/L) in indoor air. Also, about 56 percent of Americans' exposure to radon occurs in homes with two pCi/L or more. Single-family detached homes were four times more likely to require mitigation than multi-family homes. The survey's findings were used in constructing EPA's estimate of U.S. lung cancer risks from radon, in setting the four pCi/L action level, and in crafting

testing and mitigation guidance for the American public (EPA, OAR, October 1992).

Indicator Data Gaps and Limitations

The study is several years old and may not reflect changes brought about as a result of significant EPA radon public education campaigns since that time. Since the mid-1980s, about 18 million homes have been tested for radon and about 700,000 of them have been mitigated. In addition, since 1990 approximately one million new homes have been built with radon-resistant features.

Data Source

The data source for this indicator was *National Radon Residential Survey: Summary Report* EPA, 1992. (See Appendix B, page B-7, for more information.)

Indicator

Percentage of homes where young children are exposed to environmental tobacco smoke - Category 2

Environmental tobacco smoke (ETS)—smoke emitted from the burning end of a cigarette, pipe, or cigar, and smoke exhaled by a smoker—is a complex mix of more than 4,000 chemical compounds, containing many known or suspected carcinogens and toxic agents, including particles, carbon monoxide, and formaldehyde.

What the Data Show

The National Center for Health Statistics has conducted a major nationwide survey, known as the National Health Interview Survey, continuously since 1957. The survey estimated that in 1998, young children were exposed to ETS in 20 percent of homes in the U.S.—down from approximately 39 percent in 1986. About 43,000 households and 106,000 people participated in the survey (DHHS, NCHS, 2001).

Indicator Data Gaps and Limitations

The estimate is not based on a specific question about children's exposure to ETS, but rather is calculated based on the number of houses with smokers and with children.

Data Source

The data source for this indicator was *Healthy People 2000 Final Review*, Department of Health and Human Services, National Center for Health Statistics, 2001. (See Appendix B, page B-7, for more information.)

1.3.2 What contributes to indoor air pollution?

Indoor air pollutants come from a wide array of sources. In considering the potential impact of these sources on indoor air quality, it is vital to recognize the exchange between indoor and outdoor air. Exchange rates vary considerably from building to building, from one part of the country to another, and by seasons. Tight building construction improves energy efficiency but reduces indoor-outdoor air exchange and may contribute to indoor air pollution.

Among the sources of indoor air pollution are:

- Combustion of fuel used for heating and cooking, including oil, gas, kerosene, coal, and wood.
- Environmental tobacco smoke.
- Some adhesives, paints, and coatings (building materials).
- Furniture made of certain pressed wood products.
- Deteriorated, asbestos-containing insulation.
- Some products for household cleaning and maintenance, personal care, or hobbies.
- Inadequate maintenance of central heating and cooling systems.
- Radon, pesticides, and outdoor air pollution.
- Biological sources, including animal dander, cockroaches, dust mites, molds, and fungi.

1.3.3 What human health effects are associated with indoor air pollution?

In general, indoor air pollution can cause headaches, tiredness, dizziness, nausea, and throat irritation. More serious effects include cancer and exacerbation of chronic respiratory diseases, such as asthma. The most sensitive and vulnerable population groups—the elderly, the young, and the infirm—tend to spend the most time indoors; therefore, they may face higher than usual exposures.

Radon is estimated to be the second leading cause of lung cancer in the U.S. In an EPA-sponsored study, the National Research Council (NRC) found between 15,000 and 22,000 radon-related lung cancer deaths annually in the U.S. (NRC, 1998).

Environmental tobacco smoke causes eye, nose, and throat irritation, and is a carcinogen. Children exposed to ETS are at increased risk for respiratory problems and experience increased episodes of asthma (Mannino, et al., 2001). In studies of lifelong nonsmoking women, there was a 24 percent excess risk of lung cancer as a result of ETS exposures from a spouse's smoking (Hackshaw, 1998).

Asthma, particularly in children, is associated with poor indoor air quality. Dust mite proliferation in moist indoor environments can lead to asthma attacks. Other allergens and irritants such as animal dander, ETS, pesticide sprays, cockroach particles, and chemical fumes from household products have also been shown to increase asthma attack rates (IOM, 2000).

Fungal spores from mold growth in moist areas in homes have been associated with health effects in occupants, including allergies and asthma (IOM, 1993). Headaches, respiratory distress, and cardiovascular effects are also associated with exposure to molds.

No specific indicators have been identified at this time to address the human health effects associated with indoor air pollution.

1.4 Stratospheric Ozone

Although ozone is a harmful pollutant at ground level, it plays a valuable role in the stratosphere—the part of the atmosphere at an altitude of 10 to 30 km—by filtering harmful radiation from the sun. The sun's radiation bathes the Earth in ultraviolet (UV) wavelengths of 150 to 400 nanometers (nm). Ultraviolet radiation in the band between 280 and 320 nm, known as UV-B, is harmful to most organisms.

About 90 percent of the planet's ozone at a given time is in a thin layer of the lower stratosphere called the ozone layer, which also includes other gases. Ozone is constantly being created and destroyed by UV radiation. About 95 to 99 percent of UV-B radiation that reaches the Earth's surface is absorbed by ozone and oxygen in the ozone layer (NASA, 2002).

The ozone layer varies in space and time and is highly susceptible to changes in atmospheric chemical reactions by which it is created and destroyed. Scientists in the 1970s and 1980s discovered that human-caused changes to the composition of the atmosphere were leading to depletion of stratospheric ozone (NASA, 2002). They initially identified chlorofluorocarbons (CFCs) as being particularly significant stratospheric ozone depleters. Scientists subsequently identified additional human-produced ozone-depleting substances (ODSs).

This section poses four questions about stratospheric ozone:

- What are the trends in the Earth's ozone layer? (Section 1.4.1)
- What is causing changes to the ozone layer? (Section 1.4.2)
- What human health effects are associated with stratospheric ozone depletion? (Section 1.4.3)
- What ecological effects are associated with stratospheric ozone depletion? (Section 1.4.4)

1.4.1 What are the trends in the Earth's ozone layer?

Indicators

Ozone levels over North America

The most recent authoritative assessment of the Earth's stratospheric ozone is the *Scientific Assessment of Ozone Depletion: 2002* (Scientific Assessment Panel, 2003), conducted under the auspices of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The study found an average decrease of about 6 percent in average ozone concentrations between 35 and 60 degrees South for the period 1997 to 2001, compared with pre-1980 average values. It also found an

average decrease of 3 percent between 35 and 60 degrees North for the same period (Scientific Assessment Panel, 2003).

It is generally believed that, after years of continuing thinning of the stratospheric ozone layer, the ozone layer will recover over the next several years as a result of international controls of ODSs. The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol), for example, restricts global manufacturing of CFCs (Scientific Assessment Panel, 2003).

Scientists largely agree that a thinning of the stratospheric ozone layer causes an increase in the amount of UV radiation, especially UV-B, that reaches the Earth's surface. This outcome is consistent with theories about the physical processes involved, measurable locally by ground-based and satellite-based instruments.

While acknowledging high uncertainty in the estimates, it is estimated that UV irradiance has increased since the early 1980s by 6 to 14 percent at more than ten sites distributed over mid and high latitudes of both hemispheres. Over the past two decades, UV increases are believed to have been considerably greater at higher latitudes. In the Northern Hemisphere, they are believed to be greater in the winter/spring than in the summer/fall (Scientific Assessment Panel,

2003). The estimates of increasing UV-B levels are based on indirect methods and models rather than direct measurements.

Because of the phase-out of ODS, total stratospheric concentrations of ODS seem to have peaked; it is believed that stratospheric ozone concentrations, near the lowest point since systematic measurements began, will not decrease any further and will eventually recover. These developments lead to the conclusion that UV radiation levels reaching the Earth's surface are close to the maximum they will reach as a result of human-induced stratospheric ozone depletion (Scientific Assessment Panel, 2003).

Obtaining reliable measurements of broad trends in levels of UV radiation reaching ground level in North America, however, is a complex task. It is particularly challenging to measure in ways that highlight the relationship between ozone depletion and UV radiation. The amount of incoming UV radiation is affected by several variables, including latitude, season, time of day, snow cover, sea ice cover, surface reflectivity, altitude, clouds, and aerosols. Determining which portion of any change is attributable to ozone depletion is difficult.

The indicator used to address the extent of change to the ozone layer is ozone levels over North America.

Indicator Ozone levels over North America, - Category I

Data mapped for this indicator are derived from the Total Ozone Mapping Spectrometer (TOMS), flown on NASA's Nimbus-7 satellite. The TOMS measures amounts of backscattered UV radiation at various wavelengths. Backscattered radiation levels at wavelengths where ozone absorption does and does not take place are compared with radiation directly from the sun at the same wavelengths, allowing scientists to derive a "total ozone" amount in the Earth's atmosphere.

The data for this indicator are presented in Dobson Units (DU) which measure how thick the ozone layer would be if compressed in the Earth's atmosphere (at sea level and at 0°C.) One DU is defined to be 0.01 mm thickness at standard temperature and pressure.

What the Data Show

The ozone maps illustrate graphically and quantitatively the thinning of total column ozone over North America during a 15-year period. For example, in 1979, the ozone column over the Seattle

area was 391 Dobson Units (DU), but in 1994 it had dropped to 360 DU. Over Los Angeles, the ozone column during that time dropped from 368 DU to 330 DU, and over Miami from 303 DU to 296 DU (Exhibit 1-26) (NASA, March 1979 and March 1994). Although exact calculations cannot be made from Exhibit 1-26, the graph demonstrates thinning of the ozone layer over much of the globe.

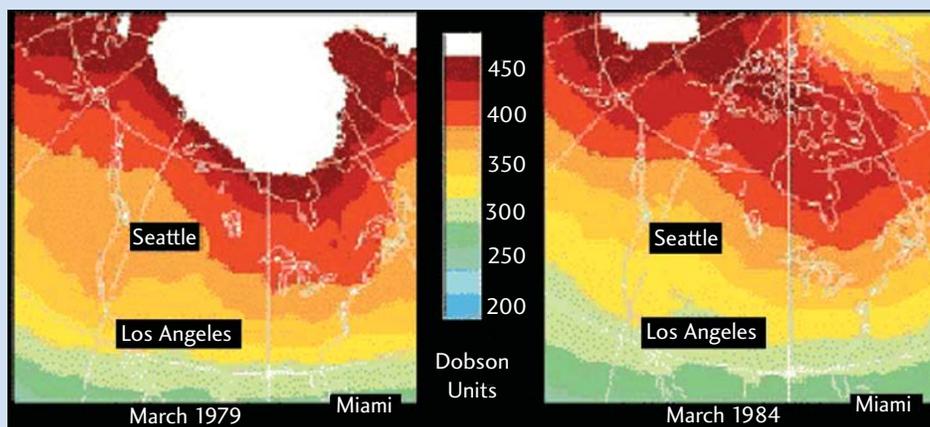
In general, ozone depletion is greater at higher latitudes. Therefore, it is predictable that the decrease in the ozone layer over Seattle is greater than over Los Angeles, with the ozone layer over Miami experiencing the lowest depletion among the three cities. However, southern cities also have higher levels of UV-B, so even with less depletion, the net increase in UV-B can exceed that over northern latitudes.

According to the latest estimates in the *Scientific Assessment*, the global-average total column ozone during 1997 to 2001 was about 3 percent below average pre-1980 values (Scientific

Indicator

Ozone levels over North America, March 1979 and March 1994 - Category I (continued)

Exhibit I-26: Ozone levels over North America, 1979 and 1994



Source: NASA, Goddard Space Flight Center. Total Ozone Mapping Spectrometer (TOMS), flown on Nimbus-7 satellite. (January 24, 2003; Available: http://www.epa.gov/ozone/science/glob_dep.html).

Assessment Panel, 2003). Trends over North America reflect this global phenomenon.

Indicator Gaps and Limitations

TOMS provides no data during nighttime or during the longer periods of darkness in polar regions.

Data Source

The data source for this indicator was NASA, Total Ozone Mapping Spectrometer, flown on the Nimbus-7 satellite. March 1979 and March 1994. (See Appendix B, page B-7, for more information.)

1.4.2 What is causing changes to the ozone layer?

Indicators

Worldwide and U.S. production of ozone-depleting substances (ODSs)
 Concentrations of ozone-depleting substances (effective equivalent chlorine)

Analyses have shown that the presence of CFCs and other ODSs was negligible before commercial production of CFCs and other ODSs began in the 1930s and 1940s (Scientific Assessment Panel, 2003).

The adoption of the 1987 Montreal Protocol significantly affected production levels, resulting in reduced concentrations of ODSs.

Worldwide emissions are estimated to have been reduced significantly, since peaking in 1993 (Scientific Assessment Panel, 2003). Likewise, there have been marked decreases in U.S. emissions of ODSs over the past decade, resulting in a 79 percent decrease in total ODP-weighted emissions from 1990 to 2000 (EPA, OAP, April 2002).

Two indicators are used to address this question:

- Worldwide and U.S. production of ODSs.
- Concentration of ODSs (effective equivalent stratospheric chlorine).

Indicator

Worldwide and U.S. production of ozone-depleting substances (ODSs) - Category 2

Worldwide ODS production estimates are derived from reports produced by each nation, as required under the Montreal Protocol and subsequent amendments.

Production, consumption, and emissions of ODSs are not identical; even though the ultimate destiny of a given pound of CFCs might be release to the atmosphere, a time lag is involved. ODSs initially are contained—and isolated from the atmosphere—after they are produced. They are likely to stay contained until they are consumed—for example, used as coolant in a refrigerator or as a foaming agent in polystyrene-foam hot cups. Once they are consumed, the ODSs still might not be released to the atmosphere until years later, such as when the cup degrades in a landfill, or when the refrigerator is disposed of or recycled (at which time the ODS may actually be reclaimed for further use).

Because of these complexities, consumption and emissions figures involve significant uncertainties—they are estimated based on rates of conversion. Production figures may be more meaningful,

because they are compiled from data which a relatively small number of producing companies must report by law.

What the Data Show

There have been marked decreases in worldwide production, and consumption of ODSs over the past 2 decades (Exhibit 1-27). Worldwide ODS production declined from approximately 1.8 million tons in 1986 to 313,000 tons in 1999 (UNEP, 2002). Worldwide measures are presented in ozone depletion potential (ODP)-weighted tons. Each ODS is weighted based on its damage to the stratospheric ozone; this is its ODP. U.S. production of selected ODSs peaked in 1988 and declined by nearly 65 percent in 5 years (Exhibit 1-28) (USITC, 1994).

Indicator Gaps and Limitations

In some cases ODS production data are reliable because laws require that they be reported. Coverage from nation to nation is incomplete, however, and sometimes methods are inconsistent. Production estimates for the U.S. are generally reliable as a result of the legal reporting requirement for production figures and the small number of producers involved.

Data Sources

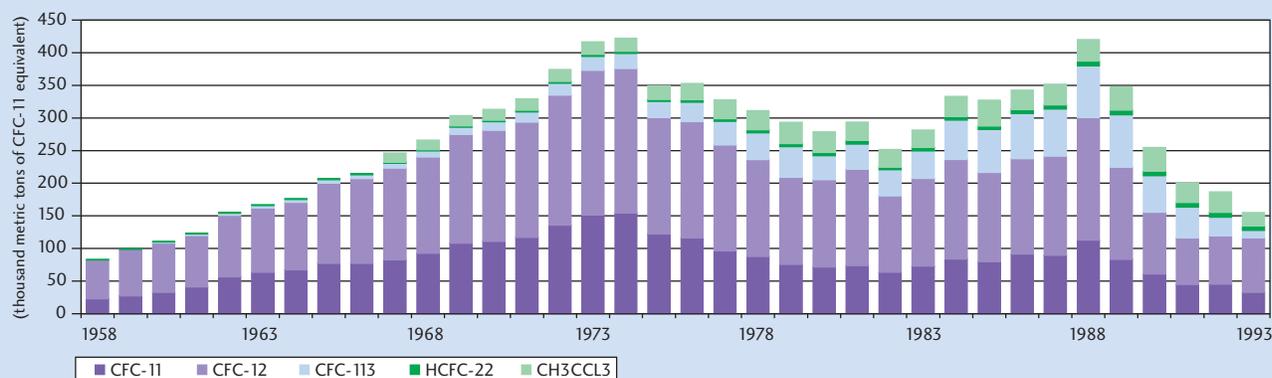
The data sources for this indicator were *Worldwide Estimates: Production and Consumption of Ozone Depleting Substances 1986-2000*, Ozone Secretariat/UNEP, 2002, and 1993 *Synthetic Organic Chemicals; U.S. Production and Sales*, U.S. International Trade Commission, 1994. (See Appendix B, page B-7, for more information.)

Exhibit 1-27: Worldwide ODS production and consumption (ODP-weighted tons), 1986 and 1999

Year	Production	Consumption
1986	1,768,789	1,784,015
1999	312,731	275,382

Source: United Nations Environment Programme, Ozone Secretariat. *Production and Consumption of Ozone Depleting Substances under the Montreal Protocol: 1986-2000*. April 2002.

Exhibit 1-28: U.S. production of selected ozone-depleting chemicals, 1958-1993



Source: U.S. International Trade Commission. 1993 *Synthetic Organic Chemicals; U.S. Production and Sales*. 1994 (July 3, 2002); <http://www.epa.gov/ozone/science/indicat/index.html>.

Indicator Concentrations of ozone-depleting substances (effective equivalent chlorine) - Category 2

Effective equivalent chlorine (EECI), the amount of chlorine and bromine in the lower atmosphere, is used to represent concentrations of ozone-depleting substances. It is a convenient parameter for measuring with a single number the overall potential human effect on stratospheric ozone. EECI is derived by considering the changing concentrations of about a dozen gases that can affect the stratospheric ozone concentration. An index is then developed based on the ability of those gases to catalyze the destruction of ozone relative to the ability of chlorine to do so. The units of EECI are parts per trillion by volume.

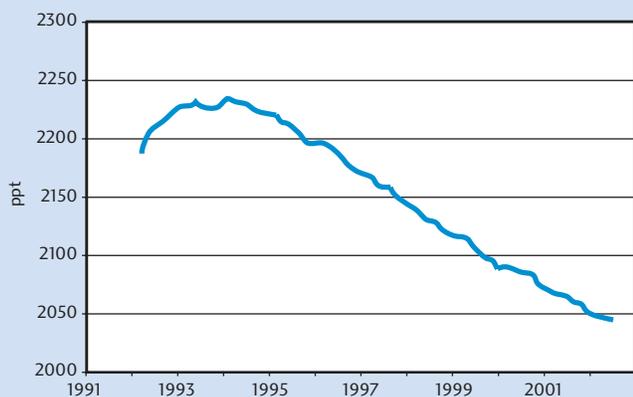
What the Data Show

The *Scientific Assessment* states that the total effect of all ozone-depleting halogens in the atmosphere, estimated by calculating chlorine equivalents from atmospheric measurements of chlorine-

and bromine- containing gases, continues to decrease. As of mid-2000, equivalent organic chlorine in the troposphere was nearly five percent below the peak value in 1992 to 1994 (Exhibit 1-29). The recent decrease is slightly slower than in the mid-1990s due to the reduced influence of methyl chloroform on this decline (Scientific Assessment Panel, 2003).

In 1996, EPA measurements indicated that concentrations of methyl chloroform had started to fall, indicating that emissions had been reduced. Concentrations of other ozone-depleting substances in the upper layers of the atmosphere, like CFCs, are also beginning to decrease. Stratospheric chlorine levels have apparently peaked and are expected to slowly decline in coming years (EPA, OAQPS, September 2002). The best current estimate from computer models is that the atmospheric burden of halogens will return to 1980 levels (pre-Antarctic ozone hole) around the middle of this century if the Montreal Protocol and its Amendments are fully adhered to (Scientific Assessment Panel, 2003).

Exhibit 1-29: Global total effective equivalent chlorine (EECI), 1992-2002



Source: Updated from Montzka, Stephen A., et al. *Present and future trends in the atmospheric burden of ozone-depleting halogens*. April 1999; NOAA, Climate Monitoring & Diagnostics Laboratory. Halocarbons and other Atmospheric Trace Species (HATS). 2002. March 18, 2003; <http://www.cmdl.noaa.gov/hats/graphs/graphs.html>.

Indicator Gaps and Limitations

The precision of this indicator depends on understanding the chemistry and behavior of the many different gases involved. For example, accurate estimates of the atmospheric lifetime of a gas are essential to assigning it the proper weight relative to other gases. As scientific understanding of atmospheric chemistry improves, calculations continue to be refined.

Data Source

The data source for this indicator was *Scientific Assessment of Ozone Depletion: 2002*, Scientific Assessment Panel of the Montreal Protocol on Substances that Deplete the Ozone Layer, WMO, 2003. (See Appendix B, page B-8, for more information.)

1.4.3 What human health effects are associated with stratospheric ozone depletion?

The increased ground-level UV radiation that can result from stratospheric ozone depletion is expected to have significant adverse human health effects. UV-B radiation is linked to skin cancer, increased incidence of cataracts, and suppression of the immune system (EPA, OAQPS, September 2002). Approximately 1.3 million new cases of skin cancer are diagnosed every year in the U.S., according to the Centers for Disease Control and Prevention (CDC) and the American

Cancer Society. Malignant melanoma accounts for about 75 percent of the approximately 9,800 skin cancer deaths in the U.S. annually. The incidence rate of malignant melanoma is increasing by about 3 percent annually, although death rates have remained constant (Wingo, et al., 1999).

Possible increased UV radiation levels is only one of many factors that could affect skin cancer incidence. Others include behavioral changes (people spending more time at the beach or outdoors) and changes in screening for, diagnosis of, and reporting of the disease.

Data on UV-B radiation and tropospheric ozone are used to calculate benefits from accelerated phase-out schedules for ODSs. EPA

Exhibit I-30: Estimated benefits of phaseout of ozone-depleting substances (sections 604, 606, and 609 of the Clean Air Act)

Health Effects - Quantified	Estimate	Basis for Estimate
■ Melanoma and nonmelanoma skin cancer (fatal)	6.3 million lives saved from skin cancer in the U.S. between 1990 and 2165	Dose-response function based on UV exposure and demographics of exposed populations ¹
■ Melanoma and nonmelanoma skin cancer (non-fatal)	299 million avoided cases of non-fatal skin cancers in the U.S. between 1990 and 2165	Dose-response function based on UV exposure and demographics of exposed populations ¹
■ Cataracts	27.5 million avoided cases in the U.S. between 1990 and 2165	Dose-response function uses a multivariate logistic risk function based on demographic characteristics and medical history ¹
Ecological Effects - Quantified	Estimate	Basis for Estimate
■ American crop harvests	Avoided 7.5 percent decrease from UV-b radiation by 2075	Dose-response sources: Teramura and Murali (1986), Rowe and Adams (1987)
■ American crops	Avoided decrease from tropospheric ozone	Estimate of increase in tropospheric ozone: Whitten and Gery (1986). Dose-response source: Rowe and Adams (1987)
■ Polymers	Avoided damage to materials from UV-b radiation	Source of UV-b/stabilizer relationship; Horst (1986)
Health Effects - Unquantified	Skin cancer: reduced pain and suffering	
Reduced morbidity effects of increased UV. For example:		
<ul style="list-style-type: none"> ■ reduced actinic keratosis (pre-cancerous lesions resulting from excessive sun exposure) ■ reduced immune system suppression 		
Ecological Effects - Unquantified	Ecological effects of UV. For example, benefits relating to the following:	
<ul style="list-style-type: none"> ■ recreational fishing ■ forests ■ overall marine ecosystem ■ avoided sea level rise, including avoided beach erosion, loss of coastal wetlands, salinity of estuaries and aquifers ■ other crops ■ other plant species ■ fish harvests 		
Ecological benefits of reduced tropospheric ozone relating to the overall marine ecosystem, forests, man-made materials, crops, other plant species, and fish harvests		
Benefits to people and the environment outside the U.S.		
Effects, both ecological and human health, associated with global warming		
Notes:		
1) For more detail see EPA's <i>Regulatory Impact Analysis: Protection of Stratospheric Ozone</i> (1988).		
2) Note that the ecological effects, unlike the health effects, do not reflect the accelerated reduction and phaseout schedule of section 606.		
3) Benefits due to the section 606 methyl bromide phaseout are not included in the benefits total because EPA provides neither annual incidence estimates nor a monetary value. The EPA does provide, however, a total estimate of 2,800 avoided skin cancer fatalities in the U.S.		

Source: EPA, Office of Air and Radiation. *The Benefits and Costs of the Clean Air Act 1990 to 2010. EPA Report to Congress.* November 1999.

estimates that between 1990 and 2165, in the U.S. alone 6.3 million fatal skin cancers, 299 million cases of non-fatal skin cancers, and 27.5 million cases of cataracts will be prevented because of the worldwide phase-out of ODSs. (EPA, OAR, November 1999) (Exhibit 1-30). These are estimated cumulative effects, so there are no data series or trends to evaluate.

No specific indicators have been identified at this time for human health effects of stratospheric ozone depletion.

1.4.4 What ecological effects are associated with stratospheric ozone depletion?

UV radiation in sunlight affects the physiological and developmental processes of plants. Even though plants have mechanisms to reduce or repair these effects and some ability to adapt to increased UV-B levels, UV radiation can still directly affect plant growth. It can also produce indirect effects such as changes in plant form, distribution of nutrients within the plant, timing of developmental phases, and secondary metabolism. These changes can be even more important than direct damage because of their implications for plant competitive balance, herbivory, plant diseases, and biogeochemical cycles (UNEP, 1994).

UV radiation can also affect aquatic life. UV exposure affects both orientation mechanisms and motility in phytoplankton, resulting in reduced survival rates for these organisms. Scientists have demonstrated a direct reduction in phytoplankton production as a result of ozone depletion-related increases in UV-B (DeMora, et al., 2000). Small increases in UV-B radiation have been found to cause damage in the early developmental stages of fish, shrimp, crab, amphibians, and other animals, the most severe effects being decreased reproductive capacity and impaired larval development. Animals higher on the food chain that depend on these organisms for food could, in turn, be affected (UNEP, 1994).

Increases in UV radiation could also affect terrestrial and aquatic biogeochemical cycles, and, as a result, alter both sources and sinks of greenhouse and chemically important trace gases. These potential changes would contribute to biosphere-atmosphere feedback that attenuates or reinforces the atmospheric buildup of these gases (UNEP, 1994). Synthetic polymers, naturally occurring biopolymers, and some other materials of commercial interest also are adversely affected by UV radiation, but special additives somewhat protect some modern materials from UV-B. Increases in UV-B levels nonetheless will likely accelerate their breakdown, limiting their usefulness outdoors (UNEP, 1994).

No specific indicators have been identified at this time to address the ecological effects associated with stratospheric ozone depletion.

1.5 Climate Change

The issue of global climate change involves changes in the radiative balance of the Earth—the balance between energy received from the sun and emitted from the Earth. This report does not attempt to address the complexities of this issue. For information on the \$1.7 billion annual U.S. Global Climate Research Program and Climate Change Research Initiative, please find *Our Changing Planet: The Fiscal Year 2003 U.S. Global Climate Research Program* (November 2002) at www.usgcrp.gov and the *Draft Ten-Year Strategic Plan for the Climate Change Science Program* at www.climate-science.gov.

1.6 Challenges and Data Gaps

Outdoor Air Quality and Acid Deposition

In general, some very good indicators of outdoor air quality exist. The national air monitoring network for the six criteria air pollutants is extensive; however, there are far more monitors in urban areas than in rural areas. Monitoring in urban areas helps to characterize population exposures, because population tends to be concentrated in urban areas. More rural monitoring might help scientists assess transport and ecological effects, although EPA uses additional tools and techniques (e.g., models and spatial analyses) to augment limited monitoring in some areas and to better characterize pressures on ecological condition. EPA is currently conducting a national assessment of the existing ambient monitoring networks and is analyzing, among other issues, the need for and appropriateness of each of the nation's urban monitors.

Many major metropolitan areas monitor air quality for the presence of selected air toxics. However, there is no national monitoring network with standard data collection guidance for air toxics; therefore, numerous air toxics are not being measured. National assessments of levels of air toxics would benefit from a more extensive ambient monitoring network for toxics. EPA is currently working with state and local partners to design and deploy such a network.

Questions still exist about how indicators of concentrations and emissions relate to exposure and human health effects. The use of one approach to determining how various air pollution levels affect health would be to use established and quantified effects and surrogates for air pollution health impacts from epidemiology studies, such as asthma hospitalizations and childhood school absences. Research needs to be conducted that will develop these health endpoints into useful indicators.

As highlighted in Chapter 4, Human Health, for most health outcomes other than mortality, no national systems for data collection currently exist. With regard to criteria air pollutants, it would be useful to track asthma and chronic respiratory diseases, cardiovascular diseases, and adverse birth outcomes. For air pollutants in general, including air toxics and indoor pollutants, the list can also include neurological diseases, developmental disabilities, reproductive disorders, and endocrine/metabolic disorders.

As described in Chapter 5, Ecological Condition, there are large gaps in our ability to report on the condition of ecological systems and linkages between indicators of atmospheric stressors and specific ecological effects. There is a need for improved monitoring information for deposition and concentrations of both criteria and toxic air pollutants to ecosystems. Data on exposure of high-elevation forests and their watersheds to ozone and acid deposition are especially sparse, relative to data on lower elevations. And exposure patterns are likely to be significantly different at higher elevations because of higher acid deposition rates due to higher rainfall and fog, and less diurnal variation in ozone concentrations due to less nighttime scavenging (NAPAP, 1991). Furthermore, despite considerable progress, there is still no index of ozone exposure that relates optimally to plant response (EPA, NCEA, July 1996). Although mercury monitoring has begun as part of the National Atmospheric Deposition Program, the availability of data is inadequate to assess national trends (EPA, OAQPS, ORD, December 1997). There are inadequate data on indicators of actual UV exposures of ecosystems of all types.

Indoor Air Quality

While environmental indicators have been developed for some aspects of indoor air, significant gaps exist in our knowledge about the conditions inside the nation's buildings. For schools and residences, a large amount of information on IAQ is available, but it is composed primarily of case studies and, at best, small regional studies. Exposure studies on a national scale would help better characterize IAQ of schools and residential indoor environments, including multiple family residences. Ideally, these studies would collect exposure data on air toxics and PM in these indoor environments, and data for the various biological contaminants found in indoor air.

Stratospheric Ozone

In general, high quality data exists with which to predict the human health effects of increased ultraviolet exposure resulting from depletion of the stratospheric ozone. These include robust satellite data on stratospheric ozone concentrations and UV-B levels, comprehensive and well documented incidence and mortality rates for cutaneous melanoma, and well characterized action spectra for skin cancers and cataracts. However, there are areas where additional data would be useful. First, no national system exists that collects incidence data for squamous cell carcinoma and basal cell carcinoma, the non-melanoma skin-cancers caused by increased UV-B exposure. Thus, our incidence estimates are modeled using data from a nation-wide survey of non-melanoma skin cancer incidence and mortality, and may not represent the most current non-melanoma skin cancer rates. Second, there is a lack of adequate

ground level UV monitoring with which to compare the satellite data. Satellites cannot directly measure ground level UV, and are sensitive to pollution. Therefore, while satellite data compare fairly well to ground level UV measurements in clean locations, this is not the case in polluted areas. Additional UV monitoring in cities is crucial to support future epidemiological research on the human health effects of UV-B exposure. Third, increased UV-B levels have been associated with other human and non-human endpoints including immune suppression and effects on aquatic ecosystems and agricultural crops. However, additional research on these topics is necessary before these effects can be modelled or quantified. Finally, the future behavior of the ozone layer will be affected by changing atmospheric abundances of various atmospheric gases. It remains unclear how these changes will affect the predicted recovery of the ozone layer. Additional research on the interaction between climate and stratospheric ozone could provide more accurate predictions of ozone recovery and the human health effects resulting from ozone depletion.