CHAPTER 2

AIR

AIR CHAPTER CONTENTS

2.1 INTRODUCTION

Air provides the oxygen and carbon dioxide needed to sustain human, animal, and plant life on Earth, and the composition of trace gases in the atmosphere plays an important role for the climate. Air pollution can adversely affect these critical functions of the atmosphere in many ways. High levels of air pollution, whether indoors or outdoors, can harm human health by triggering asthma attacks, aggravating allergies, and contributing to or potentially causing various diseases. Certain types of outdoor air pollution can impair visibility and damage other valued resources, such as forests, lakes and streams, and building surfaces. On a global scale, air pollution released worldwide can eventually change the atmosphere’s composition with important consequences, including depletion of the Earth’s ozone layer and climate change.

An important component of EPA’s mission is to protect and improve air quality in order to avoid or mitigate the consequences of air pollution’s harmful effects. State and tribal air pollution control agencies help fulfill this mission by implementing many of the air pollution control requirements that EPA sets at the federal level. Other federal partners, the academic community, industry and trade associations, and non-government organizations all conduct important research that contributes to the current understanding of regional, national, and global air quality issues.

Efforts to maintain good air quality are complicated by population increase, energy consumption, motor vehicle use, and other factors that can lessen air quality. Outdoor air is polluted by emissions from a broad array of industrial and mobile sources, as well as everyday activities like dry cleaning, painting, and refueling vehicles. Emissions from natural sources, such as wildfires, also contribute to outdoor air pollution. Similarly, indoor air quality is affected not only by these outdoor sources, but also by sources found within buildings, such as home heating devices, tobacco smoke, consumer products, and building materials. In this chapter, EPA assesses national trends in the condition of air, stressors that influence air quality, and associated exposures and effects among humans and ecological systems. ROE indicators are presented to address three fundamental questions about the state of the nation’s air:

- ***What are the trends in outdoor air quality and their effects on human health and the environment?*** This question examines a broad spectrum of outdoor air quality issues, including polluted air that people breathe at ground level, deposition of air pollutants to land and water, and depletion of the Earth’s ozone layer. For each issue, information is provided both on the main stressors (emission sources) and potential health and environmental effects.
- ***What are the trends in greenhouse gas emissions and concentrations?*** This question focuses on releases and atmospheric concentrations of certain so-called “greenhouse gases,” or gases in the atmosphere that help regulate Earth’s temperature and thus contribute to climate change—a topic introduced in this chapter and revisited in Chapter 6, Ecological Condition.
- ***What are the trends in indoor air quality and their effects on human health?*** This question considers air quality in indoor settings, such as homes, offices, and schools, and how poor indoor air quality can affect human health, whether through causing adverse health effects or by impairing productivity.

These ROE questions are posed without regard to whether indicators are available to answer them. This chapter presents the indicators available to answer these questions, and also points out important gaps where nationally representative data are lacking.

While this chapter focuses on air quality, readers should not infer that air quality trends are completely independent of the other themes in ROE: Water, Land, Human Health, and Ecological Condition. High levels of air pollution are linked to many broader environmental concerns. Because air interfaces directly with water and land, air pollutants can enter these media through various fate and transport mechanisms, such as wet deposition onto surface waters and gravitational settling onto soils. Conversely, chemicals in surface water and soil can enter outdoor air through processes like evaporation and resuspension of wind-blown dust. Thus, in a very general sense, air quality is related to selected topics covered in the Water Chapter and the Land Chapter. Further, nearly every topic addressed in this chapter is primarily motivated by some specific concern regarding human health or ecological effects. Therefore, air quality and climate change are conceptually linked to many topics addressed in the Human Health and Ecological Condition Chapters. Air quality issues that are connected with other ROE themes are introduced and examined in this chapter, and addressed further in later sections of ROE as appropriate.

2.1.1 Overview of the Data

When developing the 27 ROE indicators in this chapter, EPA accessed and compiled data collected by many parties. The individual data sources that were evaluated can be classified into four general categories:

- **National emission inventories**. Emissions data were queried from databases known as emission inventories. These inventories are composites of measured and estimated emission rates for industrial sources, mobile sources, and natural sources. Industry and state, tribal, and local agencies provide most of the data compiled in these inventories.
- **Ground-level ambient air monitoring data.** Ambient air concentrations measured at ground level primarily come from measurements collected in a nationwide network of ambient air monitoring stations (i.e., State and Local Air Monitoring Stations, National Air Monitoring Stations). State, tribal, and local agencies operate most of these stations and submit their validated measurement results to a centralized database.
- **Deposition measurements.** Representative data on deposition of outdoor air pollutants come from samples collected and analyzed at fixed locations throughout the country as part of the National Atmospheric Deposition Program and the Clean Air Status and Trends Network.
- **Other data sources.** The remaining ROE indicators in this chapter draw from various other data sources, including satellite measurements of stratospheric ozone depletion, an evaluation of pollution-related injury to forest plants, surveys on radon in homes and evidence of exposure to environmental tobacco smoke, an inter-agency assessment of regional haze, and articles in the peer-reviewed literature on historical concentrations of greenhouse gases estimated from ice core samples.

Tracking the country’s air quality is a complicated endeavor and cannot be done with any single indicator. Multiple indicators are needed to characterize indoor air quality separately from outdoor air quality, air quality trends at ground level separately from changing atmospheric conditions aloft, and air pollution levels for the many different pollutants of potential concern. Regardless of the issue of interest, a particular challenge in developing this chapter’s indicators is that air quality can vary considerably with location and time. Consequently, all underlying data sources must be sufficiently representative, both spatially and temporally.

Spatial resolution is a critical consideration due to associated spatial variations in population density, industrial emissions sources, traffic patterns, and meteorological conditions that dictate relevant atmospheric fate and transport processes. Temporal resolution also must be considered because ambient air concentrations of certain pollutants vary considerably with time of day (due to sunlight's contribution to photochemical reactions), day of week (due to commuting patterns), and season (due to changes in meteorological conditions). Temporal resolution is particularly important when interpreting air quality trends, because sufficiently long time frames often must be considered to ensure that trends reflect actual changes in air quality, rather than natural fluctuations in atmospheric conditions.

This chapter presents only data that meet the ROE indicator definition and criteria (see Chapter 1, Introduction). Note that non-scientific indicators, such as administrative and economic indicators, are not included in this definition. Thorough documentation of the indicator data sources and metadata can be found online at [INSERT URL]. All indicators were peer-reviewed during an independent peer review process (see [INSERT URL] for more information). Readers should not infer that the indicators included reflect the complete state of knowledge on the nation's air. Many other data sources, publications, and site-specific research projects have contributed substantially to the current understanding of air quality trends, but are not used in this report because they did not meet some aspect of the ROE indicator criteria.

2.1.2 Organization of This Chapter

This chapter's remaining three sections are framed around the three overarching questions that EPA seeks to answer about trends in air. Each section introduces the question and its importance, presents the National Indicators that help answer the question, and discusses what these indicators, taken together, say about the question. The chapter also presents two Regional Indicators that meet the ROE indicator definition and criteria and help to answer a question at a smaller geographic scale. Each section concludes by listing major challenges to answering the questions and identifying important data gaps.

The table on the next page lists the indicators used to answer the three questions in this chapter and shows the locations where the indicators are presented.

Table 2.1.1. Air—ROE Questions and Indicators

Question	Indicator Name	Section	Page #
What are the trends in outdoor air quality and their effects on human health and the environment?	Carbon Monoxide Emissions (N/R)	2.2.2	2-13
	Ambient Concentrations of Carbon Monoxide (N/R)	2.2.2	2-16
	Lead Emissions (N)	2.2.2	2-19
	Ambient Concentrations of Lead (N)	2.2.2	2-21
	Nitrogen Oxides Emissions (N/R)	2.2.2	2-23
	Ambient Concentrations of Nitrogen Dioxide (N/R)	2.2.2	2-26
	Volatile Organic Compounds Emissions (N/R)	2.2.2	2-29
	Ambient Concentrations of Ozone (N/R)	2.2.2	2-32
	Ozone Injury to Forest Plants (N/R)	2.2.2	2-37
	Particulate Matter Emissions (N/R)	2.2.2	2-40
	Ambient Concentrations of Particulate Matter (N/R)	2.2.2	2-44
	Regional Haze (N)	2.2.2	2-50
	Sulfur Dioxide Emissions (N/R)	2.2.2	2-53
	Acid Deposition (N)	2.2.2	2-56
	Lake and Stream Acidity (N)	2.2.2	2-62
	Percent of Days with Air Quality Index Values Greater Than 100 (N/R)	2.2.2	2-65
	Mercury Emissions (N)	2.2.2	2-68
	Air Toxics Emissions (N/R)	2.2.2	2-70
	Ambient Concentrations Benzene (N)	2.2.2	2-74
	Concentrations of Ozone-Depleting Substances (N)	2.2.2	2-76
	Ozone Levels over North America (N)	2.2.2	2-79
	Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region (R)	2.2.2	2-82
	Ambient Concentrations of Manganese Compounds in EPA Region 5 (R)	2.2.2	2-86
What are the trends in greenhouse gas emissions and concentrations?	U.S. Greenhouse Gas Emissions (N)	2.3.2	2-96
	Atmospheric Concentrations of Greenhouse Gases (N)	2.3.2	2-100
What are the trends in indoor air quality and their effects on human health?	U.S. Homes Above EPA's Radon Action Level (N)	2.4.2	2-111
	Blood Cotinine Level (N)	2.4.2	2-114

N = National Indicator
R = Regional Indicator
N/R = National Indicator displayed at EPA Regional scale

2.2 WHAT ARE THE TRENDS IN OUTDOOR AIR QUALITY AND THEIR EFFECTS ON HUMAN HEALTH AND THE ENVIRONMENT?

2.2.1 Introduction

Outdoor air—the air outside of buildings, from ground level to several miles above the Earth's surface—is a valuable resource for current and future generations because it provides essential gases to sustain life and it shields the Earth from harmful radiation. Air pollution can compromise outdoor air quality in many ways. Outdoor air pollution, for instance, is associated with various adverse health effects including asthma attacks and cancer; and outdoor air pollution can contribute to "smog" and "acid rain," damage crops and surfaces of treasured buildings and monuments, and diminish the protective ozone layer in the upper atmosphere. Maintaining clean air is a challenging task, especially considering the growing stressors on outdoor air quality such as increased population growth, increased use of motor vehicles, and increased energy consumption.

Outdoor air pollution contains numerous substances of both natural and anthropogenic origin. While natural sources release some potentially harmful substances into the air (e.g., pollen, mold spores, dust), emissions sources of anthropogenic origin are of particular interest because regulatory and voluntary reductions can lead to decreased emissions and associated air quality improvements. Accordingly, this section focuses on outdoor air quality issues caused at least in part by human activity and acknowledges and quantifies contributions from natural sources, as appropriate.

Most outdoor air pollution issues can be traced back to emissions sources that release pollutants into the air. Emissions sources are typically classified into different categories, such as point sources (e.g., power plants, industrial facilities), area sources (e.g., air pollution sources over a diffuse area, such as gasoline stations, dry cleaners, and waste treatment facilities), mobile sources (e.g., cars, trucks, airplanes, off-road vehicles), and natural sources (e.g., wildfires, wind-blown dust, volcanoes). Once pollutants are airborne, prevailing wind patterns carry them from their sources to downwind locations, and pollutants disperse in air as they mix in the atmosphere. Depending on their chemical and physical properties, some pollutants deposit to the Earth's surface near their corresponding emissions sources, while others remain airborne for hours, days, or years. Deposition of air pollutants, especially those that are persistent and bioaccumulative, can lead to accumulation of contaminants in other media. The levels of air pollution at a given location and at a given time are influenced by emissions from nearby and distant sources as well as by atmospheric factors, such as meteorology.

Human exposure to outdoor air pollution is a function of the composition and magnitude of air pollution, combined with human activity patterns. Whether people are harmed by poor air quality depends on exposure doses and durations, individuals' susceptibilities to diseases, and other factors. Similarly, air pollutants' interactions with ecosystems determine whether air pollution causes harmful environmental effects. For a complete understanding of a given air pollution issue, information is therefore typically sought on emissions sources, ambient air concentrations, exposures, and effects.

Outdoor air pollution can contain hundreds of different pollutants, which are typically grouped into various categories based on shared attributes. Some categories are defined by pollutants' physical attributes (e.g., gases, aerosols, particulates), while others by regulatory terminology (e.g., criteria pollutants, air toxics). The indicators used to answer the question regarding outdoor air quality are organized into the following three categories, which were selected based on the different parts of the atmosphere to which they pertain and the different types of information available to support indicator development:

- **Criteria Pollutants**. The following six common pollutants are referred to as criteria pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter of different size fractions, and sulfur dioxide. For each criteria pollutant, EPA has established National Ambient Air Quality Standards (NAAQS) to protect public health and the environment. Extensive data are available on criteria pollutants' emissions (or emissions of the pollutants' precursors) and ambient concentrations.
- **Air Toxics and Other Air Pollutants**. Air toxics, also known as hazardous air pollutants, are known or suspected to cause cancer and are associated with other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. The Clean Air Act specifically identifies 188 air toxics. Numerous other air pollutants exhibit toxicity even though they are not classified as air toxics; included among these other pollutants are several hundred additional chemicals whose emissions are tracked in EPA's Toxics Release Inventory.
- **Stratospheric Ozone Issues**. The ozone layer occurs in the stratosphere between 6 and 20 miles above the Earth's surface and protects the Earth's biota from harmful effects of the sun's ultraviolet radiation. Past and ongoing releases of a number of synthetic chemicals from throughout the world have depleted the ozone layer, allowing more ultraviolet radiation to reach the Earth's surface. This can lead to increased incidence of skin cancer, cataracts, and other health problems.[1] Further, high levels of ultraviolet radiation can cause detrimental ecological effects, such as stressing productivity of marine phytoplankton, which are essential components of the oceanic food web.[2]

Air pollution is manifest over a range of spatial and temporal domains—an important factor to consider when evaluating trends for the three categories considered in this section. The spatial domains of air pollution issues vary widely. Air pollution can be local in nature. For instance, ambient concentrations of benzene tend to be greatest in the proximity of major sources (e.g., oil refineries, chemical production facilities) and in high-traffic areas; long-range transport is relatively unimportant due to benzene's high photochemical reactivity. Air pollution can also extend over regional and national scales. For example, emissions sources hundreds of miles away can contribute to airborne fine particulate matter at a given location.[3] Finally, a few air pollution issues are global in nature. Stratospheric ozone depletion, for example, is affected by releases of ozone-depleting substances from countries worldwide. The spatial domains ultimately determine the minimum spatial resolution of monitors needed to adequately characterize trends.

Temporal scales also vary among pollutants and typically reflect some combination of changes in emissions and fluctuations in weather. Ambient air concentrations of some air pollutants, like ground-level ozone, have considerable diurnal and seasonal variations.[4] However, temporal variations are far less

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[1] World Meteorological Organization, et al. 2003. Scientific assessment of ozone depletion: 2002. Geneva, Switzerland.

[2] DeMora, S., S. Demers, and M. Vernet. 2000. The effects of UV radiation in the marine environment. Cambridge, United Kingdom: Cambridge University Press.

[3] U.S. EPA. 2004. The particle pollution report: current understanding of air quality and emissions through 2003. EPA/454/R-04/002. Research Triangle Park, NC.

[4] U.S. EPA. 2004. The ozone report: measuring progress through 2003. EPA/454/K-04/001. Research Triangle Park, NC.

pronounced for pollutants that are long-lived in the atmosphere, including many ozone-depleting substances. Temporal variations largely determine the appropriate monitoring frequency for quantifying trends and the most meaningful statistic (or averaging time) used to report ambient air concentrations. When quantifying and interpreting long-term trends in outdoor air quality, attention also must be paid to changes in emissions estimation techniques and advances in ambient air monitoring technologies. Unless otherwise noted, the outdoor air quality indicators only come from data sets generated using consistent methodologies over the entire time frame of interest.

The nationwide air quality trends in this section are generally consistent with those documented in other EPA publications, though readers should not expect to find perfect concordance among individual data points. This is because some publications address different spatial domains or time frames and may use less rigorous selection criteria when identifying and compiling data sets.

2.2.2 ROE Indicators

The 23 outdoor air quality indicators track emissions, ambient concentrations, and pollution-related effects over varying spatial domains and time spans, depending on the availability of underlying data. The indicators include 21 National Indicators (12 of which break national data down into the 10 EPA Regions) and 2 Regional Indicators. The most extensive temporal coverage of these indicators tracks trends from 1965 to the present.

Indicators were developed using data compiled from multiple sources. Emissions indicators are based on EPA's National Emissions Inventory (NEI), a database of measured and estimated emissions for numerous pollutants and source categories. At the writing of this report, NEI data were available from 1990 to 2002, but the indicators only present data for those inventory years that are fully updated and are developed using consistent methodologies. Ground-level ambient air concentration indicators were developed from data in EPA's Air Quality System (AQS), a clearinghouse of validated ambient air monitoring results submitted largely by tribal, state, and local environmental agencies. The ambient concentration indicators present data through calendar year 2004, which is the most recent calendar year having a complete, validated set of monitoring data available from AQS when this report was prepared. Remaining indicators draw from different monitoring programs, including regional haze data from the Interagency Monitoring of Protected Visual Environments, acid deposition measurements from the multi-agency National Atmospheric Deposition Program and Clean Air Status and Trends Network, ozone injury observations from the U.S. Forest Service's Forest Health Monitoring Program, and monitoring of stratospheric ozone levels and concentrations of ozone-depleting substances conducted by the National Oceanic and Atmospheric Administration.

Table 2.2.1 shows how indicators are classified into three general categories (criteria pollutants, air toxics and other pollutants, stratospheric ozone issues) and then further organized by pollutant. For each pollutant and to the extent supported by ROE indicators, relevant emissions indicators are presented first, immediately followed by ambient concentration indicators, and next by effects indicators. With this organization, readers can readily compare relevant trends in emissions, ambient concentrations, and effects for the same pollutant.

Table 2.2.1. ROE Indicators of Trends in Outdoor Air Quality and Their Effects on Human Health and the Environment

NATIONAL INDICATORS	**LOCATION**
Criteria Pollutants and Their Precursors	
Carbon Monoxide Emissions (N/R)	2.2.2 – p. 2-13
Ambient Concentrations of Carbon Monoxide (N/R)	2.2.2 – p. 2-16
Lead Emissions	2.2.2 – p. 2-19
Ambient Concentrations of Lead	2.2.2 – p. 2-21
Nitrogen Oxides Emissions (N/R)	2.2.2 – p. 2-23
Ambient Concentrations of Nitrogen Dioxide (N/R)	2.2.2 – p. 2-26
Volatile Organic Compounds Emissions (N/R)	2.2.2 – p. 2-29
Ambient Concentrations of Ozone (N/R)	2.2.2 – p. 2-32
Ozone Injury to Forest Plants (N/R)	2.2.2 – p. 2-37
Particulate Matter Emissions (N/R)	2.2.2 – p. 2-40
Ambient Concentrations of Particulate Matter (N/R)	2.2.2 – p. 2-44
Regional Haze	2.2.2 – p. 2-50
Sulfur Dioxide Emissions (N/R)	2.2.2 – p. 2-53
Acid Deposition	2.2.2 – p. 2-56
Lake and Stream Acidity	2.2.2 – p. 2-62
Percent of Days with Air Quality Index Values Greater Than 100 (N/R)	2.2.2 – p. 2-65
Air Toxics and Other Air Pollutants	
Mercury Emissions	2.2.2 – p. 2-68
Air Toxics Emissions (N/R)	2.2.2 – p. 2-70
Ambient Concentrations of Benzene	2.2.2 – p. 2-74
Stratospheric Ozone Issues	
Concentrations of Ozone-Depleting Substances	2.2.2 – p. 2-76
Ozone Levels over North America	2.2.2 – p. 2-79
REGIONAL INDICATORS	**LOCATION**
Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region	2.2.2 – p. 2-82
Ambient Concentrations of Manganese Compounds in EPA Region 5	2.2.2 – p. 2-86

N/R = National Indicator displayed at EPA Regional scale

INDICATOR: Carbon Monoxide Emissions

Carbon monoxide (CO) gas forms primarily when carbon fuels are not burned completely. Mobile sources account for the majority of CO emissions (U.S. EPA, 2003). These sources include both on-road vehicles (e.g., cars, trucks, motorcycles) and nonroad vehicles and engines (e.g., farm equipment, construction equipment, aircraft, and marine vessels). Consequently, high concentrations of CO generally occur in areas with heavy traffic congestion. In cities, as much as 95 percent of all CO emissions may come from automobile exhaust (U.S. EPA, 2003). Other sources of CO emissions include industrial processes, non-transportation fuel combustion, and natural sources, such as wildfires. Fuel-burning appliances also are a large source of CO releases in indoor environments. Undetected releases of carbon monoxide in indoor settings can present serious health risks to building occupants. The CO Concentrations indicator (p. 2-16) describes health hazards associated with inhaling CO.

This indicator presents CO emissions from traditionally inventoried anthropogenic source categories: 1) “Fuel combustion,” which includes emissions from coal, gas and oil-fired power plants, industrial, commercial, and institutional sources, as well as residential heaters (e.g., wood-burning stoves) and boilers; 2) “Industrial and other processes,” which includes chemical production, petroleum refining, and metals production; 3) “On-road vehicles” which includes cars, trucks, buses, and motorcycles; and 4) “Nonroad vehicles and engines,” such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others. The indicator also includes estimates of biogenic CO emissions in 2002 which were obtained using the Biogenic Emissions Inventory System (BEIS) Model, Version 3.12.

CO emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For most fuel combustion sources and industrial sources, emissions are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2005).

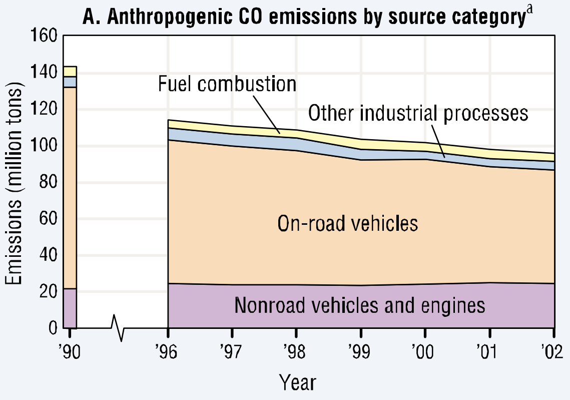
NEI data have been collected since 1990 and cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and Virgin Islands, and some of the territories of federally-recognized American Indian nations. Data are presented for 1990 and from 1996 to 2002; prior to 1996, only the 1990 data have been updated to be comparable to the more recent inventories.

What the Data Show

Only CO emissions from anthropogenic sources are included in the NEI. However, CO emissions from biogenic sources were estimated for 2002 to provide a sense of the relative contributions of natural versus anthropogenic emissions (Exhibit 2-1, panel B). Nationally, biogenic emissions were estimated to contribute approximately 5 percent to the CO emissions from all sources during 2002.

Nationwide estimated anthropogenic CO emissions have decreased 33 percent between 1990 and 2002, the most recent year for which aggregate NEI emissions estimates are available (Exhibit 2-1, panel A). Almost the entire emissions reduction is attributed to decreased emissions from on-road mobile sources. In 2002, mobile sources (both on-road and nonroad sources combined) accounted for 91 percent of the nation’s total anthropogenic CO emissions. The CO emissions reductions are reflected in corresponding reductions in ambient concentrations (the CO Concentrations indicator, p. 2-16).

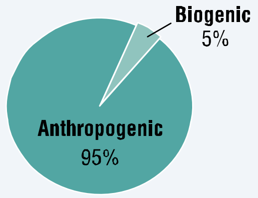
Exhibit 2-1. CO emissions in the U.S. by source category, 1990 and 1996-2002



A. Anthropogenic CO emissions by source category[a]

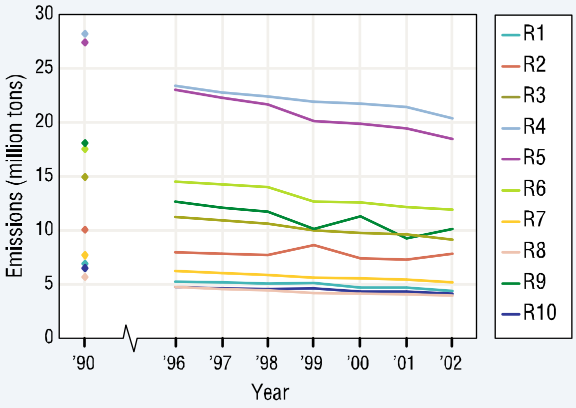
[a]Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

B. Relative amounts of CO emissions from anthropogenic and biogenic sources, 2002



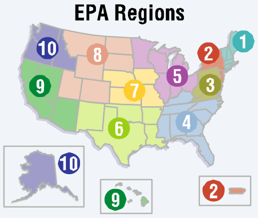
Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Exhibit 2-2. CO emissions in the U.S. by EPA Region, 1990 and 1996-2002[a]



[a]Data are presented for 1990 and 1996-2002, as datasets from these inventory years are all fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

EPA Regions



Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Net estimated anthropogenic CO emissions declined in all EPA Regions between 1990 and 2002 (Exhibit 2-2). The largest decrease (8.95 million pounds) occurred in Region 5, and the smallest decrease (1.74 million pounds) occurred in Region 8.

Indicator Limitations

- Comparable CO emissions estimates through the NEI are available only for 1990 and 1996-2002. Data for 1991-1995 are not provided due to differences in emission estimation methodologies from other inventory years which could lead to improper trend assessments.
- CO emissions from "miscellaneous sources," including wildfires, are not included in the total emissions. Yearly fluctuations in wildfire emissions have the potential to mask trends in anthropogenic emissions and therefore have been excluded from the trends graphics. Details on emissions from miscellaneous sources can be found at http://www.epa.gov/ttn/chief/eiinformation.html.
- The emissions data for CO are largely based on estimates that employ emission factors generated from empirical and engineering studies, rather than on actual measurements of CO emissions. Although these estimates are generated using well-established approaches, the estimates have uncertainties inherent in the emission factors and emission models used to represent sources for which emissions have not been directly measured.

- The methodology for estimating emissions is continually reviewed and is subject to revision. Trend data prior to any revisions must be considered in the context of those changes.
- Not all states and local agencies provide the same data or level of detail for a given year.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw CO emissions data in EPA's National Emissions Inventory (NEI) (U.S. EPA, 2006) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

References

U.S. EPA. 2006. Data from the National Emissions Inventory. Accessed 2006. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

U.S. EPA. 2005. Documentation for the final 2002 mobile National Emissions Inventory. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_onroadandnonroad.pdf>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

INDICATOR: Ambient Carbon Monoxide Concentrations

Carbon monoxide (CO) gas forms primarily when carbon fuels are not burned completely. Elevated ambient air concentrations of CO are hazardous because inhaled CO enters the bloodstream and reduces the amount of oxygen that the blood can deliver to the body's organs and tissues. If exposure concentrations are high enough, potentially serious cardiovascular and neurological effects can result. Visual impairment, reduced work capacity, reduced manual dexterity, poor learning ability, and difficulty in performing complex tasks are all associated with exposure to elevated CO levels (U.S. EPA, 2000).

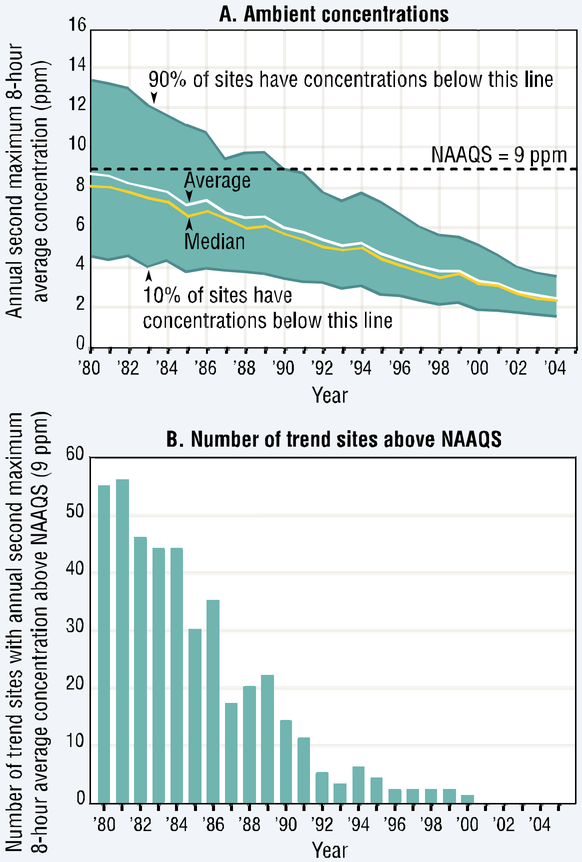
Motor vehicle exhaust currently accounts for the majority of CO emissions nationwide, and as much as 95 percent of CO emissions in cities with high traffic congestion. Other anthropogenic emissions sources of CO include fossil fuel combustion for heating and power generation, metals processing, and chemical manufacturing. The highest ambient air concentrations of CO often occur during nighttime inversion conditions, which trap pollutants near ground level. These conditions are most frequently observed during the cold winter months (U.S. EPA, 2003).

This indicator presents ambient CO concentrations in parts per million (ppm) from 1980 to 2004, based on continuous measurements averaged over 8-hour time frames. The 8-hour standard is indicative of exposures occurring over a sustained period of time, for example, an outdoor worker's exposure over the course of a work day. This indicator displays trends in the second highest annual 8-hour average CO concentrations for 160 sites that have consistent data for the period of record in the National Air Monitoring Stations (NAMS), State and Local Air Monitoring Stations (SLAMS) network, and other special purpose monitors. It also shows trends in the average 8-hour measurements in each EPA Region. This indicator's exhibits display the National Ambient Air Quality Standard (NAAQS) for CO as a point of reference, but the fact that the national or any regional 8-hour values fall below the standard does not mean that all monitoring sites nationally or in the EPA Region also are below the standard. The indicator displays trends in the number of the 160 sites nationwide at which CO concentrations exceeded the 8-hour standard, but this statistic is not displayed for each EPA Region.

What the Data Show

The 2004 CO concentration averaged across 160 monitoring sites nationwide was 72 percent lower than that for 1980, and is the lowest level recorded during the past 25 years (Exhibit 2-3, panel A). The downward trend in CO concentrations in the 1990s parallels the downward trend observed in CO emissions, which has been attributed largely to decreased emissions from mobile sources (the CO Emissions indicator, p. 2-13). In addition, of the 160 sites comprising this trend (out of 425 total monitoring sites that were operating in 2004), the number reporting CO concentrations above the CO standard declined to zero over the same period (Exhibit 2-3, panel B).

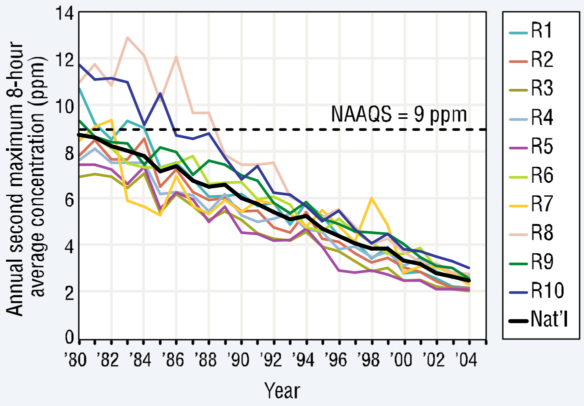
Exhibit 2-3. Ambient CO concentrations in the U.S., 1980-2004[a]



[a]**Coverage:** 160 monitoring sites nationwide (out of a total of 425 sites measuring CO in 2004) that have sufficient data to assess CO trends since 1980.

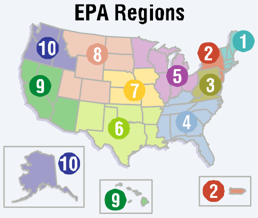
Data source: *U.S. EPA, Air Quality System, 2005*

Exhibit 2-4. Ambient CO concentrations in the contiguous U.S. by EPA Region, 1980-2004[a]



[a]**Coverage:** 155 monitoring sites in the EPA Regions (out of a total of 425 sites measuring CO in 2004) that have sufficient data to assess CO trends since 1980.

Data source: *U.S. EPA, Air Quality System, 2005*



Also shown on Exhibit 2-3 (panel A) are the 90th and 10th percentiles based on the distribution of annual statistics at the monitoring sites. This provides additional graphical representation of the distribution of measured concentrations across the monitoring sites for a given year. Thus, the graphic displays the concentration range where 80 percent of measured values occurred for that year.

Consistent with the nationwide trend, CO levels in all ten EPA Regions have steadily decreased since 1980, with percent reductions over this period ranging from 64 percent (Region 4) to 80 percent (Region 1) (Exhibit 2-4).

Indicator Limitations

- Because most CO monitoring sites are located in high-traffic urban areas, the nationwide trends presented in this indicator might not accurately reflect conditions outside the immediate urban monitoring areas.
- Because of the relatively small number of trend sites in some EPA Regions, the regional trends are subject to greater uncertainty than the national trends. Some EPA Regions with low average concentrations may include areas with high local concentrations, and vice versa.
- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of CO monitoring sites with sufficient data to

assess trends since 1980. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported CO concentrations above the CO standard over the time frame covered by this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw CO ambient air monitoring data in EPA's Air Quality System (AQS) (U.S. EPA, 2006) (http://www.epa.gov/ttn/airs/airsaqs/). National and regional trends in this indicator are based on the subset of CO monitoring stations that have sufficient data to assess trends since 1980.

References

U.S. EPA. 2006. Data from the Air Quality System. Accessed 2006. <http://www.epa.gov/ttn/airs/airsaqs/>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

U.S. EPA. 2000. Air quality criteria for carbon monoxide, 2000. EPA/600/P-99/001F. Research Triangle Park, NC.

INDICATOR: Lead Emissions

Lead is a naturally occurring metal found in small amounts in rock and soil. Lead has been used industrially in the production of gasoline, ceramic products, paints, metal alloys, batteries, and solder. In the past, automotive sources were the major contributors of lead emissions to the atmosphere. After leaded motor vehicle fuels were phased out during the 1970s and 1980s, the contribution of air emissions of lead from the transportation sector, and particularly the automotive sector, greatly declined. Today, industrial processes, primarily metals processing, account for a large portion of lead emissions to the atmosphere and the highest levels of airborne lead are usually found near industrial operations that process materials containing lead, such as smelters (U.S. EPA, 2003). Exposure to lead occurs mainly through inhalation of air and ingestion of lead in food, water, soil, or dust. The Lead Concentrations indicator (p. 2-21) describes health hazards associated with lead exposures.

This indicator presents lead emissions from traditionally inventoried anthropogenic source categories: 1) “Fuel combustion,” which includes emissions from coal, gas and oil-fired power plants, industrial, commercial, and institutional sources, as well as residential heaters and boilers; 2) “Other sources,” which include chemical production and petroleum refining; 3) “On-road vehicles,” which includes cars, trucks, buses, and motorcycles; 4) “Nonroad vehicles and engines,” such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others; and 5) “Metals industrial processing.” Since metals processing is one of the largest sources of lead emissions, the indicator includes a metals source category in addition to the four categories presented in the other emissions indicators.

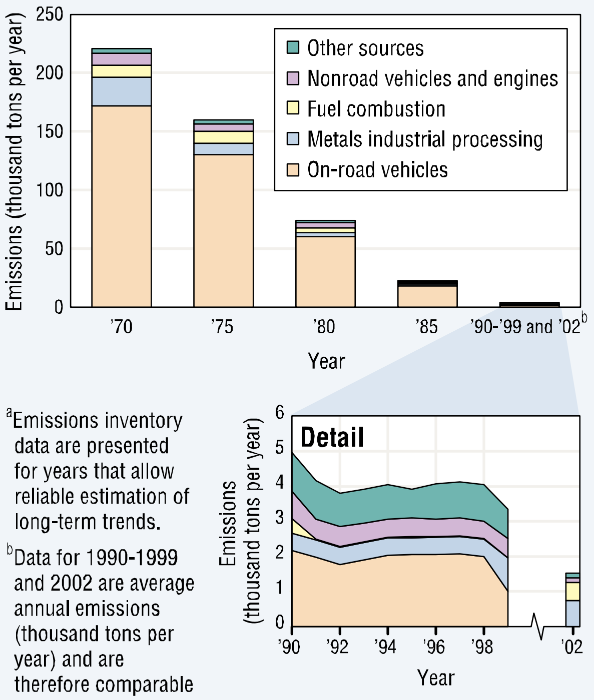
For the years 1970 through 1985, the primary source for lead emissions data was the National Emissions Data System (NEDS) archives. Since 1990, lead emissions data have been tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For most industrial processes and fuel combustion sources, emissions are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2005).

Data for lead emissions cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and Virgin Islands, and some of the territories of federally-recognized American Indian nations.

What the Data Show

Between 1970 and 2002, estimated nationwide lead emissions decreased by 99 percent (219,350 tons), mostly due to reductions from on-road vehicle sources after lead was removed from gasoline (Exhibit 2-5). Since 1990, further declines in lead emissions occurred, mostly due to reductions from on-road vehicles, nonroad vehicles and engines, and metals industrial processing . Sharp declines in nationwide air concentrations of lead between 1980 and 1990 paralleled the emissions reductions (the Lead Concentrations indicator, p. 2-21).

Exhibit 2-5. Lead emissions in the U.S. by source category, 1970-1999 and 2002[a]



[a] Emissions inventory data are presented for years that allow reliable estimation of long-term trends.

[b] Data for 1990-1999 and 2002 are average annual emissions (thousand tons per year) and are therefore comparable to the annual emissions shown for the earlier years.

Data source: *1970-1985 data from National Emissions Data System (NEDS) archives, and 1990-1999 and 2002 data from U.S. EPA, National Emissions Inventory (NEI), 2005*

Indicator Limitations

- Although lead emissions trends have been generated using well-established estimation methods, the data reflect estimates based on empirical and engineering models and not actual measurement of lead emissions. These estimates have uncertainties inherent in the emission factors and emission models used to represent sources for which emissions have not been directly measured.
- The method for estimating lead emissions for fuel combustion and industrial sources changed in 1999 to reduce uncertainties inherent in the previous method (U.S. EPA, 2003). Despite the change in methodology, the long-term trend is still reliable.
- Not all states and local agencies provide the same data or level of detail for a given year.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw lead emissions data from two sources. Raw emissions data from 1970 to 1985 are from EPA's National Emissions Data System (NEDS) archives, and data summaries for this time frame can be found in various EPA publications (e.g., U.S. EPA, 2001). Raw emissions data for 1990-1999 and 2002 are available from EPA's National Emissions Inventory (NEI) (U.S. EPA, 2006) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw emissions data by source category.

References

U.S. EPA. 2006. Data from the National Emissions Inventory. Accessed 2006. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

U.S. EPA. 2005. Documentation for the final 2002 mobile National Emissions Inventory. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_onroadandnonroad.pdf>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

U.S. EPA. 2001. National air quality and emissions trends report, 1999. EPA/454/R-01-004. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd99/>

INDICATOR: Ambient Concentrations of Lead

Lead is a naturally occurring metal found in small amounts in rock and soil. Despite steep decreases in emissions since 1970 (the Lead Emissions indicator, p. 2-19), lead remains an important environmental health issue because exposure to high levels has been associated with serious health effects, including neurological impairments such as seizures, mental retardation, and behavioral disorders (CDC, 2005). Even at low doses, lead exposure can have adverse effects to the nervous systems of fetuses and young children (the Blood Lead indicator, p. 5-76) (U.S. EPA, 2006a). Lead exposure can occur by inhalation of airborne particles that contain lead, drinking contaminated water, eating contaminated food items, or by ingesting non-food items that contain lead, such as dust and paint chips.

Lead has been used industrially in the production of gasoline, ceramic products, paints, metal alloys, batteries, and solder. Some chemicals containing lead were previously added to gasoline to enhance vehicle performance, but that practice was phased out during the 1970s and 1980s. As a result, air emissions of lead from the transportation sector decreased dramatically during that period (the Lead Emissions indicator, p. 2-19). Today, the highest levels of airborne lead are usually found near industrial operations that process materials containing lead, such as smelters (U.S. EPA, 2003).

This indicator reflects ambient lead concentrations in micrograms per cubic meter ($\mu g/m^3$) from 1980 to 2004. Trends for this indicator are based on measurements made at the 18 monitoring stations in the National Air Monitoring Stations (NAMS) and State and Local Air Monitoring Stations (SLAMS) network that have consistently measured ambient air concentrations of lead over the entire period of interest. Reported values are annual maximum quarterly averages. This indicator's exhibit displays the lead National Ambient Air Quality Standard (NAAQS) as a point of reference, but the fact that the national lead concentrations fall below the standard does not mean that all monitoring sites also are below the standard.

What the Data Show

Between 1980 and 2004, average lead concentrations decreased 97 percent nationally (Exhibit 2-6, panel A). This decrease, which occurred mostly during the 1980s and early 1990s, is largely attributed to reduced lead content in gasoline (U.S. EPA, 2003). In addition, of the 18 sites comprising this trend (out of 185 total monitoring sites that were operating in 2004), the number reporting lead concentrations above the NAAQS declined to zero over the same period (Exhibit 2-6, panel B).

Also shown in Exhibit 2-6 (panel A) are the 90th and 10th percentiles based on the distribution of annual statistics at the monitoring sites. This provides additional graphical representation of the distribution of measured concentrations across the monitoring sites for a given year. Thus, the exhibit displays the concentration range where 80 percent of measured values occurred for each year.

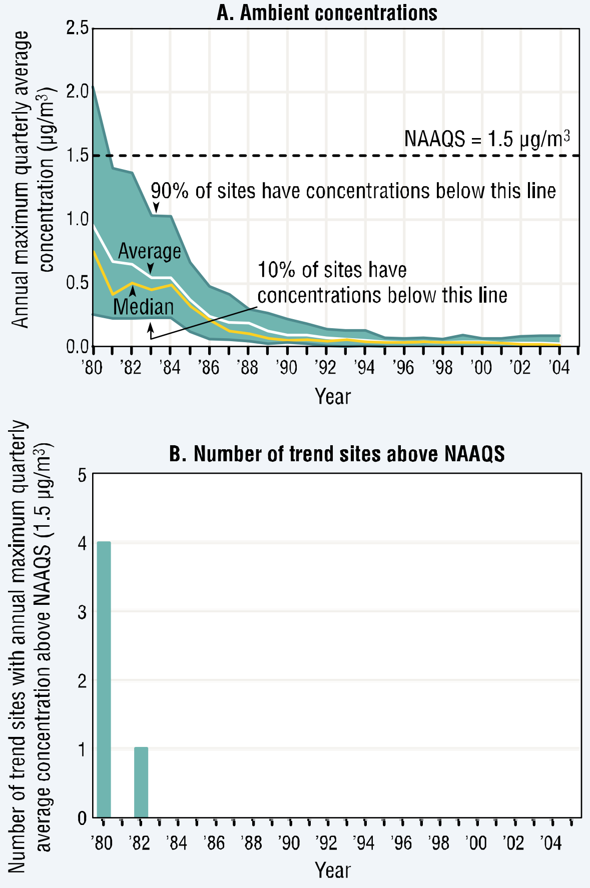
Indicator Limitations

- Because most lead monitoring sites are located in urban areas, the nationwide trends might not accurately reflect conditions outside the immediate urban monitoring areas.
- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of lead monitoring sites with sufficient data to assess trends since 1980. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported lead concentrations above the lead standard over the time frame covered by this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw lead ambient air monitoring data in EPA's Air Quality System (AQS) (U.S. EPA, 2006b) (http://www.epa.gov/ttn/airs/airsaqs/). National trends in this indicator are based on the subset of lead monitoring stations that have sufficient data to assess trends since 1980.

Exhibit 2-6. Ambient lead concentrations in the U.S., 1980-2004[a]



[a]**Coverage:** 18 monitoring sites nationwide (out of a total of 185 sites measuring lead in 2004) that have sufficient data to assess lead trends since 1980.

Data source: *U.S. EPA, Air Quality System, 2005*

References

CDC (Centers for Disease Control and Prevention, National Center for Environmental Health). 2005. Third national report on human exposure to environmental chemicals. NCEH Pub. No. 05-0570. July 2005. (Accessed September 9, 2005) <http://www.cdc.gov/exposurereport/3rd/results_01.htm>

U.S. EPA. 2006a. Air quality criteria for lead. EPA/600/R-5/144aF.

U.S. EPA. 2006b. Data from the Air Quality System. Accessed 2006. <http://www.epa.gov/ttn/airs/airsaqs/>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

INDICATOR: Nitrogen Oxides Emissions

Nitrogen oxides (NO_x) is the term used to describe the sum of nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Most airborne NO_x come from combustion-related emissions sources of human origin, primarily fossil fuel combustion in electrical utilities, high temperature operations at other industrial sources, and operation of motor vehicles. However, natural sources, like biological decay processes and lightning, also contribute to airborne NO_x. Fuel-burning appliances, like home heaters and gas stoves, produce substantial amounts of NO_x in indoor settings (U.S. EPA, 2003).

NO_x plays a major role in several important environmental and human health issues. Short-term and long-term exposures to elevated air concentrations of NO_2 are associated with various acute and chronic respiratory effects (U.S. EPA, 1993). NO_x and volatile organic compounds (VOCs) react in the presence of sunlight to form ozone, which also is associated with human health and ecological effects (the Ozone Concentrations indicator, p. 2-32). NO_x and other pollutants react in the air to form compounds that contribute to acid deposition, which can damage forests and cause lakes and streams to acidify (the Acid Deposition indicator, p. 2-56). Deposition of NO_x also affects nitrogen cycles and can contribute to nuisance growth of algae that can disrupt the chemical balance of nutrients in water bodies, especially in coastal estuaries (the Lake and Stream Acidity indicator, p. 2-62; the Trophic State of Coastal Waters indicator, p. 3-62). NO_x also plays a role in several other environmental issues, including formation of particulate matter (the PM Concentrations indicator, p. 2-44), decreased visibility (the Regional Haze indicator, p. 2-50), and global climate change (the U.S. Greenhouse Gas Emissions indicator, p. 2-96; the Greenhouse Gas Concentrations indicator, p. 2-100).

This indicator presents NO_x emissions from traditionally inventoried anthropogenic source categories: 1) “Fuel combustion: selected power generators,” which includes emissions from coal, gas and oil-fired power plants that are required to use continuous emissions monitors (CEMs) to report emissions as part of the Acid Rain Program (ARP); 2) “Fuel combustion: other sources,” which includes industrial, commercial, and institutional sources, as well as residential heaters and boilers not required to use CEMs; 3) “Other industrial processes,” which include chemical production and petroleum refining; 4) “On-road vehicles,” which includes cars, trucks, buses, and motorcycles; 5) “Nonroad vehicles and engines,” such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others. Since a substantial portion of airborne NO_x comes from fossil fuel combustion in electric utilities, this indicator includes the separate category for “selected power generators” in addition to the four categories presented in the other emissions indicators. The indicator also includes estimates of biogenic NO_x emissions in 2002 which were obtained using the Biogenic Emissions Inventory System (BEIS) Model, Version 3.12.

NO_x emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For major electric generating units, most data come from continuous emissions monitors that measure actual emissions. For other fuel combustion sources and industrial processes, data are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2005).

NEI data have been collected since 1990 and cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and Virgin Islands, and some of the territories of federally-recognized American

Indian nations. Data are presented only for 1990 and the years from 1996 to 2002; prior to 1996, only the 1990 data have been updated to be comparable to the more recent inventories.

What the Data Show

Only NO_x emissions from anthropogenic sources are included in the NEI. However, NO_x emissions from biogenic sources were estimated for 2002 to provide a sense of the relative contributions of natural versus anthropogenic emissions. Nationally, biogenic emissions were estimated to contribute approximately 5 percent to NO_x emissions from all sources during 2002 (Exhibit 2-7, panel B).

According to the NEI data, estimated nationwide anthropogenic emissions of NO_x decreased by 18 percent between 1990 and 2002 (from 25,160,000 to 20,746,000 tons) (Exhibit 2-7, panel A). This downward trend results primarily from emissions reductions at electrical utilities and among on-road mobile sources. Although total nationwide anthropogenic NO_x emissions decreased during this period, emissions from some sources (such as nonroad vehicles and engines) have increased since 1990.

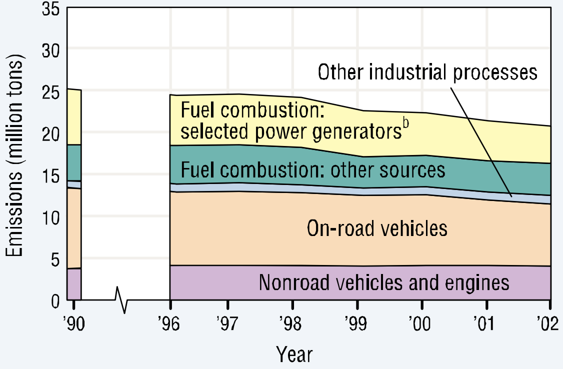
Estimated anthropogenic NO_x emissions in all ten EPA Regions decreased between 1990 and 2002 (Exhibit 2-8). The percent reductions in emissions over this time frame ranged from 3 percent (in Region 6) to 35 percent (in Region 1), and the largest absolute reduction (1,020,000 pounds) occurred in Region 5.

Indicator Limitations

- Comparable NO_x emissions estimates through the NEI are available only for 1990 and 1996-2002. Data for 1991-1995 are not provided due to differences in emission estimation methodologies from other inventory years which could lead to improper trend assessments.
- NO_x emissions from miscellaneous sources are not included in the total emissions.
- Though NO_x emissions from most electric utilities are measured directly using continuous monitoring devices, NO_x emissions data for most other source types are estimates. These estimates are generated using well-established approaches, but still have uncertainties inherent in the emission factors and emission models used to represent sources for which emissions have not been directly measured.
- The methodology for estimating emissions is continually reviewed and is subject to revision. Trend data prior to any revisions

Exhibit 2-7. NO_X emissions in the U.S., 1990 and 1996-2002

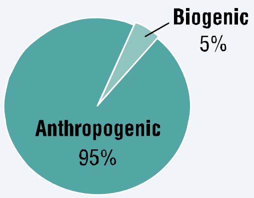
A. Anthropogenic NO_X emissions by source category[a]



[a]Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

[b]This category includes emissions from only those power plants required to use continuous emissions monitors under the Acid Rain Program.

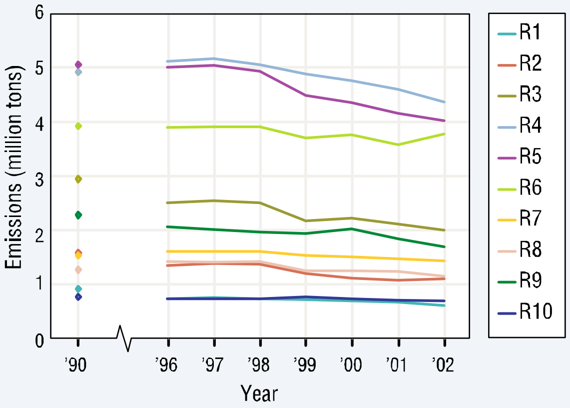
B. Relative amounts of NO_X emissions from anthropogenic and biogenic sources, 2002



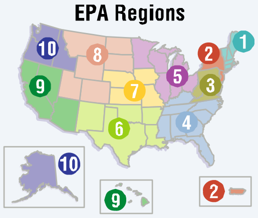
Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005* must be considered in the context of those changes.

- Not all states and local agencies provide the same data or level of detail for a given year.

Exhibit 2-8. NO_X emissions in the U.S. by EPA Region, 1990 and 1996-2002[a]



[a]Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.



Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw NO_x emissions data in EPA's National Emissions Inventory (NEI) (U.S. EPA, 2006) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

References

U.S. EPA. 2006. Data from the National Emissions Inventory. Accessed 2006. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

U.S. EPA. 2005. Documentation for the final 2002 mobile National Emissions Inventory. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_onroadandnonroad.pdf>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

U.S. EPA. 1993. Air quality criteria for oxides of nitrogen. EPA/600/8-91/049aF-cF. Research Triangle Park, NC.

INDICATOR: Ambient Concentrations of Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a reddish-brown, highly reactive gas that is formed in the ambient air through the oxidation of nitric oxide (NO). Nitrogen dioxide is one in a group of highly reactive gases generically referred to as "nitrogen oxides" (NO_X), all of which contain nitrogen and oxygen in varying amounts. Nitrogen oxides play a major role in the formation of ozone in the atmosphere through a complex series of reactions with volatile organic compounds (VOCs). Nitrogen dioxide is the most widespread and commonly found nitrogen oxide (U.S. EPA, 2003).

Short-term exposures (e.g., less than 3 hours) to low-levels of NO_2 may lead to changes in airway responsiveness and lung function in individuals with preexisting respiratory illnesses. These exposures may also increase respiratory illnesses in children. Long-term exposures to NO_2 may lead to increased susceptibility to respiratory infection and may cause irreversible alterations in lung structure (U.S. EPA, 1995).

Atmospheric transformation of NO_X can lead to the formation of ozone and nitrogen-bearing particles (e.g., nitrates and nitric acid). Deposition of nitrogen can lead to fertilization, eutrophication, or acidification of terrestrial, wetland, and aquatic (e.g., fresh water bodies, estuaries, and coastal water) systems. These effects can alter competition among existing species, leading to changes in species abundance and distribution within communities. For example, eutrophic conditions in aquatic systems can produce explosive growth of algae leading to hypoxia or an increase in levels of toxins harmful to fish and other aquatic life (U.S. EPA, 1993).

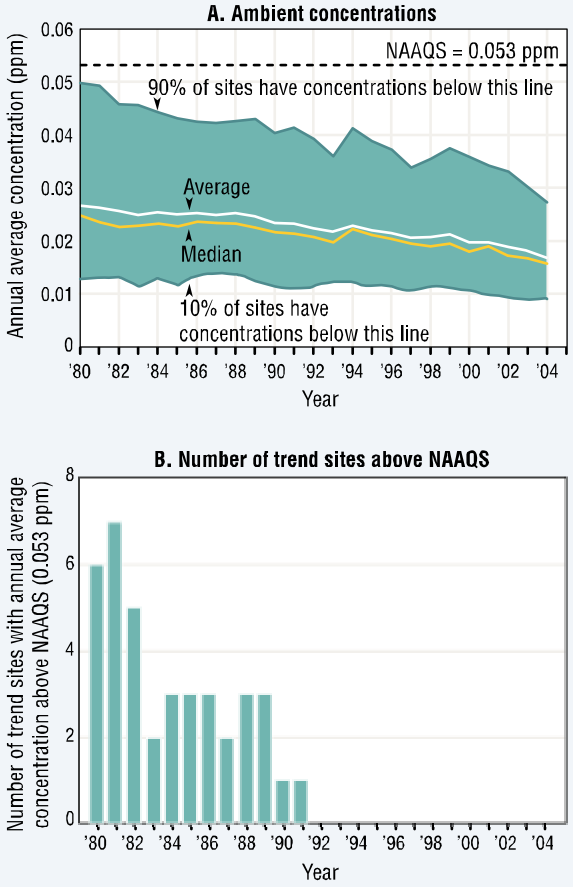
This indicator presents ambient NO_2 concentrations in parts per million (ppm) from 1980 to 2004, based on the annual arithmetic average. The indicator displays trends averaged over 91 sites that have consistent data for the period of record in the National Air Monitoring Stations (NAMS), State and Local Air Monitoring Stations (SLAMS) network, and other special purpose monitors. It also shows trends in the annual average NO_2 measurements in each EPA Region. This indicator's exhibits display the NO_2 National Ambient Air Quality Standard (NAAQS) as a point of reference, but the fact that the national or any regional mean values fall below the standard does not mean that all monitoring sites nationally or in the EPA Region also are below the standard. This indicator displays trends in the number of the 91 sites nationwide at which NO_2 concentrations exceeded the annual average standard over the period of record, but this statistic is not displayed for each EPA Region.

What the Data Show

The national annual mean NO_2 concentration in 2004 was 37 percent lower than that recorded in 1980 (Exhibit 2-9, panel A). Also shown on this graph are the 90th and 10th percentiles of NO_2 concentrations based on the distribution of annual statistics at the monitoring sites. This provides additional graphical representation of the distribution of measured concentrations across the monitoring sites for a given year. Thus, for each year, the graphic displays the concentration range where 80 percent of measured values occurred. The highest annual mean NO_2 concentrations are typically found in urban areas. In addition, of the 91 sites comprising this trend (out of 373 total monitoring sites that were operating in 2004), the number reporting NO_2 concentrations above the NO_2 standard declined from seven sites in 1981 to zero sites since 1992 (Exhibit 2-9, panel B).

NO_2 levels in all ten EPA Regions have steadily decreased since 1980, with percent reductions over this time ranging from 25 percent in Region 8 to 44 percent in Region 9 (Exhibit 2-10).

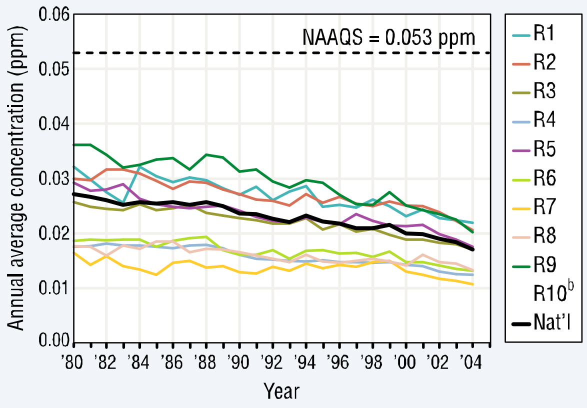
Exhibit 2-9. Ambient NO_2 concentrations in the U.S., 1980-2004[a]

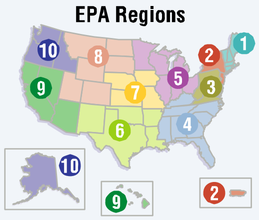


[a]**Coverage:** 91 monitoring sites nationwide (out of a total of 373 sites measuring NO_2 in 2004) that have sufficient data to assess NO_2 trends since 1980.

Data source: *U.S. EPA, Air Quality System, 2005*

Exhibit 2-10. Ambient NO_2 concentrations in the contiguous U.S. by EPA Region, 1980-2004[a,b]





[a]**Coverage:** 91 monitoring sites in the EPA Regions (out of a total of 373 sites measuring NO_2 in 2004) that have sufficient data to assess NO_2 trends since 1980.

[b]Because NO_2 in Region 10 has been at such low concentrations, none of this Region's monitoring sites have a complete record dating back to 1980. Thus, no trend line for Region 10 is shown.

Data source: *U.S. EPA, Air Quality System, 2005*

The decrease in NO_2 concentrations in this indicator is consistent with decreasing NO_x emissions observed over the past decade (the Nitrogen Oxides Emissions indicator, p. 2-23).

Indicator Limitations

- Because ambient monitoring for NO_2 occurs almost exclusively in high traffic urban areas, the average concentrations presented in this indicator likely are not representative of NO_2 levels in rural areas. Also, in rural areas, air mass aging could foster greater relative levels of peroxyacetyl nitrate (PAN) and nitric acid which can cause a positive interference in NO_2 measurements.
- The measurement of NO_2 is based on the conversion of NO_2 to NO and the subsequent detection of NO using the chemiluminescence technique. Because there are other nitrogen-containing compounds, such as PAN and nitric acid that can be converted to NO, the chemiluminescence technique may overestimate NO_2 due to these interferences. Measurement devices with ultraviolet photolytic converters are less prone to interferences than devices with heated surfaces (or catalysts) upstream of the chemiluminescence detector.

- Because of the relatively small number of trend sites in some EPA Regions, the regional trends are subject to greater uncertainty than the national trends. Some EPA Regions with low average concentrations may include areas with high local concentrations, and vice versa.
- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of NO_2 monitoring sites with sufficient data to assess trends since 1980. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported NO_2 concentrations above the NO_2 standard over the time frame covered by this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw NO_2 ambient air monitoring data in EPA's Air Quality System (AQS) (U.S. EPA, 2006) (http://www.epa.gov/ttn/airs/airsaqs/). National and regional trends in this indicator are based on the subset of NO_2 monitoring stations that have sufficient data to assess trends since 1980.

References

U.S. EPA. 2006. Data from the Air Quality System. Accessed 2006. <http://www.epa.gov/ttn/airs/airsaqs/>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

U.S. EPA. 1995. Review of the national ambient air quality standards for nitrogen oxides: assessment of scientific and technical information. EPA/452/R-95/005. Research Triangle Park, NC.

U.S. EPA. 1993. Air quality criteria for oxides of nitrogen. EPA/600/8-91/049aF-cF. Research Triangle Park, NC.

INDICATOR: Volatile Organic Compounds Emissions

Volatile organic compounds (VOCs) are a large group of organic chemicals that include any compound of carbon (excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate) and that participate in atmospheric photochemical reactions. VOCs are of interest because they contribute to ozone formation (U.S. EPA, 2003a) and because many individual VOCs are known to be harmful to human health (the Benzene Concentrations indicator, p. 2-74; the Air Toxics Emissions indicator, p. 2-70). Health effects vary by pollutant. Emissions of all VOCs combined are also considered an important environmental and human health issue because ozone, another air pollutant (the Ozone Concentrations indicator, p. 2-32), is formed from chemical reactions involving airborne VOCs, airborne nitrogen oxides, and sunlight. VOCs are emitted from a variety of sources, including motor vehicles, chemical manufacturing facilities, refineries, factories, consumer and commercial products, and natural (biogenic) sources (mainly trees) (U.S. EPA, 2003b).

This indicator presents VOC emissions from traditionally inventoried anthropogenic source categories: 1) “Fuel combustion,” which includes emissions from coal, gas and oil-fired power plants, industrial, commercial, and institutional sources, as well as residential heaters and boilers; 2) “Industrial and other processes,” which includes chemical production, petroleum refining, and metals production; 3) “On-road vehicles,” which includes cars, trucks, buses, and motorcycles; and 4) “Nonroad vehicles and engines,” such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others. The indicator also includes estimates of biogenic VOC emissions in 2002 which were obtained using the Biogenic Emissions Inventory System (BEIS) Model, Version 3.12.

VOC emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For most fuel combustion sources and industrial sources, emissions are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2005).

NEI data have been collected since 1990 and cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and Virgin Islands, and some of the territories of federally-recognized American Indian nations. Data are presented only for 1990 and the years from 1996 to 2002; prior to 1996, only the 1990 data have been updated to be comparable to the more recent inventories.

What the Data Show

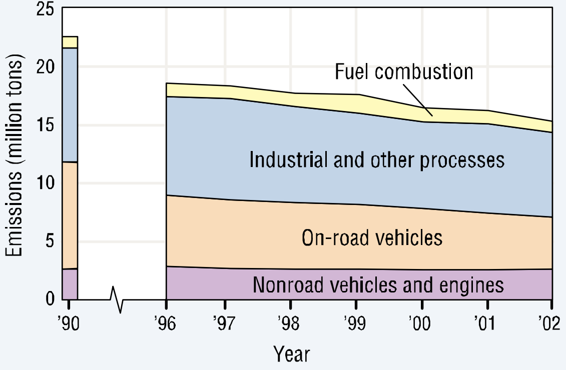
Only VOC emissions from anthropogenic sources are included in the NEI. However, VOC emissions from biogenic sources were estimated for 2002 to provide a sense of the relative contributions of natural versus anthropogenic emissions. Nationally, biogenic emissions were estimated to contribute approximately 72 percent to VOC emissions from all sources during 2002 (Exhibit 2-11, panel B). Thus, VOC emissions from biogenic sources are larger than the VOC emissions from all anthropogenic sources combined.

According to NEI data, national total estimated VOC emissions from anthropogenic sources, excluding wildfires and prescribed burns, decreased by 32 percent between 1990 and 2002 (from 23,048,000 to 15,662,000 tons) (Exhibit 2-11, panel A). The overwhelming majority of anthropogenic emissions reductions were observed among industrial processes and on-road mobile sources. Combined, these two source categories accounted for 84 percent of the total nationwide estimated anthropogenic VOC emissions in 1990 (excluding wildfires and prescribed burns), but accounted for only 76 percent of the nationwide anthropogenic emissions in 2002.

Trends in estimated anthropogenic VOC emissions among the ten EPA Regions were consistent with the overall decline seen nationally from 1990 to 2002 (Exhibit 2-12). VOC emissions decreased in every EPA Region, with the percent decrease ranging from 12 percent (Region 10) to 44 percent (Region 9).

Exhibit 2-11. VOC emissions in the U.S., 1990 and 1996-2002

A. Anthropogenic VOC emissions by source category[a]



[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

B. Relative amounts of VOC emissions from anthropogenic and biogenic sources, 2002

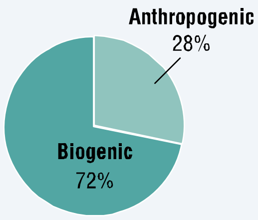
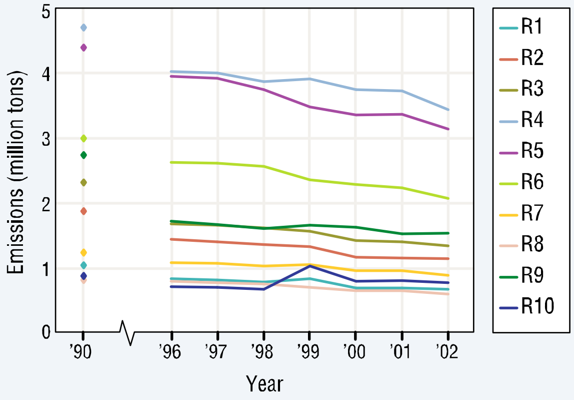
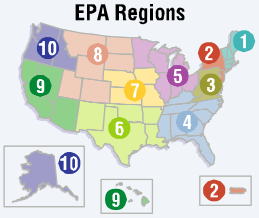


Exhibit 2-12. VOC emissions in the U.S. by EPA Region, 1990 and 1996-2002[a]



[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

EPA Regions



Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Indicator Limitations

- Comparable VOC emissions estimates through the NEI are available only for 1990 and 1996-2002. Data for 1991-1995 are not provided due to differences in emission estimation methodologies from other inventory years which could lead to improper trend assessments.
- VOC emissions from "miscellaneous sources" are not included in the total emissions. Details on emissions from miscellaneous sources can be found at http://www.epa.gov/ttn/chief/eiinformation.html.
- VOC emissions data are largely based on estimates that employ emission factors generated from empirical and engineering studies, rather than on actual measurements of VOC emissions. Although these estimates are generated using well-established approaches, the

estimates have uncertainties inherent in the emission factors and emission models used to represent sources for which emissions have not been directly measured.

- The methodology for estimating emissions is continually reviewed and is subject to revision. Trend data prior to any revisions must be considered in the context of those changes.
- Not all states and local agencies provide the same data or level of detail for a given year.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw VOC emissions data in EPA's National Emissions Inventory (NEI) (U.S. EPA, 2006) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

References

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INDICATOR: Ambient Concentrations of Ozone

Ozone is a gas found in different parts of the atmosphere. Ozone in the upper atmosphere, or stratosphere, helps protect the Earth from the sun's harmful rays. (The Ozone Levels over North America indicator, on page 2-79, describes trends in stratospheric ozone levels over the U.S.) In the lowest level of the atmosphere, or troposphere, ozone is harmful to both human health and the environment. For this reason, ozone is often described as being "good up high and bad nearby" (U.S. EPA, 2003a). Although some industrial sources release ozone directly into the environment, most ground-level ozone forms in the air from chemical reactions involving nitrogen oxides (NO_X), volatile organic compounds (VOCs), and sunlight. Ozone levels are typically highest during the afternoon hours of the summer months when the influence of direct sunlight is the greatest. These highest levels occur during what is known as the "ozone season" which typically occurs from May 1 to September 30, but the time frame of the ozone season varies by state (U.S. EPA, 2003b).

Variations in weather conditions play an important role in determining ozone levels. Daily temperatures, relative humidity, and wind speed can affect ozone levels. In general, warm dry weather is more conducive to ozone formation than cool wet weather. Wind can affect both the location and concentration of ozone pollution. NO_X and VOC emissions can travel hundreds of miles on air currents, forming ozone far from the original emission sources. Ozone also can travel long distances, affecting areas far downwind. High winds tend to disperse pollutants and can dilute ozone concentrations. However, stagnant conditions or light winds allow pollution levels to build up and become more concentrated.

Inhalation exposure to ozone has been linked to numerous respiratory health effects, including acute reversible decrements in lung function, airway inflammation, cough, and pain when taking a deep breath. Ozone exposure can aggravate lung diseases such as asthma, leading to increased medication use and increased hospital admission and visits to emergency rooms. In addition, evidence is highly suggestive that ozone directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but the underlying mechanisms by which such effects occur have not been fully established (U.S. EPA, 2006a). Although people with lung disease are most susceptible to the effects of ozone, even healthy people who are active outdoors can suffer from ozone-related health effects. Further, evidence suggests that older adults (greater than 65 years old) appear to be at excess risk of ozone-related mortality or hospitalization (U.S. EPA, 2006a). Elevated concentrations of ozone can also affect vegetation and ecosystems, as the Ozone Injury to Forest Plants indicator (p. 2-37) describes further (U.S. EPA, 1996).

This indicator presents ambient ground-level ozone concentrations in parts per million (ppm) from 1978 to 2004. Data are shown for 1-hour and 8-hour averaging times, based on continuous ozone monitoring data and consistent with this pollutant's National Ambient Air Quality Standards (NAAQS). The 1-hour standard is useful in indicating potential effects during short-term "spikes" in concentrations. The longer 8-hour standard is indicative of exposures occurring over a more sustained period of time (e.g., an outdoor worker's exposure over the course of a work day). Trends for this indicator represent 213 sites that have data for the period of record in the National Air Monitoring Stations (NAMS), the State and Local Air Monitoring Stations (SLAMS) network, and other special purpose monitors. The indicator also displays trends in ozone measurements in each EPA Region. This indicator's exhibits display the corresponding NAAQS as points of reference, but the fact that the national or regional concentrations fall below the standards does not mean that all monitoring sites nationally or in any EPA Region also are below the standard. The indicator displays trends in the number of the 213 sites nationwide at which ozone concentrations exceeded standards, but these statistics are not displayed for each EPA Region.

Trends in ozone concentrations can be difficult to discern because of the year-to-year variations in the concentrations. By presenting data on a rolling 3-year time period, this indicator smooths out the “peaks” and “valleys” in the trend, making it easier to read without changing the overall trend statistic. Three years is consistent with the 3-year period used to assess compliance with the ozone standards. For the 1-hour trends in this report, the second highest daily maximum over a 3-year period is used to be consistent with the 1-hour ozone standard. For the 8-hour trends in this report, a 3-year average of the fourth highest daily maximum in each year is used to be consistent with the 8-hour ozone standard. The 3-year statistic is assigned to the last year in each 3-year period. For example, 1980 is based on 1978-1980, and 2004 is based on 2002-2004. Thus, when endpoint comparisons are used in this report to describe long-term changes (i.e., 1978-2004), they are based on the first 3-year period and the last 3-year period.

What the Data Show

Between the 1978-1980 and 2002-2004 averaging periods, nationwide 1-hour average ambient ozone levels decreased by 26 percent (Exhibit 2-13, panel A). In addition, among the 213 monitoring sites used to estimate the 1978-2004 trend, the number measuring ozone concentrations above the 1-hour NAAQS (National Ambient Air Quality Standard) declined 77 percent over the same period (Exhibit 2-13, panel B).

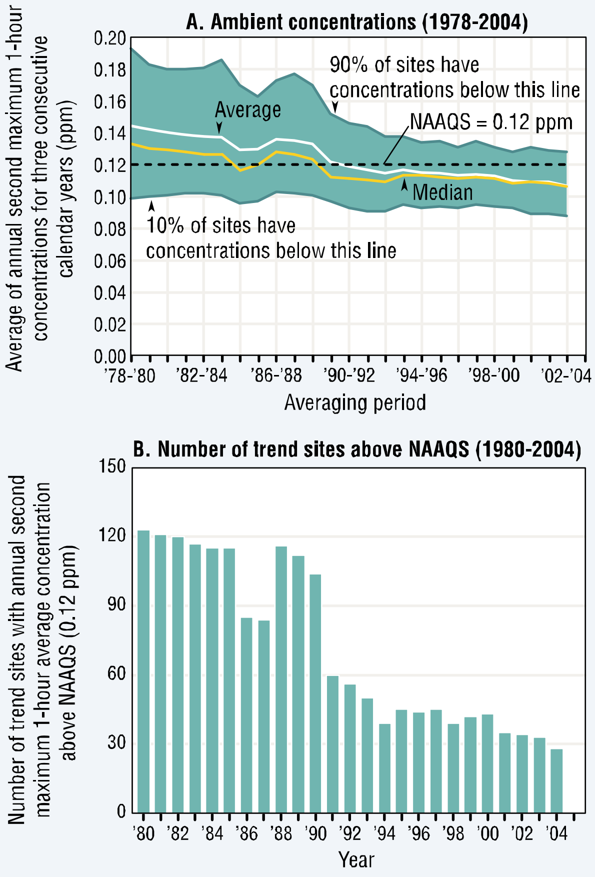
All ten EPA Regions also experienced some decline in 1-hour average ozone levels dating back to the 1978-1980 averaging period (Exhibit 2-14). The greatest percent reductions in 1-hour ozone concentrations were observed in the two EPA Regions (Regions 1 and 9) that had the highest ozone levels in 1980, although the South Coast area in EPA Region 9 continues to have some of the highest ozone levels in the nation. EPA Region 10 showed the lowest ambient ozone concentrations over most of the period of record.

Between the 1978-1980 and 2002-2004 averaging periods, nationwide 8-hour average ambient ozone concentrations decreased by 21 percent (Exhibit 2-15, panel A). Although the 8-hour ozone levels in 2004 ranked among the lowest on record and the number of trend sites measuring ozone concentrations above the 8-hour NAAQS decreased by 84 percent over the time frame covered in this indicator (Exhibit 2-15, panel B), ambient air monitoring data collected in 2005 and reported to EPA’s Air Quality System indicates that approximately 118 million people live in 47 metropolitan areas where 8-hour average ozone concentrations do not meet EPA’s health-based air quality standards.Among the ten EPA Regions, the most substantial declines in 8-hour levels were again observed in EPA Regions that originally had the highest ozone concentrations (EPA Regions 1 and 9) (Exhibit 2-16). Most other Regions showed less pronounced declines (e.g., EPA Regions 6 to 10). Region 10 again consistently showed the lowest Regional ozone levels.

Also shown in Exhibits 2-13 and 2-15 (panel A, in both cases) are the 90th and 10th percentiles based on the distribution of annual statistics at the monitoring sites. This provides additional graphical representation of the variability of measured concentrations across the monitoring sites for a given year. Thus, the graphic displays the concentration range where 80 percent of measured values occurred for that year.

In summary, despite reductions in ambient concentrations of ozone over the past quarter century and decreases in the emissions of ozone precursors since 1990 (the Nitrogen Oxides Emissions indicator, p. 2-23; the VOC Emissions indicator, p. 2-29), ozone remains one of the most persistent and ubiquitous air pollution issues in the U.S.

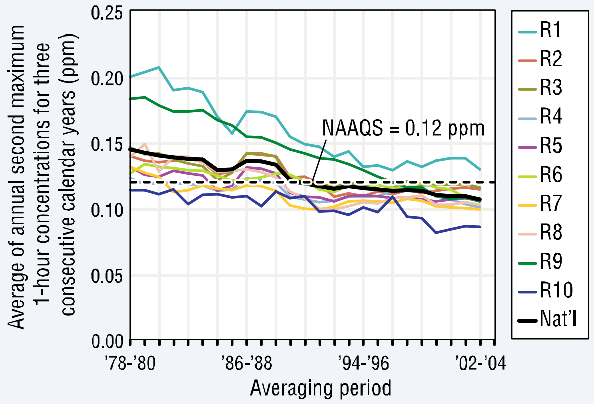
Exhibit 2-13. Ambient 1-hour ozone concentrations in the U.S., 1978-2004[a]



[a]**Coverage:** 213 monitoring sites nationwide (out of a total of 1,203 sites measuring ozone in 2004) that have sufficient data to assess ozone trends since 1978.

Data source: *U.S. EPA, Air Quality System, 2005*

Exhibit 2-14. Ambient 1-hour ozone concentrations in the contiguous U.S. by EPA Region, 1978-2004[a]



[a]**Coverage:** 213 monitoring sites in the EPA Regions (out of a total of 1,203 sites measuring ozone in 2004) that have sufficient data to assess ozone trends since 1978.

Data source: *U.S. EPA, Air Quality System, 2005*

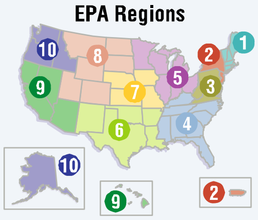
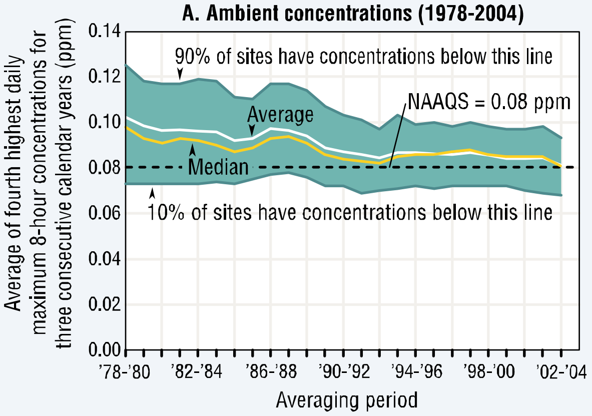
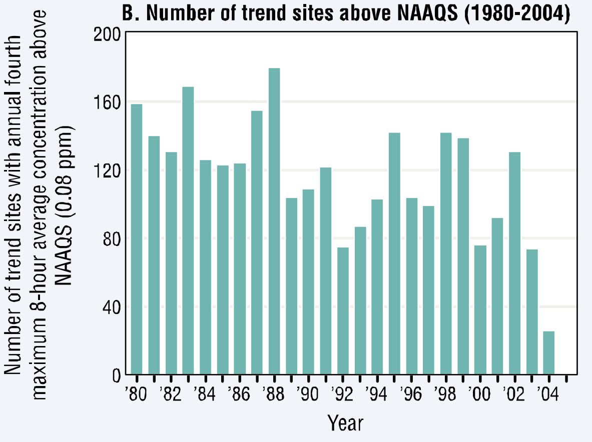


Exhibit 2-15. Ambient 8-hour ozone concentrations in the U.S., 1978-2004[a]

A. Ambient concentrations (1978-2004)



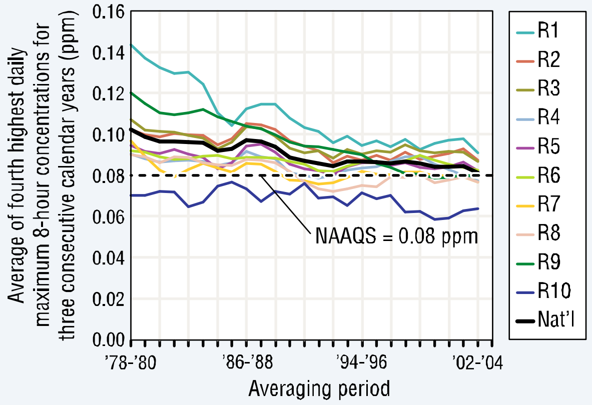
B. Number of trend sites above NAAQS (1980-2004)



[a]**Coverage:** 213 monitoring sites nationwide (out of a total of 1,203 sites measuring ozone in 2004) that have sufficient data to assess ozone trends since 1978.

Data source: *U.S. EPA, Air Quality System, 2005*

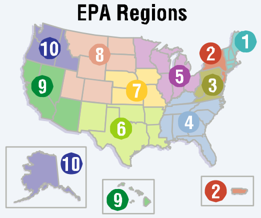
Exhibit 2-16. Ambient 8-hour ozone concentrations in the contiguous U.S. by EPA Region, 1978-2004[a]



[a]**Coverage:** 213 monitoring sites in the EPA Regions (out of a total of 1,203 sites measuring ozone in 2004) that have sufficient data to assess ozone trends since 1978.

Data source: *U.S. EPA, Air Quality System, 2005*

EPA Regions



Indicator Limitations

- Short-term trends in ozone concentrations are often highly dependent on meteorological conditions. This complicates efforts to interpret data for any given year. Air quality trends over the longer term are far less likely to be influenced by unusual meteorological conditions.
- Because most of the monitoring sites are located in urban areas, the trends might not accurately reflect conditions outside the immediate urban monitoring areas.
- Because of the relatively small number of trend sites in some EPA Regions, the regional trends are subject to greater uncertainty than the national trends. Some EPA Regions with low average concentrations may include areas with high local concentrations, and vice versa.
- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of ozone monitoring sites with sufficient data to assess trends since 1978. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported ozone concentrations above the ozone standard over the time frame covered by this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw ozone ambient air monitoring data in EPA's Air Quality System (AQS) (U.S. EPA, 2006b) (http://www.epa.gov/ttn/airs/airsaqs/). National and regional trends in this indicator are based on the subset of ozone monitoring stations that have sufficient data to assess trends since 1978.

References

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INDICATOR: Ozone Injury to Forest Plants

Air pollution can have noteworthy cumulative impacts on forested ecosystems by affecting regeneration, productivity, and species composition (U.S. EPA, 1996). In the U.S., ozone in the lower atmosphere is one of the pollutants of primary concern. Ozone injury to forest plants can be diagnosed by examination of plant leaves. Foliar injury is usually the first visible sign of injury to plants from ozone exposure and indicates impaired physiological processes in the leaves (Grulke, 2003).

This indicator is based on data from the U.S. Department of Agriculture Forest Service Forest Health Monitoring (FHM) Program (USDA, 2004). The FHM Program, now known as Phase 3 of the Forest Inventory Analysis, examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country. For this indicator, forest land does not include woodlots and urban trees. Sites are selected using a systematic sampling grid, based on a global sampling design (White et al., 1992; Smith et al., 2003). At each site that has at least 30 individual plants of at least three ozone-sensitive species and enough open space to ensure that sensitive plants are not protected from exposure by the forest canopy, FHM looks for damage on the foliage of ozone-sensitive forest plant species. Because ozone injury is cumulative over the course of the growing season, examinations are conducted in July and August, when ozone injury is typically highest.

Monitoring of ozone injury to plants in the FHM program has expanded over the last 10 years from monitoring sites in ten states in 1994 to nearly 1,000 monitoring sites in 41 states in 2002. The data underlying this indicator are based on averages of all observations collected in 2002, the latest year for which data are publicly available, and are broken down by EPA Region. The ozone damage to forest plants is classified using a subjective five-category biosite index based on expert opinion, but designed to be equivalent from site to site. Ranges of biosite values translate to no injury, low or moderate foliar injury (visible foliar injury to highly sensitive or moderately sensitive plants, respectively), and high or severe foliar injury, which would be expected to result in tree-level or ecosystem-level responses, respectively (Coulston et al., 2004; U.S. EPA, 1996).

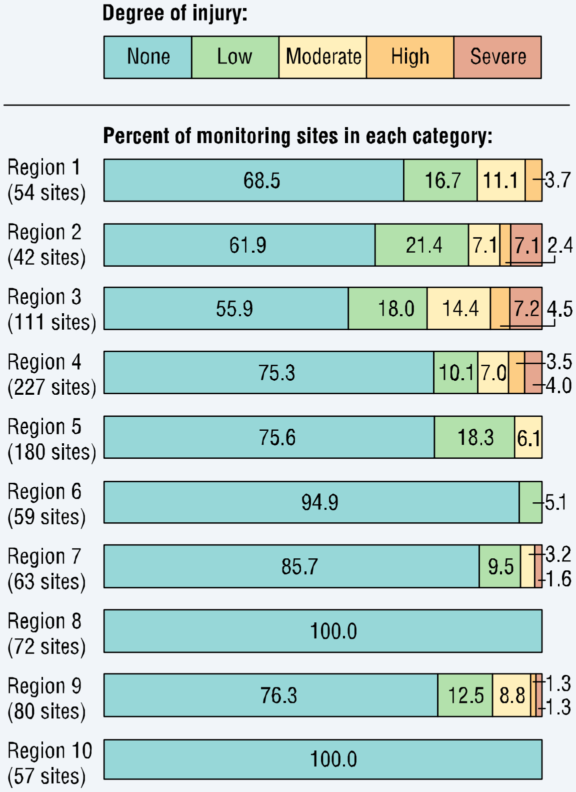
What the Data Show

There is considerable regional variation in ozone injury to sensitive plants (Exhibit 2-17). The highest percentages of observed high and severe foliar injury, which are most likely to be associated with tree or ecosystem-level responses, are primarily found in the Mid-Atlantic and Southeast Regions. In EPA Region 3, 12 percent of ozone-sensitive plants showed signs of high or severe foliar damage, and in Regions 2 and 4, the values were 10 percent and 7 percent, respectively. High and severe ozone injury ranged from 2 percent to 4 percent in EPA Regions 1, 7, and 9, and no high or severe foliar damage was observed in EPA Regions 5, 6, 8, and 10. The percentage of sites showing no damage was greater than 50 percent in every EPA Region, and no ozone-related foliar damage was observed at any of the 129 biosites in EPA Regions 8 and 10.

Indicator Limitations

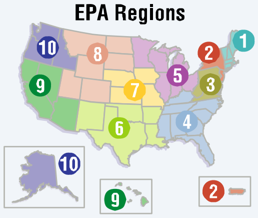
- Field and laboratory studies were reviewed to identify the forest plant species in each region that are highly sensitive to ozone air pollution. Other forest plant species, or even genetic variants of the same species, may not be harmed at ozone levels that cause effects on the selected ozone-sensitive species.
- Because species distributions vary regionally, different ozone-sensitive plant species were examined in different parts of the country. These target species could vary with respect to ozone sensitivity, which might account for some of the apparent differences in ozone injury among EPA Regions.
- Ozone damage to foliage is considerably reduced under conditions of low soil moisture, but most of the variability in the index (70 percent) was explained by ozone concentration (Smith et al., 2003).
- Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury (U.S. EPA, 1996).
- Though the FHM has extensive spatial coverage based on a robust sample design, not all forested areas in the U.S. are monitored for ozone injury.
- Even though the biosite data have been collected over a seven year period, most biosites were not monitored over the entire period, so these data cannot provide more than a baseline for future trends.

Exhibit 2-17. Ozone injury to forest plants in the U.S. by EPA Region, 2002[a]



[a]**Coverage:** 945 monitoring sites, located in 41 states.

Data source: *USDA Forest Service, Forest Health Monitoring (FHM) Program database*



Data Sources

Data were provided by the USDA Forest Service's Ozone Biomonitoring Program, which maintains a database of plant injury statistics by state (USDA Forest Service, 2006) (http://www.fiaozone.net/tabular.html). This indicator aggregates the state data by EPA Region.

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INDICATOR: Particulate Matter Emissions

Particulate matter (PM) is the general term used to describe solid particles and liquid droplets found in the air. The composition and size of these airborne particles and droplets vary. Some particles are large enough to be seen as dust or dirt, while others are so small they can only be seen using a powerful microscope. Two size ranges, known as PM_{10} and $PM_{2.5}$, are widely monitored, both at major emissions sources and in ambient air. PM_{10} includes particles that have aerodynamic diameters less than or equal to 10 microns (µm), approximately equal to one-seventh the diameter of human hair. $PM_{2.5}$ is the subset of PM_{10} particles that have aerodynamic diameters less than or equal to 2.5 µm.

Particles within the two size ranges behave differently in the atmosphere. $PM_{2.5}$, or fine particles, can remain airborne for long periods and travel hundreds of miles. Coarse particles, or the subset of PM_{10} that is larger than 2.5 µm, do not remain airborne as long and their spatial impact is typically limited because they tend to deposit on the ground downwind of emissions sources. Larger coarse particles are not readily transported across urban or broader areas because they are generally too large to follow air streams and they tend to be removed easily on contact with surfaces. In short, as the particle size increases, the amount of time the particles remain airborne decreases. The PM Concentrations indicator (p. 2-44) describes the various ways PM can harm human health and the environment (U.S. EPA, 2004).

PM can be emitted directly or formed in the atmosphere. “Primary” particles refer to those released directly to the atmosphere. These include dust from roads and soot from combustion sources. In general, coarse PM is composed largely of primary particles. “Secondary” particles, on the other hand, are formed in the atmosphere from chemical reactions involving primary gaseous emissions. Thus, these particles can form at locations distant from the sources that release the precursor gases. Examples include sulfates formed from sulfur dioxide emissions from power plants and industrial facilities and nitrates formed from nitrogen oxides released from power plants, mobile sources, and other combustion sources. Unlike coarse PM, a much greater portion of fine PM ($PM_{2.5}$) contains secondary particles (U.S. EPA, 2004).

This indicator presents trends in annual average primary PM emissions data tracked by the National Emissions Inventory (NEI). The NEI tracks emission rate data, both measured and estimated, for primary particles only. Because secondary particles are not released directly from stacks, the NEI instead tracks the precursors that contribute to formation of secondary particles. These precursors include nitrogen oxides, sulfur dioxide, ammonia, and other gases (e.g., particle-producing organic gases), some of which are addressed in separate indicators (the Nitrogen Oxides Emissions indicator, p. 2-23; the Sulfur Dioxide Emissions indicator, p. 2-53). Particles formed through secondary processes are not included in this indicator.

Primary emissions of particulate matter can exist as solid or liquid matter (the “filterable” portion) or as gases (the “condensable” portion). Data for the condensable portion exist only for the years 1999 to 2002. To allow for a valid comparison of emission trends from 1990 to 2002, only data for the filterable portion of PM_{10} and $PM_{2.5}$ are included in the trend graphs. Condensables are, however, included in the anthropogenic sources displayed in the inset pie charts in Exhibits 2-18 and 2-20.

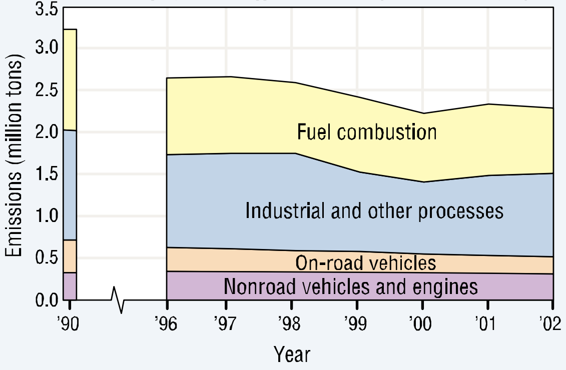
NEI data are presented for the traditionally inventoried anthropogenic source categories including: 1) “Fuel combustion,” which includes emissions from coal, gas, and oil-fired power plants, industrial, commercial, and institutional sources, as well as residential heaters and boilers; 2) “Industrial and other processes,” which includes chemical production, petroleum refining, and metals production; 3) “On-road vehicles” which includes cars, trucks, buses, and motorcycles; and 4) “Nonroad vehicles and engines,” such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others. This indicator includes a comparison of these anthropogenic sources with emissions from miscellaneous and natural sources, such as agriculture and forestry, wildfires and managed burning, and fugitive dust from paved and unpaved roads. The indicator also includes estimates of miscellaneous and natural sources in 2002 which were obtained using the Biogenic Emissions Inventory System (BEIS) Model, Version 3.12.

The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For most fuel combustion sources and industrial sources, emissions are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2005).

NEI data have been collected since 1990 and cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and Virgin Islands, and some of the territories of federally-recognized American Indian nations. Data are presented for 1990 and the years from 1996 to 2002; prior to 1996, only the 1990 data have been updated to be comparable to the more recent inventories.

Exhibit 2-18. PM_{10} emissions in the U.S., 1990 and 1996-2002

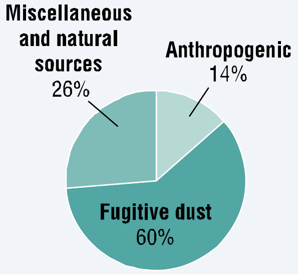
A. Anthropogenic PM_{10} emissions by source category[a,b]



[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

[b] Starting in 1999, EPA began tracking condensable particulate emissions separately from filterable particulate emissions. In order to display data generated using a consistent methodology, emissions of condensable particulate from 1990 to 2002 are not included in Panel A. However, condensable particulate emissions are included in Panel B.

B. Relative amounts of PM_{10} emissions from anthropogenic and other sources, 2002[b]



Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

What the Data Show

PM_{10} Emissions Trends

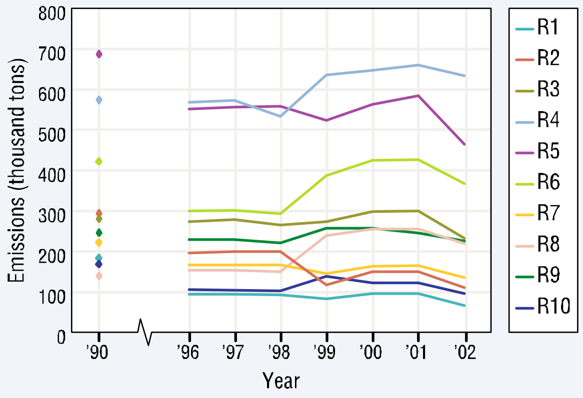
Estimated PM_{10} emissions from anthropogenic sources decreased 29 percent nationally between 1990 and 2002 (Exhibit 2-18, panel A). Of these sources, the fuel combustion category saw the largest absolute decrease in emissions (422,000 tons; 35 percent), and the on-road vehicle sector showed the largest relative decrease (47 percent; 183,000 tons). PM_{10} emissions from the group of sources including miscellaneous and natural sources and fugitive dust were estimated to account for 86 percent of total PM_{10} emissions (including condensables from stationary and mobile sources) in 2002, the majority of which was attributable to fugitive dust from roads (Exhibit 2-18, panel B).

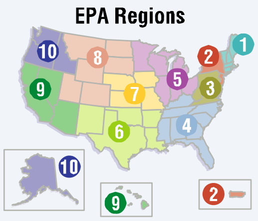
Changes in estimated anthropogenic PM_{10} emissions from 1990 to 2002 varied widely among EPA Regions, ranging from an increase of 56 percent (Region 8) to a decrease of 64 percent (Region 1) (Exhibit 2-19).

$PM_{2.5}$ Emissions Trends

Estimated $PM_{2.5}$ emissions from anthropogenic sources decreased 27 percent nationally between 1990 and 2002 (Exhibit 2-20, panel A). Like PM_{10}, the largest absolute decline in $PM_{2.5}$ was seen in the

Exhibit 2-19. PM_{10} emissions in the U.S. by EPA Region, 1990 and 1996-2002[a,b]





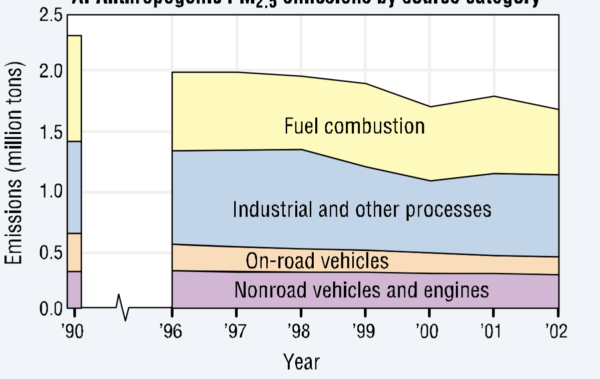
[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

[b] Starting in 1999, EPA began tracking condensable particulate emissions separately from filterable particulate emissions. In order to display data generated using a consistent methodology, emissions of condensable particulate from 1999 to 2002 are not included in this figure.

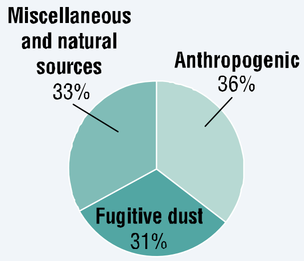
Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Exhibit 2-20. $PM_{2.5}$ emissions in the U.S., 1990 and 1996-2002

A. Anthropogenic $PM_{2.5}$ emissions by source category[a,b]



B. Relative amounts of $PM_{2.5}$ emissions from anthropogenic and other sources, 2002[b]



[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

[b] Starting in 1999, EPA began tracking condensable particulate emissions separately from filterable particulate emissions. In order to display data generated using a consistent methodology, emissions of condensable particulate from 1990 to 2002 are not included in Panel A. However, condensable particulate emissions are included in Panel B.

Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

fuel combustion source category (347,000 tons; 38 percent), and the largest relative decline was in the on-road vehicle category (54 percent; 175,000 tons). Emissions from the group of miscellaneous and natural sources were estimated to account for 64 percent of the total $PM_{2.5}$ emissions (including condensables from stationary and mobile sources) nationally in 2002 (Exhibit 2-20, panel B).

Anthropogenic $PM_{2.5}$ emissions decreased in all ten EPA Regions from 1990 to 2002, with percent reductions ranging from 6 percent (Region 8) to 71 percent (Region 1) (Exhibit 2-21).

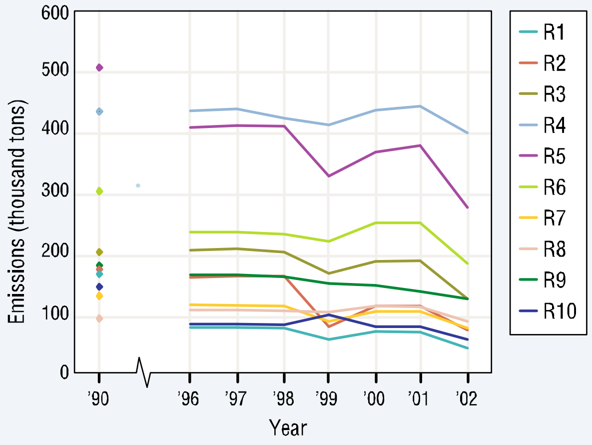
Indicator Limitations

- Comparable PM emissions estimates through the NEI are available only for 1990 and 1996-2002. Data for 1991-1995 are not provided due to differences in emission estimation methodologies from other inventory years which could lead to improper trend assessments.
- Because the emissions indicators focus on sources of anthropogenic origin, PM emissions from miscellaneous sources (e.g., wildfires) are not included in the trend line. Details on

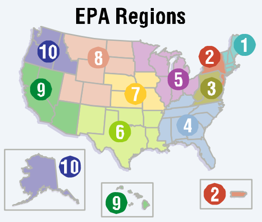
emissions from these sources can be found at http://www.epa.gov/ttn/chief/eiinformation.html.

- The emissions data for PM are largely based on estimates that employ emission factors generated from empirical and engineering studies, rather than on actual measurements of PM emissions. Although these estimates are generated using well-established approaches, the estimates have uncertainties inherent in the emission factors and emission models used to represent sources for which emissions have not been directly measured.
- The methodology for estimating emissions is continually reviewed and is subject to revision. Trend data prior to these revisions must be considered in the context of those changes.
- The indicator tracks primary PM emissions. Particles that form in the air through secondary processes are not included in this indicator, but are considered in the PM Concentrations indicator (p. 2-44).
- Not all states and local agencies provide the same data or level of detail for a given year.

Exhibit 2-21. $PM_{2.5}$ emissions in the U.S. by EPA Region, 1990 and 1996-2002[a,b]



[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.



[b] Starting in 1999, EPA began tracking condensable particulate emissions separately from filterable particulate emissions. In order to display data generated using a consistent methodology, emissions of condensable particulate from 1999 to 2002 are not included in this figure.

Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw PM emissions data in EPA's National Emissions Inventory (NEI) (U.S. EPA, 2006) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

References

U.S. EPA. 2006. Data from the National Emissions Inventory. Accessed 2006. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

U.S. EPA. 2005. Documentation for the final 2002 mobile National Emissions Inventory. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_onroadandnonroad.pdf>

U.S. EPA. 2004. Air quality criteria for particulate matter (October 2004). EPA 600/P-99/002aF-bF. Research Triangle Park, NC.

INDICATOR: Ambient Concentrations of Particulate Matter

Particulate matter (PM) is the general term used for a mixture of solid particles and liquid droplets found in the air. Airborne PM comes from many different sources. Primary particles are released directly into the atmosphere from sources such as cars, trucks, heavy equipment, forest fires, and burning waste. Primary particles also consist of crustal material from sources such as unpaved roads, stone crushing, construction sites, and metallurgical operations. Secondary particles are formed in the air from reactions involving precursor chemicals such as sulfates (which are formed from sulfur dioxide emissions from power plants and industrial facilities), nitrates (which are formed from nitrogen dioxide emissions from cars, trucks, and power plants) and carbon (which comes from reactive organic gas emissions from cars, trucks, industrial facilities, forest fires, and biogenic sources such as trees).

Ambient air monitoring stations throughout the country measure air concentrations of two size ranges of particles: $PM_{2.5}$ and PM_{10}. $PM_{2.5}$ consists of “fine particles” with aerodynamic diameters less than or equal to 2.5 μm. PM_{10} includes both fine particles ($PM_{2.5}$) and “coarse particles,” which is the subset of PM_{10} that is larger than 2.5 μm,. The chemical makeup of particles varies across the U.S. For example, fine particles in the eastern half of the U.S contain more sulfates than those in the West, while fine particles in southern California, for example, contain more nitrates than those in other areas of the U.S. Carbon is a substantial component of fine particles everywhere (U.S. EPA, 2004a).

Fine particles also have a seasonal pattern. $PM_{2.5}$ values in the eastern half of the U.S. are typically higher in the third calendar quarter (July-September) when sulfates are more commonly formed from sulfur dioxide emissions from power plants in that part of the country. Fine particle concentrations tend to be higher in the fourth calendar quarter in many areas of the West, in part because fine particle nitrates are more readily formed in cooler weather, and wood stove and fireplace use produces more carbon.

Many recent epidemiologic studies show statistically significant associations of various ambient PM indicators (e.g., coarse or fine particulate, short-term or long-term concentrations) with a variety of cardiovascular and respiratory health endpoints, including mortality, hospital admissions, emergency department visits, other medical visits, respiratory illness and symptoms, and physiologic changes in pulmonary function (U.S. EPA 2004b). Sensitive groups that appear to be at greatest risk to such PM effects include older adults, individuals with cardiopulmonary disease such as asthma or congestive heart disease, and children (U.S. EPA, 2004b). Unlike other criteria pollutants, PM is not a single specific chemical entity, but rather a mixture of particles from different sources with different sizes and chemical compositions. Toxicological studies suggest that some airborne particles are more toxic than others, due to differences in their chemical composition—a topic that is thoroughly reviewed in other publications (e.g., U.S. EPA, 2004b).

PM also can cause adverse impacts to the environment. Fine particles are the major cause of reduced visibility in parts of the U.S., including many National Parks and Wilderness Areas (the Regional Haze indicator, p. 2-50). PM deposition affects vegetation and ecosystems by altering nutrient and chemical cycles in soils and surface water. For example, deposition of particles containing nitrogen and sulfur may change the nutrient balance and acidity of aquatic environments so that species composition and buffering capacity change (the Lake and Stream Acidity indicator, p. 2-62). Some particles that deposit onto plant leaves can corrode leaf surfaces or interfere with plant metabolism. PM also causes soiling and erosion damage to materials, including monuments, statues, and other objects of cultural importance (U.S. EPA, 2004b).

This indicator presents trends in PM_{10} and $PM_{2.5}$ concentrations, using averaging times consistent with the pollutants' corresponding National Ambient Air Quality Standards (NAAQS). For PM_{10}, trend data from 1990 to 2004 are presented for the second maximum 24-hour average concentrations measured at the trend sites during each calendar year. For $PM_{2.5}$, trend data from 1999 to 2004 are presented for seasonally-weighted annual average concentrations and for the 98th percentiles of 24-hour average concentrations measured at the trend sites during each calendar year. Trend data are based on measurements from two nationwide networks of monitoring stations: the National Air Monitoring Stations (NAMS) and the State and Local Air Monitoring Stations (SLAMS). For both PM_{10} and $PM_{2.5}$, the indicator displays trends for the entire nation and for the ten EPA Regions.

The indicator's exhibits display the pollutants' NAAQS as points of reference. However, the fact that the national values or those shown for EPA Regions fall below the standards does not mean that all monitoring sites nationally or in any particular EPA Region also are below the standards. The indicator displays trends in the number of the 489 PM_{10} monitoring sites and 707 $PM_{2.5}$ monitoring sites nationwide that exceed the standards, but these statistics are not displayed for each EPA Region.

What the Data Show

PM_{10} Concentration Trends

(1988-1989 PM_{10} data will be added)

In 2004, the national 24-hour PM_{10} concentration was 31 percent lower than the average 1990 level (Exhibit 2-22, panel A). Additionally, of the 489 sites comprising this trend (out of 808 total monitoring sites that were operating in 2004), the number reporting PM_{10} concentrations above the 24-hour standard declined 88 percent between 1990 and 2004 (Exhibit 2-22, panel B). All EPA Regions experienced a steady decrease in 24-hour PM_{10} levels over this period (Exhibit 2-23). EPA Regions 9 and 10 showed the greatest decreases since 1990.

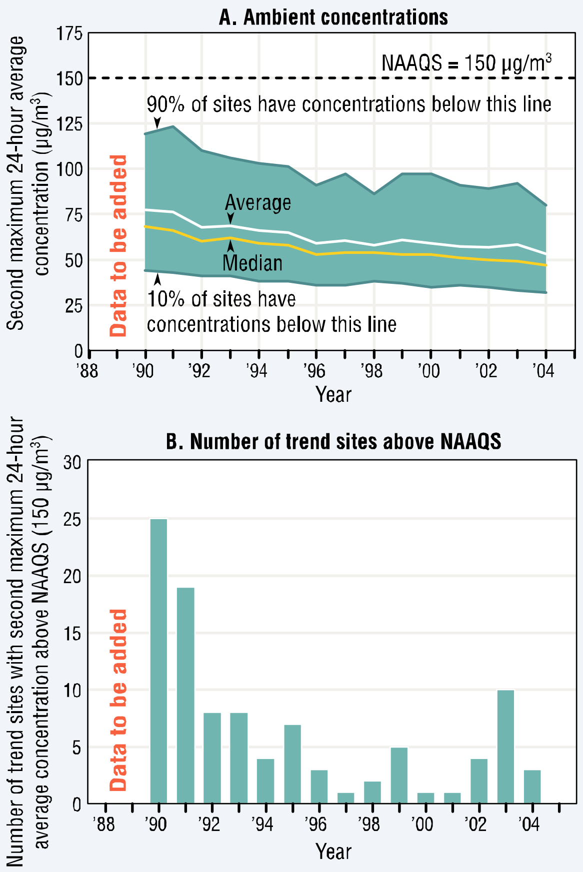
Also shown in Exhibit 2-22 (panel A) are the 90th and 10th percentiles based on the distribution of annual statistics at the monitoring sites. This provides additional graphical representation of the distribution of measured concentrations across the monitoring sites for a given year. Thus, the graphic displays the concentration range where 80 percent of measured values occurred for that year. (Note, this presentation style also applies to panel A in Exhibits 2-24 and 2-26, discussed below.)

$PM_{2.5}$ Concentration Trends

Annual average $PM_{2.5}$ concentrations in 2004 were the lowest since nationwide monitoring began in 1999 (Exhibit 2-24, panel A). The trend is based on measurements collected at 707 monitoring stations that have sufficient data to assess trends over that period (U.S. EPA, 2003). The seasonally-weighted annual average concentrations decreased 14 percent between 1999 and 2004. The number of monitoring sites in this trend (707 out of 781 total sites that were operating in 2004) reporting violations of the annual average $PM_{2.5}$ standard declined 69 percent over this period (Exhibit 2-24, panel B).

Regional declines were greatest in portions of the West (EPA Region 9) and the Southeast (EPA Region 4), where annual average $PM_{2.5}$ levels in 2004 were 21 percent and 18 percent lower than those in 1999, respectively (Exhibit 2-25). However, annual average $PM_{2.5}$ levels in the Rocky Mountains (EPA Region 8) were essentially unchanged over the period.

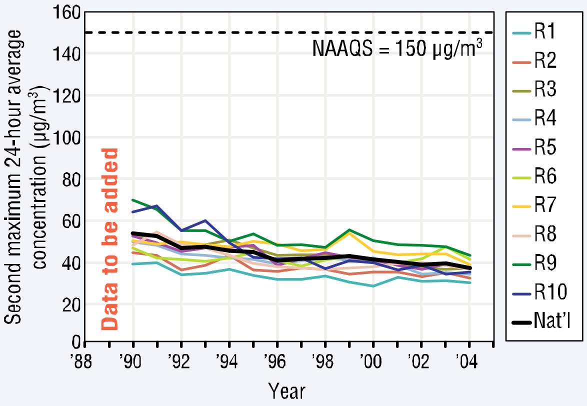
Exhibit 2-22. Ambient 24-hour PM_{10} concentrations in the U.S., 1988-2004[a]



[a] **Coverage:** 489 monitoring sites nationwide (out of a total of 808 sites measuring PM_{10} in 2004) that have sufficient data to assess PM_{10} trends since 1988.

Data source: *U.S. EPA, Air Quality System, 2005*

Exhibit 2-23. Ambient 24-hour PM_{10} concentrations in the contiguous U.S. by EPA Region, 1988-2004[a]



[a] **Coverage:** 477 monitoring sites in the EPA Regions (out of a total of 808 sites measuring PM_{10} in 2004) that have sufficient data to assess PM_{10} trends since 1988.

Data source: *U.S. EPA, Air Quality System, 2005*

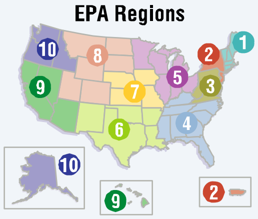
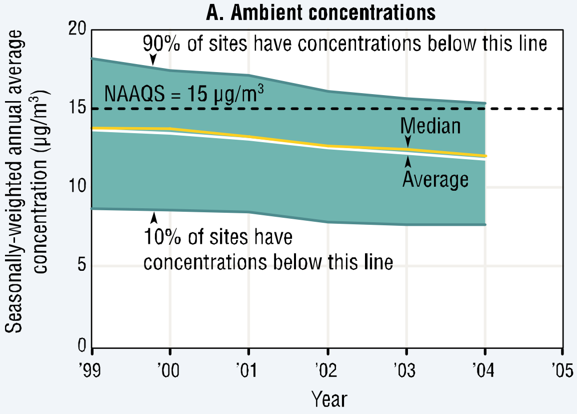
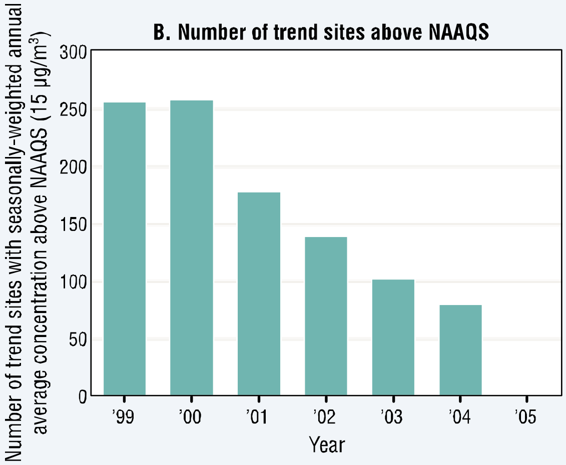


Exhibit 2-24. Ambient annual $PM_{2.5}$ concentrations in the U.S., 1999-2004[a]

A. Ambient concentrations



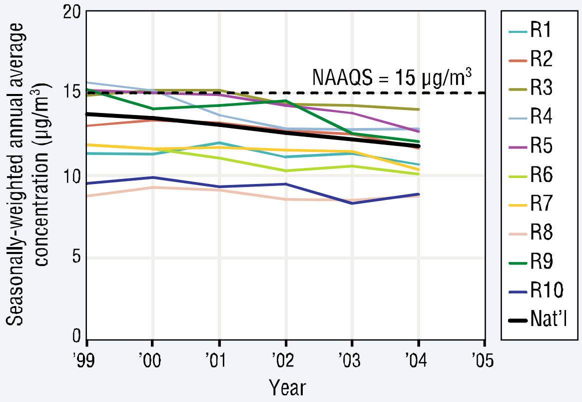
B. Number of trend sites above NAAQS



[a] **Coverage:** 707 monitoring sites nationwide (out of a total of 781 sites measuring $PM_{2.5}$ in 2004) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

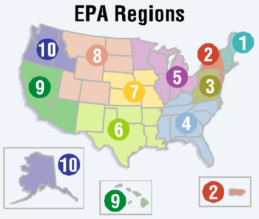
Data source: *U.S. EPA, Air Quality System, 2005*

Exhibit 2-25. Ambient annual $PM_{2.5}$ concentrations in the contiguous U.S. by EPA Region, 1999-2004[a]



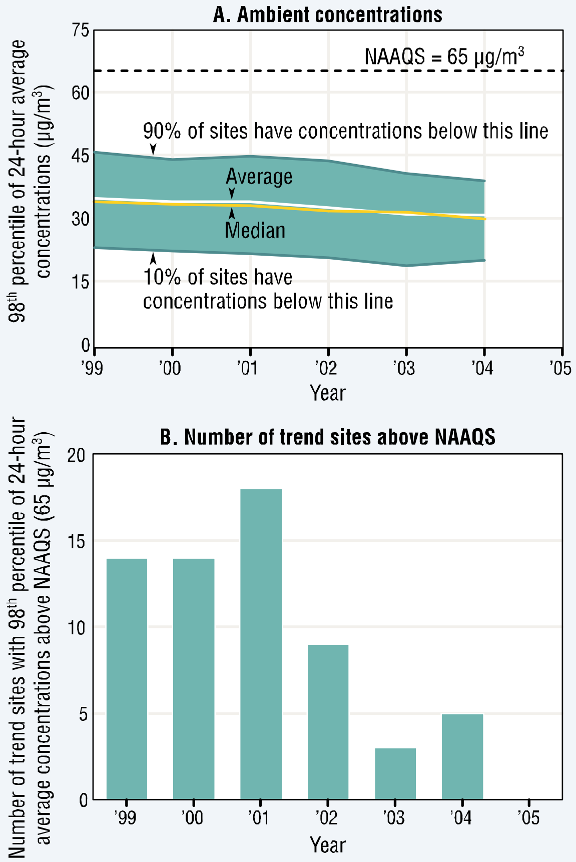
[a] **Coverage:** 691 monitoring sites in the EPA Regions (out of a total of 781 sites measuring $PM_{2.5}$ in 2004) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

Data source: *U.S. EPA, Air Quality System, 2005*



In 2004, the average of 98th percentiles of 24-hour $PM_{2.5}$ concentrations at the 707 monitoring sites used for the trend was 11 percent lower than the average 1999 level (Exhibit 2-26, panel A). The number of monitoring sites in this trend (707 out of 781 total sites that were operating in 2004) reporting violations of the 24-hour $PM_{2.5}$ standard declined 64 percent over this period (Exhibit 2-26, panel B). All EPA Regions except Region 8 experienced decreasing 24-hour $PM_{2.5}$ levels, and Regions 9 and 4 again showed the largest declines (25 percent and 17 percent, respectively) (Exhibit 2-27).

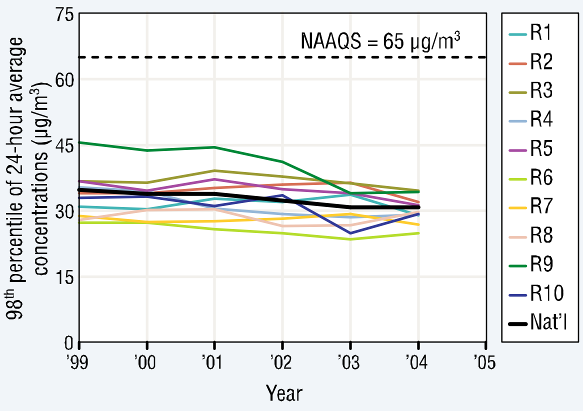
Exhibit 2-26. Ambient 24-hour $PM_{2.5}$ concentrations in the U.S., 1999-2004[a]



[a] **Coverage:** 707 monitoring sites nationwide (out of a total of 781 sites measuring $PM_{2.5}$ in 2004) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

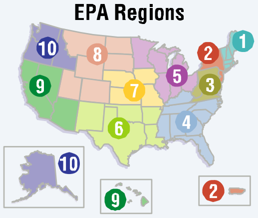
Data source: *U.S. EPA, Air Quality System, 2005*

Exhibit 2-27. Ambient 24-hour $PM_{2.5}$ concentrations in the contiguous U.S. by EPA Region, 1999-2004[a]



[a] **Coverage:** 691 monitoring sites in the EPA Regions (out of a total of 781 sites measuring $PM_{2.5}$ in 2004) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

Data source: *U.S. EPA, Air Quality System, 2005*



Indicator Limitations

- Because there are far more PM_{10} and $PM_{2.5}$ monitors in urban areas than in rural areas, the trends might not accurately reflect conditions outside the immediate urban monitoring areas.
- Potential biases may exist for some $PM_{2.5}$ ambient concentration measurements due to losses from volatilization of nitrates and other semi-volatile materials and retention of particle-bound water associated with hygroscopic species.
- Due to the relatively small number of monitoring sites in some EPA Regions, the regional trends are subject to greater uncertainty than the national trends. Some EPA Regions with low average concentrations may include areas with high local concentrations, and vice versa.
- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of PM monitoring sites with sufficient data to assess trends over the time frames covered by this indicator. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported PM concentrations above the PM standard during the years covered by this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw PM ambient air monitoring data in EPA's Air Quality System (AQS) (U.S. EPA, 2006) (http://www.epa.gov/ttn/airs/airsaqs/). National and regional trends in this indicator are based on the subset of PM monitoring stations that have sufficient data to assess trends over the period of record (i.e., since 1990 for PM_{10} and since 1999 for $PM_{2.5}$).

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U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

INDICATOR: Regional Haze

Regional haze is the term describing visibility impairment that results from fine particles and their precursors emitted by a variety of sources and activities (U.S. EPA, 2004a). Visibility impairment is observed not only in urban areas, but also in many of the best known and most treasured National Parks and Wilderness Areas, such as the Grand Canyon, Great Smoky Mountains, Mount Rainier, Shenandoah, Yellowstone, and Yosemite National Parks (U.S. EPA, 2003). Visibility impairment occurs when air pollution, both particles and gases, scatter and absorb light. Haze not only limits the distance one can see, but also degrades the color, clarity, and contrast of scenes. As the PM Concentrations indicator (p. 2-44) describes further, the same pollutants that impair visibility are also linked to serious health effects.

The particles that impair visibility include both primary and secondary pollutants. The primary pollutants of concern are particles that are emitted directly into the atmosphere, such as dust from roads or soot (elemental carbon) from combustion sources, such as wood combustion. Secondary pollutants of concern are particles that form in the atmosphere from chemical reactions and physical processes, such as sulfates (formed from sulfur dioxide emissions from power plants and other industrial facilities) and nitrates (formed from nitrogen oxides emitted from power plants, automobiles, and other types of combustion sources).

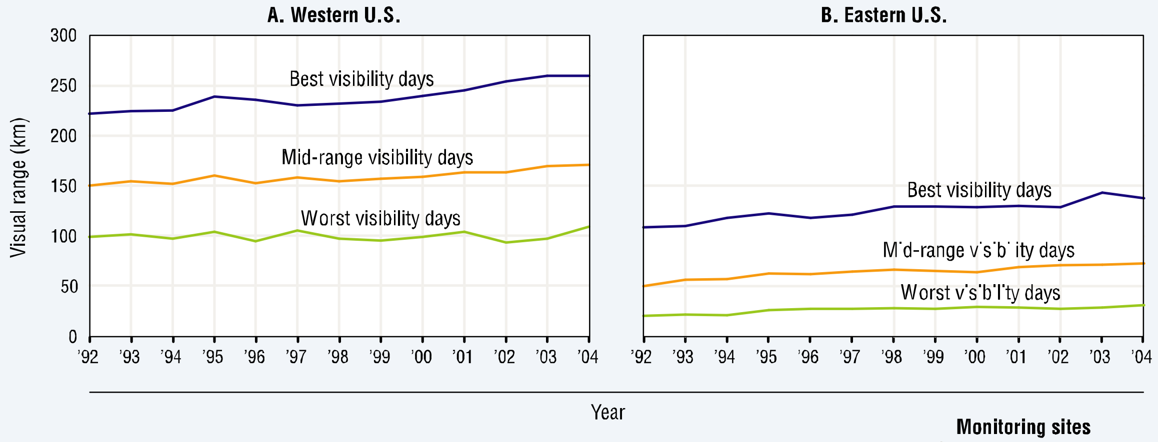
Humidity can increase the effect of pollution on visibility, causing some particles to become more efficient at scattering light and impairing visibility (U.S. EPA, 2003). In the eastern U.S., where annual average relative humidity levels are between 70 percent and 80 percent, reduced visibility mainly results from secondarily formed sulfates and high humidity, along with a somewhat lower contribution from organic carbon and nitrates (U.S. EPA, 2004b). The effect of humidity is particularly strong in summer. Humidity is less of a factor in the West, as average values are generally between 50 percent and 60 percent. In western states, primary emissions from sources like wood smoke and nitrates contribute a large percentage of the total particulate loading, though secondarily formed sulfates also contribute to visibility impairment. Without the effects of anthropogenic sources of pollution, the natural visual range in the U.S. would vary with location, and is estimated to range from 75 to 150 km (45 to 90 miles) in the East and from 200 to 300 km (120 to 180 miles) in the West (U.S. EPA, 2003).

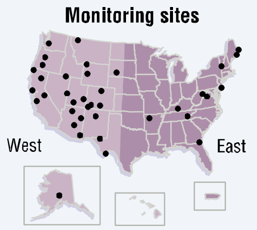
This indicator reports visibility data calculated from measurements of particulate matter constituents collected at 38 monitoring sites between 1992 and 2004 at National Parks, Wilderness Areas, and other protected sites under the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. Data are presented for 10 Eastern (east of 100^o W longitude) sites and 28 Western (west of 100^o W longitude) sites. Visibility, or visual range, is calculated from the measured levels of different components within airborne particles and these components' light extinction efficiencies. The algorithm includes an adjustment for ammonium sulfate and ammonium nitrate to account for their adsorption of water vapor from the atmosphere under elevated relative humidity conditions. The IMPROVE particle data are generated by laboratory analysis of 24-hour duration filter samples collected at each site on a one-day-in-three schedule. The indicators track visibility in three categories: worst visibility conditions refer to the mean of the 20 percent worst visibility days; best visibility conditions refer to the mean of the 20 percent best visibility days; and mid-range visibility conditions refer to the mean of the remaining 60 percent of days.

What the Data Show

On average, the best visibility in the East, as calculated from the measured concentrations of components of PM, is only slightly better than the worst visibility in the West (Exhibit 2-28). In 2004, the mean visual

Exhibit 2-28. Visibility in selected National Parks and Wilderness Areas in the U.S., 1992-2004[a,b]





[a]**Coverage:** 28 monitoring sites in the western U.S. and 10 monitoring sites in the eastern U.S. with sufficient data to assess visibility trends from 1992 to 2004.

[b]Visual ranges are calculated from the measured levels of different components within airborne particles and these components' light extinction efficiencies.

Data source: *Interagency Monitoring of Protected Visual Environments (IMPROVE) network, 2006*

range for the worst days in the East was 31 km (19.3 miles), compared to 137 km (85.1 miles) for the best visibility days. In the West, the mean visual range extended from 109 km (67.7 miles) on the worst days to 260 km (161.6 miles) on the best days. In both regions, the average visual range increased since 1992 for worst, mid-range, and best visibility days. The increased visual ranges between 1992 and 2004 for mid-range visibility days were 46 percent in the East and 14 percent in the West.

Indicator Limitations

- These data represent visibility in a sampling of selected National Parks and Wilderness Areas and are not representative of other rural or urban areas.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw ambient air monitoring data collected as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network (IMPROVE, 2006) (http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm). Visibility trends in this indicator are derived from the subset of IMPROVE monitoring stations outside of urban areas that have sufficient data to assess trends between 1992 and 2004.

References

IMPROVE. 2006. Data from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. Accessed 2006. <http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm>

U.S. EPA. 2004a. The particulate pollution report: current understanding of air quality and emissions through 2003. EPA/454/R-04/002. Research Triangle Park, NC.

U.S. EPA. 2004b. The ozone report: measuring progress through 2003. EPA/454/K-04/001. Research Triangle Park, NC.

U.S. EPA. 2003. Latest findings on national air quality—2002 status and trends. EPA/454/K-03/001. Research Triangle Park, NC.

INDICATOR: Sulfur Dioxide Emissions

Sulfur dioxide (SO_2) belongs to the family of sulfur oxide (SO_x) gases. These gases are formed when fuel containing sulfur (mainly coal and oil) is burned (e.g., for electricity generation) and during metal smelting and other industrial processes. High concentrations of SO_2 are associated with multiple health and environmental effects (U.S. EPA, 2003). The highest concentrations of SO_2 have been recorded in the vicinity of large industrial facilities. Although relatively few people live in areas where SO_2 concentrations exceed the National Ambient Air Quality Standards (NAAQS), a much larger number of people live in $PM_{2.5}$ non-attainment areas, and SO_2 is a major precursor to $PM_{2.5}$ which also has human health and ecological effects (the PM Concentrations indicator, p. 2-44).

Health effects associated with SO_2 depend on the exposure concentrations and durations, and on the susceptibility of exposed populations. Asthmatics are much more susceptible to SO_2 exposure than people who do not have asthma (U.S. EPA, 1986). Effects associated with longer-term exposures to high concentrations of SO_2, in conjunction with high levels of PM, include respiratory illness, alterations in the lungs' defenses, and aggravation of existing heart or lung disease. The most susceptible populations under these conditions include individuals with cardiovascular disease or chronic lung disease, children, and older adults (U.S. EPA, 1982).

Many other environmental concerns are associated with high concentrations of SO_2. For example, airborne SO_2, along with NO_x, contribute to acidic deposition (the Acid Deposition indicator, p. 2-56); SO_2 is a major precursor to $PM_{2.5}$ (the PM Concentrations indicator, p. 2-44); and SO_2 contributes to impaired visibility (the Regional Haze indicator, p. 2-50). SO_2 exposure also can harm vegetation by increasing foliar injury, decreasing plant growth and yield, and decreasing the number and variety of plant species in a given community. Finally, SO_2 can accelerate the corrosion of natural and man-made materials (e.g., concrete and limestone) that are used in buildings, statues, and monuments that are part of the nation's cultural heritage (U.S. EPA, 1982).

This indicator presents SO_2 emissions from traditionally inventoried anthropogenic source categories: 1) "Fuel combustion: selected power generators," which includes emissions from coal, gas, and oil-fired power plants that are required to use continuous emissions monitors (CEMs) to report emissions as part of the Acid Rain Program (ARP); 2) "Fuel combustion: other sources," which includes industrial, commercial, and institutional sources, as well as residential heaters and boilers not required to use CEMs; 3) "Other industrial processes," which include chemical production and petroleum refining; 4) "On-road vehicles," which includes cars, trucks, buses, and motorcycles; 5) "Nonroad vehicles and engines," such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others. Since a substantial portion of airborne SO_2 comes from fossil fuel combustion in electric utilities, this indicator includes the separate "Fuel combustion: selected power generators" category in addition to the four categories presented in the other emissions indicators.

SO_2 emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For major electric generating units, most data come from continuous emissions monitors that measure actual emissions. For other fuel combustion sources and industrial processes, data are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2005).

NEI data have been collected since 1990 and cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and Virgin Islands, and some of the territories of federally-recognized American Indian nations. Data are presented only for 1990 and the years from 1996 to 2002; prior to 1996, only the 1990 data have been updated to be comparable to the more recent inventories.

What the Data Show

National estimated SO_2 emissions decreased 34 percent between 1990 and 2002 (from 23,060,000 to 15,260,000 tons) (Exhibit 2-29). This downward trend resulted primarily from emissions reductions at electrical utilities. Between 1990 and 2002, air emissions from electric utilities have consistently accounted for roughly two-thirds of the nationwide SO_2 emissions.

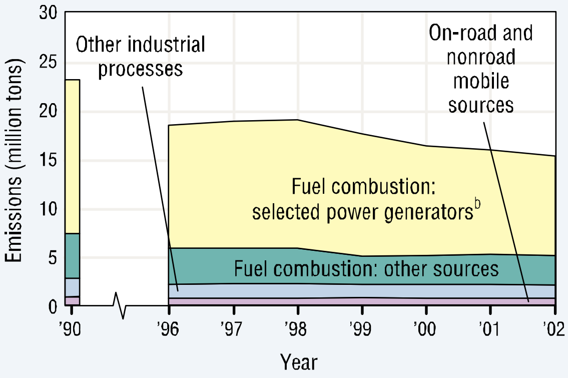
Net SO_2 emissions declined in all EPA Regions between 1990 and 2002 except in Region 6 where there was a slight increase (Exhibit 2-30). Since 1996, the largest percent reductions in SO_2 emissions were seen in Regions 9 (33 percent), 10 (30 percent), 1 (29 percent), and 5 (25 percent), and the smallest reductions were observed in Regions 6 (7 percent) and 3 (10 percent).

Indicator Limitations

- Though emissions from most electric utilities are measured directly using continuous monitoring devices, SO_2 emissions data for other source types are based on estimates that employ emission factors generated from empirical and engineering studies. Although these estimates are generated using well-established approaches, the estimates have uncertainties inherent in the emission factors and emission models used to represent sources for which emissions have not been directly measured.

- Comparable SO_2 emissions estimates through the NEI are available only for 1990 and 1996-2002. Data for 1991-1995 are not provided due to

Exhibit 2-29. SO_2 emissions in the U.S. by source category, 1990 and 1996-2002[a]

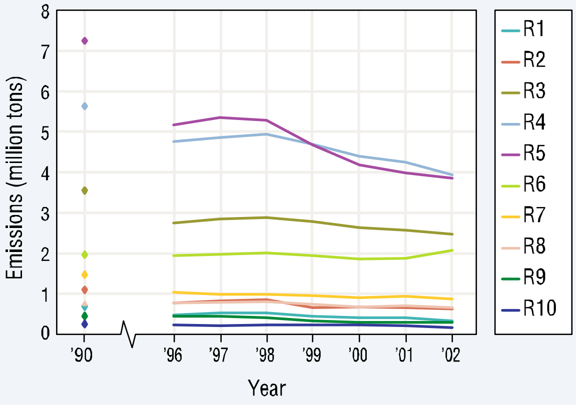


[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

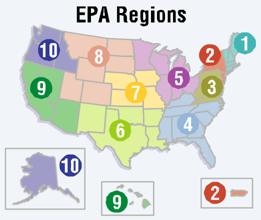
[b] This category includes emissions from only those power plants required to use continuous emissions monitors under the Acid Rain Program.

Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Exhibit 2-30. SO_2 emissions in the U.S. by EPA Region, 1990 and 1996-2002[a]



[a] Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up-to-date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.



Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005* differences in emission estimation methodologies from other inventory years which could lead to improper trend assessments.

- SO_2 emissions from “miscellaneous sources” are not included in the total emissions. Details on emissions from miscellaneous sources can be found at http://www.epa.gov/ttn/chief/eiinformation.html.
- The methodology for estimating emissions is continually reviewed and is subject to revision. Trend data prior to these revisions must be considered in the context of those changes.
- Not all states and local agencies provide the same data or level of detail for a given year.

Data Sources

Summary data in this indicator were provided by EPA’s Office of Air Quality Planning and Standards, based on raw SO_2 emissions data in EPA’s National Emissions Inventory (NEI) (U.S. EPA, 2006) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw NEI data by source category and EPA Region.

References

U.S. EPA. 2006. Data from the National Emissions Inventory. Accessed 2006. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

U.S. EPA. 2005. Documentation for the final 2002 mobile National Emissions Inventory. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_onroadandnonroad.pdf>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

U.S. EPA. 1986. Second addendum to the air quality criteria for particulate matter and sulfur oxides (1982): assessment of newly available health effects information. EPA/450/S-86/012. Research Triangle Park, NC.

U.S. EPA. 1982. Air quality criteria for particulate matter and sulfur oxides. EPA/600/P-82/020a-c. Research Triangle Park, NC.

INDICATOR: Acid Deposition

Every year, millions of tons of sulfur dioxide and nitrogen oxides are emitted to the atmosphere as a result of the burning of fossil fuels and from other high temperature sources (the Sulfur Dioxide Emissions indicator, p. 2-53; the Nitrogen Oxides Emissions indicator, p. 2-23). These gases react with water, oxygen, and oxidants to form acidic compounds, which may be carried hundreds of miles by the wind—even across state or national borders. Acid deposition occurs when these compounds fall to the Earth in one of two forms: wet (dissolved in rain, snow, and fog) or dry (solid and gaseous particles deposited on surfaces during periods of no precipitation). While wet deposition is the more widely recognized form (more commonly referred to as “acid rain”), dry deposition can account for 20 percent to 80 percent of total acid deposition depending on location and climate (MACTEC Engineering and Consulting, 2005). In the environment, acid deposition causes soils and water bodies to acidify, which can make the water unsuitable for some fish and other wildlife. Some types of ecosystems, those with less “buffering” capacity, are more sensitive to acid deposition than others.

Scientists often use acid neutralizing capacity (ANC), a measure of the amount of anions, protons, and non-proton cations in the water, as an indicator of which lakes and streams are most sensitive to acidification (NAPAP, 1991). Most surface waters in the West do not exhibit many symptoms of acidification, because relatively small amounts of acid deposition occur in acid-sensitive regions. In the Northeast and along the Appalachian Mountains, however, relatively high levels of acid deposition occur in acid-sensitive regions, or regions without enough geochemical buffering capacity to prevent acidification of surface waters by acid deposition (the Lake and Stream Acidity indicator, p. 2-62). Therefore, reductions in acid deposition have the largest impact on acidification of lakes and streams in those areas.

Acid deposition damages some trees, particularly at high elevations, and speeds the decay of buildings, statues, and sculptures that are part of our national heritage (U.S. EPA, 2003). The nitrogen portion of acid deposition also contributes to eutrophication in coastal ecosystems, the symptoms of which include potentially toxic algal blooms, fish kills, and loss of plant and animal diversity. Acidification of lakes and streams can increase the amount of methylmercury available in aquatic systems (Winfrey and Rudd, 1990). Finally, increased levels of sulfate in ground-level air, a phenomenon related to dry deposition, can contribute to decreased visibility as well as a variety of human health problems (U.S. EPA, 2003).

Total acid deposition in this indicator is determined using wet deposition measurements and dry deposition calculated from ambient air concentration measurements. Wet deposition is measured through chemical analysis of rainwater collected at sites across the U.S. The primary source of wet deposition information comes from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). The chemical components of wet deposition include sulfate, nitrate, and ammonium. Dry deposition is not measured directly. EPA’s Clean Air Status and Trends Network (CASTNET) determines dry deposition inferentially by measuring ambient air concentrations of acidic compounds and then calculating deposition rates using a multi-layer model that depends on meteorological data collected at the sites as well as local vegetative conditions (http://www.epa.gov/castnet/). Chemicals measured include components of particulate matter (sulfate (SO_4) and nitrate (NO_3)), gaseous nitric acid (HNO_3), sulfur dioxide (SO_2), and ammonium (NH_4). This indicator uses the three-year average from 1989-1991 as a baseline, as this period immediately predates controls on sulfur and nitrogen oxide emissions mandated by the 1990 Clean Air Act Amendments. Use of three-year average data helps ensure that trends reflect actual changes in acid deposition, instead of shorter-term fluctuations in meteorological conditions.

What the Data Show

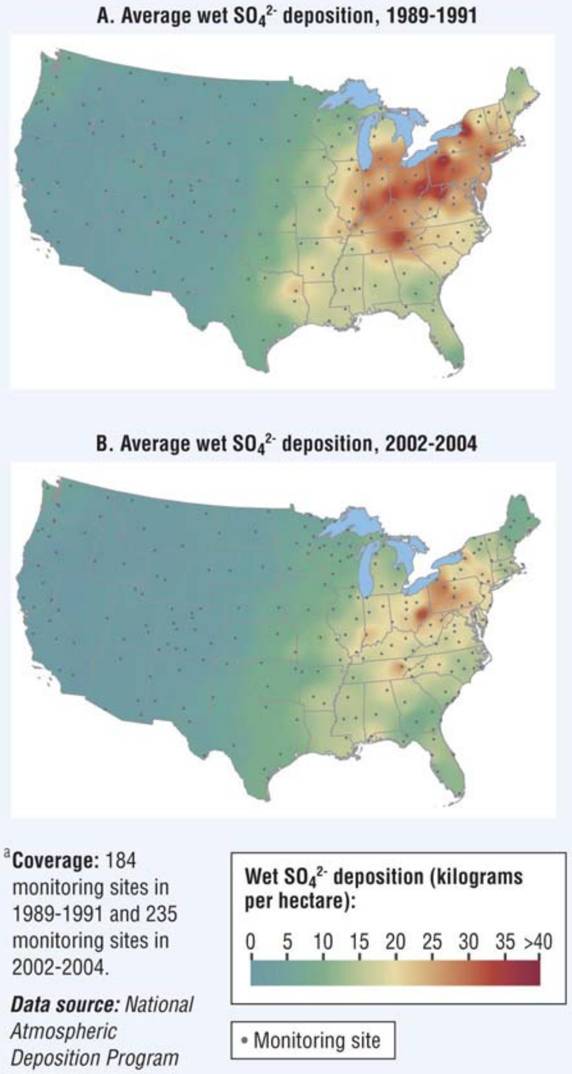
Analyses of long-term monitoring data from the National Atmospheric Deposition Program (NADP) show that *wet deposition* of both sulfur and nitrogen compounds has decreased over the last 15 years (Exhibits 2-31 and 2-32).

Wet sulfate deposition decreased across much of the U.S. during the 1990s (Exhibit 2-31). The greatest reductions in wet sulfate deposition occurred in the Mid-Appalachian region (Maryland, New York, West Virginia, Virginia, and most of Pennsylvania) and the Ohio River Valley. Less dramatic reductions were observed across much of New England and portions of the Southern Appalachians. Average regional decreases in wet deposition of sulfate between the periods 1989-1991 (panel A) and 2002-2004 (panel B) were approximately 36 percent in the Northeast, 32 percent in the Midwest, 24 percent in the Mid-Atlantic and 19 percent in the Southeast.

Wet nitrate deposition decreased approximately 16 percent across the Northeast and 8 percent in the Mid-Atlantic between the periods 1989-1991 (Exhibit 2-32, panel A) and 2002-2004 (panel B). Wet deposition of inorganic nitrogen has not changed substantially in the rest of the country over this period.

As with wet deposition, *total deposition* (the sum of wet and dry deposition) decreased between 1989-1991 and 2002-2004, and reductions were more substantial for sulfur compounds than for nitrogen compounds (Exhibits 2-33 and 2-34). Note that total nitrogen deposition in this indicator does not include nitrogen components, such as ammonia, which can be a significant portion of the dry deposition.

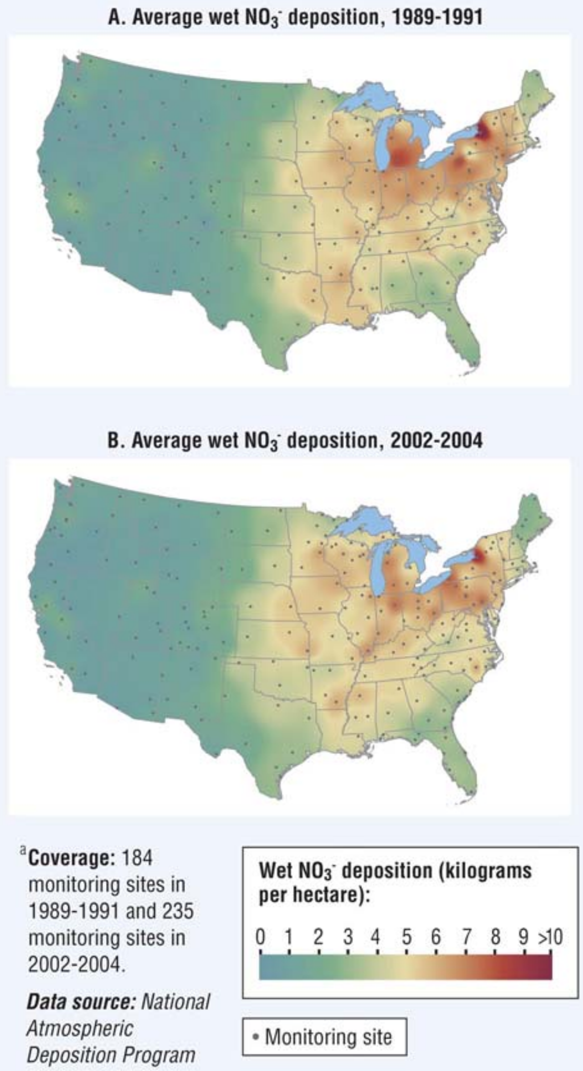
Exhibit 2-31. Wet sulfate (SO_4^{2-}) deposition in the contiguous U.S., 1989-1991 and 2002-2004[a]



[a] **Coverage:** 184 monitoring sites in 1989-1991 and 235 monitoring sites in 2002-2004.

Data source: *National Atmospheric Deposition Program (NADP), 2005*

Exhibit 2-32. Wet nitrate (NO_3^-) deposition in the contiguous U.S., 1989-1991 and 2002-2004[a]

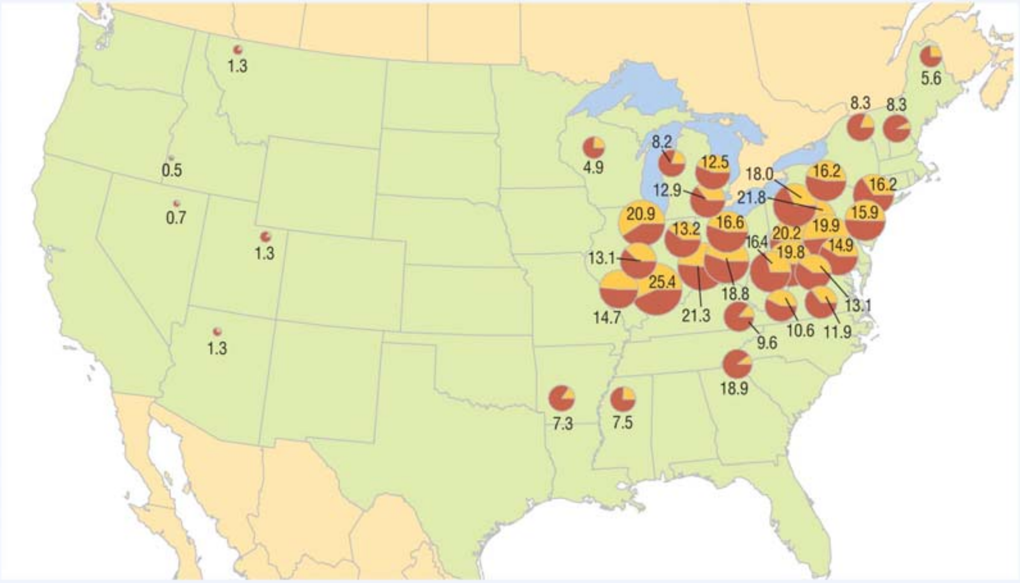


[a] **Coverage:** 184 monitoring sites in 1989-1991 and 235 monitoring sites in 2002-2004.

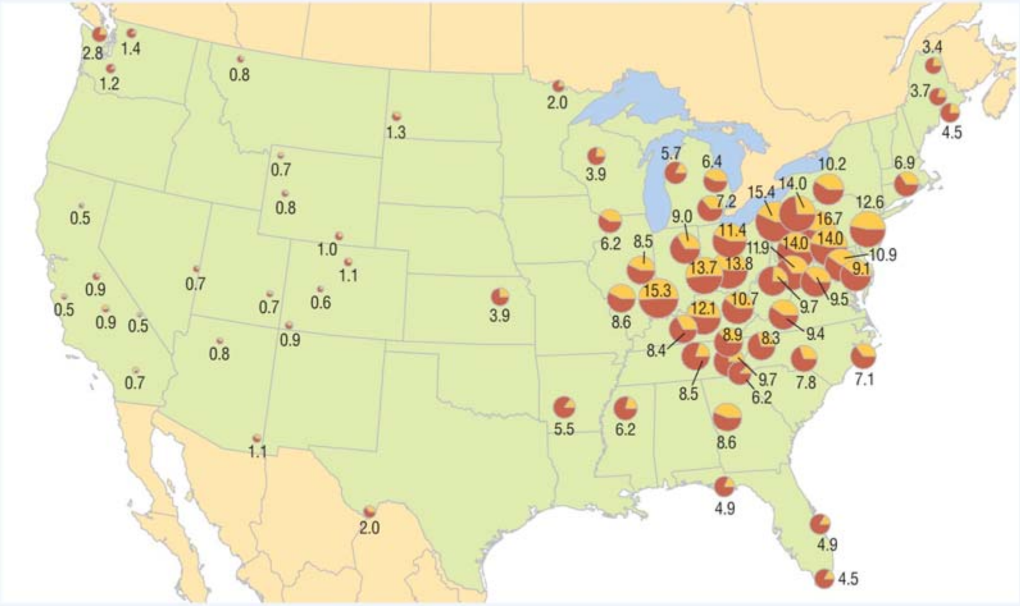
Data source: *National Atmospheric Deposition Program (NADP), 2005*

Exhibit 2-33. Total sulfur deposition in the contiguous U.S., 1989-1991 and 2002-2004[a]

A. Average total sulfur deposition, 1989-1991

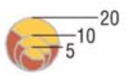


B. Average total sulfur deposition, 2002-2004



[a] **Coverage:** 37 monitoring sites in 1989-1991 and 70 monitoring sites in 2002-2004.

Data source: *National Atmospheric Deposition Program (NADP), 2005, and U.S. EPA, Clean Air Status and Trends Network (CASTNet), 2005*



Numbers indicate total sulfur deposition (kilograms per hectare), averaged over a 3-year period.

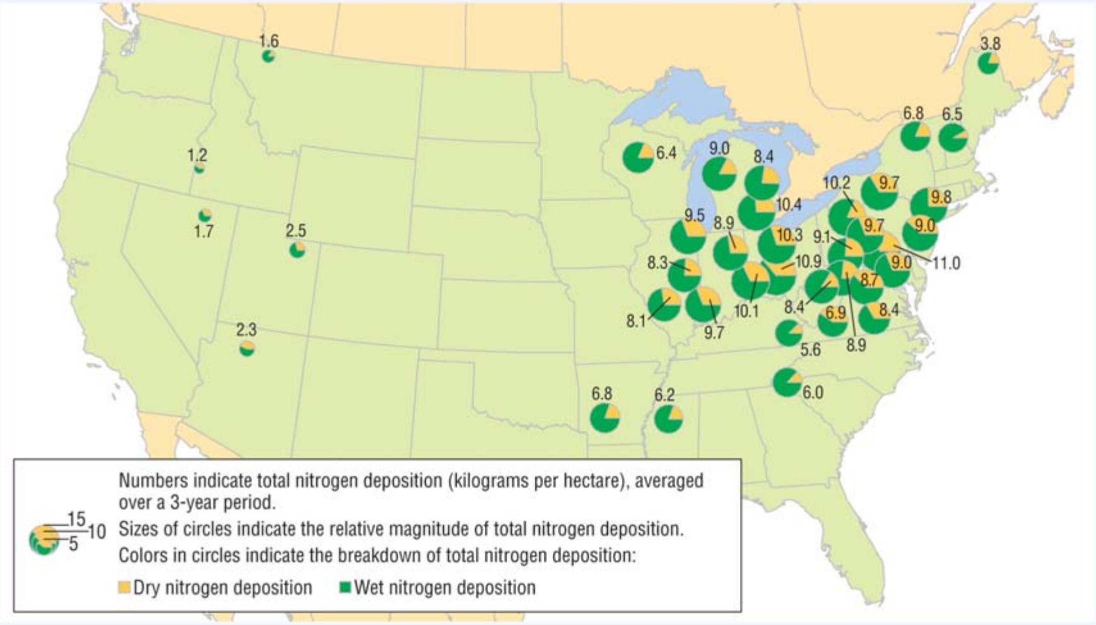
Sizes of circles indicate the relative magnitude of total sulfur deposition.

Colors in circles indicate the breakdown of total sulfur deposition:

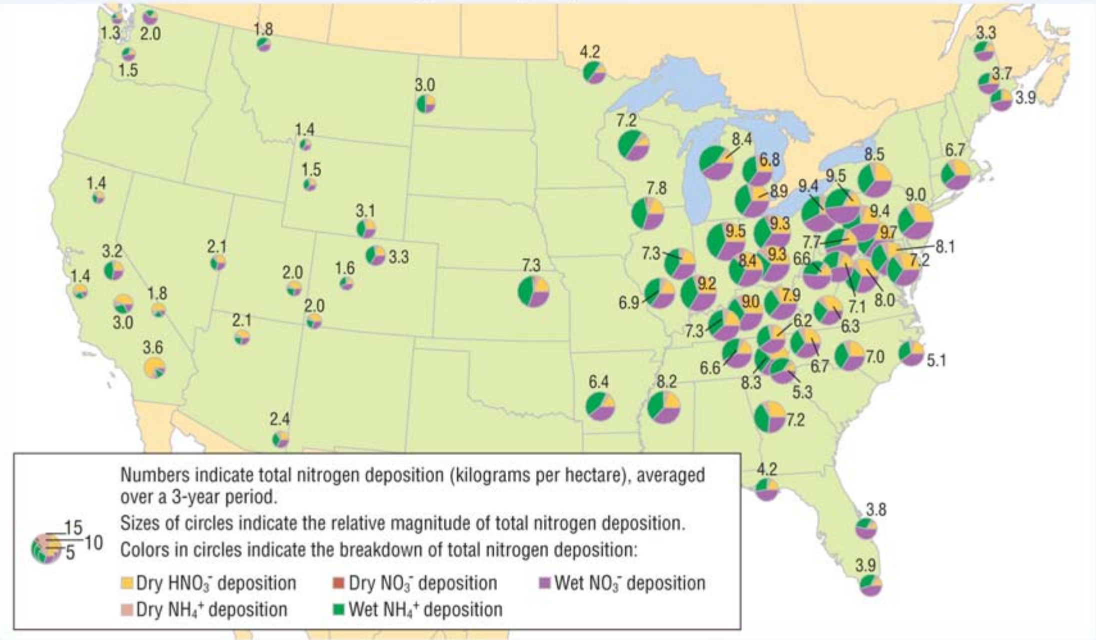
🟨 Dry sulfur deposition 🟥 Wet sulfur deposition

Exhibit 2-34. Total nitrogen deposition in the contiguous U.S., 1989-1991 and 2002-2004[a]

A. Average total nitrogen deposition, 1989-1991



B. Average total nitrogen deposition, 2002-2004



[a] **Coverage:** 37 monitoring sites in 1989-1991 and 70 monitoring sites in 2002-2004.

Data source: *National Atmospheric Deposition Program (NADP), 2005, and U.S. EPA, Clean Air Status and Trends Network (CASTNet), 2005*

Indicator Limitations

- Geographic coverage is limited, particularly for dry deposition (and thus total deposition as well), but the concentration of sites in the Midwest and Northeast is justified by the fact that acid rain is much more of a problem in those regions than it is in the West, Great Plains, or Southeast.
- Measurement techniques for dry deposition have improved substantially, but characterization of dry deposition still requires a combination of measurements and modeling, which has inherent uncertainties. Further, dry deposition presented in this indicator does not include contributions from deposition of gaseous ammonia.

Data Sources

Summary data in this indicator were provided by EPA's Office of Atmospheric Programs, based on raw deposition data from two sources. Raw wet deposition data are from the National Atmospheric Deposition Program/National Trends Network (NADP, 2006) (http://nadp.sws.uiuc.edu/), and raw dry deposition data are from the Clean Air Status and Trends Network (U.S. EPA, 2006) (http://www.epa.gov/castnet). This indicator aggregates raw data across 3-year periods to avoid influences from short-term fluctuations in meteorological conditions, and wet deposition data were interpolated among monitoring stations to generate the maps shown in Exhibits 2-31 and 2-32.

References

MACTEC Engineering and Consulting, Inc. 2005. Clean Air Status and Trends Network (CASTNET): 2004 annual report. Prepared for U.S. EPA, Office of Air and Radiation.

NADP. 2006. Data from the National Atmospheric Deposition Program/National Trends Network. Accessed 2006. <http://nadp.sws.uiuc.edu>

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U.S. EPA. 2003. Latest findings on national air quality: 2002 status and trends. EPA/454/K-03/001. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd02/2002_airtrends_final.pdf>

U.S. EPA. 2006. Data from the Clean Air Status and Trends Network. Accessed 2006. <http://www.epa.gov/castnet/>

Winfrey, M.R., and J.W.M. Rudd. 1990. Environmental factors affecting the formation of methyl mercury in low pH lakes. Environ. Toxicol. Chem. 9(7):853-869.

INDICATOR: Lake and Stream Acidity

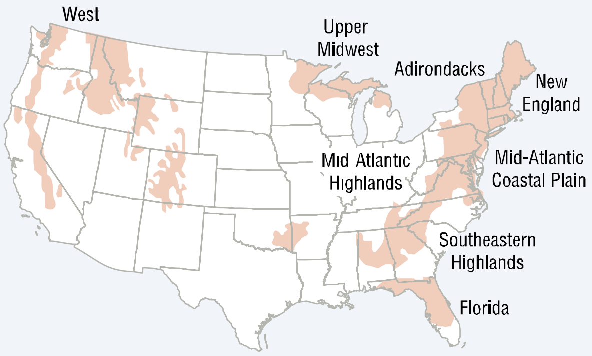
Acid deposition can have serious effects on aquatic ecosystems. For example, aquatic organisms in acidified waters can develop calcium deficiencies that weaken bones and exoskeletons and cause eggs to be weak or brittle. Acidified waters can impair the ability of fish gills to extract oxygen from water and change the mobility of certain trace metals (e.g., aluminum, cadmium, manganese, iron, arsenic, mercury), which in turn can place fish and other species sensitive to these metals at risk (NAPAP, 1991). The Acid Deposition indicator (p. 2-56) explains the factors that contribute to acid deposition and describes how acid deposition patterns have changed over the last 15 years.

The susceptibility of a water body to acidification depends on the ability of the water and watershed soils to neutralize the acid deposition it receives. The best measure of this ability is acid neutralizing capacity (ANC), which characterizes the amount of dissolved compounds that will counteract acidity. All bodies of water have a measurable acid neutralizing capacity. ANC depends largely on the surrounding watershed's physical characteristics, such as geology, soils, and size. The ANC of a body of water reflects the relative proportions of positive and negative ions entering the water from sources such as atmospheric inputs and the soil and bedrock surrounding and underlying the water body. The higher the ANC, the more acid a water body can neutralize and the less susceptible it is to acidification. As ANC approaches zero, the ability to neutralize acidity decreases. Surface water with an ANC greater than 200 micro equivalents per liter (µeq/L) is usually considered non-acidic; surface water with an ANC less than 50 µeq/L is considered highly sensitive to acidification (is often seasonally acidic); and surface water with an ANC less than 0 µeq/L is considered chronically acidic, meaning the watershed no longer has the capacity to neutralize further acid deposition (U.S. EPA, 2003). ANC can be negative when anions exceed non-proton cations (i.e., when there are free protons [H^+ ions] in solution).

The National Acid Precipitation Assessment Program identified several regions in the U.S. as containing many of the surface waters sensitive to acidification (Exhibit 2-35). Where soil buffering capacity is poor, lakes and streams may be vulnerable to acidification (NAPAP, 1991).

This indicator is derived from ANC measurements on probability survey samples representing 5,617 lakes and 72,000 stream miles in the five geographic regions shown in Exhibit 2-36. These measurements were collected as part of the Temporally Integrated Monitoring of Ecosystems (TIME) project and on 120 additional acid-sensitive lakes and 78 acid-sensitive streams in the Long-Term Monitoring (LTM) project, for which data were available between 1990 and 2000 (U.S. EPA, 2003). The lakes sampled include only those in areas potentially sensitive to acidification with areas greater than 4 hectares. Smaller lakes generally are not used in this type of assessment because they are more likely to be naturally acidic, although acid deposition can cause them to become further acidified. This indicator focuses only on the northeastern U.S.; because monitoring

Exhibit 2-35. Areas with acid-sensitive waters in the contiguous U.S.



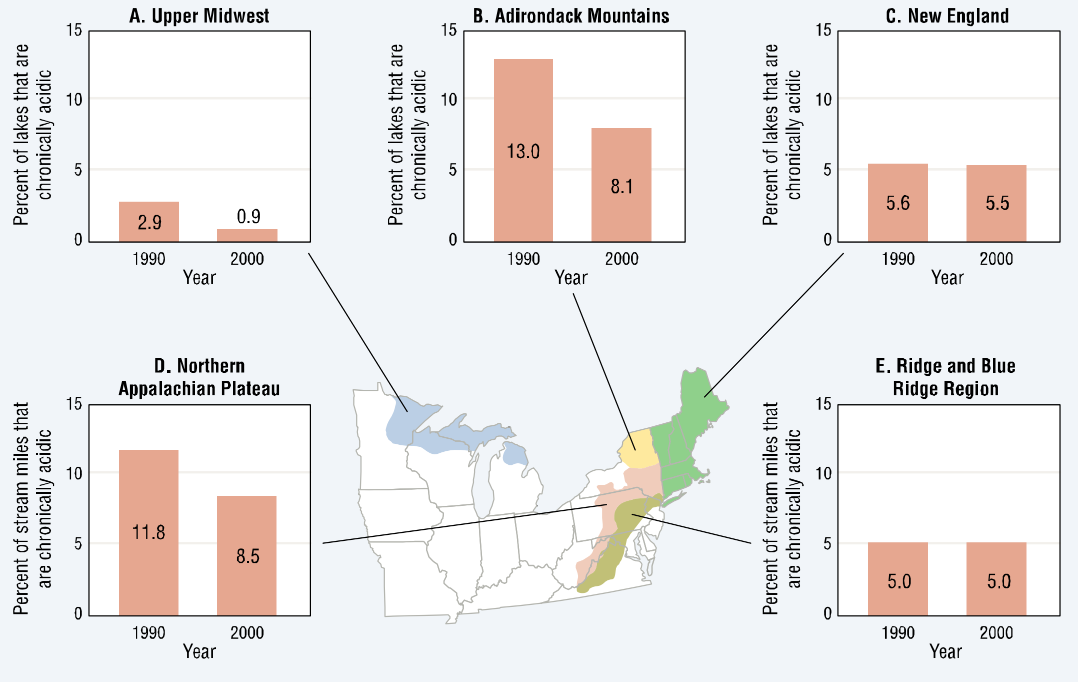
Data source: *National Acid Precipitation Assessment Program (NAPAP), 1991* is not ongoing for western and southeastern water bodies, trend data for those parts of the country are not available.

What the Data Show

Between 1990 and 2000, ANC in lakes in the Upper Midwest (northeastern Minnesota, northern Wisconsin, and northern Michigan), in lakes in the Adirondack Mountains, and in streams in the Northern Appalachians (southern New York, west-central Pennsylvania, and eastern West Virginia) increased to a degree where many water bodies that were considered “chronically acidic” in 1990 were no longer classified as such in 2000 (Exhibit 2-36, panels A, B, and D). Specifically, between 1990 and 2000, the percent of chronically acidic water bodies decreased in the Adirondack Mountains (from 13.0 percent to 8.1 percent), in the Upper Midwest (from 2.9 percent to 0.9 percent), and in the Northern Appalachian Plateau (from 11.8 percent to 8.5 percent). This trend suggests that surface waters in these areas are beginning to recover from acidification, though acidic surface waters are still found in these regions.

The trend of increasing ANC in the Adirondack Mountains, the Upper Midwest, and the Northern Appalachian Plateau during the 1990s corresponds with a decrease in acid deposition in each of these regions (the Acid Deposition indicator, p. 2-56) and reduced air emissions of the main precursors to acid deposition, which are sulfur dioxide (the Sulfur Dioxide Emissions indicator, p. 2-53) and nitrogen oxides (the Nitrogen Oxides Emissions indicator, p. 2-23).

Exhibit 2-36. Lake and stream acidity in selected acid-sensitive regions in the U.S., 1990 and 2000



Data source: *U.S. EPA, 2003*

The ANC in lakes in New England and streams in the Ridge and Blue Ridge Region (east-central Pennsylvania, western Maryland, and western Virginia) have not risen from their 1990 levels (Exhibit 2-36, panels C and E). Therefore, the number of water bodies classified as "chronically acidic" in these regions remained essentially unchanged between 1990 and 2000.

Indicator Limitations

- ANC sampling is limited to five regions, concentrated in the Northeast. There is no coverage in the Southeast, West, or much of the Midwest. These regions were chosen for sampling because previous research has shown that they are among the most sensitive to acid deposition due to the soils and other watershed characteristics. In addition, as the Acid Deposition indicator (p. 2-56) shows, many of these regions receive the highest rates of acid deposition in the U.S. For these two reasons the waters sampled are likely to be at the greatest risk of becoming acidified.
- Interpreting trends for this indicator is complicated because multiple factors contribute to changes in ANC levels. For example, in areas where watershed soil characteristics are changing (e.g., decreases in concentrations of base cations in the soil), even dramatic reductions in acid deposition will not necessarily result in large rebounds in ANC levels.

Data Sources

Summary data in this indicator were provided by EPA's Office of Atmospheric Programs and are taken from a publication documenting how surface waters have responded to reduced air emissions of acid rain precursors (U.S. EPA, 2003). Trends are based on data collected in two networks: the Temporally Integrated Monitoring of Ecosystems (TIME) project and the Long-Term Monitoring project. Because both networks are operated by numerous collaborators in state agencies, academic institutions, and other federal agencies, the raw monitoring data are not available in a single publication or database. The trend data in this indicator are based on observations documented in several publications (see pages 15-17 of U.S. EPA, 2003).

References

NAPAP (National Acid Precipitation Assessment Program). 1991. Acid deposition: state of science and technology, volume II, aquatic processes and effects. Washington, DC.

U.S. EPA. 2003. Response of surface water chemistry to the Clean Air Act Amendments of 1990. EPA/620/R-03/001. Research Triangle Park, NC.

INDICATOR: Percent of Days with Air Quality Index Values Greater Than 100

The Air Quality Index (AQI) provides information on pollutant concentrations of ground level ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide. Formerly known as the Pollutant Standard Index (PSI), the nationally uniform AQI is used by state and local agencies for reporting daily air quality and air quality related health advisories to the public.

In 1999, the AQI was updated to reflect the latest science on air pollution health effects and to make it more appropriate for use in contemporary news media (U.S. EPA, 2003a). It also serves as a basis for community-based programs that encourage the public to take action to reduce air pollution on days when levels are projected to be of concern. The index has been adopted by many other countries (e.g., Mexico, Singapore, and Taiwan) to provide the public with information on air quality.

The AQI is based on pollutant concentration data measured by the State and Local Air Monitoring Stations (SLAMS). The AQI is monitored in city groupings known as metropolitan statistical areas (MSAs) which are defined by the Office of Management and Budget. For most pollutants in the index, the concentration is converted into index values between 0 and 500, “normalized” so that an index value of 100 represents the short term, health-based standard for that pollutant as established by EPA (U.S. EPA, 1999). The higher the index value, the greater the level of air pollution and health risk. An index value of 500 reflects a risk of imminent and substantial endangerment to public health. The level of the pollutant with the highest index value is reported as the AQI level for that day. An AQI value greater than 100 means that at least one criteria pollutant has reached levels at which people in sensitive groups may experience health effects. A complete description of how AQI values are calculated and what they represent is documented in many publications (e.g., U.S. EPA, 2003b).

This indicator is based on the percent of days across 93 large MSAs (500,000 people or more) during the year that recorded an AQI greater than 100 at one or more monitoring sites in the MSA. While the AQI indicator is calculated from ambient concentration data for criteria pollutants, this indicator’s trends should not be expected to mirror the trends in the other ambient concentration indicators, due to the differing spatial coverage of monitoring stations across the various indicators. The percent of days with AQI greater than 100 was calculated in two steps: (1) For each year, the total number of days with AQI>100 in each of the 93 MSAs was summed in order to get a national total. (2) The national total was then divided by the total number of days in the annual sample (365 x 93) to obtain the percentage of days with AQI>100 in a year. Data are presented from 1990 to 2005. However, because meteorology can strongly influence AQI values in a given year, the change in AQI over time is evaluated by comparing the 3-year average observation at the beginning of the period of record (i.e., 1990-1992) to the 3-year average at the end (i.e., 2003-2005). Comparing 3-year averages reduces the potential for biases introduced by years with unique meteorological conditions. The air quality data that go into the index consist of daily (24-hour) measurements for PM_{10} and $PM_{2.5}$ and continuous (1-hour) measurements for CO, NO_2, ozone, and SO_2. However, of these pollutants, only four (CO, ozone, PM, and SO_2) usually exhibit AQI values greater than 100. The data come from a subset of ambient monitoring sites that meet the trends requirements in Appendix B of the 2003 National Air Quality and Emissions Trends Report (U.S. EPA, 2003a).

What the Data Show

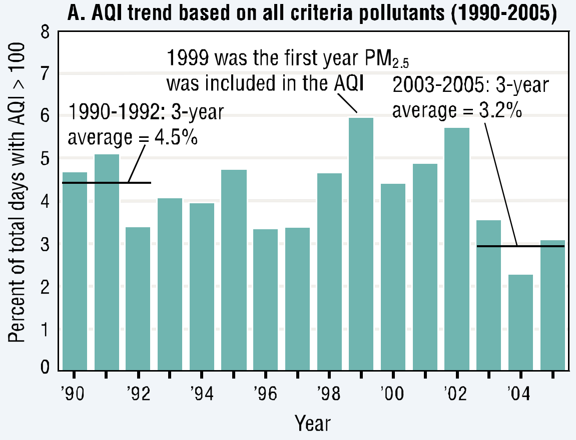
The percent of days with AQI greater than 100 in 93 large MSAs based on all criteria pollutants decreased from 4.5 percent over the 1990-1992 time frame to 3.2 percent over the 2003-2005 time frame (Exhibit 2-37, panel A). The AQI data based on all criteria pollutants are not directly comparable over this time frame, because $PM_{2.5}$ measurements started to factor into the index in 1999. For this reason, the indicator also presents AQI trends based strictly on ozone and $PM_{2.5}$ measurements.

For the same subset of MSAs and time frame, the percent of days with AQI values greater than 100 decreased from 4.4 percent to 2.1 percent (Exhibit 2-37, panel B). Before PM2.5 became part of the index in 1999, ozone typically accounted for more than 90 percent of the days with AQI greater than 100.

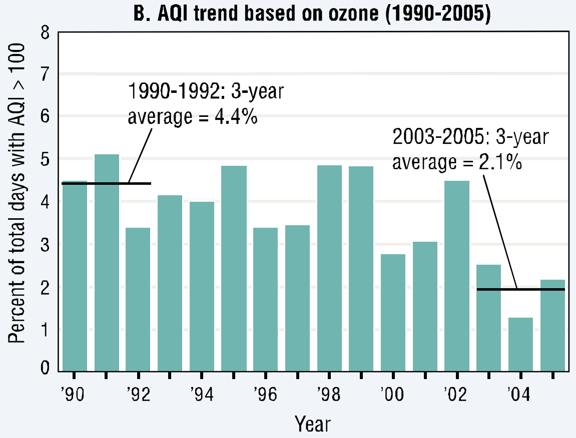
Between 1999 and 2005, $PM_{2.5}$ accounted for some of the days with AQI greater than 100. From 1999 to 2001, 2.1 percent of days with AQI greater than 100 occurred due to $PM_{2.5}$ concentrations, with this contribution decreasing to 1.4 percent from 2003 to 2005.

Exhibit 2-37. Percent of days with Air Quality Index (AQI) greater than 100 in selected U.S. metropolitan areas, 1990-2005[a]

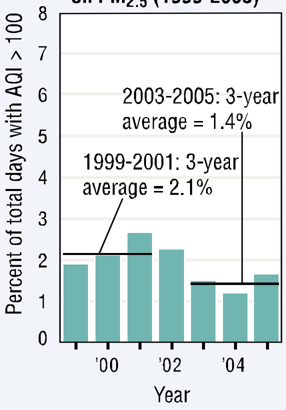
A. AQI trend based on all criteria pollutants (1990-2005)



B. AQI trend based on ozone (1990-2005)



C. AQI trend based on $PM_{2.5}$ (1999-2005)[b]

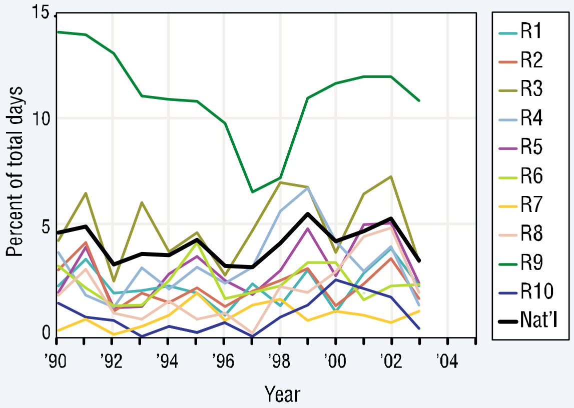


[a] **Coverage:** 93 metropolitan areas.

[b] Data for 1990-1998 are not shown because 1999 was the first year that $PM_{2.5}$ was included in the AQI.

Data source: *U.S. EPA, Air Quality System, 2006*

Exhibit 2-38. Percent of days with Air Quality Index (AQI) greater than 100 in selected U.S. metropolitan areas by EPA Region, 1990-2003[a,b]

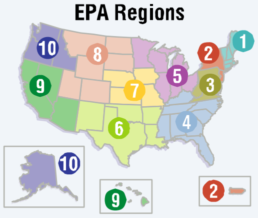


[a] **Coverage:** 93 metropolitan areas.

[b] 1999 was the first year that $PM_{2.5}$ was included in the AQI.

Data source: *U.S. EPA, Air Quality System, 2005*

EPA Regions



Trends in AQI between 1990 and 2003 varied across the ten EPA Regions (Exhibit 2-38). In EPA Regions 2, 6, and 9, the percent of total days with AQI greater than 100 averaged over 2001-2003 was lower than the percent of total days with AQI greater than 100 averaged over the 1990-1992 time frame. In the other seven EPA Regions, the percent of total days with AQI greater than 100 increased between these two time frames. However, as noted above, the AQI values for 1990-1992 and 2001-2003 are not directly comparable, because $PM_{2.5}$ measurements did not factor into AQI prior to 1999.

Indicator Limitations

- The AQI does not address hazardous air pollutants (HAPs).
- Air quality may vary across a single MSA. In assigning a single number for each pollutant in each MSA, the AQI does not reflect this potential variation.
- The data for this indicator are limited to MSAs comprising urban and suburban areas with populations greater than 500,000. Thus, this indicator does not reflect MSAs smaller than 500,000 or rural areas.
- The AQI does not show which pollutants are causing the days with an AQI of more than 100, or distinguish between days >100 and days with much higher AQIs.
- This composite AQI indicator does not show which specific MSAs, or how many MSAs, have problems—a specific number of days could reflect a few areas with persistent problems or many areas with occasional problems.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on AQI values computed from raw ambient air monitoring data for criteria pollutants found in EPA's Air Quality System (U.S. EPA, 2006). Spreadsheets with the processed AQI data for the 93 MSAs considered in this indicator are publicly available (http://epa.gov/air/airtrends/factbook.html). This indicator aggregates the processed AQI data nationally and by EPA Region.

References

U.S. EPA. 2006. Data from the Air Quality System. Accessed 2006. <http://www.epa.gov/ttn/airs/airsaqs/>

U.S. EPA. 2003a. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

U.S. EPA. 2003b. Air Quality Index: a guide to air quality and your health. EPA-454/K-03-002. <http://www.epa.gov/airnow//aqibroch/AQI_2003_9-3.pdf>

U.S. EPA. 1999. Air quality index reporting, 40 CFR part 58. <http://www.epa.gov/ttn/oarpg/t1/fr_notices/airqual.pdf>

INDICATOR: Mercury Emissions

Mercury is an element that occurs naturally in the environment. However, many industrial processes, such as coal combustion, medical and hazardous waste incineration, municipal waste combustion, gold mining, and certain chemical manufacturing operations have increased the amount of mercury released to the air. What happens to mercury after it is emitted depends on several factors: the form of mercury emitted, the location of the emission sources, how high above the landscape the mercury is released (e.g., the height of the stack), the surrounding terrain, and the weather. Depending on these factors, atmospheric mercury can be transported over a range of distances before it is deposited, potentially resulting in deposition on a local, regional, continental, or global scale. While some domestic anthropogenic mercury emissions are deposited within the contiguous U.S., the majority of such emissions combine with anthropogenic emissions from other countries and natural emissions worldwide to form a pool of mercury that circulates globally (Seigneur et al., 2004; U.S. EPA, 1996).

Because it does not degrade in the environment, most mercury emitted to the atmosphere eventually deposits onto land or water bodies. Through a series of chemical transformations and environmental transport processes, airborne mercury that deposits to the Earth's surface can eventually accumulate in the food web (the Lake Fish Tissue indicator, p. 3-107), most profoundly in those species near the top of the food web (e.g., shark, swordfish). The Blood Mercury indicator (p. 5-79) describes the human health effects associated with mercury exposure.

This indicator presents mercury emissions from the following categories: 1) "Industrial processes: gold mining"; 2) "Industrial processes: hazardous waste incineration"; 3) "Industrial processes: electric arc furnaces"; 4) "Industrial processes: chlorine production"; 5) "Industrial processes: medical waste combustors"; 6) "Industrial processes: municipal waste combustors"; 7) "Industrial processes: other sources," which includes chemical production and other miscellaneous industrial processes; 8) "Fuel combustion: industrial, commercial, and institutional boilers"; and 9) "Fuel combustion: utility coal boilers." In order to better characterize mercury emissions, this indicator presents different source categories than other emissions indicators in the Report on the Environment, including separate categories for utility coal boilers and various industrial processes that release mercury (e.g., medical waste incineration, municipal waste combustion, hazardous waste incineration, gold mining).

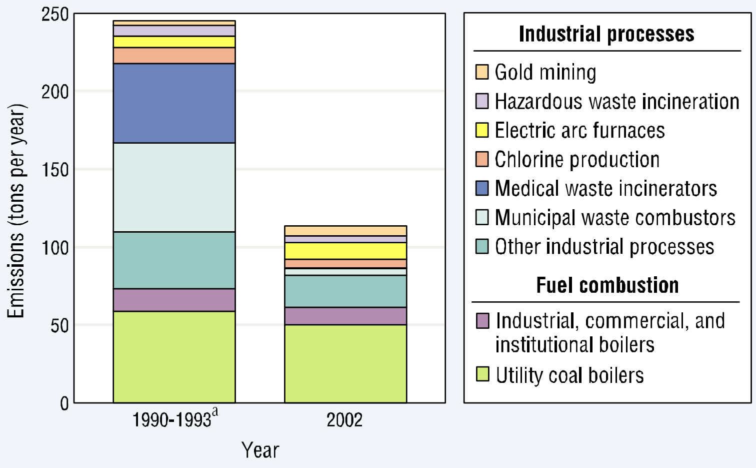
Mercury emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For most fuel combustion sources and industrial processes emissions are estimated using emission factors.

NEI data have been collected since 1990 and cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and Virgin Islands, and some of the territories of federally-recognized American Indian nations. Data are presented for the baseline year (1990-1993) and the latest period for which data are available (2002). The baseline period 1990 to 1993 represents a mix of years depending on data availability for various source types. While NEI data for air toxics (including mercury) were also compiled for 1996 and 1999, the methodology used in those years for air toxics differs considerably from the methodology used in 1990-1993 and 2002 and therefore cannot be compared directly to those data.

What the Data Show

Between 1990-1993 and 2002, annual nationwide air emissions of mercury decreased from 245 tons per year to 114 tons per year, a decrease of 54 percent (Exhibit 2-39). The decline in mercury emissions is attributed primarily to decreased emissions from medical waste incinerators and municipal waste combustors. In 2002, coal-burning power plants were the largest anthropogenic source of mercury emissions to the air in the U.S., accounting for 44 percent of all domestic anthropogenic mercury emissions.

Exhibit 2-39. Mercury emissions in the U.S. by source category, 1990-1993 and 2002



[a] 1990-1993 is considered the baseline period for mercury emissions. The baseline period spans multiple years due to the availability of emissions data for various source categories. The data presented for the baseline period are annual emissions (tons per year) and are therefore comparable to the 2002 data.

Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Indicator Limitations

- The emissions data in this indicator are primarily based on estimates, not direct measurements. Although these estimates have inherent uncertainties, the data have been generated using well-established estimation methods.
- The trend shown is based on nationwide aggregate data. Regional and state trends may be different.
- Not all states and local agencies provide the same data or level of detail for a given year.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw mercury emissions data in EPA's National Emissions Inventory (NEI) (U.S. EPA, 2006) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw NEI data by source category.

References

Seigneur, C., K. Jayaraghavan, K. Lohman, P. Karamchandani, and C. Scott. 2004. Global source attribution for mercury deposition in the United States. Environ. Sci. Technol. 38:555-569.

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U.S. EPA. 1996. Mercury study report to Congress, volumes I to VII. EPA/452/R-96/001b. Washington, DC. <http://www.epa.gov/mercury/report.htm>

INDICATOR: Air Toxics Emissions

Toxic air pollutants, also known as air toxics or hazardous air pollutants (HAPs), are those pollutants that are known or suspected to cause cancer or are associated with other serious health (e.g., reproductive problems or birth defects) or ecological effects. Examples of air toxics include benzene, found in gasoline; perchloroethylene, emitted from some dry cleaning facilities; and methylene chloride, used as a solvent by a number of industries. Most air toxics originate from anthropogenic sources, including mobile sources (e.g., cars, trucks, construction equipment), stationary sources (e.g., factories, refineries, power plants), and indoor sources (e.g., building materials, cleaning solvents). Some air toxics are also released from natural sources such as volcanic eruptions and forest fires. Secondary formation of certain air toxics, such as acetaldehyde and formaldehyde, can also occur when precursor chemicals react in the atmosphere. The Clean Air Act identifies 188 air toxics associated with industrial sources. Twenty of these air toxics also are associated with mobile sources (U.S. EPA, 2003).

People who inhale certain air toxics at sufficient concentrations may experience various health effects, including cancer, damage to the immune system, and neurological, reproductive (e.g., reduced fertility), developmental, or respiratory health problems (CDC, 2005). Air toxics also can present risks through other exposure pathways. For example, air toxics may deposit onto soils or surface waters, where they can then enter the food web and may eventually be ingested by humans. Plants and animals also may be harmed by exposures to air toxics (U.S. EPA, 2003).

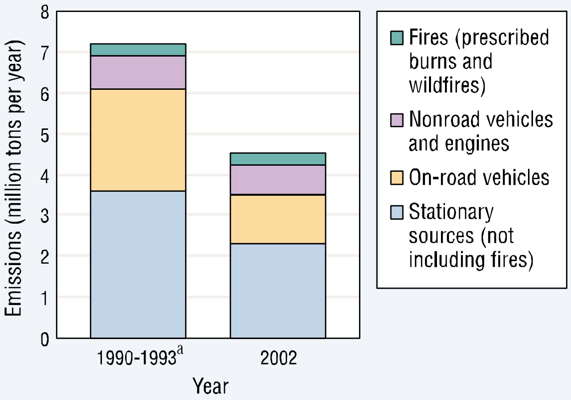
Air toxics emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different data sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For most fuel combustion sources and industrial sources, emissions are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2005).

NEI data have been collected since 1990 and cover all 50 states and their counties, D.C., the U.S. territories of Puerto Rico and the Virgin Islands, and some of the territories of federally-recognized American Indian nations. The NEI includes baseline air toxics data for the period 1990-1993 and since then has been updated every 3 years. The baseline period 1990 to 1993 represents a mix of years depending on data availability for various source types. While NEI data for air toxics were also compiled for 1996 and 1999, the methodology used in those years for air toxics differed considerably from the methodology that was used in 2002. Therefore, the 1996 and 1999 data are not presented because comparing the two inventories might lead to invalid conclusions.

This indicator first presents emissions data for all air toxics combined, both at the national level and broken down into the ten EPA Regions. Consistent with the other emissions indicators, the national data are organized into the following source categories: 1) “Stationary sources,” which include fuel combustion sources (coal, gas and oil-fired power plants, industrial, commercial, and institutional sources, as well as residential heaters and boilers) and industrial processes (chemical production, petroleum refining, and metals production) categories; 2) “Fires: prescribed burns and wildfires,” for insights on contributions from some natural sources; 3) “On-road vehicles” which include cars, trucks, buses, and motorcycles; and 4) “Nonroad vehicles and engines,” such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others.

In addition to presenting emissions data aggregated across all 188 air toxics, the indicator presents emissions trends for five individual air toxics: acrolein, benzene, 1,3-butadiene, ethylene dibromide, and

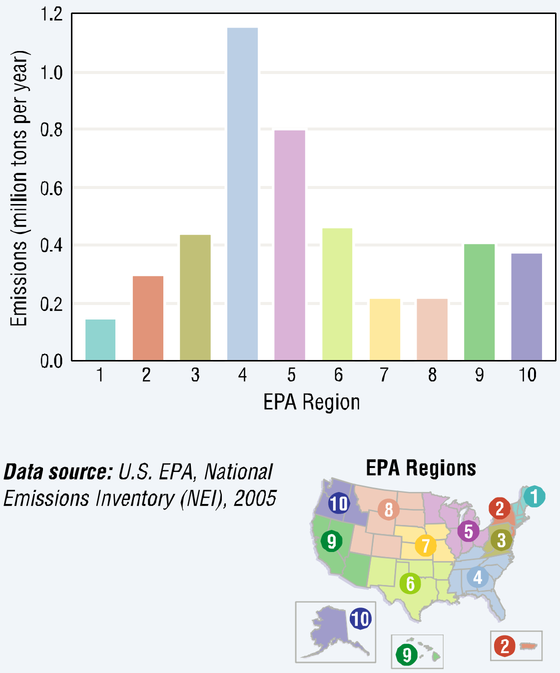
Exhibit 2-40. Air toxics emissions in the U.S. by source category, 1990-1993 and 2002



[a] 1990-1993 is considered the baseline period for air toxics emissions. The baseline period spans multiple years due to the availability of emissions data for various source categories. The data presented for the baseline period are annual emissions (tons per year) and are therefore comparable to the 2002 data.

Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Exhibit 2-41. Air toxics emissions in the U.S. by EPA Region, 2002



Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

hydrazine. These compounds were selected for display because EPA's 2002 National Air Toxics Assessment estimates that these air toxics present the greatest nationwide health risks (whether for cancer or non-cancer endpoints) among the subset of air toxics for which available emissions and toxicity data supported an evaluation (U.S. EPA, 2006a). This indicator breaks the emissions data for these five air toxics into multiple source categories, with the most appropriate categories for display purposes differing from one air toxic to the next.

What the Data Show

Trends Aggregated Across All 188 Air Toxics

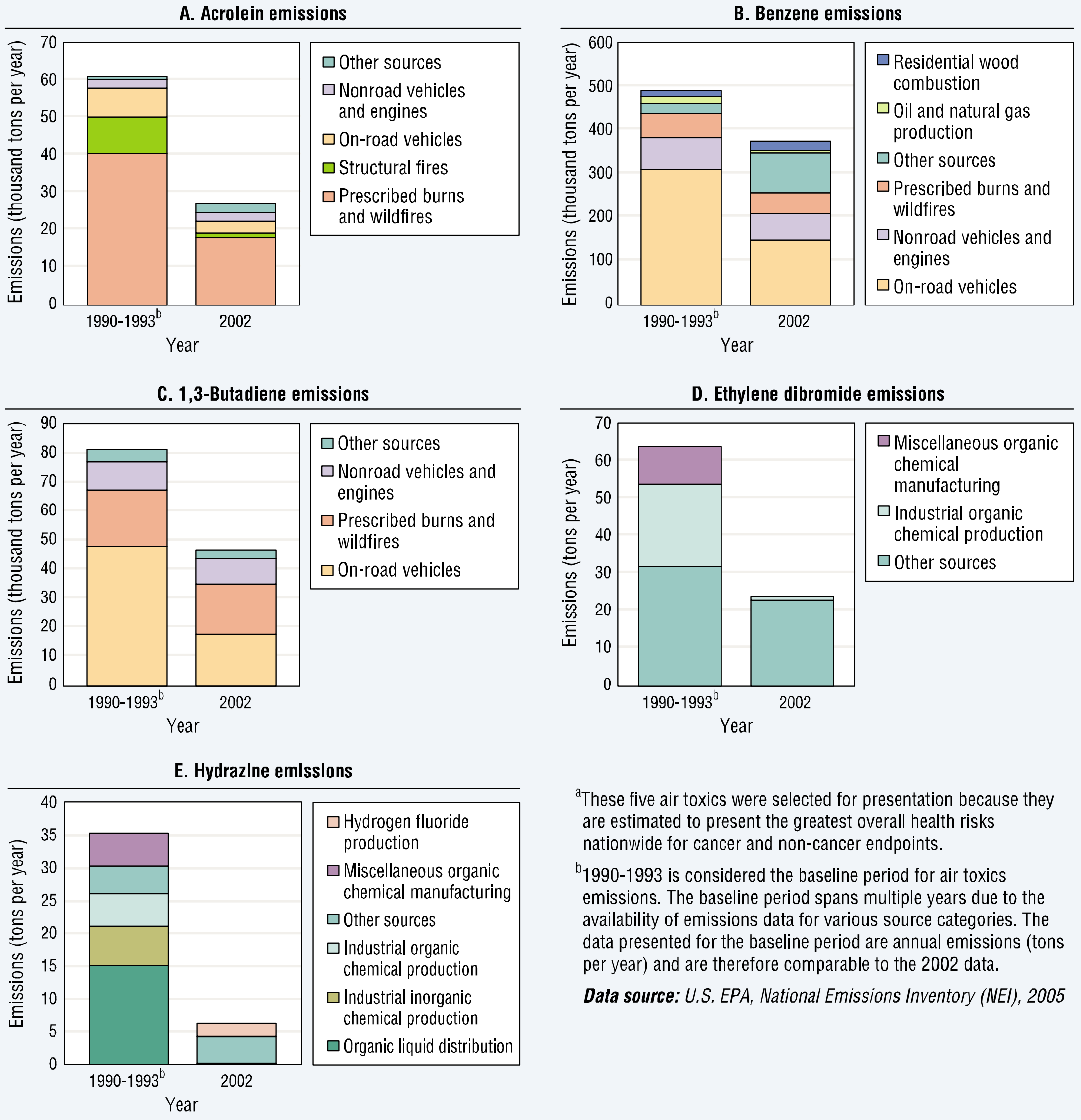
According to NEI data, estimated annual emissions for the 188 air toxics combined decreased 29 percent from 7.2 million tons per year in the baseline period of 1990-1993 to 4.5 million tons per year in 2002 (Exhibit 2-40). This downward trend resulted primarily from reduced emissions from stationary sources and on-road mobile sources.

In 2002, air toxics emissions in the ten EPA Regions ranged from 153,000 tons per year in Region 1 to 1,150,000 tons per year in Region 4 (Exhibit 2-41). Regional trends cannot be quantified, because a complete set of state and local air toxics emissions data are not available for the 1990-1993 baseline period.

Trends for Selected Air Toxics

Exhibit 2-42 shows emissions trends for five compounds believed to account for the greatest health risks that are attributed to air toxics, according to a recent modeling study (U.S. EPA, 2006a). The five plots in this exhibit show how emissions trends vary from compound to compound. Estimated emissions decreased between the baseline period (1990-1993) and 2002 for all five selected air toxics: acrolein (55 percent decrease; see panel A), benzene (24 percent; panel B), 1,3-butadiene (43 percent; panel C), ethylene dibromide (62 percent; panel D), and hydrazine (82 percent; panel E).

Exhibit 2-42. Emissions of selected air toxics in the U.S. by source category, 1990-1993 and 2002[a]



[a] These five air toxics were selected for presentation because they are estimated to present the greatest overall health risks nationwide for cancer and non-cancer endpoints.

[b] 1990-1993 is considered the baseline period for air toxics emissions. The baseline period spans multiple years due to the availability of emissions data for various source categories. The data presented for the baseline period are annual emissions (tons per year) and are therefore comparable to the 2002 data.

Data source: *U.S. EPA, National Emissions Inventory (NEI), 2005*

Indicator Limitations

- The emissions data are largely based on estimates. Although these estimates are generated using well-established approaches, the estimates have inherent uncertainties. The methodology for estimating emissions is continually reviewed and is subject to revision. Trend data prior to any revisions must be considered in the context of those changes.

- The indicator is an aggregate number that represents contributions from 188 different chemicals with widely varying toxicities and human exposures. Therefore, the nationwide trend for total air toxics and the resulting health effects likely differs from emissions trends for specific chemicals. Similarly, because the indicator is a nationwide aggregate statistic, the trend may not reflect emissions trends for specific locations.

- Not all states and local agencies provide the same data or level of detail for a given year.

- There is uncertainty associated with identifying which air toxics account for the greatest health risk nationwide. Toxicity information is not available for every compound, and emissions and exposure estimates used to characterize risk have inherent uncertainties. Additional limitations associated with the National Air Toxics Assessment are well documented (U.S. EPA, 2006a).

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw air toxics emissions data in EPA's National Emissions Inventory (NEI) (U.S. EPA, 2006b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the raw NEI data by source category, EPA Region, and selected air toxics.

References

CDC (Centers for Disease Control and Prevention). 2005. Third national report on human exposure to environmental chemicals. NCEH Pub. No. 05-0570. Accessed September 9, 2005. <http://www.cdc.gov/exposurereport/3rd/results_01.htm>

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INDICATOR: Ambient Concentrations of Benzene

Benzene is an air toxic emitted from gasoline service stations, motor vehicle exhaust, and the burning of coal and oil. In addition to being a common air pollutant, benzene may also contaminate water. Urban areas generally have higher concentrations of benzene than other areas.

People exposed to benzene at sufficient concentrations may experience various health effects, including cancer, damage to the immune system, as well as neurological, reproductive (e.g., reduced fertility), developmental, respiratory, and other health problems. Plants and animals may also be harmed by exposures to benzene (U.S. EPA, 2003).

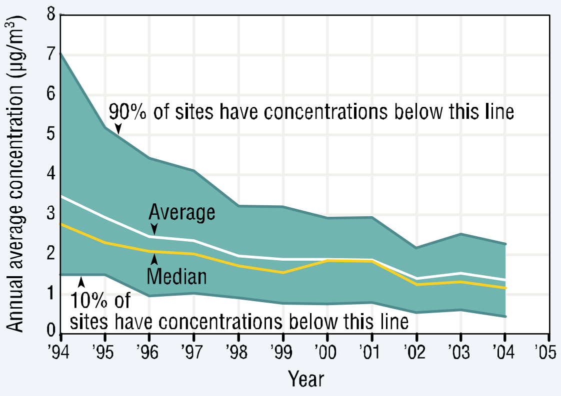
Benzene is the most widely monitored air toxic. Data from the National Air Toxics Trends Sites (NATTS) network is expected to provide trends information for other air toxics pollutants in the next Report on the Environment.

This indicator reflects ambient concentrations in micrograms per cubic meter (µg/m^3) of benzene from 1994 to 2004, based on the annual arithmetic average. This indicator displays trends averaged over 35 urban monitoring sites that have consistent data for the period of record in Photochemical Assessment Monitoring Stations (PAMS), Urban Air Toxics Monitoring (UATMP) Stations, and Non-Methane Organic Compound (NMOC) Monitoring Stations.

What the Data Show

Benzene concentrations declined 61 percent from 1994 to 2004 (Exhibit 2-43).

Exhibit 2-43. Ambient benzene concentrations in the U.S., 1994-2004[a]



[a] **Coverage:** 35 monitoring sites nationwide (out of a total of 251 sites measuring benzene in 2004) that have sufficient data to assess benzene trends since 1994.

Data source: *U.S. EPA, Air Quality System, 2005*

Indicator Limitations

- Benzene data represent only 35 urban sites in the U.S.
- Because of the limited number of sites that are primarily located in urban areas, Exhibit 2-43 does not necessarily represent an overall national trend in benzene concentrations.
- Benzene, while an important air toxic, represents only one of many air toxics that may occur in air.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on raw benzene ambient air monitoring data in EPA's Air Quality System (AQS) (U.S. EPA, 2006) (http://www.epa.gov/ttn/airs/airsaqs/). National trends in this indicator are based on the subset of benzene monitoring stations that have sufficient data to assess trends since 1994.

References

U.S. EPA. 2006. Data from the Air Quality System. Accessed 2006. <http://www.epa.gov/ttn/airs/airsaqs/>

U.S. EPA. 2003. National air quality and emissions trends report—2003 special studies edition. EPA/454/R-03/005. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd03/>

INDICATOR: Concentrations of Ozone-Depleting Substances

Ozone, a gas present throughout the Earth's atmosphere, is a pollutant at the Earth's surface but forms a protective layer in the stratosphere, helping shield the Earth from the sun's ultraviolet (UV) radiation. Exposure to UV-rays is associated with skin cancer, cataracts, and other human health and ecological problems (U.S. EPA, 1996).

Starting in the late 1970s, stratospheric ozone levels were observed to be declining due to worldwide releases of various human-produced chemicals referred to as ozone-depleting substances (ODS), particularly halocarbons such as the long-lived chlorofluorocarbons (CFCs), bromine-containing halons, and methyl bromide. Through rapid catalytic reactions with ozone, the chlorine and bromine from these chemicals have depleted the protective ozone layer (the Ozone Levels over North America indicator, p. 2-79).

Worldwide production and consumption of ODS is being progressively eliminated under the provisions of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. Over time, reducing the atmospheric loading of ODS is expected to result in global increases in stratospheric ozone. However, because some ODS gases have long atmospheric lifetimes, and because of pre-phaseout ODS stockpiling for post-phaseout use, ambient concentrations of ODS have only recently begun to stabilize and in some cases begun to decline. While some gases, like methyl chloroform, decay quickly in the atmosphere, other gases, like CFCs and halons, have atmospheric lifetimes on the order of hundreds or thousands of years.

Measures of effective equivalent troposphere chlorine (EECl) and effective equivalent stratospheric chlorine (EESC) are commonly used to represent atmospheric concentrations of ODS. Both represent ODS concentrations weighted by their potential to catalyze the destruction of stratospheric ozone relative to the ability of chlorine to do so. EECl is the equivalent effective chlorine in the troposphere. (EESC is typically derived by adding a 3-year time lag to EECl to account for the time it takes for emissions of ODS at the Earth's surface to migrate to the stratosphere and cause stratospheric ozone depletion.)

This indicator presents trends in concentrations of tropospheric ODS as EECl. The EECl trend is based on measurements from the National Oceanic and Atmospheric Association (NOAA) Climate Monitoring and Diagnostics Laboratory and estimates of halocarbon emissions from industrial and international sources from 1995 to 2004. Concentrations of EECl are presented as weighted averages based on ground-based measurements of mixing ratios[5] since 1995 at the following remote locations: Alert, North West Territories, Canada; Barrow, Alaska; Niwot Ridge, Colorado; Mauna Loa, Hawaii; American Samoa; Cape Grim, Tasmania, Australia; and the South Pole (NOAA CMDL, 2003). Data on total EECl are also available for 1992 and 1994, but these years' of monitoring are only presented in the chemical-specific graphs because the monitoring did not include methyl bromide, a quantitatively important ODS. Because most ODS have long atmospheric half-lives, the ODS concentrations shown in this indicator reflect past and recent contributions from emissions sources within the U.S. and worldwide.

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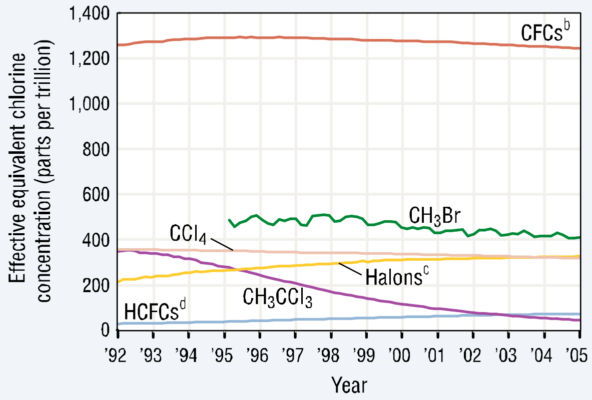
[5] The mixing ratio is the ratio of the partial pressure of a gas to the total atmospheric pressure.

Exhibit 2-44. Global effective equivalent chlorine concentrations, 1995-2005[a]

[a] Effective equivalent chlorine (EECl) is typically used to represent atmospheric concentrations of ozone-depleting substances. The EECl reflects contributions from multiple ozone-depleting substances, weighted by their potential to catalyze the destruction of stratospheric ozone.

Data source: *NOAA/ESRL/GMD, 2006*

Exhibit 2-45. Global effective equivalent chlorine concentrations of selected ozone-depleting substances, 1992-2005[a]



[a] Effective equivalent chlorine (EECl) is typically used to represent atmospheric concentrations of ozone-depleting substances. The EECl of ozone-depleting substances is calculated from the substances' atmospheric concentrations and their potential to catalyze the destruction of stratospheric ozone.

[b] The chlorofluorocarbons (CFCs) considered in this figure are CFC-11, CFC-12, and CFC-113.

[c] The halons considered in this figure are halon 1311 and halon 1201.

[d] The hydrochlorofluorocarbons (HCFCs) considered in this figure are HCFC-22, HCFC-141b, and HCFC-142b.

Data source: *NOAA/ESRL/GMD, 2006*

What the Data Show

Total effective equivalent chlorine (EECl) resulting from ODS emissions reached its peak concentration in the mid-1990s at slightly over 2,700 parts per trillion of air by volume (pptv) and has slowly declined by approximately 11 percent since then (Exhibit 2-44). Although concentrations of CFCs and several other individual ODS compounds have begun to decline, concentrations of halons and hydrochlorofluorocarbons (HCFCs) have not yet stabilized.

Declines in EECl abundances of several ODSs in the troposphere between 1992 and 2005 have contributed to the decline in total EECl (Exhibit 2-45). EECl attributed to methyl chloroform has decreased more than 80 percent over this period due to decreased emissions as well as its short atmospheric lifetime. EECl associated with CFCs has decreased more slowly—more than 3 percent from its peak tropospheric concentration in 1995-1996. The slow decay of CFCs is a result of continued emissions of CFCs from stockpiles in developed countries, continued use in developing countries, and their longer atmospheric lifetimes. EECl from methyl bromide (CH_3Br) has decreased nearly 20 percent from its peak in 1998; however, continued use of methyl bromide in developing countries and in developed countries through critical use exemptions slows the decrease in EECl associated with this compound. EECl from methyl bromide exhibits seasonal variations, which likely results from the seasonal use of this chemical as a soil fumigant.

Despite declines in concentrations of some tropospheric ODS, others, including halons and HCFCs, continue to increase (Exhibit 2-45). EECl estimated from halon emissions has increased by more than 50 percent from 1992 to 2005, and EECl attributed to HCFCs in 2005 is more than 2.5 times higher than that from 1992. These trends reflect continued emissions of these ODS from stockpiles in developed countries and continued production and consumption in developing countries (and developed countries for HCFCs), as well as the longer atmospheric lifetimes of halons.

Indicator Limitations

- The calculation of EECl depends on the understanding of the interactions and atmospheric residence times of many different gases; incorrect knowledge about these factors could affect trends in the EECl.
- EECl is calculated by weighing individual ODS concentrations by the substances' abilities to catalyze destruction of stratospheric ozone, or the ozone destruction potential. The ozone destruction potentials used to transform the data have inherent uncertainties, which can affect the trend analyses.
- Factors additional to trends in halocarbons affect trends in stratospheric ozone, including changes in climate (e.g., temperature, winds), changes in emissions and concentrations of trace gases like nitrous oxide and methane, and changes in aerosol loading such as occurs after an explosive volcanic eruption.

Data Sources

Tropospheric concentrations of ODSs presented in this indicator are based on measurements made by NOAA's Global Monitoring Division and summarized at an online data repository (NOAA, 2006) (ftp://ftp.cmdl.noaa.gov/hats/Total_Cl_Br/). The trend in this indicator was developed from a 2006 data file available from the repository, which updates tropospheric ODS concentrations previously reported in the peer-reviewed literature (Montzka et al. 1999, 2003).

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INDICATOR: Ozone Levels over North America

Ozone (O_3) is a gas present throughout the Earth's atmosphere; 90 percent resides in the stratosphere, the layer of the atmosphere that starts about 6 to 9 miles above the Earth's surface at mid-latitudes, and the rest is located in the troposphere, the atmospheric layer that lies between the stratosphere and the Earth's surface. The environmental and human health implications of ground-level ozone are very different from those of ozone higher in the atmosphere, leading to the maxim: "Good up high, bad nearby" (U.S. EPA, 2003). In the troposphere, ozone poses both health and ecological risks, but the natural layer of ozone in the stratosphere shields and protects the Earth's surface from the sun's harmful ultraviolet (UV) rays which can in turn lead to more cases of skin cancer, cataracts, and other health problems (U.S. EPA, 1996).

Increases in surface UV radiation have been associated with reductions in total column ozone levels based on spectral measurements at a number of sites in Europe, North America, South America, Antarctica, and New Zealand (Kerr and McElroy, 1993; Booth and Madronich, 1994; WMO et al., 2003). For example, measurements between 1989 and 1993 over Toronto indicated that for every 1 percent decrease in total column ozone, after accounting for seasonal and daily variables not related to ozone, there was a corresponding increase between 1.1 percent and 1.3 percent in erythemally active UV-B radiation (Kerr and McElroy, 1993).

Ozone in the stratosphere is constantly being produced naturally from dissociation of oxygen molecules by highly energetic UV solar radiation. While this ozone is being transported poleward and downward through the natural motions of air in the stratosphere, it also is being naturally destroyed through catalytic reactions involving primarily nitrogen and hydrogen oxides.

Releases of various human-produced chemicals, such as the long-lived chlorofluorocarbons, bromine-containing halons, and methyl bromide (the Concentrations of Ozone-Depleting Substances indicator, p. 2-76) have depleted the levels of protective stratospheric ozone starting in the late 1970s, particularly at mid- to high latitudes. The U.S. has been a major contributor to the global emissions of these halocarbons, accounting for about a quarter of total worldwide emissions before the major ozone-depleting substances (ODS) were banned in the 1990s. It takes about 3 years for emissions of ODS at the Earth's surface to migrate to the stratosphere and cause stratospheric ozone depletion (WMO et al., 2003).

This indicator tracks trends in the deviation from pre-1980 levels in total annually-averaged ozone values integrated over the 35° to 60°N latitude belt (the latitudes roughly corresponding to North America) from 1965 to 2005. The estimates are based on data from several different sources including ground-based and satellite measurements. The data on total ozone from ground-based measurements are from a network of surface stations, which are equipped with spectrophotometers. These instruments measure how thick the ozone layer would be if compressed in the Earth's atmosphere (at sea level and at 0°C), where one Dobson Unit (DU) is defined to be 0.01 mm thickness at standard temperature and pressure. Reliable data from regular measurements at these stations are available extending back to the 1960s, although geographical coverage is limited before the 1970s (Fioletov et al., 2002; WMO et al., 2003).

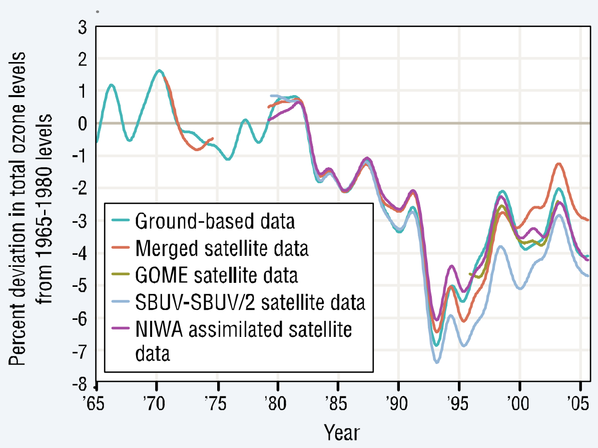
Near-continuous global total ozone data are available from satellite measurements beginning in 1979. The first set of satellite data are obtained from the Total Ozone Mapping Spectrometer (TOMS). The TOMS instrument measures total ozone using the "backscattered albedo," which is the ratio of the radiance backscattered from the Earth's atmosphere to the extraterrestrial solar irradiance. The second dataset consists of total ozone measurements from the Solar Backscatter Ultraviolet (SBUV) spectrometer (Fioletov et al., 2002; WMO et al., 2003).

In addition to the ground-based and satellite data, two merged datasets are presented for this indicator. The Goddard merged ozone dataset and the National Institute of Water and Atmospheric Research (NIWA) ozone dataset were derived using measurements from a number of satellite instruments (Fioletov et al., 2002; WMO et al., 2003).

What the Data Show

There was little ozone change (beyond natural variations such as those resulting from the 11-year solar sunspot cycle) before the late 1970s, but decreases in stratospheric ozone began to occur after 1979 (Exhibit 2-46). The ground-based data and satellite data (TOMS, SBUV, Goddard and NIWA) have similar ozone variations, with differences typically less than 0.5 percent. The mid-latitude decline of approximately 6 percent between 1979 and 1995 is in general agreement with previous profile trend estimates from satellite and ground-based records. For the mid-latitudes of the Northern Hemisphere, the average of the total ozone levels for the 3-year period from 1998 to 2001 is about 3 percent lower than the average for the 3-year period from 1977 to 1980, and average total ozone levels have not changed considerably between 2001 and 2005. While this indicator covers the entire 35° to 60°N latitude belt, ozone varies little by longitude and the estimated 3 percent change in total ozone levels can be taken to apply to North America.

Exhibit 2-46. Total ozone levels over North America, 1965-2005[a,b]



[a] Total ozone refers to the total ozone concentration in a column of air between the Earth's surface and the top of the atmosphere.

[b] Trend data are representative of latitudes ranging from 35 degrees North to 60 degrees North.

Data source: *1965-2003 data from WMO et al., 2003, and 2004-2005 data from unpublished results provided by WMO*

This 3 percent change over North America is very similar to the statistically significant globally-averaged decrease in total ozone over the 1979 to 2001 period (WMO et al., 2003). The decrease in the mid-latitudes of the Southern Hemisphere, by contrast, has been twice as high, associated with the springtime "ozone hole" over Antarctica. The trends in this indicator are consistent with well understood seasonal variations in ozone, and with natural variations such as those due to the 11-year solar cycle and the effects of volcanic eruptions, suggesting that the long-term trends are those resulting from the emissions of ODS.

Indicator Limitations

- Fioletov et al. (2002) used estimates of ozone changes from several different, independent sources to derive the figure used for this indicator. Differences in the calibration of instruments used to obtain the ground-based and satellite datasets together with interruptions in the observational records produce datasets with measurement errors typically around a few percent (WMO et al., 2003). The figure presented does, however, show good overall agreement among the different data sources for changes in total ozone.

Data Sources

Summary data for this indicator were provided by the World Meteorological Organization (WMO). The 1965-2003 data in this indicator are taken from WMO's 2002 Scientific Assessment of Ozone Depletion (WMO et al. 2003), which presents ozone data based on multiple sets of measurements (e.g., Fioletov et al., 2002). The 2004-2005 data in this indicator were not publicly available at the time this report went to press, but they will be published in WMO's upcoming 2006 Scientific Assessment of Ozone Depletion.

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INDICATOR: Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region

The border between the U.S. and Mexico spans approximately 2,000 miles, from the Pacific Ocean to the Gulf of Mexico. The area is subjected to a unique blend of increased industrial development (especially on the Mexico side of the border), intense pressures because of the shifting and growing population related to this development, and an arid climate that can exacerbate many air quality problems. Ozone and particulate matter are air pollutants of particular concern. Rapid population growth in urban areas of the (U.S./Mexico) border has resulted in unplanned development, greater demand for land and energy, traffic congestion, increased waste generation, overburdened or unavailable waste treatment and disposal facilities, increased frequency of chemical emergencies, and had had an adverse impact on air quality (U.S. EPA, 2003).

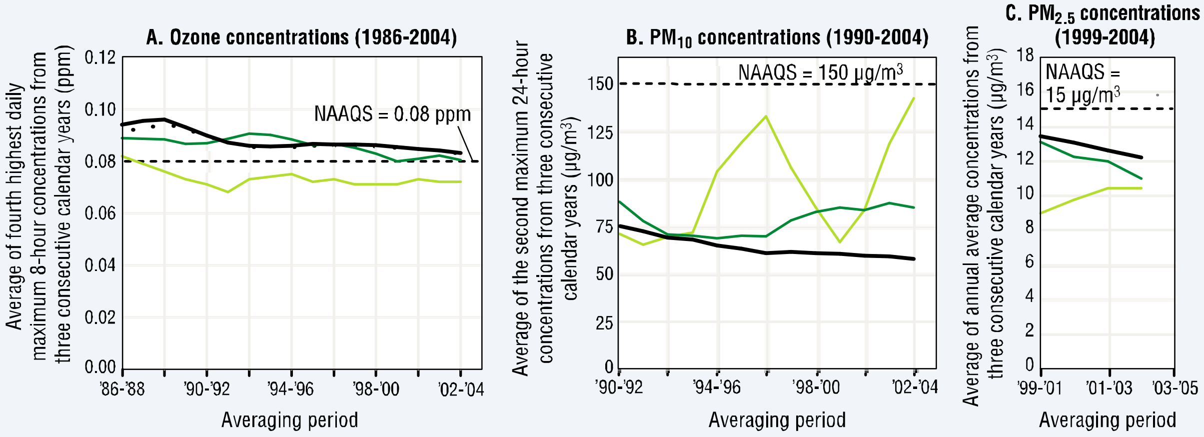
Ground-level ozone is harmful to both human health and the environment (the Ozone Concentrations indicator, p. 2-32). Although some industrial sources release ozone directly into the environment, most ground-level ozone forms from chemical reactions involving nitrogen oxides (NO_x), volatile organic compounds (VOCs), and sunlight. Ozone levels are typically highest during the afternoon hours of the summer months, when the influence of direct sunlight is the greatest (U.S. EPA, 2006a).

Particulate matter (PM) is the general term used for a mixture of solid particles and liquid droplets found in the air. Primary PM is released directly from emissions sources into the atmosphere, while secondary PM is formed in the air from reactions involving precursor chemicals (e.g., nitrogen oxides, sulfur dioxide, particle-producing organic gases). Ambient air monitoring stations measure air concentrations of two size ranges of particles: $PM_{2.5}$ (fine particles with aerodynamic diameter less than or equal to 2.5 micrometers (µm)) and PM_{10} (both fine particles ($PM_{2.5}$) and coarse particles with aerodynamic diameters between 2.5 and 10 µm). Exposure to coarse particles can aggravate respiratory conditions such as asthma, and exposure to fine particles is associated with various additional human health effects (the PM Concentrations indicator, p. 2-44) (U.S. EPA, 2004).

This indicator shows trends in the design values for ozone and particulate matter in the U.S. counties at the U.S./Mexico border area in comparison to U.S. national trends. These trends are shown for the longest duration of time supported by the underlying monitoring data. The ozone design value is defined as a 3-year average of the fourth highest daily maximum in each year. The design value for PM_{10} is the 3-year average of the second maximum 24-hour concentrations, and the design value for PM2.5 is the 3-year average of the seasonally-weighted annual mean concentration. This indicator establishes a baseline for measuring against future air quality levels and is based on all monitoring stations that operated on the U.S. side of the border during this time period.

In EPA Region 6, ozone monitoring data from border locations were collected in Dona Ana County in New Mexico, and El Paso, Brewster, Webb, Hidalgo, and Cameron Counties in Texas. In EPA Region 9, ozone monitoring data from border locations were collected in the Counties of Cochise, Pima, and Yuma in Arizona and Imperial and San Diego in California. PM_{10} sampling data for EPA Region 6 are from Cameron, Hidalgo, Webb and El Paso Counties in Texas and Dona Ana, Luna, and Grant Counties in New Mexico. $PM_{2.5}$ data were available for all of the above counties except for Luna County, New Mexico. For EPA Region 9, PM_{10} monitoring data were collected in the Counties of Cochise, Pima, Santa Cruz, and Yuma in Arizona and Imperial and San Diego in California. For EPA Region 9, $PM_{2.5}$ monitoring data were collected in the Counties of Cochise, Pima, and Santa Cruz in Arizona and Imperial and San Diego in California.

Exhibit 2-47. Ambient ozone, PM_{10}, and $PM_{2.5}$ concentrations in U.S. counties in the U.S.-Mexico border area, 1986-2004[a]

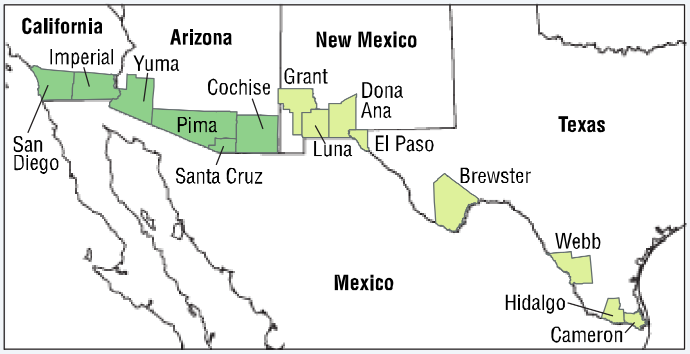


[a]**Coverage:** 27 ozone monitoring sites, 51 PM_{10} monitoring sites, and 16 $PM_{2.5}$ monitoring sites located in U.S. counties along the U.S.-Mexico border that have sufficient data to assess trends over the corresponding time frames that these pollutants were monitored.

Data source: *U.S. EPA, Air Quality System, 2005*

- Region 6 border counties
- Region 9 border counties
- National average

Counties with ambient air monitoring sites included in this indicator



What the Data Show

Trends for 8-Hour Ozone Concentrations

In EPA Region 6, average border ozone concentrations decreased by 11 percent between the 1986-1988 and 1992-1994 time periods and by 3 percent between the 1993-1995 and 2002-2004 periods, which was similar to the national decreases of 9 percent and 3 percent, respectively (Exhibit 2-47, panel A). In EPA Region 9, however, border ozone concentrations increased by 2 percent between the 1986-1988 and 1992-1994 time periods but decreased by 11 percent between the 1993-1995 and 2002-2004 periods.

Trends for 24-Hour PM_{10} Concentrations

In EPA Region 6, the average second maximum 24-hour PM_{10} concentrations at border monitoring sites varied considerably from year to year, most likely due to variation in meteorological conditions (e.g., rainfall, wind speed) and soil erosion (Exhibit 2-47, panel B). In EPA Region 9, on the other hand, corresponding PM_{10} concentrations at border monitoring sites did not exhibit such strong temporal variations, and the average second maximum 24-hour concentration at border monitoring sites for the 2002-2004 time frame was only slightly lower than that for the 1990-1992 time frame.

Trends for Annual Average $PM_{2.5}$ Concentrations

Mean annual ambient $PM_{2.5}$ concentrations increased by 16 percent in the border counties of EPA Region 6 between 1999-2001 and 2002-2004, but decreased by 16 percent in the border counties of EPA Region 9 (Exhibit 2-47, panel C). Mean annual ambient $PM_{2.5}$ concentrations decreased 9 percent nationwide over the same period.

Indicator Limitations

- Many counties along the U.S./Mexico border do not have ambient air quality monitors; these counties are not characterized by this indicator.
- This indicator does not include data from the Mexican side of the border. When the technical review concludes the quality of this data is appropriate for the intended use, the indicator will be updated.
- Short-term trends in PM_{10} concentrations are often highly dependent on meteorological conditions. The maximum concentration for a given site can be influenced by wind-blown dust and will exhibit considerable variations from day to day. Trends over the longer term are far less likely to be influenced by unusual meteorological conditions.
- The long-term ozone trends are derived from an increasing number of monitors over the course of time from 1986-2004, but an analysis of the limited number of border sites that have full periods of record show that the slopes of the trends are similar to those in this indicator.
- Mean air pollutant concentrations may mask higher values in some areas along the border and in the nation.
- Because most of the monitoring sites are located in urban areas, the trends might not accurately reflect conditions outside the immediate urban monitoring areas.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, Region 6, and Region 9. These summaries were based on raw ozone and PM ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2006b) (http://www.epa.gov/ttn/airs/airsaqs/). Trends in this indicator are based on the subset of ozone and PM monitoring stations located in counties along the U.S./Mexico border that have sufficient data to assess trends over the period of record.

References

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INDICATOR: Ambient Concentrations of Manganese Compounds in EPA Region 5

Manganese is a naturally occurring metal that is ubiquitous in the environment. Exposure to low levels of manganese in the diet is considered to be nutritionally essential for people and animals (ATSDR, 1997). However, exposures to elevated concentrations of manganese are harmful to human health and have been associated with subtle neurological effects, such as slowed eye-hand coordination. Manganese compounds are hazardous air pollutants emitted by iron and steel production plants, power plants, coke ovens, and many smaller metal processing facilities. Manganese also may be contributed in border communities by vehicles using Canadian fuel with the additive methylcyclopentadienyl manganese tricarbonyl (MMT).

Although manganese compounds are air pollutants of concern nationwide, they are of special concern in EPA Region 5. The 1999 National Emissions Inventory showed that Region 5 had the highest manganese emissions of all EPA Regions, contributing 36.6 percent of all manganese compounds emitted nationwide (U.S. EPA, 2005a). Emissions from industrial sources in Region 5 occurred from various facilities, such as those that manufacture steel or process iron ores and alloys for steelmaking. Between 1988 and 2003, manganese emissions from point sources declined both nationally (26.2 percent) and in EPA Region 5 (36.7 percent). Year-to-year variability in manganese emissions is high, however, and recent emissions data (1996-2003) suggest a weaker trend: emissions dropped 7.6 percent and 12.4 percent nationwide and in EPA Region 5, respectively (U.S. EPA, 2005b).

EPA's National-Scale Air Toxics Assessment (NATA) is intended to provide a better understanding of the health risks resulting from inhalation exposure to air toxics. Based on 1999 emission inventories, the most recent NATA results (U.S. EPA, 2006a) identify manganese compounds as the largest contributor to neurological non-cancer health risk in the U.S. Modeled estimates of ambient manganese compounds in all 3,222 U.S. counties show that among the 50 counties with the highest concentrations nationwide, 20 are located in EPA Region 5.

This indicator presents ambient concentrations of manganese compounds measured as total suspended particulates (TSP) by direct monitoring. This indicator addresses manganese in the TSP fraction (not PM_{10} or $PM_{2.5}$) because it is the most complete dataset in EPA Region 5 in terms of geographic and temporal coverage. TSP metals data have been commonly used in human health risk assessments. EPA recently has begun to recommend PM_{10} as the most appropriate fraction for evaluating people's exposure to toxic metals (U.S. EPA, 2002), but PM_{10} metals data are sparse at this time, both nationally and in EPA Region 5. Data from a limited number of sites in AQS with collocated PM_{10} and TSP speciation monitors suggest that the proportion of manganese in PM_{10} versus TSP is about 50 percent at most sites and can be as high as 75 percent. TSP manganese data therefore should be considered a conservative estimate of PM_{10} manganese exposures. $PM_{2.5}$ metals data are plentiful since the establishment of the Speciation Trends Network (STN) in 2000, but this size fraction is believed to underestimate human exposures.

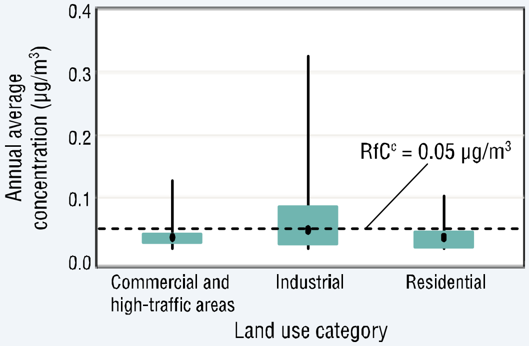
Data were considered for 53 monitoring sites in EPA Region 5 that had a complete year of data reported to the Air Quality System (AQS) national database in 2004. Average manganese concentrations were calculated for each monitoring site. A concentration trend was determined using a subset of 21 of the monitoring sites with four or more complete years of data between 2000 and 2004. As annual average concentrations are representative of long-term inhalation exposures, the ambient monitoring data are displayed in comparison with the manganese Reference Concentration (RfC). The RfC is an estimate of a chronic inhalation exposure that is likely to be without appreciable risk of adverse non-cancer effects during a lifetime. The RfC for manganese is 0.05 micrograms per cubic meter (ug/m^3), based on impairment of neurobehavioral function in people. At exposures increasingly greater than the RfC, the potential for harmful effects increases (ATSDR, 1997; U.S. EPA, 1999). Monitoring sites were classified into different categories based on land use as defined in AQS.

What the Data Show

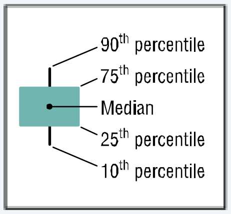
In 2004 the median average annual ambient concentrations of manganese as TSP in EPA Region 5 were: 0.035 µg/m^3 at the 16 residential sites, 0.036 µg/m^3 at the 14 sites in commercial or high-traffic areas, and 0.049 µg/m^3 at the 19 industrial sites (Exhibit 2-48). The median average annual ambient concentration of manganese at 4 predominantly agricultural and forest sites in EPA Region 5 was 0.02 µg/m^3, but this is not depicted in the figure due to the limited number of monitoring sites to characterize a distribution. Greater concentration differences were observed in the 90th percentile values, with average concentrations ranging from 0.10 µg/m^3 at the residential sites to 0.33 µg/m^3 at the predominantly industrial sites. Eighteen of the 53 sites had average manganese concentrations higher than the RfC; 10 of these sites were categorized as industrial, 4 commercial or mobile, and 4 residential.

The median annual manganese concentration averaged across 21 trend sites showed a 15 percent decline between 2000 and 2004 (Exhibit 2-49). Additional years of data will be needed to confirm this apparent trend. The trend sites had the following land use designations: commercial and mobile (6 sites), industrial (9 sites), residential (6 sites), and agricultural and forest (no sites).

Exhibit 2-48. Ambient manganese concentrations in EPA Region 5 by land use category, 2004[a,b]



[a] **Coverage:** 53 monitoring sites in EPA Region 5, with 14 sites in commercial or high-traffic land use areas, 19 sites in industrial areas, and 16 sites in residential areas.

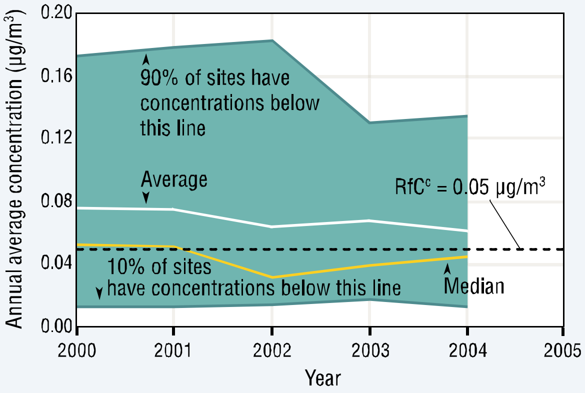


[b] Concentrations are for manganese in total suspended particulate (TSP) matter.

[c] The reference concentration (RfC) is an estimate of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Data source: *U.S. EPA, Air Quality System, 2005*

Exhibit 2-49. Ambient manganese concentrations in EPA Region 5, 2000-2004[a,b]



[a] **Coverage:** 21 monitoring sites in EPA Region 5 (out of a total of 53 sites measuring manganese in 2004) that have sufficient data to assess manganese trends since 2000.

[b] Concentrations are for manganese in total suspended particulate (TSP) matter.

[c] The reference concentration (RfC) is an estimate of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Data source: *U.S. EPA, Air Quality System, 2005*

Indicator Limitations

- AQS data represent several sites per state, but do not have full geographic or temporal coverage. Some emissions "hotspots" are included, while others may exist that have not been monitored.
- The land use categories are only generally indicative of the area represented by an ambient air monitor. For example, a site categorized as "industrial" may adjoin a densely populated community where many residents are exposed to ambient pollution.

Data Sources

Summary data in this indicator were provided by EPA Region 5, based on raw ambient air monitoring data for manganese compounds reported in EPA's Air Quality System (U.S. EPA, 2006b) (http://www.epa.gov/ttn/airs/airsaqs/). Trends in this indicator are based on the subset of monitoring stations located in EPA Region 5 that have sufficient manganese concentration data to assess trends over the period of record.

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2.2.3 Discussion

What These Indicators Say About Trends in Outdoor Air Quality and Their Effects on Human Health and the Environment

Criteria Pollutants and Their Precursors

Because of statutory monitoring and reporting requirements, criteria pollutants have some of the most extensive data available to support National Indicators for emissions and ambient air concentrations. Nationwide, air emissions of every criteria pollutant (or their corresponding precursors) have decreased between 1990 and 2002—the period of record covered by the National Emissions Inventory. During that time frame, substantial decreases in air emissions were observed for carbon monoxide, nitrogen oxides, particulate matter, sulfur dioxide, and volatile organic compounds. Even more pronounced emissions reductions occurred for lead, but this decrease extends back to the 1970s. With few exceptions, downward trends in criteria pollutant emissions were observed in the 10 EPA Regions, similar to the corresponding national trends.

Consistent with the emissions trends, every criteria pollutant showed decreasing ambient air concentrations based on aggregate measurements from the nation's ambient air monitoring system, which measures levels of air pollution primarily in urban and suburban areas. The magnitude of air quality improvements, observed both nationally and in all 10 EPA Regions, varies across pollutants. Carbon monoxide, lead, and nitrogen dioxide concentrations decreased considerably between 1980 and the present, and ambient concentrations of these three pollutants in most or all areas in the U.S. are now below the corresponding air quality standards that protect human health and the environment. In contrast, air quality improvements for ozone and particulate matter (particularly $PM_{2.5}$) were less pronounced; and, based on monitoring data collected in 2005 and reported in EPA's Air Quality System, ambient concentrations in 68 metropolitan statistical areas where approximately 128 million people live did not meet the health-based NAAQS for ozone, particulate matter, or both pollutants. In short, every criteria pollutant has showed improving air quality over the past one or two decades, but the progress has been slowest for the two pollutants—ozone and $PM_{2.5}$—most influenced by meteorology and secondary formation processes.

The nationwide trends and those presented for the 10 EPA Regions are based on aggregate statistics across numerous monitoring stations and may not reflect air quality trends at finer scales or for different subsets of monitoring stations. For example, the significant downward trend in ozone in EPA Region 9 is largely influenced by air quality improvements in Los Angeles and other metropolitan areas in southern California. In other urban areas in EPA Region 9, ozone improvements have been more modest or even different directionally.[6] Similarly, $PM_{2.5}$ concentrations have increased over the last 5 years at selected monitoring stations near the border between U.S. and Mexico (the Ozone and PM Concentrations Along U.S./Mexico Border indicator, p. 2-82), even though the national trend for this pollutant is downward.

The ROE indicators on criteria pollutants' environmental effects are limited to three issues. First, long-term monitoring data show that wet deposition of acidic sulfates and nitrates decreased between 1989 and 2004, consistent with the decreased emissions for sulfur dioxide and nitrogen oxides over roughly the

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[6] U.S. EPA. 2004. The ozone report: measuring progress through 2003. EPA/454/K-04-001. Research Triangle Park, NC.

same time frame. As a result of the decreased acid deposition, many surface waters throughout the Upper Midwest, the Adirondack Mountains, and the Northern Appalachian region have begun to recover from past acidification (the Lake and Stream Acidity indicator, p. 2-62). Second, data on ozone injury to forest plants are sufficient for establishing national and regional baseline conditions against which future data can be compared. These baseline conditions show considerable variation in ozone damage across EPA Regions (the Ozone Injury to Forest Plants indicator, p. 2-37). Third, visibility in protected areas (e.g., National Parks, Wilderness Areas) has remained relatively unchanged between 1992 and 2004 (the Regional Haze indicator, p. 2-50).

Overall, for criteria pollutants, the ROE indicators provide fairly complete information on outdoor air quality trends, but limited insights on associated health and environmental effects. As expected, emissions trends are generally consistent with trends observed among corresponding ambient concentrations and, where data are available, effects.

Air Toxics and Other Air Pollutants

Between 1990 and 2002, nationwide emissions aggregated across 188 air toxics (hazardous air pollutants) decreased (the Air Toxics Emissions indicator, p. 2-70), and decreased emissions were also observed for two air toxics of particular interest: benzene and mercury (the Mercury Emissions indicator, p. 2-68). However, sufficiently complete and consistent monitoring data currently cannot support ROE indicators for ambient concentration of air toxics, with two exceptions. First, ambient air concentrations of benzene at 35 monitoring sites across the nation decreased 61 percent between 1994 and 2004—a decrease reasonably consistent with corresponding emissions reductions. Second, ambient air concentrations of manganese compounds measured at 21 monitoring sites in EPA Region 5 decreased between 2000 and 2004, but the period of record evaluated may be too short to consider this decrease an actual air quality trend.

Stratospheric Ozone Issues

Since 1990, the U.S. phased out most production and import of ozone-depleting substances. Consequently, consumption of ozone-depleting substances in the U.S. decreased during this last decade,[7] along with globally representative ambient air concentrations of ozone-depleting substances in the lower atmosphere (the Concentrations of Ozone-Depleting Substances indicator, p. 2-76). While such decreases are expected to help restore the stratospheric ozone layer, stratospheric ozone levels over North America actually decreased slightly in the last decade (the Ozone Levels over North America indicator, p. 2-79) due to various factors, including ongoing use of ozone-depleting substances worldwide and the fact that ozone-depleting substances are extremely long-lived in the atmosphere.

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[7] U.S. EPA. 2005. Ozone depleting substances (ODS) allowance tracking system.

Limitations, Gaps, and Challenges[8]

The 23 ROE indicators in this section characterize trends for numerous important outdoor air quality issues, but also have notable limitations. All emissions indicators, for instance, are partly based on estimates. Although these estimates have inherent uncertainties, the emissions inventory data are believed to be of high quality and are periodically updated to remain consistent with the current scientific understanding of emissions from different source categories. The main limitation of the ambient concentration indicators is the monitoring sites' limited spatial coverage. These indicators are composites of air quality measurements taken across the country, but primarily in populated areas and may not totally characterize trends for rural settings. While the national trends for criteria pollutants and benzene are toward improved air quality, ambient concentrations for these pollutants can vary greatly on a local scale. In some areas, such as those experiencing rapid population growth or near newly constructed point sources, ambient air concentrations of selected pollutants are increasing, contrary to the national trends; conversely, ambient air concentration in other parts of the country are decreasing more rapidly than the national trends depict.

Though the emissions and ambient concentration indicators are reasonably complete for the criteria pollutants, gaps in nationally representative indicators remain for most air toxics and other air pollutants. However, a large number of these air toxics and other air pollutants are released by a small number of sources nationwide, and these pollutants' emissions and ambient concentrations are more appropriately tracked at the local level, rather than with National Indicators. Another gap in National Indicators is for air toxics and other air pollutants that are ubiquitous in the nation's outdoor air (e.g., mobile source air toxics). Although nationwide trends in air toxics concentrations have been estimated with models, nationally representative ambient air monitoring data on air toxics would provide EPA a more direct measure of important outdoor air quality trends. Many local-scale monitoring networks have tracked trends for some of these pollutants, but nationwide indicators could not be developed for pollutants other than benzene due to limited spatial coverage of monitoring sites, use of differing sampling and analytical methods over the years, inconsistent application of quality assurance and quality control practices, and other factors.

ROE indicators for ambient concentrations of some common air toxics are expected to be developed in coming years, based on measurements currently being collected at National Air Toxics Trends Stations. This network of monitoring sites is specifically designed to characterize long-term trends in several air toxics believed to account for the greatest health risks nationwide.[9] Additionally, ongoing operation of the Mercury Deposition Network (part of the National Atmospheric Deposition Program) is gathering data to support trends analysis on atmospheric deposition of mercury—an issue of particular significance when evaluating contamination levels in fish and shellfish.

National-level exposure and effects indicators can help EPA better characterize nationwide trends in outdoor air quality and their effects, but key challenges complicate efforts to develop these. For example, ambient concentration data do not quantify exposures, because ambient air monitoring equipment

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[8] While the ROE indicators provide valuable information about trends in outdoor air quality, the indicators are more limited in their ability to describe trends in associated effects on human health and the environment. As described in Chapter 1, it is difficult to establish causal relationships between specific stressors and outcomes. In the case of outdoor air, there are few "effects" indicators with clear causal linkages.

[9] U.S. EPA. 2004. National monitoring strategy: air toxics component. Final draft. July.

measures air quality at fixed outdoor locations, while people breathe air in multiple indoor and outdoor settings during a typical day. Actual human exposure to air pollution can be measured through use of personal monitoring devices, which sample the air that people breathe as they move through different microenvironments. Some researchers have used such devices to quantify exposures to specific pollutants in some locations.[10] However, conducting such studies on a national scale over an extended time frame would be an extremely resource-intensive task. Consequently, no nationally representative studies currently support ROE indicators that characterize exposure to outdoor air pollutants. Another gap pertaining to effects attributed to outdoor air quality is that the scientific understanding of how all air pollutants, whether acting alone or in combination, can affect human health and the environment is incomplete and continues to evolve.

While the indicators document what is currently known about selected outdoor air quality issues, ongoing scientific research continues to broaden the knowledge base on many important topics, ranging from designing innovative emission control technologies to enhancing atmospheric fate and transport modeling to developing metrics that better connect air quality to public health and ecological outcomes.

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[10] Jantunen, M., O. Hanninen, K. Koistinen, and J.H. Hashim. 2002. PM measurements: personal and indoor air monitoring. Chemosphere 49:993-1007.

2.3 WHAT ARE THE TRENDS IN GREENHOUSE GAS EMISSIONS AND CONCENTRATIONS?

2.3.1 Introduction

Greenhouse gases, such as carbon dioxide, methane, nitrous oxide, and certain synthetic chemicals, trap some of the Earth's outgoing energy, thus retaining heat in the atmosphere.[11] Changes in the radiative balance of the Earth—the balance between energy received from the sun and emitted from Earth—as a result of this heat trapping alter weather patterns and climates at global and regional scales.[12] Natural factors, such as variations in the sun's output, volcanic activity, the Earth's orbit, the carbon cycle, and others also affect the radiative balance.[13] However, increasing concentrations of greenhouse gases due to human activity are likely affecting various aspects of climate, such as surface air temperature and subsurface ocean temperature; while these and other changes observed over the past few decades are likely mostly due to human activities, scientists cannot rule out the possibility that some significant part of these changes is also a reflection of natural variability.[14] Human health, agriculture, water resources, forests, wildlife, and coastal areas all are vulnerable to climate change.[15] The purpose of this section is to evaluate long-term trends in air emissions and ambient concentrations of greenhouse gases that are contributing to climate change, but not to evaluate the effects that these emissions and concentrations cause.[16]

Though the focus of this question is on greenhouse gases, related factors can also alter the Earth's climate. Certain radiatively important substances, like black carbon (soot), are technically not greenhouse gases due to their physical state, but they nonetheless affect the flow of energy through the atmosphere. Some of these substances, such as sulfate aerosols, have negative radiative forcings that can lead to cooling effects. Another related factor is albedo (the reflectivity of the Earth's surface), which affects the portions of absorbed and outgoing energy. Natural and human factors can affect albedo on a global scale through changes in large-scale features like the polar ice caps or on a local or regional scale (e.g., by increased amounts of dark paved surfaces that absorb energy). Although this question does not address radiatively important substances that are not greenhouse gases or non-chemical factors like albedo, these

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[11] National Research Council, Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, March 2005. p. 1, 9, vii, and others.

[12] Op. cit. p. 11.

[13] Op cit. p. 13.

[14] National Research Council, Climate Change Science: An Analysis of Some Key Questions, 2001. p. 1.

[15] NRC op. cit., p. 4 and p. 19-20.

[16] In a general sense, climate change is conceptually connected to every other theme in this report. The broadest discussion of potential effects associated with greenhouse gases in this report is in Section 6.5, which discusses critical physical and chemical attributes of ecosystems, including ROE indicators that track changes in air temperature, precipitation, sea-surface temperature, and sea level—all of which affect ecosystems.

influences are also important to understanding the planet's energy balance and the ways human activities may affect that balance.[17]

Some greenhouse gases are emitted exclusively from human activities (e.g., synthetic halocarbons). Others occur naturally but are found at elevated levels due to human inputs (e.g., carbon dioxide). The anthropogenic sources result from energy-related activities (e.g., combustion of fossil fuels in the electrical utility and transportation sectors), agriculture, land-use change, waste management and treatment activities, and various industrial processes. Major greenhouse gases and emission sources include:

- **Carbon dioxide (CO_2),** which occurs naturally as part of the global carbon cycle, but human activities have increased atmospheric loadings through combustion of fossil fuels and other emissions sources.[18] Natural sinks that remove CO_2 from the atmosphere (e.g., oceans, plants) help regulate CO_2 concentrations, but human activities can disturb these processes (e.g., deforestation) or enhance them.
- **Methane (CH_4),** which comes from many sources, including human activities such as coal mining, natural gas distribution, waste decomposition in landfills, and digestive processes in livestock and agriculture.[19] Natural sources include wetlands and termite mounds.
- **Nitrous oxide (N_2O),** which is emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.
- **Various synthetic chemicals,** such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and other synthetic gases, which are released as a result of commercial, industrial, or household uses.
- **Many other gases** that are known to trap heat in the atmosphere. Examples include water vapor, which occurs naturally as part of the global water cycle, and ozone, which occurs naturally in the stratosphere and is found in the troposphere largely due to human activities.

Each gas has a different ability to absorb heat in the atmosphere, due to differences in its atmospheric half-life and the amount and type of energy that it absorbs. For example, it would take thousands of molecules of CO_2 to equal the warming effect of a single molecule of sulfur hexafluoride—the most potent greenhouse gas in terms of ability to absorb heat evaluated by the Intergovernmental Panel on Climate Change (IPCC).[20] To facilitate comparisons between gases that have substantially different

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[17] Detailed information on these related factors may be found in various scientific publications, such as those prepared by the Intergovernmental Panel on Climate Change, a panel formed by the Worldwide Meteorological Organization to compile and synthesize the growing body of scientific literature on climate change.

[18] U.S. EPA. 2006. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2004. EPA/430/R-06/002. Washington, DC.

[19] National Research Council. 2001. Climate change science: an analysis of some key questions. Washington, DC: National Academy Press.

[20] Intergovernmental Panel on Climate Change. 2001. Climate change 2001: the scientific basis (third assessment report). Cambridge, UK: Cambridge University Press.

properties, IPCC has developed a set of scaling factors called "global warming potentials" (GWPs), as discussed further in the indicator write-ups.

2.3.2 ROE Indicators

To characterize trends in greenhouse gases, this chapter presents two indicators—one describing emissions from U.S. sources and the other describing concentrations (Table 2.3.1).

The U.S. Greenhouse Gas Emissions indicator covers the period 1990-2003, with data from EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks. This inventory is a database that tracks both greenhouse gas emissions directly attributable to human activities and greenhouse gas sinks (e.g., sequestration of carbon in forests). The indicator stratifies emissions into trends for different gases and source categories. Emissions are weighted by "global warming potentials" to facilitate comparison among the gases.

The Atmospheric Concentrations of Greenhouse Gases indicator summarizes both direct measurements of ambient air concentrations from the last half-century and observations for earlier time frames based on chemical analyses of air bubbles found in ice core samples. The gases in these bubbles represent the outdoor air that was trapped in ice at the time the ice was formed. Combined, these two measurements provide extensive historical coverage for the atmospheric concentrations of greenhouse gases.

Because many greenhouse gases are extremely long-lived in the atmosphere, with some remaining airborne for tens to hundreds of years after being released, these long-lived greenhouse gases become globally mixed in the atmosphere and their concentrations reflect past and recent contributions from emissions sources worldwide. This context is an important backdrop for the two greenhouse gas indicators in this section: increasing atmospheric concentrations of greenhouse gases is a global issue, resulting from emissions from sources in the U.S. combined with emissions from sources in other countries.

Table 2.3.1. ROE Indicators of Trends in Greenhouse Gas Emissions and Concentrations

NATIONAL INDICATORS	LOCATION
U.S. Greenhouse Gas Emissions	2.3.2 – p. 2-96
Atmospheric Concentrations of Greenhouse Gases	2.3.2 – p. 2-100

INDICATOR: U.S. Greenhouse Gas Emissions

The Earth's climate is determined by the balance between energy received from the sun and emitted back to space from the Earth and its atmosphere. Certain gases in the atmosphere, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), water vapor and others, trap some of the outgoing energy, retaining heat in the Earth's atmosphere. These are the so-called "greenhouse gases" (GHG). The best understood greenhouse gases emitted by human activities are CO_2, CH_4, N_2O, and certain fluorinated compounds.

Changes in GHG emissions are influenced by many long-term factors, including population and economic growth, land use, energy prices, technological changes, and inter-annual temperatures. On an annual basis, consumption of fossil fuels, which accounts for most GHG emissions in the U.S., generally fluctuates in response to changes in general economic conditions, energy prices, weather, and the availability of non-fossil alternatives (U.S. EPA, 2005).

This indicator uses data and analysis from the Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA, 2005), an assessment of the anthropogenic sources and sinks of greenhouse gas emissions for the U.S. and its Territories for the period 1990 through 2003. The inventory constitutes estimates derived from direct measurements, aggregated national statistics, and validated models in most source categories. An extensive discussion of the methods for each source type and gas and the uncertainties inherent in the calculations is available in EPA (2005) and its Annex 7.

The indicator is expressed in terms of CO_2 equivalents, meaning that emissions of different gases are weighted by their "global warming potential" (GWP). A GWP is a measure of how much a given mass of GHG is estimated to contribute to radiative forcing that contributes to global warming over a selected period of time, compared to the same mass of carbon dioxide, for which the GWP is 1.0. EPA is mandated to use the GWPs documented in the Intergovernmental Panel on Climate Change's Second Assessment Report (IPCC, 1996) and these characterize GWP for a 100 year time horizon—the effect of the gas on radiative forcing over 100 years. Annex 6 of the U.S. GHG Inventory includes extensive information on GWPs and how they relate to emissions estimates (U.S. EPA, 2005).

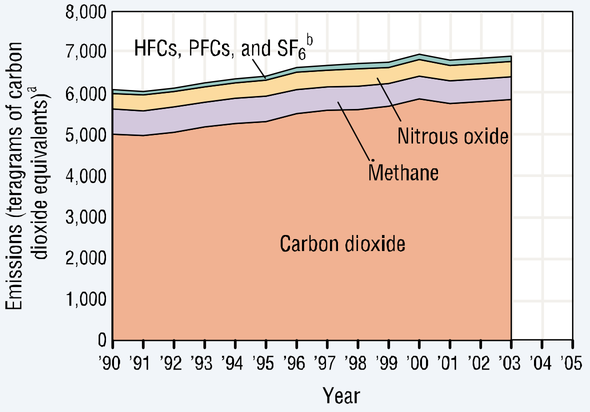
This indicator focuses on the six types of compounds currently covered by agreements under the United Nations Framework Convention on Climate Change. These compounds are CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). This indicator does not include emissions estimates for substances such as chlorofluorocarbons (CFCs), methyl bromide, sulfates, black carbon, and organic carbon. These substances are excluded primarily because either their emissions have not been quantified in the U.S. GHG Inventory or they have different types of effects on climate than those of the six GHG included in the U.S. inventory and, therefore, most cannot be compared directly to the GHG. Combined, these excluded substances may account for a considerable portion of climate change, but their omission cannot be scientifically quantified in comparable terms.

This indicator presents emissions data in units of teragrams of CO_2 equivalents (Tg CO_2 Eq). These units are conventionally used in GHG inventories prepared worldwide. For reference, one teragram (Tg) is equal to one million metric tons.

What the Data Show

In 2003, total U.S. greenhouse gas emissions were 6,900 Tg CO_2 Eq, up 13 percent from 1990 (Exhibit 2-50). CO_2 is the primary greenhouse gas emitted by human activities, representing approximately 85 percent of greenhouse gas emissions in 2003. From 1990 to 2003, total emissions of CO_2 increased by 832 Tg CO_2 Eq (17 percent). Methane (CH_4) represents the second largest U.S. GHG emission, accounting for 8 percent of net emissions in 2003. Methane emissions declined about 10 percent from 1990 to 2003, due largely to reduced emissions from landfills and coal mining operations. The primary sources of methane emissions include decomposition of wastes in landfills, coal mine seepage, natural gas systems, and enteric fermentation in domestic livestock. Nitrous oxide (N_2O) constituted about 5 percent of net U.S. GHG emissions in 2003; these emissions declined by about 1 percent from 1990 to 2003. The main anthropogenic activities producing N_2O are agricultural soil management, fuel combustion in motor vehicles, manure management, nitric acid production, human sewage, and stationary fuel combustion. Emissions of HFCs, PFCs, and SF_6 accounted for the remaining 2 percent of GHG emissions in 2003, and the aggregate weighted emissions of this group of gases rose by 46 Tg CO_2 Eq (50 percent) since 1990. Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF_6 are important because many of them have extremely high global warming potentials and, in the cases of PFCs and SF_6, atmospheric lifetimes of 700 to 50,000 years. The emissions in this indicator are a continuation of the trend of increasing GHG emissions observed over many decades, with total CO_2-equivalent emissions increasing by about one fifth since 1970 (U.S. EPA, 2005; RIVM/TNO, 2003). CO_2 has constituted a slightly growing portion, while CH_4 has been a declining component of the total.

Exhibit 2-50. Greenhouse gas emissions in the U.S. by gas, 1990-2003

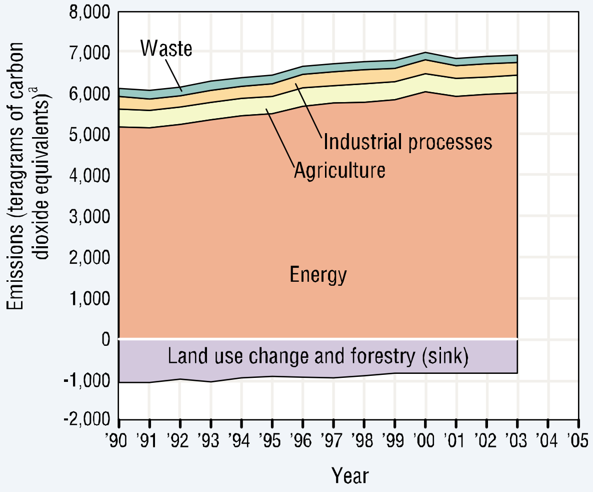


[a] Teragrams of carbon dioxide equivalents are the units conventionally used in greenhouse gas inventories prepared worldwide. For reference, one teragram equals one million metric tons.

[b] HFCs are hydrofluorocarbons, PFCs are perfluorocarbons, and SF_6 is sulfur hexafluoride.

Data source: *U.S. EPA, 2005*

Exhibit 2-51. Greenhouse gas emissions in the U.S. by industrial sector, 1990-2003



[a] Teragrams of carbon dioxide equivalents are the units conventionally used in greenhouse gas inventories prepared worldwide. For reference, one teragram equals one million metric tons.

Data source: *U.S. EPA, 2005*

Looking at GHG emissions by source shows that energy use (i.e., fuel combustion and gas leakage) has accounted for about 84 percent of net U.S. emissions since 1990 (Exhibit 2-51). Emissions due to energy use have increased 16 percent between 1990 and 2003. Agriculture is the second largest source of GHG emissions, accounting for 6 percent of the total in 2003. U.S. GHG emissions are partly offset by uptake of carbon and "sequestration" in forests, trees in urban areas, agricultural soils, and landfilled yard trimmings and food scraps. In aggregate, these removals of CO_2 from the atmosphere offset about 12 percent of U.S. emissions in 2003 (Exhibit 2-51).

With one-twentieth of the world's population (U.S. Bureau of the Census, 2006), the U.S. currently emits about one-fifth of global greenhouse gases, CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 (Baumert et al., 2005).

Indicator Limitations

- This indicator does not yet include emissions of greenhouse gases or other radiatively important substances that are not explicitly covered by the United Nations Framework Convention on Climate Change and its subsidiary protocol. Thus, it excludes such gases as those controlled by the Montreal Protocol and its Amendments, including CFCs and hydrochlorofluorocarbons (HCFCs). Although the U.S. reports the emissions of these substances as part of the U.S. GHG inventory (see Annex 6.2 of the U.S. GHG Inventory), the origin of the estimates is fundamentally different from those of the other GHG and therefore cannot be compared directly with the other emissions discussed in this indicator.
- This indicator does not include aerosols and other emissions that do affect radiative forcing and that are not well-mixed in the atmosphere, such as sulfate, ammonia, black carbon and organic carbon. Emissions of these compounds are highly uncertain and have qualitatively different effects than the six types of emissions in this indicator.
- This indicator does not include emissions of other compounds such as CO, NO_x, nonmethane volatile organic compounds (VOCs), and substances that deplete the stratospheric ozone layer, which indirectly affect the Earth's radiative balance, for example, by altering greenhouse gas concentrations, changing the reflectivity of clouds, or changing the distribution of heat fluxes.
- The U.S. GHG Inventory does not account for "natural" emissions of greenhouse gases, such as from wetlands, tundra soils, termites, and volcanoes. These excluded sources are discussed in Annex 5 of the U.S. GHG Inventory (U.S. EPA, 2005). The U.S. GHG Inventory does include, in its Land Use and Land Use Change and Forestry categories, emissions from changes in the forest inventory due to fires, harvesting, and other activities, and from agricultural soils.

Data Sources

The data used for this indicator were published in EPA's inventory of greenhouse gas emissions and sinks for years 1990-2003 (U.S. EPA, 2005). Specifically, emissions by GHG shown in Exhibit 2-50 are taken from Table ES-2 of that reference, and emissions by industrial sector are taken from Table ES-4.

References

Baumert, K., T. Herzog, and J. Pershing. 2005. Navigating the numbers: greenhouse gas data and international climate policy. Washington DC: World Resources Institute. <http://pdf.wri.org/navigating_numbers_chapter2.pdf>

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RIVM/TNO. 2003. Emission database for global atmospheric research. Version 3.2. 2003. (Olivier, J.G.J., and J.J.M. Berdowski. 2001. Global emission sources and sinks.) <http://www.mnp.nl/edgar/>

U.S. Bureau of the Census. 2006. World POPClock; USPOPClock. <http://www.census.gov/ipc/www/popclockworld.html>

U.S. EPA. 2005. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2003. <http://www.epa.gov/climatechange/emissions/usgginv_archive.html>

INDICATOR: Atmospheric Concentrations of Greenhouse Gases

The Earth's temperature depends mainly on the amount of energy received from the sun, the portion reflected back into space, and the extent to which the atmosphere retains heat. Natural forces (e.g., volcanoes, changes in the Earth's orbit) and human activities (e.g., emissions of so-called "greenhouse gases," land use change) affect the amount of energy held in the Earth-atmosphere system and therefore affect the Earth's climate. Human activities in all countries have altered the chemical composition of the atmosphere by the emissions and accumulation in the atmosphere of greenhouse gases. The primary gases that retain heat in the atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and certain manufactured gases such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and sulfur hexafluoride (SF_6).

Once emitted, gases remain in the atmosphere for varying amounts of time. Very "short-lived" compounds, such as particulate matter, may remain airborne on average for only hours or days. Methane also has a relatively short average lifetime, though much longer than PM, remaining in the atmosphere for roughly 12 years. The half-life of CO_2 emissions is roughly 100 years (5 to 200 years: IPCC, 2001), but about a quarter of emissions today will still be in the atmosphere after hundreds of years and about one-tenth for hundreds of thousands of years (Archer, 2005; Archer et al., 1998). Finally, many of the synthetic gases such as halocarbons are extremely long-lived, remaining in the atmospheric for hundreds or even tens of thousands of years. When emissions—from the U.S. (the U.S. Greenhouse Gas Emissions indicator, p. 2-96) as well as other countries—remain in the atmosphere over long periods, they accumulate and are measured as atmospheric concentrations. U.S. GHG emissions from 1890 to 2000 are estimated to have contributed about one-fifth of the increase in global GHG concentrations (den Elzen et al., 2005).

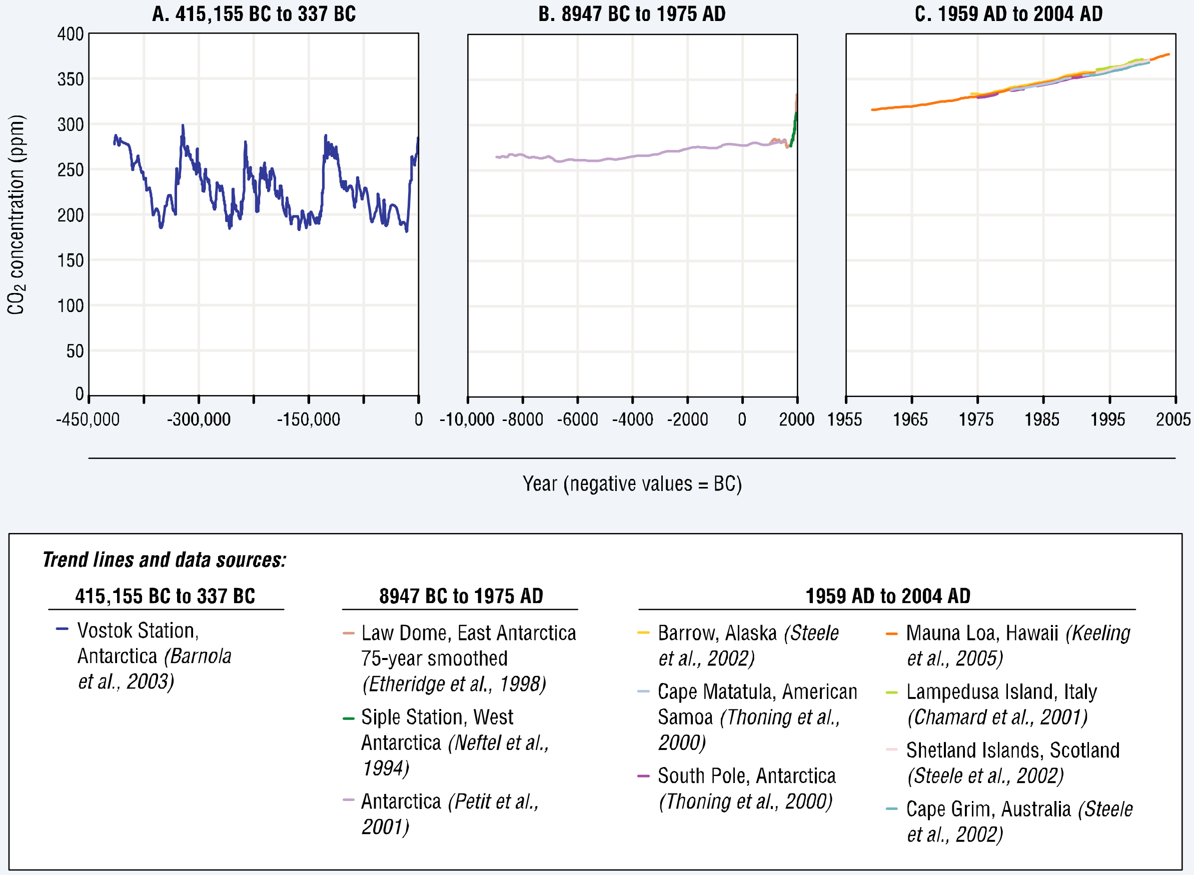
This indicator shows trends in the accumulation of the following principal greenhouse gases in the atmosphere: CO_2, CH_4, N_2O, and selected halocarbons. Recent data are from global networks that monitor the concentrations of these gases in the atmosphere. Geologic data result from gas measurements made of air trapped in ice cores at the time the ice was formed. Because the gases shown in this indicator remain in the atmosphere for long periods, they are well-mixed, so that measurements at individual locations are globally representative. This indicator summarizes greenhouse gas concentration measurements reported in a collection of studies published in the peer-reviewed literature. In order to provide the most extensive temporal coverage, this indicator aggregates comparable, high quality data from individual studies that each focused on different time frames. None of the data in this indicator is based on modeled concentrations.

What the Data Show

Exhibits 2-52 through 2-54 show the evolution of concentrations of three principal greenhouse gases in the atmosphere over three intervals: geologic time (hundreds of thousands of years), the past 11,000 years, and in recent decades. The exhibits represent data sets covering a wide range of latitudes, showing some latitudinal differences in concentrations, but also showing a high level of consistency—indicating that the gases are well-mixed and that the sampling can be considered spatially representative. The graphs show patterns of large cycles of concentrations over geologic time, but also increases in concentrations since the Industrial Revolution that exceed concentrations over the past hundreds of thousands of years.

The concentration of CO_2 has varied considerably over geological time (Exhibit 2-52). Over the past 420,000 years, CO_2 concentrations have cycled over several thousand year periods from highs around 285-300 ppm to lows around 180-185 ppm. From at least 900 A.D. to 1800 A.D., CO_2 concentrations

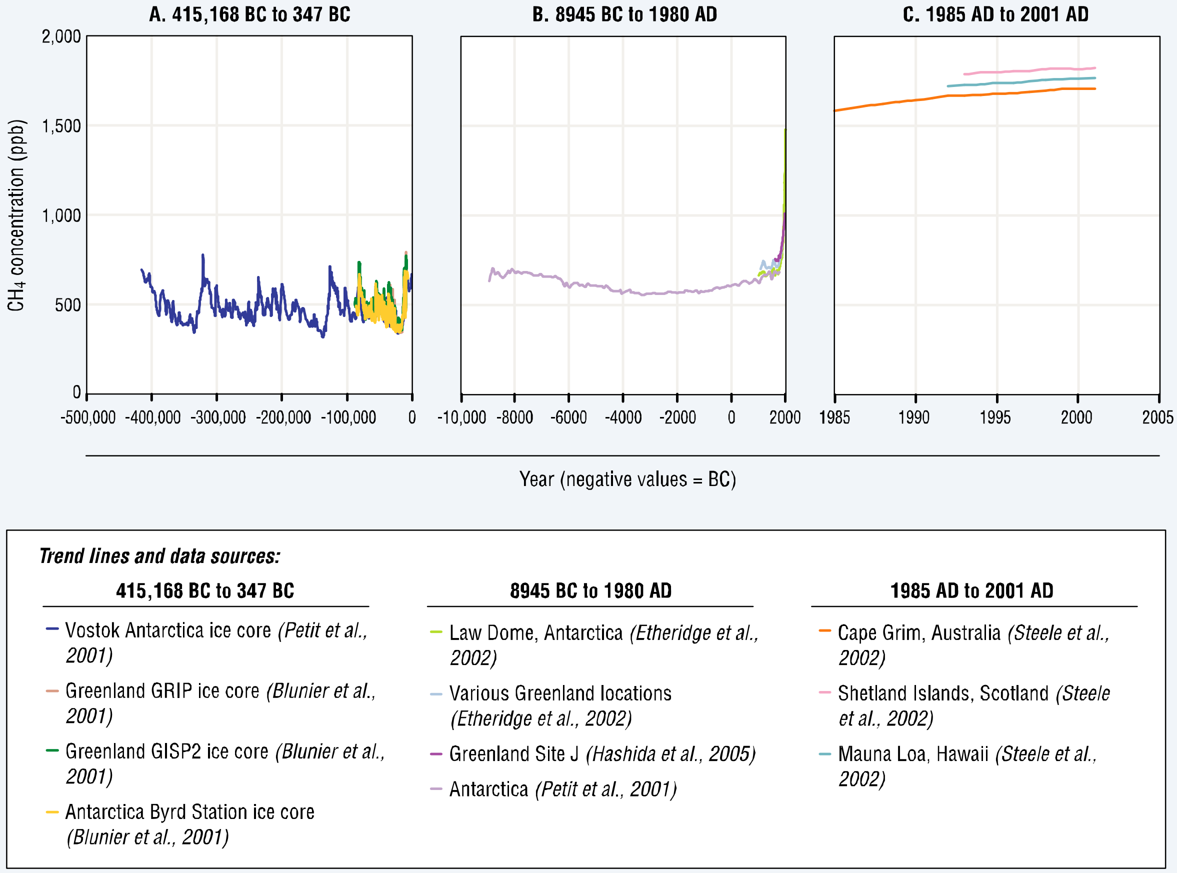
Exhibit 2-52. Global atmospheric concentrations of carbon dioxide (CO_2) over geological time and in recent years



stayed relatively constant at about 270-290 ppm (panel B). Over the past 150 years, CO_2 concentrations have increased by 31 percent; from 1958 to 2002, they have increased by about 18 percent (plus or minus 1 percent) to 374 ppm (panels B and C).

Methane (CH_4) concentrations also cycled widely over the past 420,000 years but peaks remained below 800 ppb until after 1800 A.D. (Exhibit 2-53). Essentially no increase occurred from 1000 A.D. to 1730 A.D. (panel B). It then took approximately 175 years (c. 1905) to add 200 ppb to atmospheric CH_4 concentrations, 40 years (c. 1945) to add the next 200 ppb, 20 years to add the next 200 ppb (c. 1965), and 10 years (c. 1975) to add the next 200 ppb (panels B and C). The rates of methane increase began to slow by the late 1970s, with less than 200 ppb added to atmospheric concentrations between 1978 and the present (panel C). Overall, global methane concentrations more than doubled in the past 150 years. The most recent data show that there is a significant difference in methane concentrations across latitudes, with a pattern of peak concentrations in the most northern latitudes decreasing toward the southern latitudes, which suggests net sources of methane in northern latitudes. Yet, despite the latitudinal differences in concentrations, the pattern over the past two centuries shows a common trend in all locations.

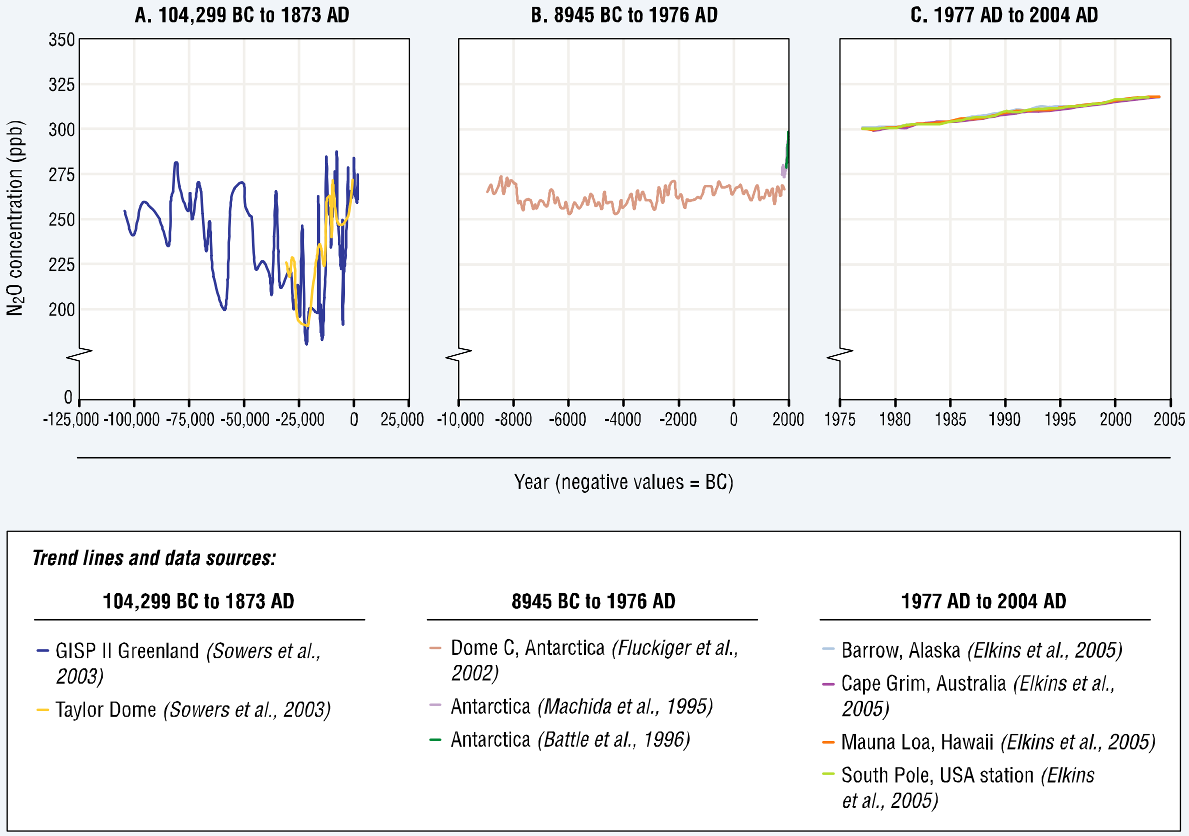
Exhibit 2-53. Global atmospheric concentrations of methane (CH_4) over geological time and in recent years



Nitrous oxide (N_2O) concentrations (Exhibit 2-54) vacillated widely through geologic time, with ice sample measurements ranging from as low as 180 ppb to above 280 ppb. Despite considerable inter-decadal variability, N_2O stayed mostly below 280 ppb from 1756 A.D. until the 1920s (panel B), from which point levels began to rise rapidly to approximately 318 ppb in 2004 (panels B and C), the highest level ever recorded.

Concentrations of the halocarbons (or gases that contain the halogens chlorine, fluorine, bromine, or iodine) were essentially zero a few decades ago, but have increased rapidly as they were incorporated into industrial products and processes (Exhibit 2-55). Concentrations of hydrochlorofluorocarbons HCFC-141b and HCFC-142b increased sharply through 2005 (panel A), but are expected to gradually stabilize over this decade as they are phased out in industrialized countries as part of the Montreal Protocol on Substances the Deplete the Ozone Layer. The concentration of HFC-23, which is a by-product of HCFC-22 production, has increased more than five-fold between 1978 and 2005 (panel B). HFCs that are not controlled by the Protocol (because they do not contribute to stratospheric ozone losses) mostly continue to increase because of their widespread use as substitutes for the Montreal Protocol gases.

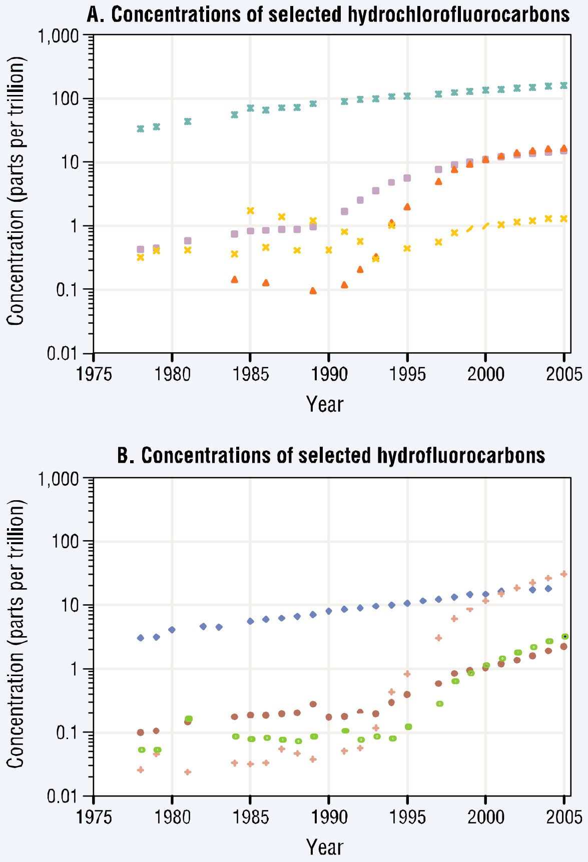
Exhibit 2-54. Global atmospheric concentrations of nitrous oxide (N_2O) over geological time and in recent years



Indicator Limitations

- Water vapor is not tracked in this indicator as it is generally accepted that human activities have not increased the concentration of water vapor in the atmosphere.
- Some radiatively important atmospheric constituents that are substantially affected by human activities such as tropospheric ozone, black carbon, aerosols, and sulfates are not included in this indicator because of their spatial and temporal variability and the inadequacy of available data to characterize long-term averages or trends.
- Concentration data are not available for all the halogenated compounds that are potentially important greenhouse gases. For instance, global concentration data are not sufficient yet to track trends in concentrations of SF_6 and PFCs.
- Ice core measurements are not taken in real time, which introduces some error into the date of the sample. Dating accuracy for the ice cores ranged up to ±20 years (often less), depending on the method used and the time period of the sample. Diffusion of gases from the samples, which would tend to reduce the measured values, may also add a small amount of uncertainty. More information on the accuracy of measurements of ice samples and other measurement methods can be found at: http://cdiac.esd.ornl.gov/by_new/bysubjec.html#atmospheric.

Exhibit 2-55. Global atmospheric concentrations of selected halocarbons, 1978-2005[a]


A. Concentrations of selected hydrochlorofluorocarbons

B. Concentrations of selected hydrofluorocarbons

[a]Trends are presented for hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) with sufficient data to support long-term trend analysis.

Data source: *IPCC, 2001, and Australia Commonwealth Scientific and Industrial Research Organisation (CSIRO), Marine and Atmospheric Research, 2006*

Data Sources

The data in this indicator come from multiple sources. Summary global atmospheric concentration data for CO_2 (Exhibit 2-52), CH_4 (Exhibit 2-53), and N_2O (Exhibit 2-54) were provided by EPA's Office of Atmospheric Programs, based on greenhouse gas concentration measurements reported in a collection of studies published in the peer-reviewed literature. Citations for these studies and links to the corresponding underlying data can be found online at: http://www.epa.gov/climatechange/science/recentac_majorghg.html.

Summary global atmospheric concentration data for selected halocarbons (Exhibit 2-55) were provided by the Australia Commonwealth Scientific and Industrial Research Organisation (CSIRO). The 1975-2001 data in this exhibit are taken from IPCC's third assessment report on climate change (IPCC, 2001). The 2002-2005 data in this exhibit were not publicly available at the time this report went to press, but they will be published in IPCC's upcoming fourth assessment report on climate change.

References

Exhibits 2-52, 2-53, and 2-54 refer to 16 data sources. Complete citations for these references and links to the corresponding underlying data can be found online at: http://www.epa.gov/climatechange/science/recentac_majorghg.html.

Archer, D., and A. Ganopolski. 2005. A movable trigger: fossil fuel CO_2 and the onset of the next glaciation. Geochem Geophys Geosys 6(Q05003) <http://geosci.uchicago.edu/~archer/reprints/archer.ms.next_ice_age.pdf>

Archer, D., H. Kheshgi, and E. Maier-Reimer. 1998. Dynamics of fossil fuel neutralization by Marine $CaCO_3$. Global Biogeochem Cycles 12:259-276. <http://geosci.uchicago.edu/~archer/reprints/gbc98/neutral_gbc.pdf>

den Elzen, M., J. Fuglestvedt, N. Höhne, C. Trudinger, J. Lowe, B. Matthewso, B. Romstadv, C. Pires de Campos, and N. Andronova. 2005. Analysing countries' contribution to climate change: scientific and policy-related choices. Env Sci percent Policy June 05.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate change 2001: the scientific basis (third assessment report). Cambridge, UK: Cambridge University Press.

2.3.3 Discussion

What These Indicators Say About Trends in Greenhouse Gas Emissions and Concentrations

The nation's estimated combined emissions of several greenhouse gases that are directly attributable to human activity have increased 13 percent between 1990 and 2003 (the U.S. Greenhouse Gas Emissions indicator, p. 2-96). Emissions sources occur from several sectors of the U.S. economy, with the highest contribution—and the greatest recent growth—attributed to energy use, which primarily includes electricity generation and transportation sources. This indicator also compares contributions of different greenhouse gases by normalizing for each gas's ability to affect the Earth's energy balance. The results show that CO_2 makes up the bulk of the nation's anthropogenic greenhouse gas emissions. Both observations demonstrate that fossil fuel combustion is clearly the country's major source of anthropogenic greenhouse gas emissions.

Data on atmospheric concentrations of greenhouse gases have extraordinary temporal coverage (the Greenhouse Gas Concentrations indicator, p. 2-100). For CO_2, methane, and N_2O, concentration data span several hundred thousand years; and for selected halocarbons, concentration data span virtually the entire time frame that these synthetic gases were widely used. Thus, these concentration data provide an excellent basis for answering the question regarding trends in greenhouse gas concentrations. The historical data for CO_2, methane, and N_2O show considerable temporal variability in these gases' concentrations; however, concentrations observed in the past 50 years are higher than those over the entire period of record evaluated—even when considering natural fluctuations. In short, the historical context provided by ice cores shows that present concentrations of these three greenhouse gases are unprecedented over the last 420,000 years, and strongly suggest that the recently increasing levels mostly reflect the influence of human activity. For the various halocarbons considered, concentrations have increased between 1980 and 2000, with some increases spanning more than two orders of magnitude, but the rate at which these concentrations is increasing has slowed in recent years.

Taken together, the well-documented long-term trends in concentrations of greenhouse gases, along with corresponding increases in emissions from anthropogenic sources, show that human activity is causing increased concentrations of greenhouse gases in the Earth's atmosphere—a finding echoed in many prominent reviews on the science of climate change.[21, 22]

Limitations, Gaps, and Challenges

Although they provide extensive insights into greenhouse gas emissions and concentrations, the two greenhouse gas indicators have limitations and gaps that should be acknowledged. The emissions trends, for instance, are based largely on estimates, which have uncertainties inherent in the engineering calculations and estimation methodologies developed for the U.S. greenhouse gas emissions inventory. Uncertainty of the magnitude of the emissions vary among the gases and sources, though estimated emissions from some of the largest sources (e.g., CO_2 emissions from fossil fuel combustion) are

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[21] National Research Council. 2001. Climate change science: an analysis of some key questions. Washington, DC: National Academy Press.

[22] Intergovernmental Panel on Climate Change. 2001. Climate change 2001: the scientific basis (third assessment report). Cambridge, United Kingdom: Cambridge University Press.

considered highly accurate.[23] One gap in the emissions indicator is that EPA's GHG inventory does not track every greenhouse gas or every emissions source. Examples of greenhouse gases not included in the inventory are ozone and selected chlorofluorcarbons. The most notable sources not tracked in the inventory are natural sources, such as CH_4 from wetlands, CO_2 and CH_4 from thawing permafrost, and multiple emissions from volcanoes. Although worldwide emissions of greenhouse gases from natural sources actually far outweigh inputs attributed to human origin,[24] the incremental increases of anthropogenic emissions are environmentally noteworthy because they upset the balance of natural sources and sinks of greenhouse gases. Though not necessarily a limitation or a gap, it is important to note that EPA's Greenhouse Gas Inventory, by design, tracks only this nation's anthropogenic emissions of greenhouse gases. For perspective on how the nation's emissions compare to those from other countries, recent data estimate that the U.S. emits approximately 20 percent of the total worldwide amounts of selected greenhouse gases.[25] Having national emissions indicators on a more complete set of greenhouse gases and emissions sources would further improve EPA's ability to track pressures that affect climate change.

The Greenhouse Gas Concentrations indicator (p. 2-100) tracks trends in measured airborne levels of greenhouse gases regardless of the anthropogenic or natural sources that released them, which helps account for some of the inherent limitations and uncertainties in the emissions indicator. However, the concentration data have limitations and gaps of their own. Historical concentrations from ice core samples are not measured in real time, which introduces some minor uncertainty into the data set; consistency among measurements made by multiple laboratories at different locations suggests this uncertainty is relatively low.[26] A gap in the concentration data, as with the emissions data, is that not all greenhouse gases have been monitored. Long-term trend data for ozone, for instance, are currently not available. Measuring globally representative trends in tropospheric ozone concentrations presents technical challenges, because ozone is a short-lived gas (which does not lend well to ice core measurements) with concentrations that exhibit tremendous spatial variations (which would require extensive monitoring to characterize worldwide trends). Another gap is the lack of ROE indicators for radiatively important substances, such as soot and aerosols. Though these substances technically are not greenhouse gases, tracking trends in these substances' concentrations is important due to their ability to alter the Earth's energy balance.

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[23] U.S. EPA. 2003. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2003. EPA/430/R-05/003. Washington, DC.

[24] U.S. EPA. 2000. Global warming and our changing climate: answers to frequently asked questions. EPA/430/F-00/011. Washington, DC.

[25] den Elzen, M., J. Fuglestvedt, N. Höhne, C. Trudinger, J. Lowe, B. Matthews, B. Romstad, C. Pires de Campos, and N. Andronova. 2005. Analysing countries' contribution to climate change: scientific and policy-related choices. Env. Sci. Policy 8(6):614-636.

[26] Barnola, J., D. Raynaud, C. Lorius, and N.I. Barkov. 2003. Historical CO_2 record from the Vostok ice core. In: Trends: a compendium of data on global change. Oak Ridge, TN: U.S. Department of Energy.

2.4 WHAT ARE THE TRENDS IN INDOOR AIR QUALITY AND THEIR EFFECTS ON HUMAN HEALTH?

2.4.1 Introduction

Indoor air quality refers to the quality of the air in a home, school, office, or other building environment. Most pollutants affecting indoor air quality come from sources inside buildings, although some originate outdoors. Typical pollutants of concern include combustion products such as carbon monoxide, particulate matter, and environmental tobacco smoke; substances of natural origin such as radon; biological agents such as molds; pesticides; lead; asbestos; ozone (from some air cleaners); and various volatile organic compounds (VOCs) from a variety of products and materials. Indoor concentrations of some pollutants have increased in recent decades due to such factors as energy-efficient building construction and increased use of synthetic building materials, furnishings, personal care products, pesticides, and household cleaners.

The potential impact of indoor air quality on human health nationally is considerable, for several reasons. Americans, on average, spend approximately 90 percent of their time indoors,[27] where the concentrations of some pollutants are often 2 to 5 times higher than typical outdoor concentrations.[28] Moreover, people who are often most susceptible to the adverse effects of pollution (e.g., the very young, older adults, and people with cardiovascular or respiratory disease) tend to spend even more time indoors.[29] Health effects that have been associated with indoor air pollutants include irritation of the eyes, nose, and throat; headaches, dizziness, and fatigue; respiratory diseases; heart disease; and cancer.

Indoor air pollutants originate from many sources. These sources can be classified into two general categories:

- **Indoor sources (sources within buildings themselves).** Combustion sources in indoor settings, including tobacco, heating and cooking appliances, and fireplaces, can release harmful combustion by-products such as carbon monoxide and particulate matter directly into the indoor environment. Cleaning supplies, paints, insecticides, and other commonly used products introduce many different chemicals, including volatile organic compounds, directly into the indoor air. Building materials are also potential sources, whether through degrading materials (e.g., asbestos fibers released from building insulation) or from new materials (e.g., chemical off-gassing from pressed wood products). Other substances in indoor air are of natural origin, such as mold and pet dander.

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[27] U.S. EPA. 1989. Report to Congress on indoor air quality: volume 2. EPA/400/1-89/001C. Washington, DC.

[28] U.S. EPA. 1987. The total exposure assessment methodology (TEAM) study: summary and analysis. EPA/600/6-87/002a. Washington, DC.

[29] U.S. EPA. 1997. Exposure factors handbook: volume 3—activity factors. EPA/600/P-95/002Fa. Washington, DC.

- **Outdoor sources.** Outdoor air pollutants can enter buildings through open doors, open windows, ventilation systems, and cracks in structures. Some pollutants come indoors through building foundations. For instance, radon forms in the ground as naturally occurring uranium in rocks and soils decays. The radon can then enter buildings through cracks or gaps in structures. In areas with contaminated ground water or soils, volatile chemicals can enter buildings through this same process. Finally, when people enter buildings, they can inadvertently bring in soils and dusts on their shoes and clothing from the outdoors, along with pollutants that adhere to those particles.

In addition to pollutant sources, the air exchange rate with the outdoors is an important factor in determining indoor air pollutant concentrations. The air exchange rate is affected by the design, construction, and operating parameters of buildings and is ultimately a function of infiltration (air that flows into structures through openings, joints, and cracks in walls, floors, and ceilings and around windows and doors), natural ventilation (air that flows through opened windows and doors), and mechanical ventilation (air that is forced indoors or vented outdoors by ventilation devices, such as fans or air handling systems). Outdoor climate and weather conditions combined with occupant behavior can also affect indoor air quality. Weather conditions influence whether building occupants keep windows open or closed, or whether occupants operate air conditioners, humidifiers, or heaters, all of which can impact indoor air quality. Weather also has a large effect on infiltration. Certain climatic conditions can increase the potential for indoor moisture and mold growth if not controlled by adequate ventilation or air conditioning.

The link between some common indoor air pollutants and health effects is very well established. Radon is a known human carcinogen and is the second leading cause of lung cancer.[30,31] Carbon monoxide is toxic and short-term exposure to elevated carbon monoxide levels in indoor settings can be lethal.[32] Episodes of "Legionnaires' Disease," a form of pneumonia caused by exposure to the *Legionella* bacterium, have been associated with buildings with poorly maintained air conditioning or heating systems.[33,34] In addition, numerous indoor air pollutants—dust mites, mold, pet dander, environmental tobacco smoke, cockroach allergens, and others—are "asthma triggers," meaning that some asthmatics might experience asthma attacks following exposure.[35]

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[30] U.S. EPA. 2003. EPA assessment of risks from radon in homes. EPA/402/R-03/003. Washington, DC.

[31] National Research Council. 1999. Health effects of exposure to indoor radon: biological effects of ionizing radiation (BEIR), report VI. Washington, DC: National Academy Press. <http://www.epa.gov/iaq/radon/beirvi.html>

[32] Raub, J.A., M. Mathieu-Nolf, N.B. Hampson, S.R. Thom. 2000. Carbon monoxide poisoning—a public health perspective. Toxicology 145:1-14.

[33] Allan, T., et al. 2001. Outbreak of legionnaires' disease among automotive plant workers—Ohio, 2001. MMWR 50(18):357-359.

[34] Fields, B.S., R.F. Benson, and R.E. Besser. 2002. *Legionella* and legionnaires' disease: 25 years of investigation. Clin. Microbiol. Rev. 15(3):506-526.

[35] U.S. Institute of Medicine. 2000. Clearing the air: asthma and indoor air exposures. Washington, DC: National Academy Press.

While these and other adverse health effects have been attributed to specific pollutants, the scientific understanding of some indoor air quality issues continues to evolve. One example is “sick building syndrome,” which occurs when building occupants experience similar symptoms after entering a particular building, with symptoms diminishing or disappearing after leaving the building, and these symptoms are increasingly being attributed to a variety of building indoor air attributes.

Researchers also have been investigating the relationship between indoor air quality and important issues not necessarily related to health, such as student performance in the classroom and productivity in occupational settings.[36] Another evolving area is research in “green building” design, construction, operation, and maintenance that achieves energy efficiency and enhances indoor air quality.

2.4.2 ROE Indicators

Two National Indicators that fully meet the indicator criteria are discussed in this section. These indicators address two specific issues and do not cover the wide range of issues associated with indoor air quality. The two indicators focus on radon and environmental tobacco smoke. The indicator on radon levels in homes is based on EPA’s 1992 National Residential Radon Survey, 2000 U.S. Census data, and production and sales statistics for radon mitigation systems. Environmental tobacco smoke is addressed using biomarker data for cotinine, a metabolite linked exclusively to chemicals found in tobacco smoke. The Centers for Disease Control and Prevention (CDC) have reported these biomarker data in multiple releases of its National Health and Nutrition Examination Survey.

Table 2.4.1. ROE Indicators of Trends in Indoor Air Quality and Their Effects on Human Health

NATIONAL INDICATORS	LOCATION
U.S. Homes Above EPA’s Radon Action Level	2.4.2 – p. 2-111
Blood Cotinine Level	2.4.2 – p. 2-114

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[36] U.S. EPA. 2003. Indoor air quality and student performance. EPA/402/K-03/006. Washington, DC.

INDICATOR: U.S. Homes Above EPA's Radon Action Level

Radon is a radioactive gas. It comes from the decay of uranium that is naturally occurring and commonly present in rock and soils. It typically moves up through the ground to the air above and into a home through pathways in ground contact floors and walls. Picocuries per liter of air (pCi/L) is the unit of measure for radon in air (the metric equivalent is becquerels per cubic meter of air, or Bq/m^3).

Each year radon is associated with an estimated 21,100 lung cancer deaths in the U.S. with smokers at an increased risk; radon is the second leading cause of lung cancer after smoking, and 14.4 percent of lung cancer deaths in the U.S. are believed to be radon-related (U.S. EPA, 2003). To reduce the risk of lung cancer, EPA has set a recommended "action level" of 4 pCi/L for homes. At that level, it is cost-effective for occupants to reduce their exposure by implementing preventive measures in their homes.

This indicator presents: (1) the number of U.S. homes estimated to be at or above the EPA recommended radon action level of 4 pCi/L; and (2) the number of homes with an operating radon mitigation system. The gap between the homes in (1) and in (2) is the number of homes that have not yet been mitigated (generally, homes are only mitigated if the EPA recommended radon action level of 4 pCi/L or more is measured). The data for this indicator were extracted from the National Residential Radon Survey (U.S. EPA, 1992a) which estimated radon levels in the U.S. housing stock. The number of homes at or above 4 pCi/L was estimated by applying: (1) the results of the National Residential Radon Survey (U.S. EPA, 1992a) to (2) 2000 U.S. Census data on the number of U.S. households. The 1992 National Residential Radon Survey was based on the housing stock that would be covered by EPA's radon testing policy (i.e., homes that should test). This included only homes intended for regular (year-round) use but covers single-family homes, mobile homes, multi-unit and group quarters (U.S. EPA, 1992b). The 1992 residential survey estimated that about one in fifteen homes in EPA's "should test" category would have a radon level of 4 pCi/L or more. The measure of the number of homes with an operating mitigation system (HOMS) was developed from radon vent fan (RVF) sales data provided voluntarily by fan manufacturers.

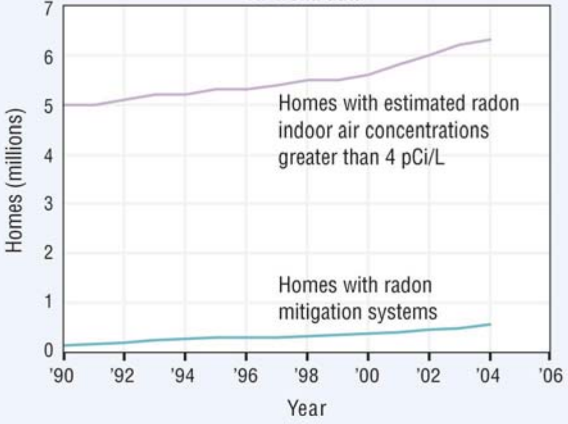
What the Data Show

There was a 272 percent increase in the number of homes with an operating mitigation system from 1990 to 2004, going from 155,000 to 577,000 homes over 15 years; but during the same period, there has been a 26 percent increase in the estimated number of homes with radon levels greater than 4 pCi/L, from about 5 million to 6.3 million (Exhibit 2-56, panel A). Panel B of Exhibit 2-56 shows radon potential in homes at the county level based on indoor radon measurements, geology, aerial radioactivity, soil permeability, and foundation type. Zone 1 is the highest radon potential area, followed by Zone 2 (medium), and Zone 3 (low).

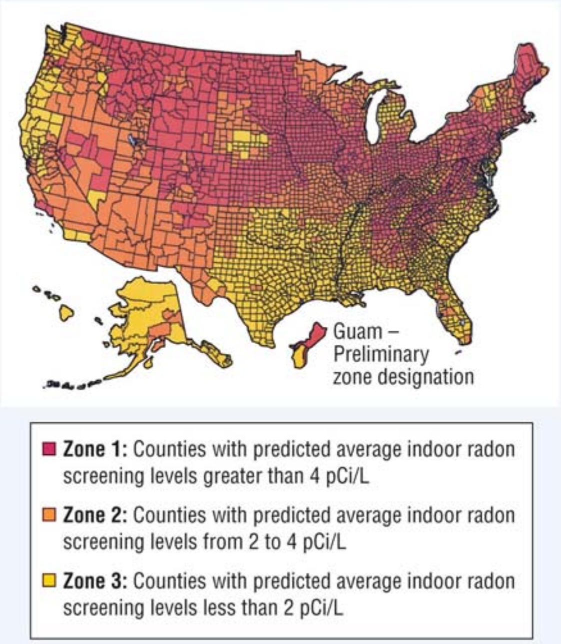
It has been reported anecdotally that radon vent fans and mitigation systems are also being used to control for soil gases/intrusion in homes in the vicinity of RCRA, Superfund, UST/AST and similar sites as an element of corrective action plans. While fans used in this way may provide a radon reduction benefit, they could be considered a subtraction from the number of homes with an operating mitigation system, thus reducing slightly the slope of the trend line.

Exhibit 2-56. Homes above EPA's radon action level and homes with operating mitigation systems in the U.S., 1990-2004

A. Trend data



B. EPA map of radon zones



Data source: *Number of homes above 4 pCi/L provided by U.S. EPA, 1992b, updated with 2000 U.S. Census data. Mitigation system data provided by U.S. EPA, unpublished industry data on mitigation system sales, 2005. Radon map provided by U.S. EPA, 1999.*

Indicator Limitations

- The indicator presumes that radon vent fans are used for their intended purpose; the available information supports this premise.
- Homes with an operating mitigation system are presumed to have a vent fan with an average useful life of 10 years. Each year the total of HOMS is adjusted to reflect new additions and subtractions (i.e., fans added 11 years earlier).
- The number of homes with radon levels at or greater than 4 pCi/L is an estimate based on one year of measurement data extrapolated for subsequent years based on population data, rather than on continuing measurements.
- This indicator does not track the number of homes designed and built with radon-resistant new construction features, which can prevent radon from entering homes. Thus, more people are likely being protected from elevated indoor air exposures to radon than suggested by the trends in radon mitigation systems alone.

Data Sources

Summary data in this indicator were provided by EPA's Office of Radiation and Indoor Air, based on two types of information. The number of homes with estimated radon indoor air concentrations above EPA's radon action level was derived from the National Residential Radon Survey (EPA, 1992a) and U.S. Census data; and the number of homes with radon mitigation systems was developed from unpublished sales data provided by radon vent fan manufacturers.

References

U.S. EPA. 2003. EPA assessment of risks from radon in homes. EPA/402/R-03/003. Washington, DC. <http://www.epa.gov/radiation/docs/assessment/402-r-03-003.pdf>

U.S. EPA. 1992a. National residential radon survey: summary report. EPA/402/R-92/011. Washington, DC. October.

U.S. EPA. 1992b. Technical support document. EPA/400/R-92/011.

INDICATOR: Blood Cotinine Level

Environmental tobacco smoke (ETS) contains a mixture of toxic chemicals, including known human carcinogens. Persistent exposure to ETS is associated with numerous health related disorders or symptoms, such as coughing, chest discomfort, reduced lung function, acute and chronic coronary heart disease, and lung cancer (IARC, 2004; NTP, 2002; U.S. EPA, 1992; CDC, 2005). Children are at particular risk from exposure to ETS, which may exacerbate existing asthma among susceptible children and also greatly increase the risk for lower respiratory tract illness, such as bronchitis and pneumonia, among younger children (CDC, 2005). Younger children appear to be more susceptible to the effects of ETS than are older children (U.S. EPA, 1992).

Household ETS exposure is an important issue because many people, especially young children, spend much time inside their homes. Based on data reported from the 1994 National Health Interview Survey, the Department of Health and Human Services (DHHS) estimates that 27 percent of children aged 6 years and younger are exposed to ETS in the home (U.S. DHHS, 2000).

Exposure to ETS leaves traces of specific chemicals in people’s blood, urine, saliva, and hair. Cotinine is a chemical that forms inside the body following exposure to nicotine, an ingredient in all tobacco products and a component of ETS. Following nicotine exposures, cotinine can usually be detected in blood for at least 1 or 2 days (Pirkle et al., 1996). Active smokers almost always have blood cotinine levels higher than 10 nanograms per milliliter (ng/mL), while non-smokers exposed to low levels of ETS typically have blood concentrations less than 1 ng/mL (CDC, 2005). Following heavy exposure to ETS, non-smokers can have blood cotinine levels between 1 and 10 ng/mL.

This indicator reflects blood cotinine concentrations in ng/mL among non-smokers for the U.S. population, aged 3 years and older, as measured in the 1999-2000 and 2001-2002 National Health and Nutrition Examination Survey (NHANES). NHANES is a series of surveys conducted by CDC’s National Center for Health Statistics (NCHS) that is designed to collect data on the health and nutritional status of the civilian, non-institutionalized U.S. population using a complex, stratified, multistage, probability-cluster design. Blood cotinine also was monitored in non-smokers aged 4 years and older as part of NHANES III, between 1988 and 1991. CDC’s National Center for Environmental Health (NCEH) conducted the laboratory analyses for the biomonitoring samples. Beginning in 1999, NHANES became a continuous and annual national survey.

What the Data Show

As part of NHANES III (1988-1991), CDC estimated that the median blood serum level (50th percentile) of cotinine among non-smokers in the general U.S. population was 0.20 ng/mL. In NHANES 1999-2000, the estimated median serum level among non-smokers nationwide was 0.06 ng/mL. During the 2001-2002 survey, the estimated blood cotinine levels for the U.S. population were very similar to 1999-2000, with the median concentration actually below the limit of detection, and the geometric mean 0.06 ng/mL (see Exhibit 2-57). This marks a 70 percent decrease from levels measured in the 1988-1991 NHANES III survey—a reduction that suggests a marked decrease in exposure to ETS.

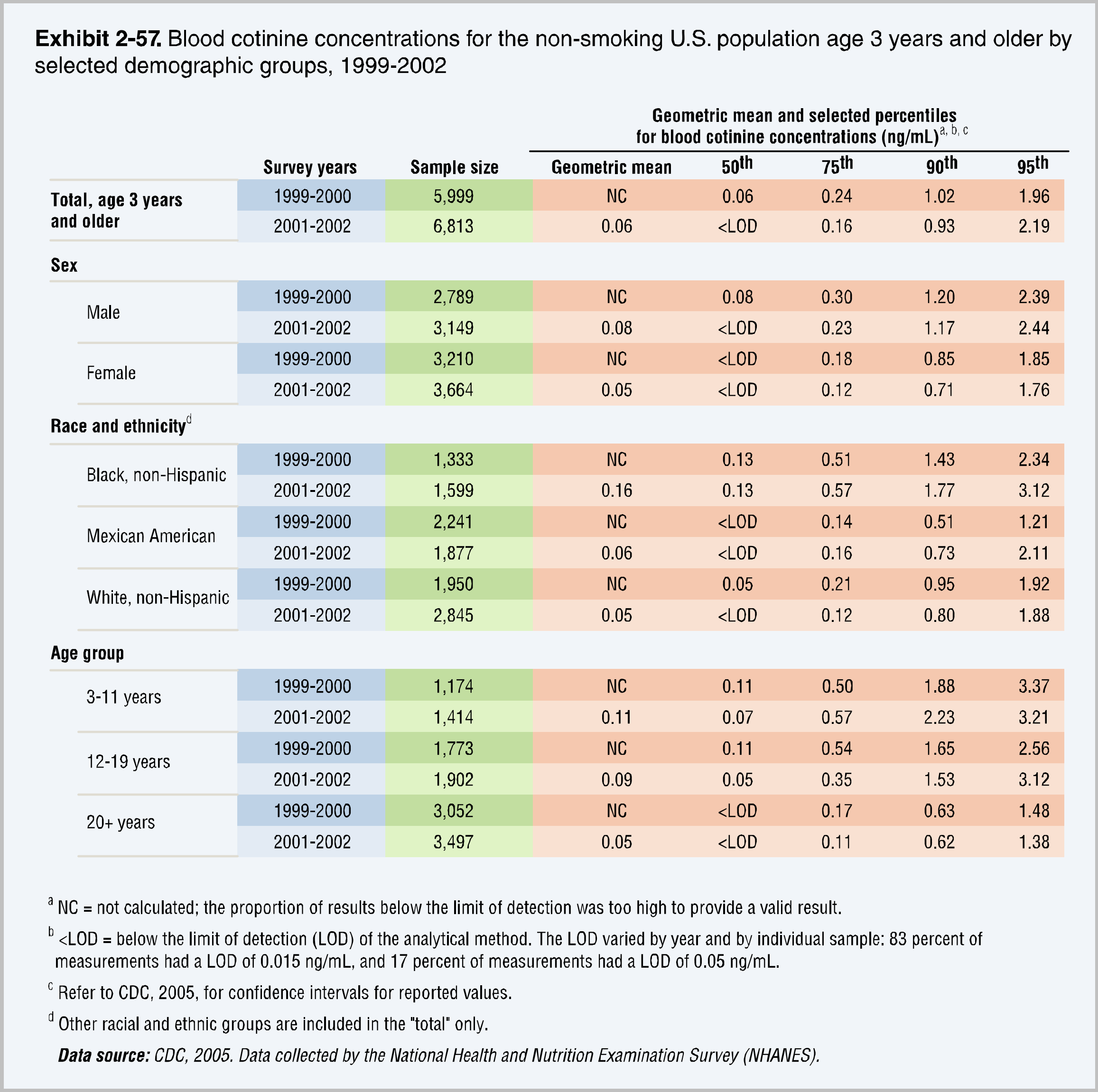


Exhibit 2-57. Blood cotinine concentrations for the non-smoking U.S. population age 3 years and older by selected demographic groups, 1999-2002

	Survey years	Sample size	Geometric mean and selected percentiles for blood cotinine concentrations (ng/mL)[a, b, c]				
			Geometric mean	50th	75th	90th	95th
Total, age 3 years and older	1999-2000	5,999	NC	0.06	0.24	1.02	1.96
	2001-2002	6,813	0.06	<LOD	0.16	0.93	2.19
Sex							
Male	1999-2000	2,789	NC	0.08	0.30	1.20	2.39
	2001-2002	3,149	0.08	<LOD	0.23	1.17	2.44
Female	1999-2000	3,210	NC	<LOD	0.18	0.85	1.85
	2001-2002	3,664	0.05	<LOD	0.12	0.71	1.76
Race and ethnicity[d]							
Black, non-Hispanic	1999-2000	1,333	NC	0.13	0.51	1.43	2.34
	2001-2002	1,599	0.16	0.13	0.57	1.77	3.12
Mexican American	1999-2000	2,241	NC	<LOD	0.14	0.51	1.21
	2001-2002	1,877	0.06	<LOD	0.16	0.73	2.11
White, non-Hispanic	1999-2000	1,950	NC	0.05	0.21	0.95	1.92
	2001-2002	2,845	0.05	<LOD	0.12	0.80	1.88
Age group							
3-11 years	1999-2000	1,174	NC	0.11	0.50	1.88	3.37
	2001-2002	1,414	0.11	0.07	0.57	2.23	3.21
12-19 years	1999-2000	1,773	NC	0.11	0.54	1.65	2.56
	2001-2002	1,902	0.09	0.05	0.35	1.53	3.12
20+ years	1999-2000	3,052	NC	<LOD	0.17	0.63	1.48
	2001-2002	3,497	0.05	<LOD	0.11	0.62	1.38

[a] NC = not calculated; the proportion of results below the limit of detection was too high to provide a valid result.

[b] <LOD = below the limit of detection (LOD) of the analytical method. The LOD varied by year and by individual sample: 83 percent of measurements had a LOD of 0.015 ng/mL, and 17 percent of measurements had a LOD of 0.05 ng/mL.

[c] Refer to CDC, 2005, for confidence intervals for reported values.

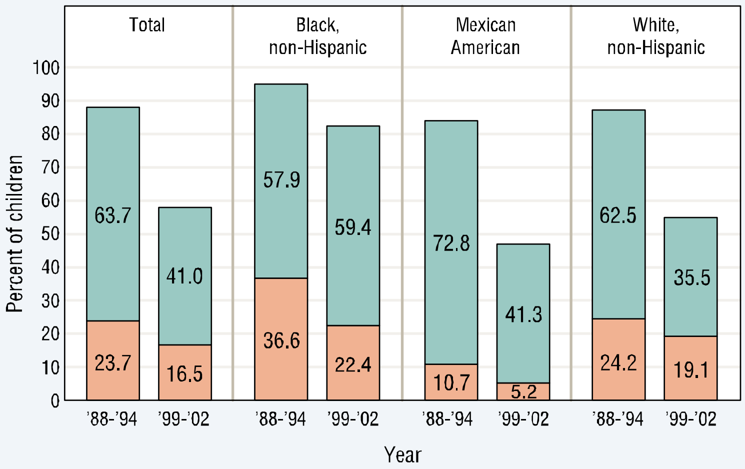
[d] Other racial and ethnic groups are included in the "total" only.

Data source: *CDC, 2005. Data collected by the National Health and Nutrition Examination Survey (NHANES).*

Exhibit 2-57 also shows the results of the NHANES 1999-2000 and 2001-2002 survey, for different subpopulations. Similar decreasing trends in blood cotinine levels between NHANES III (1988-1991) and the most recent 2001-2002 survey were observed in each of the population groups defined by age, sex, and race/ethnicity (CDC, 2005). These data reveal three additional observations: (1) non-smoking males have higher cotinine levels than non-smoking females; (2) of the ethnic groups presented, non-Hispanic blacks had the highest cotinine levels; and (3) on average, people below age 20 have higher levels of blood cotinine than people aged 20 years and older.

Exhibit 2-58 shows the percentage of children between the ages of 4 and 17 with specified blood cotinine levels, for the total age group and by selected race and ethnicity breakdowns within the specified age group. Among the three subgroup populations presented, Mexican American children had the lowest percentage of blood cotinine levels greater than 1.0 ng/mL and this was evident for both 1988-1994 and 1999-2002 time periods (10.7 percent and 5.2 percent, respectively). Black, non-Hispanic children had the largest decline of the three subgroups in the percentage of blood cotinine levels greater than 1.0 ng/mL, however, this population also started off with the highest percentage above 1.0 ng/mL (36.6 percent) (Federal Interagency Forum on Child and Family Statistics, 2005).

Exhibit 2-58. Blood cotinine concentrations in U.S. children age 4 to 17 by race and ethnicity, 1988-1994 and 1999-2002[a]



[a] Cotinine concentrations are reported for non-smoking children only.

[b] Concentrations below 0.05 ng/mL are not presented here because this was the detection limit for many of the samples.

Data source: *Federal Interagency Forum on Child and Family Statistics, 2006. Data collected by the National Health and Nutrition Examination Survey (NHANES).*

Indicator Limitations

- The measurement of an environmental chemical in a person's blood or urine does not by itself mean that the chemical has caused or will cause harmful effects.
- Because the data from NHANES 1999-2000 and 2001-2002 represent only two survey periods, changes in estimates between the two time periods do not necessarily reflect a trend. Earlier data sets are available (e.g., NHANES III), but the data are not directly comparable to NHANES 1999-2002. When CDC releases additional survey results (e.g., 2003-2004) it will become possible to more fully evaluate trends (CDC, 2002; 2004).

Data Sources

Data used for this indicator were extracted from two reports that present results of the ongoing National Health and Nutrition Examination Survey (NHANES): the data shown in Exhibit 2-57 were obtained from a CDC report (2005), and the data shown in Exhibit 2-58 were obtained from a report by the Federal Interagency Forum on Child and Family Statistics (2005). The underlying laboratory data supporting both reports are available online in SAS® transport file formats at: http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm.

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2.4.3 Discussion

What These Indicators Say About Trends in Indoor Air Quality and Their Effects on Human Health

The two indoor air quality indicators provide insights into issues of very different origin: radon is a substance from a natural source, while environmental tobacco smoke (as evaluated by the presence of blood cotinine) is linked entirely to human behavior.

The Homes Above EPA's Radon Action Level indicator (p. 2-111) tracks two statistics: the number of homes estimated to be at or above EPA's action level (4 pCi/L) for radon, and the number of homes with operating radon mitigation systems. Evaluating trends in radon mitigation systems is relevant because properly operated systems are expected to reduce radon to levels below the action level, and therefore also are expected to reduce radon-related health risks among building occupants. Between 1990 and 2004, the number of homes with radon mitigation systems increased nearly four-fold, but these homes account for less than 10 percent of the nation's homes currently believed to have radon levels greater than EPA's action level. Some residents are being protected against radon exposures through radon-resistant new construction techniques used when a home is built. Estimates of radon-resistant new construction practices are not included in the indicator, however, because while they substantially reduce radon levels in homes with high radon potential, they do not always reduce the levels below the action level.

The Blood Cotinine indicator (p. 2-114) tracks blood concentrations of cotinine, a metabolite of nicotine, and shows that exposure to environmental tobacco smoke among non-smokers decreased considerably in the last decade. This decrease was observed for all population groups, defined by age (including children), sex, and ethnicity. However, children's blood cotinine levels, on average, are still more than twice the levels observed in adults. A logical explanation for the downward trend in blood cotinine levels is modified behavior, whether reduced smoking prevalence or more widespread practices of restricting areas in which individuals are allowed to smoke.

Taken together, these indicators show an increasing number of Americans have reduced indoor air exposures to two known carcinogens. Though these improvements are encouraging, both radon and environmental tobacco smoke remain important indoor air quality issues.

Limitations, Gaps, and Challenges

The two indicators in this section provide extensive, but not comprehensive, information on the corresponding indoor air quality issues that they characterize. An important limitation of the Homes Above EPA's Radon Action Level indicator, for instance, is that it does not track the number of homes designed and built with radon-resistant new construction features, which can prevent radon from entering homes and therefore reduce radon exposures and associated health risks. Thus, more people are likely being protected from elevated indoor air exposures to radon than suggested by trends in radon mitigation systems alone.

The Blood Cotinine indicator also has certain limitations. For example, exposure to environmental tobacco smoke does not occur exclusively indoors: some proportion of blood cotinine levels measured in non-smokers reflects exposures that occurred outdoors. In addition, nationally representative blood cotinine data are not available for children under 3 years old—an age group with documented susceptibilities to environmental tobacco smoke.[37] Nonetheless, none of these limitations call into question this indicator's main finding: nationwide, exposures to environmental tobacco smoke among non-smokers are decreasing. Moreover, reliable survey data on smoking behavior corroborates this downward trend.[38]

The two indoor air quality indicators provide useful insights into trends for radon and environmental tobacco smoke, but they leave some gaps that EPA would like to fill to better answer the overarching question on nationwide indoor air quality trends and associated health effects. For example, ROE indicators could not be developed for indoor air quality trends for molds, some combustion products, chemicals found in common household cleaners and building materials, and certain persistent pollutants and endocrine disruptors that have been identified in household dust.[39,40] There is no quantitative, nationally representative inventory of emission sources in indoor environments, nor is there a nationwide monitoring network that routinely measures air quality inside homes, schools, and office buildings. These gaps in nationwide indicators do not mean that nothing is known about the broad range of indoor air quality issues and associated health effects. Rather, information on these issues can be gleaned from numerous publications by governmental agencies and in the scientific literature. Data from these other publications and information resources, though valuable in understanding indoor air quality, are not presented in this report as indicators because they are not sufficiently representative on a national scale or because they do not track an issue over time.

The challenges associated with filling these indicator gaps are well known. Although methods to monitor indoor air quality are available, there is considerable variability among building types, occupants' behaviors, climate conditions, and ventilation systems for indoor environments in the U.S. This variability, combined with access issues and the number of different pollutants to address, makes a statistically based evaluation of our nation's millions of residences, thousands of office buildings, and more than 100,000 schools a challenging and resource-intensive task. Further, it is difficult to directly measure how changes in indoor air quality translate into corresponding changes in human health effects, because many health outcomes attributed to poor indoor air quality (e.g., asthma attacks) have numerous environmental and non-environmental risk factors.

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