EPA
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Environmental Protection
Agency

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EPA's Report on the Environment

Indicators Presenting Data for EPA Region 3

ROE Indicators Presenting Data for EPA Region 3

EPA's 2008 Report on the Environment (ROE) compiles, in one place, the most reliable indicators currently available to answer 23 questions that EPA believes are of critical importance to its mission to protect human health and the environment.

The indicators are supported by data gathered from federal and state agencies and non-governmental organizations. All ROE indicators were peer-reviewed to meet exacting standards for accuracy, representativeness, and reliability, and the report has undergone extensive internal and interagency review, SAB review, and public comment. The indicators present trends wherever adequate data are available, and establish national baselines where they are not. The report also identifies key limitations of these indicators and gaps where reliable indicators do not yet exist. The report does not propose actions to reduce data limitations, fill gaps, or analyze the costs and benefits of doing so.

The ROE presents 78 environmental indicators at the national scale. In response to recommendations from within and outside EPA, 32 of these indicators also present information at regional scales, most of them by EPA Region. There are also seven special pilot indicators developed by EPA Regional Offices that cover only one EPA Region or parts of one or two EPA Regions.

The table on the next page lists (1) all of the ROE indicators that present data relevant to EPA Region 3, and (2) the ROE questions they help to answer. Copies of all of the indicators listed are provided following the table. Additional information on the ROE is available at www.epa.gov/roe.

Indicators with Data Specific to EPA Region 3

Indicators with Data Specific to EPA Region 3 (cont.)

Indicators with Data Specific to EPA Region 3 (cont.)

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INDICATOR | Carbon Monoxide Emissions

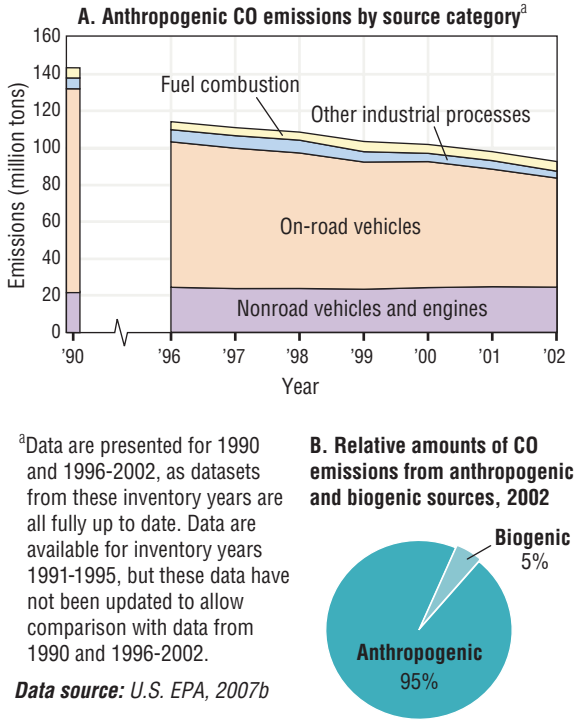
Carbon monoxide (CO) gas forms primarily when carbon fuels are not burned completely. Mobile sources account for the majority of CO emissions (U.S. EPA, 2003). These sources include both on-road vehicles (e.g., cars, trucks, motorcycles) and nonroad vehicles and engines (e.g., farm equipment, construction equipment, aircraft, 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 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 and industrial, commercial, and institutional sources, as well as residential heaters (e.g., wood-burning stoves) and boilers; (2) "Other industrial processes," which includes chemical production, petroleum refining, metals production, and industrial processes other than fuel combustion; (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. Biogenic emissions were estimated using the Biogenic Emissions Inventory System Model, Version 3.12, with data from the Biogenic Emissions Landcover Database and 2001 annual meteorological data.

CO emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different 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, 2007a).

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.

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



[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.

Data source: *U.S. EPA, 2007b*

What the Data Show

This indicator focuses on trends in CO emissions from anthropogenic sources. 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 35 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 90 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).

Net estimated anthropogenic CO emissions declined in all EPA Regions between 1990 and 2002 (Exhibit 2-2). The largest decrease (10.84 million tons) occurred in Region 9, and the smallest decrease (1.33 million tons) occurred in Region 10.

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 emissions 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 by downloading 2002 NEI inventory data for the "nonpoint sector" (http://www.epa.gov/ttn/chief/net/2002inventory.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 emissions 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 biogenic and anthropogenic CO emissions data in the NEI (U.S. EPA, 2007b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

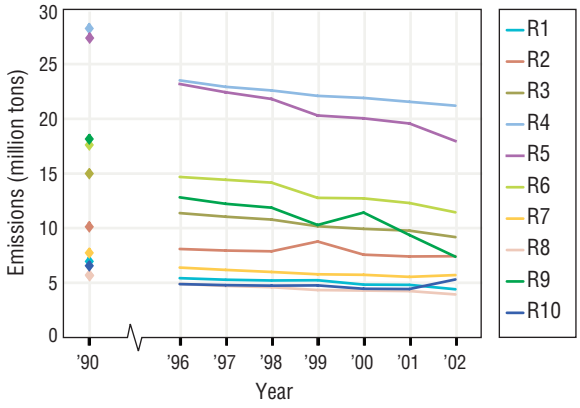
References

U.S. EPA (United States Environmental Protection Agency). 2007a. Documentation for the final 2002 mobile National Emissions Inventory, Version 3. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002_mobile_nei_version_3_report_092807.pdf>

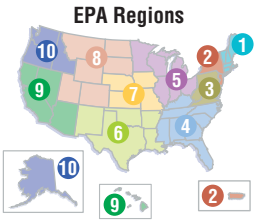
U.S. EPA. 2007b. Data from the 2002 National Emissions Inventory, Version 3.0. Accessed 2007. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

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/>

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.



Data source: *U.S. EPA, 2007b*

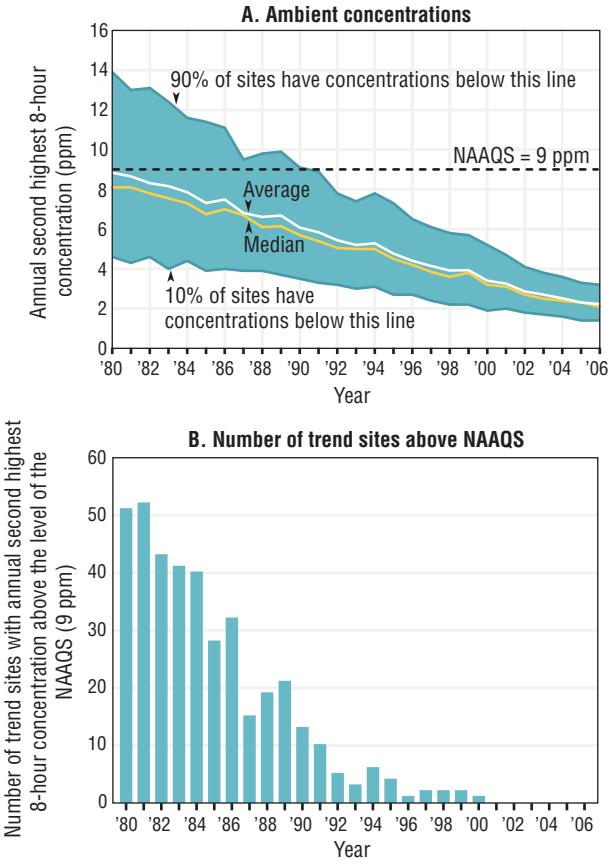
INDICATOR | Ambient Concentrations of Carbon Monoxide

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 sources of CO emissions 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 2006, 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 annual second highest 8-hour CO concentrations for 144 sites in 102 counties nationwide that have consistent data for the period of record in the State and Local Air Monitoring Stations network or by 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 second highest 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 144 sites nationwide at which reported CO concentrations were above the level of the 8-hour standard, but this statistic is not displayed for each EPA Region.

Exhibit 2-3. Ambient CO concentrations in the U.S., 1980-2006[a]



[a]**Coverage:** 144 monitoring sites in 102 counties nationwide (out of a total of 375 sites measuring CO in 2006) that have sufficient data to assess CO trends since 1980.

Data source: *U.S. EPA, 2007*

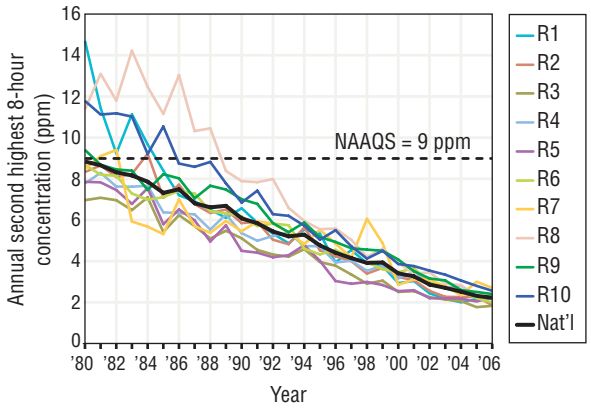
What the Data Show

The 2006 annual second highest 8-hour CO concentration averaged across 144 monitoring sites nationwide was 75 percent lower than that for 1980, and is the lowest level recorded during the past 27 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). In addition, of the 144 sites used to determine this trend (out of 375 total monitoring sites that were operating in 2006), the number reporting CO concentrations above the level of the CO standard declined to zero over the same period (Exhibit 2-3, panel B).

Also shown in 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.

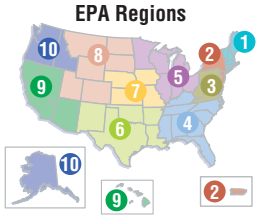
Consistent with the nationwide trend, CO levels in all ten EPA Regions have steadily decreased since 1980, with percent reductions over this period ranging from 68 percent (Region 7) to 85 percent (Region 1) (Exhibit 2-4).

Exhibit 2-4. Ambient CO concentrations in the contiguous U.S. by EPA Region, 1980-2006[a]



[a]**Coverage:** 141 monitoring sites in the EPA Regions (out of a total of 375 sites measuring CO in 2006) that have sufficient data to assess CO trends since 1980.

Data source: *U.S. EPA, 2007*



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 level of the CO standard over the time frame covered by this indicator. In 2006, for example, one monitoring site in the U.S. recorded CO concentrations above the level of the NAAQS, but did not have sufficient long-term data to be considered a trend site for this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on CO ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (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 (United States Environmental Protection Agency). 2007. Data from the Air Quality System. Accessed 2007. <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. <http://www.epa.gov/NCEA/pdfs/coaqcd.pdf>

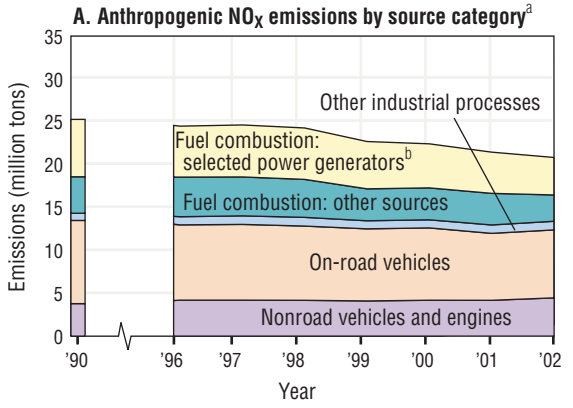
INDICATOR | Nitrogen Oxides Emissions

"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 comes from combustion-related emissions sources of human origin, primarily fossil fuel combustion in electric 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 react in the presence of sunlight to form ozone, which also is associated with human health and ecological effects (the Ozone Concentrations indicator). 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). 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; the Trophic State of Coastal Waters indicator). NO_x also plays a role in several other environmental issues, including formation of particulate matter (the PM Concentrations indicator), decreased visibility (the Regional Haze indicator), and global climate change (the U.S. Greenhouse Gas Emissions indicator; the Greenhouse Gas Concentrations indicator).

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 includes 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. Biogenic emissions were estimated using the Biogenic Emissions Inventory System Model, Version 3.12, with data from the Biogenic Landcover Database and 2001 annual meteorological data.

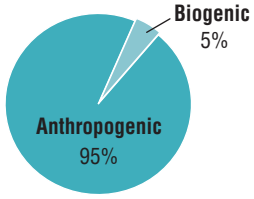
Exhibit 2-7. NO_X emissions in the U.S. by source category, 1990 and 1996-2002



[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, 2007b*

NO_x emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different 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 electricity generating units, most data come from CEMs 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, 2007a).

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

This indicator focuses on trends in NO_x emissions from anthropogenic sources. 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).

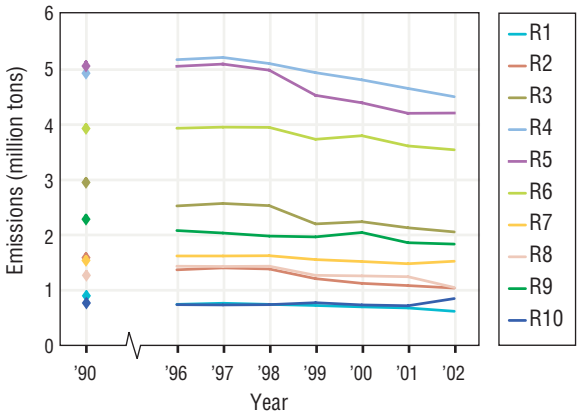
According to the NEI data, estimated nationwide anthropogenic emissions of NO_x decreased by 17 percent between 1990 and 2002 (from 25,160,000 to 20,917,000 tons) (Exhibit 2-7, panel A). This downward trend results primarily from emissions reductions at electric utilities and among on-road mobile sources. 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 nine of the ten EPA Regions decreased between 1990 and 2002 (Exhibit 2-8). The percent change in emissions over this time frame ranged from a 36 percent decrease (in Region 2) to a 6 percent increase (in Region 10), and the largest absolute reduction (919,000 tons) occurred in Region 3.

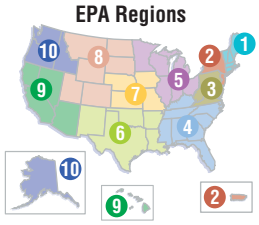
Indicator Limitations

- 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 emissions 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 emissions 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.

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, 2007b*

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on anthropogenic and biogenic NO_x emissions data in EPA's NEI (U.S. EPA, 2007b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

References

U.S. EPA (United States Environmental Protection Agency). 2007a. Documentation for the final 2002 mobile National Emissions Inventory, Version 3. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002_mobile_nei_version_3_report_092807.pdf>

U.S. EPA. 2007b. Data from the 2002 National Emissions Inventory, Version 3.0. Accessed 2007. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

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

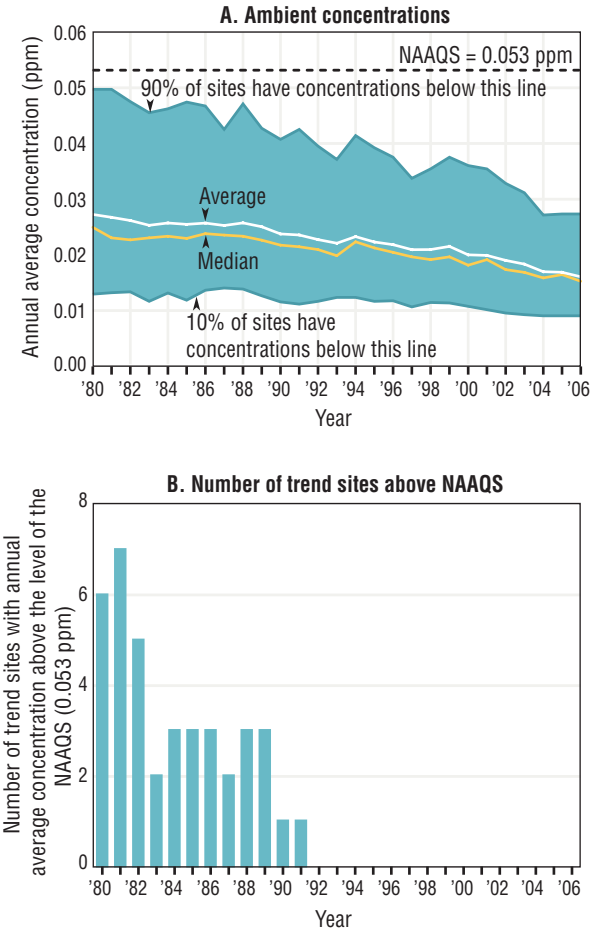
Nitrogen dioxide (NO_2) is a reddish-brown, highly reactive gas that is formed in the ambient air through the oxidation of nitric oxide (NO). Nitrogen dioxide is one in a group of highly reactive gases generically referred to as "nitrogen oxides" (NO_x), all of which contain nitrogen and oxygen in varying amounts. NO_x plays a major role in the formation of ozone in the atmosphere through a complex series of reactions with volatile organic compounds. NO_2 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, nitric acid). Deposition of nitrogen can lead to fertilization, eutrophication, or acidification of terrestrial, wetland, and aquatic (e.g., fresh water bodies, estuaries, 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 2006, based on the annual arithmetic average. The indicator displays trends averaged over 87 sites in 64 counties nationwide that have consistent data for the period of record in the State and Local Air Monitoring Stations network or by 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 average 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 87 sites nationwide at which NO_2 concentrations exceeded the level of the annual average standard over the period of record, but this statistic is not displayed for each EPA Region.

Exhibit 2-9. Ambient NO_2 concentrations in the U.S., 1980-2006[a]



[a]**Coverage:** 87 monitoring sites in 64 counties nationwide (out of a total of 369 sites measuring NO_2 in 2006) that have sufficient data to assess NO_2 trends since 1980.

Data source: *U.S. EPA, 2007*

What the Data Show

The national annual average NO_2 concentration in 2006 was 41 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 average NO_2 concentrations are typically found in urban areas. In addition, of the 87 sites used to determine this trend (out of 369 total monitoring sites that were operating in 2006), the number reporting NO_2 concentrations above the level of 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 20 percent in Region 8 to 49 percent in Region 1 (Exhibit 2-10).

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

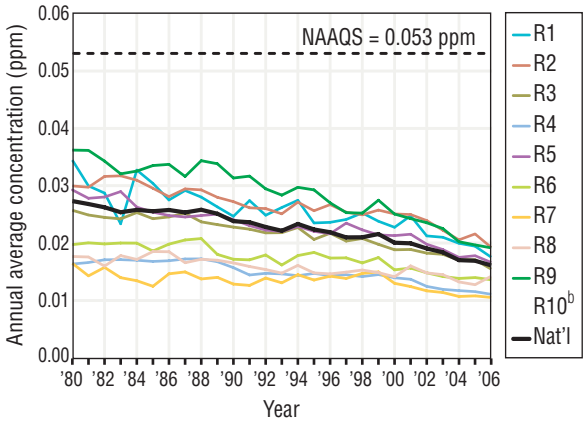
Indicator Limitations

- Because ambient monitoring for NO_2 occurs almost exclusively in high-traffic urban areas, the average concentrations presented in this indicator likely may not reflect 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 concentrations 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 level of the NO_2 standard over the time frame covered by this indicator. In 2006, however, no monitoring sites in the U.S. measured NO_2 concentrations above the level of the NAAQS.

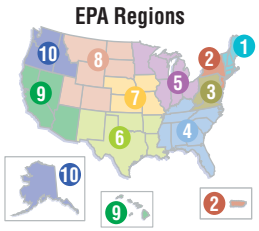
Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on NO_2 ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (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.

Exhibit 2-10. Ambient NO_2 concentrations in the contiguous U.S. by EPA Region, 1980-2006[a,b]



[a]**Coverage:** 87 monitoring sites in the EPA Regions (out of a total of 369 sites measuring NO_2 in 2006) 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, 2007*

References

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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 in part because they contribute to ozone formation (U.S. EPA, 2003a). Ozone (the Ozone Concentrations indicator) is formed from chemical reactions involving airborne VOCs, airborne nitrogen oxides, and sunlight. VOCs are also of interest because many individual VOCs are known to be harmful to human health (the Benzene Concentrations indicator; the Air Toxics Emissions indicator). Health effects vary by pollutant. 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).

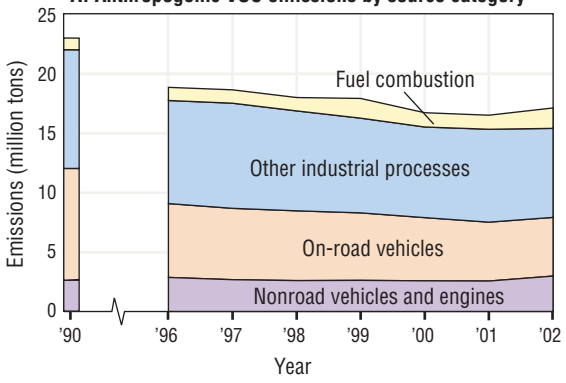
This indicator presents VOC emissions from traditionally inventoried anthropogenic source categories: (1) "Fuel combustion," which includes emissions from coal-, gas-, and oil-fired power plants and industrial, commercial, and institutional sources, as well as residential heaters and boilers; (2) "Other industrial processes," which includes chemical production, petroleum refining, metals production, and processes other than fuel combustion; (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. Biogenic emissions were estimated using the Biogenic Emissions Inventory System Model, Version 3.12, with data from the Biogenic Emissions Landcover Database and 2001 annual meteorological data.

VOC emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different 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, 2007a).

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.

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

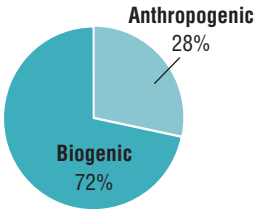
A. Anthropogenic VOC emissions by source category[a]



[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, 2007b*

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



What the Data Show

This indicator focuses on trends in VOC emissions from anthropogenic sources. 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 25 percent between 1990 and 2002 (from 23,048,000 to 17,194,000 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 72 percent of the nationwide anthropogenic emissions in 2002.

Trends in estimated anthropogenic VOC emissions in nine of the ten EPA Regions were consistent with the overall decline seen nationally from 1990 to 2002 (Exhibit 2-12). Changes in VOC emissions ranged from a 52 percent reduction (Region 9) to a 16 percent increase (Region 10).

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 emissions 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 by downloading 2002 NEI inventory data for the "nonpoint sector" (http://www.epa.gov/ttn/chief/net/2002inventory.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. These estimates are generated using well-established approaches, and quality assurance measures are implemented to ensure that the emissions data entered in NEI meet data quality standards (U.S. EPA, 2006). Nonetheless, the estimates have uncertainties inherent in the emission factors and emissions 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.

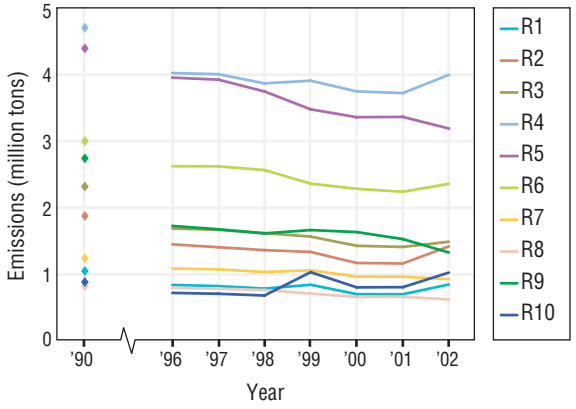
Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on biogenic and anthropogenic VOC emissions data in the NEI (U.S. EPA, 2007b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

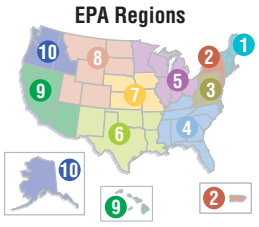
References

U.S. EPA (United States Environmental Protection Agency). 2007a. Documentation for the final 2002 mobile National Emissions Inventory, Version 3. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002_mobile_nei_version_3_report_092807.pdf>

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.



Data source: *U.S. EPA, 2007b*

U.S. EPA. 2007b. Data from the 2002 National Emissions Inventory, Version 3.0. Accessed 2007. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

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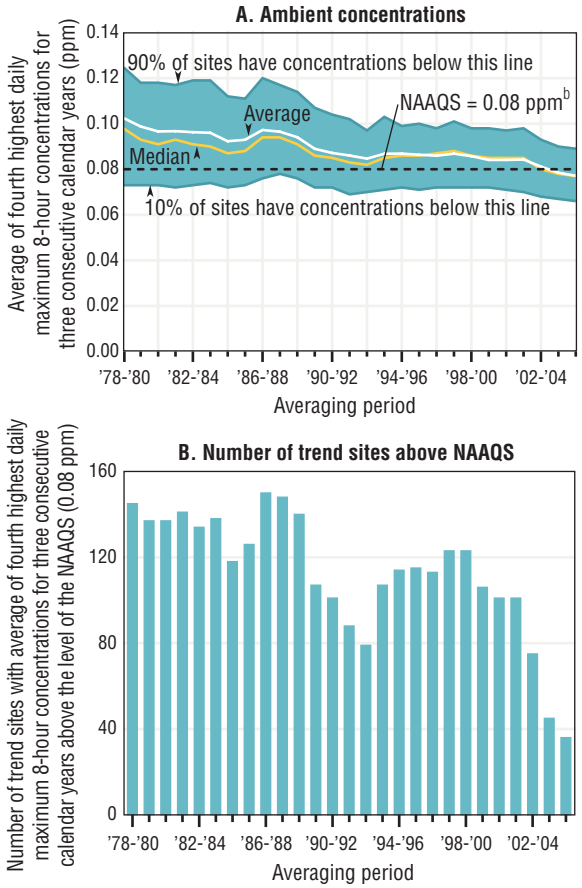
INDICATOR | Ambient Concentrations of Ozone

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 describes trends in stratospheric ozone levels over the U.S.) In the lowest level of the atmosphere, the 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 whose time frame 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 emissions 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, 2006). 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 (more than 65 years old) appear to be at excess risk of ozone-related mortality or hospitalization (U.S. EPA, 2006). Elevated concentrations of ozone can also affect vegetation and ecosystems, as the Ozone Injury to Forest Plants indicator describes further (U.S. EPA, 2006).

Exhibit 2-13. Ambient 8-hour ozone concentrations in the U.S., 1978-2006[a]



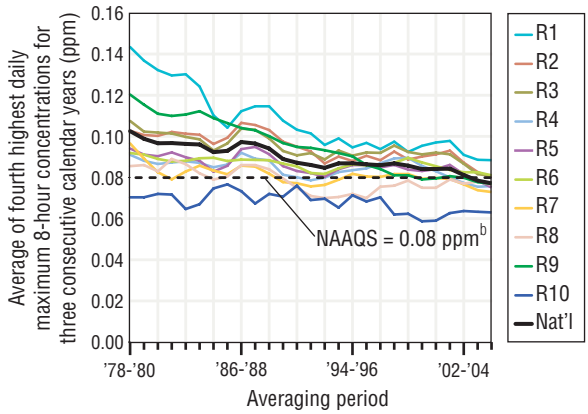
[a] **Coverage:** 201 monitoring sites in 150 counties nationwide (out of a total of 1,194 sites measuring ozone in 2006) that have sufficient data to assess ozone trends since 1978.

[b] The figure displays the 1997 NAAQS (0.08 ppm). Future versions of the ROE will compare ozone concentrations to the recently promulgated 2008 NAAQS (0.075 ppm) or to the NAAQS in effect at the time.

Data source: *U.S. EPA, 2007*

This indicator presents ambient ground-level ozone concentrations in parts per million (ppm) from 1978 to 2006. Data are shown for 8-hour averaging times, based on continuous ozone monitoring data and consistent with this pollutant's National Ambient Air Quality Standard (NAAQS). The 8-hour standard is indicative of exposures occurring over a sustained period of time (e.g., an outdoor worker's exposure over the course of a work day). Trends for this indicator represent 201 sites in 150 counties nationwide that have data for the period of record in the State and Local Air Monitoring Stations network or by other special purpose monitors. The indicator also displays trends

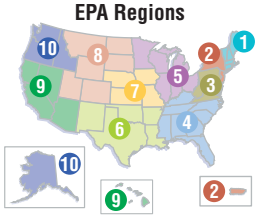
Exhibit 2-14. Ambient 8-hour ozone concentrations in the contiguous U.S. by EPA Region, 1978-2006[a]



[a]**Coverage:** 201 monitoring sites in the EPA Regions (out of a total of 1,194 sites measuring ozone in 2006) that have sufficient data to assess ozone trends since 1978.

[b]The figure displays the 1997 NAAQS (0.08 ppm). Future versions of the ROE will compare ozone concentrations to the recently promulgated 2008 NAAQS (0.075 ppm) or to the NAAQS in effect at the time.

EPA Regions



Data source: *U.S. EPA, 2007*

in ozone measurements in each EPA Region. This indicator's exhibits display the corresponding 1997 NAAQS as a point of reference, but the fact that the national or regional concentrations fall below the standard 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 201 sites nationwide at which ozone concentrations exceeded the level of the 1997 standard, but this statistic is 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 for rolling 3-year time periods, this indicator smoothes out the "peaks" and "valleys" in the trend, making it easier to see the long-term trend. Three years is consistent with the 3-year period used to assess compliance with the ozone standards. For the 8-hour trends in this report, a 3-year average of the fourth highest daily maximum 8-hour concentration in each year is used to be consistent with the 8-hour ozone standard.

What the Data Show

Between the 1978-1980 and 2004-2006 averaging periods, nationwide fourth highest daily maximum 8-hour ambient ozone concentrations decreased by 25 percent (Exhibit 2-13, panel A). Although the 8-hour ozone levels in 2004-2006 were the lowest on record and the number of trend sites measuring ozone concentrations above the level of the 1997 8-hour NAAQS decreased by 75 percent over the time frame covered in this indicator (Exhibit 2-13, panel B), ambient air monitoring data collected in 2006 and reported to EPA's Air Quality System indicate that approximately 77 million people lived in counties where 8-hour average ozone concentrations are above the level of the 1997 primary ozone NAAQS. Among the ten EPA Regions, the most substantial declines in 8 hour levels were observed in EPA Regions that originally had the highest ozone concentrations (EPA Regions 1 and 9) (Exhibit 2-14). Over the entire period of record, Region 10 consistently showed the lowest Regional ozone levels.

Also shown in Exhibit 2-13 (panel A) are the 90th and 10th percentiles based on the distribution of statistics at the monitoring sites. This provides additional graphical representation of the variability of measured concentrations across the monitoring sites for a given 3-year period. Thus, the graphic displays the concentration range where 80 percent of measured values occurred for that 3-year period.

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; the VOC Emissions indicator), ozone remains one of the most persistent and ubiquitous air pollution issues in the U.S.

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 level of the ozone standard over the time frame covered by this indicator. In 2006, for example, 187 monitoring sites (in addition to the trend sites shown in Exhibit 2-13, panel B) recorded ozone concentrations above the level of the 1997 NAAQS, but did not have sufficient long-term data to be included in this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on ozone ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (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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U.S. EPA. 2003b. 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>

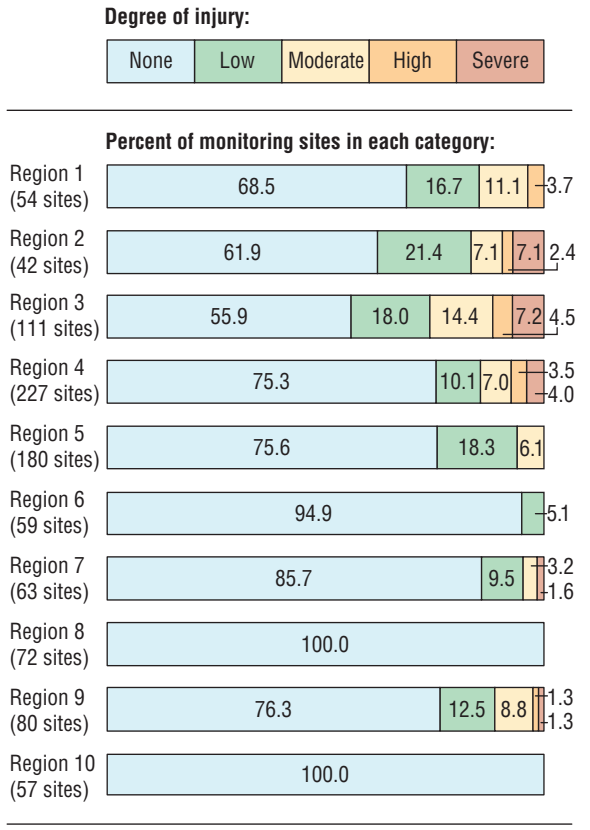
INDICATOR | Ozone Injury to Forest Plants

Air pollution can have noteworthy cumulative impacts on forested ecosystems by affecting regeneration, productivity, and species composition (U.S. EPA, 2006). 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 (USDA) Forest Service Forest Inventory and Analysis (FIA) program. As part of its Phase 3 program, formerly known as Forest Health Monitoring, FIA 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, FIA 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 by the USDA Forest Service 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. 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, 2006).

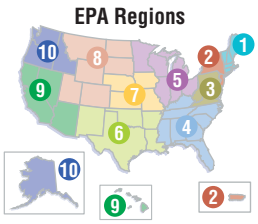
Exhibit 2-15. Ozone injury to forest plants in the U.S. by EPA Region, 2002[a,b]



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

[b]Totals may not add to 100% due to rounding.

Data source: *USDA Forest Service, 2006*



What the Data Show

There is considerable regional variation in ozone injury to sensitive plants (Exhibit 2-15). 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. The sum of 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 55 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, 2006).
- Though FIA 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 multiple years, most biosites were not monitored over the entire period, so these data cannot provide more than a baseline for future trends.

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://nrs.fs.fed.us/fia/topics/ozone/data/). This indicator aggregates the state data by EPA Region.

References

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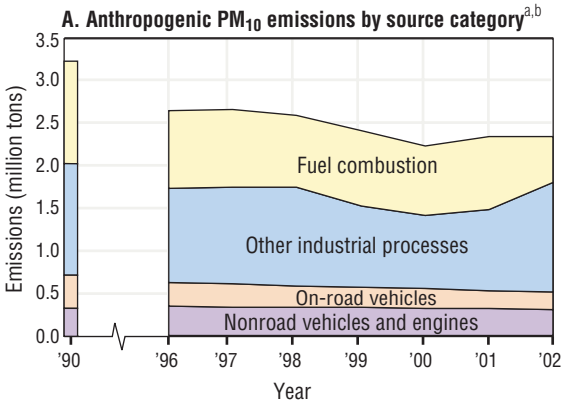
"Particulate matter" (PM) is the general term used to describe solid particles and liquid droplets found in the air. The composition and size of these airborne particles and droplets vary. Some particles are large enough to be seen as dust or dirt, while others are so small they can only be seen using 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 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 are 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; the Sulfur Dioxide Emissions indicator). Particles formed through secondary processes are not included in this indicator.

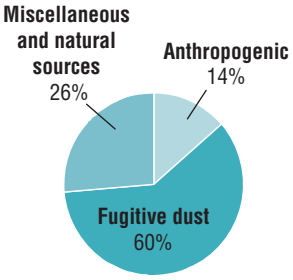
Exhibit 2-16. PM_{10} emissions in the U.S. by source category, 1990 and 1996-2002



[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]

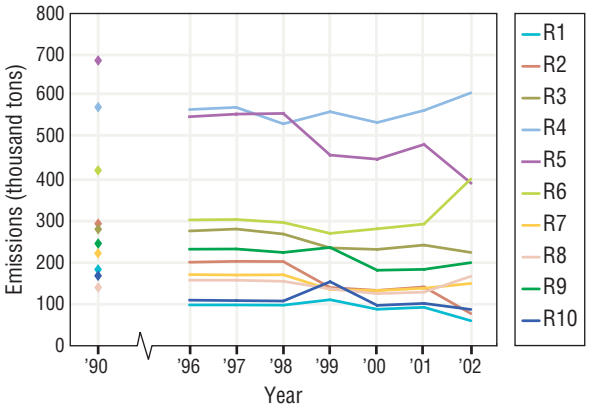


Data source: *U.S. EPA, 2007b*

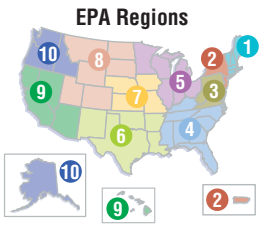
Primary emissions of PM can exist as solid or liquid matter (the "filterable" portion) or as gases (the "condensable" portion). Data for the condensable portion exist only for the years 1999 to 2002. To allow for a valid comparison of emissions trends from 1990 to 2002, only data for the filterable portion of PM_{10} and $PM_{2.5}$ are included in the trend graphs. Condensables are, however, included in the inset pie charts shown in Exhibits 2-16 and 2-18 (i.e., panel B in both exhibits).

All emissions data presented in this indicator are taken from the NEI. Primary particulate emissions data are presented for the traditionally inventoried anthropogenic source categories: (1) "Fuel combustion," which includes emissions from coal-, gas-, and oil-fired power plants and industrial,

Exhibit 2-17. 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, 2007b*

commercial, and institutional sources, as well as residential heaters and boilers; (2) "Other industrial processes," which includes chemical production, petroleum refining, metals production, and processes other than fuel combustion; (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. For 2002 only, 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. Biogenic emissions were estimated using the Biogenic Emissions Inventory System Model, Version 3.12, with data from the Biogenic Emissions Landcover Database and 2001 annual meteorological data. The NEI also documents estimates of primary emissions from fugitive dust and miscellaneous sources.

The NEI is a composite of data from many different 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, 2007a).

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.

What the Data Show

Primary PM_{10} Emissions Trends

Estimated primary PM_{10} emissions from anthropogenic sources decreased 27 percent nationally between 1990 and 2002 (Exhibit 2-16, panel A). Of these sources, those in the fuel combustion category saw the largest absolute and relative decrease in emissions (656,000 tons; 55 percent). Primary 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 primary PM_{10} emissions (including condensables from stationary and mobile sources) in 2002, the majority of which was attributable to fugitive dust from roads (Exhibit 2-16, panel B).

Changes in estimated primary anthropogenic PM_{10} emissions from 1990 to 2002 varied widely among EPA Regions, ranging from an increase of 16 percent (Region 8) to a decrease of 75 percent (Region 2) (Exhibit 2-17).

Primary $PM_{2.5}$ Emissions Trends

Estimated primary $PM_{2.5}$ emissions from anthropogenic sources decreased 44 percent nationally between 1990 and 2002 (Exhibit 2-18, panel A). The largest absolute and relative decline in $PM_{2.5}$ was seen in the fuel combustion source category (621,000 tons; 68 percent). Primary emissions from the group of sources including miscellaneous and natural sources and fugitive dust 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 2-18, panel B).

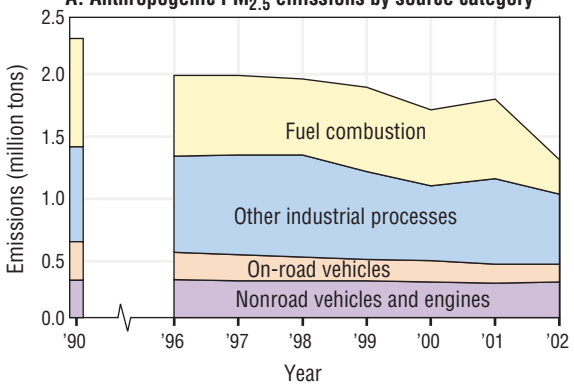
Primary anthropogenic $PM_{2.5}$ emissions decreased in all ten EPA Regions from 1990 to 2002, with percent reductions ranging from 21 percent (Region 4) to 71 percent (Region 2) (Exhibit 2-19).

Indicator Limitations

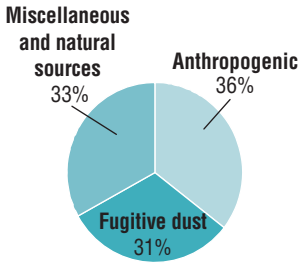
- Comparable PM emissions estimates through the NEI are available only for 1990 and 1996-2002. Data for 1991-1995 are not provided due to differences in emissions estimation methodologies from other inventory years, which could lead to improper trend assessments.

Exhibit 2-18. $PM_{2.5}$ emissions in the U.S. by source category, 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]

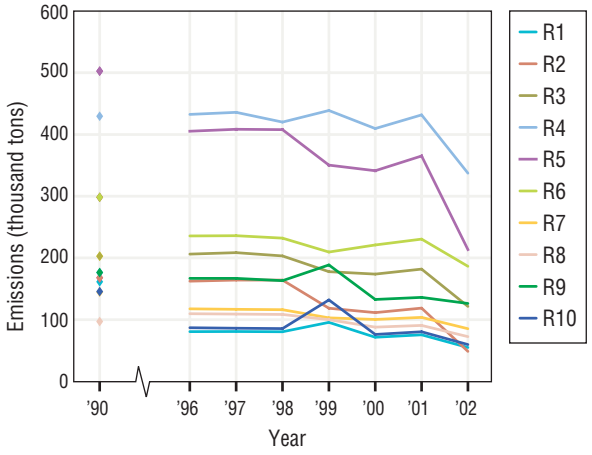


[a]Data are presented for 1990 and 1996-2002, as datasets from these inventory years are fully up to date. Data are available for inventory years 1991-1995, but these data have not been updated to allow comparison with data from 1990 and 1996-2002.

[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.

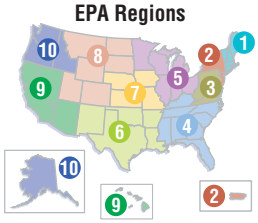
Data source: *U.S. EPA, 2007b*

Exhibit 2-19. $PM_{2.5}$ 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.

EPA Regions



[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, 2007b*

- 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 by downloading 2002 NEI inventory data for the "nonpoint sector" (http://www.epa.gov/ttn/chief/net/2002inventory.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 emissions 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.
- 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 biogenic and anthropogenic PM emissions data in the NEI (U.S. EPA, 2007b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the NEI data by source type (anthropogenic or biogenic), source category, and EPA Region.

References

U.S. EPA (United States Environmental Protection Agency). 2007a. Documentation for the final 2002 mobile National Emissions Inventory, Version 3. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002_mobile_nei_version_3_report_092807.pdf>

U.S. EPA. 2007b. Data from the 2002 National Emissions Inventory, Version 3.0. Accessed 2007. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

U.S. EPA. 2004. Air quality criteria for particulate matter (October 2004). EPA 600/P-99/002aF-bF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=87903>

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-containing reactive organic gas emissions from cars, trucks, industrial facilities, forest fires, and biogenic sources such as trees.

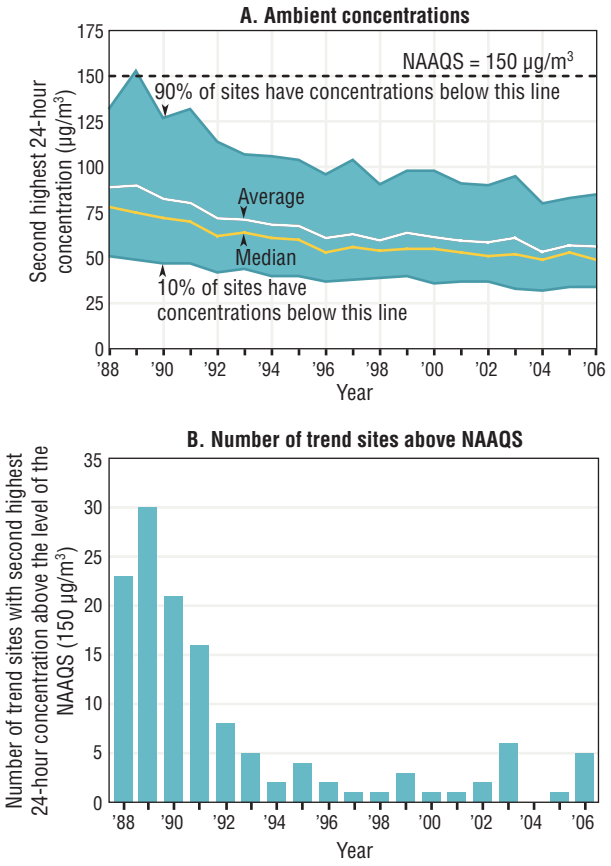
Ambient air monitoring stations throughout the country measure air concentrations of two size ranges of particles: $PM_{2.5}$ and PM_{10}. $PM_{2.5}$ consists of "fine particles" with aerodynamic diameters less than or equal to 2.5 microns (μm). PM_{10} includes both fine particles ($PM_{2.5}$) and "coarse particles," which is the subset of PM_{10} that is larger than 2.5 μm and smaller than 10 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 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 seasonal patterns. $PM_{2.5}$ 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 (October-December) 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). 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). Some particles that deposit onto plant leaves can corrode

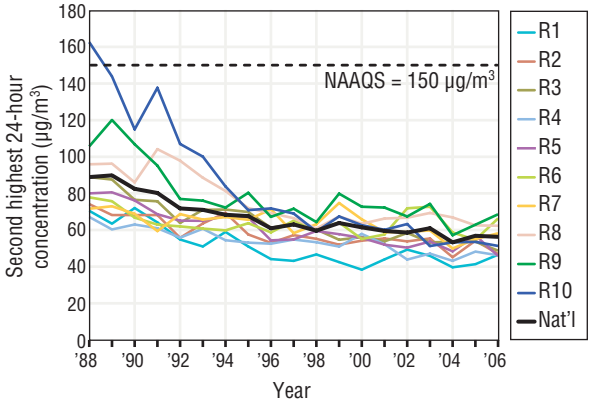
Exhibit 2-20. Ambient 24-hour PM_{10} concentrations in the U.S., 1988-2006[a]



[a] **Coverage:** 301 monitoring sites in 199 counties nationwide (out of a total of 902 sites measuring PM_{10} in 2006) that have sufficient data to assess PM_{10} trends since 1988.

Data source: *U.S. EPA, 2007*

Exhibit 2-21. Ambient 24-hour PM_{10} concentrations in the contiguous U.S. by EPA Region, 1988-2006[a]



[a]**Coverage:** 292 monitoring sites in the EPA Regions (out of a total of 902 sites measuring PM_{10} in 2006) that have sufficient data to assess PM_{10} trends since 1988.

Data source: *U.S. EPA, 2007*

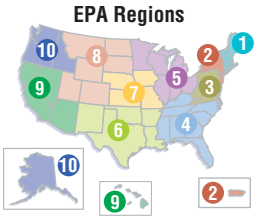
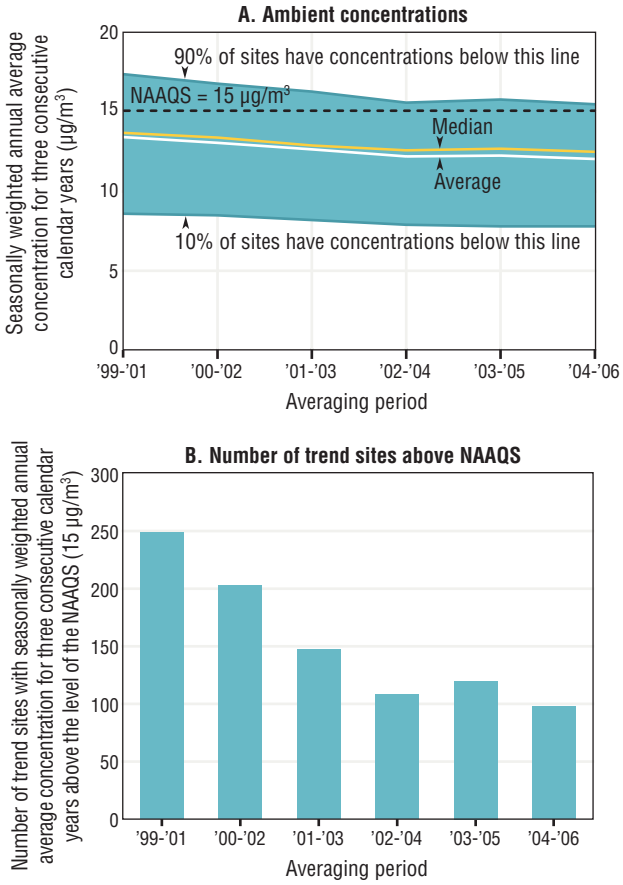


Exhibit 2-22. Ambient annual $PM_{2.5}$ concentrations in the U.U.S., 1999-2006[a]



[a]**Coverage:** 752 monitoring sites in 508 counties nationwide (out of a total of 786 sites measuring $PM_{2.5}$ in 2006) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

Data source: *U.S. EPA, 2007*

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 1988 to 2006 are presented for the second highest 24-hour concentrations measured at the trend sites during each calendar year. For $PM_{2.5}$, trend data from 1999 to 2006 are presented for seasonally weighted annual average concentrations and for the 98th percentiles of 24-hour average concentrations measured at the trend sites over three consecutive calendar years. Trend data are based on measurements from the State and Local Air Monitoring Stations network and from other special purpose monitors. This indicator presents PM_{10} trends for 301 monitoring sites in 199 counties nationwide and $PM_{2.5}$ trends for 752 monitoring sites in 508 counties nationwide. For both PM_{10} and $PM_{2.5}$, the indicator displays trends for the entire nation and for the ten EPA Regions.

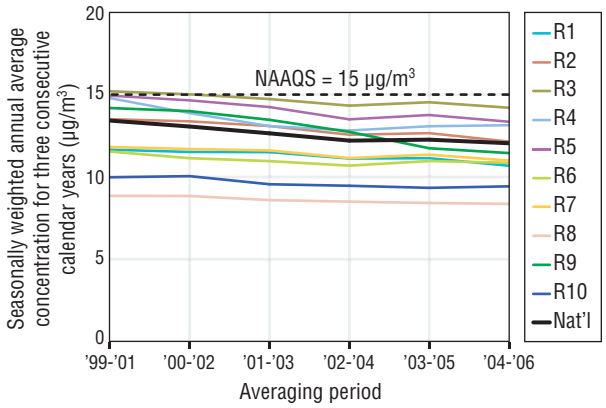
The indicator's exhibits display the pollutants' NAAQS as points of reference. However, the fact that the national values or those shown for EPA Regions fall below the standards does not mean that all monitoring sites nationally or in any particular EPA Region also are below the standards. The indicator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

What the Data Show

PM_{10} Concentration Trends

In 2006, the national 24-hour PM_{10} concentration (based on the second highest 24-hour concentration at each site) was 37 percent lower than the average 1988 level (Exhibit 2-20, panel A). Additionally, of the 301 sites used to determine this trend (out of 902 total monitoring sites that were operating in 2006), the number reporting PM_{10} concentrations above the level of the 24-hour standard declined 78 percent between 1988 and 2006 (Exhibit 2-20, panel B). All EPA Regions experienced a steady

Exhibit 2-23. Ambient annual $PM_{2.5}$ concentrations in the contiguous U.S. by EPA Region, 1999-2006[a]



[a]**Coverage:** 736 monitoring sites in the EPA Regions (out of a total of 786 sites measuring $PM_{2.5}$ in 2006) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

Data source: *U.S. EPA, 2007*

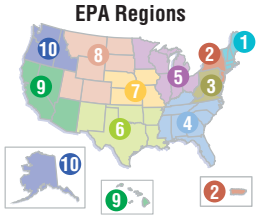
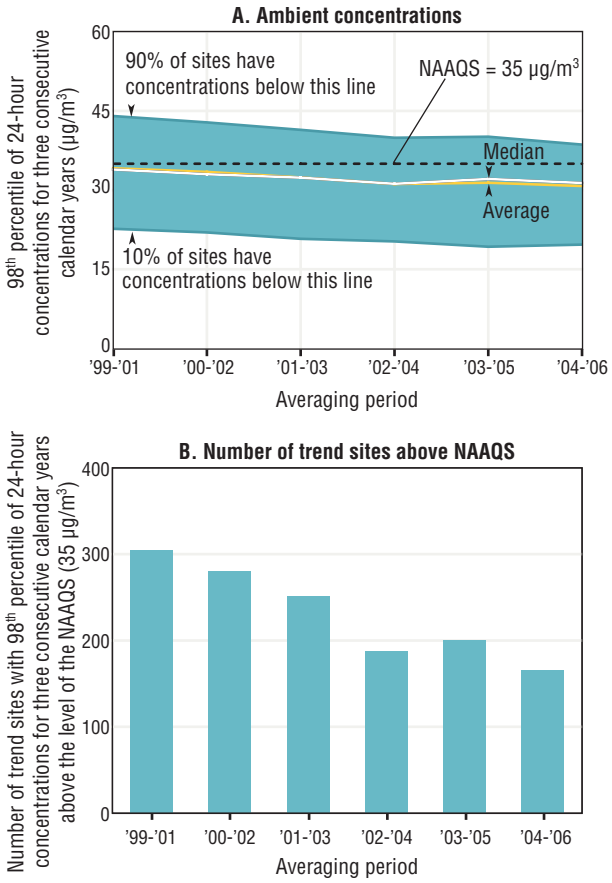


Exhibit 2-24. Ambient 24-hour $PM_{2.5}$ concentrations in the U.S., 1999-2006[a]



[a]**Coverage:** 752 monitoring sites in 508 counties nationwide (out of a total of 811 sites measuring $PM_{2.5}$ in 2006) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

Data source: *U.S. EPA, 2007*

decrease in 24-hour PM_{10} levels over this period (Exhibit 2-21). EPA Region 10 showed the greatest relative decrease (68 percent) since 1988.

Also shown in Exhibit 2-20 (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 that this presentation style also applies to panel A in Exhibits 2-22 and 2-24, discussed below.)

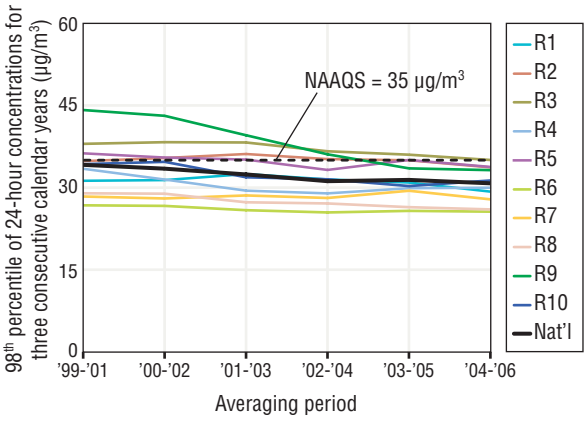
$PM_{2.5}$ Concentration Trends

Seasonally weighted average $PM_{2.5}$ concentrations over the 2004-2006 averaging period were the lowest since nationwide monitoring began in 1999 (Exhibit 2-22, panel A). The trend is based on measurements collected at 752 monitoring stations that have sufficient data to assess trends over that period. The seasonally weighted annual average concentrations decreased 10 percent between the 1999-2001 averaging period and the 2004-2006 averaging period. The number of monitoring sites in this trend (752 out of 786 total sites that were operating in 2006) reporting ambient air concentrations above the level of the annual average $PM_{2.5}$ standard declined 61 percent over this period (Exhibit 2-22, panel B).

Regional declines were greatest in portions of the West (EPA Region 9), the Southeast (EPA Region 4), and the Midwest (EPA Region 5), where seasonally weighted average $PM_{2.5}$ levels over the 2004-2006 averaging period were 19 percent, 11 percent, and 11 percent lower than those in 1999-2001 averaging period, respectively (Exhibit 2-23).

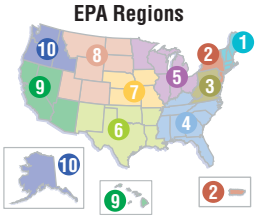
In 2004-2006, the average of 98th percentiles of 24-hour $PM_{2.5}$ concentrations at the 752 monitoring sites used for the trend was 10 percent lower than the 1999-2001 level (Exhibit 2-24, panel A). The number of monitoring sites in this trend (752 out of a total of 811 sites that were operating in 2006) reporting ambient air concentrations above the level of the 24-hour $PM_{2.5}$ standard declined 46 percent over this period (Exhibit 2-24, panel B). All ten EPA Regions experienced decreasing 24-hour $PM_{2.5}$ levels between the 1999-2001 averaging period and the

Exhibit 2-25. Ambient 24-hour $PM_{2.5}$ concentrations in the contiguous U.S. by EPA Region, 1999-2006[a]



[a]**Coverage:** 736 monitoring sites in the EPA Regions (out of a total of 811 sites measuring $PM_{2.5}$ in 2006) that have sufficient data to assess $PM_{2.5}$ trends since 1999.

Data source: *U.S. EPA, 2007*



2004-2006 averaging period, with Region 9 showing the largest decline (25 percent) (Exhibit 2-25).

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 level of the PM standard during the years covered by this indicator. In 2006, for example, 41 monitoring sites (in addition to the trend sites shown in Exhibit 2-20, panel B) recorded PM_{10} concentrations above the level of the NAAQS, but did not have sufficient long-term data to be included in this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on PM ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (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 1988 for PM_{10} and since 1999 for $PM_{2.5}$).

References

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U.S. EPA. 2004a. The particle pollution report: Current understanding of air quality and emissions through 2003. EPA 454/R-04/002. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd04/pm.html>

U.S. EPA. 2004b. Air quality criteria for particulate matter (October 2004). EPA 600/P-99/002aF-bF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=87903>

INDICATOR | Regional Haze

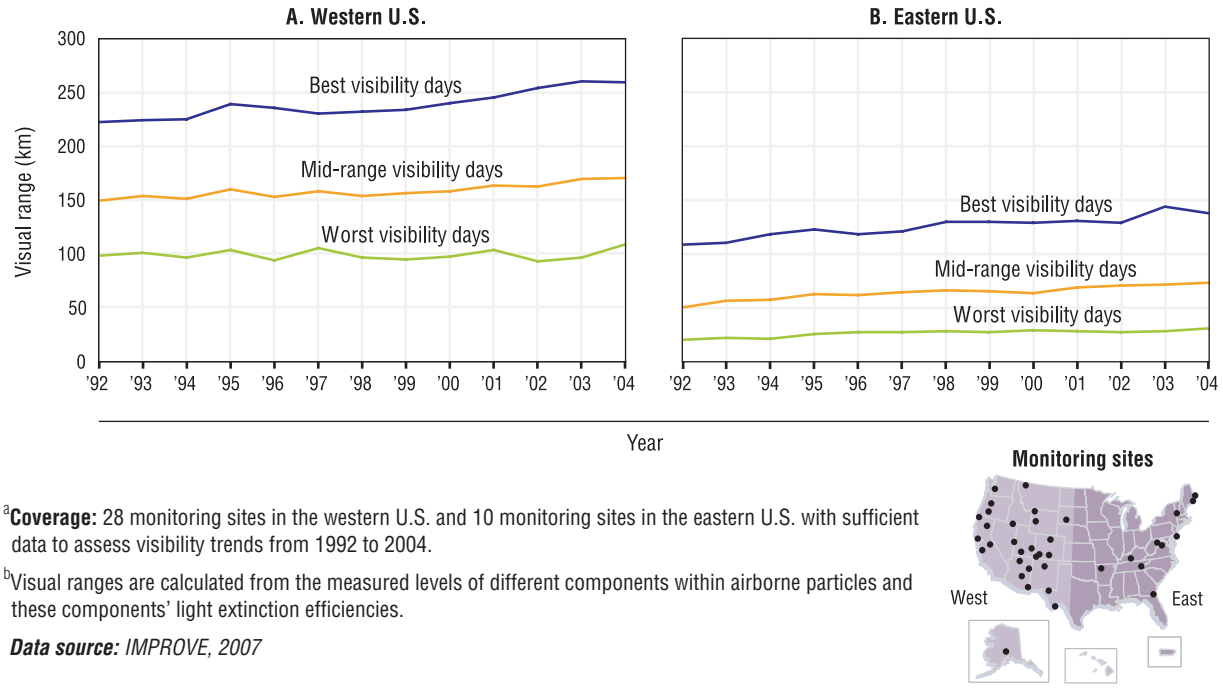
Visibility impairment occurs when air pollution, especially particles, scatter and absorb light. The resulting haze not only limits the distance one can see, but also degrades the color, clarity, and contrast of scenes. As the PM Concentrations indicator describes further, the same pollutants that impair visibility are linked to serious health effects. Visibility impairment occurs throughout the country, including both urban and rural areas. Regional haze is visibility impairment caused by the cumulative air pollutant emissions from numerous sources over a wide geographic area (U.S. EPA, 2004a). Regional haze has been identified as an important issue for all of the 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).

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 (e.g., 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 annual average 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 estimates calculated from measurements of particulate matter (PM) 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. Values are presented

Exhibit 2-26. 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: *IMPROVE, 2007*

for 10 Eastern (east of 100 degrees west longitude) sites and 28 Western (west of 100 degrees west longitude) sites. Visibility, expressed as visual range, is calculated from the measured levels of different components within airborne particles and these components' light extinction efficiencies. The IMPROVE algorithm (Debell et al., 2006) 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. This indicator tracks visibility in three categories: worst visibility conditions (the average of the 20 percent worst visibility days); best visibility conditions (the average of the 20 percent best visibility days); and mid-range visibility conditions (the average of the remaining 60 percent of days).

What the Data Show

On average, the best visibility in selected National Parks and Wilderness Areas in the East, as calculated from the measured concentrations of components of PM, is only slightly better than the worst visibility in selected National Parks and Wilderness Areas in the West (Exhibit 2-26). In 2004, the average visual range for the worst days in the East was 31 km (19 miles), compared to 137 km (85 miles) for the best visibility days. In the West, the average visual range in 2004 extended from 109 km (68 miles) on the worst days to 260 km (162 miles) on the best days. In both regions, the average visual range in selected National Parks and Wilderness Areas 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 the National Park Service Air Quality Division, based on ambient air monitoring data collected as part of the IMPROVE network (IMPROVE, 2007) and a computational algorithm last updated in August 2007 (http://vista.cira.colostate.edu/views/Web/IMPROVE/SummaryData.aspx). Visibility trends in this indicator are derived from the subset of IMPROVE monitoring stations outside urban areas that have sufficient data to assess trends between 1992 and 2004.

References

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U.S. EPA. 2004b. The ozone report: Measuring progress through 2003. EPA/454/K-04/001. Research Triangle Park, NC. <http://www.epa.gov/air/airtrends/aqtrnd04/ozone.html>

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>

INDICATOR | Sulfur Dioxide Emissions

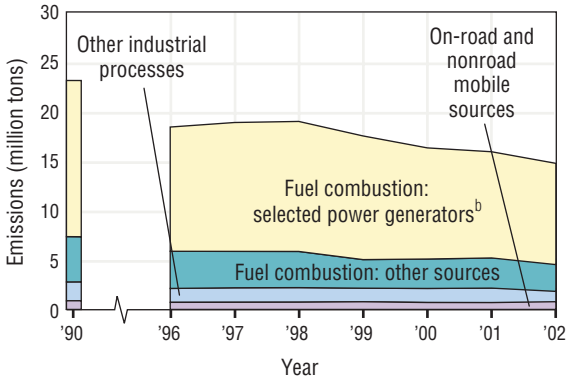
Sulfur dioxide (SO_2) belongs to the family of sulfur oxide (SO_x) gases. These gases are formed when fuel containing sulfur (mainly coal and oil) is burned (e.g., for electricity generation) and during metal smelting and other industrial processes. High concentrations of SO_2 are associated with multiple 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), SO_2 emissions are an important environmental issue because they are a major precursor to ambient $PM_{2.5}$ concentrations: many more people live in $PM_{2.5}$ non-attainment areas, which has several documented human health and ecological effects (the PM Concentrations indicator).

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, contributes to acidic deposition (the Acid Deposition indicator); SO_2 is a major precursor to $PM_{2.5}$ (the PM Concentrations indicator); and SO_2 contributes to impaired visibility (the Regional Haze indicator). 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 materials (e.g., concrete, 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 includes chemical production and petroleum refining; (4) "On-road vehicles," which includes cars, trucks, buses, and motorcycles; (5) "Nonroad vehicles and engines," which include farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others. Because 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.

Exhibit 2-27. 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, 2007b*

SO_2 emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different 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 electricity generating units, most data come from CEMs 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, 2007a).

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 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 37 percent between 1990 and 2002 (from 23,064,000 to 14,639,000 tons) (Exhibit 2-27). This downward trend resulted primarily from emissions reductions at electric 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 (Exhibit 2-28). During this time frame, the largest percent reductions in SO_2 emissions were seen in Regions 1 (59 percent), 2 (49 percent), and 5 (48 percent), and the smallest reductions were observed in Regions 6 (15 percent) and 9 (18 percent).

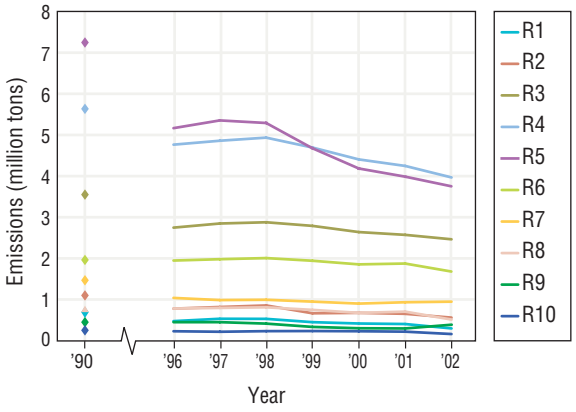
Indicator Limitations

- 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 emissions 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 differences in emissions 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 by downloading 2002 NEI inventory data for the "nonpoint sector" (http://www.epa.gov/ttn/chief/net/2002inventory.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.

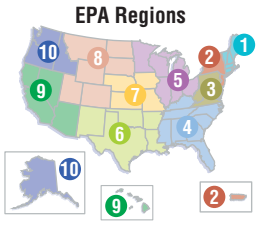
Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on SO_2 emissions data in the NEI (U.S. EPA, 2007b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the NEI data by source category and EPA Region.

Exhibit 2-28. 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, 2007b*

References

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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.

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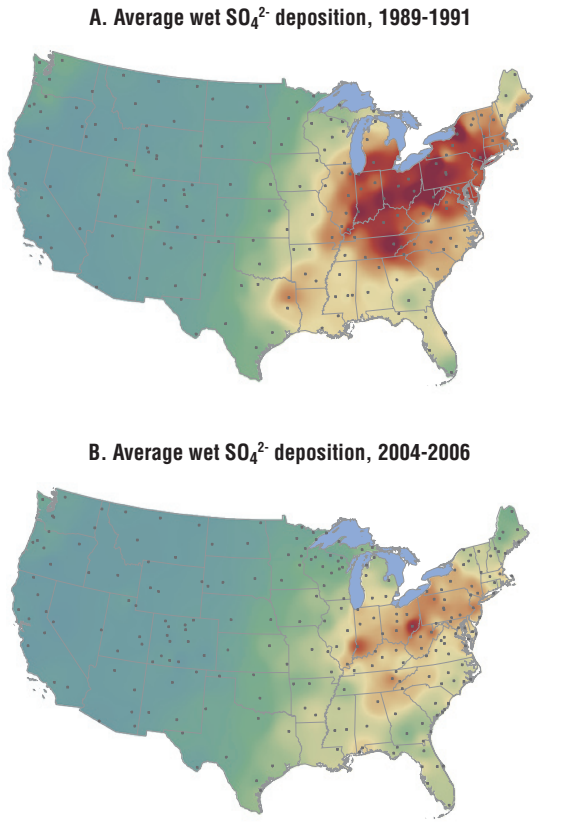
Every year, millions of tons of sulfur dioxide and nitrogen oxides are emitted to the atmosphere as a result of the burning of fossil fuels and from other high temperature sources (the Sulfur Dioxide Emissions indicator; the Nitrogen Oxides Emissions indicator). These gases react with water, oxygen, 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 to 80 percent of total acid deposition depending on location and climate (MACTEC Engineering and Consulting, Inc., 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, 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). 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. 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 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^{2-}] and nitrate [NO_3^-]), gaseous nitric acid (HNO_3), sulfur dioxide (SO_2), ammonia (NH_3), and ammonium (NH_4^+).

Exhibit 2-29. Wet sulfate (SO_4^{2-}) deposition in the contiguous U.S., 1989-1991 and 2004-2006[a]



[a]**Coverage:** 169 monitoring sites in 1989-1991 and 202 monitoring sites in 2004-2006.

Data source: *NADP, 2007*

This indicator uses the 3-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. Baseline data are compared to the most recent 3-year average data available (2004–2006). Use of 3-year average data helps ensure that trends reflect actual changes in acid deposition, instead of shorter-term fluctuations in meteorological conditions. Additionally, this indicator presents annual trend data for total deposition, which characterizes deposition over the entire period of record, not just for the baseline and most recent 3-year average periods.

What the Data Show

Wet Deposition Trends

Analyses of long-term monitoring data from the National Atmospheric Deposition Program show that wet deposition of both sulfur and nitrogen compounds has decreased over the last 17 years (Exhibits 2-29 and 2-30).

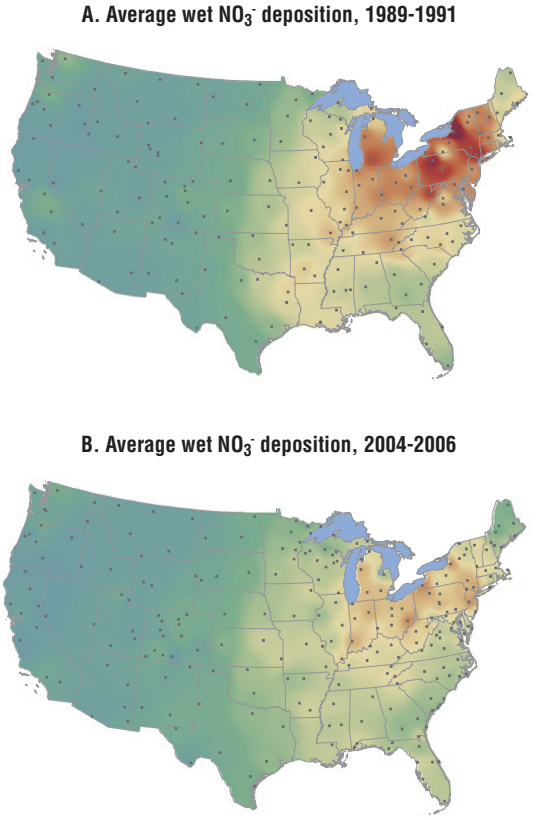
Wet sulfate deposition decreased across much of the U.S. during the 1990s (Exhibit 2-29). The greatest reductions in wet sulfate deposition occurred in the Mid-Appalachian region (Maryland, New York, West Virginia, Virginia, and most of Pennsylvania) and the Ohio River Valley. Less dramatic reductions 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 2004–2006 (panel B) were approximately 35 percent in the Northeast, 33 percent in the Midwest, 28 percent in the Mid-Atlantic, and 20 percent in the Southeast.

Wet nitrate deposition decreased approximately 33 percent across the Northeast and 27 percent in the Mid-Atlantic between the periods 1989–1991 (Exhibit 2-30, panel A) and 2004–2006 (panel B). However, there is a high degree of variability in the measurements used to calculate these percentages, complicating efforts to reliably estimate trends for wet nitrate deposition. Wet deposition of inorganic nitrogen has not changed substantially in the rest of the country over this period.

Total Deposition Trends

As with wet deposition, total deposition (the sum of wet and dry deposition) decreased between 1989–1991 and 2004–2006, and reductions were more substantial for sulfur compounds than for nitrogen compounds (Exhibits 2-31 and 2-32). In the eastern U.S., where data are most abundant, total sulfur deposition decreased by 36 percent between 1990 and 2005 (Exhibit 2-33), while total nitrogen deposition decreased by 19 percent over the same time frame (Exhibit 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 2-30. Wet nitrate (NO_3^-) deposition in the contiguous U.S., 1989-1991 and 2004-2006[a]



[a]**Coverage:** 169 monitoring sites in 1989-1991 and 202 monitoring sites in 2004-2006.

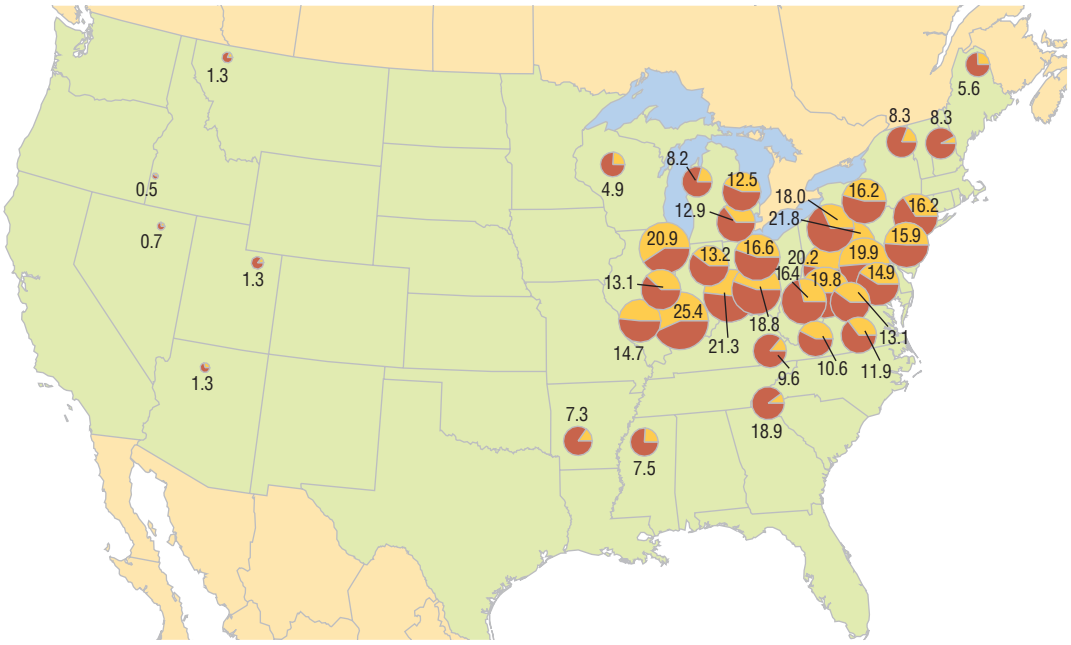
Data source: *NADP, 2007*

Indicator Limitations

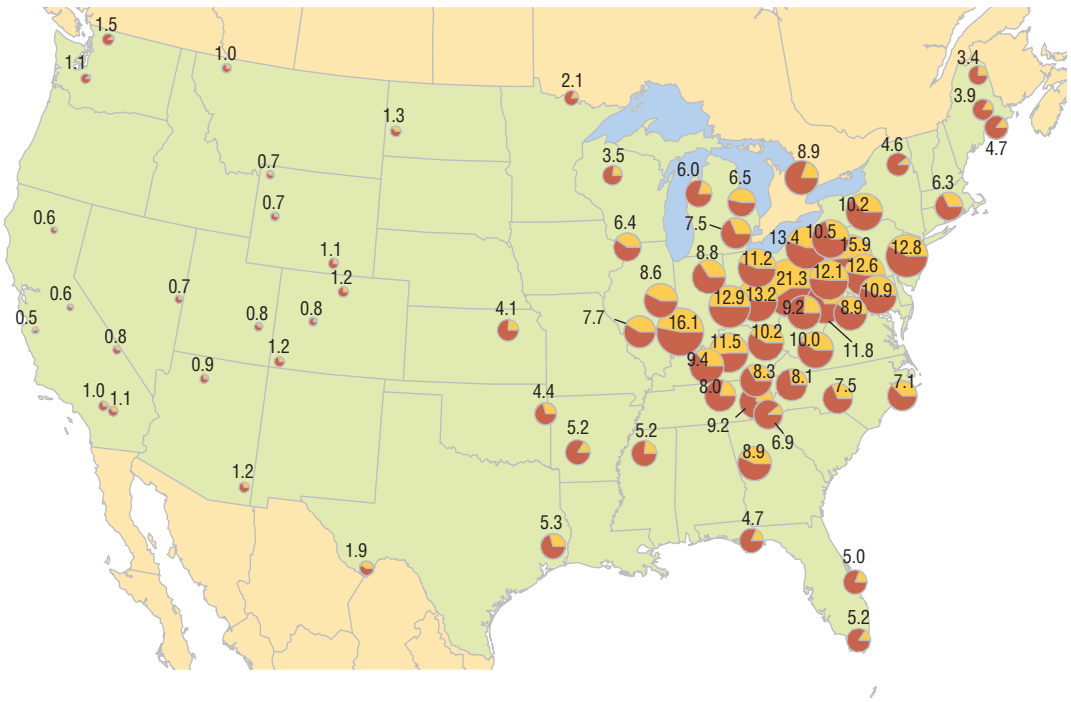
- Geographic coverage is limited, particularly for dry deposition (and thus total deposition as well), but the concentration of sites in the Midwest and Northeast is justified by the fact that acid rain is much more of a problem in those regions than it is in the West, Great Plains, or Southeast.
- Measurement 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.

Exhibit 2-31. Total sulfur deposition in the contiguous U.S., 1989-1991 and 2004-2006[a]

A. Average total sulfur deposition, 1989-1991

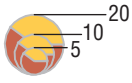


B. Average total sulfur deposition, 2004-2006



[a] **Coverage:** 37 monitoring sites in 1989-1991 and 73 monitoring sites in 2004-2006.

Data source: *NADP, 2007; U.S. EPA, 2007*



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

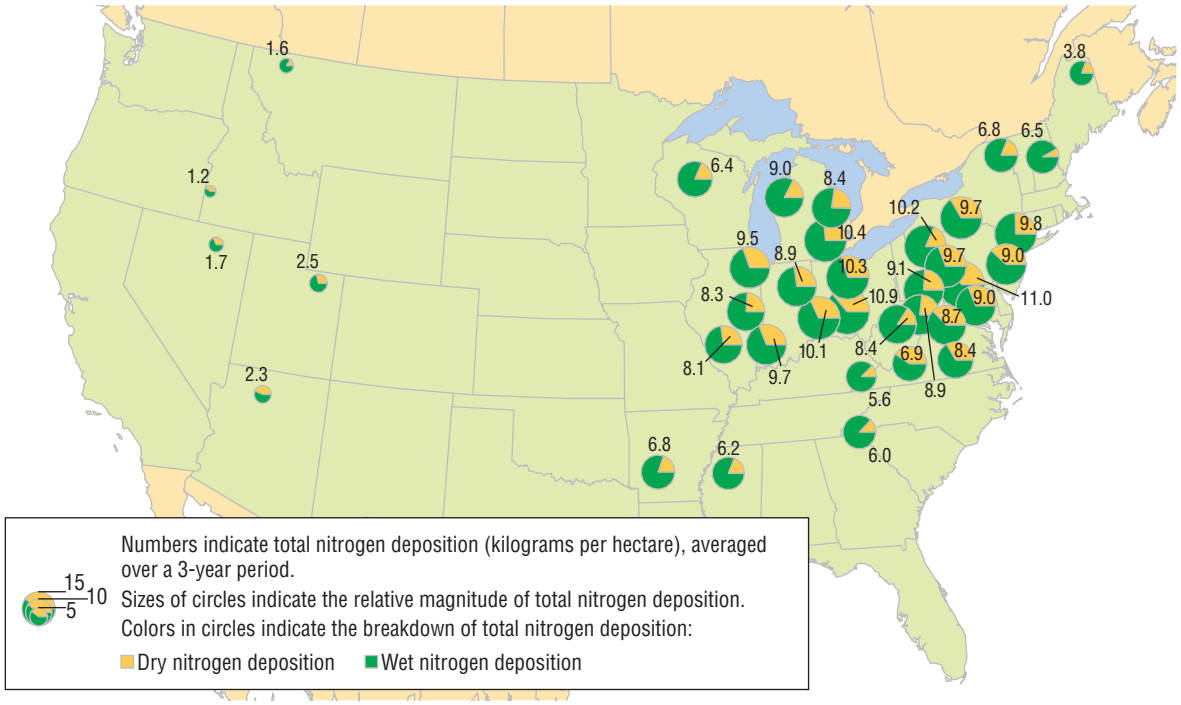
Sizes of circles indicate the relative magnitude of total sulfur deposition.

Colors in circles indicate the breakdown of total sulfur deposition:

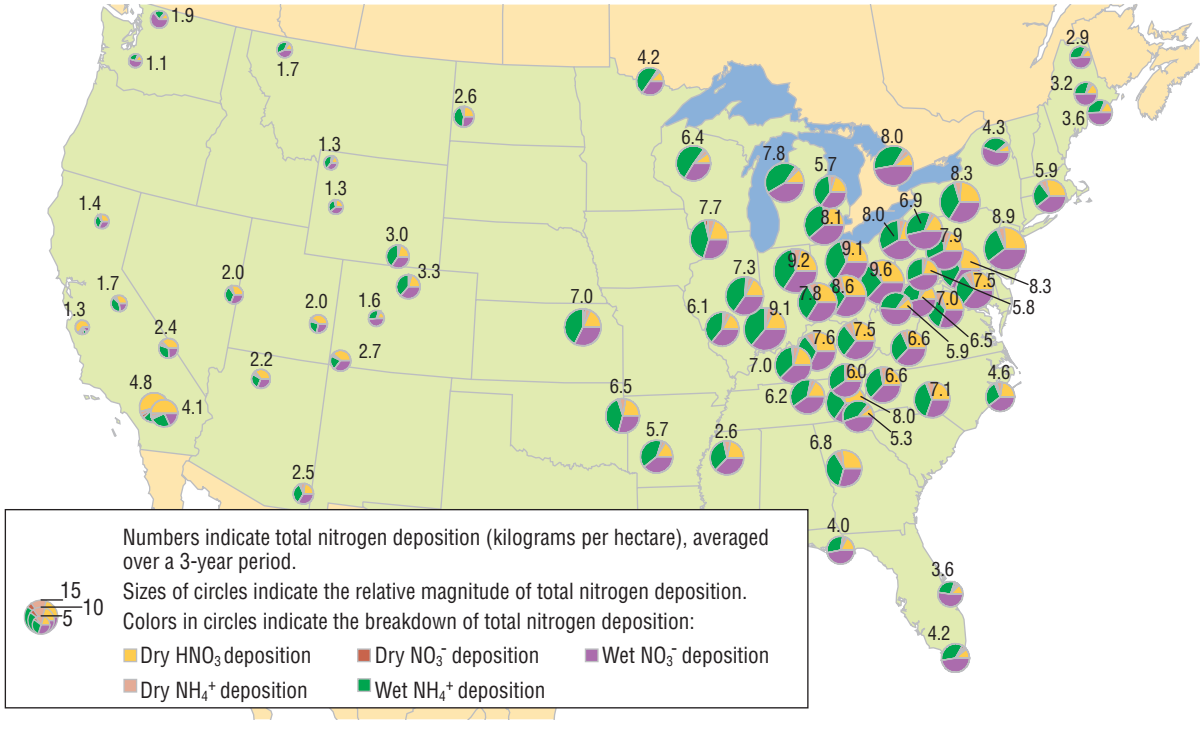
Dry sulfur deposition Wet sulfur deposition

Exhibit 2-32. Total nitrogen deposition in the contiguous U.S., 1989-1991 and 2004-2006[a]

A. Average total nitrogen deposition, 1989-1991



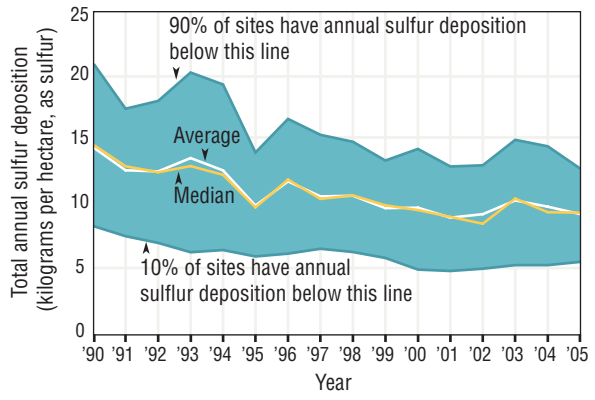
B. Average total nitrogen deposition, 2004-2006



[a] **Coverage:** 37 monitoring sites in 1989-1991 and 73 monitoring sites in 2004-2006.

Data source: *NADP, 2007; U.S. EPA, 2007*

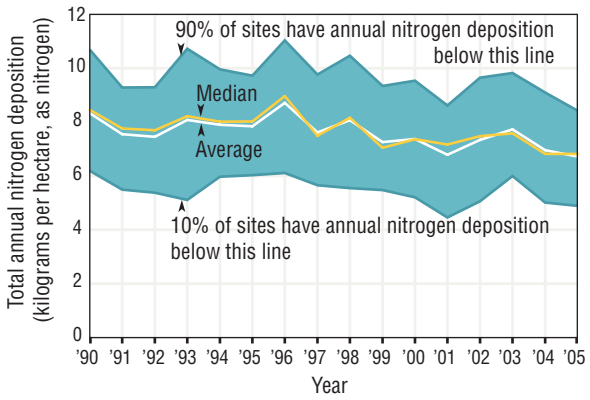
Exhibit 2-33. Total sulfur deposition in the eastern United States, 1990-2005[a]



[a]**Coverage:** 34 monitoring sites in the eastern United States.

Data source: *MACTEC Engineering and Consulting, Inc., 2006*

Exhibit 2-34. Total nitrogen deposition in the eastern United States, 1990-2005[a]



[a]**Coverage:** 34 monitoring sites in the eastern United States.

Data source: *MACTEC Engineering and Consulting, Inc., 2006*

Data Sources

Summary data in this indicator were provided by EPA's Office of Atmospheric Programs, based on deposition data from two sources. Wet deposition data are from the National Atmospheric Deposition Program/National Trends Network (NADP, 2007) (http://nadp.sws.uiuc.edu/), and dry deposition data are from the Clean Air Status and Trends Network (U.S. EPA, 2007) (http://www.epa.gov/castnet). This indicator aggregates 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 2-29 and 2-30.

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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.

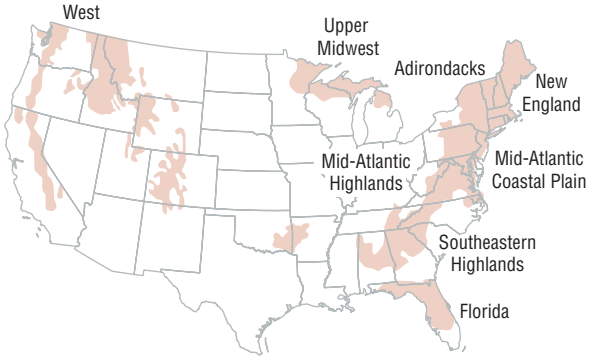
Acid deposition can have serious effects on aquatic ecosystems. For example, aquatic organisms in acidified waters can develop calcium deficiencies that weaken bones and exoskeletons and cause eggs to be weak or brittle. Acidified waters can impair the ability of fish gills to extract oxygen from water 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 explains the factors that contribute to acid deposition and describes how acid deposition patterns have changed over the last 17 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. Every body of water has a measurable ANC, which 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 microequivalents per liter (μeq/L) is usually considered insensitive to acidification; 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 8,664 lakes and 75,113 km of streams in the four geographic regions shown in Exhibit 2-36. These measurements were collected as part of the Temporally Integrated Monitoring of Ecosystems (TIME) project and on 78 additional acid-sensitive lakes and 78 acid-sensitive streams in the Long-Term Monitoring (LTM) project, for which data were available between 1992 and 2005 (U.S. EPA, 2003, 2007). The lakes sampled include only those in areas potentially sensitive to acidification with areas greater than 1 hectare. This indicator focuses only on the northeastern U.S.; because monitoring is not ongoing for western, Midwestern, and southeastern water bodies, trend data for those parts of the country are not available.

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



Data source: *NAPAP, 1991*

What the Data Show

Between the early 1990s and 2005, ANC 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 the early 1990s were no longer classified as such in 2005 (Exhibit 2-36, panels A and C). Specifically, between 1991-1994 and 2005, the percent of chronically acidic water bodies decreased in the Adirondack Mountains (from 13.0 percent to 6.2 percent) and in the Northern Appalachian Plateau (from 11.8 percent to 8.0 percent). Additionally, acid-sensitive lakes in New England are beginning to show a decrease in acidity: the percent of chronically acidic lakes in this region decreased from 5.6 percent in 1991-1994 to 4.3 percent in 2005 (panel B). This trend suggests that surface waters in these three regions 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 Northern Appalachian Plateau, and New England between the early 1990s and 2005 corresponds with a decrease in acid deposition in each of these regions (the Acid Deposition indicator) and reduced air emissions of the main precursors to acid deposition, which are sulfur dioxide (the Sulfur Dioxide Emissions indicator) and nitrogen oxides (the Nitrogen Oxides Emissions indicator).

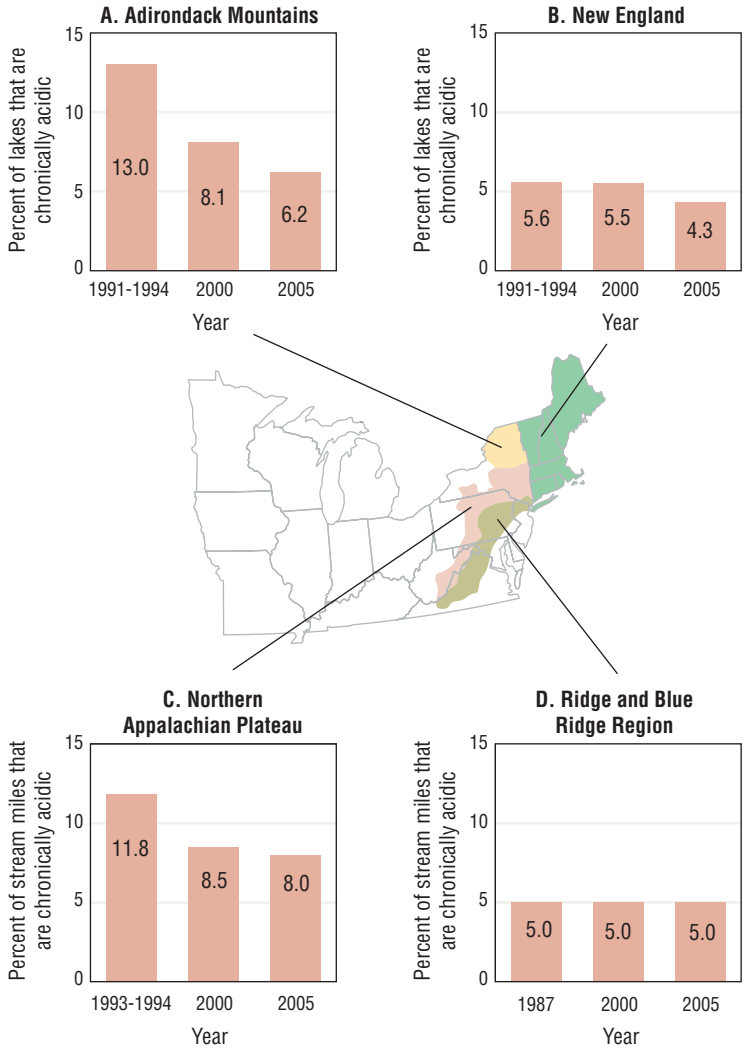
ANC in the Ridge and Blue Ridge Region (east-central Pennsylvania, western Maryland, and western Virginia) has not risen from its 1987 level (Exhibit 2-36, panel D). Therefore, the number of water bodies classified as "chronically

acidic" in this region remained essentially unchanged between 1987 and 2005.

Indicator Limitations

- ANC sampling is limited to four regions, all in the Northeast. (There is no long-term coverage in the Southeast, West, or Midwest.) These four 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 shows, many of these regions receive the highest rates of acid deposition in the U.S. For these 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.

Exhibit 2-36. Lake and stream acidity in selected acid-sensitive regions in the U.S., 1987-2005



Data source: *U.S. EPA, 1988, 2003, 2007*

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) and from more recent unpublished results (U.S. EPA, 2007). Trends are based on data collected in two networks: the TIME project and the LTM project. Because both networks are operated by numerous collaborators in state agencies, academic institutions, and other federal agencies, the 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).

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U.S. EPA. 1988. Chemical characteristics of streams in the mid-Atlantic and southeastern United States. Volume I: Population descriptions and physico-chemical relationships. EPA/600/3-88/021a. Washington, DC.

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, 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.

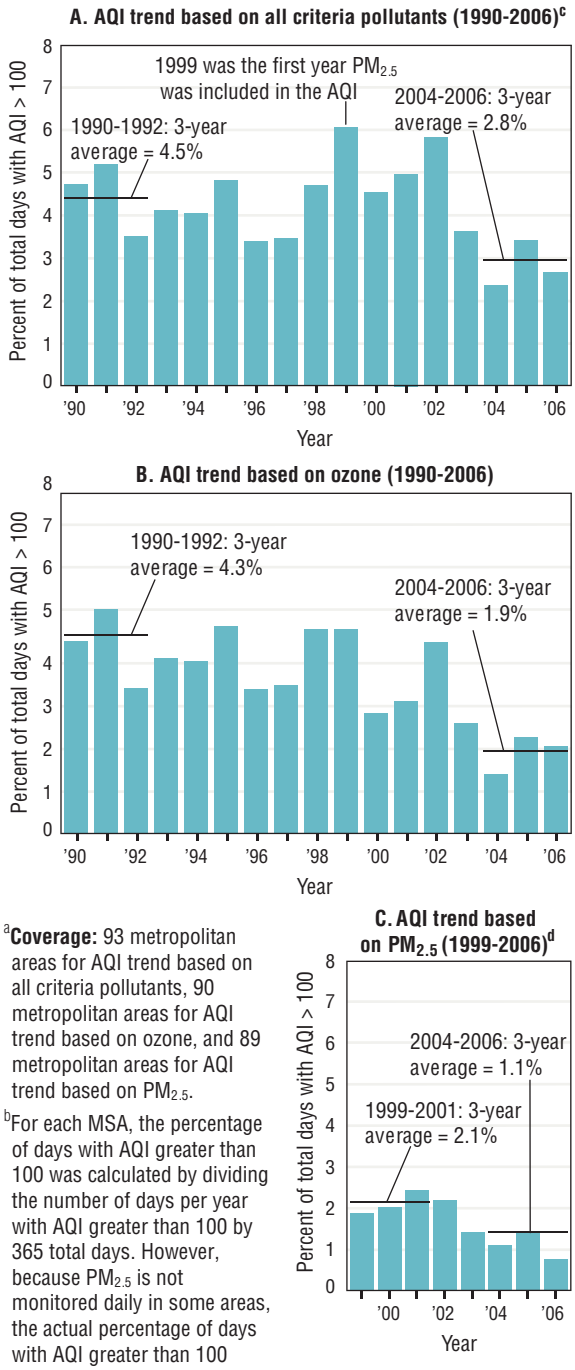
In 1999, the AQI was updated to reflect the latest science on air pollution health effects and to make it more appropriate for use in contemporary news media (U.S. EPA, 2003a). It also serves as a basis for community-based programs that encourage the public to take action to reduce air pollution on days when levels are projected to be of concern. The index has been adopted by many other countries (e.g., Mexico, Singapore, 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 network and by other special purpose monitors. 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 of 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. First, for each year, the total number of days with AQI above 100 in each of the 93 MSAs was summed in order to get a national total. Then, the national total was divided by the total number of days in the annual sample (365 × 93, or 33,945 days) to obtain the percentage of days with AQI above 100 in a year. Note that this

Exhibit 2-37. Percent of days with Air Quality Index (AQI) greater than 100 in selected U.S. metropolitan areas, 1990-2006[a,b]



[a]**Coverage:** 93 metropolitan areas for AQI trend based on all criteria pollutants, 90 metropolitan areas for AQI trend based on ozone, and 89 metropolitan areas for AQI trend based on $PM_{2.5}$.

[b]For each MSA, the percentage of days with AQI greater than 100 was calculated by dividing the number of days per year with AQI greater than 100 by 365 total days. However, because $PM_{2.5}$ is not monitored daily in some areas, the actual percentage of days with AQI greater than 100 might be higher than what is shown in Panels A and C.

[c]Lead does not factor into the AQI calculation for all criteria pollutants.

[d]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, 2007*

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

calculation will understate the actual percentage of days with AQI above 100 for pollutants that are not measured daily (e.g., $PM_{2.5}$).

Data are presented for 1990 through 2006. 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., 2004-2006). 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. Lead measurements do not factor into the AQI. Of the pollutants considered, only four (CO, ozone, PM, and SO_2) usually exhibit AQI values greater than 100.

What the Data Show

AQI Based on All Criteria Pollutants (Except Lead)

The percent of days with AQI greater than 100 in 93 large MSAs based on all criteria pollutants (except lead) decreased from 4.5 over the 1990-1992 time frame to 2.8 over the 2004-2006 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.

AQI Based on Ozone Only

For a nearly identical subset of MSAs, the percent of days with AQI values greater than 100 due to ozone levels alone (based on the 1997 NAAQS) decreased from 4.3 over the 1990-1992 time frame to 1.9 over the 2004-2006 time frame (Exhibit 2-37, panel B). Before $PM_{2.5}$ became part of the index in 1999, ozone typically accounted for more than 90 percent of the days with AQI greater than 100.

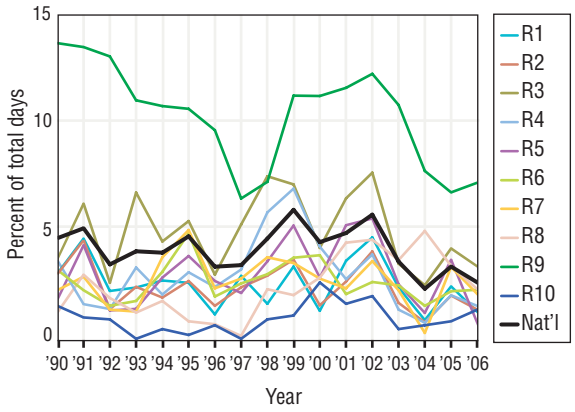
AQI Based on $PM_{2.5}$ Only

In the 1999-2001 period, $PM_{2.5}$ concentrations accounted for 2.1 percent of days with AQI greater than 100. This contribution decreased in subsequent years, falling to 1.1 percent for the 2004-2006 period.

AQI in the EPA Regions Based on All Criteria Pollutants (Except Lead)

Trends in AQI based on all criteria pollutants (except lead) between 1990 and 2006 varied across the ten EPA Regions (Exhibit 2-38). For nine of the Regions, the percent of days with AQI greater than 100 in 2006 was lower than that in 1990, though substantial year-to-year variability occurred. In Region 8, the percent of days with AQI greater than 100 in 2006 was higher than that observed in 1990. However, as noted above, the AQI values for 1990 and 2006 are not directly comparable, because $PM_{2.5}$ measurements did not factor into AQI prior to 1999.

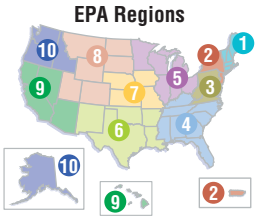
Exhibit 2-38. Percent of days with Air Quality Index (AQI) greater than 100 in selected U.S. metropolitan areas by EPA Region, 1990-2006[a,b]



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

[b]Trend is based on AQI data for all criteria pollutants, except for lead. Note that 1999 was the first year that $PM_{2.5}$ was included in the AQI.

Data source: *U.S. EPA, 2007*



Indicator Limitations

- The AQI does not address hazardous air pollutants.
- Air quality can 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 with AQI slightly above 100 and days with much higher AQI.
- 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.

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

- This indicator only covers the days on which ambient monitoring occurred. Because $PM_{2.5}$ is not sampled daily in some areas, the data presented in this indicator may understate the actual number of days on which AQI values were greater than 100 due to $PM_{2.5}$ concentrations. Although ozone is not sampled throughout the year, the percent of days with AQI greater than 100 is believed to be accurate because monitoring occurs throughout the summer, when ozone concentrations are highest.

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 ambient air monitoring data for criteria pollutants found in EPA's Air Quality System (U.S. EPA, 2007). Spreadsheets with the processed AQI data for the 93 MSAs considered in this indicator are publicly available (http://www.epa.gov/air/airtrends/factbook.html). This indicator aggregates the processed AQI data nationally and by EPA Region.

References

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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 | Air Toxics Emissions

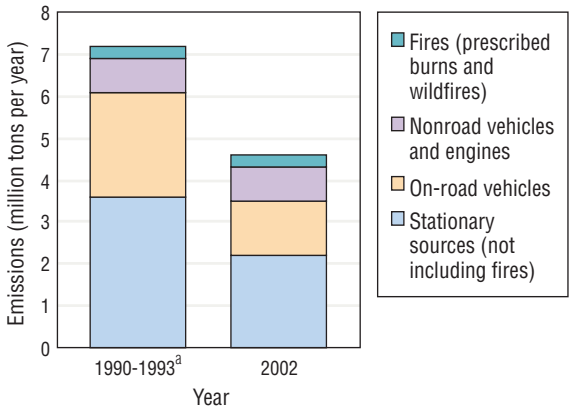
Toxic air pollutants, also known as air toxics or hazardous air pollutants (HAPs), are those pollutants that are known or suspected to cause cancer or are associated with other serious health (e.g., reproductive problems, birth defects) or ecological effects. Examples of air toxics include benzene, found 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 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, 2007a).

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 1990-1993 period and since then has been updated every 3 years. The baseline period 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.

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, 2007b*

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 hydrazine. These compounds were selected for display because EPA's 1999 National Air Toxics Assessment estimates that they 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, 2006). 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

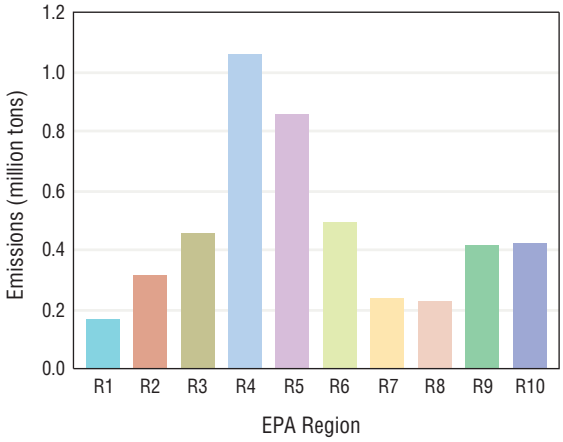
According to NEI data, estimated annual emissions for the 188 air toxics combined decreased 36 percent, from 7.2 million tons per year in the baseline period (1990–1993) to 4.6 million tons per year in 2002 (Exhibit 2-40). This downward trend resulted primarily from reduced emissions from stationary sources and on-road mobile sources.

In 2002, air toxics emissions in the ten EPA Regions ranged from 166,000 tons in Region 1 to 1,056,000 tons in Region 4 (Exhibit 2-41). Regional trends cannot be characterized, because a complete set of state and local air toxics emissions data are not available for the 1990–1993 baseline period.

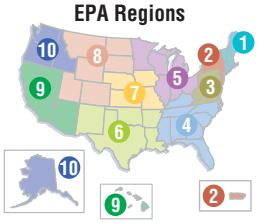
Trends for Selected Air Toxics

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, 2006). 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 (51 percent decrease; see panel A), benzene (17 percent; panel B), 1,3-butadiene (38 percent; panel C), ethylene dibromide (63 percent; panel D), and hydrazine (84 percent; panel E).

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



Data source: *U.S. EPA, 2007b*



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, 2006).

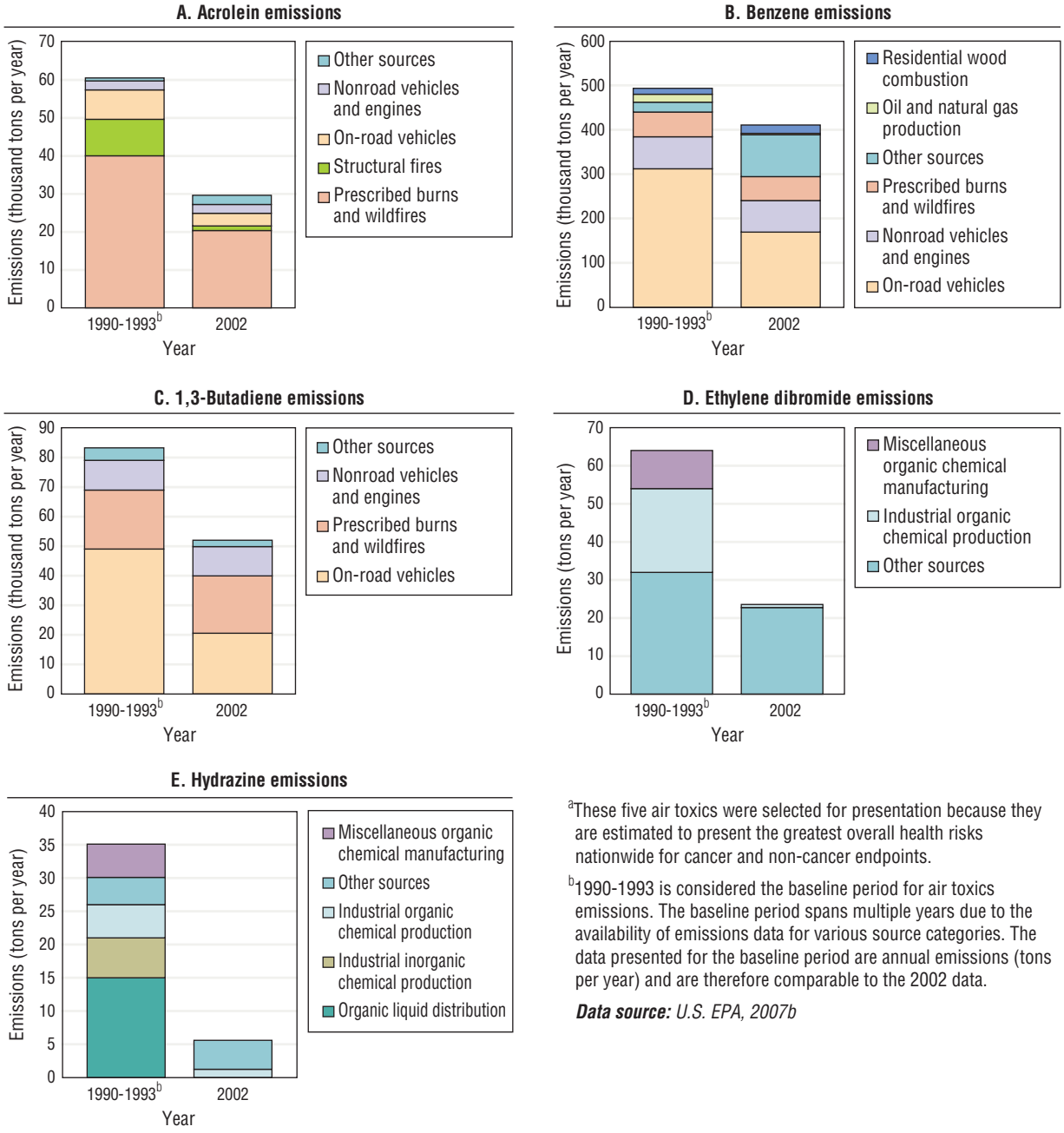
Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on air toxics emissions data in the NEI (U.S. EPA, 2007b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the 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/report.htm>

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, 2007b*

U.S. EPA (United States Environmental Protection Agency). 2007a. Documentation for the final 2002 mobile National Emissions Inventory, Version 3. <ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002_mobile_nei_version_3_report_092807.pdf>

U.S. EPA. 2007b. Data from the 2002 National Emissions Inventory, Version 3.0. Accessed 2007. <http://www.epa.gov/ttn/chief/net/2002inventory.html>

U.S. EPA. 2006. 1999 national-scale air toxics assessment. <http://www.epa.gov/ttn/atw/nata1999> February.

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 and Phosphorus Loads in Large Rivers

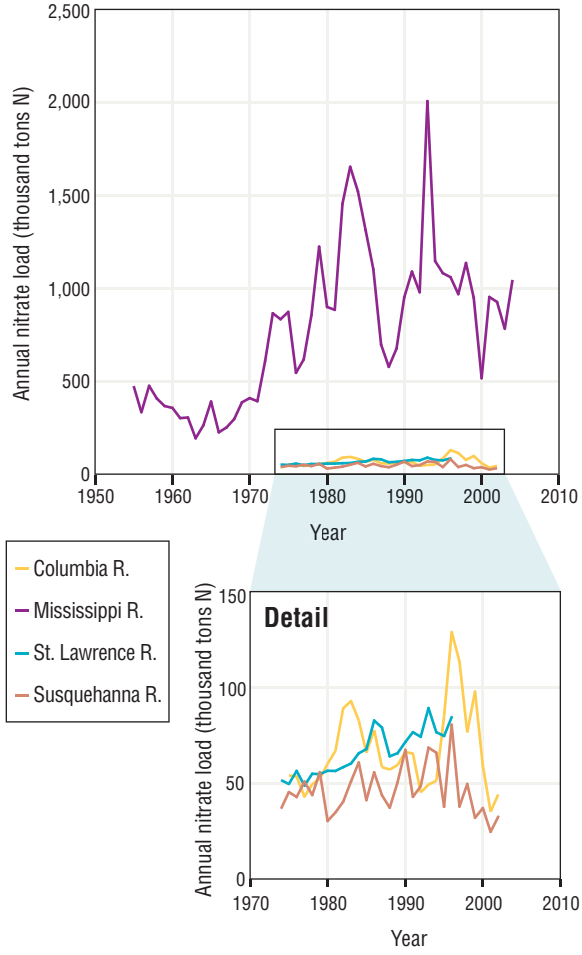
Nitrogen is a critical nutrient for plants and animals, and terrestrial ecosystems and headwater streams have a considerable ability to capture nitrogen or to reduce it to N_2 gas though the process of denitrification. Nitrogen cycling and retention is thus one of the most important functions of ecosystems (Vitousek et al., 2002). When loads of nitrogen from fertilizer, septic tanks, and atmospheric deposition exceed the capacity of terrestrial systems (including croplands), the excess may enter surface waters, where it may have "cascading" harmful effects as it moves downstream to coastal ecosystems (Galloway and Cowling, 2002). Other sources of excess nitrogen include direct discharges from storm water or treated wastewater. This indicator specifically focuses on nitrate, which is one of the most bioavailable forms of nitrogen in bodies of water.

Phosphorus is a critical nutrient for all forms of life, but like nitrogen, phosphorus that enters the environment from anthropogenic sources may exceed the needs and capacity of the terrestrial ecosystem. As a result, excess phosphorus may enter lakes and streams. Because phosphorus is often the limiting nutrient in these bodies of water, an excess may contribute to unsightly algal blooms, which cause taste and odor problems and deplete oxygen needed by fish and other aquatic species. In some cases, excess phosphorus can combine with excess nitrogen to exacerbate algal blooms (i.e., in situations where algal growth is co-limited by both nutrients), although excess nitrogen usually has a larger effect downstream in coastal waters. The most common sources of phosphorus in rivers are fertilizer and wastewater, including storm water and treated wastewater discharged directly into the river. In most watersheds, the atmosphere is not an important source or sink for phosphorus.

This indicator tracks trends in nitrate and phosphorus loads carried by four of the largest rivers in the United States: the Mississippi, Columbia, St. Lawrence, and Susquehanna. While not inclusive of the entire nation, these four rivers account for approximately 55 percent of all freshwater flow entering the ocean from the contiguous 48 states, and have a broad geographical distribution. This indicator relies on stream flow and water-quality data collected by the U.S. Geological Survey (USGS), which has monitored nutrient export from the Mississippi River since the mid-1950s and from the Susquehanna, St. Lawrence, and Columbia Rivers since the 1970s. Data were collected near the mouth of each river except the St. Lawrence, which was sampled near the point where it leaves the United States.

At the sites for which data are included in this indicator, USGS recorded daily water levels and volumetric discharge using permanent stream gauges. Water quality samples were collected at least quarterly over the period of interest, in some cases up to 15 times per year. USGS calculated annual nitrogen load from these data using regression models relating nitrogen concentration to discharge, day-of-year (to capture seasonal effects), and time (to capture any trend over the period). These models were used to make daily estimates of concentrations, which were multiplied by the daily flow to calculate the daily nutrient load (Aulenbach, 2006; Heinz Center, 2005). Because data on forms of nitrogen other than nitrate and nitrite are not as prevalent in the historical record, this indicator only uses

Exhibit 3-10. Nitrate loads in four major U.S. rivers, 1955-2004[a]



[a]Most measurements include nitrate plus nitrite, but because concentrations of nitrite are typically insignificant relative to nitrate, this mixture is simply called "nitrate."

Data source: *USGS, 2007a*

Areas drained by these four rivers

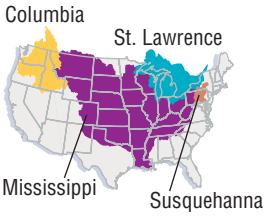
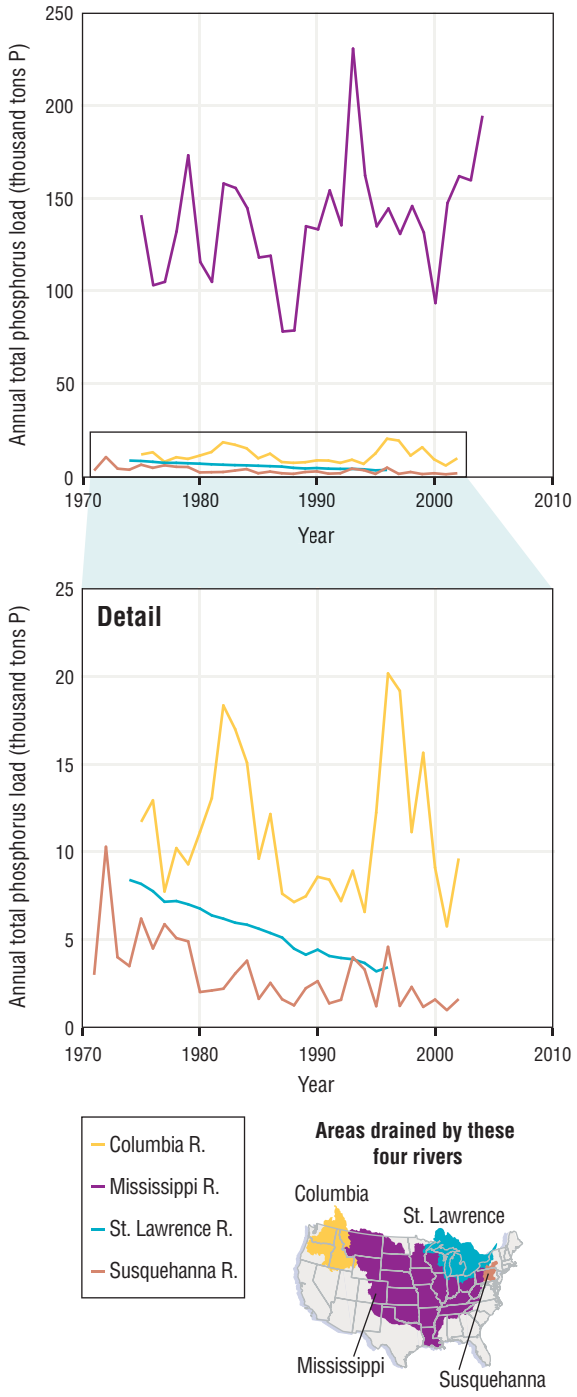


Exhibit 3-11. Total phosphorus loads in four major U.S. rivers, 1971-2004



Data source: *USGS, 2007a*

measurements of nitrate plus nitrite. As nitrite concentrations are typically very small relative to nitrate, this mixture is simply referred to as nitrate.

What the Data Show

The Mississippi River, which drains more than 40 percent of the area of the contiguous 48 states, carries roughly 15 times more nitrate than any other U.S. river. Nitrate load in the Mississippi increased noticeably over much of the last half-century, rising from 200,000-500,000 tons per year in the 1950s and 1960s to an average of about 1,000,000 tons per year during the 1980s and 1990s (Exhibit 3-10). Large year-to-year fluctuations are also evident. The Mississippi drains the agricultural center of the nation and contains a large percentage of the growing population, so it may not be surprising that the watershed has not been able to assimilate all the nitrogen from sources such as crop and lawn applications, animal manure and human wastes, and atmospheric deposition (e.g., Rabalais and Turner, 2001).

The Columbia River's nitrate load increased to almost twice its historical loads during the later half of the 1990s, but by the last year of record (2002), the nitrate load had returned to levels similar to those seen in the late 1970s (Exhibit 3-10). The St. Lawrence River showed an overall upward trend in nitrate load over the period of record, while the Susquehanna does not appear to have shown an appreciable trend in either direction. Over the period of record, the Columbia and St. Lawrence carried an average of 67,000 and 66,000 tons of nitrate per year, respectively, while the Susquehanna averaged 46,000 tons. By comparison, the Mississippi carried an average of 772,000 tons per year over its period of record.

The total phosphorus load decreased in the St. Lawrence and Susquehanna Rivers over the period of record (Exhibit 3-11). There is no obvious trend in the Mississippi and Columbia Rivers, and the year-to-year variability is quite large. Nitrogen and phosphorus loads tend to be substantially higher during years of high precipitation, because of increased erosion and transport of the nutrients to stream channels (Smith et al., 2003). Over the full period of record, average annual phosphorus loads for the Mississippi, Columbia, St. Lawrence, and Susquehanna were 138,000; 11,000; 6,000; and 3,000 tons, respectively.

Indicator Limitations

- The indicator does not include data from numerous coastal watersheds whose human populations are rapidly increasing (e.g., Valigura et al., 2000).
- It does not include smaller watersheds in geologically sensitive areas, whose ability to retain nitrogen might be affected by acid deposition (e.g., Evans et al., 2000).

- It does not include forms of nitrogen other than nitrate. Although nitrate is one of the most bioavailable forms of nitrogen, other forms may constitute a substantial portion of the nitrogen load. Historically, nitrate data are more extensive than data on other forms of nitrogen.
- Not all forms of phosphorus included in the total phosphorus loads are equally capable of causing algal blooms.

Data Sources

Data were compiled for EPA by USGS (USGS, 2007a), which provided a similar analysis to the Heinz Center for its updated report. Nutrient loads for the Columbia, St. Lawrence, and Susquehanna were originally reported in Aulenbach (2006); portions of the Mississippi analysis were previously published in Goolsby et al. (1999), while other portions have not yet been published. Underlying nutrient sampling and daily stream flow data can be obtained from USGS's public databases (USGS, 2007b,c).

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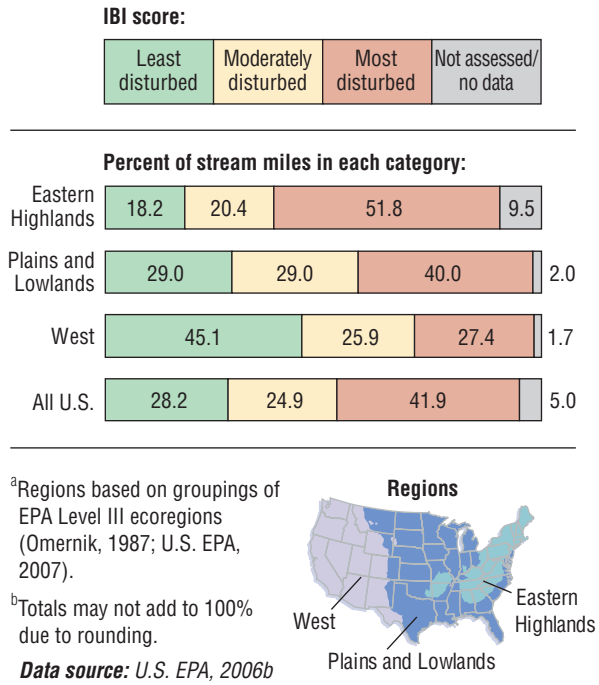
Freshwater benthic macroinvertebrate communities are composed primarily of insect larvae, mollusks, and worms. They are an essential link in the aquatic food web, providing food for fish and consuming algae and aquatic vegetation (U.S. EPA, 2006b). The presence and distribution of macroinvertebrates in streams can vary across geographic locations based on elevation, stream gradient, and substrate (Barbour et al., 1999). These organisms are sensitive to disturbances in stream chemistry and physical habitat, both in the stream channel and along the riparian zone, and alterations to the physical habitat or water chemistry of the stream can have direct and indirect impacts on their community structure. Because of their relatively long life cycles (approximately 1 year) and limited migration, benthic macroinvertebrates are particularly susceptible to site-specific stressors (Barbour et al., 1999).

This indicator is based on data collected for EPA's Wadeable Streams Assessment (WSA). Wadeable streams are streams, creeks, and small rivers that are shallow enough to be sampled using methods that involve wading into the water. They typically include waters classified as 1st through 4th order in the Strahler Stream Order classification system (Strahler, 1952). Between 2000 and 2004, crews sampled 1,392 sites throughout the contiguous U.S. using standardized methods (U.S. EPA, 2004a,b). Sites were sampled between mid-April and mid-November. At each site, a composite bottom sample was collected from eleven equally spaced transects within the sample reach. The WSA is based on a probabilistic design, so results from the sample sites can be used to make statistically valid statements about the percentage of wadeable stream miles that fall above or below reference values for the indicator.

For this analysis, the 48 contiguous states were divided into nine broad ecoregions (U.S. EPA, 2006b), which were defined by the WSA based on groupings of EPA Level III ecoregions (Omernik, 1987; U.S. EPA, 2007). Benthic community condition was determined using two different approaches, each reflecting a distinct aspect of the indicator: an Index of Biological Integrity (IBI) and an observed/expected (O/E) predictive model.

The IBI is an index that reduces complex information about community structure into a simple numerical value based on measures of taxonomic richness (number of taxa); taxonomic composition (e.g., insects vs. non-insects); taxonomic diversity; feeding groups (e.g., shredders, scrapers, or predators); habits (e.g., burrowing, clinging, or climbing taxa); and tolerance to stressors. Separate metrics were used for each of these categories in the nine WSA ecoregions, based on their ability to best discriminate among streams. Each metric was scaled against the 5th-95th percentiles for the streams in each region to create an overall IBI, whose value ranges from 0 to 100 (Stoddard et al., 2005).

Exhibit 3-13. Index of Biological Integrity (IBI) for benthic macroinvertebrates in wadeable streams of the contiguous U.S., by region, 2000-2004[a,b]



[a]Regions based on groupings of EPA Level III ecoregions (Omernik, 1987; U.S. EPA, 2007).

[b]Totals may not add to 100% due to rounding.

Data source: *U.S. EPA, 2006b*

Once the overall IBI was established, a set of relatively undisturbed sites was selected in order to determine the range of IBI scores that would be expected among "least disturbed" sites. A separate reference distribution was developed for each ecoregion. Next, the IBI score for every sampled site was compared to the distribution of IBI scores among the ecoregion's reference sites. If a site's IBI score was below the 5th percentile of the regional reference distribution, the site was classified as "most disturbed." This threshold was used because it offers a high degree of confidence that the observed condition is statistically different from the "least disturbed" reference condition. Streams with IBI scores above the 25th percentile of the reference range were labeled "least disturbed," indicating a high probability that they are similar to the relatively undisturbed reference sites. Streams falling between the 5th and 25th percentiles were classified as "moderately disturbed." In addition to national totals, this indicator displays IBI scores for three broad regions, which are composed of multiple WSA ecoregions and which share major climate and landform characteristics (U.S. EPA, 2006b).

The O/E predictive model compares the actual number of macroinvertebrate taxa observed at each WSA site (O) with the number expected (E) to be found at a site that is

in minimally disturbed condition (Armitage, 1987). First, reference sites were divided into several groups based on the observed benthic assemblages, and the probability of observing each taxon in each group of sites was determined. Next, a multivariate model was used to characterize each group of reference sites in terms of their shared physical characteristics (variables that are largely unaffected by human influence, such as soil type, elevation, and latitude). This predictive model then was applied to each test site to determine which group(s) of reference sites it should be compared to. For each test site, the "expected" probability of observing each taxon was calculated as a weighted average based on the probability of observing that taxon in a particular group of reference sites and the probability that the test site is part of that particular group of sites, based on physical characteristics. The total "E" for the test site was generated by adding the probabilities of observing each of the individual taxa. The actual number of taxa collected at the site (O) was divided by "E" to arrive at an O/E ratio (Hawkins et al., 2000; Hawkins and Carlisle, 2001). An O/E of 1.0 means the site's taxa richness is equal to the average for the reference sites. Each tenth of a point below 1 suggests a 10 percent loss of taxa.

What the Data Show

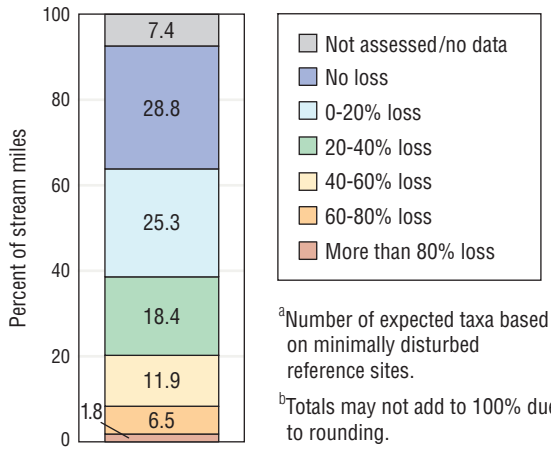
Based on the IBI, slightly more than one-quarter of wadeable stream miles nationwide (28.2 percent) were classified as "least disturbed" with respect to benthic macroinvertebrate condition, while 41.9 percent were in the "most disturbed" category (Exhibit 3-13). Of the three major stream regions in the nation (see the inset map, Exhibit 3-13), the eastern highlands had the lowest percentage of "least disturbed" stream miles (18.2 percent), while the western region had the highest percentage (45.1 percent).

Because there are no agreed-upon thresholds for the O/E model, the results are presented in 20 percent increments of taxa losses for the contiguous 48 states (Exhibit 3-14). Nearly 40 percent (38.6 percent) of wadeable stream miles have lost more than 20 percent of their macroinvertebrate taxa, compared to comparable minimally disturbed reference sites, and 8.3 percent of stream miles have lost more than 60 percent of their macroinvertebrate taxa.

Indicator Limitations

- Although the probability sampling design results in unbiased estimates for the IBI and O/E in wadeable streams during the April-November index period, values may be different during other seasons.
- Reference conditions for the IBI and O/E vary from one ecoregion to another in both number and quality, which limits the degree of ecoregional resolution at which this indicator can be calculated.

Exhibit 3-14. Percent loss of benthic macroinvertebrate taxa in wadeable streams of the contiguous U.S., relative to the number of expected taxa, 2000-2004[a,b]



[a]Number of expected taxa based on minimally disturbed reference sites.

[b]Totals may not add to 100% due to rounding.

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

- Because "E" is subject to both model error and sampling error, O/E values near 1.0 (above or below) do not necessarily imply a gain or loss of species relative to the reference conditions.
- Trend data are unavailable because this is the first time that a survey on this broad scale has been conducted, and the survey design does not allow trends to be calculated within a single sampling period (2000-2004). These data will serve as a baseline for future surveys.

Data Sources

The results shown in Exhibit 3-13 were previously published in EPA's 2006 Wadeable Streams Assessment (WSA) report (U.S. EPA, 2006b). The data in Exhibit 3-14 are based on frequency distributions provided by the WSA program (U.S. EPA, 2005) (U.S. EPA [2006b] also presents results from the O/E analysis, but using different categories). Data from individual stream sites can be obtained from EPA's STORET database (U.S. EPA, 2006a) (http://www.epa.gov/owow/streamsurvey/web_data.html).

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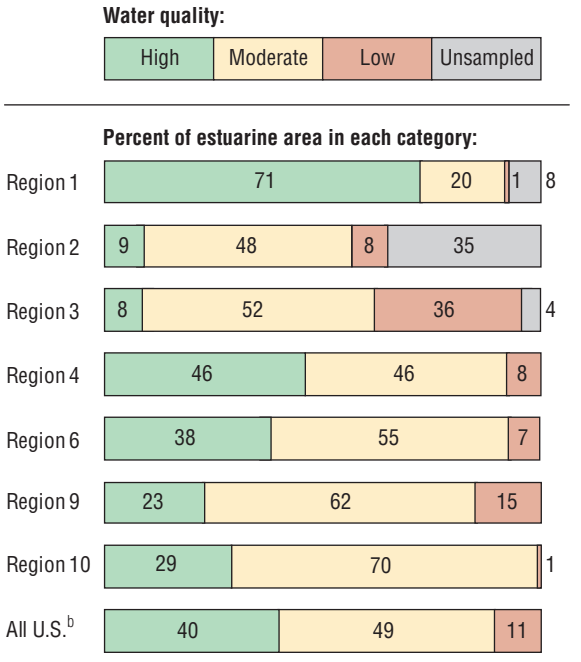
While the presence of many water pollutants can lead to decreases in coastal water quality, four interlinked components related to trophic state are especially critical: nutrients (nitrogen and phosphorus), chlorophyll-*a,* dissolved oxygen, and water clarity. "Trophic state" generally refers to aspects of aquatic systems associated with the growth of algae, decreasing water transparency, and low oxygen levels in the lower water column that can harm fish and other aquatic life. Nitrogen is usually the most important limiting nutrient in estuaries, driving large increases of microscopic phytoplankton called "algal blooms" or increases of large aquatic bottom plants, but phosphorus can become limiting in coastal systems if nitrogen is abundant in a bioavailable form (U.S. EPA, 2003). Nitrogen and phosphorus can come from point sources, such as wastewater treatment plants and industrial effluents, and nonpoint sources, such as runoff from farms, over-fertilized lawns, leaking septic systems, and atmospheric deposition. Chlorophyll-*a* is a surrogate measure of phytoplankton abundance in the water column. Chlorophyll-*a* levels are increased by nutrients and decreased by filtering organisms (e.g., clams, mussels, or oysters). High concentrations of chlorophyll-*a* indicate overproduction of algae, which can lead to surface scums, fish kills, and noxious odors (U.S. EPA, 2004). Low dissolved oxygen levels and decreased clarity caused by algal blooms or the decay of organic matter from the watershed are stressful to estuarine organisms. Reduced water clarity (usually measured as the amount and type of light penetrating water to a depth of 1 meter) can be caused by algal blooms, sediment inputs from the watershed, or storm-related events that cause resuspension of sediments, and can impair the normal growth of algae and other submerged aquatic vegetation.

This indicator, developed as part of EPA's Coastal Condition Report, is based on an index constructed from probabilistic survey data on five components: dissolved inorganic nitrogen, dissolved inorganic phosphorus, chlorophyll-*a,* daytime dissolved oxygen in bottom or near-bottom waters (where benthic life is most likely to be affected), and water clarity (U.S. EPA, 2004). The survey, part of EPA's National Coastal Assessment (NCA), was designed to provide a national picture of water quality by sampling sites in estuarine waters throughout the contiguous 48 states and Puerto Rico. Each site was sampled once during the 1997-2000 period, within an index period from July to September. The indicator reflects average condition during this index period.

Key factors like sediment load, mixing processes, and ecosystem sensitivity naturally vary across biogeographic regions and even among estuaries within regions. Thus, reference guidelines for nutrients, water clarity, and chlorophyll-*a* were established based on variable expectations for conditions in different biogeographic regions. For example, due to Pacific upwelling during the summer, higher nutrient and chlorophyll-*a* concentrations are expected in West Coast estuaries than in other estuaries. Water clarity reference guidelines are lower for estuaries that support seagrass than for naturally turbid estuaries. A single national reference range of 2-5 milligrams per liter (mg/L) was used for dissolved oxygen, because concentrations below 2 mg/L are almost always harmful to many forms of aquatic life and concentrations above 5 mg/L seldom are (Diaz and Rosenberg, 1995; U.S. EPA, 2000). The process of classifying individual sites varies by region and is described in detail, along with the regional reference conditions, in U.S. EPA (2004).

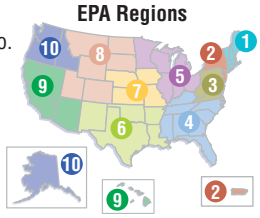
The overall water quality index is a compilation of the five components. For each site, the index is rated high if none of the five components received a score that would

Exhibit 3-21. Coastal water quality index for the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a]



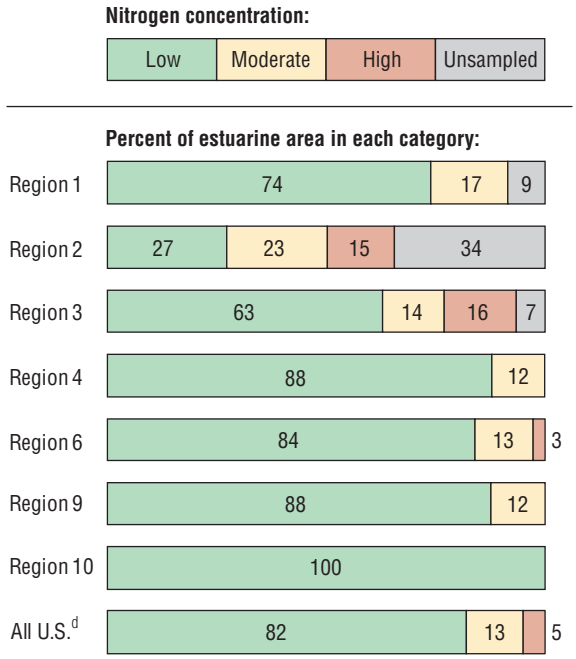
[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico. Does not include the hypoxic zone in offshore Gulf Coast waters.

[b]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.



Data source: *U.S. EPA, 2004, 2005a*

Exhibit 3-22. Nitrogen concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a,b,c]



[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

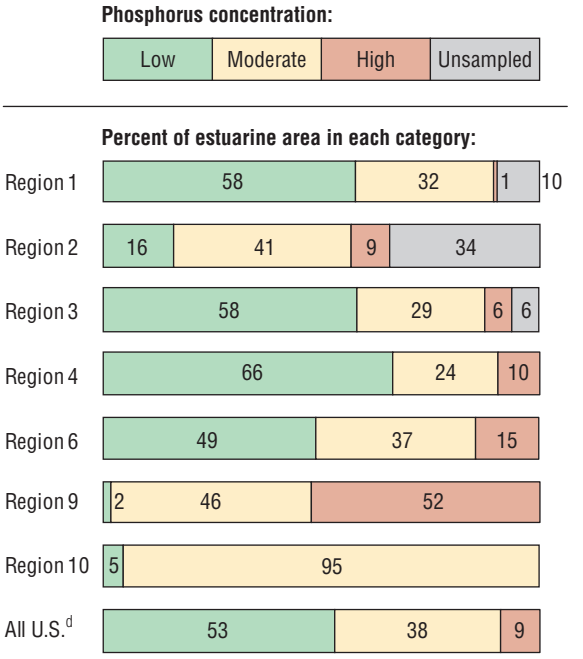
[b]This indicator measures dissolved inorganic nitrogen (DIN), which is the sum of nitrate, nitrite, and ammonia.

[c]Totals may not add to 100% due to rounding.

[d]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

Data source: *U.S. EPA, 2004, 2005a*

Exhibit 3-23. Phosphorus concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a,b,c]



[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

[b]This indicator measures dissolved inorganic phosphorus (DIP), which equals orthophosphate.

[c]Totals may not add to 100% due to rounding.

[d]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

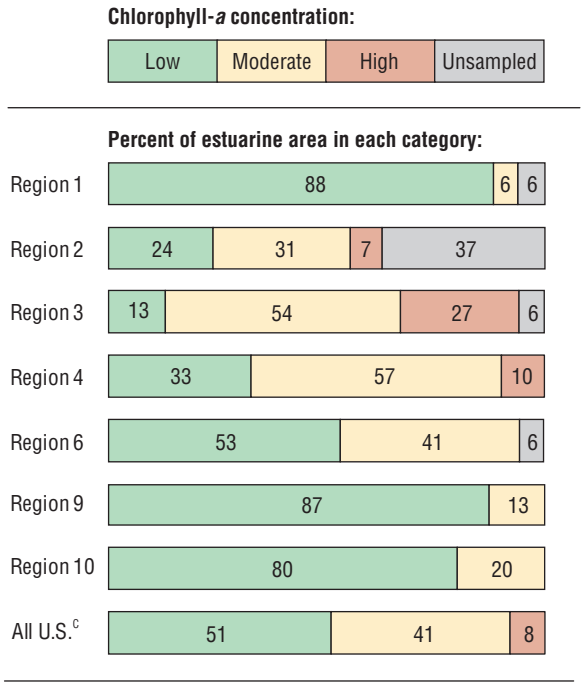
Data source: *U.S. EPA, 2004, 2005a*

be considered environmentally unfavorable (high nitrogen, phosphorus, or chlorophyll-*a* levels or low dissolved oxygen or water clarity), and no more than one component was rated moderate. Overall water quality is low if more than two components received the most unfavorable rating. All other sites receive a moderate index score. If two or more components are missing, and the available components do not suggest a moderate or low index rating, the site is classified as "unsampled." Data from the individual sites were expanded from the probability sample to provide unbiased estimates of the water quality index and each of its components for each EPA Region. Results were also aggregated and weighted by estuarine area for the entire nation.

What the Data Show

According to the index, 40 percent of estuarine surface area nationwide exhibited high water quality over the 1997-2000 period, 11 percent had low water quality, and the remaining 49 percent was rated moderate (Exhibit 3-21). Scores vary considerably among EPA Regions, ranging from high water quality in 71 percent of estuarine area in Region 1 to less than 10 percent in Regions 2 and 3. Only one EPA Region had low water quality in more than 15 percent of its estuarine area (EPA Region 3, with 36 percent). These percentages do not include the Great Lakes or the hypoxic zone in offshore Gulf Coast waters (see the Hypoxia in Gulf of Mexico and Long Island Sound indicator).

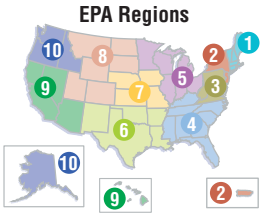
Exhibit 3-24. Chlorophyll-*a* concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a,b]



[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

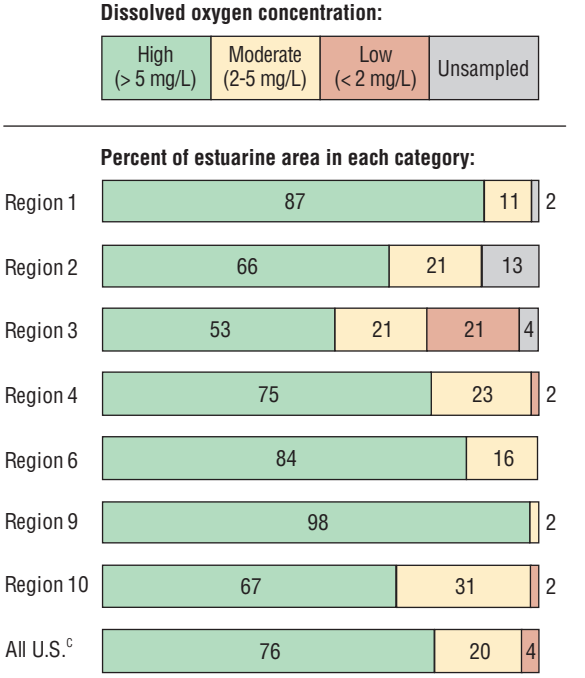
[b]Totals may not add to 100% due to rounding.

[c]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.



Data source: *U.S. EPA, 2004, 2005a*

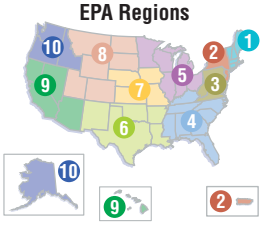
Exhibit 3-25. Dissolved oxygen levels in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a,b]



[a]**Coverage:** Bottom- or near bottom-water dissolved oxygen in estuarine waters of the contiguous 48 states and Puerto Rico. Does not include the hypoxic zone in offshore Gulf Coast waters.

[b]Totals may not add to 100% due to rounding.

[c]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.



Data source: *U.S. EPA, 2004, 2005a*

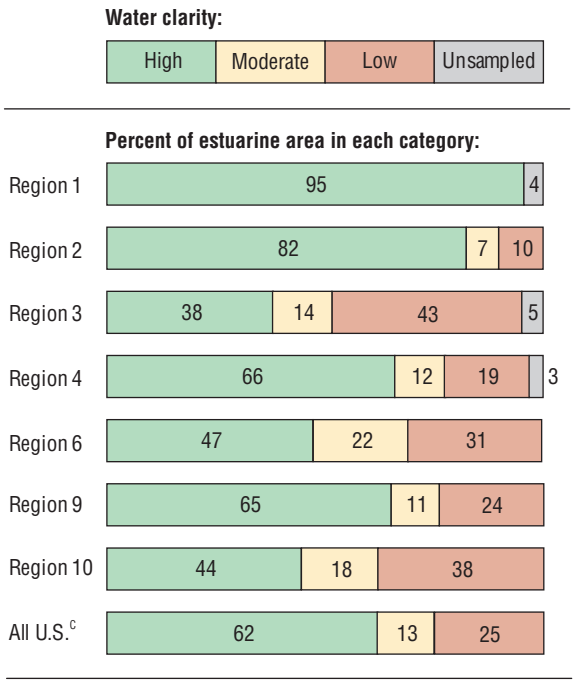
Nitrogen concentrations were low in 82 percent of estuarine area and high in 5 percent nationwide, and were low in a majority of the estuarine area in all but one EPA Region (Exhibit 3-22). Regions 2 and 3 had the largest percentage of area with high concentrations (15 percent and 16 percent, respectively); several other EPA Regions had no areas with high concentrations.

Phosphorus concentrations were low in 53 percent of estuarine area and high in 9 percent nationwide (Exhibit 3-23). Region 9 had the largest proportion of area exceeding reference conditions (52 percent), while Region 10 had the least (none).

Chlorophyll-*a* concentrations were low in 51 percent and high in 8 percent of estuarine area nationwide (Exhibit 3-24). Region 3 had the largest percentage of area exceeding reference conditions (27 percent); all other EPA Regions had 10 percent or less in this category.

Bottom-water dissolved oxygen was above 5 mg/L in over three-fourths of the nation's estuarine area and below 2 mg/L in only 4 percent (Exhibit 3-25). While effects vary with temperature and salinity, as a general rule, concentrations of dissolved oxygen above 5 mg/L are considered supportive of marine life, concentrations below 5 mg/L are potentially harmful, and concentrations below 2 mg/L—a common threshold for hypoxia—are associated with a wider range of harmful effects (e.g., some juvenile fish and crustaceans that cannot leave the area may die). Region 3 had the greatest proportion of estuarine area with low dissolved oxygen (21 percent), while four EPA Regions had no area below 2 mg/L.

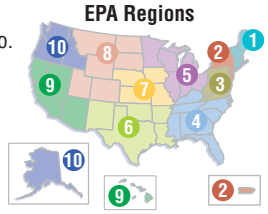
Exhibit 3-26. Water clarity in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a,b]



[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

[b]Totals may not add to 100% due to rounding.

[c]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.



Data source: *U.S. EPA, 2004, 2005a*

Water clarity exceeded reference conditions (i.e., higher clarity) in 62 percent of the nation's estuarine area, while low water clarity was observed in 25 percent of estuarine area (Exhibit 3-26). Region 3 had the largest proportion of area with low clarity (43 percent), while Region 1 had the smallest (none).

Indicator Limitations

- The coastal areas of Hawaii and a portion of Alaska have been sampled, but the data had not yet been assessed at the time this indicator was compiled. Data are also not available for the U.S. Virgin Islands and the Pacific territories.
- Trend data are not yet available for this indicator. Because of differences in methodology, the data presented here are not comparable with data that appeared in EPA's first National Coastal Condition Report. The data presented here will serve as a baseline for future surveys.
- The NCA surveys measure dissolved oxygen conditions only in estuarine waters and do not include observations of dissolved oxygen concentrations in offshore coastal shelf waters, such as the hypoxic zone in Gulf of Mexico shelf waters.
- At each sample location, the components of this indicator may have a high level of temporal variability. This survey is intended to characterize the typical distribution of water quality conditions in coastal waters during an index period from July through September. It does not consistently identify the "worst-case" condition for sites experiencing occasional or infrequent hypoxia, nutrient enrichment, or decreased water clarity at other times of the year.

Data Sources

This indicator is based on an analysis published in EPA's second National Coastal Condition Report (U.S. EPA, 2004). Summary data by EPA Region have not been published, but were provided by EPA's NCA program (U.S. EPA, 2005a). Underlying sampling data are housed in EPA's NCA database (U.S. EPA, 2005b) (http://www.epa.gov/emap/nca/html/data/index.html).

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Contaminated sediments can pose an immediate threat to benthic organisms and an eventual threat to entire estuarine ecosystems. Sediments can be resuspended by anthropogenic activities, storms, or other natural events; as a result, organisms in the water column can be exposed to contaminants, which may accumulate through the food web and eventually pose health risks to humans (U.S. EPA, 2004a).

There are several ways to measure sediment quality. Sediments can be assessed in terms of their toxicity to specific organisms in bioassays, or in terms of the levels of contaminants that are present. Sediment quality also can be inferred by assessing the condition of benthic communities, which largely reflect the quality of the sediments in which they live (although other stressors may be reflected as well). To generate a more complete picture of sediment quality, scientists frequently use several of these measures together.

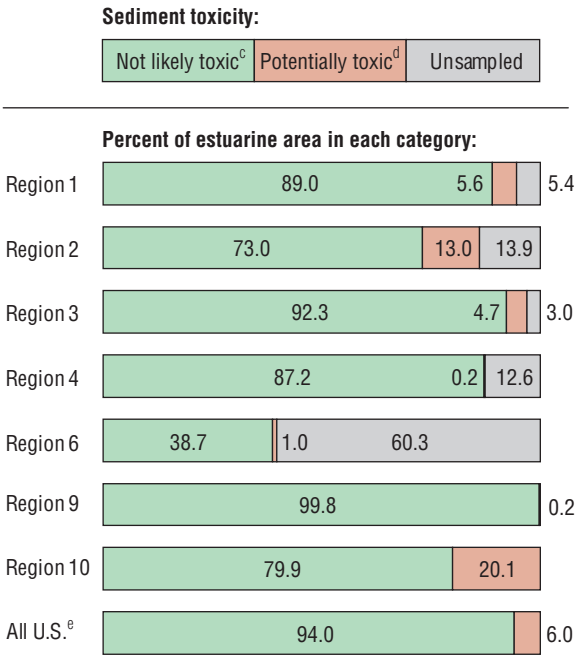
This indicator presents data on sediment toxicity and contaminant levels. The data are from probabilistic surveys conducted as part of EPA's National Coastal Assessment (NCA) and presented in EPA's second National Coastal Condition Report (U.S. EPA, 2004b). The survey was designed to provide a national picture of sediment quality by sampling sites in estuarine waters throughout the contiguous 48 states and Puerto Rico. Each site was sampled once during the 1997-2000 period, within an index period from July to September. The indicator reflects average condition in each EPA Region during this index period. Results were also aggregated and weighted by estuarine area for the entire nation.

Sediment toxicity is typically determined using bioassays that expose test organisms to sediments and evaluate their effects on the organisms' survival. For this indicator, toxicity was determined using a 10-day static test on the benthic amphipod *Ampelisca abdita,* which is commonly used as a screening tool to identify sediments that pose sufficient concern to warrant further study. Sediments were classified as "potentially toxic" if the bioassays resulted in greater than 20 percent mortality (a reference condition), or "not likely toxic" if the bioassays resulted in 20 percent mortality or less (U.S. EPA, 2004c).

Contaminant concentrations do not directly reflect toxicity because toxicity also depends on contaminants' bioavailability, which is controlled by pH, particle size and type, organic content, and other factors (e.g., mercury vs. methylmercury). Contaminant concentrations are a useful screening tool for toxicity, however, when compared with concentrations known to cause particular effects on benthic life. For this indicator, sediment samples were homogenized and analyzed for nearly 100 contaminants, including 25 polycyclic aromatic hydrocarbons (PAHs), 22 polychlorinated biphenyls (PCBs), 25 pesticides, and 15 metals, using standard wet chemistry and mass spectroscopy. The observed concentrations were then compared with "effects range median" (ERM) values established through an extensive review of toxicity tests involving benthic organisms, mostly *Ampelisca* (Long et al., 1995). ERM values were available for 28 contaminants. For each contaminant, the ERM represents the concentration at which there is a 50 percent likelihood of adverse effects to an organism, based on experimental data. For this indicator, a site was rated "potentially toxic" if one or more contaminants exceeded an ERM value. In practice, about 25 percent of samples that exceed one ERM also cause more than 20 percent mortality in the *Ampelisca* bioassay (Long, 2000).

Benthic community condition also can be a useful indication of sediment quality, particularly in terms of chronic or community effects that would not be captured in an acute exposure bioassay. The NCA evaluated estuarine

Exhibit 3-27. Sediment toxicity in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a,b]

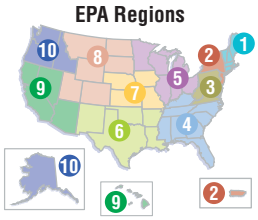


[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

[b]Totals may not add to 100% due to rounding.

[c]**Not likely toxic:** Mortality of test species = 20% or lower

[d]**Potentially toxic:** Mortality of test species > 20%



[e]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

Data source: *U.S. EPA, 2004b, 2005a*

sites for several aspects of benthic community condition, and these results are presented as a separate ROE indicator (Coastal Benthic Communities).

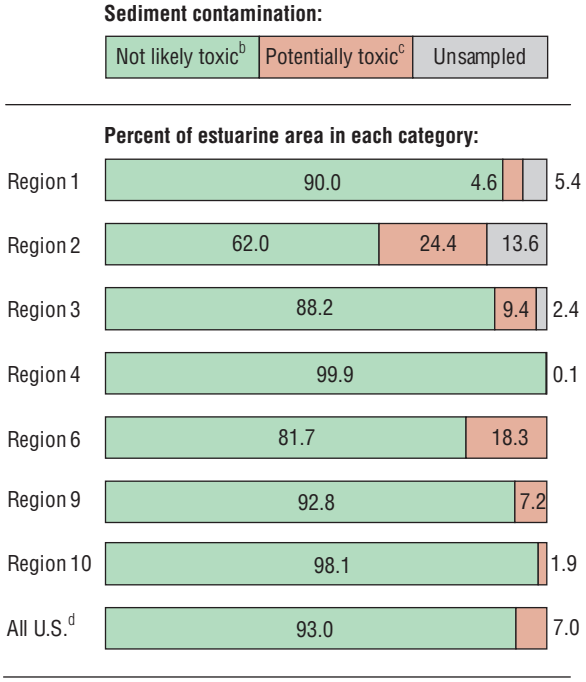
What the Data Show

Nationwide, 6 percent of coastal sediments were rated "potentially toxic" based on the *Ampelisca* toxicity screening assay, although there was considerable variability from one EPA Region to the next (Exhibit 3-27). In Region 9, nearly 100 percent of estuarine area exhibited low sediment toxicity, while in some other EPA Regions, as much as 20 percent of estuarine sediments were "potentially toxic." Data for Region 6 are inconclusive because more than half of the Region's estuarine area was not sampled.

Nationally, contaminants were present at "potentially toxic" levels in 7 percent of estuarine sediments for which contamination data were available (Exhibit 3-28). There was considerable variability in sediment contamination from one EPA Region to the next, with Region 4 showing the largest proportion of estuarine area with sediments not likely to be toxic (99.9 percent) and Region 2 showing the largest proportion with "potentially toxic" sediments (24.4 percent).

Although the two figures suggest that a similar percentage of the nation's estuarine sediments are "potentially toxic," the original data source reports very little correlation between sites that caused more than 20 percent mortality in the *Ampelisca* bioassay and sites where one or more contaminants exceeded the ERM (U.S. EPA, 2004b). It is not unusual to find a lack of correlation—particularly in cases where sediment contaminants are neither highly concentrated nor completely absent—in part because some toxic chemicals may not be bioavailable, some may not be lethal, and not all potentially toxic chemicals are analyzed (see O'Connor et al., 1998, and O'Connor and Paul, 2000). These results underscore the utility of a combined approach to screen for potentially toxic sediments.

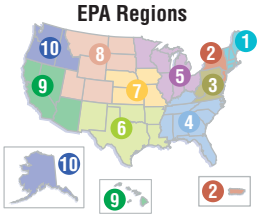
Exhibit 3-28. Sediment contamination in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a]



[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

[b]**Not likely toxic:** No contaminants above effects range median (ERM)

[c]**Potentially toxic:** One or more contaminants above effects range median (ERM)



[d]U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

Data source: *U.S. EPA, 2004b, 2005a*

Indicator Limitations

- The coastal areas of Hawaii and a portion of Alaska have been sampled, but the data had not yet been assessed at the time this indicator was compiled. Data are also not available for the U.S. Virgin Islands and the Pacific territories.
- Trend data are not yet available for this indicator. Because of differences in methodology, the data presented here are not comparable with data that appeared in EPA's first National Coastal Condition Report. The data presented here will serve as a baseline for future surveys.
- Sample collection is limited to an index period from July to September. It is not likely that contaminant levels vary from season to season, however.
- The *Ampelisca* bioassay is a single-organism screening tool, and the ERMs are general screening guidelines based largely on toxicity data from *Ampelisca*. Thus, these measures do not necessarily reflect the extent to which sediments may be toxic to the full range of biota (including microbes and plants) that inhabit a particular sampling location.
- The *Ampelisca* bioassay tests only for short-term, not long-term, exposure. Both screening tests characterize sediments in terms of their effects on benthic organism mortality. This indicator does not capture other effects of sediment contaminants on benthic organisms, such as disease, stress, and reproductive effects.
- This indicator cannot be compared quantitatively with indicators that use other types of contaminant guidelines. For example, the Pesticides in Agricultural Streams indicator uses thresholds intended to be protective of aquatic life with a margin of safety, instead of thresholds shown

to cause biological effects (e.g., ERMs). The ERM approach also is not directly comparable with other sediment contaminant approaches, such as EPA's equilibrium partitioning (EqP) benchmarks.

Data Sources

This indicator is based on an analysis published in EPA's second National Coastal Condition Report (U.S. EPA, 2004b). Summary data by EPA Region have not been published, but were provided by EPA's NCA program (U.S. EPA, 2005a). Underlying sampling data are housed in EPA's NCA database (U.S. EPA, 2005b) (http://www.epa.gov/emap/nca/html/data/index.html).

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O'Connor, T.P., and J.F. Paul. 2000. Misfit between sediment toxicity and chemistry. Mar. Pollut. Bull. 40(1):59-64.

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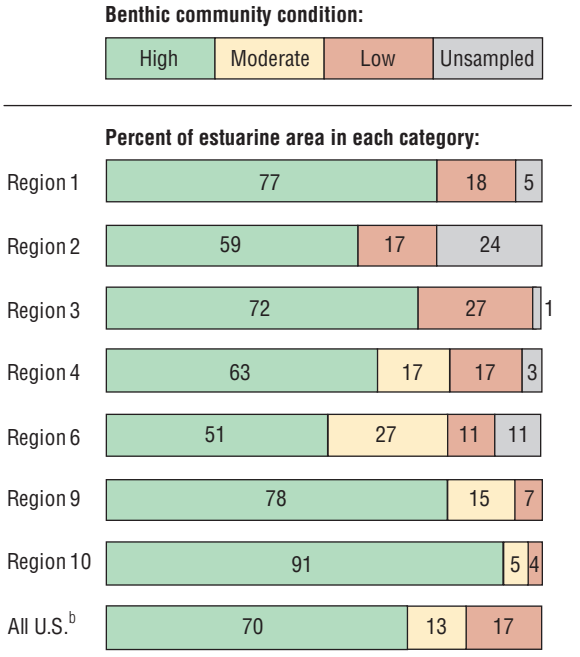
Benthic communities are largely composed of macroinvertebrates, such as annelids, mollusks, and crustaceans. These organisms inhabit the bottom substrates of estuaries and play a vital role in maintaining sediment and water quality. They also are an important food source for bottom-feeding fish, invertebrates, and birds. Communities of benthic organisms are important indicators of environmental stress because they are particularly sensitive to pollutant exposure (Holland et al., 1987). This sensitivity arises from the close relationship between benthic organisms and sediments—which can accumulate environmental contaminants over time—and the fact that these organisms are relatively immobile, which means they receive prolonged exposure to any contaminants in their immediate habitat (Sanders et al., 1980; Nixon et al., 1986).

This indicator is based on a multi-metric benthic communities index that reflects overall species diversity in estuarine areas throughout the contiguous United States (adjusted for salinity, if necessary) and, for some regions, the presence of pollution-tolerant and pollution-sensitive species (e.g., Weisberg et al., 1997; Engle and Summers, 1999; U.S. EPA, 2004). The benthic community condition at each sample site is given a high score if the index exceeds a particular threshold (e.g., has high diversity or populations of many pollution-sensitive species), a low score if it falls below the threshold conditions, and a moderate score if it falls within the threshold range. The exact structure of the index and the threshold values vary from one biogeographic region to another, but comparisons between predicted and observed scores based on expert judgment are used to ensure that the classifications of sites from one region to another are consistent (U.S. EPA, 2004). Data were collected using probability samples, so the results from the sampling sites provide unbiased estimates of the distribution of index scores in estuaries throughout each region.

The data for this indicator are from probabilistic surveys conducted as part of EPA's National Coastal Assessment (NCA) and presented in EPA's second National Coastal Condition Report (U.S. EPA, 2004). The survey was designed to provide a national picture of coastal benthic community condition by sampling sites in estuarine waters throughout the contiguous 48 states and Puerto Rico. Each site was sampled once during the 1997-2000 period, within an index period from July to September. The indicator reflects average condition in each EPA Region during this index period. Results were also aggregated and weighted by estuarine area for the entire nation.

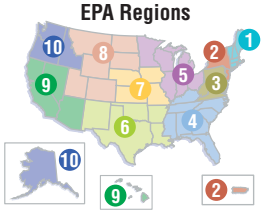
Exhibit 3-29. Coastal benthic communities index for the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a]



[a] **Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

[b] U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

Data source: *U.S. EPA, 2004, 2005a*



What the Data Show

Nationally, 70 percent of the sampled estuarine area had a high benthic communities index score, with 13 percent in the moderate range and 17 percent scoring low (Exhibit 3-29). Condition varied somewhat by EPA Region, with high index scores ranging from 51 percent of the estuarine area in Region 6 to 91 percent in Region 10. Region 3 had the largest proportion of estuarine area rated low (27 percent), while Region 10 had the lowest (4 percent). In the figure, the portion of the estuarine area not represented by the sample is noted for each Region.

The National Coastal Condition Report found that many of the sites with low benthic community condition also showed impaired water quality or sediment condition—which is not surprising given the extent to which these stressors and effects are related. Of the 17 percent of national estuarine area rated low on the benthic communities index, 38 percent also exhibited degraded sediment quality, 9 percent exhibited degraded water quality (U.S. EPA, 2004), and 33 percent exhibited degraded quality of both sediment and water.

Indicator Limitations

- The coastal areas of Hawaii and a portion of Alaska have been sampled, but the data had not yet been assessed at the

time this indicator was compiled. Data are also not available for the U.S. Virgin Islands and the Pacific territories.

- Trend data are not yet available for this indicator. Because of differences in methodology, the data presented here are not comparable with data that appeared in EPA's first National Coastal Condition Report. The data presented here will serve as a baseline for future surveys.
- Benthic indices for the Northeast, West, and Puerto Rico do not yet include measures of pollution-tolerant or pollution-sensitive species. Although species diversity has the largest impact on index scores in the other regions, index values could change in the future as these components are added to the index values for these regions.
- Sample collection is limited to an index period from July to September. Further, because benthic communities can be strongly influenced by episodic events, trawling, or climate perturbations, this indicator may not reflect the full range of conditions that occur at each sampling location throughout these months.

Data Sources

This indicator is based on an analysis published in EPA's second National Coastal Condition Report (U.S. EPA, 2004). Summary data by EPA Region have not been published, but were provided by EPA's NCA program (U.S. EPA, 2005a). Underlying sampling data are housed in EPA's NCA database (U.S. EPA, 2005b) (http://www.epa.gov/emap/nca/html/data/index.html).

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INDICATOR | Coastal Fish Tissue Contaminants

Contaminants in fish not only affect the fish's own health and ability to reproduce, but also affect the many species that feed on them. Contaminants also may make fish unsuitable for human consumption (U.S. EPA, 2000).

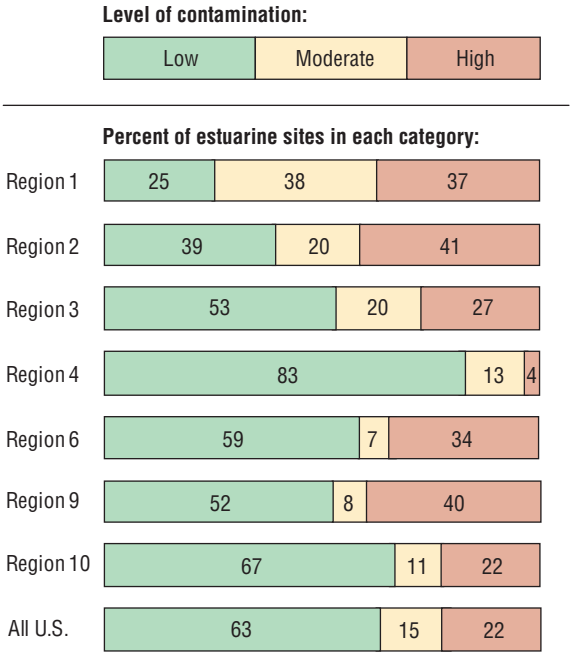
This indicator, derived from an indicator presented in EPA's second National Coastal Condition Report (U.S. EPA, 2004), is based on National Coastal Assessment (NCA) fish tissue survey data from 653 estuarine sites throughout the United States. The survey was designed to provide a national picture of coastal fish tissue contaminants by sampling sites in estuarine waters throughout the contiguous 48 states. Each site was sampled once during the 1997-2000 period, within an index period from July to September. The indicator reflects average condition in each EPA Region during this index period. Results were also aggregated and weighted by estuarine area for the entire nation.

Fish and shellfish analyzed in the survey included Atlantic croaker, white perch, catfish, flounder, scup, blue crab, lobster, shrimp, whiffs, mullet, tomcod, spot, weakfish, halibut, sole, sculpins, sanddabs, bass, and sturgeon. At each site, five to 10 whole-body fish samples were tested for 90 contaminants. This indicator is based on data collected from 1997 to 2000.

To assess risks to human health, contaminant concentrations in fish tissue were compared with established EPA guideline ranges for recreational fishers, which were available for 16 of the 90 analytes. These guideline ranges are based on the consumption of four 8-ounce fish meals per month, and generally reflect non-cancer risks (U.S. EPA, 2000, 2004). For most contaminants, this is done using whole-body concentrations; for mercury, which concentrates in the edible fillet portion of the fish, a factor of 3.0 was used to correct whole-body concentrations in order to approximate fillet concentrations. The 3.0 factor represents the median value (range 1.5-5.0) found in the available literature (Windom and Kendall, 1979; Mikac et al., 1985; Schmidt and Brumbaugh, 1990; Kannan et al., 1998; Canadian Council of Ministers of the Environment, 1999).

For this indicator, a site was given a high contamination score if one or more contaminants were present at a concentration above the guideline ranges. A site was rated moderate if one or more contaminants were within the guideline ranges but none was in exceedance. Sites with all contaminants below their guideline ranges were given a low contamination score.

Exhibit 3-38. Coastal fish tissue contaminants in the contiguous U.S. by EPA Region, 1997-2000[a,b,c]

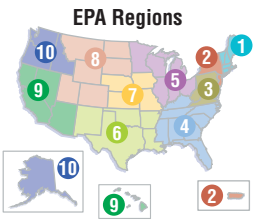


[a]**Coverage:** Estuarine waters of the contiguous 48 states.

[b]This indicator is based on a whole-body analysis of the fish. See text for definitions of categories.

[c]Totals may not add to 100% due to rounding.

Data source: *U.S. EPA, 2004, 2005a*



What the Data Show

Nationwide, 63 percent of sites showed low fish tissue contamination, 15 percent had moderate contamination, and 22 percent exhibited high contamination (Exhibit 3-38). Fish tissue contamination varied substantially from one EPA Region to the next; for example, the percentage of sites with low contamination ranged from 25 percent (Region 1) to 83 percent (Region 4). Regions 2 and 9 had the largest proportion of sites with high contamination (41 percent and 40 percent, respectively).

Data from EPA's National Coastal Database show that nationwide, PCBs were the contaminants most frequently responsible for high fish tissue contamination, with 19 percent of sites above EPA guideline ranges (Exhibit 3-39). Other chemicals present above EPA guideline ranges at many sites were mercury in muscle tissue (18 percent of sites), DDT (8 percent), and PAHs (3 percent) (Exhibit 3-39). Inorganic arsenic, selenium, chlordane, endosulfan, endrin, heptachlor epoxide, hexachlorobenzene, lindane, and mirex were below EPA guideline ranges for all fish sampled in the NCA.

Indicator Limitations

- The indicator is limited to estuarine samples, and does not include data from Louisiana, Florida, Puerto Rico, Alaska, or Hawaii, which had not been assessed at the time this

indicator was compiled. Some of these areas (e.g., portions of Alaska) have now been surveyed, and may be included in future indicators.

- The data are not broken out by trophic level of the fish and shellfish species, which influences bioaccumulation of contaminants.
- Whole-body contaminant concentrations in fish overestimate the risk associated with consuming only the fillet portion of the fish, with the exception of mercury and cadmium, which are generally underestimated.
- This indicator focuses on contaminants from a human health risk perspective. No EPA guidance criteria exist to assess the ecological risk of whole-body contaminants in fish (U.S. EPA, 2004).
- Some fish samples used in the survey were non-market-size juveniles, which are known to have lower contaminant levels than larger, market-sized fish.
- Samples are collected during an index period from July to September, and the indicator is only representative of this time period. It is unlikely, however, that contaminant levels vary substantially from season to season.
- There are no trend data for this indicator. In EPA's second National Coastal Condition Report, fish tissue contaminants are characterized by whole-body concentrations and compared to EPA risk-based consumption guideline ranges. For the first National Coastal Condition Report, fish contaminants were measured as fillet concentrations and compared to U.S. Food and Drug Administration (FDA) criteria. The data presented here will serve as a baseline for future surveys, however.

Data Sources

This indicator is based on an analysis published in EPA's second National Coastal Condition Report (U.S. EPA, 2004). Summary data by EPA Region and by contaminant have not been published, but were provided by EPA's NCA program (U.S. EPA, 2005a). Underlying sampling data are housed in EPA's NCA database (U.S. EPA, 2005b) (http://www.epa.gov/emap/nca/html/data/index.html).

Exhibit 3-39. Coastal fish tissue contaminant concentrations in the contiguous U.S., compared with health-based guidelines, 1997-2000[a,b,c]

Contaminant	Guideline range (ppm)	Percent of estuarine sites: Below guideline range	Within guideline range	Exceeding guideline range
Arsenic (inorganic)[d]	3.5-7.0	100	0	0
Cadmium	0.35-0.70	99	<1	<1
Mercury (total body)	0.12-0.23	99	<1	<1
Mercury (muscle tissue)	0.12-0.23	58	24	18
Selenium	5.9 -12	100	0	0
Chlordane	0.59-1.2	100	0	0
DDT	0.059-0.12	88	4	8
Dieldrin	0.059-0.12	99	0	<1
Endosulfan	7.0-14	100	0	0
Endrin	0.35-0.70	100	0	0
Heptachlor epoxide	0.015-0.031	100	0	0
Hexachlorobenzene	0.94-1.9	100	0	0
Lindane	0.35-0.70	100	0	0
Mirex	0.23-0.47	100	0	0
Toxaphene	0.29-0.59	99	0	<1
PAH (Benzo[a]pyrene)	0.0016-0.0032	95	2	3
Total PCBs	0.023-0.047	70	11	19

[a] **Coverage:** Estuarine waters of the contiguous 48 states.

[b] Concentrations were measured in whole fish tissue. Mercury data were adjusted to reflect concentrations in edible fillets, where mercury accumulates (adjustment factor of 3.0, based on the available literature). All other contaminants are presented as whole-body concentrations.

[c] Concentrations are compared with risk guidelines for recreational fishers for four 8-ounce meals per month (U.S. EPA, 2000, 2004). Guidelines presented here are for non-cancer risk, except for PAH, which is a cancer risk guideline.

[d] Inorganic arsenic estimated at 2% of total arsenic.

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

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INDICATOR | Submerged Aquatic Vegetation in the Chesapeake Bay

Rooted aquatic plants, also called submerged aquatic vegetation (SAV), represent an important component of many coastal ecosystems. SAV supports the health of these ecosystems by generating food and habitat for waterfowl, fish, shellfish, and invertebrates; adding oxygen to the water column during photosynthesis; filtering and trapping sediment that otherwise would bury benthic organisms and cloud the water column; inhibiting wave action that erodes shorelines; and absorbing nutrients, such as nitrogen and phosphorus, that otherwise could fuel the growth of unwanted planktonic algae.

One area where SAV plays an important role is the Chesapeake Bay, where SAV has historically contributed to high primary and secondary productivity (Kemp et al., 1984). In the early 1960s, researchers began to note the loss of SAV from shallow waters of the Chesapeake Bay, which has since become a widespread, well-documented problem (Batiuk et al., 2000). Review of aerial photographs taken from a number of sites taken between the mid-1930s and the mid-1960s suggests that SAV acreage is currently less than half of what it was during the 1930s-1960s period (Moore et al., 2004).

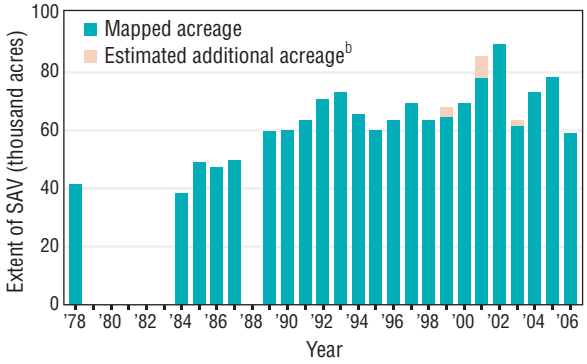
Trends in the distribution and abundance of SAV over time are useful in understanding trends in water quality (Moore et al., 2004). Although other factors such as climatic events and herbicide toxicity may have contributed to the decline of SAV in the Bay, the primary causes are eutrophication and associated reductions in light availability (Batiuk et al., 2000). Like all plants, SAV needs sunlight to grow and survive. Two key stressors that impact the growth of SAV are suspended sediments and excess nutrient pollution. Suspended sediments—loose particles of clay and silt that are suspended in the water—make the water dingy and block sunlight from reaching the plants. Similarly, excess nutrients in the water fuel the growth of planktonic algae, which also block sunlight.

This indicator presents the distribution of SAV in the Chesapeake Bay and its tributaries from 1978 to 2006, as mapped from black and white aerial photographs. The surveys follow fixed flight routes to comprehensively survey all shallow water areas of the Bay and its tidal tributaries. Non-tidal areas are omitted from the survey. SAV beds less than 1 square meter in area are not included due to the limits of the photography and interpretation. Annual monitoring began in 1978; however, no surveys were conducted from 1979 to 1983 or in 1988. In years when the entire area could not be surveyed due to flight restrictions or weather events, acreages in the non-surveyed areas were estimated based on prior years' surveys.

What the Data Show

The extent of SAV in the Chesapeake Bay increased from 41,000 acres in 1978 to a peak of 90,000 acres in 2002, before declining to 59,000 acres in 2006 (Exhibit 3-30). The extent of SAV reached a minimum of 38,000 acres in 1984. Year-to-year changes reflect a variety of phenomena. For example, the notable decline in SAV distribution between 2002 and 2003 appears to be the result of substantial reductions in widgeongrass populations in the lower and mid-bay regions. In addition to the large declines in widgeongrass, major declines in freshwater SAV species occurred in the upper portion of the Potomac River and the Susquehanna region. While populations of SAV appeared to be present in these segments very early in the growing season, persistent turbidity resulting from rain occurring throughout the spring and summer may have contributed to a very early decline, well before Hurricane Isabel affected the Chesapeake Bay (Orth et al., 2004). The extent of SAV gradually increased again through 2004 and 2005, then declined from 2005 to 2006. Factors causing this latest decline are thought to include above-average water temperatures in the fall of 2005, a dry spring in 2006, and an early summer rain event in 2006 (EcoCheck, 2007).

Exhibit 3-30. Extent of submerged aquatic vegetation (SAV) in the Chesapeake Bay, 1978-2006[a]



[a]There were no Bay-wide surveys from 1979 to 1983, or in 1988.

[b]For years with incomplete photographic coverage, SAV acreage in the non-surveyed areas was estimated based on prior years' surveys.

Data source: *Chesapeake Bay Program, 2007*

Indicator Limitations

- There were no surveys in the years 1979-1983 or in 1988.
- The indicator includes some estimated data for years with incomplete photographic coverage. Spatial gaps in 1999 occurred due to the inability to reliably photograph SAV following hurricane disturbance. Spatial gaps in 2001 occurred due to flight restrictions near Washington D.C.

after the September 11th terrorist attacks. Other gaps occurred in 2003 due to adverse weather in the spring, summer, and fall (Hurricane Isabel). Acreage in the non-surveyed areas was estimated based on prior years' surveys. In all cases, the estimated area accounted for less than 10 percent of the total acreage of SAV.

- Photointerpretation methods changed over the course of this study. However, data have been adjusted to account for any methodological inconsistencies.
- Extent is just one of the variables that can be used to measure the condition of SAV communities. Other useful attributes that have been studied include vegetation health, density, and species diversity.

Data Sources

Data were obtained from the Chesapeake Bay Program, which has published a version of this indicator (Chesapeake Bay Program, 2007) along with a link to download the annual summary data presented in Exhibit 3-30 (http://www.chesapeakebay.net/pubs/statustrends/88-data-2002.xls). These acreage statistics are based on annual SAV distribution maps, which are available from the Virginia Institute of Marine Science (VIMS, 2007) (http://www.vims.edu/bio/sav/index.html).

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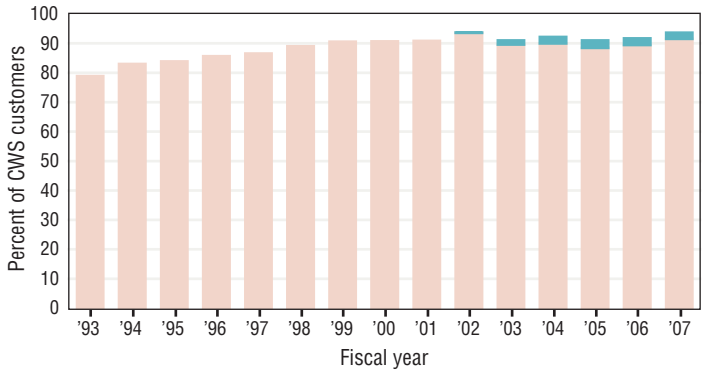
INDICATOR | Population Served by Community Water Systems with No Reported Violations of Health-Based Standards

Community water systems (CWS), public water systems that supply water to the same population year-round, served over 286 million Americans in fiscal year (FY) 2007 (U.S. EPA, 2007)—roughly 95 percent of the U.S. population (U.S. Census Bureau, 2007). This indicator presents the percentage of Americans served by CWS for which states reported no violations of EPA health-based standards for over 90 contaminants (U.S. EPA, 2004b).

Health-based standards include Maximum Contaminant Levels (MCLs) and Treatment Techniques (TTs). An MCL is the highest level of a contaminant that is allowed in drinking water. A TT is a required treatment process (such as filtration or disinfection) intended to prevent the occurrence of a contaminant in drinking water (U.S. EPA, 2004c). TTs are adopted where it is not economically or technologically feasible to ascertain the level of a contaminant, such as microbes, where even single organisms that occur unpredictably or episodically can cause adverse health effects. Compliance with TTs may require finished water sampling, along with quantitative or descriptive measurements of process performance to gauge the efficacy of the treatment process. MCL-regulated contaminants tend to have long-term rather than acute health effects, and concentrations vary seasonally (if at all; e.g., levels of naturally occurring chemical contaminants or radionuclides in ground water are relatively constant). Thus, compliance is based on averages of seasonal, annual, or less frequent sampling.

This indicator tracks the population served by CWS for which no violations were reported to EPA for the period from FY 1993 to FY 2007, the latest year for which data are available. Results are reported as a percentage of the overall population served by CWS, both nationally and by EPA Region. This indicator also reports the number of persons served by systems with reported violations of standards covering surface water treatment, microbial contaminants (microorganisms that can cause disease), and disinfection byproducts (chemicals that may form when disinfectants, such as chlorine, react with naturally occurring materials in water and may pose health risks) (U.S. EPA, 2004b). The indicator is based on violations reported quarterly by states, EPA, and the Navajo Nation Indian Tribe, who each review monitoring results for the CWS that they oversee.

Exhibit 3-35. U.S. population served by community water systems with no reported violations of EPA health-based standards, fiscal years 1993-2007[a]



[a]**Coverage:** U.S. residents served by community water systems (CWS) (approximately 95% of the total U.S. population).

[b]Several new standards went into effect after 12/31/01, including the Interim Enhanced Surface Water Treatment Rule (CWS with surface water sources serving 10,000 or more people) and the Disinfection Byproducts (DBP) Rule for CWS that disinfect. In FY 2003, the DBP rule applied to systems serving >10,000 people; as of January 2004, it applied to all CWS. For FY 2002-2007, each column is divided into two segments: the lower portion reflects all standards in place at the time, while the upper portion covers sytems with reported violations of new standards but not pre-12/31/01 standards. Adding both segments together, the total height of each column indicates what percent of CWS customers would have been served by CWS with no reported violations if the new standards had not gone into effect.

Data source: *U.S. EPA, 2007*

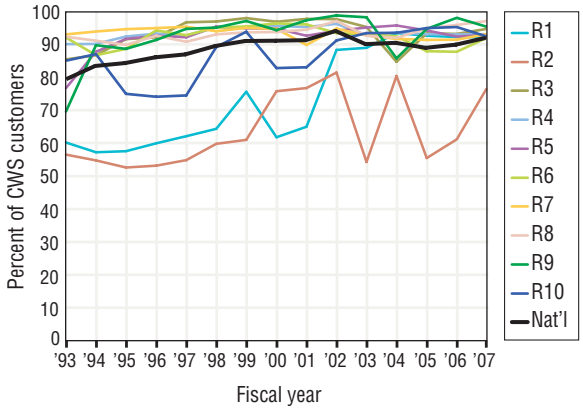
What the Data Show

Of the population served by CWS nationally, the percentage served by systems for which no health-based violations were reported for the entire year increased overall from 79 percent in 1993 to 92 percent in FY 2007, with a peak of 94 percent in FY 2002 (Exhibit 3-35). This indicator is based on reported violations of the standards in effect in any given year. Several new standards went into effect after December 31, 2001. These were the first new drinking water standards to take effect during the period of record (beginning in 1993). The results after FY 2001 would have been somewhat higher had it not been for violations of standards that became effective in FY 2002 or after (Exhibit 3-35; see the dark segment atop the columns starting in FY 2002). As EPA adds to or strengthens its requirements for water systems over time, compliance with standards comes to represent a higher level of public health protection.

When results are broken down by EPA Region, some variability over time is evident (Exhibit 3-36). Between FY 1993 and FY 2007, most Regions were consistently

INDICATOR | Population Served by Community Water Systems with No Reported Violations of Health-Based Standards

Exhibit 3-36. U.S. population served by community water systems with no reported violations of EPA health-based standards, by EPA Region, fiscal years 1993-2007[a,b]



[a]**Coverage:** U.S. residents served by community water systems (CWS) (approximately 95% of the total U.S. population).

[b]Based on reported violations of the standards in effect in any given year.

Data source: *U.S. EPA, 2007*

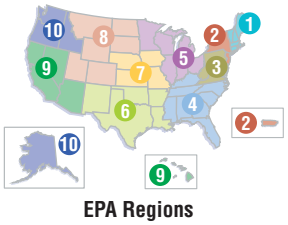


Exhibit 3-37. U.S. population served by community water systems with reported violations of EPA health-based standards, by type of violation, fiscal year 2007[a]

	Population served	Percent of CWS customers
Any violation	24,279,892	8.5
Selected violations		
Stage 1 Disinfection Byproducts Rule	3,643,104	1.3
Surface Water Treatment Rules	8,945,673	3.1
Total Coliform Rule	10,569,935	3.7
Any of these selected rules[b]	20,472,902	7.1

[a]**Coverage:** U.S. residents served by community water systems (CWS) (approximately 95% of the total U.S. population).

[b]Some CWS violated more than one of the selected rules.

Data source: *U.S. EPA, 2007*

above the national percentage. Three of the Regions were substantially below the national average over much of the period of record, but as of FY 2007, only one Region remained well below the national percentage, largely because of a small number of public water systems serving large populations.

In FY 2007, reported violations involving surface water treatment rules in large CWS were responsible for exceeding health-based standards for 8.9 million people (3.1 percent of the population served by CWS nationally) (Exhibit 3-37). Reported violations of heath-based coliform standards affected 10.6 million people (3.7 percent of the CWS-served population), and reported violations of the health-based disinfection byproducts standards (Stage 1) affected 3.6 million people (1.3 percent of the CWS-served population). Overall, of the 8.5 percent of the population served by systems with reported violations in FY 2007, 84 percent of these cases involved at least one of these three rules governing treatment to prevent waterborne diseases—the most widespread and acute threat to health from drinking water—or the contaminants created by such treatment.

Indicator Limitations

- Non-community water systems (typically relatively small systems) that serve only transient populations such as restaurants or campgrounds, or serving those in a non-domestic setting for only part of their day (e.g., a school, religious facility, or office building), are not included in population served figures.
- Domestic (home) use of drinking water supplied by private wells—which serve approximately 15 percent of the U.S. population (USGS, 2004)—is not included.
- Bottled water, which is regulated by standards set by the Food and Drug Administration, is not included.
- National statistics based on population served can be volatile, because a single very large system can sway the results by up to 2 to 3 percent; this effect becomes more pronounced when statistics are broken down at the regional level, and still more so for a single rule.
- Some factors may lead to overstating the extent of population receiving water that violates standards. For example, the entire population served by each system in

violation is reported, even though only part of the total population served may actually receive water that is out of compliance. In addition, violations stated on an annual basis may suggest a longer duration of violation than may be the case, as some violations may be as brief as an hour or a day.

- Other factors may lead to understating the population receiving water that violates standards. CWS that purchase water from other CWS are not always required to sample for all contaminants themselves, and the CWS that are wholesale sellers of water generally do not report violations for the population served by the systems that purchase the water.
- Under-reporting and late reporting of violations by states to EPA affect the ability to accurately report the national violations total. For example, EPA estimated that between 1999 and 2001, states were not reporting 35 percent of all health-based violations, which reflects a sharp improvement in the quality of violations data compared to the previous 3-year period (U.S. EPA, 2004a).
- State data verification and other quality assurance analyses indicate that the most widespread data quality problem is under-reporting of monitoring and health-based violations and inventory characteristics. Under-reporting occurs most frequently in monitoring violations; even though these are separate from the health-based violations covered by the indicator, failures to monitor could mask violations of TTs and MCLs.

Data Sources

Data for this indicator were obtained from EPA's Safe Drinking Water Information System (U.S. EPA, 2007) (http://www.epa.gov/safewater/data/getdata.html; http://www.epa.gov/safewater/data/pivottables.html). This database contains a record of violations reported to EPA by the states or other entities that oversee CWS, along with annual summary statistics.

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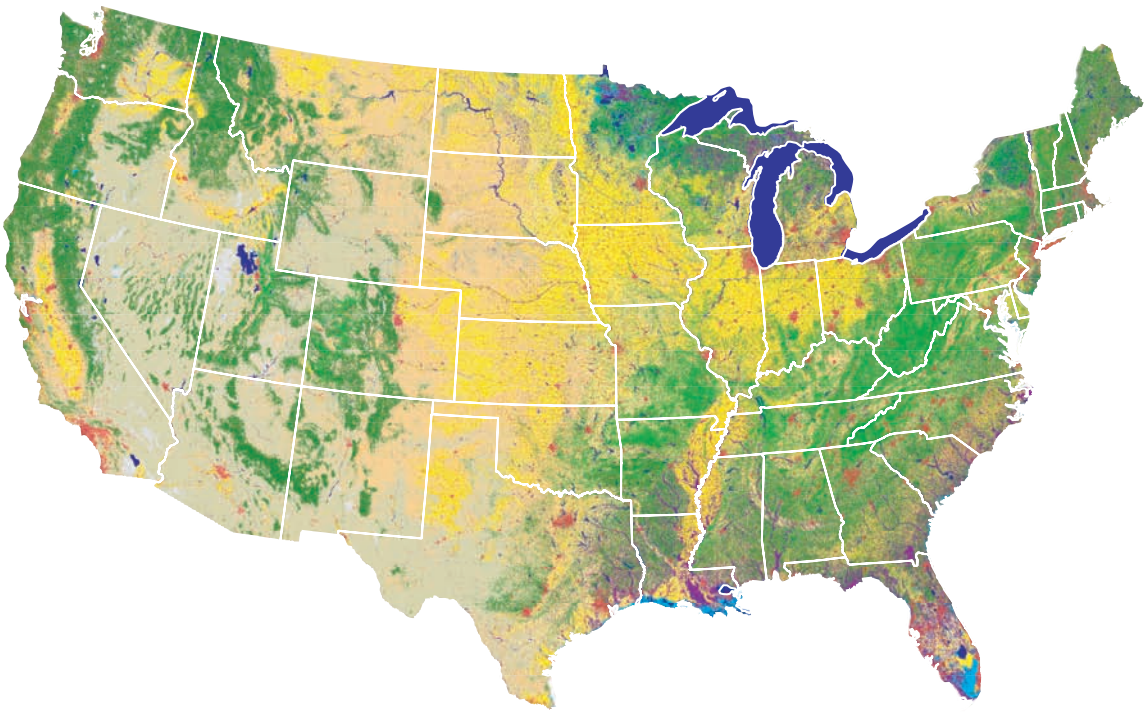
Land cover represents the actual or physical presence of vegetation (or other materials where vegetation is nonexistent) on the land surface. Land cover is also often described as what can be seen on land when viewed from above. Land cover is one means to categorize landscape patterns and characteristics, and is critical in understanding the condition of the environment, including the availability of habitat, changes in habitat, and dispersion and effects of chemicals and other pollutants in and on the environment. For the purposes of this indicator, land cover is described in terms of six major classes: forest, grass, shrub, developed, agriculture, and other (includes ice/snow, barren areas, and wetlands). A seventh category, water, is not discussed as a land cover type in this chapter. See Chapter 3 for more information on trends related to water. More information about forest land can be found in the Forest Extent and Type indicator and wetland acreage is discussed in greater detail in the Wetlands indicator.

In 1992, several federal agencies agreed to operate as a consortium, known as the Multi-Resolution Land Characteristics (MRLC) Consortium, to acquire and analyze satellite-based remotely sensed data for environmental monitoring programs (MRLC Consortium, 2006). The initial result of the MRLC effort was development of the 1992 National Land Cover Dataset (NLCD), which, until recently, was the only comprehensive recent classification of land cover in the contiguous U.S. (USGS, 2007). In 2007, the MRLC Consortium published the 2001 National Land Cover Database, an updated and improved version of the 1992 NLCD (Homer et al., 2007). The database provides information about 16 land cover classes at a 30-meter resolution, comprising approximately 27 billion cells covering

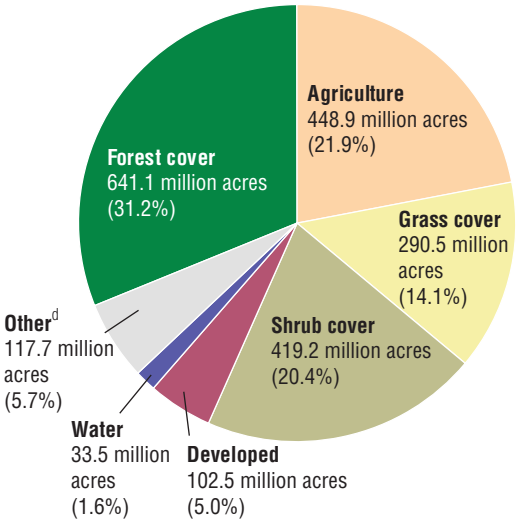
Exhibit 4-1. Land cover of the contiguous U.S., based on 2001 NLCD [a]



[a] See box in text for definitions of land cover categories.

Data source: *U.S. EPA, 2007b*

Exhibit 4-2. Land cover types in the U.S., based on 2001 NLCD and FIA [a,b,c]



[a]**Coverage:** All surface area of the contiguous 48 states, plus forest land in Alaska and Hawaii.

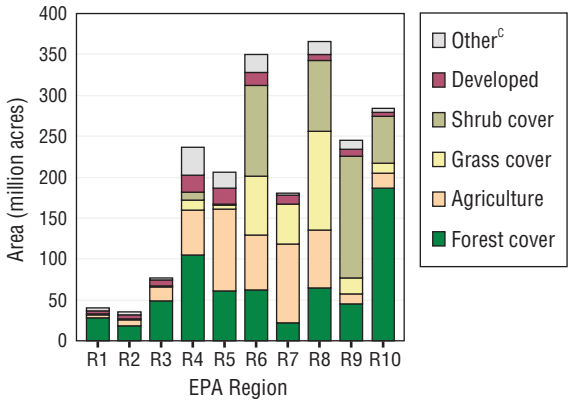
[b]See box in text for definitions of land cover categories.

[c]Totals may not add to 100% due to rounding.

[d]"Other" includes ice/snow, barren areas, and wetlands.

Data source: *Smith et al., 2004; U.S. EPA, 2007b*

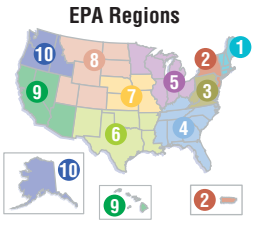
Exhibit 4-3. Land cover types in the U.S. by EPA Region, based on 2001 NLCD and FIA [a,b]



[a]**Coverage:** All land area of the contiguous 48 states (excluding water), plus forest land in Alaska and Hawaii.

[b]See box in text for definitions of land cover categories.

[c]"Other" includes ice/snow, barren areas, and wetlands.



Data source: *Smith et al., 2004; U.S. EPA, 2007b*

the contiguous U.S., based on Landsat images from 1999 to 2002. Due to differences in methodology, direct comparison of the 1992 and 2001 NLCD data sets does not currently provide valid trend data. Efforts are underway to develop an algorithm that will allow such comparisons in the near future.

This indicator represents data from the 2001 NLCD and the U.S. Department of Agriculture Forest Service's Forest Inventory and Analysis (FIA), which uses a statistical survey design and comparable methods to assess the extent, type, age, and health of forests on private and public land in all states. The 2001 NLCD provides a synoptic classification of land cover, but does not include Alaska and Hawaii, thereby classifying only 1.92 billion acres out of approximately 2.3 billion acres of land in the U.S. To supplement the NLCD, data from the 2001 FIA were used to provide forest cover estimates in Alaska and Hawaii (128.6 million acres). For this indicator, the 16 land cover classes created in the NLCD were aggregated into the six major land cover types described above, along with water (Heinz Center, 2005).

What the Data Show

The combination of the NLCD for the contiguous 48 states and the FIA for forest cover estimates in Alaska and Hawaii shows approximately 641 million acres of forest, 449 million acres of agriculture, 419 million acres of shrub, 291 million acres of grass, and 103 million acres of developed cover types (Exhibits 4-1 and 4-2).

NLCD and FIA data show variation in cover types by EPA Region, with forest dominating in Regions 1, 2, 3, 4, and 10; agriculture in Regions 5 and 7; grass in Region 8; and shrub in Region 6 and 9 (Exhibit 4-3). Two-thirds of the grass acreage in the nation is located in Regions 6 and 8, nearly two-thirds of shrub acreage is in Regions 6 and 9, and nearly half the forest acreage is in Regions 4 and 10 (including Alaska).

Indicator Limitations

- Trend data are not available for this indicator. Land cover data for the entire nation at adequate resolution to support this indicator are currently available for two points in time (1992 and 2001). However, due to differences in methodology in creation of the data sets, they are not directly comparable. The MRLC Consortium is developing a change product intended to enable valid comparisons of the two data sets (MRLC Consortium, 2007a,b). The product is scheduled to be available in 2008. Until this project is completed, there are no consistent, comprehensive, nationwide data to describe trends in land cover at the national or EPA Regional levels.

Definitions of Land Cover Categories for Exhibits 4-1, 4-2, and 4-3

Agricultural (NLCD 2001 definition): Areas characterized by herbaceous vegetation that has been planted; is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation must account for 75 to 100 percent of the cover. Includes the "orchards/vineyards/other" subcategory, which covers areas planted or maintained for the production of fruits, nuts, berries, or ornamentals. Includes two subcategories: "pasture/hay" and "cultivated crops."

Developed (NLCD 2001 definition): Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g., asphalt, concrete, buildings). Includes four subcategories: "Developed, open space" (less than 20 percent impervious surface), "Developed, low intensity" (20-49 percent impervious surface), "Developed, medium intensity" (50-79 percent impervious surface), and "Developed, high intensity" (80 percent or more impervious surface).

Shrubland (NLCD 2001 definition): Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching or interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

Grassland (NLCD 2001 definition): Upland areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of the total vegetation. These areas are not subject to intensive management, such as tilling, but can be utilized for grazing.

Forest (NLCD 2001 definition): Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25 to 100 percent of the cover.

Forest (FIA definition): Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10 percent stocked with forest trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet wide. (FIA data are used in Alaska and Hawaii, due to lack of NLCD availability.)

Other: Includes NLCD 2001 snow, ice, wetlands, and barren. Barren areas are defined as areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover. <http://www.epa.gov/mrlc/definitions.html>

Sources: U.S. EPA, 2007a; Smith et al., 2004.

- FIA data for forest land in Alaska and Hawaii were used to complement the NLCD because NLCD data do not currently exist for these states, although they are planned for late 2007. Ongoing data collection under both the FIA and the NLCD is needed to assess land cover trends.
- National estimates of land cover vary, depending on the survey approach, data sources, classification, timing, etc. The interaction of these variables will result in different estimates of the extent of any given land cover category depending on the data set used. Techniques relying on satellite data to generate land cover estimates classify what is visible from above, meaning they may underestimate developed cover in heavily treed urban areas and underestimate forest cover where trees have been harvested. For example, National Resources Inventory (USDA NRCS, 2007) estimates for developed land are 6 percent above the NLCD estimates and FIA estimates of forestland in 2002 are nearly 17 percent above the NLCD.
- No standardized land cover classification system is currently used among federal agencies. As a result of this limitation, there is no consistency in the assessment of land cover trends across agencies.

Data Sources

Land cover data for the contiguous 48 states were obtained from the NLCD (U.S. EPA, 2007b). These data were grouped into the major land cover categories as described by the Heinz Center (2005) (see technical note for the Heinz Center's "Ecosystem Extent" indicator). Forest cover estimates for 2002 in Alaska and Hawaii were obtained from a report published by the FIA program (Smith et al., 2004). FIA data in this report have a nominal date of 2002

but represent the best data available at the end of the 2001 field season for each state.

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Land use is the purpose of human activity on the land. Unlike land cover, land use may not always be visible. For example, a unit of land designated for use as timberland may appear identical to an adjacent unit of protected forestland or, if recently harvested, may appear not to be in forest land cover at all. Land use is generally designated through zoning or regulation and is one of the most obvious effects of human inhabitation of the planet. It can affect both human health and ecological systems, for example by changing the hydrologic characteristics of a watershed, the potential of land to erode, the condition or contiguity of plant and animal habitat, or the spread of vector-borne diseases.

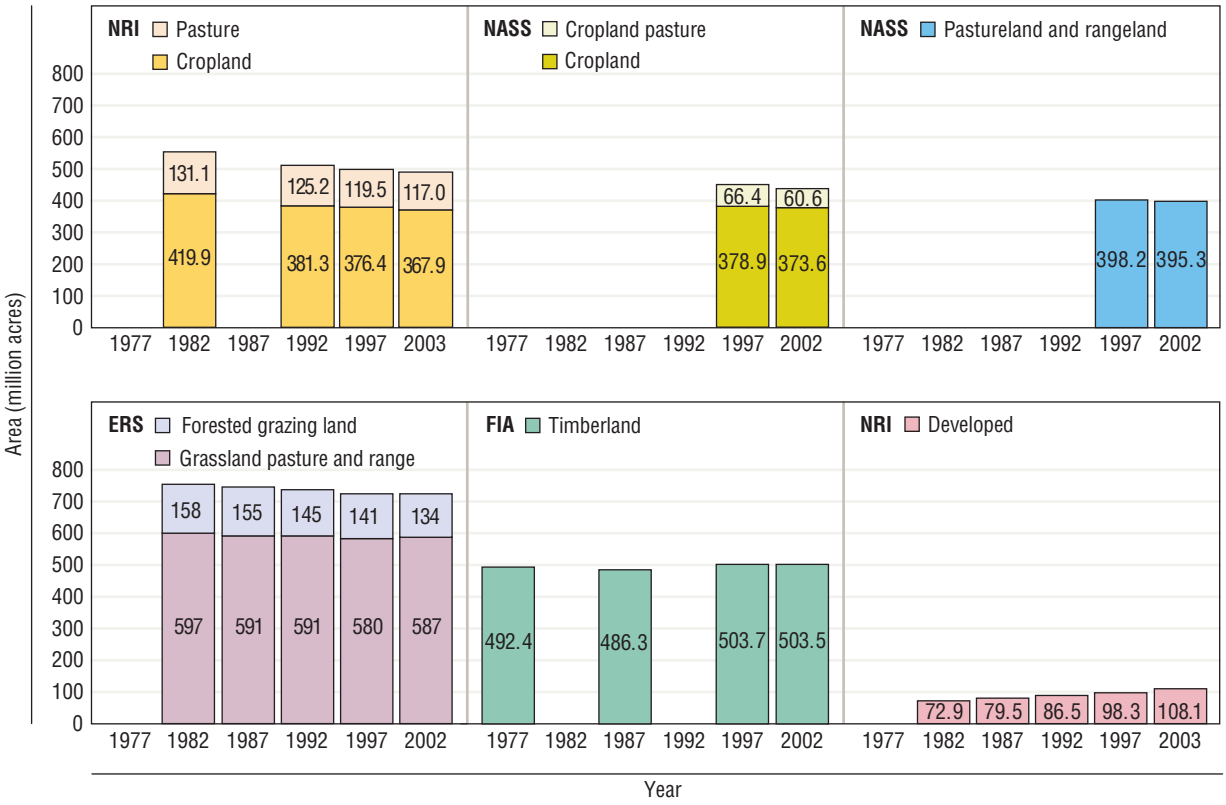
This indicator tracks trends in acreages of major land uses over the 1977-2003 period using several data sources. These sources do not always cover the same time period, sample the same resource or geography, or use the same definitions, but each of them provides an important piece of the land use picture over time. Definitions for the various land use categories in this indicator can be found on the following page.

The National Resources Inventory (NRI) conducted by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service was used to track trends in "crop and pasture" land (row crop, orchard, and pasture uses) and "developed" land (residential, commercial, industrial, and transportation uses). The NRI developed estimates every 5 years on non-federal lands in the contiguous U.S. between 1977 and 1997, and annual estimates based on a smaller sample size beginning in 2001.

The Forest Inventory and Analysis (FIA) surveys conducted by the USDA Forest Service were used to track trends in forest and timberlands. The FIA surveys include both private and public land in all 50 states. The FIA previously assessed forest and timberland acreage every 10 years, but the data are now updated on a rolling basis using surveys that sample a different portion of FIA sites every year.

The USDA National Agricultural Statistics Service (NASS) Census of Agriculture was used to track trends in the extent of cropland, cropland used only for pasture, pastureland, and rangeland. NASS data are available for 1997 and 2002 only. Data on the extent of grass and forested

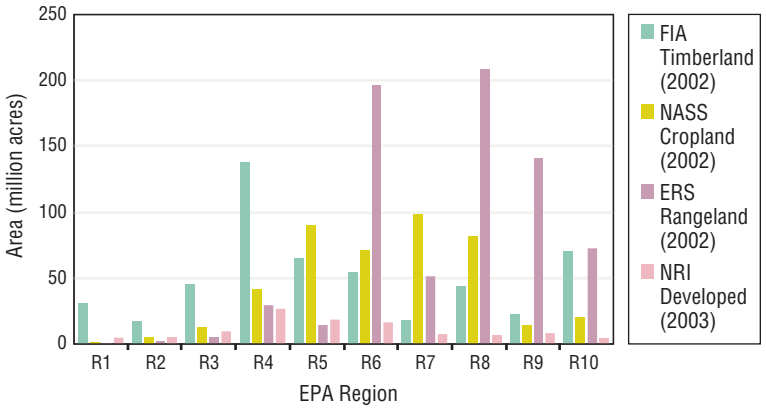
Exhibit 4-5. Land use trends in the U.S., 1977-2003[a]



[a]See box in text for definitions of land use categories.

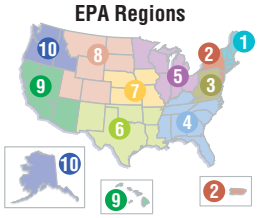
Data source: *Lubowski et al., 2006; Smith et al., 2004; USDA NASS, 2004; USDA NRCS, 2007*

Exhibit 4-6. Land use in the U.S. by EPA Region, 2002-2003[a]



[a]See box in text for definitions of land use categories.

Data source: *Lubowski et al., 2006; Smith et al., 2004; USDA NASS, 2004; USDA NRCS, 2007*



rangeland (typically "unimproved" grazing land) are available from the USDA Economic Research Service (ERS) for 5-year intervals from 1982 through 2002.

What the Data Show

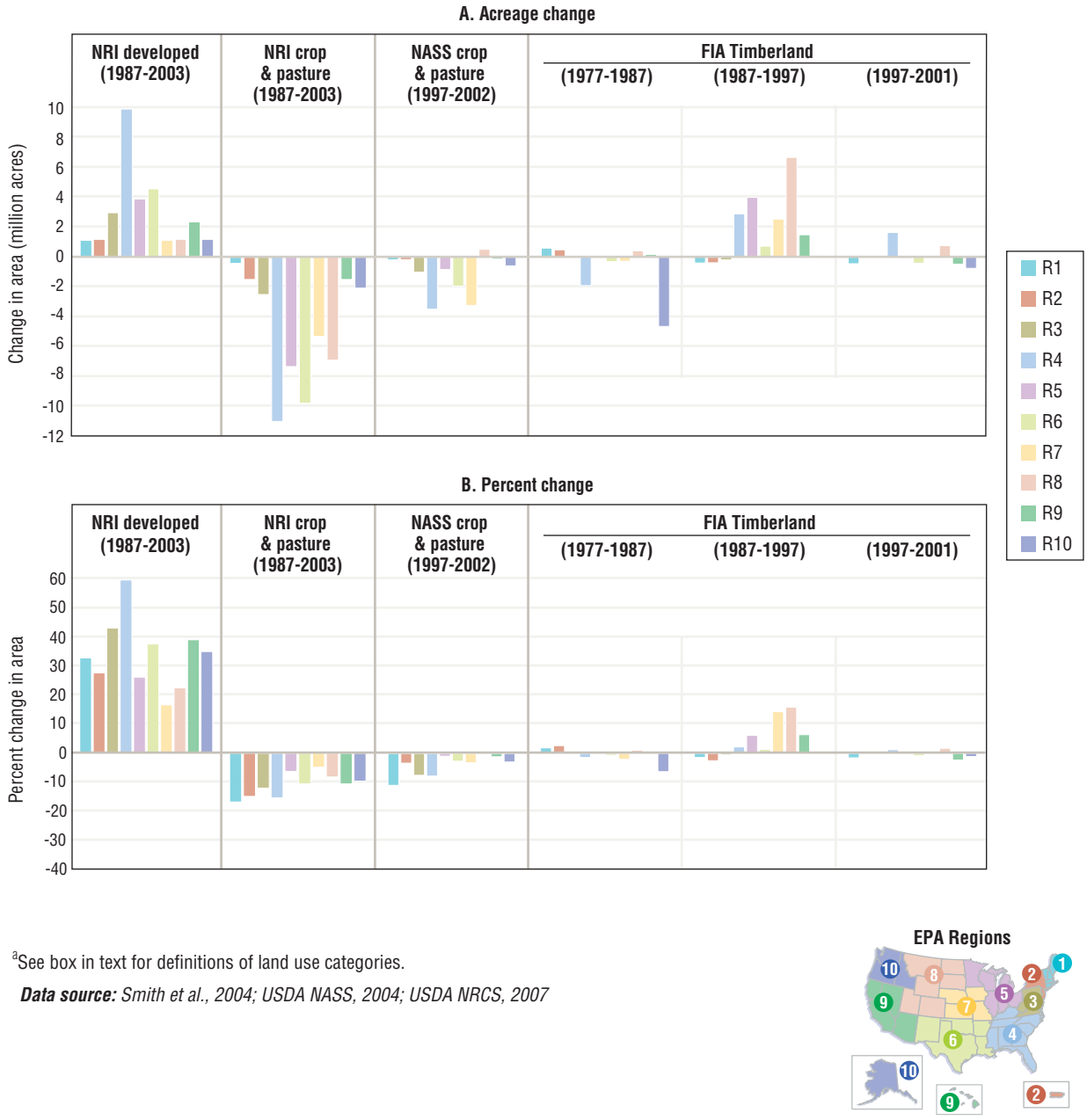
The acreage of lands used for growing food and forage crops has declined since 1982, while developed land has increased and timberland has remained approximately constant (Exhibit 4-5). As of 2002-2003, estimates from both the NRI (2003 data) and the NASS (2002 data) indicate that between 368 and 374 million acres were used for food crop production, approximately 16 percent of the U.S. land area. Estimates of pasture or land used to support forage for livestock vary, depending on the definitions. The NRI classifies 117 million acres as pasture, while the NASS classifies about 61 million acres as cropland used for pasture. The NASS classifies more than 395 million additional acres as pasture or rangeland for grazing. The broader ERS estimate of land available for grazing totals about 587 million acres, and includes grassland and other non-forested pasture and range. If forest lands used for grazing are also included, the total ERS estimate for these lands is 721 million acres for 2002. The NASS shows a decrease in the extent of cropland (5 million acres), cropland pasture (6 million acres), and pastureland and rangeland (3 million acres) between 1997 and 2002. The NRI data suggest that these declines are part of a longer trend, with NRI cropland and pasture declining by slightly more than 66 million acres (12 percent) between 1982 and 2003. ERS data also show a downward trend for pasture and rangeland between 1982 and 2002, with the largest decrease being a 24-million-acre (15 percent) decline in forest land used for grazing. According to the NRI, 5 percent (108.1 million acres) of U.S. land area was considered developed[1] as of 2003 (Exhibit 4-5). This represents a gain of 48 percent (35.2 million acres) since 1982. While the amount of developed land is a small fraction of the total, its ecological impact can be disproportionately high relative to other land use types. Paving and the creation of other impervious surfaces can change local hydrology, climate, and carbon cycling, leading to increased surface runoff, pollution, and degradation of wetlands and riparian zones.

Forest lands are managed by a complex array of interests to meet multiple purposes, including providing habitat for a variety of species, recreation, and timber production. While forest is a land *cover* classification, timberland is a land *use* classification that reflects forest land capable of producing at least 20 cubic feet per acre per year of industrial wood and not withdrawn from timber utilization by statute or regulation. Approximately 504 million acres of U.S. forest land, or 22 percent of the total U.S. land area, qualified as timberland in 2002 (Exhibit 4-5). This total reflects a net gain of about 11 million acres (2 percent) between 1977 and 2002, which the FIA attributes largely to reversion of abandoned lands and reclassification of some National Forest lands to align with classifications used on other land ownerships (Smith et al., 2004).

Land use varies widely by EPA Region (Exhibit 4-6). According to the most recent data for each land use type, Regions 6, 8, and 9 together have more than three-quarters of the nation's grazing land, while Region 4 has the largest portion of timberland (27 percent of total U.S. timberland). Trends also vary widely among regions. About 83 percent of the cropland lost between 1987 and 2003 was in five EPA Regions (Regions 4, 5, 6, 7, and 8) (Exhibit 4-7, panel A). Increases in developed land are responsible for part of this decline; for example, developed land increased by nearly 60 percent from 1987 to 2003 in Region 4 (Exhibit 4-7, panel B). Other factors include the federal Conservation Reserve Program, which has assisted private landowners in converting about 35 million acres of

[1] The land *use* classification for developed land uses NRI data and is considerably different from the land *cover* classification for developed land, which uses NLCD data. See Section 4.2 for more information.

Exhibit 4-7. Changes in land use in the U.S. by EPA Region, 1977-2003[a]



[a]See box in text for definitions of land use categories.

Data source: *Smith et al., 2004; USDA NASS, 2004; USDA NRCS, 2007*

highly erodable cropland to vegetative cover since 1985 (as of 2004) (USDA Farm Service Agency, 2004).

Indicator Limitations

- Estimates are derived from a variety of inventories and samples, conducted over different time periods and for different purposes. This limits the ability to integrate the data and track changes over time.
- The NRI does not report land use data for Alaska, which encompasses 365 million acres of the 2.3 billion acres nationwide. The NRI also does not provide data on federal lands (representing 20 percent of the contiguous U.S. land and one-third of Alaska). Because federal land is seldom used for agriculture or urban development, and there is relatively little developed or agricultural land in Alaska, the NRI data likely offer a reasonable approximation of national trends in these categories.

Definitions of Land Use Categories for Exhibits 4-5, 4-6, and 4-7

NRI (USDA NRCS, 2004)

Developed: A combination of land cover/use categories: *urban and built-up areas* and *rural transportation land*.

- **Urban and built-up areas.** A land cover/use category consisting of residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; other land used for such purposes; small parks (less than 10 acres) within urban and built-up areas; and highways, railroads, and other transportation facilities if they are surrounded by urban areas. Also included are tracts of less than 10 acres that do not meet the above definition but are completely surrounded by urban and built-up land. Two size categories are recognized in the NRI: areas of 0.25 acre to 10 acres, and areas of at least 10 acres.
  - **Large urban and built-up areas.** A land cover/use category composed of developed tracts of at least 10 acres—meeting the definition of urban and built-up areas.
  - **Small built-up areas.** A land cover/use category consisting of developed land units of 0.25 to 10 acres, which meet the definition of urban and built-up areas.
- **Rural transportation land.** A land cover/use category which consists of all highways, roads, railroads and associated right-of-ways outside urban and built-up areas; also includes private roads to farmsteads or ranch headquarters, logging roads, and other private roads (field lanes are not included).

Cropland: A land cover/use category that includes areas used for the production of adapted crops for harvest. Two subcategories of cropland are recognized: cultivated and noncultivated. Cultivated cropland comprises land in row crops or close-grown crops and also other cultivated cropland, for example, hay land or pastureland that is in a rotation with row or close-grown crops. Noncultivated cropland includes permanent hay land and horticultural cropland.

Pastureland: A land cover/use category of land managed primarily for the production of introduced forage plants for livestock grazing. Pastureland cover may consist of a single species in a pure stand, a grass mixture, or a grass-legume mixture. Management usually consists of cultural treatments: fertilization, weed control, reseeding or renovation, and control of grazing. For the NRI, pastureland includes land that has a vegetative cover of grasses, legumes, and/or forbs, regardless of whether or not it is being grazed by livestock.

FIA (Smith et al., 2004)

Forest land: Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10 percent stocked with forest trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet wide.

Timberland: Forest land that is producing or can produce crops of industrial wood and is not withdrawn from timber utilization by statute or administrative regulation. (Areas qualifying as timberland must be able to produce more than 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)

NASS (USDA NASS, 2004)

Cropland: A category including cropland harvested, cropland idle or used for cover crops or soil improvement but not harvested and not pastured, cropland on which all crops failed, and cropland in cultivated summer fallow. Not included is cropland used only for pasture or grazing.

Cropland pasture: Cropland used only for pasture or grazing, which could have been used for crops without additional improvement. Also included are acres of crops hogged or grazed but not harvested prior to grazing. However, cropland pastured before or after crops were harvested counts as harvested cropland rather than cropland for pasture or grazing.

Pastureland and rangeland: All grazable land—irrigated or dry—that does not qualify as cropland or woodland pasture. In some areas, this is high-quality pastureland but cannot be cropped without improvements. In others, it can barely be grazed and is only marginally better than waste land.

ERS (Lubowski et al., 2006)

Grassland pasture and range: All open land used primarily for pasture and grazing, including shrub and brush land types of pasture; grazing land with sagebrush and scattered mesquite; and all tame and native grasses, legumes, and other forage used for pasture or grazing. Because of the diversity in vegetative composition, grassland pasture and range are not always clearly distinguishable from other types of pasture and range. At one extreme, permanent grassland may merge with cropland pasture; grassland is also often found in transitional areas with forested grazing land.

Forested land grazed: Forested grazing land consists mainly of forest, brush-grown pasture, arid woodlands, and other areas within forested areas that have grass or other forage growth. The total acreage of forested grazing land includes woodland pasture in farms plus estimates of forested grazing land not in farms. For many states, the estimates include significant areas grazed only lightly or sporadically. The Census of Agriculture, the National Resources Inventory, and the Forest Inventory and Analysis are the principal sources of data.

- NRI data use three subcategories of types of developed land: large built-up areas, small built-up areas, and rural transportation land. Because ecological effects from developed land depend on the density of development and many other factors, the limited NRI categories are not discriminating enough to support detailed analyses of ecological effects of developed land.
- The FIA data are aggregated from state inventories in many cases, and dates of data collection for these inventories vary by state—for example, ranging from 1980 to 2001 for reporting 2002 estimates.
- Some land uses may be administratively designated but not physically visible (e.g., lands that are reserved for parks or wilderness may appear similar to lands that are managed for natural resources).
- Land use designations are most frequently managed and monitored by local governments, each using different approaches and classifications. This makes national summaries difficult.
- The extent of lands used for energy production, resource extraction, or mining is not known and represents a data gap.
- Lands specifically protected for certain uses such as wilderness or parks have been periodically inventoried for the nation. These statistics are currently not reported in a form that allows comparison with other statistics.

Data Sources

Data were obtained from several original sources and compiled by EPA Region. ERS data were obtained from Lubowski et al. (2006). FIA data were obtained from Smith et al. (2004). NASS data were published by the USDA National Agricultural Statistics Service (2004).

References

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The total number of people and their distribution on the landscape can affect the condition of the environment in many ways. Increasing population often means increased urbanization, including conversion of forest, farm, and other lands for housing, transportation, and commercial purposes. In recent years, many communities in the U.S. have seen an increase in developed land (residential, commercial, industrial, and transportation uses) that outpaces population growth. This pattern is of concern for numerous health and environmental reasons (Frumkin et al., 2004). For example, studies indicate that when land consumption rates exceed the rate of population growth, per capita air pollutant emissions from driving tend to be higher. Urbanization and population growth also tend to increase the amount of impervious surfaces and the quantity and types of products that humans produce, use, and discard, thereby affecting waste generation and management, water quality, and chemical production and use.

The information presented in this indicator is based on population data collected and analyzed on a decadal basis by the U.S. Census Bureau—as well as annual "intercensal" population estimates—and data collected by the U.S. Department of Agriculture Natural Resources Conservation Service's National Resources Inventory (NRI) to track "developed" land. Between 1977 and 1997, the NRI developed estimates every 5 years on non-federal lands in the contiguous U.S. Since 2001 the NRI has developed annual estimates, but based on a smaller sample size. This indicator captures trends in overall population growth for both rural and urban populations; the amount of developed land relative to the amount of population change, nationally and by EPA Region; and overall population density, also nationally and by EPA Region.

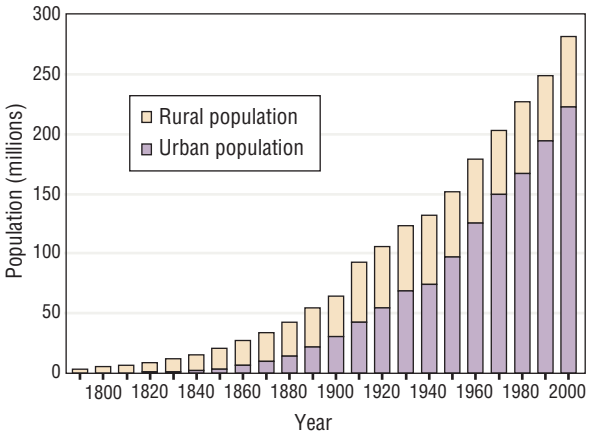
What the Data Show

The U.S. population grew from a little over 4 million people in 1790 to over 281 million in 2000; urban population is estimated to have grown a thousandfold over that period (Exhibit 4-8). The population nearly doubled between 1950 and 2000.

The rates of population and developed land growth over 5-year intervals increased between 1982 and 1997, before declining slightly between 1997 and 2002. Over all four 5-year increments, the amount of developed land increased at nearly twice the rate of the population (Exhibit 4-9). Between 1982 and 2003, the amount of developed land in the U.S. in the 48 contiguous states (not including the District of Columbia) grew by more than 35 million acres, representing a cumulative increase of more than 48 percent. The Census Bureau estimates that during the same period, the population of the 48 states grew by nearly 58 million people, or just over 25 percent (Exhibit 4-10).

There are substantial variations in population and development trends in different parts of the U.S. (Exhibit 4-10).

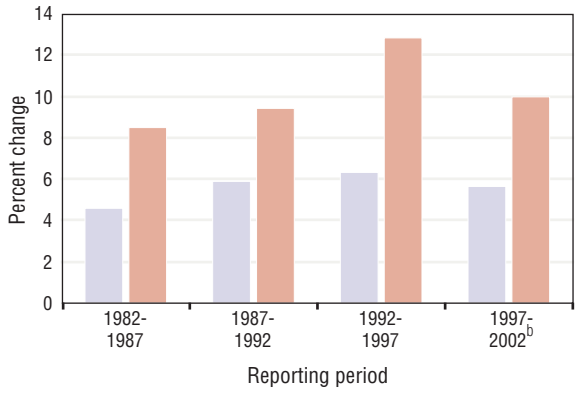
Exhibit 4-8. Population and urbanization in the U.S., 1790-2000[a]



[a]**Coverage:** 50 states and the District of Columbia.

Data source: *U.S. Census Bureau, 1993, 2004*

Exhibit 4-9. Percent change in population and developed land in the contiguous U.S. and Hawaii, 1982-2002[a,b]



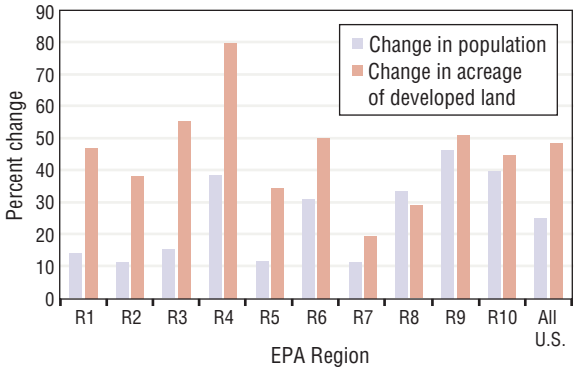
[a]**Coverage:** Contiguous 48 states (excluding the District of Columbia) and Hawaii.

[b]Based on changes in the NRI inventory approach, Hawaii was not sampled in 2002. Thus, the percent change in developed land from 1997 to 2002 is based on the 48 contiguous states only.

Data source: *U.S. Census Bureau, 1996, 2002b, 2006; USDA NRCS, 2000, 2004*

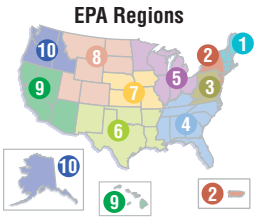
Between 1982 and 2003, the growth rates for developed land were higher than population growth rates in every region except Region 8. The largest rate of increase in

Exhibit 4-10. Percent change in population and developed land in the contiguous U.S. by EPA Region, 1982-2003[a]



[a]**Coverage:** Contiguous 48 states (excluding the District of Columbia).

Data source: *U.S. Census Bureau, 1996, 2002b, 2006; USDA NRCS, 2000, 2007*



population between 1982 and 2003 occurred in Region 9, where population increased by more than 46 percent (nearly 14 million people). Developed land in Region 9 increased by 51 percent (more than 2.8 million acres). Region 4 had the largest rate of increase in developed land (nearly 80 percent) and the largest absolute increases in both population (15.4 million) and developed land (11.8 million acres).

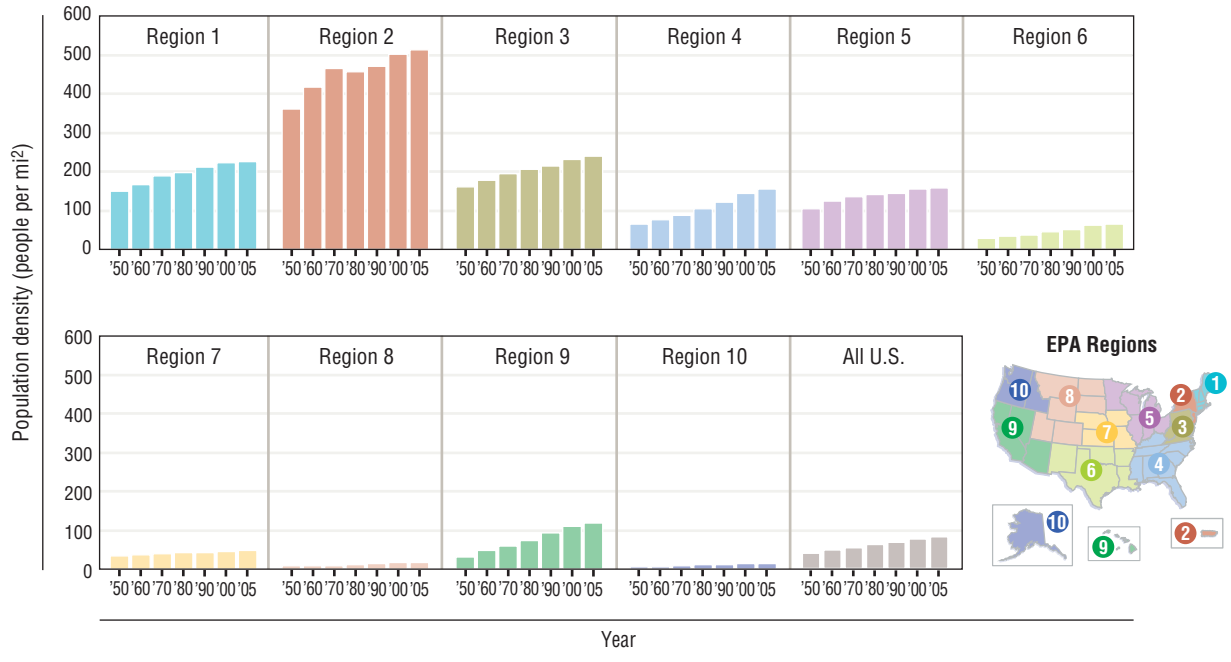
Although growth rates of population and developed land were high in most Regions, population density varies significantly from one Region to the next (Exhibit 4-11). In 2005, EPA Region 2 was the most densely populated Region, at 512 people per square mile; EPA Region 10 was the least densely populated, with an average of approximately 15 people per square mile (including Alaska). The national average in 2005 was 83.8 people per square mile.

Indicator Limitations

Census data:

- Intercensal figures are estimates based on administrative records of births, deaths, and migration, and thus differ from the decennial census data in methodology and accuracy.
- Sampling and non-sampling errors exist for all Census data as a result of errors that occur during the data collection and processing phases of the census.

Exhibit 4-11. Population density in the U.S. by EPA Region, 1950-2005[a]



[a]**Coverage:** 50 states and the District of Columbia.

Data source: *U.S. Census Bureau, 2002a,c; 2006*

- Puerto Rico and Virgin Islands data are not available for all years, and thus have not been included. This affects the accuracy of the statistics for Region 2.
- The criteria for estimating urban population have changed over time as defined by the Census Bureau.

NRI data:

- NRI sampling procedures changed in 2000 to an annual survey of fewer sample sites than had previously been sampled (starting in 1977, the NRI sampled 800,000 points every 5 years). Fewer sample points mean increased variance and uncertainty.
- The NRI collects some data across the entire nation, including Puerto Rico and the Virgin Islands. Land use statistics, however, are not reported on federal lands or for Alaska and the District of Columbia. In Exhibit 4-10, Hawaii is also excluded.

Data Sources

Urban and rural population data for Exhibit 4-8 were obtained from two U.S. Census Bureau publications: data from 1790 to 1990 are from U.S. Census Bureau (1993); 2000 data are from U.S. Census Bureau (2004).

In Exhibit 4-9, population change was calculated from annual population estimates published in U.S. Census Bureau (1996, 2002b, 2006) (estimates for 1982/1987, 1992/1997, and 2002, respectively). Changes in acreage of developed land were calculated based on acreage figures originally reported every 5 years by the NRI and now reported annually. NRI data were obtained from two publications (USDA NRCS, 2000, 2004) (1982-1997 and 2002 data, respectively).

Exhibit 4-10 is based on annual population estimates by state, published in U.S. Census Bureau (1996, 2002b, 2006), and NRI-developed land estimates by state, published in USDA NRCS (2000, 2007). The figure was developed by grouping the published state data by EPA Region, then calculating percent change between 1982 and 2003.

Population density by EPA Region (Exhibit 4-11) was calculated based on three published data sets: population every 10 years from 1900 to 2000 by state (U.S. Census Bureau, 2002a); population estimates for 2005 by state (U.S. Census Bureau, 2006); and land area by state (U.S. Census Bureau, 2002c).

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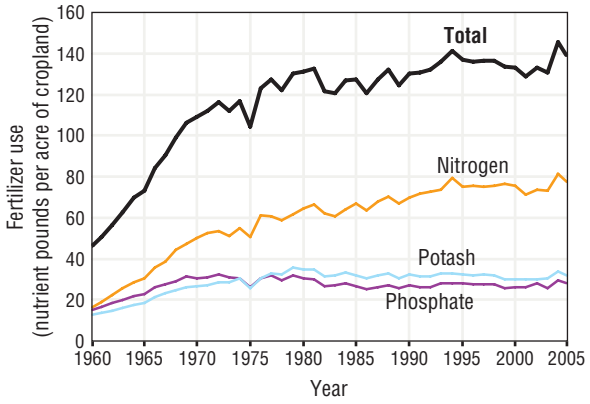
INDICATOR | Fertilizer Applied for Agricultural Purposes

Commercial fertilizers are applied to agricultural crops to increase crop yields. Prior to the 1950s, most farming occurred on small family farms with limited use of chemicals. The shift since then to larger corporate farms has coincided with the use of chemical fertilizers in modern agricultural practices. The three major types of commercial fertilizer used in the U.S. are nitrogen, phosphate, and potash.

Nitrogen (N) is found primarily in the organic form in soils, but can also occur as nitrate. Because nitrate is extremely soluble and mobile, it can lead to nuisance algal growth, mostly in downstream estuaries, and cause contamination of drinking water. Phosphorus (P) occurs in soil in several forms, both organic and inorganic. Phosphorus loss due to erosion is common and phosphate, while less soluble than nitrate, can easily be transported in runoff. Phosphorus/phosphate runoff can lead to nuisance algae and plant growth, often in freshwater streams, lakes, and estuaries. Potash is the oxide form of potassium (K) and its principal forms as fertilizer are potassium chloride, potassium sulfate, and potassium nitrate. When used at recommended application rates, there are few to no adverse effects from potassium, but it is a common component of mixed fertilizers used for high crop yields and is tracked in the fertilizer use surveys conducted.

This indicator shows use of the three major fertilizers in pounds per acre of land per year (expressed as N, P, or K) used for crop production from 1960 to 2005. Data are from an annual survey for agricultural crops conducted by the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) and from the Economic Research Service (ERS) Major Land Use series. Acreage used for crop production includes cropland harvested and crop failure as estimated in the ERS series. Cropland estimates as used in this indicator are a subset of agricultural land estimates discussed in the Land Cover and Land Use indicators. NASS also produces an annual *Agricultural Chemical Usage* report on four to five targeted field crops, based on data compiled from the Agricultural Resources Management Survey (ARMS). The ARMS surveys farmers in major agriculture-producing states that together account for a large percentage of crop acreage for corn, soybeans, cotton, and wheat. Results are presented for the years 2005-2006 by EPA Region.

Exhibit 4-16. Commercial fertilizer use in the U.S., 1960-2005[a]



[a]Based on sales data. Per-acre use based on the acreage of harvested or failed cropland, as determined by USDA's National Agricultural Statistics Service.

Data source: *Lubowski, 2006; Wiebe and Gollehon, 2006*

What the Data Show

Based on fertilizer sales data, total use of the three major commercial fertilizers has steadily increased, from 46.2 nutrient pounds per acre per year (lbs/acre/yr) in 1960 to 138 lbs/acre/yr in 2005, an increase of 199 percent (Exhibit 4-16). During this period, cropland used for crop production generally has fluctuated between 290 and 360 million acres with the largest changes occurring between 1969 (292 million acres) and 1981 (357 million acres) (Lubowski et al., 2006). Since 1996, cropland used for crop production has ranged between 321 and 328 million acres (Lubowski et al., 2006). Since 1996, aggregate commercial fertilizer use has fluctuated between 129 and 145 lbs/acre/yr with peak usage in 2004. Since 1960, nitrogen accounted for the steepest increase in use, from 17.0 lbs/acre/yr in 1960 to 81.6 lbs/acre/yr in 2004. Nitrogen currently accounts for about 56 percent of total fertilizer use, up from 37 percent in 1960. During the same period, phosphate and potash use grew more slowly; they remained steady between 25 and 36 lbs/acre/yr each since the late 1960s and now account for approximately 21 percent and 23 percent of total fertilizer usage, respectively.

The four major crops in the U.S.—corn, cotton, soybeans, and wheat—account for about 60 percent of the principal crop acreage and receive over 60 percent of the N, P, and K used in the U.S. Estimates from annual NASS *Acreage* reports show that from 1995 to 2006, between 76 and 80 million acres of corn were planted annually. In 2007, nearly 93 million acres were planted (USDA NASS, 2007a). A total of 76.5 million acres of corn were planted during the survey year (2005-2006). Corn acreage is concentrated in the center of the country (EPA Regions 5 and 7), but most EPA Regions grow some corn. Corn typically accounts for more than 40 percent of commercial fertilizer used (Daberkow and Huang, 2006).

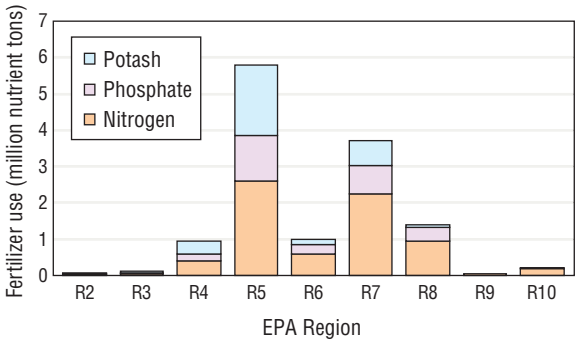
The acreage of land planted in cotton was 12.4 million acres in the most recent ARMS survey year (2006) and has ranged between 11 and 16 million acres since 1990. Major cotton-producing states include 17 southern states located in EPA Regions 4, 6, and 9.

Production of winter, durum, and other spring wheat occurred on about 57 million acres in 2006 and is distributed across EPA Regions 5, 6, 7, 8, and 10. Wheat typically accounts for about 10 percent of all commercial fertilizer used (Daberkow and Huang, 2006).

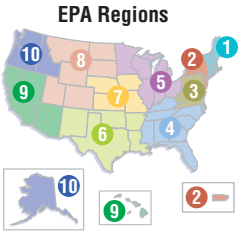
Soybeans were the fastest-growing crop in total acreage, increasing from 57.8 million acres in 1990 to 75.5 million acres in 2006 (USDA NASS, 2007c). The majority of soybean acreage (80 percent) is concentrated in the upper Midwest in EPA Regions 5 and 7. Soybeans require the least fertilizer per acre of the four crops described here.

Overall, production of these four crops in the ARMS states used slightly more than 13.25 million tons per year (MT/yr) of fertilizer in 2005-2006 (Exhibit 4-17) of the 21.7 MT/yr estimated (2005-2006 average) by ERS for all crops produced in the entire U.S. Of this amount, slightly less than half (5.8 MT/yr) was applied in EPA Region 5 (Exhibit 4-17), most of which was used for corn. An additional 3.7 MT/yr was applied in EPA Region 7, primarily on corn or soybeans.

Exhibit 4-17. Fertilizer use for four common crops (corn, cotton, soybeans, and wheat) in major agriculture-producing states, by EPA Region, 2005-2006[a]



[a]**Coverage:** States surveyed by USDA's Agricultural Resource Management Survey (ARMS) Program in 2005-2006 for corn, cotton, soybeans, and wheat. Each commodity was surveyed in a different subset of states, which together account for a substantial portion of the nation's production of that particular commodity. No states in Region 1 were surveyed by the ARMS Program for corn, cotton, soybeans, or wheat.



Data source: *USDA NASS, 2006b, 2007b*

Indicator Limitations

- USDA national estimates of fertilizer use are based on sales data provided by states, not actual fertilizer usage, and are susceptible to differing reporting procedures or accuracy from state to state.
- Data to identify cropland used for crop production are from the major land use series discussed in the Land Cover and Land Use indicators and do not include Alaska and Hawaii.
- Within the ARMS, not all states report fertilizer data every year for each crop type, making it difficult to establish year-to-year trends (a decrease in fertilizer use for a specific crop might be attributed to failure of a state to report, rather than an actual decrease of use).
- ARMS sampling is limited to program states, which represent 82 to 99 percent of crop acreage (across all surveyed crops) for the years 2005 and 2006, depending on crop type.
- The NASS *Acreage* report has estimates of acreage in production for the entire nation by crop, while fertilizer sales data are based only on USDA program states. Even though USDA program states represent the majority of U.S. planted acreage (often over 90 percent), the ability to generalize the data to the country as a whole is unknown, as non-program states, while representing a small percentage of a crop, might have much different application rates due to climate, weather, etc.
- Fertilizer applied to trees that are considered agricultural crops (e.g., nut-producing trees) is included in field crop summaries, but fertilizer applied in silviculture (e.g., southern pine plantations) is not covered by the NASS data collection system.
- Loading of nutrients in aquatic systems is not necessarily correlated directly with fertilizer use, but rather with the levels of fertilizer applied in excess of amounts used by crops, natural vegetation, and soil biota.

Data Sources

Exhibit 4-16 is based on two sets of summary data from ERS. Annual estimates of fertilizer use from 1960 through 2005, by nutrient, were obtained from Wiebe and Gollehon (2006) (see summary tables, http://www.ers.usda.gov/Data/FertilizerUse/). Fertilizer use per acre was calculated based on annual estimates of the amount of cultivated (harvested or failed) cropland from 1960 to 2005 published in Lubowski et al. (2006) (see summary tables, http://www.ers.usda.gov/Data/MajorLandUses/MLUsummarytables.pdf).

Exhibit 4-17 is based on fertilizer use data from USDA's 2005 and 2006 ARMS survey, which were obtained from USDA NASS (2006b, 2007b). The published data are by state, so additional aggregation was required to report by EPA Region (USDA NASS, 2001, 2004, 2005a,b, 2006a).

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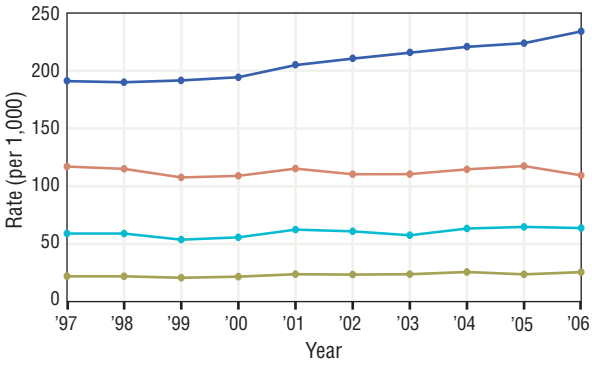
INDICATOR | Cardiovascular Disease Prevalence and Mortality

The broad category of cardiovascular disease (CVD) includes any disease involving the heart and blood vessels. Coronary heart disease, cerebrovascular disease (commonly known as stroke), and hypertension are the major cardiovascular diseases (American Heart Association, 2007). In addition to being a major risk factor for heart disease and stroke, hypertension is a commonly diagnosed disease that can also lead to kidney damage and other health problems. Obesity, physical inactivity, and sodium intake are all important risk factors for hypertension (NIH, 2004). Since 1900, CVD has been the leading cause of death in the U.S. every year except 1918 (American Heart Association, 2007) (General Mortality indicator). The U.S. age-adjusted mortality rate for CVD reached a peak in 1950 (CDC, 1999). Between 1950 and 1999, the age-adjusted mortality rate for CVD declined 60 percent. The major risk factors for CVD include tobacco use, high blood pressure, high blood cholesterol, diabetes, physical inactivity, and poor nutrition (CDC, 2004; American Heart Association, 2007).

Environmental exposures may also play a role in CVD morbidity and mortality independent of other risk factors. However, susceptible populations such as the elderly and other high-risk populations may be most impacted. For example, studies have shown exposure to ambient airborne particulate matter to be associated with increased hospitalizations and mortality among older individuals, largely due to cardiopulmonary and cardiovascular disease (U.S. EPA, 2004). Environmental tobacco smoke (ETS) may also contribute to CVD. Although the smoke to which a nonsmoker is exposed is less concentrated than that inhaled by smokers, research has demonstrated increased cardiovascular-related health risks associated with ETS (State of California, 2005).

This indicator presents U.S. adult (age 18 and older) prevalence rates for heart disease (all types), coronary heart disease, stroke, and hypertension; and mortality rates for CVD as a whole as well as coronary heart disease (including myocardial infarction), stroke, and hypertension. CVD prevalence data were compiled between 1997 and 2006 from the National Health Interview Survey (NHIS), conducted by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics (NCHS). The NHIS is the principal source of information on the health of the civilian non-institutionalized population of the U.S. and since 1960 has been one of the major data collection programs of NCHS. CVD prevalence is based on the number of adults who reported that they had ever been told by a doctor or other health practitioner that they had a specified CVD. Mortality data (all ages) were compiled between 1979 and 2004 using the National Vital Statistics System (NVSS), maintained by NCHS. The NVSS registers virtually all deaths and births nationwide, with data coverage from 1933 to 2004 and from all 50 states and the District of Columbia.

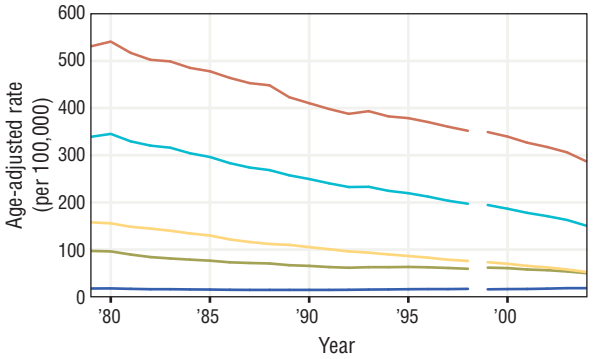
Exhibit 5-23. Cardiovascular disease prevalence in U.S. adults (age 18 and older), 1997-2006[a]



[a]Rates presented are crude rates.

Data source: *NCHS, 1999-2005, 2006a,b, 2007*

Exhibit 5-24. Age-adjusted cardiovascular disease mortality rates in the U.S., 1979-2004[a,b]



[a]Due to differences in the ICD system used for classifying mortality, data from 1979-1998 should not be directly compared to data from 1999-2004 [ICD-9 codes: 390-434, 436-448 (1979-1998); ICD-10 codes: I00-I78 (1999-2004)].

[b]Rates are age-adjusted to the 2000 U.S. standard population.

Data source: *CDC, 2007*

What the Data Show

CVD Prevalence

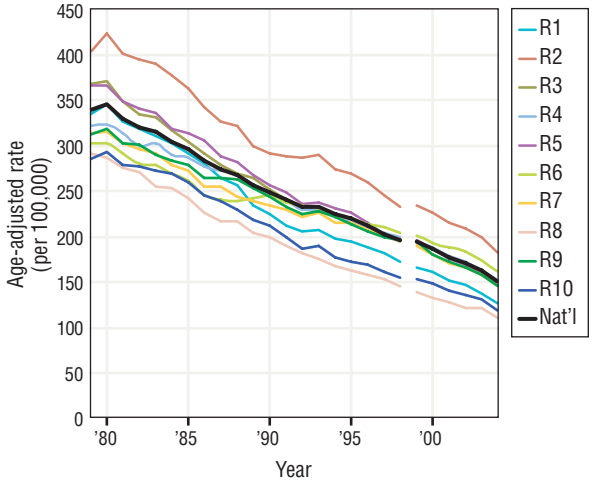
Among adults 18 years and older, the prevalence of heart disease and stroke between 1997 and 2006 has remained essentially the same (Exhibit 5-23). In contrast, the prevalence of hypertension has shown an increase from 191.6 cases per 1,000 in 1999 to 234.1 cases per 1,000 in 2006.

Gender, race, and age differences in CVD prevalence exist. The prevalence of coronary heart disease is consistently higher among males than among females (74.1 cases per 1,000 compared with 54.2 cases per 1,000 for women in 2006). In contrast, hypertension is more prevalent among women (238.4 cases per 1,000 for women compared with 229.5 for men in 2006). Among the racial groups reported, American Indians and Alaska Natives typically had the highest prevalence of coronary heart disease between 1999 and 2003. In 2006, however, whites had the highest prevalence of coronary heart disease (67.8 cases per 1,000), followed by American Indians and Alaska Natives (55.5 cases per 1,000), blacks or African Americans (52.0 cases per 1,000), and Asians (28.6 cases per 1,000). In 2006, Asians also consistently had the lowest prevalence of stroke (13.8 cases per 1,000) and hypertension (157.0 cases per 1,000) among the racial groups reported. In addition, the Hispanic or Latino population had a consistently lower prevalence of the major CVD-related diseases compared with the non-Hispanic or Latino population from 1999-2006, the period for which these data are available. For example, in 2006, prevalence in Hispanics or Latinos was lower than in non-Hispanics or Latinos for coronary heart disease (31.7 versus 68.6 cases per 1,000, respectively), hypertension (147.5 versus 247.0 cases per 1,000, respectively), and stroke (12.2 versus 27.6 cases per 1,000, respectively). (Data not shown.)

CVD Mortality

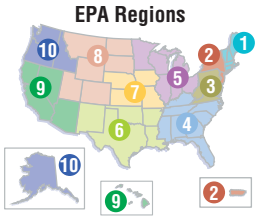
In 1998, the national age-adjusted CVD mortality rate (all types) was 352.0 per 100,000 compared to a rate of 541.0 per 100,000 in 1980 (Exhibit 5-24). This decline appears to continue after 1999, with the rate dropping from 349.3 per 100,000 in 1999 to 286.5 per 100,000 in 2004. Both coronary heart disease and stroke mortality rates have been declining in the U.S. The age-adjusted coronary heart disease mortality rate ranged from 345.2 per 100,000 in 1980 to 197.1 per 100,000 in 1998. For stroke mortality, the age-adjusted rate ranged from 97.1 per 100,000 in 1979 to 59.3 per 100,000 in 1998. The age-adjusted mortality rates for myocardial infarction ranged from 157.9 in 1979 to 76 per 100,000 in 1998. The age-adjusted mortality rates for coronary heart disease, stroke, and myocardial infarction in 2004 were 150.2, 50.0, and 52.3 per 100,000, respectively, compared to 194.6, 61.6, and 73.2 per 100,000, respectively, in 1999. Death rates from hypertension remained essentially the same between 1999 and 2004.

Exhibit 5-25. Age-adjusted coronary heart disease mortality rates in the U.S. by EPA Region, 1979-2004[a,b]



[a]Due to differences in the ICD system used for classifying mortality, data from 1979-1998 should not be directly compared to data from 1999-2004 [ICD-9 codes: 410-414, 429.2 (1979-1998); ICD-10 codes: I20-I25 (I999-2004)].

[b]Rates are age-adjusted to the 2000 U.S. standard population.



Data source: *CDC, 2007*

Both coronary heart disease and stroke mortality have been declining over time in each of the 10 EPA Regions (Exhibits 5-25 and 5-26). In 1979, coronary heart disease and stroke age-adjusted mortality rates ranged from 285.6 (Region 10) to 401.9 (Region 2) per 100,000 and 80.3 (Region 2) to 111.4 (Region 4) per 100,000, respectively. In 1998, coronary heart disease and stroke mortality rates ranged from 145.6 (Region 8) to 233.2 (Region 2) per 100,000 and 43.2 (Region 2) to 68.5 per (Region 10) 100,000, respectively. The observed decreases in coronary heart disease and stroke mortality also appear to continue in the 1999-2004 period.

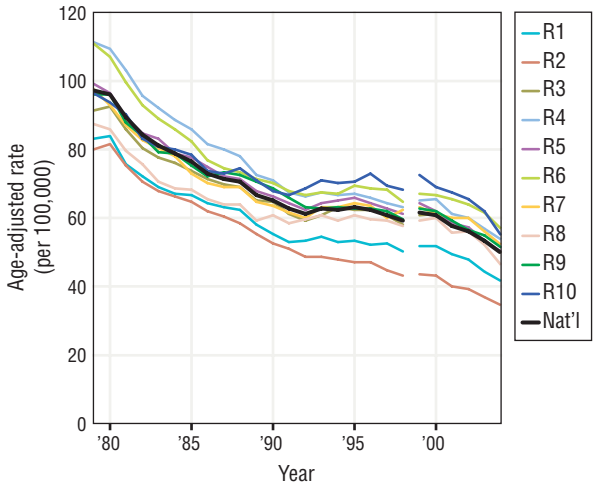
Differences exist in CVD mortality rates among gender, racial, and age groups. For example, in 2004, those age 65 and older had the highest CVD (all types), coronary heart disease, and stroke mortality (1,898.7, 990.8, and 346.2 per 100,000, respectively). For the same year, the age-adjusted CVD, coronary heart disease, and stroke mortality rates for those 45 to 64 years of age were 172.7, 98.5, and 22.5 per

100,000, respectively. Notable differences in CVD (all types) and, specifically, coronary heart disease mortality rates exist between males and females, but not for stroke mortality. Coronary heart disease mortality among males in 2004 was 194.2 per 100,000, compared to 116.7 per 100,000 for women. In 2004, black or African American males had the highest CVD mortality rate at 451.1 per 100,000 compared to white males (333.6 per 100,000), black or African American females (331.0 per 100,000), and white females (236.7 per 100,000). (Data not shown.)

Indicator Limitations

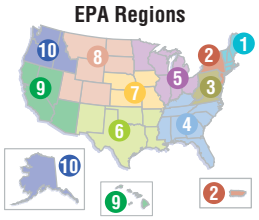
- Prevalence data reported in the NHIS are based on self-reported responses to specific questions pertaining to CVD-related illnesses, and are subject to the biases associated with self-reported data. Self-reported data can underestimate the disease prevalence being measured if, for whatever reason, the respondent is not fully aware of his/her condition.
- All prevalence data are based on crude rates and are not age-adjusted, as CDC did not report age-adjusted data prior to 2002 in the data sources used for this indicator. Therefore, the reported disease prevalence rates across time or within different race and gender subgroups may not reflect differences in the age distribution of the populations being compared.
- For one or more years for which data are presented, coronary heart disease and stroke prevalence rates presented for Native Americans and Alaska Natives have a relative standard error of greater than 30 percent. In addition, stroke prevalence rates for one or more years for which data are presented for Asians have a relative standard error of greater than 30 percent. As such, these rates should be used with caution as they do not meet the standard of reliability or precision.
- CVD mortality rates are based on underlying cause of death as entered on a death certificate by a physician. Some individuals may have had competing causes of death. "When more than one cause or condition is entered by the physician, the underlying cause is determined by the sequence of conditions on the certificate, provisions of the ICD [International Classification of Diseases], and associated selection rules and modifications" (CDC, n.d.). Consequently, some misclassification of reported mortality might occur in individuals with competing causes of death, as well as the possible underreporting of CVD as the cause of death.
- The International Classification of Diseases 9th Revision (ICD-9) codes were used to specify underlying cause of death for years 1979-1998. Beginning in 1999, cause of death is specified with the International Classification of Diseases 10th Revision (ICD-10) codes. The two revisions differ substantially, and to prevent confusion about the significance of any specific disease code, data queries are separate.

Exhibit 5-26. Age-adjusted stroke mortality rates in the U.S. by EPA Region, 1979-2004[a,b]



[a]Due to differences in the ICD system used for classifying mortality, data from 1979-1998 should not be directly compared to data from 1999-2004 [ICD-9 codes: 430-434, 436-438 (1979-1998); ICD-10 codes: I60-I69 (1999-2004)].

[b]Rates are age-adjusted to the 2000 U.S. standard population.



Data source: *CDC, 2007*

Data Sources

CVD prevalence data were obtained from annual reports published by NCHS (NCHS, 1999-2007), which summarize health statistics compiled from the NHIS (http://www.cdc.gov/nchs/products/pubs/pubd/series/ser.htm). CVD mortality statistics were obtained from CDC's "compressed mortality" database, accessed through CDC WONDER (CDC, 2007) (http://wonder.cdc.gov/mortSQL.html). EPA Regional mortality statistics were generated by combining and age-adjusting state-by-state totals for each EPA Region using data from CDC WONDER.

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INDICATOR | Chronic Obstructive Pulmonary Disease Prevalence and Mortality

Chronic obstructive pulmonary disease (COPD), sometimes referred to as chronic lung disease, is a disease that damages lung tissue or restricts airflow through the bronchioles and bronchi (NHLBI, 2003). Chronic bronchitis and emphysema are the most frequently occurring COPDs. Smoking is the most common cause of COPD, including cigarette, pipe, and cigar smoking (NHLBI, 2003). Other risk factors in the development and progression of COPD include asthma, exposure to air pollutants in the ambient air and workplace environment, genetic factors, and respiratory infections (CDC, 2003; American Lung Association, 2004).

Environmental tobacco smoke (ETS) may also increase the risk of developing COPD. The effect of chronic ETS exposure alone on pulmonary function in otherwise healthy adults is likely to be small. However, in combination with other exposures (e.g., prior smoking history, exposure to occupational irritants or ambient air pollutants), ETS exposure could contribute to chronic respiratory impairment. Children are especially sensitive to the respiratory effects of ETS exposure (State of California, 2005).

This indicator presents U.S. adult (age 18 and older) prevalence rates for chronic bronchitis and emphysema and mortality rates for COPD as a whole and for chronic bronchitis and emphysema. COPD prevalence data were compiled from 1999 to 2006 from the National Health Interview Survey (NHIS), conducted by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics (NCHS). The NHIS is the principal source of information on the health of the civilian noninstitutionalized population of the U.S. and since 1960 has been one of the major data collection programs of NCHS. COPD prevalence is based on the number of adults who reported that they had ever been told by a doctor or other health practitioner that they had chronic bronchitis or emphysema. Mortality data (all ages) were compiled between 1979 and 2004 using the National Vital Statistics System (NVSS), maintained by NCHS. The NVSS registers virtually all deaths and births nationwide, with data coverage from 1933 to 2004 and from all 50 states and the District of Columbia.

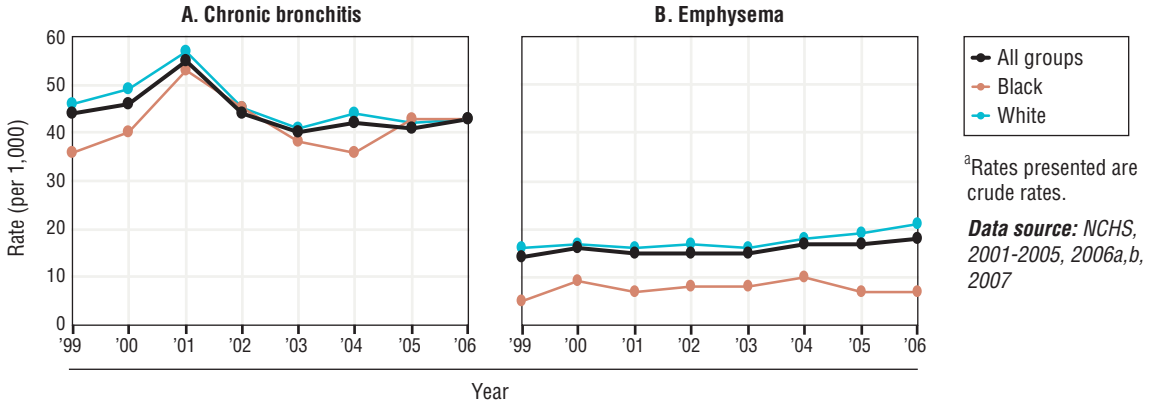
What the Data Show

COPD Prevalence

Exhibit 5-27 presents the prevalence of chronic bronchitis (panel A) and emphysema (panel B) from 1999 to 2006. The reported total prevalence of chronic bronchitis in U.S. adults over the age of 18 years ranged from a low of 40 (2003) to a high of 55 (2001) cases per 1,000. A small increase in prevalence of chronic bronchitis can be seen from 1999 to 2001, with a subsequent overall decline from 2001 to 2006. The reported total prevalence of emphysema in U.S. adults during the same time period ranged from 14 (1999) to 18 (2006) cases per 1,000. No notable change in the prevalence for emphysema was evident during this time period. Exhibit 5-27 also displays chronic bronchitis and emphysema prevalence by race. Chronic bronchitis prevalence was higher among white (designated as "white only") adults than black ("black or African American only") adults during 1999 (46 versus 36 cases per 1,000, respectively), 2000 (49 versus 40 cases per 1,000, respectively), and 2004 (44 versus 36 cases per 1,000, respectively). However, in 2006 rates in black and white adults are the same (43 cases per 1,000). Throughout the entire time period, emphysema prevalence is consistently higher among white adults than black adults.

In addition, the Hispanic or Latino population had a consistently lower prevalence of chronic bronchitis and emphysema diseases than the non-Hispanic or Latino population from 1999-2006, the period for which these

Exhibit 5-27. Chronic bronchitis and emphysema prevalence in U.S. adults (age 18 and older) by race, 1999-2006[a]



[a]Rates presented are crude rates.

Data source: *NCHS, 2001-2005, 2006a,b, 2007*

data are available. For example, in 2006, prevalence in Hispanics or Latinos was lower than non-Hispanics or Latinos for chronic bronchitis (22 compared to 46 cases per 1,000, respectively) and emphysema (4 compared to 21 cases per 1,000, respectively). (Data not shown.)

Gender differences are also seen. In 2006, females had about twice the reported prevalence of chronic bronchitis than males (57 versus 27 cases per 1,000 respectively), a consistently observed difference between 1997 and 2006. Unlike with chronic bronchitis, the prevalence rates for emphysema have been consistently higher in males than in females. (Data not shown.)

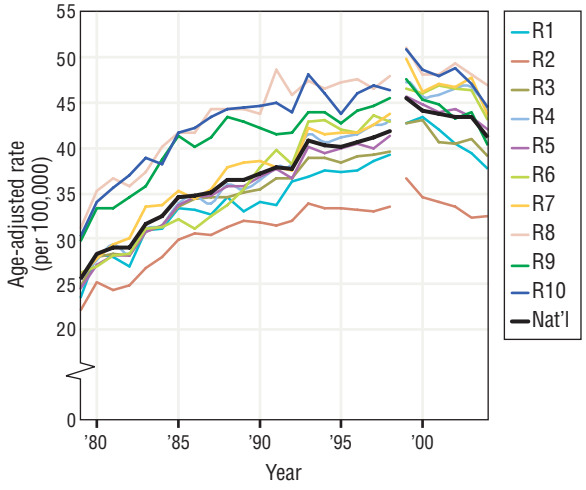
COPD Mortality

In 2004, COPD continues to be the fourth leading cause of mortality, accounting for 121,987 (5.1 percent) of all deaths (General Mortality indicator). The age-adjusted mortality rate for COPD as a whole has increased over time, with rates ranging from 25.5 per 100,000 in 1979 to 41.8 per 100,000 in 1998. From 1999 to 2004, rates held steadier, ranging from 45.4 per 100,000 in 1999 to 41.1 per 100,000 in 2004. Mortality rates for emphysema (6.9 and 6.5 per 100,000 for 1979 and 1998, respectively, and 6.5 and 4.6 per 100,000 for 1999 and 2004, respectively) and chronic bronchitis (1.7 and 0.9 per 100,000 for 1979 and 1998, respectively, and 0.2 and 0.1 per 100,000 for 1999 and 2004, respectively) have not changed substantially during the same time period. (Data not shown.)

Exhibit 5-28 presents the overall COPD mortality rates in the U.S. and the 10 EPA Regions for 1979-1998 and 1999-2004. The age-adjusted COPD mortality rates have been increasing in each of the 10 Regions from 1979 to 1998. The rates ranged from 22.2 (Region 2) to 31.2 (Region 8) per 100,000 in 1979 and 33.5 (Region 2) to 47.9 (Region 8) per 100,000 in 1998. Between 1999 and 2004, COPD mortality rates in each of the 10 EPA Regions have generally declined.

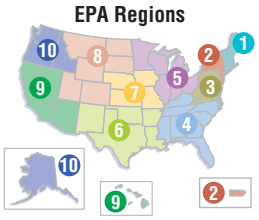
COPD age-adjusted mortality rates have been declining for males over time, with a rate of 58.7 per 100,000 in 1999 compared to 49.5 per 100,000 in 2004. For females, the rates are lower than males and have been relatively stable between 1999 and 2004 (37.7 and 36.0 per 100,000, respectively). The COPD age-adjusted mortality rate is higher among whites (43.2 per 100,000 in 2004) compared to blacks or African Americans (28.2 per 100,000 in 2004). COPD mortality rate increases with age: the 2004 rates were 0.3, 1.1, 21.0, and 284.3 per 100,000 for those age 0-14 years, 15-44 years, 45-64 years, and 65 years and older, respectively. (Data not shown.)

Exhibit 5-28. Age-adjusted chronic obstructive pulmonary disease mortality rates in the U.S. by EPA Region, 1979-2004[a,b]



[a]Due to differences in the ICD system used for classifying mortality, data from 1979-1998 should not be directly compared to data from 1999-2004 [ICD-9 codes: 490-494, 496 (1979-1998); ICD-10 codes: J40-J47 (1999-2004)].

[b]Rates are age-adjusted to the 2000 U.S. standard population.



Data source: *CDC, 2007*

Indicator Limitations

- Prevalence data presented in the NHIS are based on self-reported responses to specific questions pertaining to COPD-related illnesses, and are subject to the biases associated with self-reported data. Self-reported data can underestimate the disease prevalence being measured if, for whatever reason, the respondent is not fully aware of his/her condition.
- All prevalence data are based on crude rates and are not age-adjusted, as CDC did not report age-adjusted data prior to 2002 in the data sources used for this indicator. Therefore, the reported disease prevalence rates across time or within different race and gender subgroups may not reflect differences in the age distribution of the populations being compared.
- COPD mortality rates are based on underlying cause of death as entered on a death certificate by a physician. Some individuals may have had competing causes of death. "When more than one cause or condition is entered by the physician, the underlying cause is determined by the sequence of conditions on the certificate, provisions of the ICD [International Classification of Diseases], and associated selection rules and modifications" (CDC, n.d.). Consequently, some misclassification of reported mortality might occur in individuals

with competing causes of death, as well as the possible underreporting of COPD as the cause of death.

- The International Classification of Diseases 9th Revision (ICD-9) codes were used to specify underlying cause of death for years 1979-1998. Beginning in 1999, cause of death is specified with the International Classification of Diseases 10th Revision (ICD-10) codes. The two revisions differ substantially, and to prevent confusion about the significance of any specific disease code, data queries are separate.

Data Sources

COPD prevalence data were obtained from annual reports published by NCHS (NCHS, 2001-2005, 2006a,b, 2007), which summarize health statistics compiled from the NHIS (http://www.cdc.gov/nchs/products/pubs/pubd/series/ser.htm). Mortality statistics were obtained from CDC's "compressed mortality" database, accessed through CDC WONDER (CDC, 2007) (http://wonder.cdc.gov/mortSQL.html). EPA Regional mortality statistics were generated by combining and age-adjusting state-by-state totals for each EPA Region using data from CDC WONDER.

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INDICATOR | Forest Extent and Type

The forests of the U.S. cover extensive lands in both the eastern and western thirds of the country. While the amount of forest land has remained nearly unchanged since the beginning of the 20th century, regional changes both in amount and types of forest cover have occurred as a result of changing patterns of agriculture and development. The distribution of various forest cover types is a critical determinant of the condition of forest ecosystems.

This indicator is based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program. The FIA program, using a statistical survey design and comparable methods across the U.S., collects various data that help assess the extent, type, age, and health of the nation's forest land. Because the surveys are repeated over time, the FIA data provide an indication of trends in both the extent and composition of forest land. The extent data are collected for all forest lands across the nation, but species composition data over time are only available for *timberland* as defined by FIA data collection procedures (that is, forests capable of producing at least 20 cubic feet per acre per year of industrial wood and not withdrawn from timber utilization by statute or regulation). Timberland makes up 94 percent of the forest land area in the eastern U.S. and 39 percent of forest land in the western U.S. as of 2002 (Smith et al., 2004). Extent data are collected for individual states, but have been summarized by EPA Region for this indicator.

What the Data Show

After a slight increase in forest land nationwide between 1907 and 1938, forest acreage decreased by more than 16 million acres between 1938 and 1977, before increasing by 5.3 million acres over the past three decades (Exhibit 6-2). There are variations in trends in forest cover among the different EPA Regions. For example, between 1907 and 2002, forest land declined by roughly 22 million acres in Region 6 and more than 12 million acres in Region 9. Over the same period, forest land increased by 13 million acres in Region 3 and by 10 million acres in Region 5.

In addition to changes in the extent of forest, there have been changes in the types of forests over time (Exhibits 6-3 and 6-4). The largest changes in the eastern U.S. over the 1953-2002 period occurred in the maple-beech-birch forest type and the oak-hickory forest type, which gained 27.5 million acres and 23 million acres, respectively, since 1953. In the West, the fir-spruce type and Western hardwood type also have increased (about 11.5 million acres each) since 1953, while the hemlock-Sitka spruce, pinyon-juniper, and ponderosa-Jeffrey pine forest types have decreased by about 13.6 million, 8.8 million, and 8.7 million acres respectively. The Western white pine forest type has decreased by 5.3 million acres, or about 96 percent of its 1953 acreage.

Indicator Limitations

- Data on extent of forest land have an uncertainty of 3 to 10 percent per million acres for data reported since 1953. In 1998 Congress mandated that the FIA move to annual inventories. While data now are collected more often, fewer data are collected in any given year. Because area estimates now are based on a smaller sample size, the precision of the national estimates may be reduced relative to pre-1998 dates.
- Most of the specific data related to species and age classes are only collected on lands classified as timberland and not forest land in general.
- In addition to extent and species class, age class also influences the use of forest land as habitat by different species. Younger and older stands of forest have increased over the past half-decade, while middle-aged stands of more merchantable timber have decreased (Smith et al., 2001, 2004).

Data Sources

This indicator is based on data from two USDA Forest Service reports (Smith et al., 2001, 2004), which provide current and historical data on forest extent and type by state. Most data were obtained from the 2004 report; the 2001 report was consulted only for 1963 data, which were excluded from the more recent report. Data were originally collected by the USDA Forest Service's FIA program; original survey data are available from the FIA database (USDA Forest Service, 2005) (http://www.fia.fs.fed.us/tools-data/).

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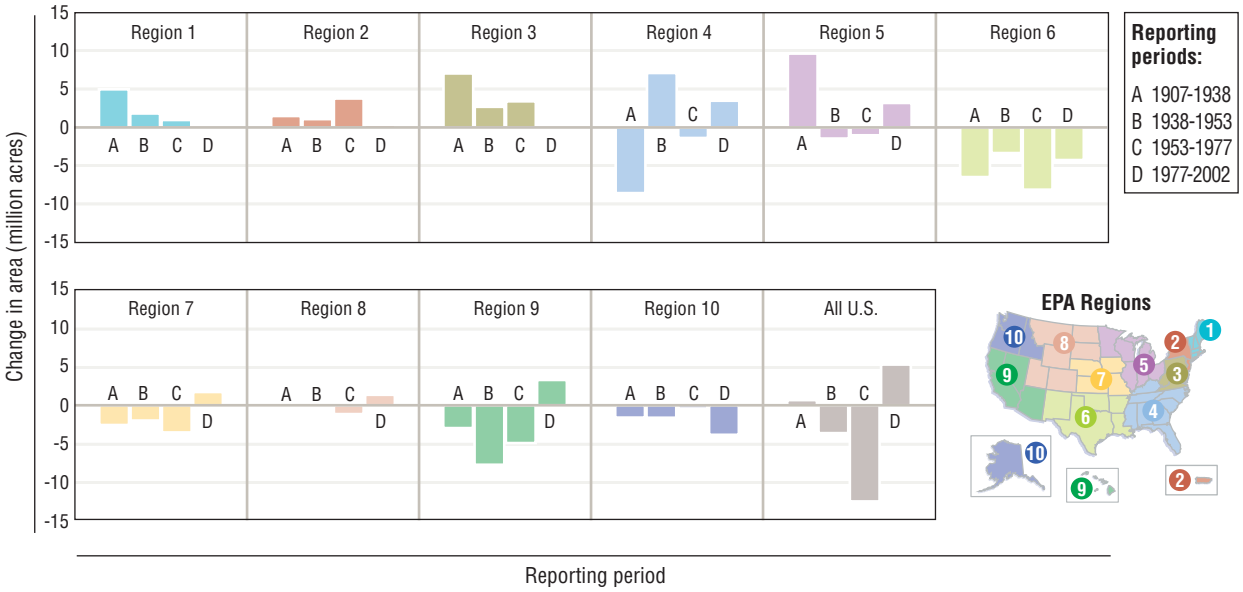
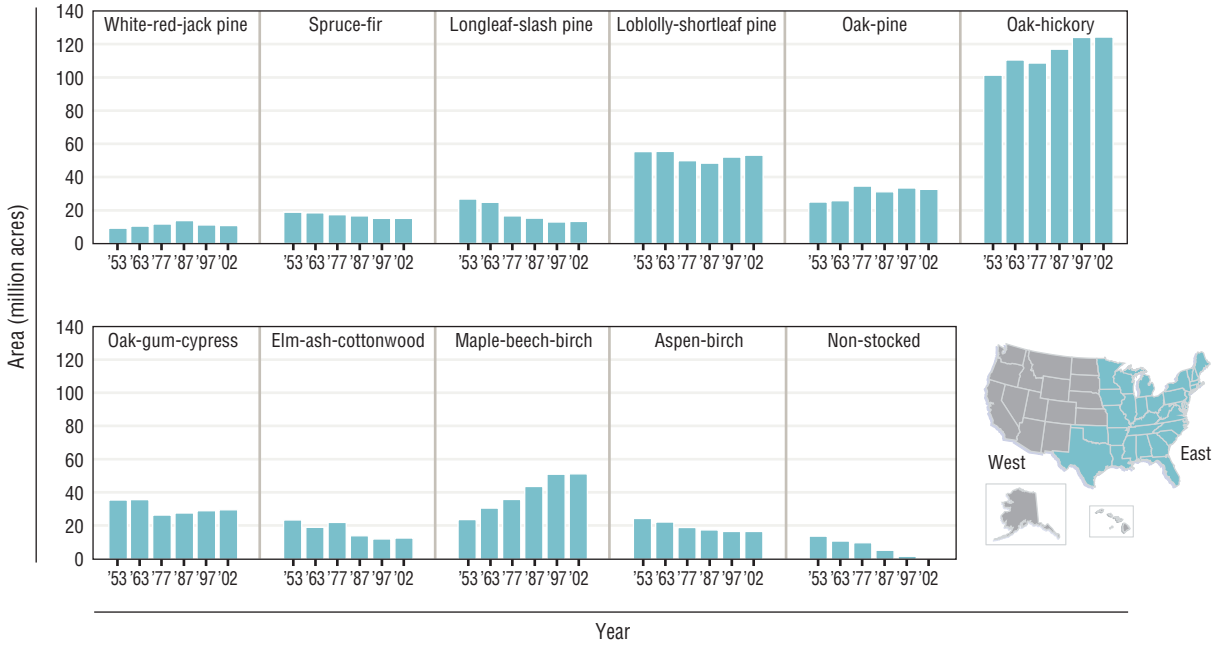
Exhibit 6-2. Changes in the extent of forest land in the U.S. by EPA Region, 1907-2002[a]



[a]**Coverage:** All 50 states.

Data source: *Smith et al., 2001, 2004*

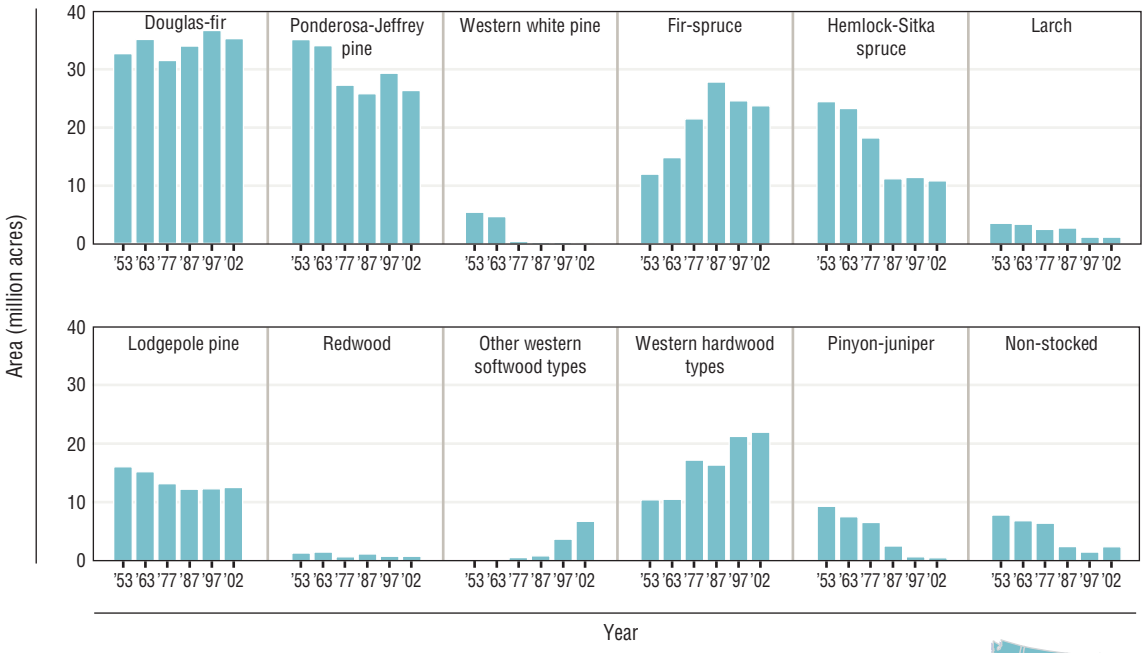
Exhibit 6-3. Timberland area in the eastern U.S. by forest type, 1953-2002[a]



[a]**Coverage:** States in the eastern U.S., based on USDA Forest Service reporting regions (see map at right). These data cover timberland, as defined by the Forest Service's Forest Inventory and Analysis (FIA) Program. Approximately 94% of the forest land in the eastern states is timberland.

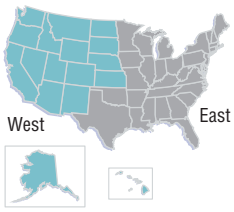
Data source: *Smith et al., 2001, 2004*

Exhibit 6-4. Timberland area in the western U.S. by forest type, 1953-2002[a]



[a]**Coverage:** States in the western U.S. (including Alaska and Hawaii), based on USDA Forest Service reporting regions (see map at right). These data cover timberland, as defined by the Forest Service's Forest Inventory and Analysis (FIA) Program. Approximately 39% of the forest land in the western states is timberland.

Data source: *Smith et al., 2001, 2004*



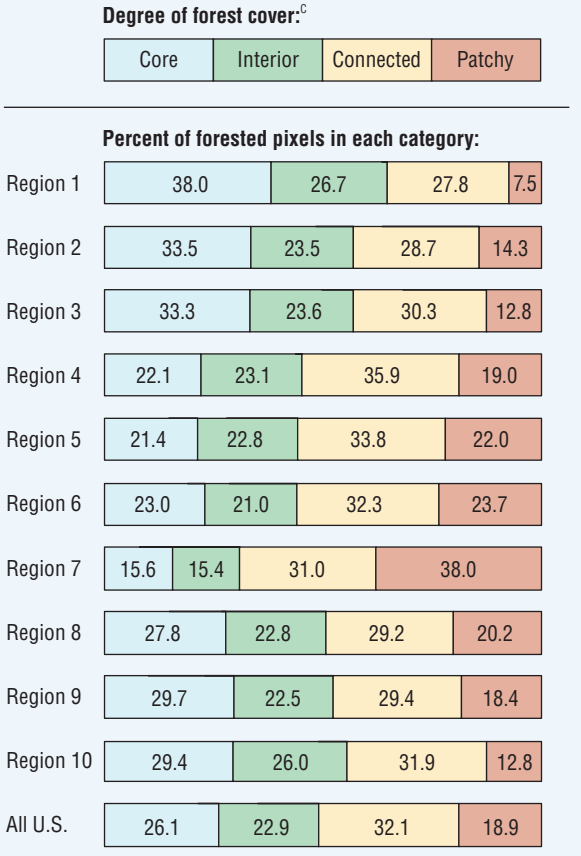
The amount of forest land in the U.S. monitored by the U.S. Department of Agriculture (USDA) Forest Service has remained nearly constant over the past century, but the patterns of human land use have affected its distribution from one region of the U.S. to another. Forest fragmentation involves both the extent of forest and its spatial pattern, and is the degree to which forested areas are being broken into smaller patches and pierced or interspersed with non-forest cover.

Forest fragmentation is a critical aspect of the extent and distribution of ecological systems. Many forest species are adapted to either edge or interior habitats. Changes in the degree or patterns of fragmentation can affect habitat quality for the majority of mammal, reptile, bird, and amphibian species found in forest habitats (Fahrig, 2003). As forest fragmentation increases beyond the fragmentation caused by natural disturbances, edge effects become more dominant, interior-adapted species are more likely to disappear, and edge- and open-field species are likely to increase.

This indicator of forest fragmentation was developed by the USDA Forest Service. The indicator is based on the 2001 National Land Cover Database (NLCD), which was constructed from satellite imagery showing the land area of the contiguous U.S. during different seasons (i.e., leaves-on and leaves-off) around the year 2001 (Homer et al., 2007). The USDA Forest Service's Southern Research Station performed a re-analysis of the NLCD, aggregating the four NLCD forest cover classes (coniferous, deciduous, mixed, and wetland forest) into one forest class and the remaining land cover classes into a single non-forest class (USDA Forest Service, 2007). A model that classifies forest fragmentation based on the degree of forest land surrounding each forest pixel (a square approximately 30 meters on each edge) for various landscape sizes (known as "windows") provides a synoptic assessment of forest fragmentation for the contiguous U.S. by assessing each pixel's "forest neighborhood" within various distances.

Results are based on four degrees of forest cover: "core" if a subject pixel is surrounded by a completely forested landscape (no fragmentation), "interior" if a subject pixel is surrounded by a landscape that is 90 to 100 percent forest, "connected" if a subject pixel is surrounded by a landscape that is 60 to 90 percent forest, and "patchy" if the subject pixel is surrounded by less than 60 percent forest. The window (landscape) size used for this analysis was 13 by 13 pixels, 390 meters on each edge, or about 15.2 hectares (37.6 acres). The window is shifted one pixel at a time over the map, so the target population for the indicator is all forested pixels in the contiguous U.S. Percent forest was resampled from 30-meter pixel data and aggregated by state to develop the EPA Region-specific breakouts.

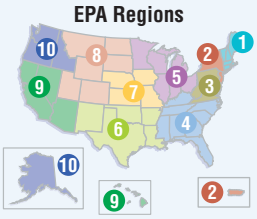
Exhibit 6-5. Forest fragmentation in the contiguous U.S. by EPA Region, based on 2001 NLCD[a,b]



[a]**Coverage:** Areas of the contiguous 48 states classified as "forested" by the 2001 National Land Cover Database (NLCD).

[b]Totals may not add to 100% due to rounding.

[c]See text for definitions of forest cover categories.



Data source: *USDA Forest Service, 2007*

What the Data Show

Slightly more than 26 percent of the forested pixels in the U.S. represent "core" forest, i.e., landscapes dominated by forest (Exhibit 6-5). However, the data for "interior" and "core" forests suggest that fragmentation is extensive, with few large areas of complete, unperforated forest cover. About 19 percent of forest pixels in the U.S. occur in a landscape where less than 60 percent of the "neighborhood" is forest (i.e., forest cover is "patchy").

There is considerable regional variation in forest fragmentation (Exhibit 6-5). Regions 1, 2, and 3 have more than 30 percent "core" forest pixels, while fewer than 20 percent of the forest pixels in Region 7 are "core" forest. From the opposite perspective, fewer than 10 percent of forest pixels in Region 1 are surrounded by less than 60 percent forest, compared to almost 40 percent of the forest pixels in Region 7.

Indicator Limitations

- Trend information is not available for this indicator. Although earlier land cover data are available as part of the 1992 NLCD, they are not directly comparable with the 2001 NLCD due to differences in classification methodology. Efforts to compare these two products are ongoing.
- The apparent degree of connectivity depends on the size of the window. In a similar analysis of 1992 NLCD data, Riitters (2003) determined that the percentages for all categories (especially "core" and "connected" forest pixels) decrease rapidly as the size of the window is increased progressively from 18 to 162, 1,459, and 13,132 acres.
- Because the non-forest land cover classes were aggregated, this indicator does not distinguish between natural and anthropogenic fragmentation (although such a distinction has been made for global fragmentation by Wade et al., 2003).
- The data do not include Hawaii or Alaska, which account for about 1 out of every 6 acres of forest land in the U.S.

Data Sources

An earlier version of this analysis was published in Riitters (2003) and Heinz Center (2005). The analysis presented here has not yet been published; data were provided by the USDA Forest Service (2007), and EPA grouped the results by EPA Region. This indicator is based on land cover data from the 2001 NLCD (MRLC Consortium, 2007).

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INDICATOR | Fish Faunal Intactness

Intactness, the extent to which ecological communities have retained their historical composition, is a critical aspect of the biological balance of the nation's ecological systems (NRC, 2000). It is of particular importance in freshwater systems that are impacted by pollution, habitat alteration, fisheries management, and invasive species.

This indicator tracks the intactness of the native freshwater fish fauna in each of the nation's major watersheds by comparing the current faunal composition of those watersheds with their historical composition. In this case, historical data are based on surveys conducted prior to 1970. The indicator specifically measures the reduction in native species diversity in each 6-digit U.S. Geological Survey hydrologic unit code (HUC) cataloguing unit in the 48 contiguous states. Intactness is expressed as a percent based on the formula:

$$\textit{reduction in diversity} = 1 - \left(\frac{\textit{\# of current native species}}{\textit{\# of historical native species}} \right)$$

The native species diversity indicator proposed by the National Research Council (NRC, 2000) compared expected native species diversity (projected from species-area-curve models) with observed diversity. This "Fish Faunal Intactness" indicator makes use of empirical, rather than modeled, data sets and focuses on a well-known group of organisms with a fairly strong historical record.

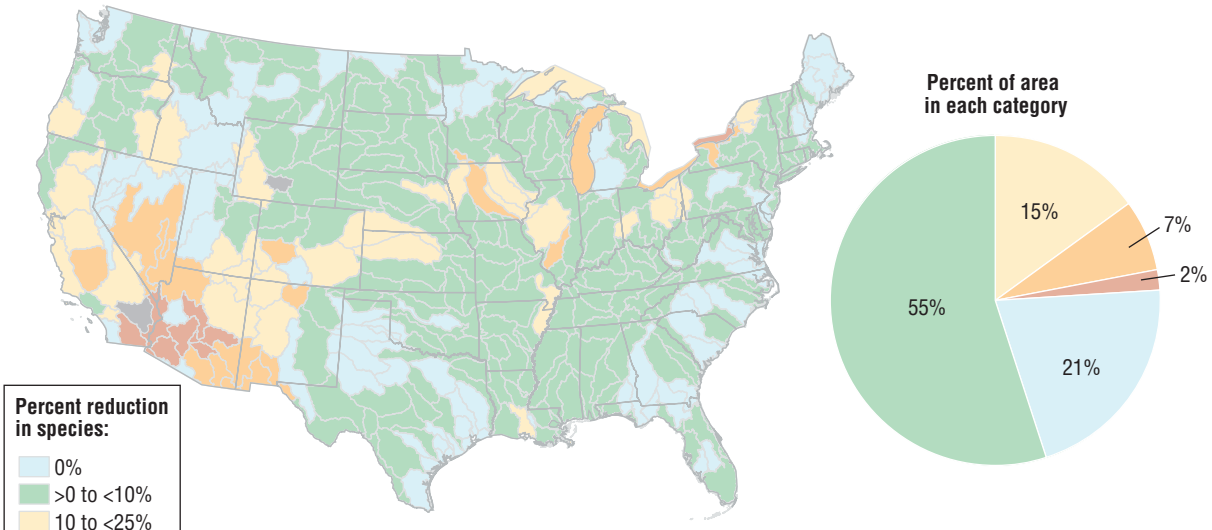
Reductions in watershed diversity may be due either to the overall extinction of a species (at least 12 U.S. freshwater fish species are known to be extinct and another three species are known only from historical records and may be extinct) or, more commonly, to the extirpation of a species from selected watersheds. In the case of regional extirpations, opportunities may exist for restoring a species to watersheds in its historical range.

The fish distributional data underlying this indicator were gathered by NatureServe, a nonprofit research organization, and are derived from a number of sources, including species occurrence data from state Natural Heritage Programs, a broad array of relevant scientific literature (e.g., fish faunas), and expert review in nearly every state. These data were assembled during the 1997–2003 period. The underlying data include distributions for 782 native freshwater fish species across small watersheds (8-digit HUC). For this indicator, data were pooled and reported by larger 6-digit HUCs to reduce potential errors of omission in the smaller watersheds.

What the Data Show

Watersheds covering about one-fifth (21 percent) of the area of the contiguous U.S. appear to have fish faunas that are fully intact, retaining the entire complement of

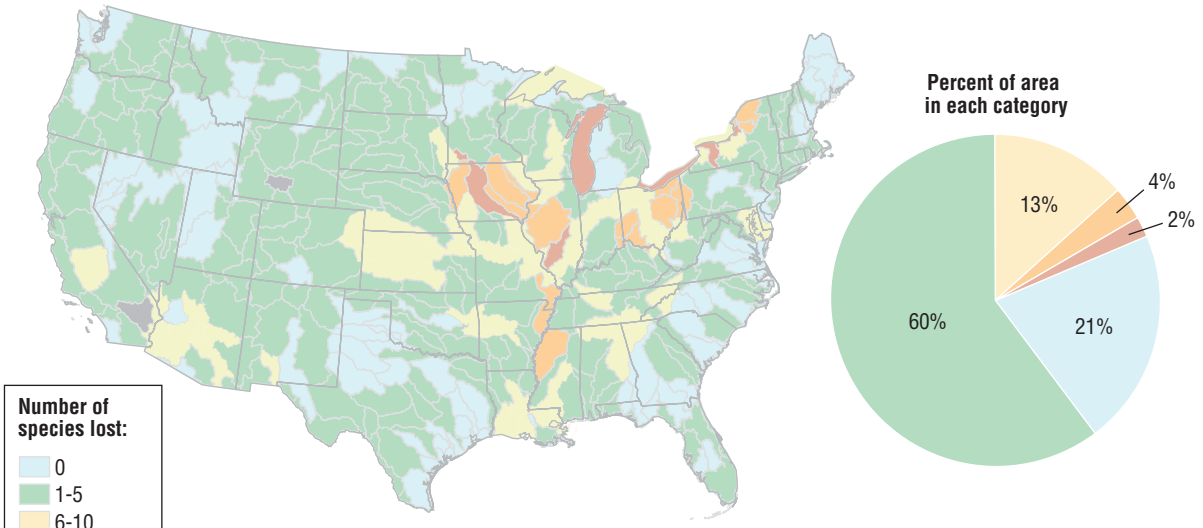
Exhibit 6-10. Percent reduction in native fish species diversity in the contiguous U.S. from historical levels to 1997-2003[a]



[a]Data are displayed by 6-digit hydrologic unit code (HUC) watershed. Percent reduction is based on the number of native species present during the period 1997-2003, compared with historical numbers documented prior to 1970. A species is considered "present" if there is at least one record of its presence in any 8-digit HUC within the 6-digit HUC.

Data source: *NatureServe, 2006*

Exhibit 6-11. Reduction in native fish species diversity in the contiguous U.S. from historical levels to 1997-2003[a]



[a]Data are displayed by 6-digit hydrologic unit code (HUC) watershed. Reduction is based on the number of native species present during the period 1997-2003, compared with historical numbers documented prior to 1970. A species is considered "present" if there is at least one record of its presence in any 8-digit HUC within the 6-digit HUC.

Data source: *NatureServe, 2006*

fish species that were present before 1970 (Exhibit 6-10). Watersheds covering nearly a quarter (24 percent) of the area, however, have lost 10 percent or more of their native fish species. Reductions in diversity are especially severe in the Southwest (e.g., the lower Colorado River watershed) and the Great Lakes, with eight major watersheds (representing 2 percent of total area) having lost at least half of their native fish species.

Some watersheds are naturally more species-rich than others, and for those with greater historical diversity, even a small percentage reduction may mean the loss of numerous species in absolute terms. Although the greatest diversity of fish species is found in the Southeast, the greatest reduction in numbers has occurred in portions of the Midwest and the Great Lakes, where several watersheds have lost more than 20 species (Exhibit 6-11). In contrast, southwestern HUCs have all lost 10 or fewer species, but because these watersheds historically supported fewer species, on a percentage basis their fish faunas are regarded as less intact.

Indicator Limitations

- The incomplete historical record for freshwater fish distributions and inconsistent inventory records for contemporary fish distributions are sources of uncertainty.
- Although NatureServe has attempted to compile the most complete distributional information possible for these species at the 8-digit HUC level, these data are dynamic; new records frequently are added and existing records are revised as new information is received and as taxonomic changes occur.

Data Sources

This indicator presents a summary of data available from the NatureServe Explorer database (NatureServe, 2006) (http://www.natureserve.org/getData/dataSets/watershedHucs/index.jsp). The identity and status (current vs. historical) of all native fish species recorded in each 8-digit HUC are available from this database, along with species-by-species distribution maps at the 8-digit HUC level. Analyses based on these data have previously been reported in Master et al. (1998, 2003) and Stein et al. (2000).

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NRC (National Research Council). 2000. Ecological indicators for the nation. Washington, DC: National Academies Press. <http://www.nap.edu/openbook/0309068452/html/>

Stein, B.A., L.S. Kutner, and J.S. Adams. 2000. Precious heritage: The status of biodiversity in the United States. New York, NY: Oxford University Press. <http://www.natureserve.org/publications/preciousHeritage.jsp>

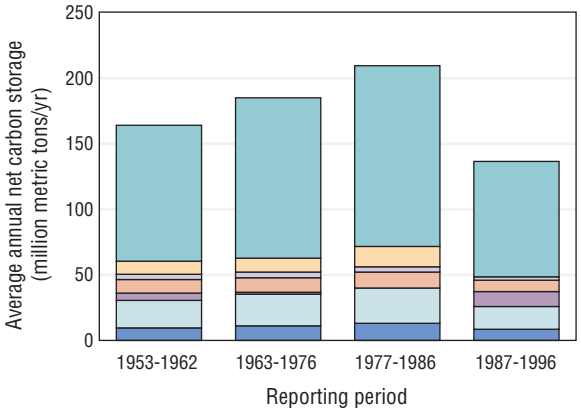
After carbon dioxide is converted into organic matter by photosynthesis, carbon is stored in forests for a period of time in a variety of forms before it is ultimately returned to the atmosphere through the respiration and decomposition of plants and animals, or harvested from forests for use in paper and wood products. A substantial pool of carbon is stored in woody biomass (roots, trunks, and branches). Another portion eventually ends up as organic matter in forest floor litter and the upper soil horizons. Carbon storage in forest biomass and forest soils is an essential physical and chemical attribute of stable forest ecosystems, and a key link in the global carbon cycle.

This indicator, developed by the U.S. Department of Agriculture (USDA) Forest Service, tracks decadal changes in net carbon storage rates in the pools of living and dead biomass in forests in the contiguous 48 states. The carbon pools for this indicator are estimated using USDA Forest Service Forest Inventory and Analysis (FIA) data from five historical periods (circa 1953, 1963, 1977, 1987, and 1997). These data cover forest classified as "timberland" under FIA data collection procedures—that is, forests capable of producing at least 20 cubic feet per acre per year of industrial wood and not withdrawn from timber utilization by statute or regulation. Timberland makes up roughly two-thirds of U.S. forest land. Alaska and Hawaii are not included because of limited historical data. The FIA program estimates carbon storage using on-the-ground measurements of tree trunk size from many forest sites; statistical models that show the relationship between trunk size and the weight of branches, leaves, coarse roots (greater than 0.1 inch in diameter), and forest floor litter; and estimates of forest land area obtained from aerial photographs and satellite imagery. Values are converted into carbon storage based on coefficients derived from previous field studies (Smith and Heath, 2002; Smith et al., 2003; Birdsey, 1996). Forest floor litter is composed of dead organic matter above the mineral soil horizons, including litter, humus, and fine woody debris. Larger branches and logs on the ground are counted as "down dead wood." Organic carbon in soil is not included.

What the Data Show

The change in carbon inventories from year to year—i.e., net storage—reflects increases in growth as well as decreases due to harvesting, land use change, and disturbances such as fire, insects, and disease. Overall, net carbon storage in forests of the contiguous 48 states has been positive since 1953 (Exhibit 6-13), indicating that over at least the last half-century, forests have served as a sink rather than a source of carbon. The average rate of net carbon storage in forests increased between the 1950s and the 1980s, peaking at 210 million metric tons of carbon per year (MtC/yr) from 1977 to 1986. The rate declined to 135 MtC/yr for the last period of record (1987-1996), with declining storage evident in live, dead, and understory pools. This decline is thought to be due to a combination of increased harvests relative to growth, more accurate data, and better accounting of emissions from dead wood (USDA Forest Service, 2004b). The rate of storage over this period is equivalent to approximately 9 to 10 percent of U.S. carbon dioxide emissions over a comparable period (U.S. EPA, 2005).

Exhibit 6-13. Average annual net carbon storage in forests of the contiguous U.S., by forest component, 1953-1996[a]



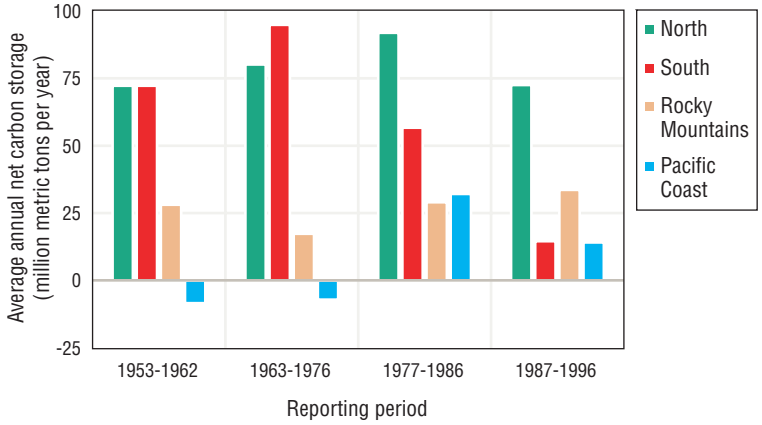
[a]**Coverage:** Forest land classified as "timberland," which accounts for approximately two-thirds of the forest land of the contiguous 48 states. These data do not include carbon stored in forest soil.

Data source: *USDA Forest Service, 2004a,b*

- Aboveground live trees
- Aboveground standing dead trees
- Understory vegetation
- Down dead wood (including stumps)
- Forest floor litter
- Belowground live trees (roots)
- Belowground dead wood

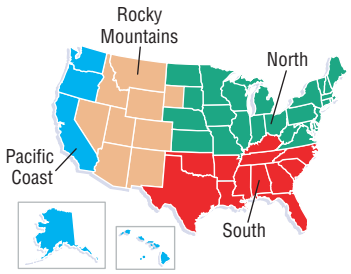
Carbon storage trends vary among regions of the country, depending on land use patterns and factors such as climate and soil quality. In three of the four major regions, net storage was positive throughout the period of record, with the North generally showing the largest net storage rates (Exhibit 6-14). The exception was the Pacific Coast region, which experienced net losses of forest carbon during two of the four reporting periods. Rates of net carbon storage appear to have decreased over time in the South; this trend is thought to be due to an increase in harvesting relative to growth (USDA Forest Service, 2004b). Some of the harvested carbon is sequestered in wood products.

Exhibit 6-14. Average annual net carbon storage in forests of the contiguous U.S. by region, 1953-1996[a]



[a]**Coverage:** Forest land classified as "timberland," which accounts for approximately two-thirds of the forest land of the contiguous 48 states. These data do not include carbon stored in forest soil.

Data source: *USDA Forest Service, 2004a,b*



Indicator Limitations

- The data include only forest classified as "timberland," which excludes about one-third of U.S. forest land cover. Historical data from Alaska and Hawaii are insufficient for inclusion in this indicator.
- Data are derived from state inventories that do not correspond exactly to the years identified in Exhibits 6-13 and 6-14.
- Carbon stored in forest soil is not included.
- Carbon pools are not measured, but are estimated based on inventory-to-carbon coefficients developed with information from ecological studies. These coefficients may change over time as new ecological studies are conducted, which could change storage rate estimates.

These limitations are discussed in detail in Heath and Smith (2000) and Smith and Heath (2000, 2001).

Data Sources

Exhibits 6-13 and 6-14 were previously published in the data supplement to USDA Forest Service (2004b). The numbers depicted in these figures have not been published, but were provided by the USDA Forest Service (2004a). The physical measurements used as inputs in the carbon storage models can be obtained from the FIA database (USDA Forest Service, 2005) (http://fia.fs.fed.us/tools-data/).

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Smith, J.E., and L.S. Heath. 2001. Identifying influences on model uncertainty: An application using a forest carbon budget model. Environ. Manage. 27:253-267.

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USDA Forest Service. 2004a. Data provided to ERG (an EPA contractor) by Linda Heath, USDA Forest Service. December 23, 2004.

USDA Forest Service. 2004b. National report on sustainable forests—2003. <http://www.fs.fed.us/research/sustain/> (main site); <http://www.fs.fed.us/research/sustain/one_pagers/indicator%2027.pdf> (data supplement: summary); <http://www.fs.fed.us/research/sustain/documents/Indicator%2027/c5i27.pdf> (data supplement: graphics and metadata)

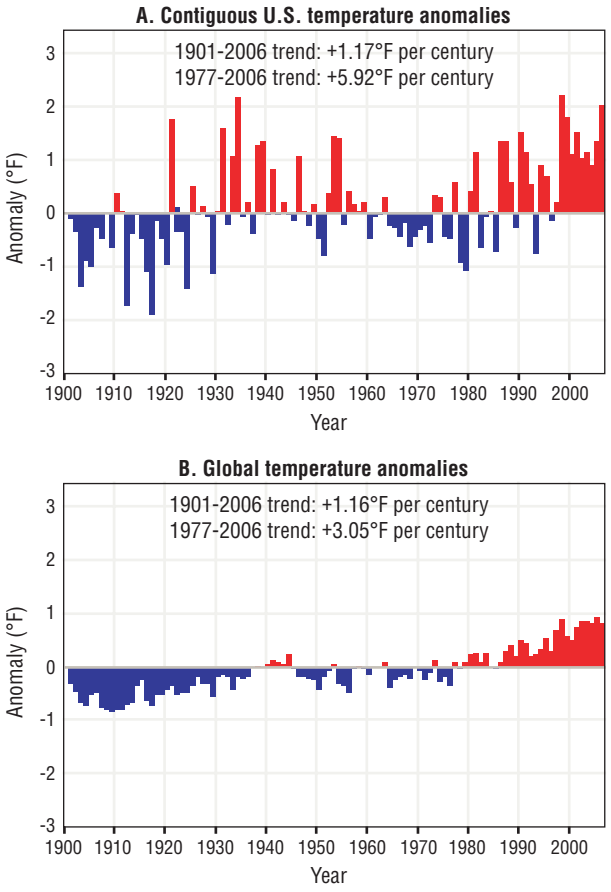
U.S. EPA (United States Environmental Protection Agency). 2005. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2003. EPA/430/R-05/003.

Air temperature and precipitation are two important properties of climate and are the most widely measured variables. Changes in these indicators may have wide-ranging direct or indirect effects on ecological condition and human health. These impacts may be positive or negative, depending on the effect, the magnitude of change, and the location. For example, changes in temperature can affect heat- and cold-related mortality and illness due to altered frequency and magnitude of heat waves and cold spells. Changes in temperature may also change the range and distribution of animal and plant species. Precipitation changes affect water availability and quality, which can have important effects on agricultural, forest, animal, and fisheries productivity, as well as human nutrition. Indirect effects of temperature and precipitation changes include changes in the potential transmission of vector-borne infectious diseases. These may result from alterations in the ranges and seasons of animals that carry disease or from accelerated maturation of certain infectious parasites.

This indicator shows trends in temperature and precipitation based on instrumental records from 1901 to 2006 (except for Alaska and Hawaii, where records begin in 1918 and 1905, respectively). Air temperature and precipitation trends are summarized for the contiguous U.S., as well as for 11 climate regions of the U.S., including Alaska and Hawaii (these climate regions are different from the ten EPA Regions). For context, this indicator also shows trends in global temperature (over land and sea) and global precipitation (over land) from 1901 to 2006.

Temperature and precipitation data are presented as trends in anomalies. An anomaly represents the difference between an observed value and the corresponding value from a baseline period. This indicator uses a 30-year baseline period of 1961 to 1990. To generate the temperature time series, measurements were converted into monthly anomalies, in degrees Fahrenheit. The monthly anomalies then were averaged to get an annual temperature anomaly for each year. Precipitation trends were calculated in similar fashion, starting with anomalies for total monthly precipitation, in millimeters. Monthly anomalies were added to get an annual anomaly for each year, which was then converted to a percent anomaly—i.e., the percent departure from the average annual precipitation during the baseline period. Trends in temperature and precipitation were calculated from the annual time series by ordinary least-squares regression. For each of the 11 climate regions, this indicator also shows a smoothed time series, which was created from the annual series using a nine-point binomial filter (4 years on each side, averaged with decreasing weights further from the center year).

Exhibit 6-15. Annual temperature anomalies in the contiguous U.S. and worldwide, 1901-2006[a]



[a]Anomalies are calculated with respect to the 1961-1990 mean.

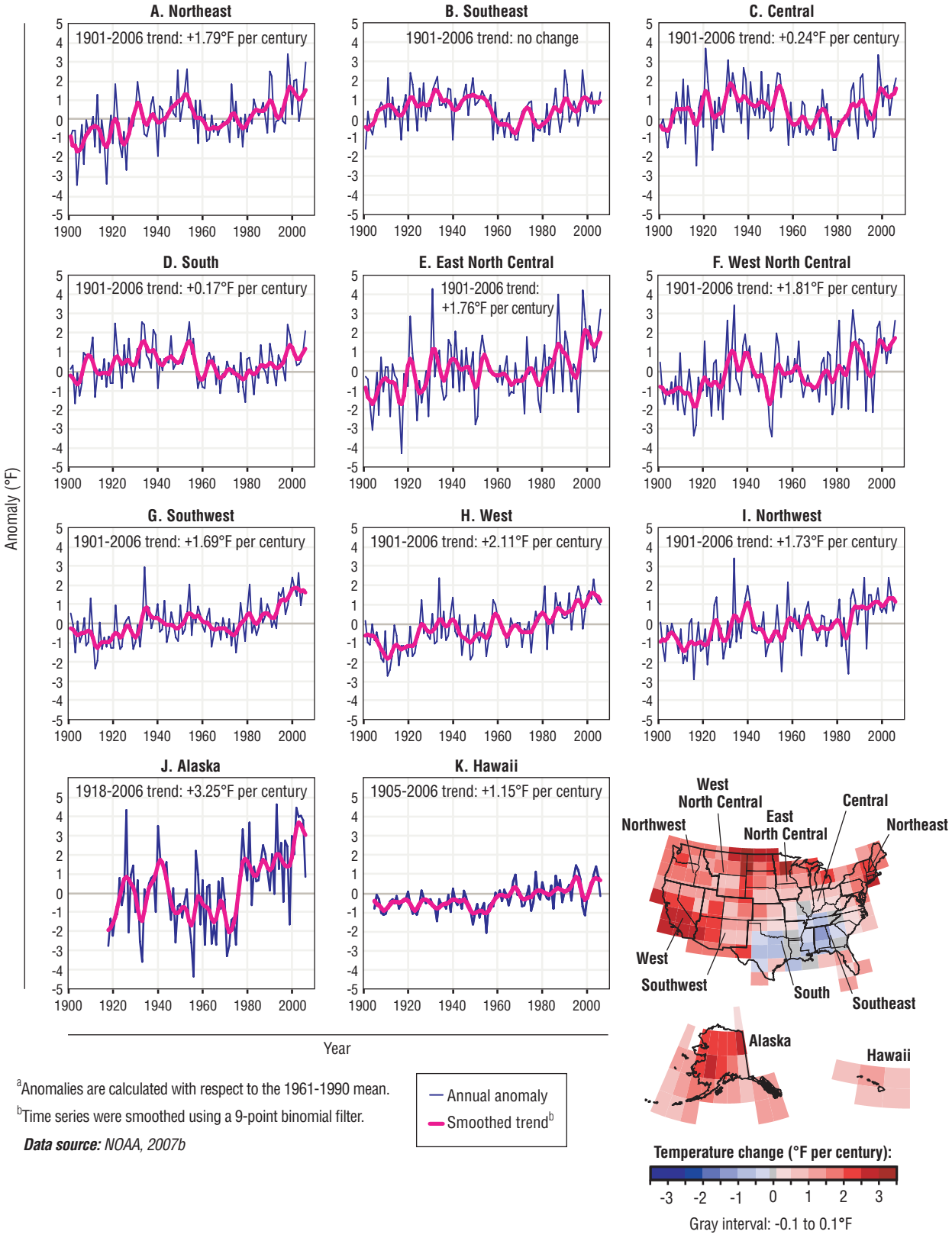
Data source: *NOAA, 2007b*

What the Data Show

Since 1901, temperatures have risen across the contiguous U.S. at an average rate of 0.12°F per decade (1.2°F per century) (Exhibit 6-15, panel A). Over the past 30 years, average temperatures rose at an increased rate of 0.59°F per decade, and 5 of the top 10 warmest years on record for the contiguous U.S. have occurred since 1990. The overall warming trend is not confined to just a few anomalous years, as the last eight 5-year periods (2002-2006, 2001-2005, …1995-1999) were the eight warmest 5-year periods on record (NOAA, 2007a). Warming occurred throughout the U.S., with all but three of the 11 climate regions (all but the Central, South, and Southeast) showing an increase of more than 1°F since 1901 (Exhibit 6-16). The greatest temperature increase occurred in Alaska (3.3°F per century).

Trends in global temperature and precipitation provide a context for interpreting trends in temperature and precipitation in the U.S. Instrumental records from land stations and ships indicate that global mean surface temperature rose by about 1.2°F during the 20th century (Exhibit 6-15, panel B),

Exhibit 6-16. Annual temperature anomalies in the U.S. by region, 1901-2006[a]



[a]Anomalies are calculated with respect to the 1961-1990 mean.

[b]Time series were smoothed using a 9-point binomial filter.

Data source: *NOAA, 2007b*

similar to the rate of warming within the contiguous U.S. During the last three decades, however, the U.S. warmed at nearly twice the global rate.

As global mean temperatures have risen, global mean precipitation also has increased (Exhibit 6-17, panel B). This is expected because evaporation increases with increasing temperature, and there must be an increase in precipitation to balance the enhanced evaporation (IPCC, 2007). Globally, precipitation over land increased at a rate of 1.7 percent per century since 1901, but the trends vary spatially and temporally. Over the contiguous U.S., total annual precipitation increased at an average rate of 6.5 percent per century since 1901 (Exhibit 6-17, panel A), although there was considerable regional variability (Exhibit 6-18). The greatest increases came in the East North Central climate region (11.2 percent per century) and the South (10.5 percent). Hawaii was the only region to show a decrease (-7.2 percent).

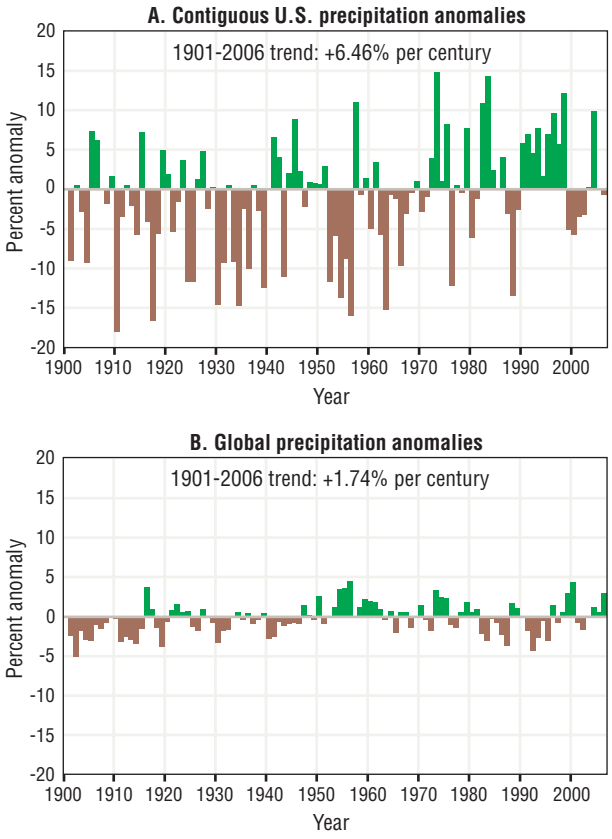
Indicator Limitations

- Biases may have occurred as a result of changes over time in instrumentation, measuring procedures (e.g., time of day), and the exposure and location of the instruments. Where possible, data have been adjusted to account for changes in these variables.
- Uncertainties in both the temperature and precipitation data increase as one goes back in time, as there are fewer stations early in the record. However, these uncertainties are not sufficient to mislead the user about fundamental trends in the data.

Data Sources

Anomaly data were provided by the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC), which calculated global, U.S., and regional temperature and precipitation time series based on monthly values from a network of long-term monitoring stations (NOAA, 2007b). Data from individual stations were obtained from the U.S. Historical Climate Network (USHCN version 1) and the Global Historical Climate Network (GHCN), which are NCDC's online databases (NOAA, 2007c).

Exhibit 6-17. Annual precipitation anomalies in the contiguous U.S. and worldwide, 1901-2006[a]



[a]Anomalies and percent change are calculated with respect to the 1961-1990 mean.

Data source: *NOAA, 2007b*

References

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>

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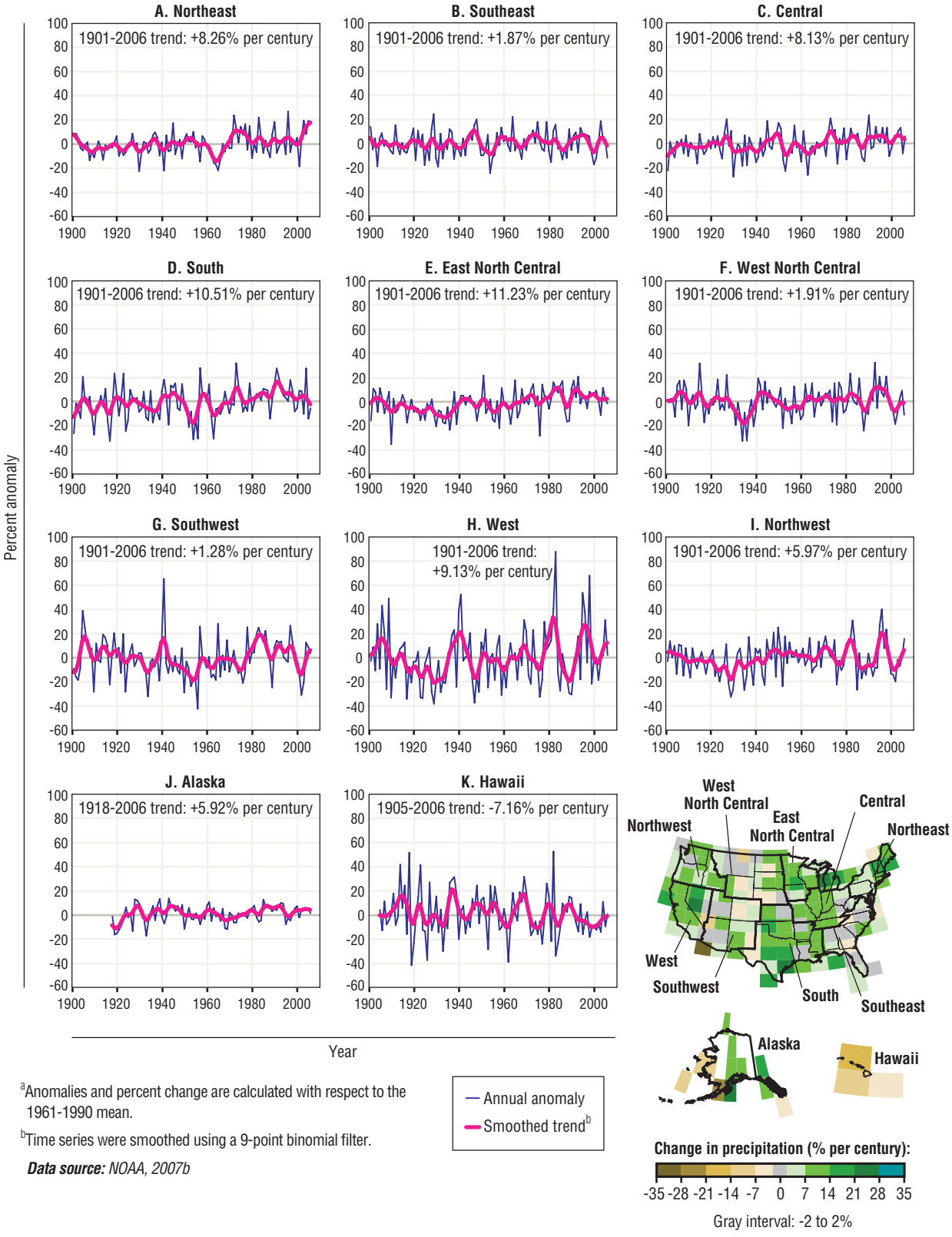
NOAA. 2007c. National Climatic Data Center. Accessed October-November 2007. <http://www.ncdc.noaa.gov/oa/ncdc.html> (NCDC home page); <http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html> (U.S. Historical Climate Network version 1); <http://www.ncdc.noaa.gov/oa/climate/research/ghcn/ghcn.html> (Global Historical Climate Network)

Exhibit 6-18. Annual precipitation anomalies in the U.S. by region, 1901-2006[a]



[a]Anomalies and percent change are calculated with respect to the 1961-1990 mean.

[b]Time series were smoothed using a 9-point binomial filter.

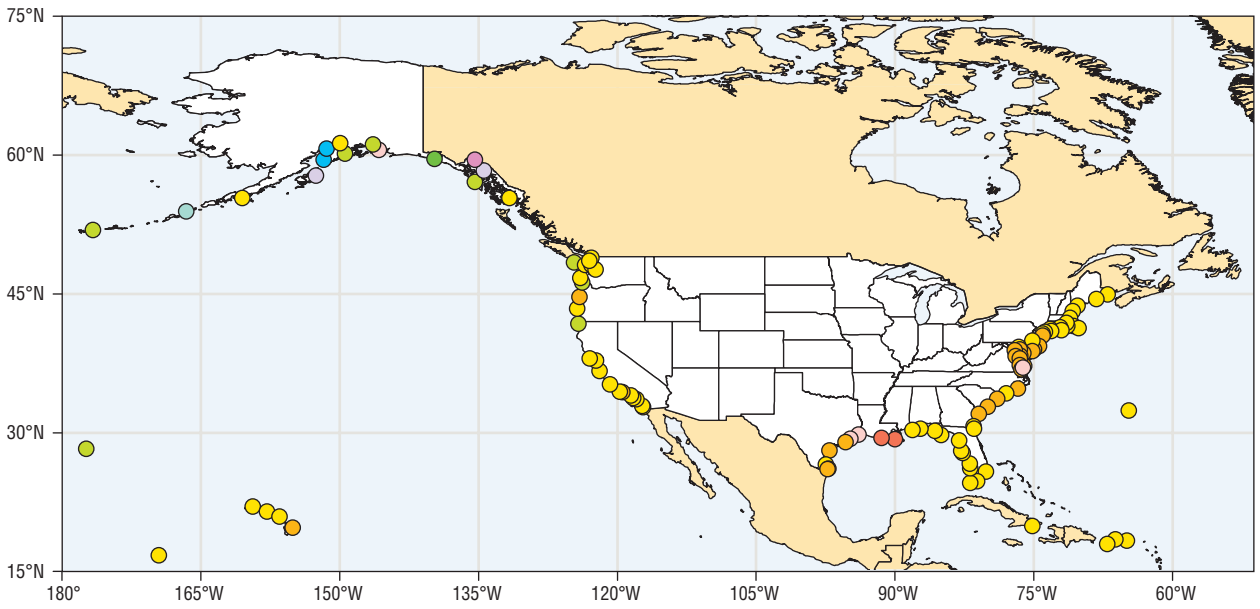
Data source: *NOAA, 2007b*

Sea level is an indicator of global and local change and a factor that affects human welfare and coastal ecosystem conditions. Coastal areas host a rich set of natural and economic resources and include some of the most developed and rapidly growing population centers in the nation. More than 100 million people globally live within 1 meter of the mean sea level and more than 40 percent of the U.S. population lives in watersheds along U.S. ocean coasts (NOAA, 2005). Changing sea levels can inundate low-lying wetlands and dry lands (Burkett et al., 2005), erode beaches (USGS, 1998), change rates of sedimentation (Olff et al., 1997), and increase the salinity of marshes, estuaries, and aquifers (Condrey et al., 1995; Williams et al., 1999). Documented consequences of sea level rise include loss of buffering against storms and floods (Burkett et al., 2005), changes in bird populations (Erwin, 2005) and land cover (Williams et al., 1999), property losses (Burkett et al., 2005), and infrastructure damage (Theiler and Hammar-Klose, 1999; U.S. Department of Transportation, 2003).

Approximately 58,000 square kilometers of land in the contiguous U.S. lie less than 1.5 meters above sea level; 80 percent of this land is in Louisiana, Florida, Texas, and North Carolina (Titus and Richman, 2001). Almost half of the shoreline studied along the U.S. Atlantic Coast was determined to be highly to very highly vulnerable to effects of sea level rise (Theiler and Hammar-Klose, 1999). The areas of highest vulnerability are high-energy coastlines where the coastal slope is low and the major landform type is a barrier island. The risks may be minimal if wetlands accretion can match or outpace sea level rises, but accretion rates vary widely (Hartig et al., 2000, Table 3).

A number of factors affect sea level, including, but not limited to, changes in sea temperature, salinity, and total water volume and mass (e.g., from melting glaciers or changes in the amount of water stored on land). Sea level rises with warming sea temperatures and falls with cooling. Changes in the total volume and mass of ocean water also result from the melting or accumulation of Antarctic and Greenland ice sheets and non-polar glaciers and changes in the amount of water stored in lakes, rivers, and ground water. As such, global average sea level change is an indicator of the physical and climatic stability of the global environment.

Exhibit 6-20. Changes in relative sea level along U.S. coasts, 1950-1999[a]



[a]Trends are based on tidal gauge measurements. Each dot represents a tidal gauge station that operated during the period 1950-1999.

Data source: *NOAA, 2006*

Temporal scale is an important factor in interpreting sea level trends. Sea level changes may reflect factors such as seasonality, inter-annual to decadal scale variability such as El Niño, and/or long-term climate change (decades to centuries). Spatial scale also is important because absolute sea height does not change uniformly around the globe.

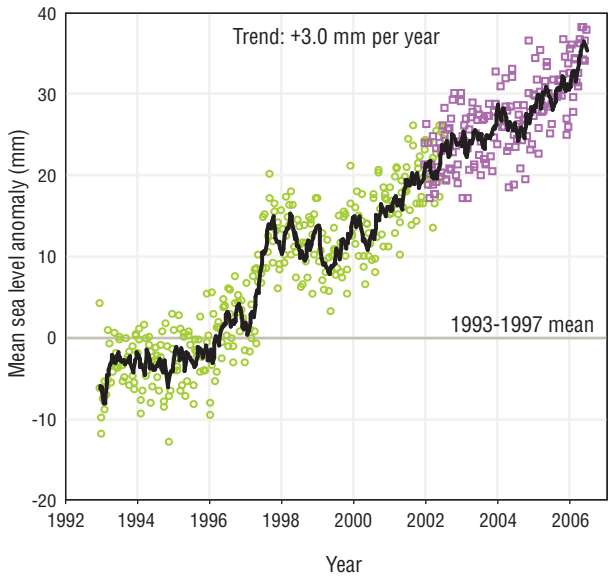
This indicator presents trends in absolute and relative sea level. Absolute sea level represents only the sea height, whereas relative sea level change is defined as sea height change plus land height changes (due to subsidence or uplift and changes in natural land accretion). Relative sea level data are from the tidal gauge measurements of the National Water Level Observation Network, composed of approximately 175 long-term, continuously operating stations located along the U.S. coast, including the Great Lakes and islands in the Atlantic and Pacific Oceans (Smith, 1980; Gill and Schultz, 2001). Tidal gauge data are presented from 1950 to 1999, although a few locations have been monitoring since the mid-1800s (NOAA, 2001). Absolute sea level data are from satellite measurements from NASA's TOPEX/Poseidon spacecraft, which uses radar to map the precise features of the ocean surface, and the "Jason" satellite, which monitors ocean circulation (Leuliette et al., 2006). The two satellites use radar altimetry to collect sea level data globally. These data have been available since 1993.

What the Data Show

Relative sea levels (combined land and sea movement) in many locations rose from 1950 to 1999, typically at rates of 0-3 millimeters per year (mm/yr) (up to 1 foot per century) (Exhibit 6-20). Relative sea level has risen more rapidly (3-6 mm/yr) along the mid-Atlantic coast from North Carolina to New Jersey and at rates as high as 9-12 mm/yr at two stations in Louisiana. Other locations, such as the southern coast of Alaska, show relative sea level drop, with a maximum decrease of 16 mm/yr. Average relative sea level rise for all U.S. coasts was not calculated because the distribution of tidal gauge stations is not spatially representative of aggregate trends, but for reference, an analysis of tidal gauge data worldwide estimated that on average, relative sea level rose between 1.5 and 2.0 mm/yr during the 20th century (Miller and Douglas, 2004).

The satellite record shows that global mean absolute sea level (i.e., independent of land movements) has increased at a rate of 3 mm (0.12 inches) per year since 1993 (Exhibit 6-21). Absolute sea levels do not change uniformly around the Earth, however. Around the U.S., areas with increasing absolute sea level include the Gulf coast and portions of the Atlantic coast (Exhibit 6-22). Areas showing a decrease include the southern part of the Pacific coast and the western Gulf of Alaska.

Exhibit 6-21. Global mean sea level, 1993-2006[a,b]



[a]Values are reported as anomalies with respect to the 1993-1997 mean.

[b]Data were collected by the TOPEX/Poseidon and Jason 1 satellite altimeters. Data were adjusted by applying an inverse barometer (air pressure) correction and removing seasonal signals.

Data source: *Leuliette et al., 2006*

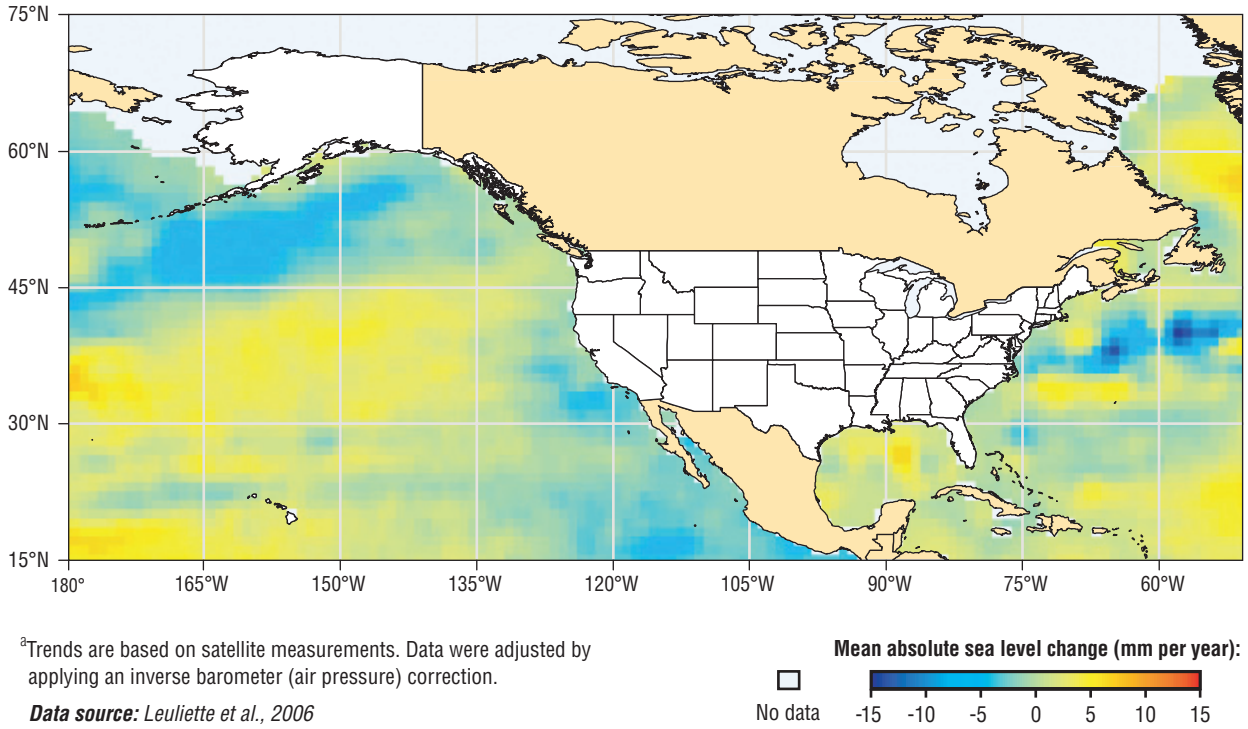
Indicator Limitations

- An estimated 50 to 60 years of data are required to obtain linear mean sea level trends having a 1 mm/yr precision with a 95 percent statistical confidence interval.
- Tidal gauge measurements do not represent more generalized (i.e., average) relative sea level change along U.S. coasts (or globally).
- Most local tidal gauge measurements cannot indicate whether changes in relative sea level are due to changes in absolute sea level or changes in land elevation.
- Satellite data are not available for a multi-decadal time series needed to separate out medium-term variability from long-term change.
- Satellite data are not horizontally precise enough to resolve sea level trends for small water bodies (such as many estuaries) or for localized interests (such as a particular harbor or beach).

Data Sources

Exhibit 6-20 is based on a map and corresponding trend data published by the National Oceanic and Atmospheric

Exhibit 6-22. Changes in absolute sea level along U.S. coasts, 1993-2006[a]



[a]Trends are based on satellite measurements. Data were adjusted by applying an inverse barometer (air pressure) correction.

Data source: *Leuliette et al., 2006*

Administration's (NOAA's) National Oceans Service (NOAA, 2006) (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml). These data were previously published in NOAA (2001), along with a list of station coordinates (NOAA, 2001, Appendix I). Individual station measurements are accessible through NOAA (2006).

Exhibits 6-21 and 6-22 were produced using data provided by Leuliette et al. (2006) (time series at http://sealevel.colorado.edu/results.php; map at http://sealevel.colorado.edu/maps.php). Leuliette et al.'s analysis was based on measurements from NASA's Ocean Topography Experiment (TOPEX) and Jason satellite altimeters; results were calibrated using a model documented in Leuliette et al. (2004). Satellite measurements can be obtained from NASA's online database (NASA, 2006) (http://topex-www.jpl.nasa.gov/science/data.html).

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