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EPA's Report on the Environment

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2008 EPA's Report on the Environment

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EPA will update the environmental indicators presented in this report when data become available. Please visit the electronic report at www. epa.gov/roe for the most up-to-date information on the Report on the Environment.

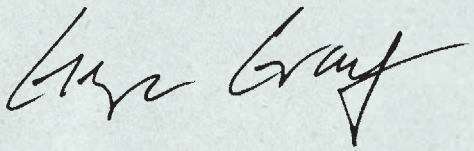
Message from the Assistant Administrator for Research and Development

I am pleased to present *EPA's 2008 Report on the Environment* (ROE). This report compiles, in one place, the most reliable indicators currently available to answer key questions about trends in human health and the condition of the nation's environment.

EPA's 2008 Report on the Environment demonstrates the importance of scientifically sound information to help us understand the state of the environment, identify areas of concern, and monitor progress. We can all celebrate the fact that our air is cleaner, our water is purer, and our land is better protected than it was just a generation ago. Today, we are beginning to measure just how much progress we have made. Though we once took our environment for granted, we now understand the importance of environmental quality for our future. Much work remains to be done, however, and we must continue to build on our record of progress.

I thank the many EPA staff members from every program and Region; our federal, tribal, state, and local government partners; and the independent scientists and research institutions who contributed to this report. The 2008 ROE represents the culmination of an effort that began in 2001 when EPA embarked on a bold initiative to assemble, for the first time, indicators of national conditions that are important to the Agency's mission to protect human health and the environment. EPA first presented this information in its 2003 *Draft Report on the Environment*. We have since revised and refined the ROE in response to feedback from EPA's Scientific Advisory Board and our stakeholders, and we have updated the indicators to reflect the latest available data.

EPA's 2008 Report on the Environment is part of an important national dialogue on how we can improve our ability to assess the nation's environmental quality and human health, and how we can use that knowledge to better manage for measurable environmental results. I invite you to participate in this dialogue with us and our partners. Your comments and feedback are essential to our future efforts.



George Gray, Ph.D.

Science Advisor and
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Chapter 1

1. Introduction

To accomplish its mission, the U.S. Environmental Protection Agency (EPA) must pay close attention to trends in the condition of the nation's air, water, and land, and to associated trends in human exposure and health and the condition of ecological systems. Data on environmental trends serve two key purposes: they provide valuable input to EPA in developing its strategic outlook and priorities, and they allow EPA and the public to assess whether the Agency is succeeding in its overall mission to protect human health and the environment. EPA prepared this *Report on the Environment* (ROE) to accomplish these purposes.

In 2001, EPA embarked on a bold initiative to assemble, for the first time, an extensive set of environmental indicators that are important to its mission. EPA presented these indicators in its *Draft Report on the Environment Technical Document*, released in 2003. Since then, EPA has revised, updated, and refined the ROE in response to scientific developments and to feedback from public stakeholders and EPA's Science Advisory Board (SAB). *EPA's 2008 Report on the Environment* presents the results of this work.

The 2008 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 and the nation's environment. The indicators are supported by data gathered from federal and state agencies and non-governmental organizations. All of the indicators were peer-reviewed to meet exacting standards for accuracy, representativeness, and reliability. This 2008 ROE presents trends wherever adequate data are currently available, and it establishes reliable national baselines where they are not. Equally important, the report identifies key limitations of these indicators and gaps where reliable indicators do not yet exist. This report does not propose actions to reduce data limitations or fill gaps, nor does it analyze the costs and benefits of doing so.

Written for a broad range of environmental professionals, the ROE provides the technical foundation for two other components of EPA's ROE project:

- *EPA's 2008 Report on the Environment: Highlights of National Trends*, which presents highlights of the ROE that EPA believes would be of significance to the interested public.
- An electronic version of the ROE (the *e*-ROE, available at http://www.epa.gov/roe), which provides online access to printable versions of both reports, as well as to the data, methodology, references, and sources of additional information behind the indicators presented in the ROE.

EPA is committed to periodically updating the ROE and its component indicators so that the latest information on environmental status and trends is available to EPA, external scientists, and interested members of the public on a long-term basis.

Organization of This Report

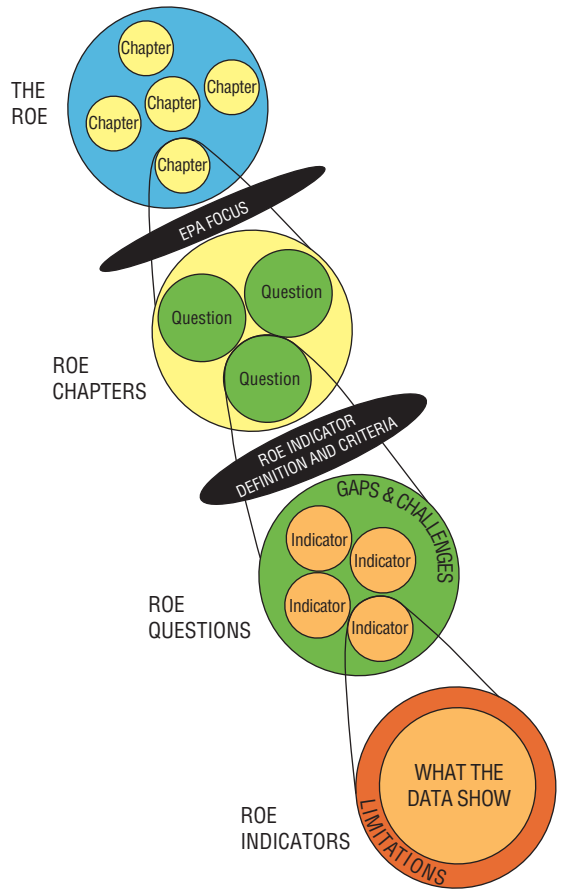
Exhibit 1-1 provides a schematic framework for *EPA's 2008 Report on the Environment*:

- **The ROE:** The report is organized around five main chapters: "Air," "Water," "Land," "Human Exposure and Health," and "Ecological Condition." These five chapters relate to EPA's five strategic goals (Clean Air, Clean and Safe Waters, Healthy Land, Healthy Communities and Ecosystems, Stewardship and Compliance) and serve to focus the ROE on issues important to EPA's mission to protect human health and the environment.
- **ROE chapters:** Each chapter is organized around a set of questions that EPA considers to be important and relevant to its mission.
- **ROE questions:** For each question, the ROE:
  - Describes the issues covered by the question. These issues include EPA's regulatory responsibilities, as well as areas where the Agency conducts or sponsors research, exerts policy leadership, provides information to the public, or shares an interest in human health and the environment with its federal, state, and tribal partners.
  - Presents indicators that are available to help answer the question; discusses critical indicator gaps that prevent the question from being fully answered; and reviews the challenges to filling these gaps.
- **ROE indicators:** All indicators presented in the ROE were peer-reviewed against an indicator definition and criteria (see Box 1-1) to ensure that they are useful, objective, transparent, and scientifically reliable. Each indicator describes what the data show and any limitations that generate uncertainty in the trend characterized by the indicator.

Further detail on the ROE chapters, questions, and indicators is provided below. Several sections follow the five main ROE chapters:

- **Chapter 7,** "Afterword," discusses the next steps for improving indicators and summarizes the challenges to answering the questions and synthesizing and integrating information across indicators.

Exhibit 1-1. The ROE framework



- **Appendix A** lists acronyms and provides a glossary of terms that have particular definitions within this document or whose definitions are not commonly available.
- **Appendix B** describes the process used to develop the 2008 ROE.
- **Appendix C** compares indicators used in the 2003 *Draft ROE Technical Document* with those in this 2008 version.

ROE Chapters

EPA has important mandates to protect air, water, and land (e.g., in the case of land, to ensure the safety of pesticides and chemicals used in commerce, to ensure the reduction and proper disposal of wastes, and to prevent and clean up contaminated lands). The Agency is therefore interested in trends in these media. In reality, however, most human health and ecosystem effects are influenced by many factors, including stressors acting through multiple media and non-environmental factors that are outside EPA's mission. EPA believes it is vitally important to conduct surveillance of trends in indicators of human health and ecological condition, even if they cannot be linked with confidence to national or regional trends in pollutant emissions or concentrations, in order to determine whether they warrant the Agency's closer attention.

Box 1-1. Indicator Definition and Criteria

Indicator definition: For *EPA's 2008 Report on the Environment*, an indicator is a numerical value derived from actual measurements of a stressor, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain, whose trends over time represent or draw attention to underlying trends in the condition of the environment.

Indicator criteria:

- The indicator is useful. It answers (or makes an important contribution to answering) a question in the ROE.
- The indicator is objective. It is developed and presented in an accurate, clear, complete, and unbiased manner.
- The indicator is transparent and reproducible. The specific data used and the specific assumptions, analytic methods, and statistical procedures employed are clearly stated.
- The underlying data are characterized by sound collection methodologies, data management systems to protect their integrity, and quality assurance procedures.
- Data are available to describe changes or trends and the latest available data are timely.
- The data are comparable across time and space, and representative of the target population. Trends depicted in this indicator accurately represent the underlying trends in the target population.

To accommodate EPA's interest in both media-specific and broader, more complex environmental trends, the Agency has used the following conceptual model to organize the ROE indicators among the chapters:

- **Air, water, and land chapters (Chapters 2, 3, and 4):** The air, water, and land chapters focus on trends in these individual media, and on resulting trends in their effects on human health and ecological systems. An effect indicator is included in a media chapter *only* if the condition or effect can be demonstrably linked at the national level to trends in stressors *associated with that particular environmental medium*. For example, indicators of lake and stream acidity and ozone damage to trees are placed in the air chapter (rather than the ecological condition chapter) because trends in these effects indicators are clearly linked to trends in the emissions and concentration of particular air pollutants. Specifically, downward trends in the acidity of lakes and streams in certain geologically sensitive regions of the country are clearly linked to declining acid deposition; the type of damage to leaves in forest plants described by the indicator can be clearly attributed to ozone exposure. However, these indicators are exceptional: the ROE's three media chapters include very few indicators of effects, because most effects indicators cannot be linked with confidence to stressors associated with a single environmental medium.
- **Human exposure and health and ecological condition chapters (Chapters 5 and 6):** These two chapters address questions about trends in human exposure and health and ecological condition that are influenced by contaminants in more than one medium and by factors that are broader than EPA's mission. For example, the human exposure and health chapter includes a question about trends in human disease and conditions for which environmental contaminants may be a risk factor; these trends also are influenced by other factors, such as lifestyle, genetics, and the quality of medical care. The ecological condition chapter includes a question about trends in diversity and biological balance of the nation's ecological systems; these trends are influenced not only by trends in contaminants in multiple media but also by factors such as land use, invasive species, and natural resource management. Trends in the health or ecological indicators covered in Chapters 5 and 6 cannot be attributed with any confidence to *particular* contaminants or other causes covered in the ROE's media chapters. This is true even though epidemiological and laboratory studies may have demonstrated a clear relationship between a contaminant and a health or ecological effect.

ROE Questions

The 23 questions presented in the ROE were developed by EPA. These are questions the Agency believes *should* be answered with confidence if it is to be adequately informed about important environmental trends; however, they are not necessarily questions that EPA *can* fully answer at present based on the indicators that meet the ROE definition and criteria.

Each question asks about environmental trends, indicating EPA's interest in monitoring how the status of the environment and human exposure and health changes over time. The latest data point in the trend represents the most current information on the status of the environment or health when the data were gathered; for some indicators, only the baseline status is available.

ROE Indicators

Environmental conditions can be represented in many ways. For reasons discussed below, the ROE relies on an indicator approach. To maintain a high level of scientific integrity and consistency among the indicators used in the ROE, EPA established an explicit definition and six criteria (see Box 1-1) that all ROE indicators must meet. The criteria are based in part on EPA's Information Quality Guidelines (http://www.epa.gov/quality/informationguidelines/), which cover important information that EPA provides to the public. Together, the six criteria are intended to ensure that all indicators in the ROE are useful to EPA and the public, and that they are objective, transparent, and based on high-quality, comparable, and representative data across space and time. The ROE emphasizes indicators that can be tracked over time; therefore, one-time studies are not included unless they serve as baselines for future trends.

The ROE indicator definition intentionally excludes some categories of indicators. For example, ROE indicators include measures of pollutant emissions, but not measures of more

Box 1-2. Changes from the 2003 Draft ROE

EPA released the first edition of the ROE as a draft report in 2003 (see http://www.epa.gov/roe). A number of changes have been incorporated into this 2008 edition in response to comments on the 2003 draft. The major changes are:

- **Questions:** The ROE questions were revised to present a more consistent format and comprehensive coverage of EPA's interests across chapters.
- **Indicators:** The indicator definitions and criteria were revised. As a result, several changes were made to the 2003 indicators, including combining some indicators and deleting others. Also, new indicators have been added that were not available for the 2003 version of the report. See Appendix C for details.
- **Indicator placement:** Indicators of health or environmental effects that are linked predominantly to a single medium (air, water, land) were moved from the human exposure and health or ecological condition chapter to the chapter for the relevant medium.
- **Spatial scale:** National-level indicators were the focus of the 2003 Draft ROE and continue to be the focus in this 2008 ROE. However, as discussed under "Regional Indicators," the 2008 ROE demonstrates how relevant indicators might be identified, developed, and presented at finer geographic scales.

general causal factors such as energy generation or agricultural production. Also excluded are economic indicators such as the value of land or natural resources and the cost of pollution control, or efficiency factors such as pollutant emissions per vehicle mile traveled. Because ROE indicators focus on actual physical measurements, administrative indicators such as permits issued, regulations promulgated, and enforcement actions undertaken also are excluded. Indicators based on results predicted by environmental fate and transport models or risks to people or ecological systems are excluded as well, because they are not based on actual measurements.

Indicators, whether they represent baseline conditions or trends, involve uncertainties. While statistical analyses could have been presented for some of the indicators in this report, such analyses require considerably more complex indicator development and peer review than was possible given the time and resource constraints for the 2008 ROE. Therefore, EPA determined that this report would not include presentations of statistical confidence in the status of and trends in the indicators. When the word "trend" is used in an indicator, it simply means the direction of change and does not imply statistical significance. EPA recognizes that uncertainty is an important issue and does plan to quantify uncertainty in future versions of the ROE and its indicators.

EPA also recognizes that many others types of environmental data and information are available, in addition to indicators, that could potentially be used to answer the ROE questions. Many environmental reports, particularly those that focus on particular issues or locations, conduct integrated assessments by gathering and weighing the strengths and weaknesses of all the relevant information available. This integrated approach is not feasible for the ROE because it covers so many different topics across the entire nation.

EPA selected the indicators for this 2008 ROE based on indicators suggested by EPA, other federal agencies, state agencies, and non-governmental organizations. EPA developed a list of proposed indicators that it believed could play a significant role in answering the questions in the ROE. These included indicators from the 2003 Draft ROE that EPA judged to be relevant and consistent with the 2008 ROE indicator definition and criteria, as well as many new indicators (see Appendix C). Indicators that did not make a significant contribution to answering the questions were excluded from further consideration. The time frame for developing the ROE did not allow for development of additional indicators.

In creating this list, EPA reviewed all the indicator reports it could find, whether developed by EPA or others, and consulted with experts within and outside the Agency. Generally, EPA used existing indicators and did not invest in developing entirely new indicators for the 2008 ROE.

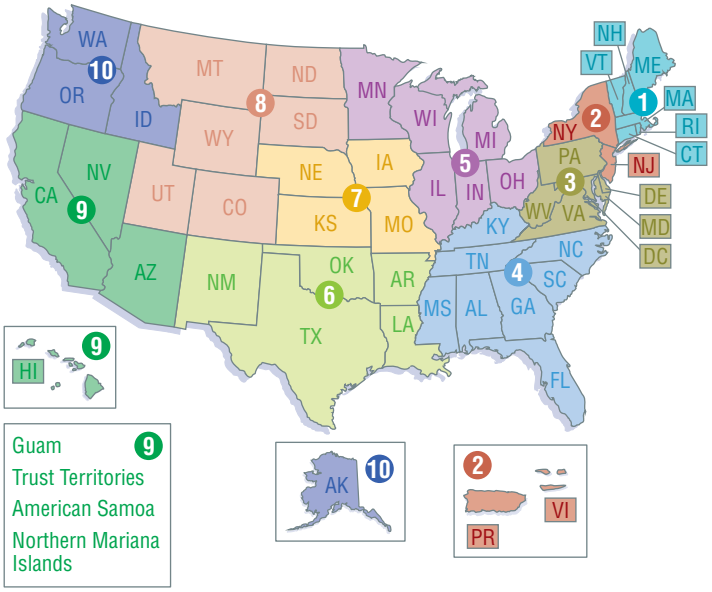
The proposed indicators were evaluated via an independent public peer review process (see http://www.epa.gov/roe for detailed information). Of the proposed indicators, 85 were ultimately selected for inclusion in the ROE. Appendix B provides more information on the indicator development process.

Each indicator consists of a graphic(s) or table(s) and explanatory text. All indicators present the most recent relevant, quality-assured data available when this report went to press. EPA intends to update these indicators in the e-ROE as new data become available. The baselines and reference levels for most indicators follow the underlying sources. Complete documentation of the indicator data sources can be found at http://www.epa.gov/roe. For ease of use in both the print and e-versions, each indicator was developed to stand alone, with sufficient information for the reader to understand its scope, origin, and data sources. As a result, some redundancies of text exist in the hardcopy version of the document.

Some indicators are used to answer more than one ROE question. In most cases, these indicators are presented with the question that they are first used to answer and referenced when they are used to answer another question later in the ROE. For example, the Blood Cotinine indicator is first used to answer a question in the air chapter and then another question in the human exposure and health chapter. The indicator is presented in the air chapter; the human exposure and health chapter refers the reader to the air chapter for details. Tables listing indicators and their page numbers are provided as navigation aids at the end of this introduction (Table 1-1), in the introduction to each chapter, and in the introduction to each question.

More than half of the indicators and supporting data derive from sources other than EPA, including other federal agencies, state agencies, and non-governmental organizations. These external sources also maintain many environmental data sets that are valuable for other purposes and offer potential for development of future ROE indicators. Many of these data sets, though important, were not included in this 2008 ROE because the data do not yet meet the ROE indicator criteria. For example, since 1971, the Centers for Disease Control and Prevention (CDC), EPA, and the Council of State and Territorial Epidemiologists have maintained a surveillance system for collecting and periodically reporting data on occurrences and causes of waterborne disease outbreaks (WBDOs). These surveillance activities are useful in characterizing the epidemiology of WBDOs, identifying changing trends in the etiologic agents that cause WBDOs, and determining why the outbreaks occurred. However, because of several limitations, including under-reporting and differences in how states investigate and report outbreaks, these data do not currently meet the ROE criteria for an indicator. EPA continues to work with CDC and other federal, state, and private organizations on important programs such as this one, so that they may meet the indicator criteria and be used in future editions of the ROE.

Exhibit 1-2. The EPA Regions



Regional Indicators

The ROE focuses on trends within the U.S., even though the indicators may be affected by sources outside U.S. borders. National-level indicators (indicators for which nationally consistent data are available) are the focus of this report. However, highly aggregated national data may mask important variations that take place at finer scales. Therefore, the ROE takes two preliminary steps to demonstrate how indicators might be identified, developed, and presented at finer geographic scales.

- National data are broken out by major geographic region for 32 indicators for which the data are sufficiently representative at that geographic scale. Rather than adopt regionalization schemes based on natural boundaries that would not be consistent among indicators, and because EPA Regions play an important role in the way EPA's environmental protection efforts are implemented, EPA chose to use EPA Regions for the 25 indicators where this was possible. EPA Regions follow state borders and do not reflect natural boundaries based on physiography, climate, or biota. To aid readers who are unfamiliar with EPA Regional boundaries, the ten EPA Regions are delineated in Exhibit 1-2, and also depicted in icons on each indicator graphic that displays regional data.
- Eight Regional Indicators (indicators that cover an EPA Region or substantial parts of one or more EPA Regions) were selected to demonstrate how such indicators can answer part of an ROE question that is unique to a particular Region, or could eventually be expanded to answer an ROE question at the national level. Like the National Indicators, all Regional Indicators were peer-reviewed against the ROE indicator definition and criteria. EPA hopes that the Regional Indicators will serve as useful models, and that lessons learned from them will help the Agency identify and present a more robust set of indicators that answer ROE questions at multiple scales in the future. However, it is important to note that the Regional Indicators are presented as *examples only:* trends in these indicators are not necessarily representative of similar trends in other regions or in the nation as a whole; they do not represent an exclusive set of indicators needed to answer the ROE questions at a regional scale; and they may or may not scale up to National Indicators. EPA may or may not include these indicators in future versions of the ROE.

Conclusion

The *Report on the Environment* represents a commitment by EPA to continually improve the quality and quantity of information available to understand the condition of human health and the environment and how it is changing over time. Within EPA, this commitment provides ongoing opportunities to use the ROE to inform strategic planning and related activities. The ROE also creates opportunities to establish and strengthen partnerships among federal, state, tribal, and non-governmental organizations for monitoring, data sharing, and data needs planning to support indicator development and improvement.

As mentioned earlier, the topics of air, water, land, human exposure and health, and ecological condition under which the indicators are presented are all interconnected. Changes in one medium affect other media; human health is affected by environmental condition; and environmental condition is affected by human factors. In reality, humans and ecological systems are exposed to multiple pollutants from multiple sources; large spatial and temporal variations in environmental exposures exist; and numerous non-environmental factors also have influence. EPA recognizes these complexities; to improve future versions of the ROE, EPA will continue to seek ways to better link and integrate indicators across questions and chapters.

Table 1-1. ROE Questions and Supporting Indicators[1]

Air Chapter	Section	Page
Outdoor Air Quality		
What are the trends in outdoor air quality and their effects on human health and the environment?	2.2	2-6
Carbon Monoxide Emissions	2.2.2	2-9
Ambient Concentrations of Carbon Monoxide	2.2.2	2-11
Lead Emissions	2.2.2	2-12
Ambient Concentrations of Lead	2.2.2	2-14
Nitrogen Oxides Emissions	2.2.2	2-16
Ambient Concentrations of Nitrogen Dioxide	2.2.2	2-18
Volatile Organic Compounds Emissions	2.2.2	2-20
Ambient Concentrations of Ozone	2.2.2	2-22
Ozone Injury to Forest Plants	2.2.2	2-24
Particulate Matter Emissions	2.2.2	2-26
Ambient Concentrations of Particulate Matter	2.2.2	2-29
Regional Haze	2.2.2	2-33
Sulfur Dioxide Emissions	2.2.2	2-34
Acid Deposition	2.2.2	2-37
Lake and Stream Acidity	2.2.2	2-42
Percent of Days with Air Quality Index Values Greater Than 100	2.2.2	2-44
Mercury Emissions	2.2.2	2-46
Air Toxics Emissions	2.2.2	2-48
Ambient Concentrations of Benzene	2.2.2	2-51
Concentrations of Ozone-Depleting Substances	2.2.2	2-52
Ozone Levels over North America	2.2.2	2-54
Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region	2.2.2	2-56
Ambient Concentrations of Manganese Compounds in EPA Region 5	2.2.2	2-58
Greenhouse Gases		
What are the trends in greenhouse gas emissions and concentrations?	2.3	2-62
U.S. Greenhouse Gas Emissions	2.3.2	2-64
Atmospheric Concentrations of Greenhouse Gases	2.3.2	2-66

[1] As mentioned earlier, some indicators are used to answer more than one question. In most cases, these indicators are presented where they are first used to answer a question and referenced under subsequent questions.

Table 1-1. ROE Questions and Supporting Indicators (continued)

Air Chapter (continued)	Section	Page
Indoor Air Quality		
What are the trends in indoor air quality and their effects on human health?	2.4	2-73
U.S. Homes Above EPA's Radon Action Level	2.4.2	2-74
Blood Cotinine Level	2.4.2	2-76
Water Chapter	**Section**	**Page**
Water and Watersheds		
What are the trends in the extent and condition of fresh surface waters and their effects on human health and the environment?	3.2	3-6
High and Low Stream Flows	3.2.2	3-8
Streambed Stability in Wadeable Streams	3.2.2	3-11
Lake and Stream Acidity	2.2.2	2-42
Nitrogen and Phosphorus in Wadeable Streams	3.2.2	3-13
Nitrogen and Phosphorus in Streams in Agricultural Watersheds	3.2.2	3-15
Nitrogen and Phosphorus Loads in Large Rivers	3.2.2	3-17
Pesticides in Streams in Agricultural Watersheds	3.2.2	3-19
Benthic Macroinvertebrates in Wadeable Streams	3.2.2	3-21
Ground Water		
What are the trends in the extent and condition of ground water and their effects on human health and the environment?	3.3	3-25
Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds	3.3.2	3-27
Wetlands		
What are the trends in the extent and condition of wetlands and their effects on human health and the environment?	3.4	3-30
Wetland Extent, Change, and Sources of Change	3.4.2	3-32
Coastal Waters		
What are the trends in the extent and condition of coastal waters and their effects on human health and the environment?	3.5.2	3-35
Wetland Extent, Change, and Sources of Change	3.4.2	3-32
Trophic State of Coastal Waters	3.5.2	3-38
Coastal Sediment Quality	3.5.2	3-42
Coastal Benthic Communities	3.5.2	3-44
Coastal Fish Tissue Contaminants	3.8.2	3-61
Submerged Aquatic Vegetation in the Chesapeake Bay	3.5.2	3-46
Hypoxia in the Gulf of Mexico and Long Island Sound	3.5.2	3-48

Table 1-1. ROE Questions and Supporting Indicators (continued)

Water Chapter (continued)	Section	Page
Drinking Water		
What are the trends in the quality of drinking water and their effects on human health?	3.6	3-52
Population Served by Community Water Systems with No Reported Violations of Health-Based Standards	3.6.2	3-54
Recreational Water		
What are the trends in the condition of recreational waters and their effects on human health and the environment?	3.7	3-57
Consumable Fish and Shellfish		
What are the trends in the condition of consumable fish and shellfish and their effects on human health?	3.8	3-59
Coastal Fish Tissue Contaminants	3.8.2	3-61
Contaminants in Lake Fish Tissue	3.8.2	3-63
Land Chapter	**Section**	**Page**
Land Cover		
What are the trends in land cover and their effects on human health and the environment?	4.2	4-5
Land Cover	4.2.2	4-7
Forest Extent and Type	6.2.2	6-8
Land Cover in the Puget Sound/Georgia Basin	4.2.2	4-10
Land Use		
What are the trends in land use and their effects on human health and the environment?	4.3	4-13
Land Use	4.3.2	4-14
Urbanization and Population Change	4.3.2	4-19
Wastes		
What are the trends in wastes and their effects on human health and the environment?	4.4	4-23
Quantity of Municipal Solid Waste Generated and Managed	4.4.2	4-24
Quantity of RCRA Hazardous Waste Generated and Managed	4.4.2	4-26
Chemicals Used on the Land		
What are the trends in chemicals used on the land and their effects on human health and the environment?	4.5	4-29
Fertilizer Applied for Agricultural Purposes	4.5.2	4-30
Toxic Chemicals in Production-Related Wastes Combusted for Energy Recovery, Released, Treated, or Recycled	4.5.2	4-33
Pesticide Residues in Food	4.5.2	4-37
Reported Pesticide Incidents	4.5.2	4-39

Table 1-1. ROE Questions and Supporting Indicators (continued)

Land Chapter (continued)	Section	Page
Contaminated Land		
What are the trends in contaminated land and their effects on human health and the environment?	4.6	4-42
Current Human Exposures Under Control at High-Priority Cleanup Sites	4.6.2	4-44
Migration of Contaminated Ground Water Under Control at High-Priority Cleanup Sites	4.6.2	4-47
Human Exposure and Health Chapter	**Section**	**Page**
Exposure to Environmental Contaminants		
What are the trends in human exposure to environmental contaminants, including across population subgroups and geographic regions?	5.2	5-7
Blood Lead Level	5.2.2	5-10
Blood Mercury Level	5.2.2	5-12
Blood Cadmium Level	5.2.2	5-13
Blood Persistent Organic Pollutants Level	5.2.2	5-15
Blood Cotinine Level	2.4.2	2-76
Urinary Pesticide Level	5.2.2	5-22
Urinary Phthalate Level	5.2.2	5-26
Health Status		
What are the trends in health status in the United States?	5.3	5-31
General Mortality	5.3.2	5-33
Life Expectancy at Birth	5.3.2	5-35
Infant Mortality	5.3.2	5-36
Disease and Conditions		
What are the trends in human disease and conditions for which environmental contaminants may be a risk factor, including across population subgroups and geographic regions?	5.4	5-39
Cancer Incidence	5.4.2	5-43
Childhood Cancer Incidence	5.4.2	5-46
Cardiovascular Disease Prevalence and Mortality	5.4.2	5-48
Chronic Obstructive Pulmonary Disease Prevalence and Mortality	5.4.2	5-52
Asthma Prevalence	5.4.2	5-55
Infectious Diseases Associated with Environmental Exposures or Conditions	5.4.2	5-59
Birth Defects Prevalence and Mortality	5.4.2	5-62
Low Birthweight	5.4.2	5-65
Preterm Delivery	5.4.2	5-67

Table 1-1. ROE Questions and Supporting Indicators (continued)

Ecological Condition Chapter	Section	Page
Extent and Distribution		
What are the trends in the extent and distribution of the nation's ecological systems?	6.2	6-7
Land Cover	4.2.2	4-7
Forest Extent and Type	6.2.2	6-8
Forest Fragmentation	6.2.2	6-11
Wetland Extent, Change, and Sources of Change	3.4.2	3-32
Land Use	4.3.2	4-14
Urbanization and Population Change	4.3.2	4-19
Land Cover in the Puget Sound/Georgia Basin	4.2.2	4-10
Ecological Connectivity in EPA Region 4	6.2.2	6-13
Relative Ecological Condition of Undeveloped Land in EPA Region 5	6.2.2	6-14
Diversity and Biological Balance		
What are the trends in the diversity and biological balance of the nation's ecological systems?	6.3	6-18
Coastal Benthic Communities	3.5.2	3-44
Benthic Macroinvertebrates in Wadeable Streams	3.2.2	3-21
Bird Populations	6.2.2	6-20
Fish Faunal Intactness	6.2.2	6-21
Submerged Aquatic Vegetation in the Chesapeake Bay	3.5.2	3-46
Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest	6.2.2	6-23
Ecological Processes		
What are the trends in the ecological processes that sustain the nation's ecological systems?	6.4	6-27
Carbon Storage in Forests	6.4.2	6-28
Physical and Chemical Attributes		
What are the trends in the critical physical and chemical attributes of the nation's ecological systems?	6.5	6-31
U.S. and Global Mean Temperature and Precipitation	6.5.2	6-32
Sea Surface Temperature	6.5.2	6-37
Streambed Stability in Wadeable Streams	3.2.2	3-11
High and Low Stream Flows	3.2.2	3-8
Sea Level	6.5.2	6-39
Nitrogen and Phosphorus Loads in Large Rivers	3.2.2	3-17
Nitrogen and Phosphorus in Wadeable Streams	3.2.2	3-13

Table 1-1. ROE Questions and Supporting Indicators (continued)

Ecological Condition Chapter (continued)	Section	Page
Physical and Chemical Attributes (continued)		
What are the trends in the critical physical and chemical attributes of the nation's ecological systems? (continued)	6.5	6-31
Nitrogen and Phosphorus in Streams in Agricultural Watersheds	3.2.2	3-15
Lake and Stream Acidity	2.2.2	2-42
Hypoxia in the Gulf of Mexico and Long Island Sound	3.5.2	3-48
Ecological Exposure to Contaminants		
What are the trends in biomarkers of exposure to common environmental contaminants in plants and animals?	6.6	6-45
Coastal Fish Tissue Contaminants	3.8.2	3-61
Contaminants in Lake Fish Tissue	3.8.2	3-63
Ozone Injury to Forest Plants	2.2.2	2-24

Chapter 2

Air

Contents

2.1 Introduction

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

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

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

- **What are the trends in outdoor air quality and their effects on human health and the environment?** This question examines a broad spectrum of outdoor air quality issues, including polluted air that people breathe at ground level, deposition of air pollutants to land and water, and depletion of the Earth's ozone layer. For each issue, information is provided both on the main stressors (emissions sources) and potential health and environmental effects.
- **What are the trends in greenhouse gas emissions and concentrations?** This question focuses on releases and atmospheric concentrations of certain so-called "greenhouse gases," or gases in the atmosphere that help regulate the Earth's temperature and thus contribute to climate change—a topic introduced in this chapter and revisited in Chapter 6, "Ecological Condition."

EPA's 2008 Report on the Environment (ROE): Essentials

ROE Approach

This 2008 Report on the Environment:

- Asks questions that EPA considers important to its mission to protect human health and the environment.
- Answers these questions, to the extent possible, with available indicators.
- Discusses critical indicator gaps, limitations, and challenges that prevent the questions from being fully answered.

ROE Questions

The air, water, and land chapters (Chapters 2, 3, and 4) ask questions about trends in the condition and/or extent of the environmental medium; trends in stressors to the medium; and resulting trends in the effects of the contaminants in that medium on human exposure, human health, and the condition of ecological systems.

The human exposure and health and ecological condition chapters (Chapters 5 and 6) ask questions about trends in aspects of health and the environment that are influenced by many stressors acting through multiple media and by factors outside EPA's mission.

ROE Indicators

An indicator is derived from actual measurements of a pressure, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain. This excludes indicators such as administrative, socioeconomic, and efficiency indicators.

Indicators based on one-time studies are included only if they were designed to serve as baselines for future trend monitoring.

All ROE indicators passed an independent peer review against six criteria to ensure that they are useful; objective; transparent; and based on data that are high-quality, comparable, and representative across space and time.

Most ROE indicators are reported at the national level. Some national indicators also report trends by region. EPA Regions were used, where possible, for consistency and because they play an important role in how EPA implements its environmental protection efforts.

Several other ROE indicators describe trends in particular regions as examples of how regional indicators might be included in future versions of the ROE. They are not intended to be representative of trends in other regions or the entire nation.

EPA will periodically update and revise the ROE indicators and add new indicators as supporting data become available. In the future, indicators will include information about the statistical confidence of status and trends. Updates will be posted electronically at http://www.epa.gov/roe.

Additional Information

You can find additional information about the indicators, including the underlying data, metadata, references, and peer review, at http://www.epa.gov/roe.

- **What are the trends in indoor air quality and their effects on human health?** This question considers air quality in indoor settings, such as homes, offices, and schools, and how poor indoor air quality can affect human health and welfare, whether by causing adverse health effects or by impairing productivity.

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

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

2.1.1 Overview of the Data

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

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

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

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

This chapter presents only data that meet the ROE indicator definition and criteria (see Box 1-1, p. 1-3). Note that non-scientific indicators, such as administrative and economic indicators, are not included in this definition. Thorough documentation of the indicator data sources and metadata can be found online at http://www.epa.gov/roe. All indicators were peer-reviewed during an independent peer review process (again, see http://www.epa.gov/roe for more information). Readers should not infer that the indicators included reflect the complete state of knowledge on the nation's air. Many other data sources, publications, and site-specific research projects have contributed substantially to the current understanding of air quality trends, but are not used in this report because they did not meet some aspect of the ROE indicator criteria.

2.1.2 Organization of This Chapter

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

Table 2-1 lists the indicators used to answer the three questions in this chapter and shows the locations where the indicators are presented.

Table 2-1. Air—ROE Questions and Indicators

Question	Indicator Name	Section	Page
What are the trends in outdoor air quality and their effects on human health and the environment?	Carbon Monoxide Emissions (N/R)	2.2.2	2-9
	Ambient Concentrations of Carbon Monoxide (N/R)	2.2.2	2-11
	Lead Emissions (N)	2.2.2	2-12
	Ambient Concentrations of Lead (N)	2.2.2	2-14
	Nitrogen Oxides Emissions (N/R)	2.2.2	2-16
	Ambient Concentrations of Nitrogen Dioxide (N/R)	2.2.2	2-18
	Volatile Organic Compounds Emissions (N/R)	2.2.2	2-20
	Ambient Concentrations of Ozone (N/R)	2.2.2	2-22
	Ozone Injury to Forest Plants (N/R)	2.2.2	2-24
	Particulate Matter Emissions (N/R)	2.2.2	2-26
	Ambient Concentrations of Particulate Matter (N/R)	2.2.2	2-29
	Regional Haze (N)	2.2.2	2-33
	Sulfur Dioxide Emissions (N/R)	2.2.2	2-34
	Acid Deposition (N)	2.2.2	2-37
	Lake and Stream Acidity (N)	2.2.2	2-42
	Percent of Days with Air Quality Index Values Greater Than 100 (N/R)	2.2.2	2-44
	Mercury Emissions (N)	2.2.2	2-46
	Air Toxics Emissions (N/R)	2.2.2	2-48
	Ambient Concentrations of Benzene (N)	2.2.2	2-51
	Concentrations of Ozone-Depleting Substances (N)	2.2.2	2-52
	Ozone Levels over North America (N)	2.2.2	2-54
	Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region (R)	2.2.2	2-56
	Ambient Concentrations of Manganese Compounds in EPA Region 5 (R)	2.2.2	2-58
What are the trends in greenhouse gas emissions and concentrations?	U.S. Greenhouse Gas Emissions (N)	2.3.2	2-64
	Atmospheric Concentrations of Greenhouse Gases (N)	2.3.2	2-66
What are the trends in indoor air quality and their effects on human health?	U.S. Homes Above EPA's Radon Action Level (N)	2.4.2	2-74
	Blood Cotinine Level (N)	2.4.2	2-76

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

2.2 What Are the Trends in Outdoor Air Quality and Their Effects on Human Health and the Environment?

2.2.1 Introduction

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

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

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

Human exposure to outdoor air pollution is a function of the composition and magnitude of air pollution, combined with human activity patterns. Ambient concentration data, while useful for characterizing outdoor air quality, ultimately do not quantify exposures, because ambient air monitoring equipment measures air quality at fixed outdoor locations, while people breathe air in multiple indoor and outdoor environs throughout a day. Whether people are harmed by poor air quality depends on the mixture of pollutants found in the air, exposure doses and durations, individuals' susceptibilities to diseases, and other factors. Similarly, air pollutants' interactions with ecosystems determine whether air pollution causes harmful environmental effects. For a complete understanding of a given air pollution issue, information is therefore typically sought on emissions sources, ambient air concentrations, exposures, and effects.

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

- **Criteria pollutants.** The following six common pollutants are referred to as criteria pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter of different size fractions, and sulfur dioxide. These pollutants are known as "criteria pollutants" because EPA regulates them by developing human health-based or environmentally based criteria (or science-based guidelines) for setting permissible levels. Specifically, the Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for these pollutants that are commonly found in outdoor air and can harm human health or the environment. The NAAQS have been modified and, in some cases, revoked since they were originally established. EPA is required to periodically review and update the NAAQS to reflect the latest scientific information on how outdoor air quality affects human health and the environment. Extensive data are available on criteria pollutants' emissions (or emissions of the pollutants' precursors) and ambient concentrations.
- **Air toxics and other air pollutants.** Air toxics, also known as hazardous air pollutants, are known or suspected to cause cancer and are associated with other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. The Clean Air Act specifically identifies 188 air toxics. Numerous other air pollutants exhibit toxicity even though they are not classified as air toxics; included among these other pollutants are several hundred chemicals whose emissions are tracked in EPA's Toxics Release Inventory.

- **Stratospheric ozone issues.** The ozone layer occurs in the stratosphere between 6 and 20 miles above the Earth's surface and protects the Earth's biota from harmful effects of the sun's ultraviolet radiation. Past and ongoing releases of a number of synthetic chemicals from throughout the world have depleted the ozone layer, allowing more ultraviolet radiation to reach the Earth's surface. This can lead to increased incidence of skin cancer, cataracts, and other health problems.[1] Further, high levels of ultraviolet radiation can cause detrimental ecological effects, such as stressing productivity of marine phytoplankton, which are essential components of the oceanic food web.[2]

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

Temporal scales also vary among pollutants and typically reflect some combination of changes in emissions and fluctuations in weather. Ambient air concentrations of some air pollutants, like ground-level ozone, have considerable diurnal and seasonal variations.[4] However, temporal variations are far less pronounced for pollutants that are long-lived in the atmosphere, including many ozone-depleting substances. Temporal variations largely determine the appropriate monitoring frequency for quantifying trends and the most meaningful statistic (or averaging time) used to report ambient air concentrations. When quantifying and interpreting long-term trends in outdoor air quality, attention also must be paid to changes in emissions estimation techniques and advances in ambient air monitoring technologies. Unless otherwise noted, the outdoor air quality indicators only come from data sets generated using consistent methodologies over the entire time frame of interest.

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

2.2.2 ROE Indicators

The 23 outdoor air quality indicators track emissions, ambient concentrations, and pollution-related effects over varying spatial domains and time spans, depending on the availability of underlying data. The indicators include 21 National Indicators (12 of which break national data down into the ten EPA Regions) and two Regional Indicators. The most extensive temporal coverage of these indicators tracks trends from 1964 to the present.

Indicators were developed using data compiled from multiple sources. Emissions indicators are based on EPA's National Emissions Inventory (NEI), a database of measured and estimated emissions for numerous pollutants and source categories. At the writing of this report, NEI data were available for 1990 through 2002, but the indicators only present data for those inventory years that are fully updated and are developed using consistent methodologies. Ground-level ambient air concentration indicators were developed from data in EPA's Air Quality System (AQS), a clearinghouse of validated ambient air monitoring results submitted largely by tribal, state, and local environmental agencies. The ambient concentration indicators present data through calendar year 2006, which is the most recent calendar year having a complete, validated set of monitoring data available from AQS when this report was prepared. Remaining indicators draw from different monitoring programs, including regional haze data from the Interagency Monitoring of Protected Visual Environments, acid deposition measurements from the multi-agency National Atmospheric Deposition Program and Clean Air Status and Trends Network, ozone injury observations from the U.S. Forest Service's Forest Health Monitoring Program, and monitoring of stratospheric ozone levels and concentrations of ozone-depleting substances conducted by the National Oceanic and Atmospheric Administration.

Table 2-2 shows how indicators are classified into three general categories (criteria pollutants, air toxics and other pollutants, stratospheric ozone issues) and then further organized by pollutant. For each pollutant and to the extent supported by ROE indicators, relevant emissions indicators are presented first, immediately followed by ambient concentration indicators, and next by effects indicators. With this organization, readers can readily compare trends in emissions, ambient concentrations, and effects for the same pollutant.

[1] World Meteorological Organization. 2007. Scientific assessment of ozone depletion: 2006. Geneva, Switzerland.

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

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

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

Table 2-2. ROE Indicators of Trends in Outdoor Air Quality and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Criteria Pollutants and Their Precusors		
Carbon Monoxide Emissions (N/R)	2.2.2	2-9
Ambient Concentrations of Carbon Monoxide (N/R)	2.2.2	2-11
Lead Emissions	2.2.2	2-12
Ambient Concentrations of Lead	2.2.2	2-14
Nitrogen Oxides Emissions (N/R)	2.2.2	2-16
Ambient Concentrations of Nitrogen Dioxide (N/R)	2.2.2	2-18
Volatile Organic Compounds Emissions (N/R)	2.2.2	2-20
Ambient Concentrations of Ozone (N/R)	2.2.2	2-22
Ozone Injury to Forest Plants (N/R)	2.2.2	2-24
Particulate Matter Emissions (N/R)	2.2.2	2-26
Ambient Concentrations of Particulate Matter (N/R)	2.2.2	2-29
Regional Haze	2.2.2	2-33
Sulfur Dioxide Emissions (N/R)	2.2.2	2-34
Acid Deposition	2.2.2	2-37
Lake and Stream Acidity	2.2.2	2-42
Percent of Days with Air Quality Index Values Greater Than 100 (N/R)	2.2.2	2-44
Air Toxics and Other Pollutants		
Mercury Emissions	2.2.2	2-46
Air Toxics Emissions (N/R)	2.2.2	2-48
Ambient Concentrations of Benzene	2.2.2	2-51
Stratospheric Ozone Issues		
Concentrations of Ozone-Depleting Substances	2.2.2	2-52
Ozone Levels over North America	2.2.2	2-54
Regional Indicators	**Section**	**Page**
Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./ Mexico Border Region	2.2.2	2-56
Ambient Concentrations of Manganese Compounds in EPA Region 5	2.2.2	2-58

N/R = National Indicator displayed at EPA Regional scale

INDICATOR | Carbon Monoxide Emissions

Carbon monoxide (CO) gas forms primarily when carbon fuels are not burned completely. Mobile sources account for the majority of CO emissions (U.S. EPA, 2003). These sources include both on-road vehicles (e.g., cars, trucks, motorcycles) and nonroad vehicles and engines (e.g., farm equipment, construction equipment, aircraft, marine vessels). Consequently, high concentrations of CO generally occur in areas with heavy traffic congestion. In cities, as much as 95 percent of all CO emissions may come from automobile exhaust (U.S. EPA, 2003). Other sources of CO emissions include industrial processes, non-transportation fuel combustion, and natural sources, such as wildfires. Fuel-burning appliances also are a large source of CO releases in indoor environments. Undetected releases of carbon monoxide in indoor settings can present serious health risks to building occupants. The CO Concentrations indicator (p. 2-11) describes health hazards associated with inhaling CO.

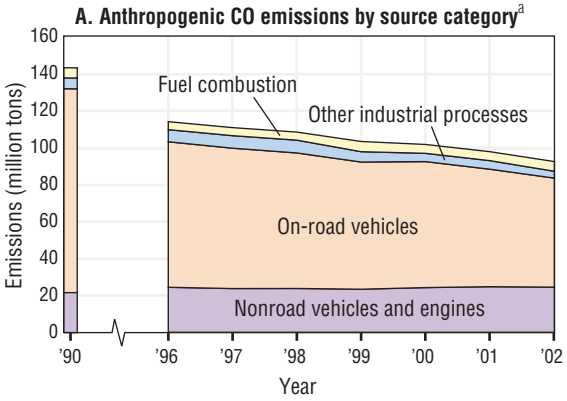
This indicator presents CO emissions from traditionally inventoried anthropogenic source categories: (1) "Fuel combustion," which includes emissions from coal-, gas-, and oil-fired power plants and industrial, commercial, and institutional sources, as well as residential heaters (e.g., wood-burning stoves) 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

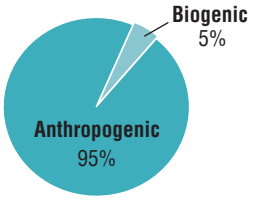
A. Anthropogenic CO emissions by source category[a]



[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*

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



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, p. 2-11).

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 | Carbon Monoxide Emissions *(continued)*

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.

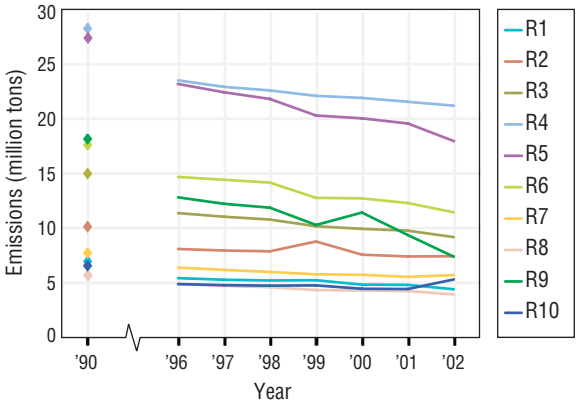
Data Sources

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.

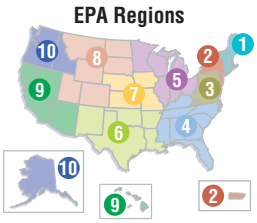
References

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>

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*

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/>

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).

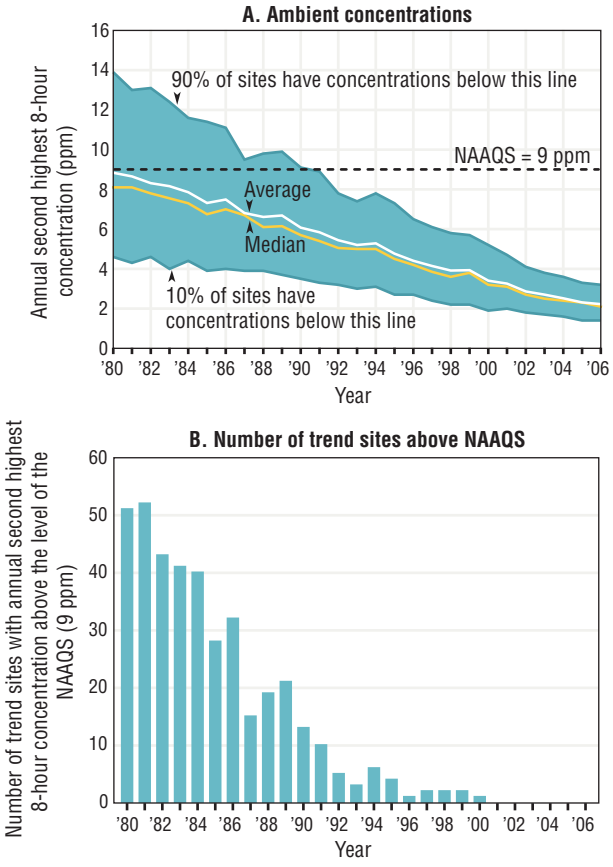
Motor vehicle exhaust currently accounts for the majority of CO emissions nationwide, and as much as 95 percent of CO emissions in cities with high traffic congestion. Other anthropogenic sources of CO emissions include fossil fuel combustion for heating and power generation, metals processing, and chemical 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.

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, p. 2-9).

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*

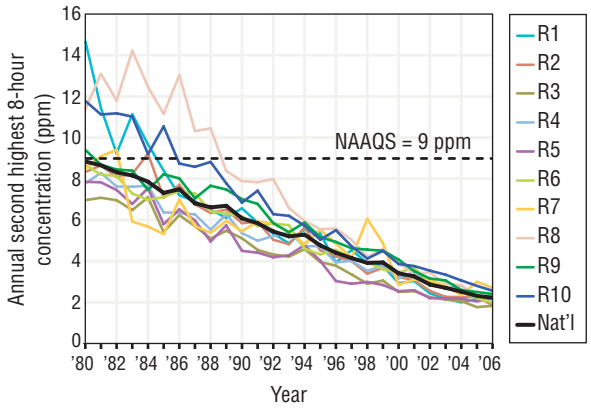
In addition, of the 144 sites used to determine this trend (out of 375 total monitoring sites that were operating in 2006), the number reporting CO concentrations above the level of the CO standard declined to zero over the same period (Exhibit 2-3, panel B).

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).

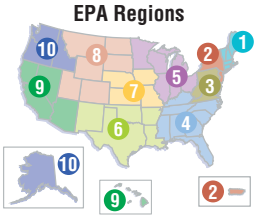
INDICATOR | Ambient Concentrations of Carbon Monoxide *(continued)*

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 | Lead Emissions

Lead is a naturally occurring metal found in small amounts in rock and soil. Lead has been used industrially in the production of gasoline, ceramic products, paints, metal alloys, batteries, and solder. In the past, automotive sources were the major contributors of lead emissions to the atmosphere. After leaded motor vehicle fuels were phased out during the 1970s and 1980s, the contribution of air emissions of lead from the transportation sector, and particularly the automotive sector, greatly declined. Today, industrial processes, primarily metals processing, account for a large portion of lead emissions to the atmosphere and the highest levels of airborne lead are usually found near industrial operations that process materials containing lead, such as smelters (U.S. EPA, 2003). Exposure to lead occurs mainly through inhalation of air and ingestion of lead in food, water, soil, or dust. The Lead Concentrations indicator (p. 2-14) describes health hazards associated with lead exposures.

This indicator presents lead emissions from traditionally inventoried anthropogenic source categories: (1) "Fuel combustion," which includes emissions from coal-, gas-, and oil-fired power plants and industrial, commercial, and institutional sources, as well as residential heaters and

boilers; (2) "Other sources," which includes chemical production and petroleum refining; (3) "On-road vehicles," which includes cars, trucks, buses, and motorcycles; (4) "Nonroad vehicles and engines," such as farm and construction equipment, lawnmowers, chainsaws, boats, ships, snowmobiles, aircraft, and others; and (5) "Metals industrial processing." Since metals processing is one of the largest sources of lead emissions, the indicator includes a metals source category in addition to the four categories presented in the other emissions indicators.

For the years 1970 through 1985, the primary source for lead emissions data was the National Emissions Data System (NEDS) archives. Since 1990, lead emissions data have been tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different sources, including industry and numerous state, tribal, and local agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For most industrial processes and fuel combustion sources, emissions are estimated using emission factors. Emissions from on-road and nonroad sources were estimated using EPA-approved modeling approaches (U.S. EPA, 2007a).

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

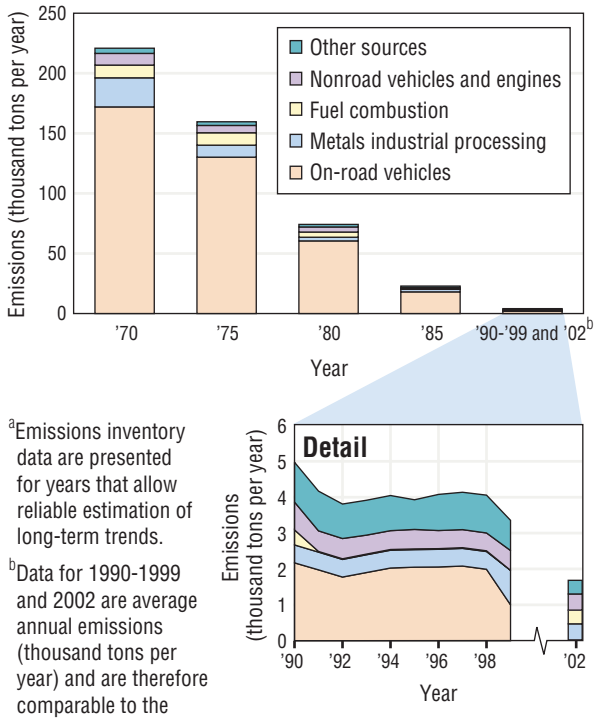
What the Data Show

Between 1970 and 2002, estimated nationwide lead emissions decreased by 99 percent (219,210 tons), mostly due to reductions from on-road vehicle sources after lead was removed from gasoline (Exhibit 2-5). Since 1990, further declines in lead emissions occurred, mostly due to reductions from on-road vehicles and nonroad vehicles and engines. Sharp declines in nationwide air concentrations of lead between 1980 and 1990 paralleled the emissions reductions (the Lead Concentrations indicator, p. 2-14).

Indicator Limitations

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

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



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

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

Data source: *U.S. EPA, 2001, 2007b*

- 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 lead emissions data from two sources. Emissions data from 1970 to 1985 are from EPA's NEDS archives, and data summaries for this time frame can be found in various EPA publications (e.g., U.S. EPA, 2001). Emissions data for 1990-1999 and 2002 are available from the NEI (U.S. EPA, 2007b) (http://www.epa.gov/ttn/chief/net/2002inventory.html). This indicator aggregates the emissions data by source category.

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>

INDICATOR | Lead Emissions *(continued)*

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

INDICATOR | Ambient Concentrations of Lead

Lead is a naturally occurring metal found in small amounts in rock and soil. Despite steep decreases in emissions since 1970 (the Lead Emissions indicator, p. 2-12), lead remains an important environmental health issue because exposure to high levels has been associated with serious health effects, including neurological impairments such as seizures, mental retardation, and behavioral disorders (CDC, 2005). Even at low doses, lead exposure can have adverse effects on the nervous systems of fetuses and young children (the Blood Lead indicator, p. 5-10) (U.S. EPA, 2006). People can be exposed to lead by inhaling airborne particles that contain lead, drinking contaminated water, eating contaminated food items, or ingesting non-food items that contain lead, such as dust and paint chips.

Lead has been used industrially in the production of gasoline, ceramic products, paints, metal alloys, batteries, and solder. Some chemicals containing lead were previously added to gasoline to enhance vehicle performance, but that practice was phased out during the 1970s and 1980s. As a result, air emissions of lead from the transportation sector decreased dramatically during that period (the Lead Emissions indicator, p. 2-12). Today, the highest levels of airborne lead are usually found near industrial operations that process materials containing lead, such as smelters (U.S. EPA, 2003).

This indicator presents ambient lead concentrations in micrograms per cubic meter ($\mu g/m^3$) from 1980 to 2006. Trends for this indicator are based on measurements made at 15 monitoring stations in 10 counties nationwide. These trend sites were selected because they are part of the State and Local Air Monitoring Stations network or are special purpose monitors and they have consistently measured ambient air concentrations of lead over the entire period of interest. Reported values are annual maximum quarterly averages. This indicator's exhibit displays the lead National Ambient Air Quality Standard (NAAQS) as a point of reference, but the fact that the average national lead concentrations fall below the standard does not mean that all monitoring sites also are below the standard.

What the Data Show

Between 1980 and 2006, average lead concentrations decreased 96 percent nationally (Exhibit 2-6, panel A). This decrease, which occurred mostly during the 1980s and early 1990s, is largely attributed to reduced lead content in gasoline (U.S. EPA, 2003). In addition, of the 15 sites used to determine this trend (out of 161 total monitoring sites that were operating in 2006), the number reporting lead concentrations above the level of the NAAQS declined to zero over the same period (Exhibit 2-6, panel B).

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

Indicator Limitations

- Because most lead monitoring sites are located in urban areas, the nationwide trends might not accurately reflect conditions outside the immediate urban monitoring areas.
- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of lead monitoring sites with sufficient data to assess trends since 1980. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported lead concentrations above the level of the lead standard over the time frame covered by this indicator. In 2006, for example, two monitoring sites recorded lead concentrations above the level of the NAAQS, but did not have sufficient long-term data to be considered trend sites for this indicator.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on lead ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (http://www.epa.gov/ttn/airs/airsaqs/). National trends in this indicator are based on the subset of lead monitoring stations that have sufficient data to assess trends since 1980.

References

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

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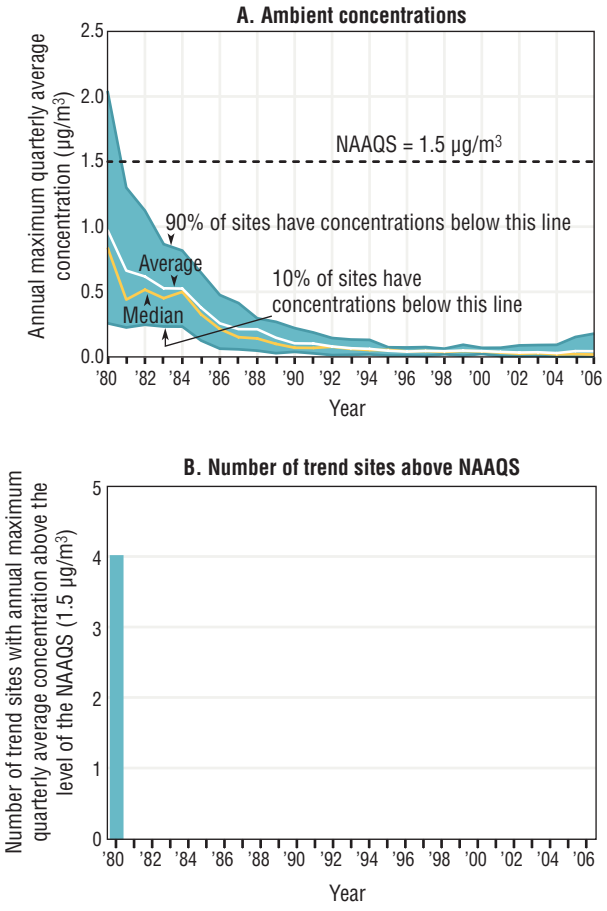
U.S. EPA. 2006. Air quality criteria for lead. EPA/600/R-5/144aF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=158823>

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 2-6. Ambient lead concentrations in the U.S., 1980-2006[a]



[a] **Coverage:** 15 monitoring in 10 counties nationwide (out of a total of 161 sites measuring lead in 2006) that have sufficient data to assess lead trends since 1980.

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

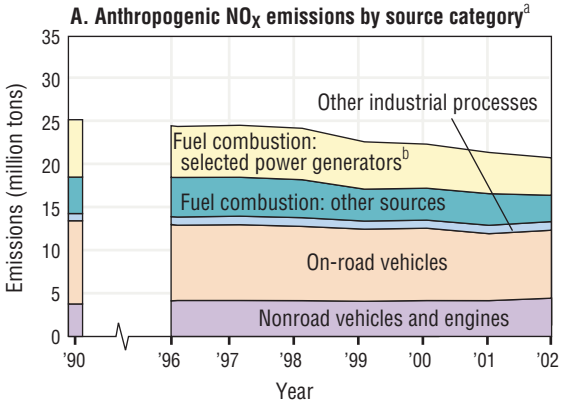
INDICATOR | Nitrogen Oxides Emissions

"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, p. 2-22). NO_x and other pollutants react in the air to form compounds that contribute to acid deposition, which can damage forests and cause lakes and streams to acidify (the Acid Deposition indicator, p. 2-37). Deposition of NO_x also affects nitrogen cycles and can contribute to nuisance growth of algae that can disrupt the chemical balance of nutrients in water bodies, especially in coastal estuaries (the Lake and Stream Acidity indicator, p. 2-42; the Trophic State of Coastal Waters indicator, p. 3-38). NO_x also plays a role in several other environmental issues, including formation of particulate matter (the PM Concentrations indicator, p. 2-29), decreased visibility (the Regional Haze indicator, p. 2-33), and global climate change (the U.S. Greenhouse Gas Emissions indicator, p. 2-64; the Greenhouse Gas Concentrations indicator, p. 2-66).

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.

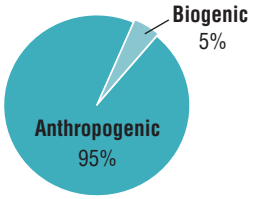
Exhibit 2-7. NO_X emissions in the U.S. by source category, 1990 and 1996-2002



[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.

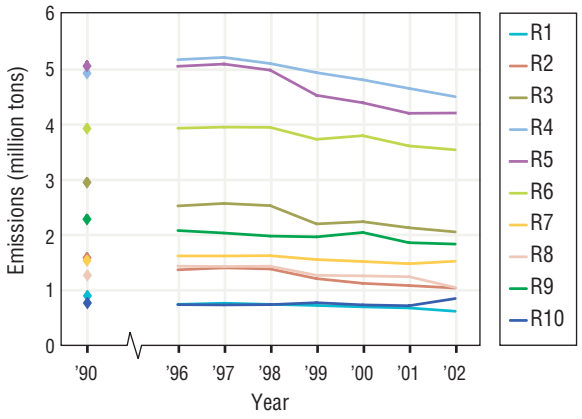
What the Data Show

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.

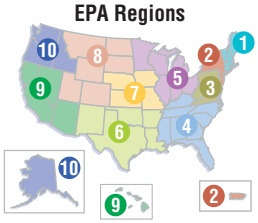
Estimated anthropogenic NO_x emissions in nine of the ten EPA Regions decreased between 1990 and 2002 (Exhibit 2-8). The percent change in emissions over this time frame ranged from a 36 percent decrease (in Region 2) to a 6 percent increase (in Region 10), and the largest absolute reduction (919,000 tons) occurred in Region 3.

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.

EPA Regions



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

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.

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

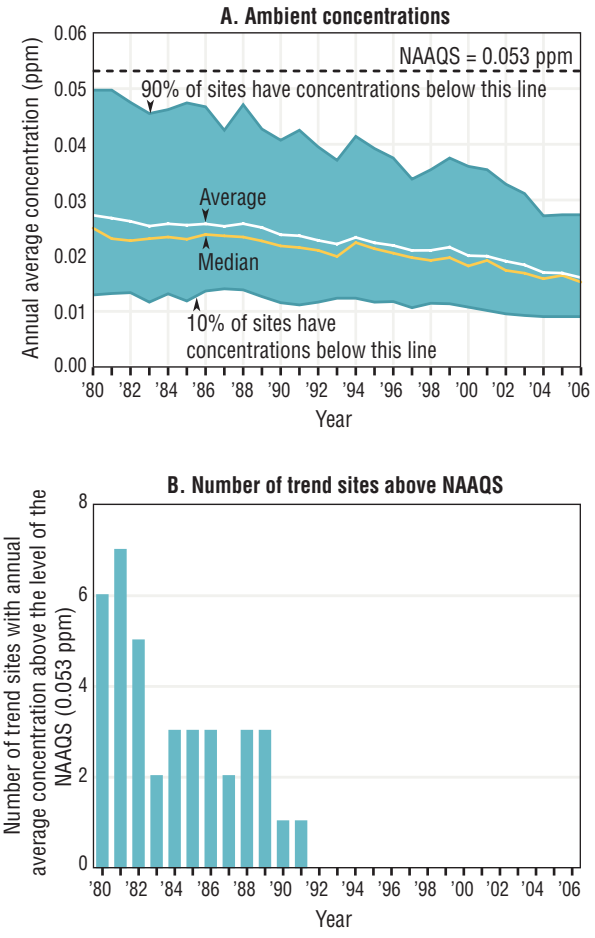
Nitrogen dioxide (NO_2) is a reddish-brown, highly reactive gas that is formed in the ambient air through the oxidation of nitric oxide (NO). Nitrogen dioxide is one in a group of highly reactive gases generically referred to as "nitrogen oxides" (NO_x), all of which contain nitrogen and oxygen in varying 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, p. 2-16).

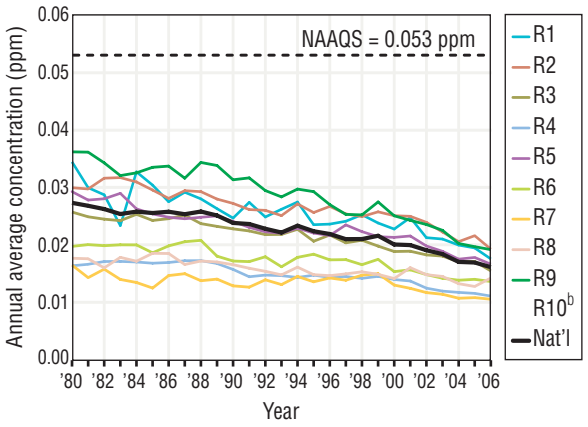
Indicator Limitations

- 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

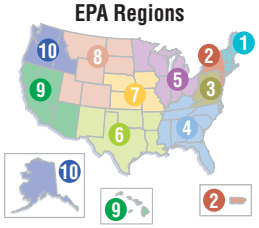
Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on NO_2 ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (http://www.epa.gov/ttn/airs/airsaqs/). National and regional trends in this indicator are based on the subset of 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.

EPA Regions



[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

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. 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, p. 2-22) 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, p. 2-51; the Air Toxics Emissions indicator, p. 2-48). 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).

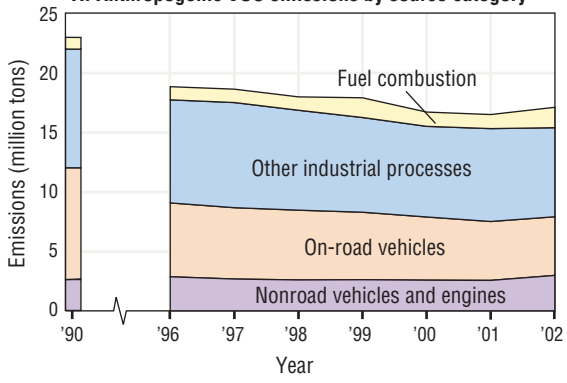
This indicator presents VOC emissions from traditionally inventoried anthropogenic source categories: (1) "Fuel combustion," which includes emissions from coal-, gas-, and oil-fired power plants and industrial, commercial, and institutional sources, as well as residential heaters and boilers; (2) "Other 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

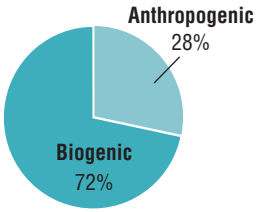
A. Anthropogenic VOC emissions by source category[a]



[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.

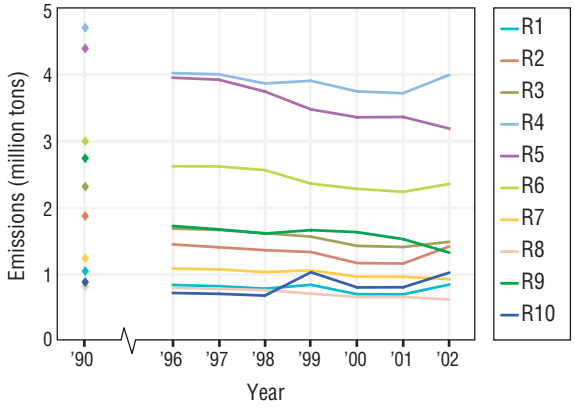
Data Sources

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.

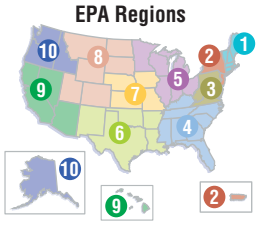
References

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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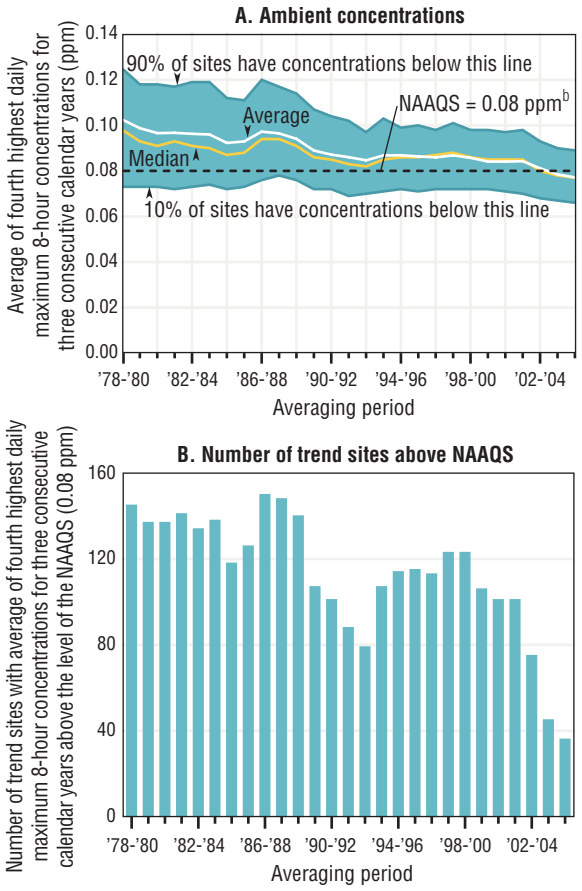
INDICATOR | Ambient Concentrations of Ozone

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, on page 2-54, 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 (p. 2-24) 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 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.

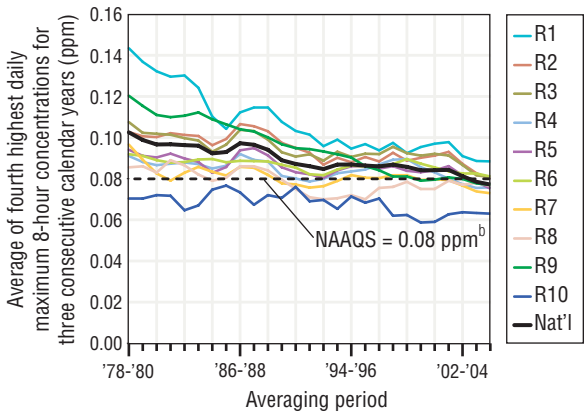
What the Data Show

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, p. 2-16; the VOC Emissions indicator, p. 2-20.), ozone remains one of the most persistent and ubiquitous air pollution issues in the U.S.

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*

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

INDICATOR | Ambient Concentrations of Ozone *(continued)*

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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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).

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.

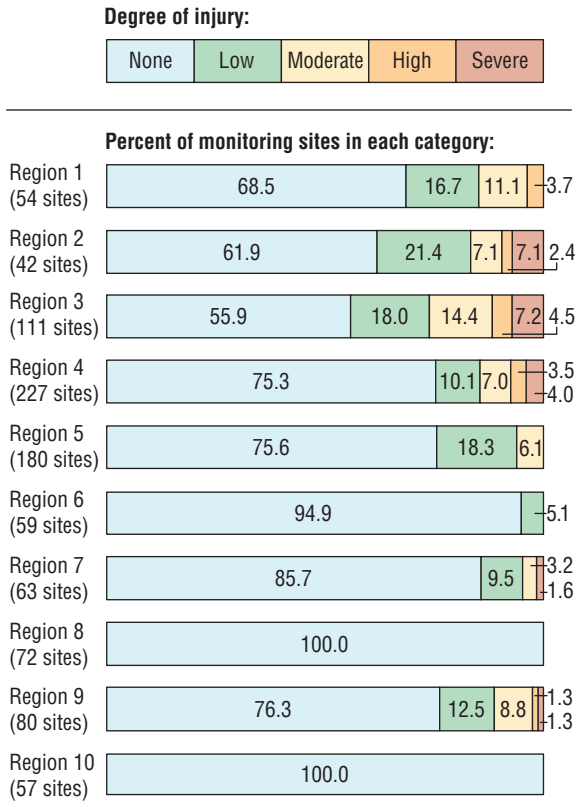
Indicator Limitations

- 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.

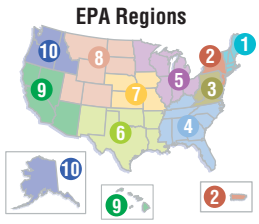
Exhibit 2-15. Ozone injury to forest plants in the U.S. by EPA Region, 2002[a,b]



[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*



References

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U.S. EPA (United States Environmental Protection Agency). 2006. Air quality criteria for ozone and related photochemical oxidants. EPA/600/R-05/004aF-cF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923>

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INDICATOR | Particulate Matter Emissions

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

Particles within the two size ranges behave differently in the atmosphere. $PM_{2.5}$, or fine particles, can remain airborne for long periods and travel hundreds of miles. Coarse particles, or the subset of PM_{10} that is larger than 2.5 μm, do not remain airborne as long and their spatial impact is typically limited because they tend to deposit on the ground downwind of emissions sources. Larger coarse particles are not readily transported across urban or broader areas because they are generally too large to follow air streams and they tend to be removed easily on contact with surfaces. In short, as the particle size increases, the amount of time the particles remain airborne decreases. The PM Concentrations indicator (p. 2-29) describes the various ways PM can harm human health and the environment (U.S. EPA, 2004).

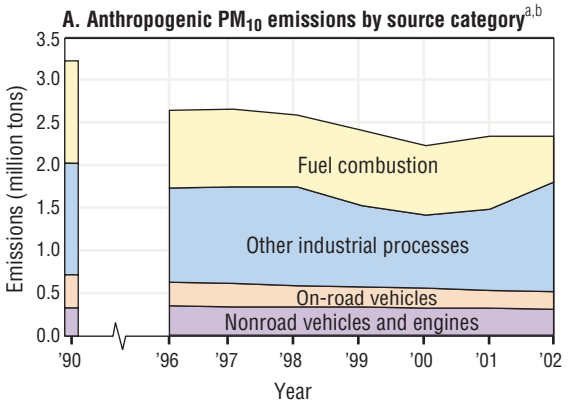
PM can be emitted directly or formed in the atmosphere. "Primary" particles are those released directly to the atmosphere. These include dust from roads and soot from combustion sources. In general, coarse PM is composed largely of primary particles. "Secondary" particles, on the other hand, are formed 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, p. 2-16; the Sulfur Dioxide Emissions indicator, p. 2-34). Particles formed through secondary processes are not included in this indicator.

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).

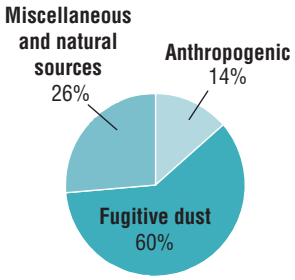
All emissions data presented in this indicator are taken from the NEI. Primary particulate emissions data are presented for the traditionally inventoried anthropogenic source categories: (1) "Fuel combustion," which includes

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.



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

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. 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.

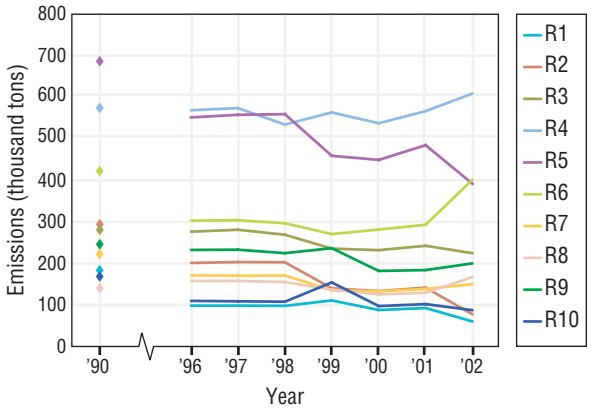
What the Data Show

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).

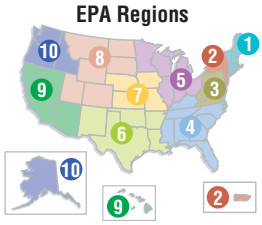
Changes in estimated primary anthropogenic PM_{10} emissions from 1990 to 2002 varied widely among EPA Regions, ranging from an increase of 16 percent (Region 8) to a decrease of 75 percent (Region 2) (Exhibit 2-17).

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.

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*

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).

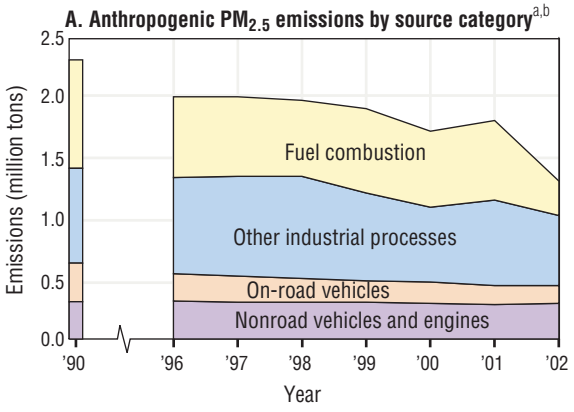
Primary anthropogenic $PM_{2.5}$ emissions decreased in all ten EPA Regions from 1990 to 2002, with percent reductions ranging from 21 percent (Region 4) to 71 percent (Region 2) (Exhibit 2-19).

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

INDICATOR | Particulate Matter Emissions *(continued)*

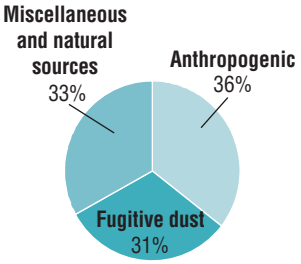
Exhibit 2-18. $PM_{2.5}$ emissions in the U.S. by source category, 1990 and 1996-2002



[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.

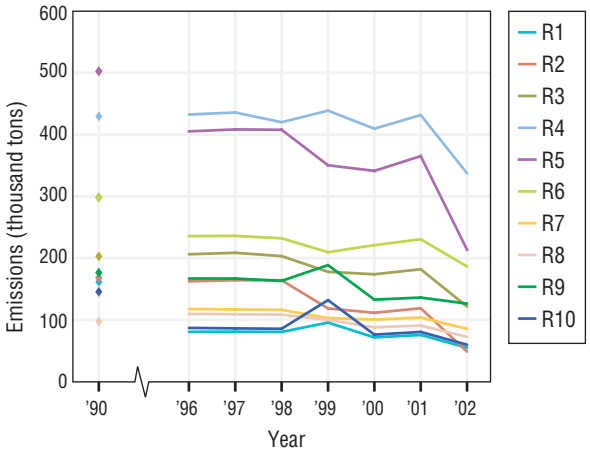
[b]Starting in 1999, EPA began tracking condensable particulate emissions separately from filterable particulate emissions. In order to display data generated using a consistent methodology, emissions of condensable particulate from 1990 to 2002 are not included in Panel A. However, condensable particulate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

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



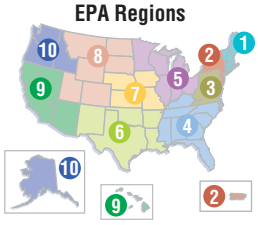
Data source: *U.S. EPA, 2007b*

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*

emissions estimation methodologies from other inventory years, which could lead to improper trend assessments.

- Because the emissions indicators focus on sources of anthropogenic origin, PM emissions from miscellaneous sources (e.g., wildfires) are not included in the trend line. Details on emissions from these sources can be found 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 (p. 2-29).
- 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

INDICATOR | Particulate Matter Emissions *(continued)*

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>

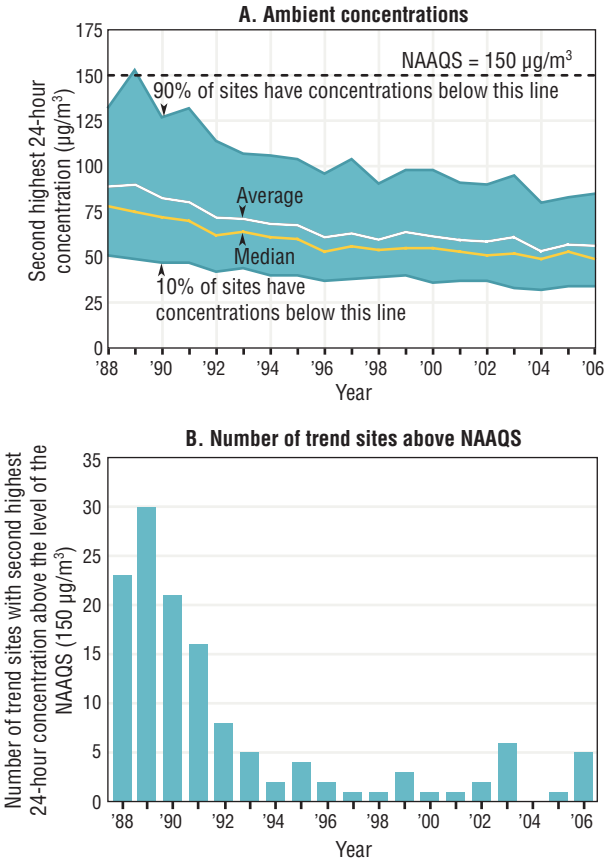
INDICATOR | Ambient Concentrations of Particulate Matter

"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

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

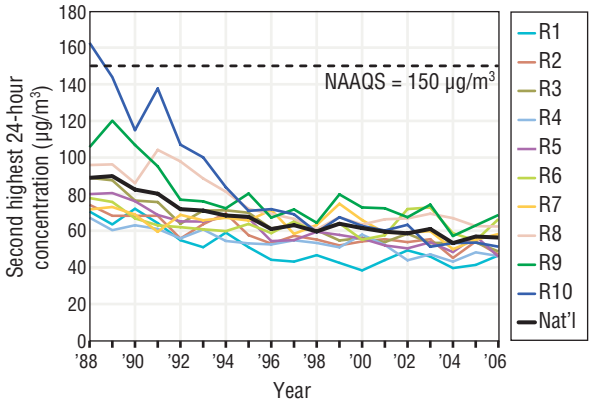


[a] **Coverage:** 301 monitoring sites in 199 counties nationwide (out of a total of 902 sites measuring PM_{10} in 2006) that have sufficient data to assess PM_{10} trends since 1988.

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

INDICATOR | Ambient Concentrations of Particulate Matter *(continued)*

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*

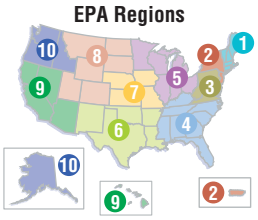
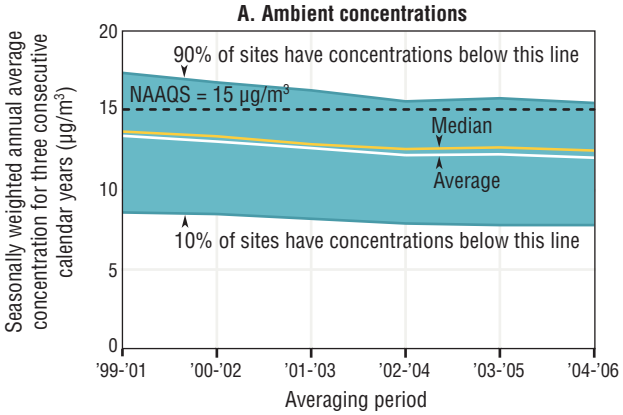
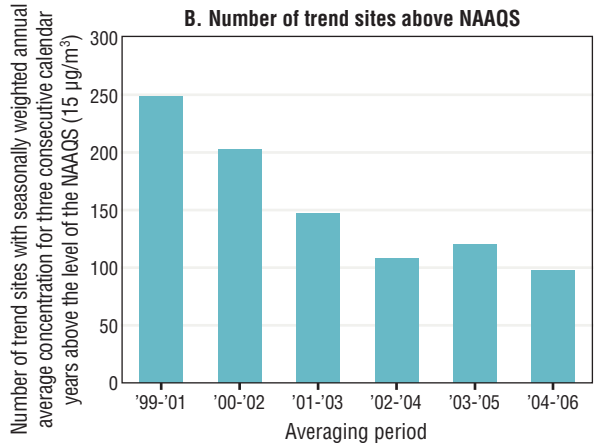


Exhibit 2-22. Ambient annual $PM_{2.5}$ concentrations in the U.S., 1999-2006[a]





[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*

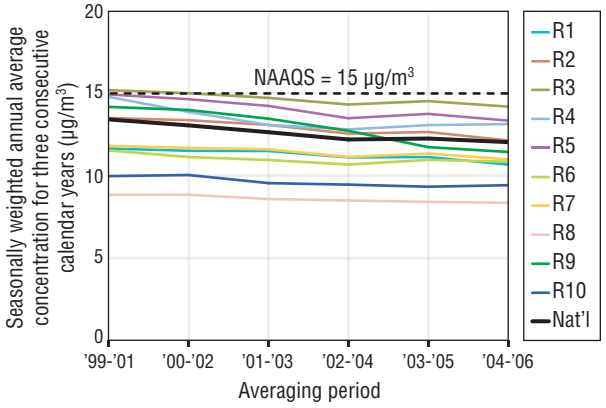
particle nitrates are more readily formed in cooler weather, and wood stove and fireplace use produces more carbon.

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

PM also can cause adverse impacts to the environment. Fine particles are the major cause of reduced visibility in parts of the U.S., including many National Parks and Wilderness Areas (the Regional Haze indicator, p. 2-33). PM deposition affects vegetation and ecosystems by altering nutrient and chemical cycles in soils and surface water. For example, deposition of particles containing nitrogen and sulfur may change the nutrient balance and acidity of aquatic environments so that species composition and buffering capacity change (the Lake and Stream Acidity indicator, p. 2-42.). Some particles that deposit onto plant leaves can corrode leaf surfaces or interfere with plant metabolism. PM also causes soiling and erosion damage to materials, including monuments, statues, and other objects of cultural importance (U.S. EPA, 2004b).

This indicator presents trends in PM_{10} and $PM_{2.5}$ concentrations, using averaging times consistent with the pollutants' corresponding National Ambient Air Quality Standards (NAAQS). For PM_{10}, trend data from 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

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*

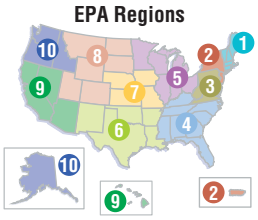
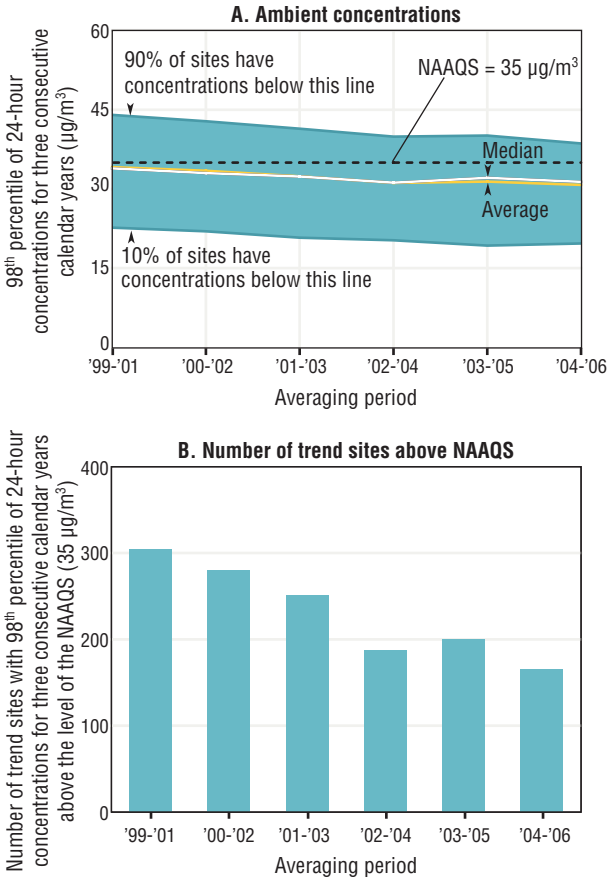


Exhibit 2-24. Ambient 24-hour $PM_{2.5}$ concentrations in the U.S., 1999-2006[a]



[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*

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 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.

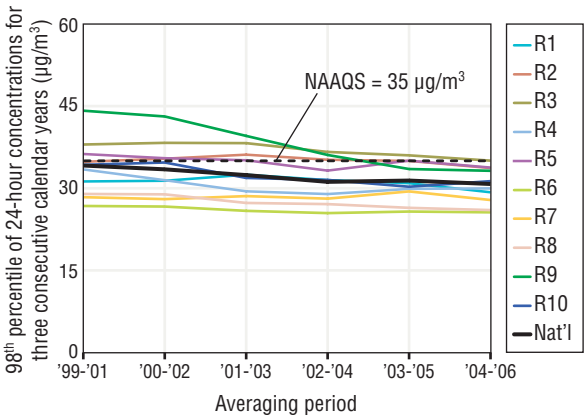
Also shown in Exhibit 2-20 (panel A) are the 90th and 10th percentiles based on the distribution of annual statistics at the monitoring sites. This provides additional graphical representation of the distribution of measured concentrations across the monitoring sites for a given year. Thus, the graphic 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

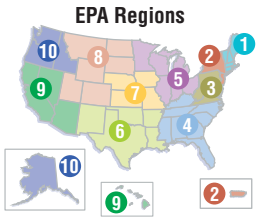
INDICATOR | Ambient Concentrations of Particulate Matter *(continued)*

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*



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 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

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. 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

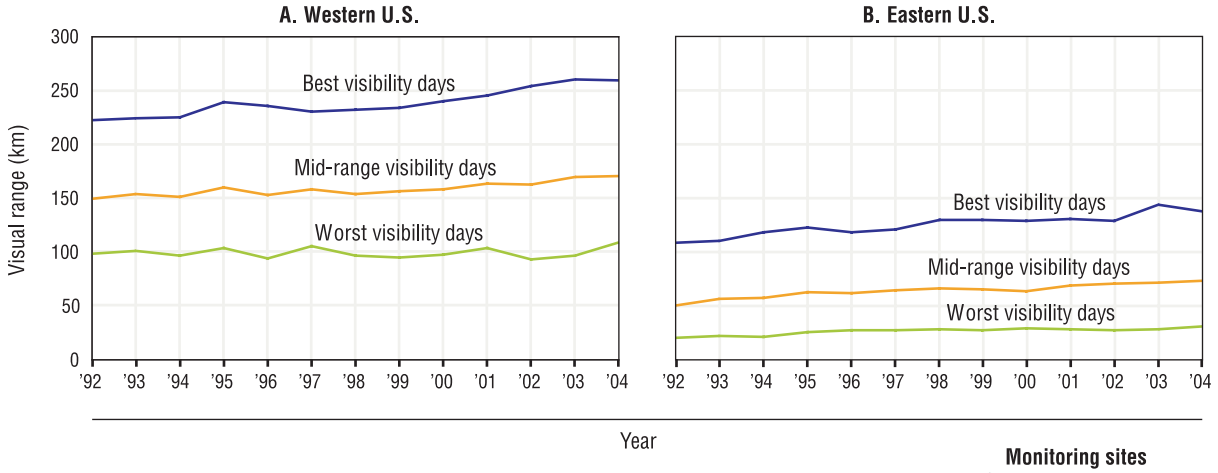
Visibility impairment occurs when air pollution, especially particles, scatter and absorb light. The resulting haze not only limits the distance one can see, but also degrades the color, clarity, and contrast of scenes. As the PM Concentrations indicator (p. 2-29) describes further, the same pollutants 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).

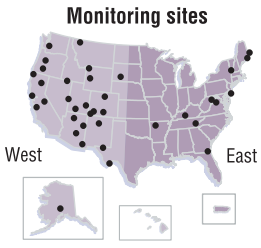
The particles that impair visibility include both primary and secondary pollutants. The primary pollutants of concern are particles that are emitted directly into the atmosphere, such as dust from roads or soot (elemental carbon) from combustion sources (e.g., wood combustion). Secondary pollutants of 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*

INDICATOR | Regional Haze *(continued)*

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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IMPROVE (Interagency Monitoring of Protected Visual Environments). 2007. Data from the IMPROVE network based on the "New IMPROVE algorithm" (updated August, 2007). Accessed 2007. <http://vista.cira.colostate.edu/views/Web/IMPROVE/SummaryData.aspx>

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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, p. 2-29).

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).

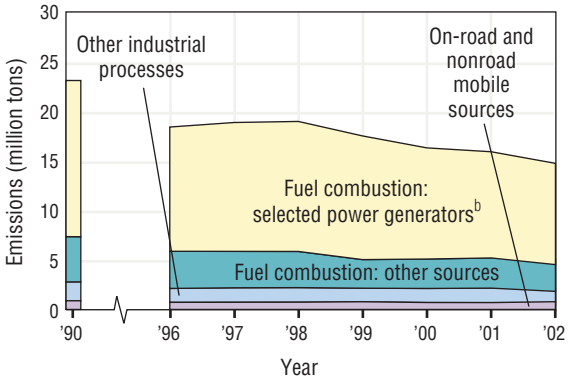
Many other environmental concerns are associated with high concentrations of SO_2. For example, airborne SO_2, along with NO_x, contributes to acidic deposition (the Acid Deposition indicator, p. 2-37); SO_2 is a major precursor to $PM_{2.5}$ (the PM Concentrations indicator, p. 2-29); and SO_2 contributes to impaired visibility (the Regional Haze indicator, p. 2-33). 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.

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.

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*

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 | Sulfur Dioxide Emissions *(continued)*

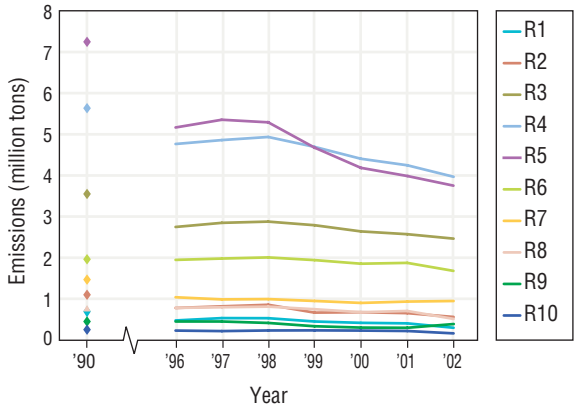
Indicator Limitations

- 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.

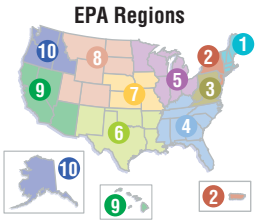
Data Sources

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*

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INDICATOR | Acid Deposition

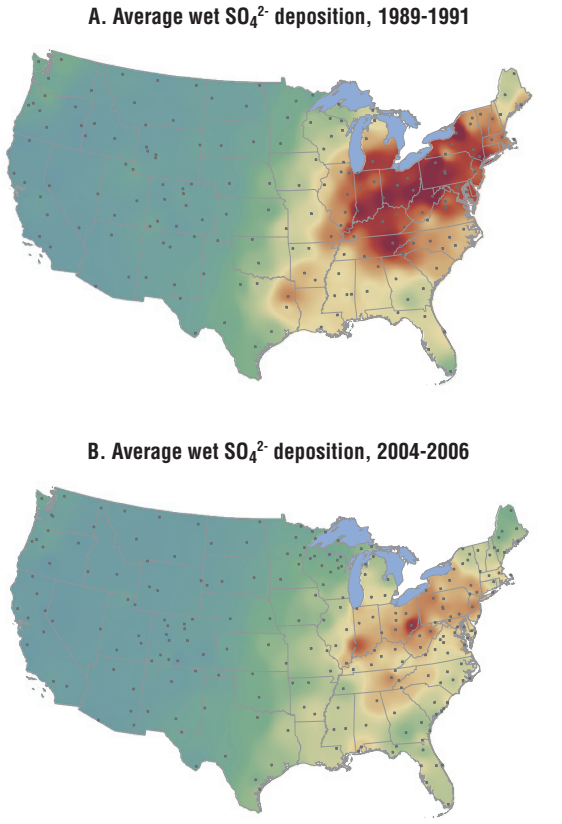
Every year, millions of tons of sulfur dioxide and nitrogen oxides are emitted to the atmosphere as a result of the burning of fossil fuels and from other high temperature sources (the Sulfur Dioxide Emissions indicator, p. 2-34; the Nitrogen Oxides Emissions indicator, p. 2-16). These gases react with 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, p. 2-42). 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*

INDICATOR | Acid Deposition *(continued)*

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).

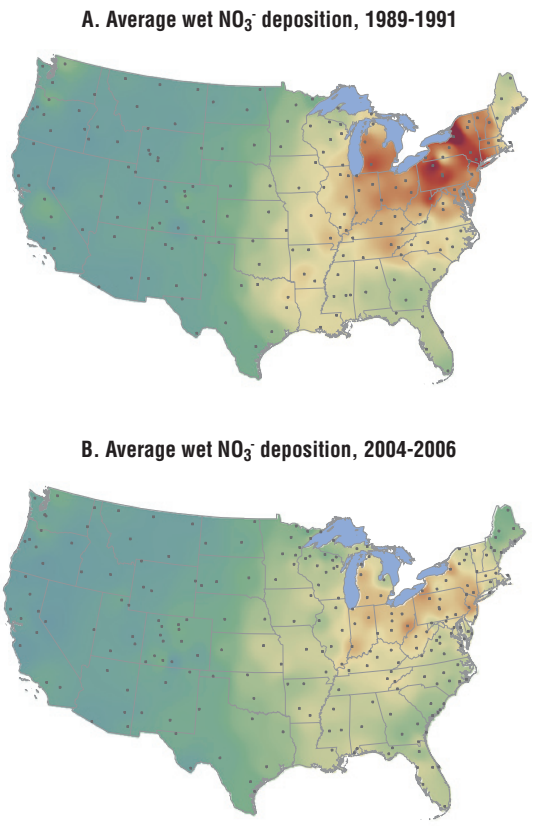
Wet sulfate deposition decreased across much of the U.S. during the 1990s (Exhibit 2-29). The greatest reductions in wet sulfate deposition occurred in the Mid-Appalachian region (Maryland, New York, West Virginia, Virginia, and most of Pennsylvania) and the Ohio River Valley. Less dramatic reductions 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.

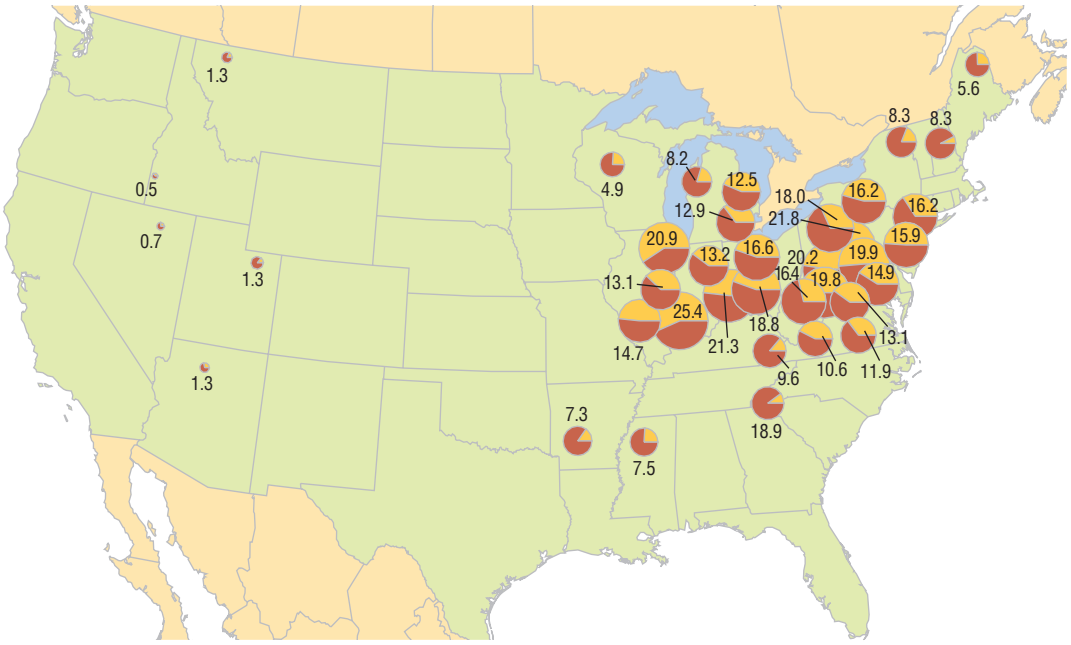
Data source: *NADP, 2007*

Indicator Limitations

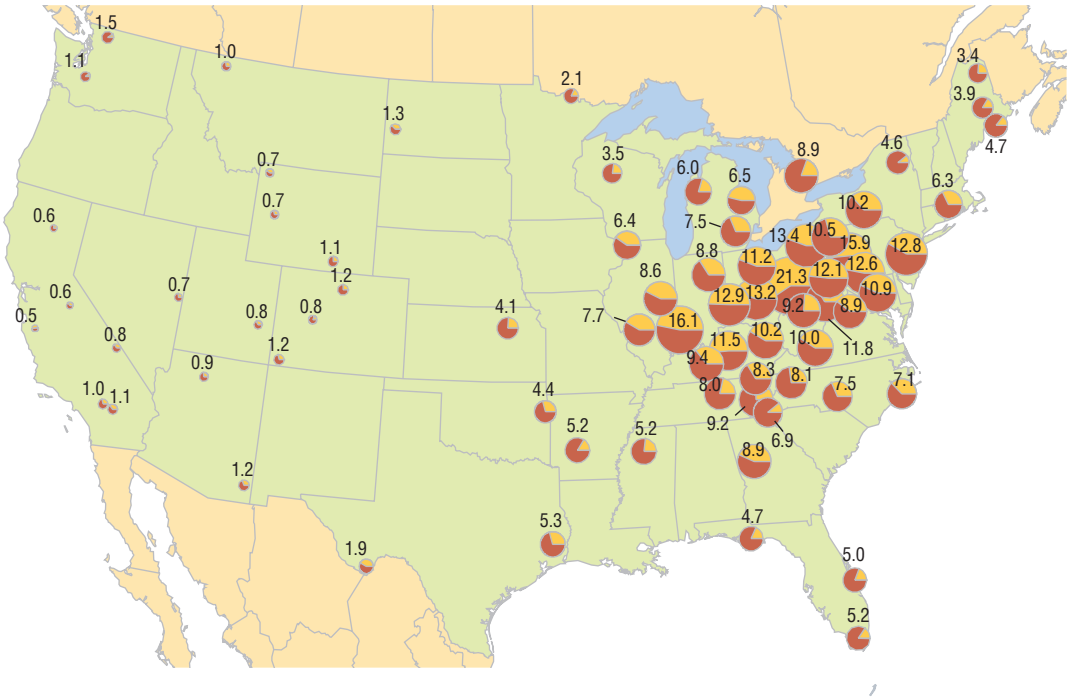
- Geographic coverage is limited, particularly for dry deposition (and thus total deposition as well), but the concentration of sites in the Midwest and Northeast is justified by the fact that acid rain is much more of a problem in those regions than it is in the West, Great Plains, or Southeast.
- Measurement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

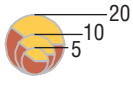


B. Average total sulfur deposition, 2004-2006



[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.

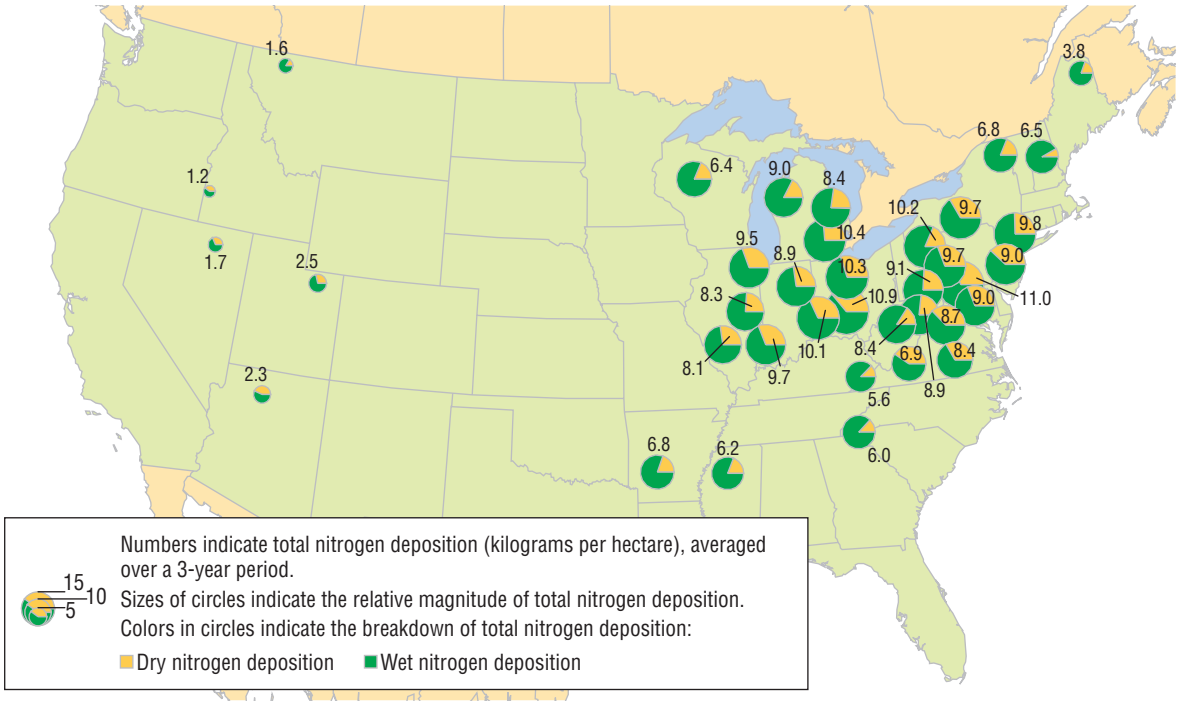
Colors in circles indicate the breakdown of total sulfur deposition:

Dry sulfur deposition Wet sulfur deposition

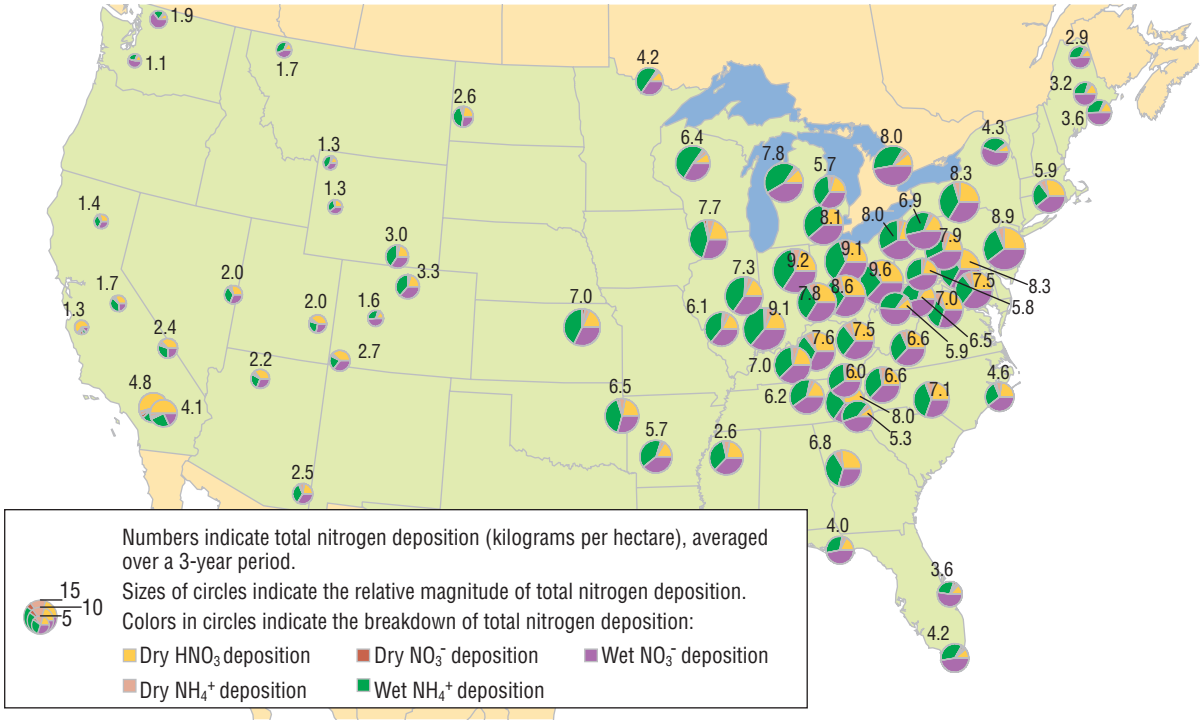
INDICATOR | Acid Deposition *(continued)*

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

A. Average total nitrogen deposition, 1989-1991



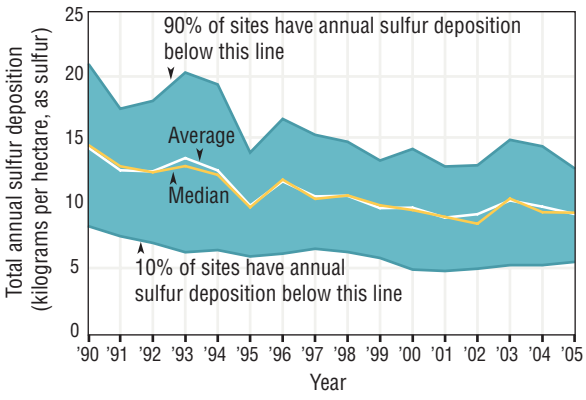
B. Average total nitrogen deposition, 2004-2006



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

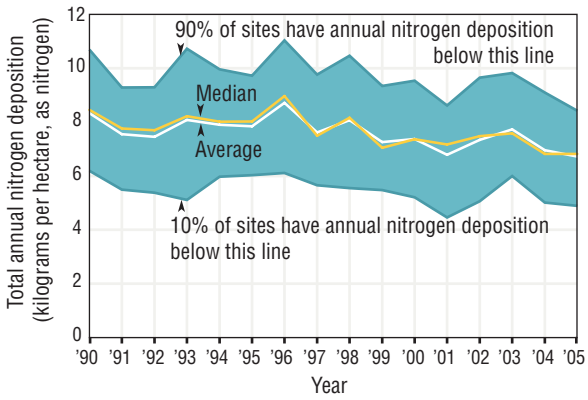
Data source: *NADP, 2007; U.S. EPA, 2007*

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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INDICATOR | Lake and Stream Acidity

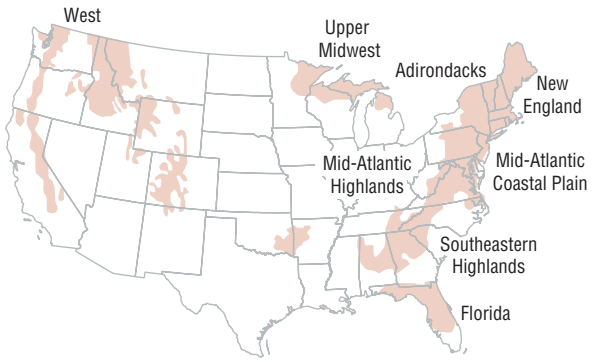
Acid deposition can have serious effects on aquatic ecosystems. For example, aquatic organisms in acidified waters can develop calcium deficiencies that weaken bones and exoskeletons and cause eggs to be weak or brittle. Acidified waters can impair the ability of fish gills to extract oxygen from water and change the mobility of certain trace metals (e.g., aluminum, cadmium, manganese, iron, arsenic, mercury), which in turn can place fish and other species sensitive to these metals at risk (NAPAP, 1991). The Acid Deposition indicator (p. 2-37) 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, p. 2-37) and reduced air emissions of the main precursors to acid deposition, which are sulfur dioxide (the Sulfur Dioxide Emissions indicator, p. 2-34) and nitrogen oxides (the Nitrogen Oxides Emissions indicator, p. 2-16).

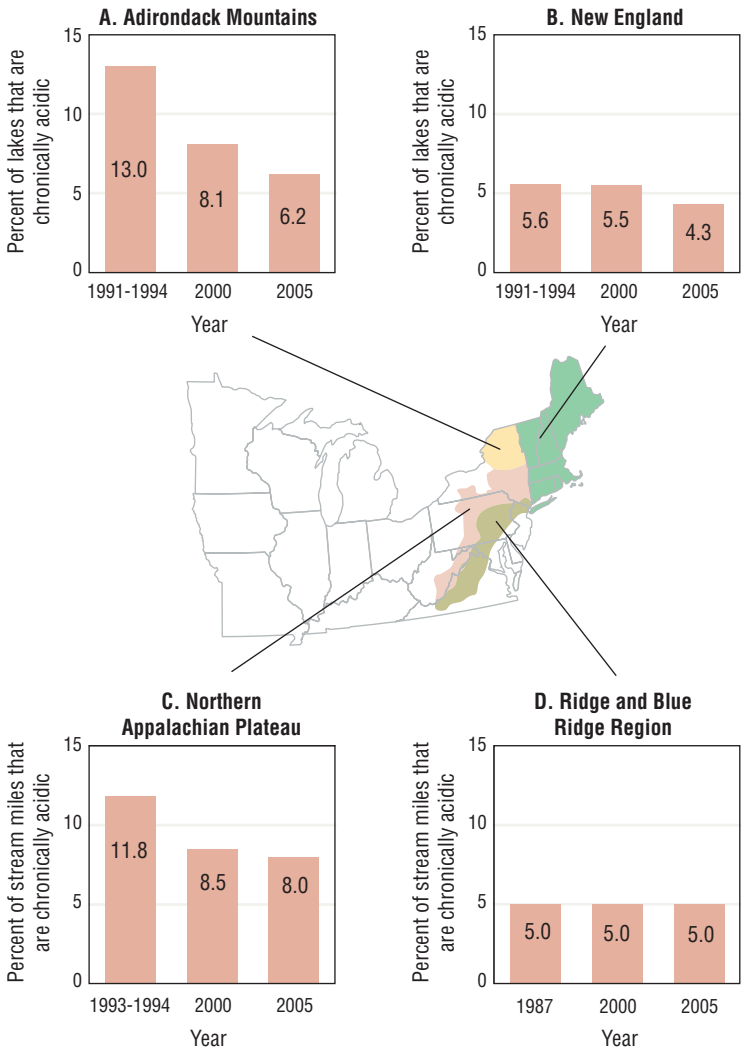
ANC in the Ridge and Blue Ridge Region (east-central Pennsylvania, western Maryland, and western Virginia)

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 (p. 2-37) 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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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.

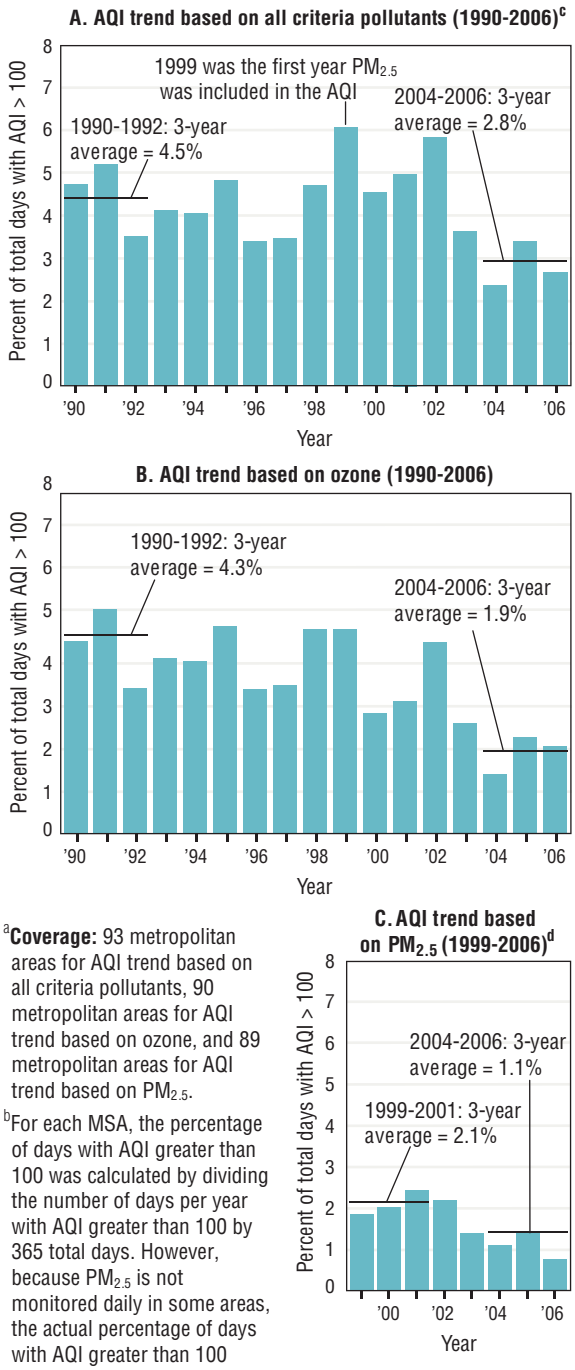
In 1999, the AQI was updated to reflect the latest science on air pollution health effects and to make it more appropriate for use in contemporary news media (U.S. EPA, 2003a). It also serves as a basis for community-based programs that encourage the public to take action to reduce air pollution on days 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

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 *(continued)*

the percentage of days with AQI above 100 in a year. Note that this 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.

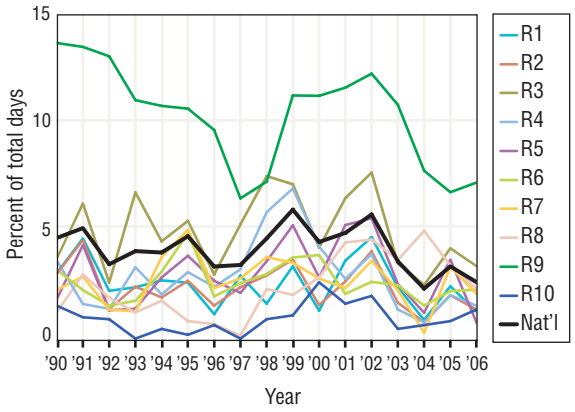
AQI Based on $PM_{2.5}$ Only

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.

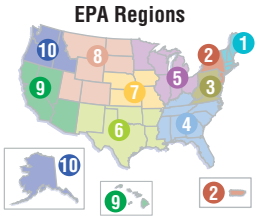
Exhibit 2-38. Percent of days with Air Quality Index (AQI) greater than 100 in selected U.S. metropolitan areas by EPA Region, 1990-2006[a,b]



[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*



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.

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 *(continued)*

- 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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INDICATOR | Mercury Emissions

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

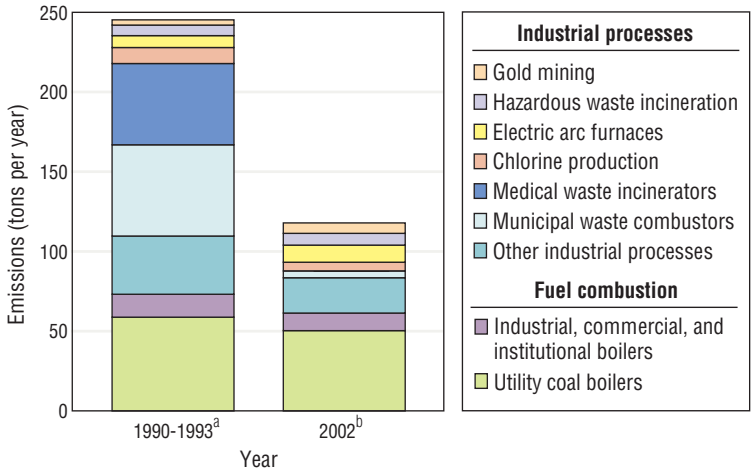
Because it does not degrade in the environment, most mercury emitted to the atmosphere eventually deposits onto land or water bodies. Through a series of chemical transformations and environmental transport processes, airborne mercury that deposits to the Earth's surface can eventually accumulate in the food web (the Lake Fish Tissue indicator, p. 3-63), most profoundly in those species near the top of the food web (e.g., shark, swordfish). The Blood Mercury indicator (p. 5-12) describes the human health effects associated with mercury exposure.

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

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

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

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



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

[b]Mercury emissions from mobile sources are not depicted because they have been estimated only for inventory year 2002 (0.8 tons) and not for the baseline period.

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

What the Data Show

Between 1990–1993 and 2002, annual nationwide air emissions of mercury decreased from 245 tons per year to 119 tons per year, a decrease of 52 percent (Exhibit 2-39). The decline in mercury emissions is attributed primarily to decreased emissions from medical waste incinerators and municipal waste combustors. In 2002, coal-burning power plants were the largest anthropogenic source of mercury emissions to the air in the U.S., accounting for 42 percent of all domestic anthropogenic mercury emissions.

Indicator Limitations

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

Data Sources

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

References

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INDICATOR | Air Toxics Emissions

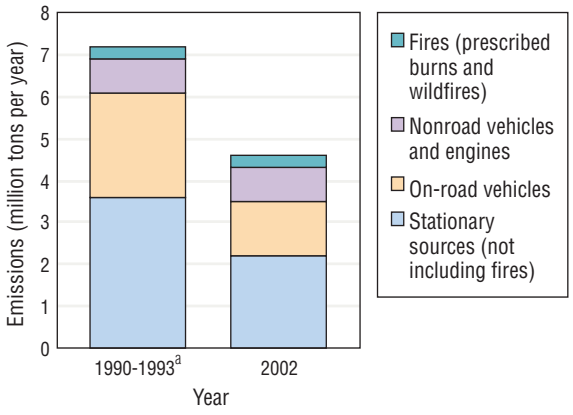
Toxic air pollutants, also known as air toxics or hazardous air pollutants (HAPs), are those pollutants that are known or suspected to cause cancer or are associated with other serious health (e.g., reproductive problems, birth defects) or ecological effects. Examples of air toxics include benzene, found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



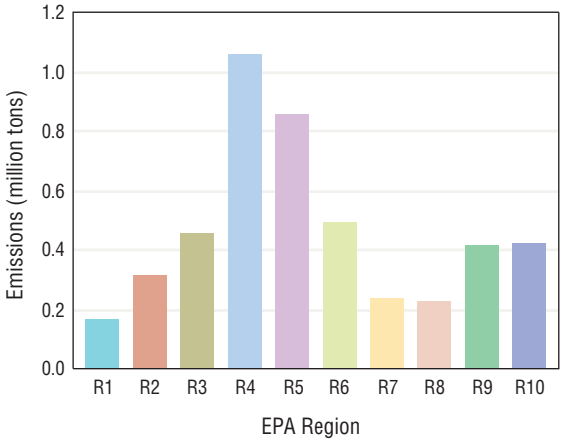
[a]1990-1993 is considered the baseline period for air toxics emissions. The baseline period spans multiple years due to the availability of emissions data for various source categories. The data presented for the baseline period are annual emissions (tons per year) and are therefore comparable to the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

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

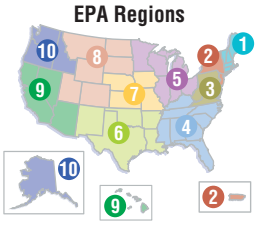
This indicator first presents emissions data for all air toxics combined, both at the national level and broken down into the ten EPA Regions. Consistent with the other emissions indicators, the national data are organized into the following source categories: (1) "Stationary sources," which include 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

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



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



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).

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.

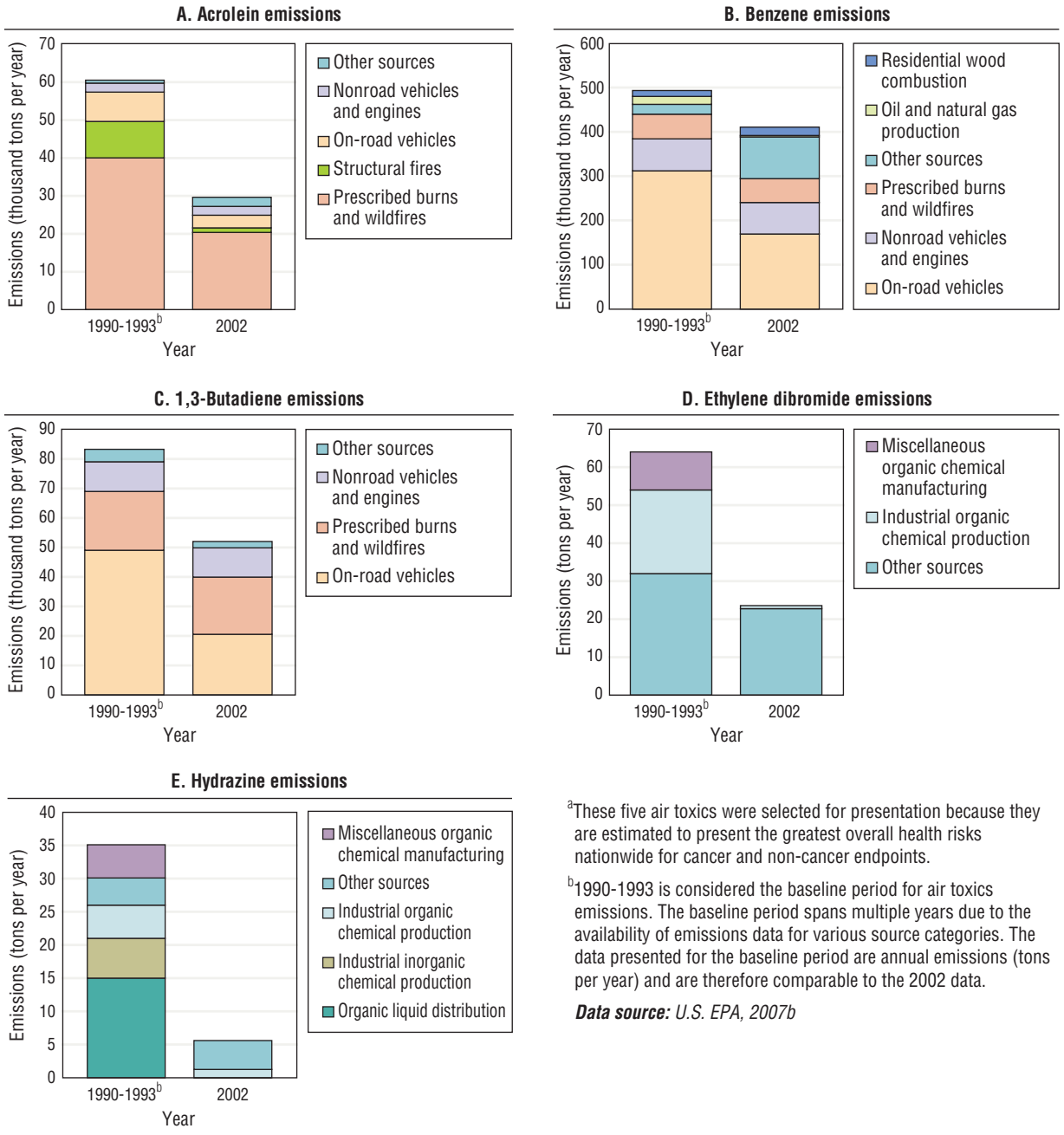
References

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>

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>

INDICATOR | Air Toxics Emissions *(continued)*

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. 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 | Ambient Concentrations of Benzene

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

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

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

This indicator reflects ambient concentrations in micrograms per cubic meter ($\mu g/m^3$) of benzene from 1994 to 2006, based on the annual average. This indicator displays trends averaged over 23 urban monitoring sites that have consistent data for the period of record from Photochemical Assessment Monitoring Stations, Urban Air Toxics Monitoring Stations, and Non-Methane Organic Compound Monitoring Stations.

What the Data Show

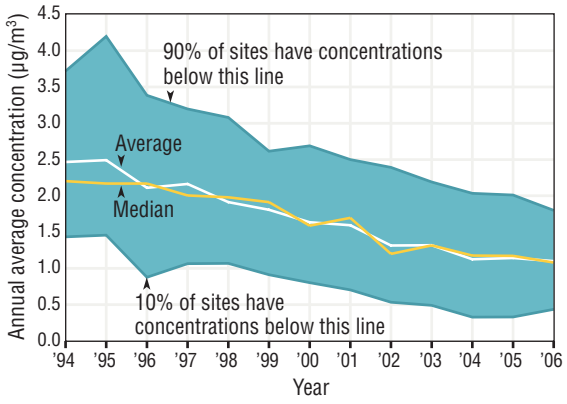
Benzene concentrations declined 55 percent from 1994 to 2006 (Exhibit 2-43).

Also shown in Exhibit 2-43 are the 90th and 10th percentiles based on the distributions of annual average concentrations at the 23 monitoring sites. These data provide additional graphical representation of the distribution of measured concentrations across the monitoring sites for a given year: the shaded area in the exhibit displays the concentration range where 80 percent of measured values occurred for each year.

Indicator Limitations

- Benzene data represent only 23 urban sites in the U.S.
- Because of the limited number of sites that are primarily located in urban areas, Exhibit 2-43 does not necessarily represent an overall national trend in benzene concentrations.
- Benzene, while an important air toxic, is only one of many toxics typically found in outdoor air.

Exhibit 2-43. Ambient benzene concentrations in the U.S., 1994-2006[a]



[a] **Coverage:** 23 monitoring sites nationwide (out of a total of 230 sites measuring benzene in 2006) that have sufficient data to assess benzene trends since 1994.

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

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on benzene ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (http://www.epa.gov/ttn/airs/airsaqs/). National trends in this indicator are based on the subset of benzene monitoring stations that have sufficient data to assess trends since 1994.

References

U.S. EPA (United States Environmental Protection Agency). 2007. Data from the Air Quality System. Accessed 2007. <http://www.epa.gov/ttn/airs/airsaqs/>

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INDICATOR | Concentrations of Ozone-Depleting Substances

Ozone, a gas present throughout the Earth's atmosphere, is a pollutant at the Earth's surface but forms a protective layer in the stratosphere, helping shield the Earth from the sun's ultraviolet (UV) radiation. Exposure to UV rays is associated with skin cancer, cataracts, and other human health and ecological problems (U.S. EPA, 2006).

Starting in the late 1970s, stratospheric ozone levels were observed to be declining due to worldwide releases of various human-produced chemicals referred to as ozone-depleting substances (ODSs), particularly halocarbons such as the long-lived chlorofluorocarbons (CFCs), bromine-containing halons, and methyl bromide. Through rapid catalytic reactions with ozone, the chlorine and bromine from these chemicals have depleted the protective ozone layer (the Ozone Levels over North America indicator, p. 2-54).

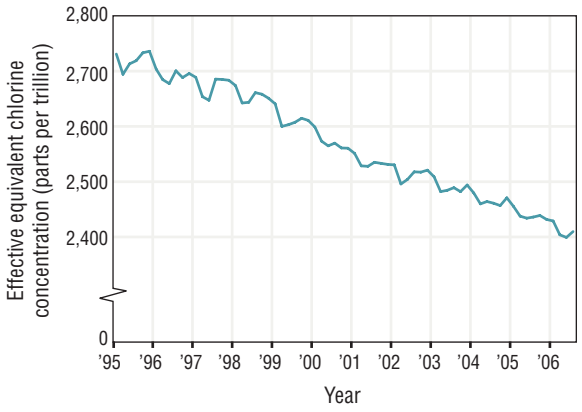
Worldwide production and consumption of ODSs is being progressively eliminated under the provisions of the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer. Over time, reducing the atmospheric loading of ODSs is expected to result in global increases in stratospheric ozone. However,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

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

This indicator presents trends in concentrations of tropospheric ODSs as EECl. The EECl trend is based on measurements from the National Oceanic and Atmospheric Association (NOAA) Climate Monitoring and Diagnostics Laboratory and estimates of halocarbon emissions from industrial and international sources from 1995 to 2006. Concentrations of EECl are presented as weighted averages based on ground-based measurements of mixing ratios[5] since 1995 at the following remote locations: Alert, Northwest Territories, Canada; Barrow, Alaska; Niwot Ridge, Colorado; Mauna Loa, Hawaii; American Samoa; Cape Grim, Tasmania, Australia; and the South Pole (NOAA CMDL, 2003). Data on total EECl are also available for 1992 through 1994, but these years of monitoring are only presented in the chemical-specific graphs because the monitoring did not include methyl bromide, a quantitatively important ODS. Because most ODSs have long atmospheric half-lives, the ODS concentrations shown in this indicator reflect past and recent contributions from emissions sources within the U.S. and worldwide.

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

Exhibit 2-44. Global effective equivalent chlorine concentrations, 1995-2006[a]



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

Data source: *NOAA, 2007*

What the Data Show

Total EECl resulting from ODS emissions reached its peak concentration in the mid-1990s at slightly over 2,700 parts per trillion of air by volume and has slowly declined by approximately 12 percent since then (Exhibit 2-44). Although tropospheric concentrations of CFCs and several other individual ODS compounds have begun to decline, concentrations of halons and selected hydrochlorofluorocarbons (HCFCs) have not yet stabilized.

Declines in EECl abundances of several ODSs in the troposphere between 1992 and 2006 have contributed to the decline in total EECl (Exhibit 2-45). EECl attributed to methyl chloroform has decreased by nearly 90 percent over this period due to decreased emissions as well as its short atmospheric lifetime. EECl associated with CFCs has decreased more slowly: 2006 levels are approximately 5 percent lower than the peak tropospheric concentration that occurred between 1995 and 1997. The slow decay of CFCs is a result of continued emissions of CFCs from stockpiles in developed countries, continued use in developing countries, and their longer atmospheric lifetimes. EECl from methyl bromide has decreased nearly 20 percent from its peak in

1998; however, continued use of methyl bromide in developing countries and in developed countries through critical use exemptions slows the decrease in EECl associated with this compound. EECl from methyl bromide exhibits seasonal variations, which likely results from the seasonal use of this chemical as a soil fumigant.

Although some tropospheric ODSs have declined in concentration, others, including halons and HCFCs, continue to increase (Exhibit 2-45). EECl estimated from halon emissions has increased by more than 50 percent from 1992 to 2006, and EECl attributed to HCFCs in 2006 is more than 2.5 times higher than that from 1992. These trends reflect continued emissions of these ODSs from stockpiles in developed countries and continued production and consumption in developing countries (and developed countries for HCFCs), as well as the longer atmospheric lifetimes of halons.

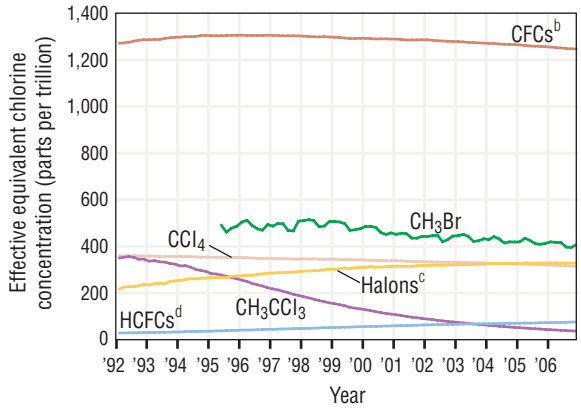
Indicator Limitations

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

Data Sources

Tropospheric concentrations of ODSs presented in this indicator are based on measurements made by NOAA's Global Monitoring Division and summarized at an online data repository (NOAA, 2007) (ftp://ftp.cmdl.noaa.gov/hats/Total_Cl_Br/). The trend in this indicator was developed from a 2007 data file available from the repository, which updates tropospheric ODS concentrations previously reported in the peer-reviewed literature (Montzka et al., 1999, 2003).

Exhibit 2-45. Global effective equivalent chlorine concentrations of selected ozone-depleting substances, 1992-2006[a]



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

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

[c]The halons considered in this figure are halon 1211 and halon 1301.

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

Data source: *NOAA, 2007*

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INDICATOR | Ozone Levels over North America

Ozone is a gas present throughout the Earth's atmosphere; 90 percent resides in the stratosphere, the layer of the atmosphere that starts about 6 to 9 miles above the Earth's surface at mid-latitudes, and the rest is located in the troposphere, the atmospheric layer that lies between the stratosphere and the Earth's surface. The environmental and human health implications of ground-level ozone are very different from those of ozone higher in the atmosphere, leading to the maxim: "Good up high, bad nearby" (U.S. EPA, 2003). In the troposphere, ozone poses both health and ecological risks, but the natural layer of ozone in the stratosphere shields and protects the Earth's surface from the sun's harmful ultraviolet (UV) rays, which can lead to more cases of skin cancer, cataracts, and other health problems (U.S. EPA, 2006).

Increases in surface UV radiation have been associated with reductions in total column ozone levels based on spectral measurements at a number of sites in Europe, North America, South America, Antarctica, and New Zealand (Kerr and McElroy, 1993; Booth and Madronich, 1994; WMO et al., 2007). For example, measurements between 1989 and 1993 over Toronto indicated that for every 1 percent decrease in total column ozone, after accounting for seasonal and daily variables not related to ozone, there was a corresponding increase—between 1.1 percent and 1.3 percent—in erythemally active UV-B radiation (Kerr and McElroy, 1993).

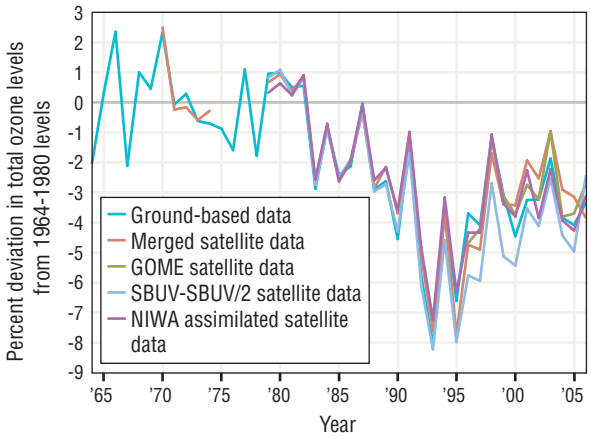
Ozone in the stratosphere is constantly being produced naturally from dissociation of oxygen molecules by highly energetic UV solar radiation. While this ozone is being transported poleward and downward through the natural motions of air in the stratosphere, it also is being naturally destroyed through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

Releases of various human-produced chemicals, such as the long-lived chlorofluorocarbons, bromine-containing halons, and methyl bromide (the Concentrations of Ozone-Depleting Substances indicator, p. 2-52), have depleted the levels of protective stratospheric ozone starting in the late 1970s, particularly at medium to high latitudes. The U.S. has been a major contributor to the global emissions of these halocarbons, accounting for about a quarter of total worldwide emissions before the major ozone-depleting substances (ODSs) were banned in the 1990s. It takes about 3 years for emissions of ODSs at the Earth's surface to migrate to the stratosphere and cause stratospheric ozone depletion (WMO et al., 2007).

This indicator tracks trends in the deviation from pre-1980 levels in total annually averaged ozone values integrated over the 35 to 60 degrees north latitude belt (the latitudes roughly corresponding to North America) from 1964 to 2006. The estimates are based on data from several different sources including ground-based and satellite measurements. The data on total ozone from ground-based measurements are from a network of surface stations, which are equipped with spectrophotometers. These instruments measure how thick the ozone layer would be if compressed in the Earth's atmosphere (at sea level and at 0°C), where one Dobson Unit (DU) is defined to be 0.01 mm thickness at standard temperature and pressure. Reliable data from regular measurements at these ground-based stations are available extending back to the 1960s, although geographical coverage is limited before the 1970s (Fioletov et al., 2002; WMO et al., 2007).

Near-continuous global total ozone data are available from satellite measurements beginning in 1979. These satellite data come from four sources: (1) The Global Ozone Monitoring Experiment (GOME) refers to data collected from instruments on board the European Space Agency's ERS-2 satellite, for which validated data are available dating back to 1996; (2) The Solar Backscatter Ultraviolet (SBUV) instruments have been collecting data since 1979, with one instrument (SBUV) on board the Nimbus 7 satellite and the other instruments (SBUV/2) on board a sequence of NOAA satellites; (3) The "merged satellite data" refer to total ozone data dating back to 1970 (not all years inclusive) constructed by merging observations from the SBUV/2 data and data collected by Total Ozone Mapping Spectrometer (TOMS) instruments on board the Nimbus 7 satellite; and (4) The National Institute of Water and Atmospheric Research (NIWA) assimilated data set

Exhibit 2-46. Total ozone levels over North America, 1964-2006[a,b]



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

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

Data source: *WMO et al., 2007*

is a merged data set constructed from observations dating back to 1979 collected by the TOMS, GOME, and SBUV instruments. Other publications provide further documentation on the four satellite data sets used in this indicator (WMO et al., 2007).

What the Data Show

There was little ozone change (beyond natural variations such as those resulting from the 11-year solar sunspot cycle) before the late 1970s, but decreases in stratospheric ozone began to occur after 1979 (Exhibit 2-46). The ground-based data and four satellite data sets have similar ozone variations, with differences typically less than 0.5 percent. The mid-latitude decline of approximately 6 percent between 1979 and 1995 is in general agreement with previous profile trend estimates from satellite and ground-based records.

However, total ozone levels have begun to recover since 1995. For the mid-latitudes of the Northern Hemisphere, the average of the total ozone levels for the 4-year period from 2002 to 2005 is about 3 percent lower than the pre-1980 levels in the Northern Hemisphere (WMO et al., 2007). While this indicator covers the entire 35 to 60 degrees north latitude belt, ozone varies little by longitude and the estimated 3 percent change in total ozone levels can be taken to apply to North America.

This 3 percent change over North America is very similar to the statistically significant globally averaged 3.5 decrease in total ozone between pre-1980 levels and 2002–2005 (WMO et al., 2007). The decrease in the mid-latitudes of the Southern Hemisphere, by contrast, has been nearly twice as high as observed in the Northern Hemisphere, due largely to the springtime "ozone hole" over Antarctica. The trends in this indicator are consistent with well understood seasonal variations in ozone, and with natural variations such as those due to the 11-year solar cycle and the effects of volcanic eruptions, suggesting that the long-term trends are those resulting from the emissions of ODSs.

Indicator Limitations

- Fioletov et al. (2002) used estimates of ozone changes from several different, independent sources to derive some data used for this indicator. Differences in the calibration of instruments used to obtain the ground-based and satellite datasets together with interruptions in the observational records produce datasets with measurement errors typically around a few percent (WMO et al., 2007). The figure presented does, however, show good overall agreement among the different data sources for changes in total ozone.

Data Sources

Summary data for this indicator were provided by the World Meteorological Organization. The 1964–2006 data in this indicator are taken from the Organization's 2006 Scientific Assessment of Ozone Depletion (WMO et al., 2007), which presents ozone data based on multiple sets of measurements (e.g., Fioletov et al., 2002).

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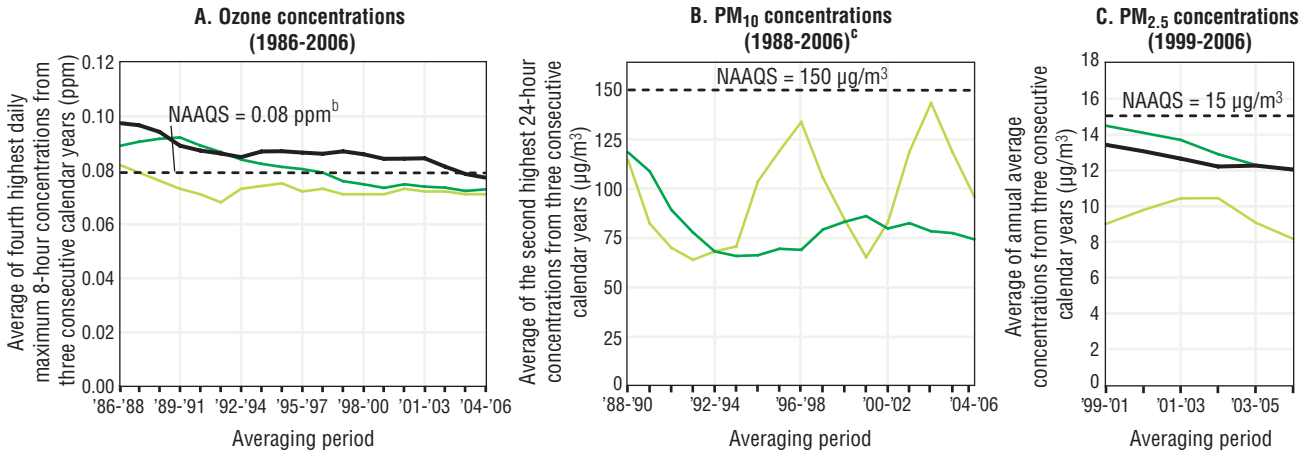
INDICATOR | Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region

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

Ground-level ozone is harmful to both human health and the environment (the Ozone Concentrations indicator, p. 2-22). Although some industrial sources release ozone directly into the environment, most ground-level ozone forms from chemical reactions involving nitrogen oxides, volatile organic compounds, and sunlight. Ozone levels are typically highest during the afternoon hours of the summer months, when the influence of direct sunlight is the greatest (U.S. EPA, 2006).

Exhibit 2-47. Ambient ozone, PM_{10}, and $PM_{2.5}$ concentrations in U.S. counties in the U.S/Mexico border area, 1986-2006[a]



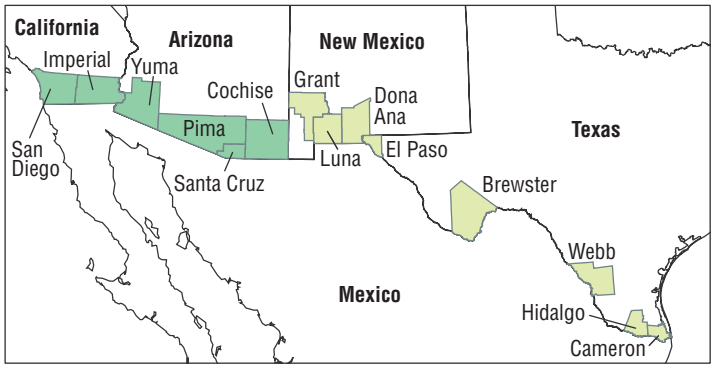
[a]**Coverage:** 29 ozone monitoring sites, 32 PM_{10} monitoring sites, and 14 $PM_{2.5}$ monitoring sites located in U.S. counties along the U.S./Mexico border that have sufficient data to assess trends over the time frames in which these pollutants were monitored.

[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.

[c] National PM_{10} data are not depicted because the approach used to track PM_{10} concentrations in the U.S./Mexico border region differs from that used on the national scale.

Region 6 border counties
Region 9 border counties
National average

Counties with ambient air monitoring sites included in this indicator



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

INDICATOR | Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region *(continued)*

"Particulate matter" (PM) is the general term used for a mixture of solid particles and liquid droplets found in the air. Primary PM is released directly from emissions sources into the atmosphere, while secondary PM is formed in the air from reactions involving precursor chemicals (e.g., nitrogen oxides, sulfur dioxide, particle-producing organic gases). Ambient air monitoring stations measure air concentrations of two size ranges of particles: $PM_{2.5}$ (fine particles with aerodynamic diameter less than or equal to 2.5 micrometers [μm]) and PM_{10} (particles with aerodynamic diameters less than or equal to 10 μm, including $PM_{2.5}$). Exposure to coarse particles (i.e., particles with aerodynamic diameters between 2.5 and 10 μm) can aggravate respiratory conditions such as asthma, and exposure to fine particles is associated with various additional human health effects (the PM Concentrations indicator, p. 2-29) (U.S. EPA, 2004).

This indicator shows trends in ambient air concentrations of ozone and particulate matter in the U.S. counties at the U.S./Mexico border area in comparison to U.S. national trends, where appropriate. These trends are shown for the longest duration of time supported by the underlying monitoring data. For ozone, this indicator reports the average of the fourth highest daily maximum 8-hour concentrations for three consecutive calendar years. For PM_{10}, this indicator reports the 3-year average of the second highest 24-hour concentrations. For $PM_{2.5}$, this indicator reports the 3-year average of the seasonally weighted annual average concentration. For ozone and $PM_{2.5}$, national trend lines are also depicted because the statistics used to report data in this indicator are the same as those used in the corresponding national indicators. For PM_{10}, national data are not presented, because this indicator tracks data over 3-year averaging periods, while the national indicator tracks data over single-year intervals. This indicator is based on all monitoring stations that operated on the U.S. side of the border during this time period.

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

What the Data Show

Trends for 8-Hour Ozone Concentrations

In EPA Region 6, average border ozone concentrations decreased by 11 percent between the 1986-1988 and 1992-1994 time periods (a smaller decrease than the national average, which was 13 percent) and by 4 percent between the 1993-1995 and 2004-2006 periods (again, smaller than the national average decrease of 11 percent) (Exhibit 2-47, panel A). In EPA Region 9, however, border ozone concentrations decreased by 6 percent between the 1986-1988 and 1992-1994 time periods and then decreased by 11 percent between the 1993-1995 and 2004-2006 periods.

Trends for 24-Hour PM_{10} Concentrations

In EPA Region 6, the second highest 24-hour PM_{10} concentrations at border monitoring sites varied considerably over the period of record, most likely due to variation in meteorological conditions (e.g., rainfall, wind speed) and soil erosion (Exhibit 2-47, panel B); no clear long-term trend is apparent from the data. In EPA Region 9, on the other hand, corresponding PM_{10} concentrations at border monitoring sites did not exhibit such strong temporal variations, and the average second highest 24-hour concentration at border monitoring sites for the 2004-2006 time frame was 37 percent lower than that for the 1988-1990 time frame.

Trends for Annual Average $PM_{2.5}$ Concentrations

Between 1999-2001 and 2004-2006, average annual ambient $PM_{2.5}$ exhibited no clear trend in the border counties of EPA Region 6, but decreased by 17 percent in the border counties of EPA Region 9 (Exhibit 2-47, panel C). Average annual ambient $PM_{2.5}$ concentrations decreased 10 percent nationwide over the same period.

Indicator Limitations

- Many counties along the U.S./Mexico border do not have ambient air quality monitors; these counties are not characterized by this indicator.
- This indicator does not include data from the Mexican side of the border. When a technical review concludes the quality of these data is appropriate for the intended use, the indicator will be updated.
- Short-term trends in PM_{10} concentrations are often highly dependent on meteorological conditions. The maximum concentration for a given site can be influenced by wind-blown dust and will exhibit considerable variations from day to day. Trends over the longer term are far less likely to be influenced by unusual meteorological conditions.

INDICATOR | Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region *(continued)*

- The long-term ozone trends are derived from an increasing number of monitors over the course of time from 1986 to 2006, but an analysis of the limited number of border sites that have full periods of record show that the slopes of the trends are similar to those in this indicator.
- Average air pollutant concentrations may mask higher values in some areas along the border and in the nation.
- Because most of the monitoring sites are located in urban areas, the trends might not accurately reflect conditions outside the immediate urban monitoring areas.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, Region 6, and Region 9. These summaries were based on ozone and PM ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2007) (http://www.epa.gov/ttn/airs/airsaqs/). Trends in this indicator are based on the subset of ozone and PM monitoring stations located in counties along the U.S./Mexico border that have sufficient data to assess trends over the period of record.

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INDICATOR | Ambient Concentrations of Manganese Compounds in EPA Region 5

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

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

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

This indicator presents ambient concentrations of manganese compounds measured as total suspended particulates (TSP) by direct monitoring. This indicator addresses manganese in the TSP fraction (not PM_{10} or $PM_{2.5}$) because it is the most complete dataset in EPA Region 5 in terms of

INDICATOR | Ambient Concentrations of Manganese Compounds in EPA Region 5 *(continued)*

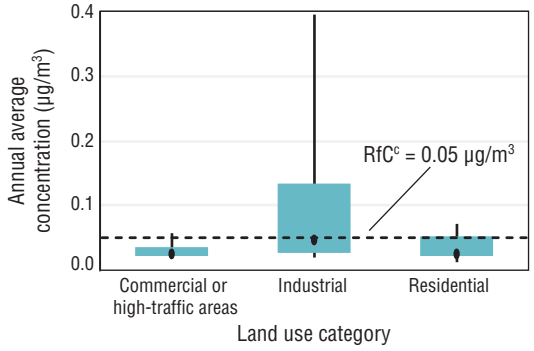
geographic and temporal coverage. TSP metals data have been commonly used in human health risk assessments. EPA recently has begun to recommend PM_{10} as the most appropriate fraction for evaluating people's exposure to toxic metals (U.S. EPA, 2002), but PM_{10} metals data are sparse at this time, both nationally and in EPA Region 5. Data from a limited number of sites in EPA's Air Quality System (AQS) with collocated PM_{10} and TSP speciation monitors suggest that the proportion of manganese in PM_{10} versus TSP is about 50 percent at most sites and can be as high as 75 percent. TSP manganese data therefore should be considered a conservative estimate of PM_{10} manganese exposures. $PM_{2.5}$ metals data are plentiful since the establishment of the Speciation Trends Network in 2000, but this size fraction is believed to underestimate human exposures.

Data were considered for 58 monitoring sites in EPA Region 5 that had a complete year of data reported to the AQS national database in 2006. Average manganese concentrations were calculated for each monitoring site. A concentration trend was determined using a subset of 21 of the monitoring sites with six or more complete years of data between 2000 and 2006. As annual average concentrations are representative of long-term inhalation exposures, the ambient monitoring data are displayed in comparison with the manganese reference concentration (RfC). The RfC is an estimate of a chronic inhalation exposure that is likely to be without appreciable risk of adverse non-cancer effects during a lifetime. The RfC for manganese is 0.05 micrograms per cubic meter (µg/m^3), based on impairment of neurobehavioral function in people. At exposures increasingly greater than the RfC, the potential for harmful effects increases (ATSDR, 1997; U.S. EPA, 1999). Monitoring sites were classified into different categories based on land use as defined in AQS.

What the Data Show

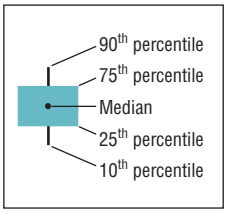
In 2006, the median average annual ambient concentrations of manganese as TSP in EPA Region 5 were 0.024 µg/m^3 at the 15 residential sites, 0.024 µg/m^3 at the 16 sites in commercial or high-traffic areas, and 0.046 µg/m^3 at the 24 industrial sites (Exhibit 2-48). The average annual ambient concentration of manganese at three predominantly agricultural and forest sites in EPA Region 5 was 0.02 µg/m^3, but this is not depicted in the figure due to the limited number of monitoring sites to characterize a distribution. Greater concentration differences were observed in the 90th percentile values: below 0.1 µg/m^3 at the residential, commercial, and high-traffic sites, compared to 0.39 µg/m^3 at the predominantly industrial sites. In 2006, 18 of the 58 sites had average manganese concentrations higher than the RfC; 12 of these sites were categorized as industrial, two commercial or high-traffic, and four residential.

Exhibit 2-48. Ambient manganese concentrations in EPA Region 5 by land use category, 2006[a,b]



[a]**Coverage:** 55 monitoring sites in EPA Region 5, with 16 sites in commercial or high-traffic land use areas, 24 sites in industrial areas, and 15 sites in residential areas.

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



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

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

The average annual manganese concentration averaged across 21 trend sites showed a 28 percent decline between 2000 and 2006 (Exhibit 2-49). Additional years of data may be needed to confirm this trend. The trend sites had the following land use designations: commercial and high-traffic (six sites), industrial (nine sites), and residential (six sites). None of the trend sites had agricultural or forest land use designations.

Indicator Limitations

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

INDICATOR | Ambient Concentrations of Manganese Compounds in EPA Region 5 *(continued)*

Data Sources

Summary data in this indicator were provided by EPA Region 5, based on ambient air monitoring data for manganese compounds reported in EPA's AQS (U.S. EPA, 2007) (http://www.epa.gov/ttn/airs/airsaqs/). Trends in this indicator are based on the subset of monitoring stations located in EPA Region 5 that have sufficient manganese concentration data to assess trends over the period of record.

References

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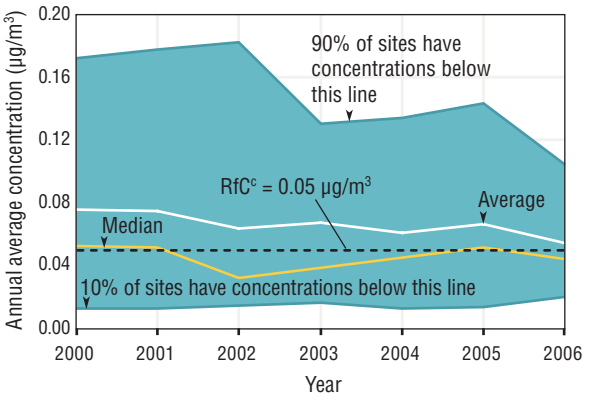
U.S. EPA. 2005a. 1999 National Emissions Inventory data. <http://www.epa.gov/air/data> August.

U.S. EPA. 2005b. 1999 Toxics Release Inventory data. <http://www.epa.gov/tri> December.

U.S. EPA. 2002. Quality assurance guidance document—model quality assurance project plan for the national air toxics trends stations. Washington, DC.

U.S. EPA. 1999. Integrated Risk Information System (IRIS) on manganese. Washington, DC. <http://www.epa.gov/iris/subst/0373.htm>

Exhibit 2-49. Ambient manganese concentrations in EPA Region 5, 2000-2006[a,b]



[a]**Coverage:** 21 monitoring sites in EPA Region 5 (out of a total of 58 sites measuring manganese in 2006) that have sufficient data to assess manganese trends since 2000.

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

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

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

2.2.3 Discussion

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

Criteria Pollutants and Their Precursors

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

Consistent with the emissions trends, every criteria pollutant showed decreasing ambient air concentrations based on aggregate measurements from the nation's ambient air monitoring system, which measures levels of air pollution primarily in urban and suburban areas. The magnitude of air quality improvements, observed both nationally and in all ten EPA Regions, varies across pollutants. Carbon monoxide, lead, and nitrogen dioxide concentrations decreased considerably between 1980 and the present, and ambient concentrations of these three pollutants in most or all areas in the U.S. are now below the level of the corresponding air quality standards that protect human health and the environment. In contrast, air

quality improvements for ozone and particulate matter (particularly $PM_{2.5}$) were less pronounced; and, based on monitoring data collected in 2006 and reported in EPA's Air Quality System, ambient concentrations of ozone, particulate matter, or both pollutants in 105 metropolitan statistical areas where approximately 138 million people lived were greater than the level of their corresponding health-based standards.[6] In short, every criteria pollutant has showed improving air quality over the past one or two decades, but the progress has been slowest for the two pollutants—ozone and $PM_{2.5}$—most influenced by meteorology and secondary formation processes.

The nationwide trends and those presented for the ten EPA Regions are based on aggregate statistics across numerous monitoring stations and may not reflect air quality trends at finer scales or for different subsets of monitoring stations. For example, the significant downward trend in ozone in EPA Region 9 is largely influenced by air quality improvements in Los Angeles and other metropolitan areas in southern California. In other urban areas in EPA Region 9, ozone improvements have been more modest or even different directionally.[7] Similarly, $PM_{2.5}$ concentrations have increased over the last 5 years at selected monitoring stations near the border between U.S. and Mexico (the Ozone and PM Concentrations Along U.S./Mexico Border indicator, p. 2-56), even though the national trend for this pollutant is downward.

The ROE indicators on criteria pollutants' environmental effects are limited to three issues. First, long-term monitoring data show that wet deposition of acidic sulfates and nitrates decreased between 1989 and 2006, consistent with the decreased emissions for sulfur dioxide and nitrogen oxides over roughly the same time frame. As a result of the decreased acid deposition, many surface waters throughout the Adirondack Mountains, the Northern Appalachian region, and New England have begun to recover from past acidification (the Lake and Stream Acidity indicator, p. 2-42). Second, data on ozone injury to forest plants are sufficient for establishing national and regional baseline conditions against which future data can be compared. These baseline conditions show considerable variation in ozone damage across EPA Regions (the Ozone Injury to Forest Plants indicator, p. 2-24). Third, visibility in protected areas (e.g., National Parks, Wilderness Areas) has increased between 1992 and 2004 (the Regional Haze indicator, p. 2-33), consistent with a corresponding decrease in fine particle concentrations.

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

Air Toxics and Other Air Pollutants

Between 1990 and 2002, nationwide emissions aggregated across 188 air toxics (hazardous air pollutants) decreased (the Air Toxics Emissions indicator, p. 2-48). Decreased emissions were also observed for two air toxics of particular interest: benzene and mercury (the Mercury Emissions indicator, p. 2-46). However, sufficiently complete and consistent monitoring data currently cannot support ROE indicators for ambient concentration of air toxics, with two exceptions. First, ambient air concentrations of benzene at 23 monitoring sites across the nation decreased 55 percent between 1994 and 2006—a decrease reasonably consistent with corresponding emissions reductions. Second, ambient air concentrations of manganese compounds measured at 21 monitoring sites in EPA Region 5 decreased by 28 percent between 2000 and 2006, though the period of record evaluated may be too short to consider this decrease an actual air quality trend.

Stratospheric Ozone Issues

Since 1990, the U.S. phased out most production and import of ozone-depleting substances. Consequently, consumption of ozone-depleting substances in the U.S. decreased during this last decade, along with globally representative ambient air concentrations of ozone-depleting substances in the lower atmosphere (the Concentrations of Ozone-Depleting Substances indicator, p. 2-52). While such decreases are expected to help restore the stratospheric ozone layer, stratospheric ozone levels over North America actually decreased slightly since the 1980s, though have remained largely unchanged in the last decade (the Ozone Levels over North America indicator, p. 2-54). This trend is due to various factors, including ongoing use of ozone-depleting substances worldwide and the fact that ozone-depleting substances are extremely long-lived in the atmosphere.

Limitations, Gaps, and Challenges[8]

The 23 ROE indicators in this section characterize trends for numerous important outdoor air quality issues, but also have notable limitations. All emissions indicators, for instance, are partly based on estimates. Although these estimates have inherent uncertainties, the emissions inventory data are believed to be of high quality and are periodically updated to remain consistent with the current scientific understanding of emissions from different source categories. The main limitation of the ambient concentration indicators is the monitoring sites' limited spatial coverage. These indicators are composites of air quality measurements taken across the country, but primarily in populated areas: they may not totally reflect trends for rural settings. While the national trends for criteria pollutants and benzene are toward improved air quality,

[6] This statement is based on the current particulate matter standards and on the 1997 8-hour ozone standard (0.08 ppm). Future versions of the ROE will be based upon the recently promulgated 2008 ozone standard (0.075 ppm) or on the NAAQS in effect at the time.

[7] U.S. Environmental Protection Agency. 2004. The ozone report: Measuring progress through 2003. EPA/454/K-04/001. Research Triangle Park, NC.

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

ambient concentrations of these pollutants can vary greatly on a local scale. In certain areas, such as those experiencing rapid population growth or near newly constructed point sources, ambient air concentrations of selected pollutants may be increasing, contrary to the national trends; conversely, ambient air concentration in other parts of the country are decreasing more rapidly than the national trends depict.

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

ROE indicators for ambient concentrations of some common air toxics are expected to be developed in coming years, based on measurements currently being collected in multiple networks. The National Air Toxics Trends Stations, for instance, are a recently implemented network of monitoring sites specifically designed to characterize long-term trends in several air toxics believed to account for the greatest health risks nationwide.[9] Additionally, data being collected as part of a nationwide $PM_{2.5}$ speciation network are expected to provide long-term trend information on concentrations of metals, ions, and carbon constituents of fine particulate matter.[10] Finally, ongoing operation of the Mercury Deposition Network (part of the National Atmospheric Deposition Program) is gathering data to support trends analysis on atmospheric deposition of mercury—an issue of particular significance when evaluating contamination levels in fish and shellfish.

National-level exposure and effects indicators can help EPA better characterize nationwide trends in outdoor air quality and their effects, but key challenges complicate efforts to develop these. For example, ambient concentration data do not quantify exposures, because ambient air monitoring equipment measures air quality at fixed outdoor locations, while people breathe air in multiple indoor and outdoor settings during a typical day. Actual human exposure to air pollution can be measured through use of personal monitoring devices, which sample the air that people breathe as they move through different microenvironments. Some researchers have used such devices to quantify exposures to specific pollutants in some locations.[11] However, conducting such studies on a national scale over an extended time frame would be an extremely resource-intensive task. Consequently, no nationally representative studies currently support ROE indicators that characterize exposure to outdoor air pollutants. Another gap pertaining to effects attributed to outdoor air quality is that the scientific understanding of how all air pollutants, whether acting alone or in combination, can affect human health and the environment is incomplete and continues to evolve.

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

2.3 What Are the Trends in Greenhouse Gas Emissions and Concentrations?

2.3.1 Introduction

Greenhouse gases, such as carbon dioxide, methane, nitrous oxide, and certain synthetic chemicals, trap some of the Earth's outgoing energy, thus retaining heat in the atmosphere.[12] Changes in the radiative balance of the Earth—the balance between energy received from the sun and emitted from Earth—as a result of this heat trapping alter weather patterns and climates at global and regional scales.[13] Natural factors, such as variations in the sun's output, volcanic activity, the Earth's orbit, the carbon cycle, and others, also affect the radiative balance.[14] However, increasing concentrations of greenhouse gases due to human activity are affecting various aspects of climate, such as surface air temperature and subsurface ocean temperature. Since 1750, the net global effect of human activities has been one of warming.[15] Human health, agriculture, water resources, forests, wildlife, and coastal areas all are vulnerable to climate change.[16] The purpose of this

[9] U.S. Environmental Protection Agency. 2004. National monitoring strategy: Air toxics component. Final draft. July. <http://www.epa.gov/ttnamti1/files/ambient/airtox/atstrat804.pdf>

[10] U.S. Environmental Protection Agency. 1999. Strategic plan: Development of the particulate matter ($PM_{2.5}$) quality system for the chemical speciation monitoring trend sites. April 16, 1999.

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

[12] National Research Council. 2005. Radiative forcing of climate change: Expanding the concept and addressing uncertainties. pp. 1, 9, vii, and others.

[13] Ibid., p. 11.

[14] Ibid., p. 13.

[15] Intergovermental Panel on Climate Change. 2007. Climate change 2007: The physical science basis (fourth assessment report), 2007. p. 3.

[16] National Research Council. 2005. Radiative forcing of climate change: Expanding the concept and addressing uncertainties. pp. 4, 19-20.

section is to evaluate long-term trends in air emissions and ambient concentrations of greenhouse gases that are contributing to climate change, but not to evaluate the effects that these emissions and concentrations cause.[17]

Though the focus of this question is on greenhouse gases, related factors can also alter the Earth's climate. Certain radiatively important substances, like black carbon (soot), are technically not greenhouse gases due to their physical state, but they nonetheless affect the flow of energy through the atmosphere. Some of these substances, such as sulfate aerosols, have negative radiative forcings that can lead to cooling effects. Another related factor is albedo (the reflectivity of the Earth's surface), which affects the portions of absorbed and outgoing energy. Natural and human factors can affect albedo on a global scale (through changes in large-scale features like the polar ice caps) or on a local or regional scale (e.g., by increased amounts of dark paved surfaces that absorb energy). Although this question does not address radiatively important substances that are not greenhouse gases or non-chemical factors like albedo, these influences are also important to understanding the planet's energy balance and the ways human activities may affect that balance.[18] Quantitative information on the relative radiative forcings from greenhouse gases, other radiatively important substances, and selected non-chemical factors is available in other publications.[19]

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

- **Carbon dioxide,** widely reported as the most important anthropogenic greenhouse gas.[20] Carbon dioxide occurs naturally as part of the global carbon cycle, but human activities have increased atmospheric loadings through combustion of fossil fuels and other emissions sources.[21] Natural sinks that remove carbon dioxide from the atmosphere (e.g., oceans, plants) help regulate carbon dioxide concentrations, but human activities can disturb these processes (e.g., deforestation) or enhance them.
- **Methane,** which comes from many sources, including human activities such as coal mining, natural gas distribution, waste decomposition in landfills, and digestive processes in livestock and agriculture.[22] Natural sources include wetlands and termite mounds.
- **Nitrous oxide,** which is emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.
- **Various synthetic chemicals,** such as hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and other synthetic gases, which are released as a result of commercial, industrial, or household uses.
- **Many other gases** that are known to trap heat in the atmosphere. Examples include water vapor, which occurs naturally as part of the global water cycle, and ozone, which occurs naturally in the stratosphere and is found in the troposphere largely due to human activities.

Each gas has a different ability to absorb heat in the atmosphere, due to differences in its atmospheric half-life and the amount and type of energy that it absorbs. For example, it would take thousands of molecules of carbon dioxide to equal the warming effect of a single molecule of sulfur hexafluoride—the most potent greenhouse gas, in terms of ability to absorb heat, evaluated by the Intergovernmental Panel on Climate Change.[23] To facilitate comparisons between gases that have substantially different properties, the Panel has developed a set of scaling factors called "global warming potentials," as discussed further in the indicator write-ups.

The remainder of this section focuses on greenhouse gas emissions and concentrations, given that greenhouse gases can affect radiative forcings, thus leading to climate change. However, climate change can also affect atmospheric concentrations of many substances through various feedback mechanisms. Other publications provide detailed information on the broader issues of how climate change can affect air quality.[24]

2.3.2 ROE Indicators

To characterize trends in greenhouse gases, this chapter presents two indicators—one describing emissions from U.S. sources and the other describing concentrations (Table 2-3).

The U.S. Greenhouse Gas Emissions indicator covers the 1990–2005 period, with data from EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks. This inventory is a database that tracks both greenhouse gas emissions directly attributable to human activities and greenhouse gas sinks (e.g., sequestration of carbon in forests). The indicator stratifies emissions into trends for different gases and source categories.

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

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

[19] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: the scientific basis (fourth assessment report). Cambridge, United Kingdom: Cambridge University Press. p. 4.

[20] Ibid., p. 2.

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

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

[23] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: The scientific basis (fourth assessment report). Cambridge, UK: Cambridge University Press.

[24] Intergovermental Panel on Climate Change. 2007. Climate change 2007: Impacts, adaptation, and vulnerability (fourth assessment report). Cambridge, UK: Cambridge University Press.

Emissions are weighted by "global warming potentials" to facilitate comparison among the gases.

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

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

Table 2-3. ROE Indicators of Trends in Greenhouse Gas Emissions and Concentrations

National Indicators	Section	Page
U.S. Greenhouse Gas Emissions	2.3.2	2-64
Atmospheric Concentrations of Greenhouse Gases	2.3.2	2-66

INDICATOR | U.S. Greenhouse Gas Emissions

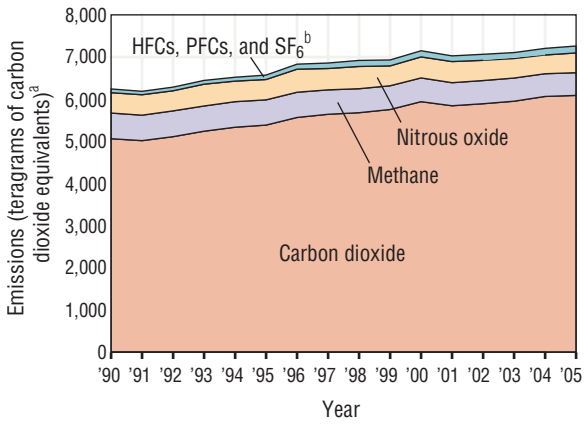
The Earth's climate is determined by the balance between energy received from the sun and energy emitted back to space from the Earth and its atmosphere. Certain gases in the atmosphere, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor, and others, trap some of the outgoing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

Changes in GHG emissions are influenced by many long-term factors, including population and economic growth, land use, energy prices, technological changes, and interannual temperatures. On an annual basis, combustion of fossil fuels, which accounts for most GHG emissions in the U.S., generally fluctuates in response to changes in general economic conditions, energy prices, weather, and the availability of non-fossil alternatives (U.S. EPA, 2007).

This indicator uses data and analysis from the Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA, 2007), an assessment of the anthropogenic sources and sinks of GHG emissions for the U.S. and its territories for the 1990–2005 period. The inventory constitutes estimates derived from direct measurements, aggregated national statistics, and validated models in most source categories. An extensive discussion of the methods for each source type and gas and the uncertainties inherent in the calculations is available in EPA (2007) and its Annex 7.

The indicator is expressed in terms of CO_2 equivalents, meaning that emissions of different gases are weighted by their "global warming potential" (GWP). A GWP is a measure of how much a given mass of GHG is estimated to contribute to radiative forcing that contributes to global warming over a selected period of time, compared to the same mass of CO_2, for which the GWP is 1.0. EPA is mandated to use the GWPs documented in the Intergovernmental Panel on Climate Change's Second Assessment Report (IPCC, 1996), which characterize GWP for a

Exhibit 2-50. Greenhouse gas emissions in the U.S. by gas, 1990-2005



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

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

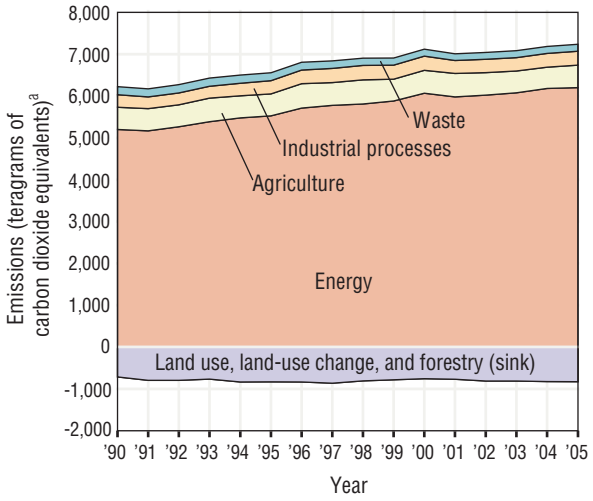
Data source: *U.S. EPA, 2007*

100-year time horizon—the effect of the gas on radiative forcing over 100 years. Annex 6 of the U.S. GHG inventory includes extensive information on GWPs and how they relate to emissions estimates (U.S. EPA, 2007).

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

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

Exhibit 2-51. Greenhouse gas emissions in the U.S. by industrial sector, 1990-2005



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

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

What the Data Show

In 2005, total U.S. greenhouse gas emissions were 7,260 Tg CO_2 Eq, up 16 percent from 1990 (Exhibit 2-50). CO_2 is the primary greenhouse gas emitted by human activities, representing approximately 84 percent of greenhouse gas emissions in 2005. From 1990 to 2005, total emissions of CO_2 increased by 1,028 Tg CO_2 Eq (20 percent). CH_4 represents the second largest U.S. GHG emission, accounting for 7 percent of net emissions in 2005. CH_4 emissions declined about 11 percent from 1990 to 2005, due largely to reduced emissions from landfills and coal mining operations. The primary sources of CH_4 emissions include decomposition of wastes in landfills, coal mine seepage, natural gas systems, and enteric fermentation in domestic livestock. N_2O constituted about 6 percent of net U.S. GHG emissions in 2005; these emissions declined by about 3 percent from 1990 to 2005. The main anthropogenic activities producing N_2O are agricultural soil management, fuel combustion in motor vehicles, manure management, nitric acid production, human sewage, and stationary fuel combustion. Emissions of HFCs, PFCs, and SF_6 accounted for the remaining GHG emissions in 2005, and the aggregate weighted emissions of this group of gases rose by 74 Tg CO_2 Eq since 1990, nearly doubling during that time frame. Despite being emitted in smaller quantities than the other principal greenhouse gases, HFCs, PFCs, and SF_6 are important because many of them have extremely high global warming potentials and, in the cases of PFCs and SF_6, atmospheric lifetimes of 700 to 50,000 years. The emissions in this indicator are a continuation of the trend of increasing GHG emissions observed over many decades, with total CO_2-equivalent emissions increasing by about one fifth since 1970 (U.S. EPA, 2007; RIVM/TNO, 2003). CO_2 has constituted a slightly growing portion, while CH_4 has been a declining component of the total.

Looking at GHG emissions by source shows that energy-related activities (e.g., fuel combustion, gas leakage) accounted for 85 percent of total U.S. emissions in 2005 (Exhibit 2-51). Emissions due to energy use have increased 19 percent between 1990 and 2005. Agriculture is the second largest source of GHG emissions, accounting for 7 percent of the total in 2005. Industrial processes and waste account for the remaining GHG emissions depicted in Exhibit 2-51. This indicator does not depict trends in GHG emissions from the use of solvents and other products or non-CO_2 GHG emissions from land use change and forestry, because GHG emissions from these source categories account for less than 0.5 percent of the total estimated emissions in EPA's GHG inventory.

U.S. GHG emissions are partly offset by uptake of carbon and "sequestration" in forests, trees in urban areas, agricultural soils, and landfilled yard trimmings and food scraps. In aggregate, these removals of CO_2 from the atmosphere offset about 14 percent of total U.S. CO_2 emissions in 2005 (Exhibit 2-51).

INDICATOR | U.S. Greenhouse Gas Emissions *(continued)*

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

Indicator Limitations

- This indicator does not yet include emissions of GHGs or other radiatively important substances that are not explicitly covered by the United Nations Framework Convention on Climate Change and its subsidiary protocol. Thus, it excludes such gases as those controlled by the Montreal Protocol and its Amendments, including CFCs and hydrochlorofluorocarbons. Although the U.S. reports the emissions of these substances as part of the U.S. GHG inventory (see Annex 6.2 of the U.S. GHG inventory), the origin of the estimates is fundamentally different from those of the other GHG and therefore cannot be compared directly with the other emissions discussed in this indicator.
- This indicator does not include aerosols and other emissions that do affect radiative forcing and that are not well-mixed in the atmosphere, such as sulfate, ammonia, black carbon, and organic carbon. Emissions of these compounds are highly uncertain and have qualitatively different effects than the six types of emissions in this indicator.
- This indicator does not include emissions of other compounds—such as CO, NO_x, nonmethane volatile organic compounds, and substances that deplete the stratospheric ozone layer—which indirectly affect the Earth's radiative balance (for example, by altering GHG concentrations, changing the reflectivity of clouds, or changing the distribution of heat fluxes).
- The U.S. GHG inventory does not account for "natural" emissions of GHGs, such as from wetlands, tundra soils, termites, and volcanoes. These excluded sources are discussed in Annex 5 of the U.S. GHG inventory (U.S. EPA, 2007). The U.S. GHG inventory does include, in its "Land Use, Land-Use Change, and Forestry" category, emissions from changes in the forest inventory due to fires, harvesting, and other activities, and from agricultural soils.

Data Sources

The data used for this indicator were published in EPA's inventory of greenhouse gas emissions and sinks for years 1990–2005 (U.S. EPA, 2007). Specifically, emissions by GHG shown in Exhibit 2-50 are taken from Table ES-2 of that reference, and emissions by industrial sector are taken from Table ES-4.

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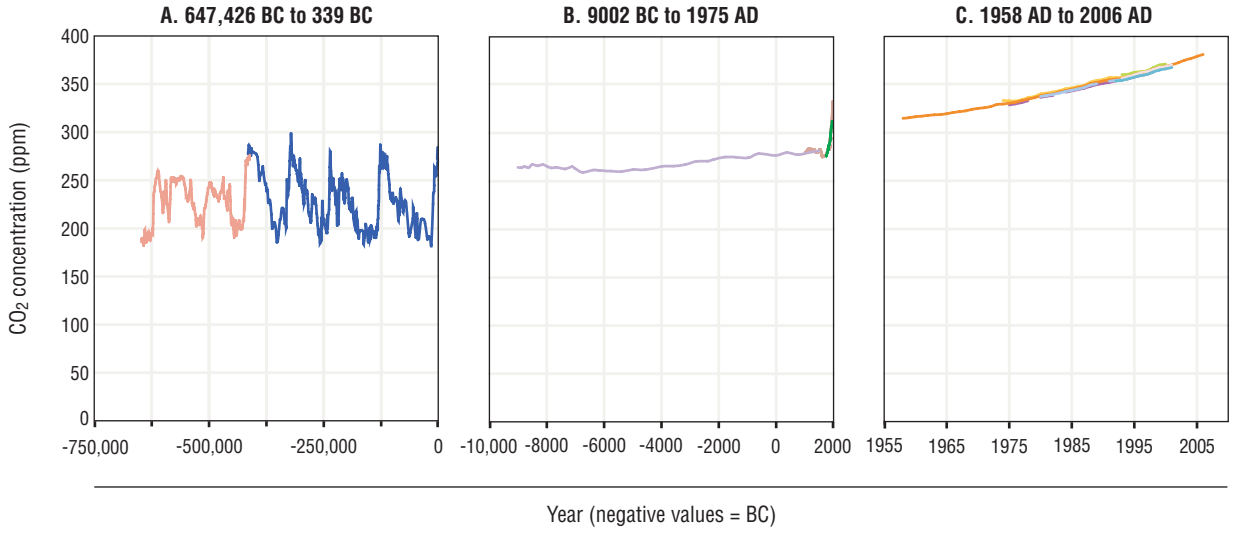
INDICATOR | Atmospheric Concentrations of Greenhouse Gases

The Earth's temperature depends mainly on the amount of energy received from the sun, the portion reflected back into space, and the extent to which the atmosphere retains heat. Natural forces (e.g., volcanoes, changes in the Earth's orbit) and human activities (e.g., emissions of so-called "greenhouse gases," land use change) affect the amount of energy held in the Earth-atmosphere system and therefore affect the Earth's climate. Human activities in all countries have altered the chemical composition of the atmosphere by the emissions and accumulation in the atmosphere of

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



Trend lines and data sources:

647,426 BC to 339 BC

- EPICA Dome C, Antarctica *(Siegenthaler et al., 2005)*
- Vostok Station, Antarctica *(Barnola et al., 2003)*

9002 BC to 1978 AD

- Law Dome, East Antarctica 75-year smoothed *(Etheridge et al., 1998)*
- Siple Station, West Antarctica *(Neftel et al., 1994)*
- EPICA Dome C, Antarctica *(Flückiger et al., 2002)*

1958 AD to 2006 AD

- Barrow, Alaska *(Thoning and Tans, 2000)*
- Cape Matatula, American Samoa *(Thoning and Tans, 2000)*
- South Pole, Antarctica *(Thoning and Tans, 2000)*
- Mauna Loa, Hawaii *(NOAA-ESRL, 2007a)*
- Lampedusa Island, Italy *(Chamard et al., 2001)*
- Shetland Islands, Scotland *(Steele et al., 2002)*
- Cape Grim, Australia *(Steele et al., 2002)*

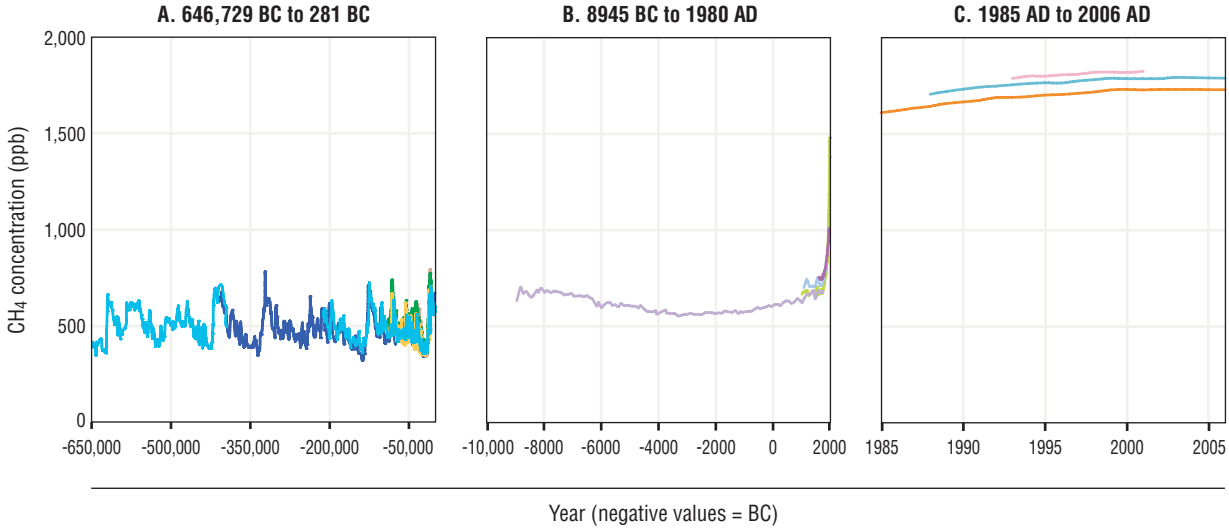
greenhouse gases. The primary gases that retain heat in the atmosphere are water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and certain manufactured gases such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and sulfur hexafluoride (SF_6).

Once emitted, gases remain in the atmosphere for varying amounts of time. Very "short-lived" compounds, such as particulate matter (PM), remain airborne on average for only hours or days. CH_4 also has a relatively short average lifetime, though much longer than PM, remaining in the atmosphere for roughly 12 years. The half-life of CO_2 emissions is roughly 100 years (5 to 200 years: IPCC, 2001), but about a quarter of emissions today will still be in the atmosphere after hundreds of years and about one-tenth for hundreds of thousands of years (Archer and Ganopolski, 2005; Archer et al., 1998). Finally, many of the synthetic gases such as halocarbons are extremely long-lived, remaining in the atmospheric for hundreds or even tens of thousands of years. When emissions—from the U.S. (the U.S. Greenhouse Gas Emissions indicator, p. 2-64) as well as other countries—remain in the atmosphere over long periods, they accumulate and are measured as atmospheric concentrations. U.S. GHG emissions from 1890 to 2000 are estimated to have contributed about one-fifth of the increase in global GHG concentrations (den Elzen et al., 2005).

This indicator shows trends in the accumulation of the following principal GHGs in the atmosphere: CO_2, CH_4, N_2O, and selected halocarbons. Recent data are from global networks that monitor the concentrations of these gases in the atmosphere. Geological data come from gas measurements made of air trapped in ice cores at the time the ice was formed. Because the gases shown in this indicator remain in the atmosphere for long periods, they are well-mixed, so that measurements at individual locations are globally representative. This indicator summarizes GHG concentration measurements reported in a collection of studies published in the peer-reviewed literature. In order to provide the most extensive temporal coverage,

INDICATOR | Atmospheric Concentrations of Greenhouse Gases *(continued)*

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



Trend lines and data sources:

646,729 BC to 281 BC

- Vostok Antarctica ice core *(Petit et al., 1999)*
- Greenland GRIP ice core *(Blunier and Brook, 2001)*
- Greenland GISP2 ice core *(Blunier and Brook, 2001)*
- Antarctica Byrd Station ice core *(Blunier and Brook, 2001)*
- EPICA Dome C, Antarctica *(Spahni et al., 2005)*

8945 BC to 1980 AD

- Law Dome, Antarctica *(Etheridge et al., 2002)*
- Various Greenland locations *(Etheridge et al., 2002)*
- Greenland Site J *(WDCGG, 2005)*
- EPICA Dome C, Antarctica *(Flückiger et al., 2002)*

1985 AD to 2006 AD

- Cape Grim, Australia *(NOAA-ESRL, 2007b)*
- Shetland Islands, Scotland *(Steele et al., 2002)*
- Mauna Loa, Hawaii *(NOAA-ESRL, 2007c)*

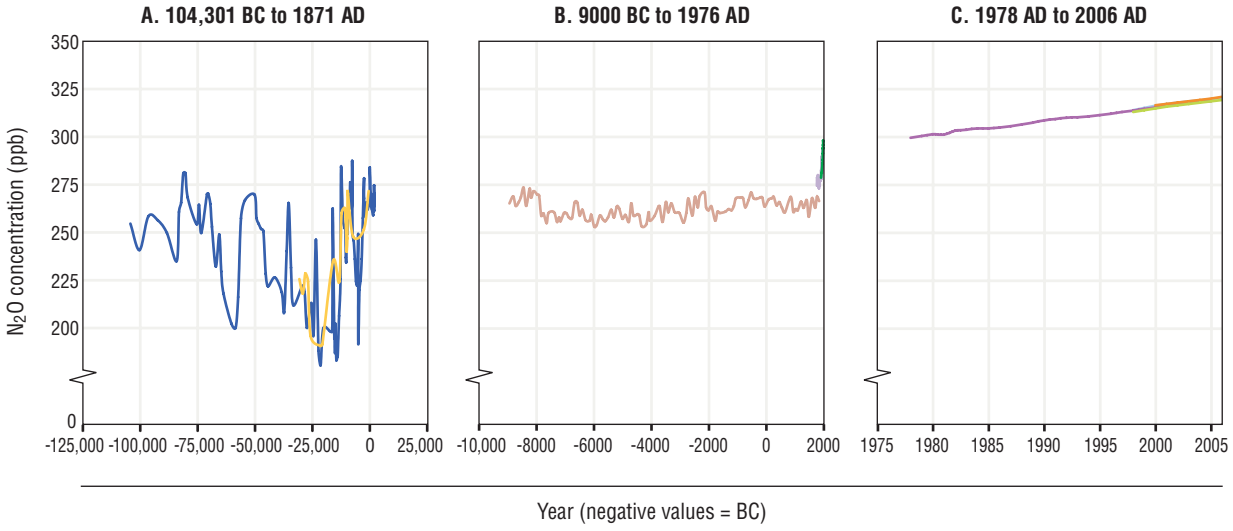
this indicator aggregates comparable, high-quality data from individual studies that each focused on different time frames. None of the data in this indicator are based on modeled concentrations.

What the Data Show

Exhibits 2-52 through 2-54 show the evolution of concentrations of three principal GHGs in the atmosphere over three intervals: geological time (hundreds of thousands of years), the past 11,000 years, and recent decades. The exhibits represent data sets covering a wide range of latitudes, showing some latitudinal differences in concentrations but also showing a high level of consistency—indicating that the gases are well-mixed and that the sampling can be considered spatially representative. The graphs show patterns of large cycles of concentrations over geological time, and they also depict increases in concentrations in the industrial era (post-1780) that exceed concentrations over the past hundreds of thousands of years.

The concentration of CO_2, the most important anthropogenic GHG, has varied considerably over geological time (Exhibit 2-52). Over the past 650,000 years, CO_2 concentrations have generally cycled over several-thousand-year periods from highs around 285-300 parts per million (ppm) to lows around 180-185 ppm. From at least 900 A.D. to 1800 A.D., CO_2 concentrations stayed relatively constant at about 270-290 ppm (panel B). Over the past 150 years, CO_2 concentrations increased steadily from approximately 270-290 ppm in pre-industrial times to 382 ppm in 2006, a 36 percent increase (panels B and C). Almost all of this increase is due to human activities (IPCC, 2007), and the concentrations measured currently are the highest observed over the entire period of record.

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



Trend lines and data sources:

104,301 BC to 1871 AD

- Greenland GISP2 ice core *(Sowers et al., 2003)*
- Taylor Dome, Antarctica *(Sowers et al., 2003)*

9000 BC to 1976 AD

- EPICA Dome C, Antarctica *(Flückiger et al., 2002)*
- Antarctica *(Machida et al., 1995)*
- Antarctica *(Battle et al., 1996)*

1978 AD to 2006 AD

- Barrow, Alaska *(NOAA-ESRL, 2007d)*
- Cape Grim, Australia *(AGAGE, 2007)*
- Mauna Loa, Hawaii *(NOAA-ESRL, 2007d)*
- South Pole, USA station *(NOAA-ESRL, 2007d)*

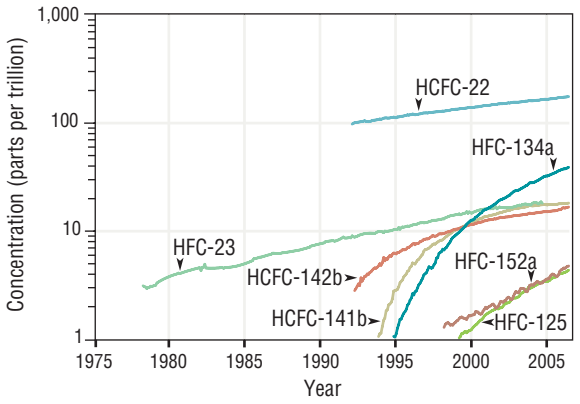
CH_4 concentrations also cycled widely over the past 650,000 years, but peaks remained below 800 parts per billion (ppb) until after 1800 A.D. (Exhibit 2-53). Concentrations slightly increased between 1000 A.D. and 1730 A.D. (panel B). It then took approximately 175 years (c. 1905) to add 200 ppb to atmospheric CH_4 concentrations, approximately 40 years (c. 1945) to add the next 200 ppb, approximately 20 years (c. 1965) to add the next 200 ppb, and approximately 10 years (c. 1975) to add the next 200 ppb (panel B). In 2006, CH_4 concentrations at the two stations considered were 1,727 ppb and 1,788 ppb (panel C), and these current levels far exceed the natural range surmised from the ice core samples. The rates of CH_4 concentration increase began to slow by the late 1970s, with approximately 300 ppb added to atmospheric concentrations between 1978 and 2006 (panels B and C). Overall, global CH_4 concentrations have more than doubled in the past 150 years. The most recent data show a significant difference in CH_4 concentrations across latitudes—a pattern of peak concentrations in the most northern latitudes decreasing toward the southern latitudes, suggesting net sources of CH_4 in northern latitudes. Yet, despite the latitudinal differences in concentrations, the pattern over the past two centuries shows a common trend in all locations.

N_2O concentrations (Exhibit 2-54) vacillated widely through geological time, with ice sample measurements ranging from as low as 180 ppb to above 280 ppb. Despite considerable inter-decadal variability, N_2O stayed mostly below 280 ppb from 1756 A.D. until the 1920s (panel B), from which point levels began to rise rapidly to approximately 320 ppb in 2006 (panels B and C), the highest level recorded over the more than 100,000 years of data available.

Concentrations of the halocarbons (or gases that contain the halogens chlorine, fluorine, bromine, or iodine) were essentially zero a few decades ago, but have increased rapidly as they were incorporated into industrial products and processes (Exhibit 2-55). Concentrations of hydrochlorofluorocarbons HCFC-141b and HCFC-142b increased through 2006, but

INDICATOR | Atmospheric Concentrations of Greenhouse Gases *(continued)*

Exhibit 2-55. Global atmospheric concentrations of selected halocarbons, 1978-2006[a]



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

Data source: *IPCC, 2007*

are expected to gradually stabilize over this decade as they are phased out in industrialized countries as part of the Montreal Protocol on Substances That Deplete the Ozone Layer. The concentration of HFC-23, which is a byproduct of HCFC-22 production, has increased more than five-fold between 1978 and 2006. Halocarbons that are not controlled by the Montreal Protocol (because they do not contribute to stratospheric ozone losses) mostly continued to increase because of their widespread use as substitutes for the Montreal Protocol gases.

Indicator Limitations

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

Data Sources

The data in this indicator come from multiple sources. Summary global atmospheric concentration data for CO_2 (Exhibit 2-52), CH_4 (Exhibit 2-53), and N_2O (Exhibit 2-54) were provided by EPA's Office of Atmospheric Programs, based on GHG concentration measurements reported in a collection of studies published in the peer-reviewed literature. References for the underlying data are included in the corresponding exhibits, and some data sets are also available in electronic format at http://www.epa.gov/climatechange/science/recentac.html.

Summary global atmospheric concentration data for selected halocarbons (Exhibit 2-55) are a subset of the data depicted in IPCC's Fourth Assessment Report (IPCC, 2007).

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2.3.3 Discussion

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

For several greenhouse gases, the nation's estimated combined emissions that are directly attributable to human activity have increased 16 percent between 1990 and 2005 (the U.S. Greenhouse Gas Emissions indicator, p. 2-64). Emissions sources occur in several sectors of the U.S. economy, with the highest contribution—and the greatest recent growth—attributed to energy use, primarily electricity generation and transportation. As well as detailing the increase, the U.S. Greenhouse Gas Emissions indicator compares contributions of different greenhouse gases by normalizing for each gas's ability to affect the Earth's energy balance. The results show that carbon dioxide (CO_2) makes up the bulk of the nation's anthropogenic greenhouse gas emissions. Both observations demonstrate that fossil fuel combustion is clearly the country's major source of anthropogenic greenhouse gas emissions.

Data on atmospheric concentrations of greenhouse gases have extraordinary temporal coverage (the Greenhouse Gas Concentrations indicator, p. 2-66). For CO_2, methane (CH_4), and nitrous oxide (N_2O), concentration data span several hundred thousand years; and for selected halocarbons, concentration data span virtually the entire period during which these synthetic gases were widely used. Thus, these concentration data provide an excellent basis for answering the question regarding trends in greenhouse gas concentrations. The historical data for CO_2, CH_4, and N_2O show considerable temporal variability in these gases' concentrations; however, concentrations observed in the past 50 years are higher than those over the entire period of record evaluated—even when considering natural fluctuations. In short, the historical context provided by ice cores shows that present concentrations of these three greenhouse gases are unprecedented over the last 650,000 years, and demonstrate that the recently increasing levels reflect the influence of human activity. For the various halocarbons considered, concentrations have increased between 1980 and 2006, with some increases spanning more than two orders of magnitude, but the rate at which these concentrations is increasing has slowed in recent years.

Taken together, the well-documented long-term trends in concentrations of greenhouse gases, along with corresponding increases in emissions from anthropogenic sources, show that human activity is causing increased concentrations of greenhouse gases in the Earth's atmosphere—a finding echoed in many prominent reviews on the science of climate change.[25,26]

Limitations, Gaps, and Challenges

Although they provide extensive insights into greenhouse gas emissions and concentrations, the two greenhouse gas indicators have limitations and gaps that should be acknowledged. The emissions trends, for instance, are based largely on estimates, which have uncertainties inherent in the engineering calculations and estimation methodologies developed for the U.S. greenhouse gas emissions inventory. Uncertainty of the magnitude of the emissions varies among the gases and sources, though estimated emissions from some of the largest sources (e.g., CO_2 emissions from fossil fuel combustion) are considered highly accurate.[27] One gap in the emissions indicator is that EPA's greenhouse gas inventory does not track every greenhouse gas or every emissions source. Examples of greenhouse gases not included in the inventory are ozone and selected chlorofluorocarbons. The most notable sources not tracked in the inventory are natural sources, such as CH_4 from wetlands, CO_2 and CH_4 from thawing permafrost, and multiple emissions from volcanoes. Though this is not necessarily a limitation or a gap, it is important to note that EPA's greenhouse gas inventory, by design, tracks only this nation's anthropogenic emissions of greenhouse gases.[28] For perspective on how the nation's emissions compare to those from other countries, recent data estimate that the U.S. emits approximately 20 percent of the total worldwide amounts of selected greenhouse gases. Having national emissions indicators on a more complete set of greenhouse gases and emissions sources would further improve EPA's ability to track pressures that affect climate change.

The Greenhouse Gas Concentrations indicator (p. 2-66) tracks trends in measured airborne levels of greenhouse gases regardless of the anthropogenic or natural sources that released them, which helps account for some of the inherent limitations and uncertainties in the emissions indicator. However, the concentration data have limitations and gaps of their own. Historical concentrations from ice core samples are not measured in real time, which introduces some minor uncertainty into the data set; consistency among measurements made by multiple laboratories at different locations suggests this uncertainty is relatively low.[29] While the concentration data thoroughly characterize trends for CO_2 (the most important anthropogenic greenhouse gas) and other extensively studied gases, a gap in the concentration data, as with the emissions data, is that not all greenhouse gases have been monitored. Long-term trend data for ozone, for instance, are currently not available. Measuring globally representative trends in tropospheric ozone concentrations presents technical challenges, because ozone is a short-lived gas (which does not lend well to ice core measurements) with concentrations that exhibit tremendous spatial variations (which would require extensive monitoring to characterize worldwide

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

[26] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: The scientific basis (fourth assessment report). Cambridge, UK: Cambridge University Press.

[27] U.S. Environmental Protection Agency. 2007. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2005. EPA/430/R-07/002. Washington, DC.

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

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

trends). Another gap is the lack of ROE indicators for radiatively important substances, such as soot and aerosols. Though these substances technically are not greenhouse gases, tracking trends in these substances' concentrations is important due to their ability to alter the Earth's energy balance.

2.4 What Are the Trends in Indoor Air Quality and Their Effects on Human Health?

2.4.1 Introduction

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

The potential impact of indoor air quality on human health nationally is considerable, for several reasons. Americans, on average, spend approximately 90 percent of their time indoors,[30] where the concentrations of some pollutants are often 2 to 5 times higher than typical outdoor concentrations.[31] Moreover, people who are often most susceptible to the adverse effects of pollution (e.g., the very young, older adults, people with cardiovascular or respiratory disease) tend to spend even more time indoors.[32] Health effects that have been associated with indoor air pollutants include irritation of the eyes, nose, and throat; headaches, dizziness, and fatigue; respiratory diseases; heart disease; and cancer.

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

- **Indoor sources (sources within buildings themselves).** Combustion sources in indoor settings, including tobacco, heating and cooking appliances, and fireplaces, can release harmful combustion byproducts such as carbon monoxide and particulate matter directly into the indoor environment. Cleaning supplies, paints, insecticides, and other commonly used products introduce many different chemicals, including volatile organic compounds, directly into the indoor air. Building materials are also potential sources, whether through degrading materials (e.g., asbestos fibers released from building insulation) or from new materials (e.g., chemical off-gassing from pressed wood products). Other substances in indoor air are of natural origin, such as mold and pet dander.
- **Outdoor sources.** Outdoor air pollutants can enter buildings through open doors, open windows, ventilation systems, and cracks in structures. Some pollutants come indoors through building foundations. For instance, radon forms in the ground as naturally occurring uranium in rocks and soils decays. The radon can then enter buildings through cracks or gaps in structures. In areas with contaminated ground water or soils, volatile chemicals can enter buildings through this same process. Volatile chemicals in water supplies can also enter indoor air when building occupants use the water (e.g., during showering, cooking). Finally, when people enter buildings, they can inadvertently bring in soils and dusts on their shoes and clothing from the outdoors, along with pollutants that adhere to those particles.

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

The link between some common indoor air pollutants and health effects is very well established. Radon is a known human carcinogen and is the second leading cause of lung cancer.[33,34] Carbon monoxide is toxic, and short-term exposure to elevated carbon monoxide levels in indoor settings can be lethal.[35] Episodes of Legionnaires' disease, a form of pneumonia caused by exposure to the *Legionella* bacterium, have been associated with buildings with poorly maintained air conditioning or heating systems.[36,37] In addition, numerous

[30] U.S. Environmental Protection Agency. 1989. Report to Congress on indoor air quality: Volume 2. EPA/400/1-89/001C. Washington, DC.

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

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

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

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

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

indoor air pollutants—dust mites, mold, pet dander, environmental tobacco smoke, cockroach allergens, and others—are "asthma triggers," meaning that some asthmatics might experience asthma attacks following exposure.[38]

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

Researchers also have been investigating the relationship between indoor air quality and important issues not necessarily related to health, such as student performance in the classroom and productivity in occupational settings.[39] Another evolving area is research in "green building" design, construction, operation, and maintenance that achieves energy efficiency and enhances indoor air quality.

2.4.2 ROE Indicators

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

Table 2-4. ROE Indicators of Trends in Indoor Air Quality and Their Effects on Human Health

National Indicators	Section	Page
U.S. Homes Above EPA's Radon Action Level	2.4.2	2-74
Blood Cotinine Level	2.4.2	2-76

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

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

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

This indicator presents (1) the number of U.S. homes estimated to be at or above the EPA recommended radon action level of 4 pCi/L and (2) the number of homes with an operating radon mitigation system. The gap between the homes in these two categories is the number of homes that have not yet been mitigated (generally, homes are only mitigated if the EPA recommended radon action level of 4 pCi/L or more is measured). The data for this indicator were extracted from the National Residential Radon Survey (U.S. EPA, 1992a), which estimated radon levels in the U.S. housing stock. The number of homes at or above 4 pCi/L was estimated by applying the results of the Radon Survey (U.S. EPA, 1992a) to 2000 U.S. Census data on the number of U.S. households. The 1992 National Residential Radon Survey was based on the housing stock that would be covered by EPA's radon testing policy (i.e., homes that should test). This included only homes

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

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

[38] Institute of Medicine. 2000. Clearing the air: Asthma and indoor air exposures. Washington, DC: National Academy Press.

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

intended for regular (year-round) use but covers single-family homes, mobile homes, and multi-unit and group quarters (U.S. EPA, 1992b). The 1992 residential survey estimated that about one in 15 homes in EPA's "should test" category would have a radon level of 4 pCi/L or more. The measure of the number of homes with operating mitigation systems was developed from radon vent fan sales data provided voluntarily by fan manufacturers.

What the Data Show

There was a 308 percent increase in the number of homes with operating mitigation systems from 1990 to 2006, going from 175,000 to 714,000 homes over 17 years; but during the same period, there has been a 22 percent increase in the estimated number of homes with radon levels at or above 4 pCi/L, from about 6.4 million to 7.8 million homes (Exhibit 2-56, panel A). Panel B of Exhibit 2-56 shows radon potential in homes at the county level based on indoor radon measurements, geology, aerial radioactivity, soil permeability, and foundation type. Zone 1 is the highest radon potential area, followed by Zone 2 (medium), and Zone 3 (low).

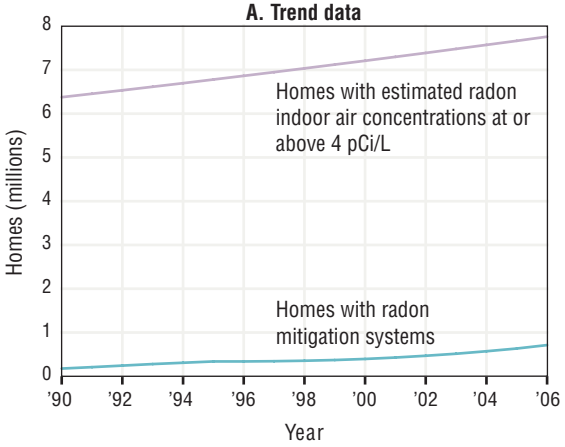
It has been reported anecdotally that radon vent fans and mitigation systems are also being used to control for soil gases and vapor intrusion in homes in the vicinity of Superfund sites, underground or aboveground storage tank sites, and similar sites as an element of corrective action plans. While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

Indicator Limitations

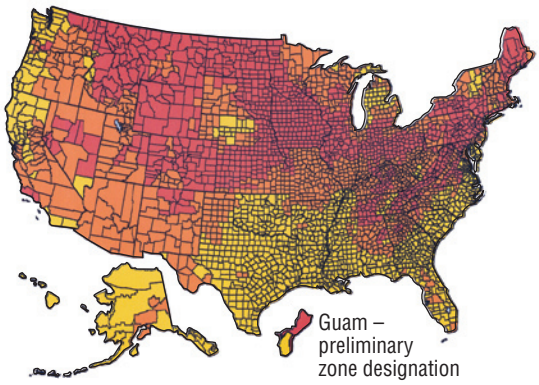
- The indicator presumes that radon vent fans are used for their intended purpose; the available information supports this premise. Even if fans are used for managing vapor intrusion, a radon risk reduction benefit still occurs.
- A home with an operating mitigation system is presumed to have a vent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

Exhibit 2-56. Homes at or above EPA's radon action level and homes with operating mitigation systems in the U.S., 1990-2006

A. Trend data



B. EPA map of radon zones



Zone 1: Counties with predicted average indoor radon screening levels greater than 4 pCi/L

Zone 2: Counties with predicted average indoor radon screening levels from 2 to 4 pCi/L

Zone 3: Counties with predicted average indoor radon screening levels less than 2 pCi/L

Data source: *U.S. EPA, 1992a, 2007*

Data Sources

Summary data in this indicator were provided by EPA's Office of Radiation and Indoor Air, based on two types of information. The number of homes with estimated indoor air concentrations at or above EPA's radon action level was originally derived from the National Residential Radon Survey (U.S. EPA, 1992a) and is updated with U.S. Census

INDICATOR | U.S. Homes Above EPA's Radon Action Level *(continued)*

data; and the number of homes with radon mitigation systems was developed from unpublished sales data provided by radon vent fan manufacturers (U.S. EPA, 2007).

References

U.S. EPA, 2007. Unpublished sales data provided by radon vent manufacturers.

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

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

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

INDICATOR | Blood Cotinine Level

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

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

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

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

What the Data Show

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

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

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

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

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

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

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

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

Data source: *CDC, 2005*

non-Hispanic blacks had the highest cotinine levels; and (3) on average, people below age 20 have higher levels of blood cotinine than people age 20 years and older.

Exhibit 2-58 shows the percentage of children between the ages of 4 and 17 with specified blood cotinine levels, for the total age group and by selected race and ethnicity breakdowns within the specified age group. Among the three subgroup populations presented, Mexican American children had the lowest percentage of blood cotinine levels greater than 1.0 ng/mL; this was evident for both 1988-1994 and 1999-2002 time periods (10.7 percent and 5.2 percent, respectively), which changed little for the 2001-2004 time frame (4.8 percent, data not shown). Black, non-Hispanic children had the largest decline of the three subgroups in the percentage of blood cotinine levels greater than 1.0 ng/mL, but that population also started off with the highest percentage above 1.0 ng/mL (36.6 percent) (Federal Interagency Forum on Child and Family Statistics, 2005, 2007).

Indicator Limitations

- Because the data from NHANES 1999-2000 and 2001-2002 represent only two survey periods, changes in estimates between the two time periods do not

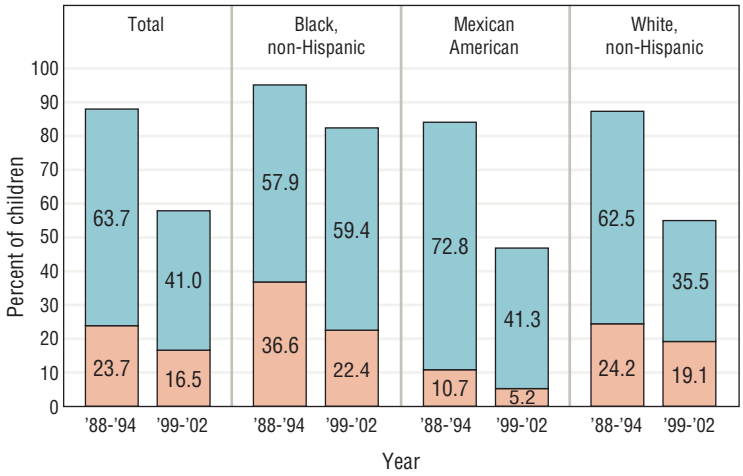
INDICATOR | Blood Cotinine Level *(continued)*

necessarily reflect a trend. Earlier data sets are available (e.g., NHANES III), but the data are not directly comparable to NHANES 1999-2002. As CDC releases additional survey results (e.g., 2003-2004), it will become possible to more fully evaluate trends (CDC, 2002, 2004).

Data Sources

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

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



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

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

Concentration:[b]
- 0.05 to 1.0 ng/mL
- More than 1.0 ng/mL

Data source: *Federal Interagency Forum on Child and Family Statistics, 2005*

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CDC. 2002. NHANES 1999-2000 addendum to the NHANES III analytic guidelines. Last update August 30, 2002. Accessed October 11, 2005. <http://www.cdc.gov/nchs/data/nhanes/guidelines1.pdf>

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IARC (International Agency for Research on Cancer). 2004. IARC working group on the evaluation of carcinogenic risks to humans. Evaluation of carcinogenic risks to humans, volume 83: Tobacco smoke and involuntary smoking. Lyon, France.

NTP (National Toxicology Program) 2002. Report on carcinogens, 10th edition.

Pirkle, J.L., K.M. Flegal, J.T. Bernert, D.J. Brody, R.A. Etzel, K.R. Maurer. 1996. Exposure of the U.S. population to environmental tobacco smoke: The third national health and nutrition examination survey, 1988 to 1991. J. Amer. Med. Assoc. 275:1233-1240.

U.S. DHHS (United States Department of Health and Human Services). 2000. Healthy people 2010. Second edition. Washington, DC: U.S. Government Printing Office <http://www.healthypeople.gov/Document/HTML/Volume2/27Tobacco.htm#_Toc489766224>

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2.4.3 Discussion

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

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

The Homes Above EPA's Radon Action Level indicator (p. 2-74) tracks two statistics: the number of homes estimated to be at or above EPA's action level (4 pCi/L) for radon, and the number of homes with operating radon mitigation systems. Evaluating trends in radon mitigation systems is relevant because properly operated systems are expected to reduce radon to levels below the action level, and therefore also are expected to reduce radon-related health risks among building occupants. Between 1990 and 2006, the number of homes with radon mitigation systems increased more than four-fold, but these homes account for less than 10 percent of the nation's homes currently believed to have radon levels at or above EPA's action level. Some residents are being protected against radon exposures through radon-resistant new construction techniques used when a home is built. Estimates of radon-resistant new construction practices are not included in the indicator, however, because while they substantially reduce radon levels in homes with high radon potential, they do not always reduce the levels below the action level.

The Blood Cotinine indicator (p. 2-76) tracks blood concentrations of cotinine, a metabolite of nicotine, and shows that exposure to environmental tobacco smoke among non-smokers decreased considerably in the last decade. This decrease was observed for all population groups, defined by age (including children), sex, and ethnicity. However, children's blood cotinine levels, on average, are still more than twice the levels observed in adults. A logical explanation for the downward trend in blood cotinine levels is modified behavior, whether reduced smoking prevalence or more widespread restriction of areas in which individuals are allowed to smoke.

Taken together, these indicators show that an increasing number of Americans have reduced indoor air exposures to two known carcinogens. Though these improvements are encouraging, both radon and environmental tobacco smoke remain important indoor air quality issues. In the case of radon, for example, the increase in the number of homes estimated to be at or above the EPA's radon action level is outpacing the increase in the use of radon mitigation systems.

Limitations, Gaps, and Challenges

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

The Blood Cotinine indicator also has certain limitations. For example, exposure to environmental tobacco smoke does not occur exclusively indoors: some proportion of blood cotinine levels measured in non-smokers reflects exposures that occurred outdoors. In addition, nationally representative blood cotinine data are not available for children under 3 years old—an age group with documented susceptibilities to environmental tobacco smoke.[40] Nonetheless, none of these limitations call into question this indicator's main finding: nationwide, exposures to environmental tobacco smoke among non-smokers are decreasing. Moreover, reliable survey data on smoking behavior corroborates this downward trend.[41]

The two indoor air quality indicators provide useful insights into trends for radon and environmental tobacco smoke, but they leave some gaps that EPA would like to fill to better answer the overarching question on nationwide indoor air quality trends and associated health effects. For example, ROE indicators could not be developed for indoor air quality trends for molds, some combustion products, chemicals found in common household cleaners and building materials, and certain persistent pollutants and endocrine disruptors that have been identified in household dust.[42,43] There is no quantitative, nationally representative inventory of emissions sources in indoor environments, nor is there a nationwide monitoring network that routinely measures air quality inside homes, schools, and office buildings. These gaps in nationwide indicators do not mean that nothing is known about the broad range of indoor air quality issues and associated health effects. Rather, information on these issues can be gleaned from numerous publications by governmental agencies and in the scientific literature. Data from these other publications and information resources, though valuable in understanding indoor air quality, are not presented in this report as indicators because they are not sufficiently representative on a national scale or because they do not track an issue over time.

The challenges associated with filling these indicator gaps are well known. Although methods to monitor indoor air

[40] U.S. Environmental Protection Agency. 1992. Respiratory health effects of passive smoking: Lung cancer and other disorders. EPA/600/6-90/006F. Washington, DC.

[41] U.S. Department of Health and Human Services. 2000. Healthy people 2010: Understanding and improving health. Second edition. Washington, DC: U.S. Government Printing Office. November. <http://www.health.gov/healthypeople/>

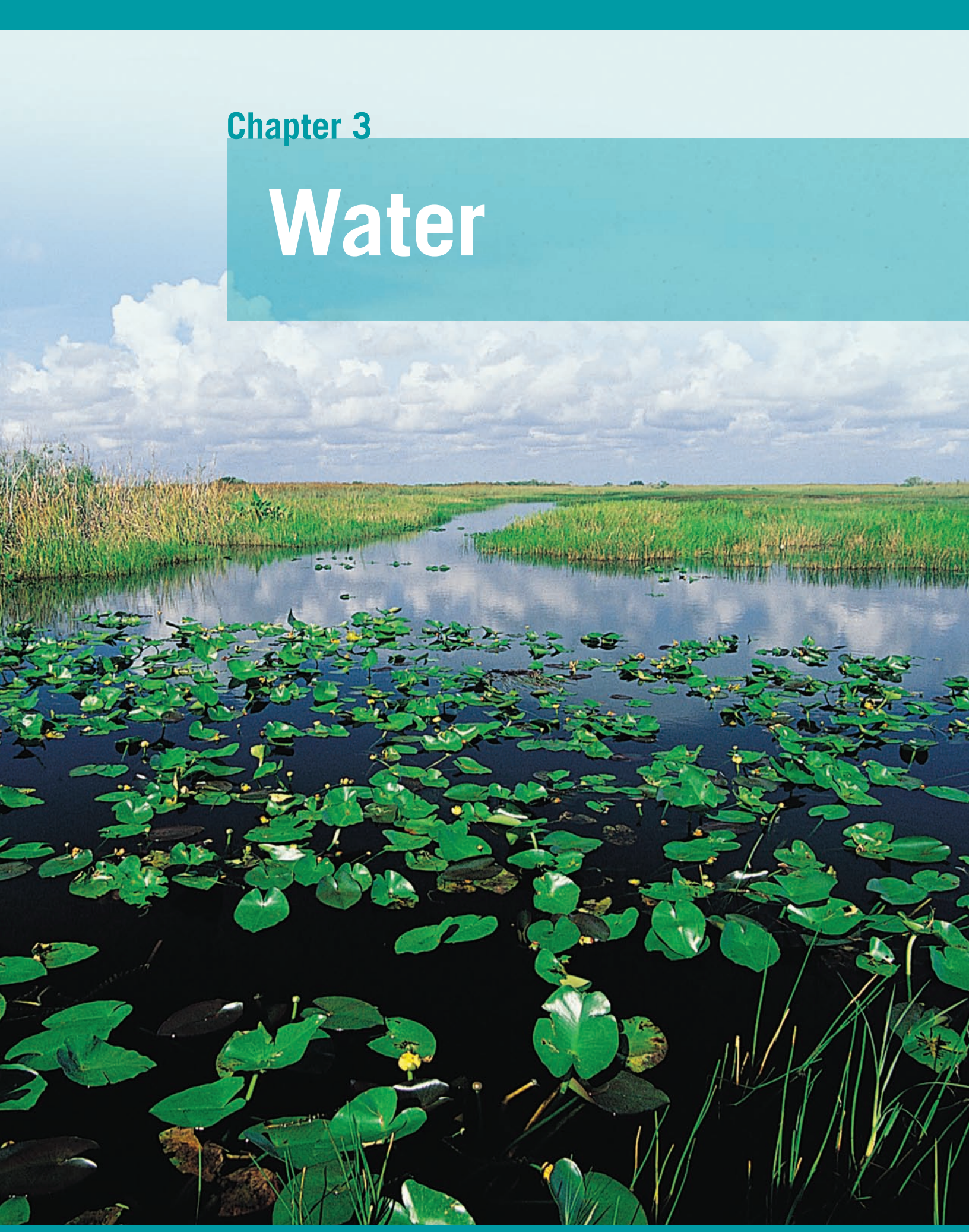
[42] Rudel, R.A., D.E. Camann, J.D. Spengler, L.R. Korn, and J.G. Brody. 2003. Phthalates, alkylphenols, pesticides, polybrominated diphenyl ethers, and other endocrine-disrupting compounds in indoor air and dust. Env. Sci. Tech. 37(20):4543-4553.

[43] Stapleton, H.M., N.G. Dodder, J.H. Offenberg, M.M. Schantz, and S.A. Wise. 2005. Polybrominated diphenyl ethers in house dust and clothes dryer lint. Env. Sci. Tech. 39(4):925-931.

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

Chapter 3

Water



Contents

3.1 Introduction

The nation's water resources have immeasurable value. These resources encompass lakes, streams, ground water, coastal waters, wetlands, and other waters; their associated ecosystems; and the human uses they support (e.g., drinking water, recreation, and fish consumption). The *extent* of water resources (their amount and distribution) and their *condition* (physical, chemical, and biological attributes) are critical to ecosystems, human uses, and the overall function and sustainability of the hydrologic cycle.

Because the extent and condition of water can affect human health, ecosystems, and critical environmental processes, protecting water resources is integral to EPA's mission. EPA works in partnership with other government agencies that are also interested in the extent and condition of water resources, both at the federal level and at the state, local, or tribal level.

In this chapter, EPA seeks to assess national trends in the extent and condition of water, stressors that influence water, and associated exposures and effects among humans and ecological systems. The ROE indicators in this chapter address seven fundamental questions about the state of the nation's waters:

- **What are the trends in the extent and condition of fresh surface waters and their effects on human health and the environment?** This question focuses on the nation's rivers, streams, lakes, ponds, and reservoirs.
- **What are the trends in the extent and condition of ground water and their effects on human health and the environment?** This question addresses subsurface water that occurs beneath the water table in fully saturated soils and geological formations.
- **What are the trends in the extent and condition of wetlands and their effects on human health and the environment?** Wetlands—including swamps, bogs, marshes, and similar areas—are areas inundated or saturated by surface or ground water often and long enough to support a prevalence of vegetation typically adapted for life in saturated soil conditions.
- **What are the trends in the extent and condition of coastal waters and their effects on human health and the environment?** Indicators in this report present data for waters that are generally within 3 miles of the coastline (except the Hypoxia in Gulf of Mexico and Long Island Sound indicator).
- **What are the trends in the quality of drinking water and their effects on human health?** People drink tap water, which comes from both public and private sources, and bottled water. Sources of drinking water can include both surface water (rivers, lakes, and reservoirs) and ground water.
- **What are the trends in the condition of recreational waters and their effects on human health and the environment?** This question addresses water used for a wide variety of purposes, such as swimming, fishing, and boating.
- **What are the trends in the condition of consumable fish and shellfish and their effects on human health?** This question focuses on the suitability of fish and shellfish for human consumption.

EPA's 2008 Report on the Environment (ROE): Essentials

ROE Approach

This 2008 Report on the Environment:

- Asks questions that EPA considers important to its mission to protect human health and the environment.
- Answers these questions, to the extent possible, with available indicators.
- Discusses critical indicator gaps, limitations, and challenges that prevent the questions from being fully answered.

ROE Questions

The air, water, and land chapters (Chapters 2, 3, and 4) ask questions about trends in the condition and/or extent of the environmental medium; trends in stressors to the medium; and resulting trends in the effects of the contaminants in that medium on human exposure, human health, and the condition of ecological systems.

The human exposure and health and ecological condition chapters (Chapters 5 and 6) ask questions about trends in aspects of health and the environment that are influenced by many stressors acting through multiple media and by factors outside EPA's mission.

ROE Indicators

An indicator is derived from actual measurements of a pressure, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain. This excludes indicators such as administrative, socioeconomic, and efficiency indicators.

Indicators based on one-time studies are included only if they were designed to serve as baselines for future trend monitoring.

All ROE indicators passed an independent peer review against six criteria to ensure that they are useful; objective; transparent; and based on data that are high-quality, comparable, and representative across space and time.

Most ROE indicators are reported at the national level. Some national indicators also report trends by region. EPA Regions were used, where possible, for consistency and because they play an important role in how EPA implements its environmental protection efforts.

Several other ROE indicators describe trends in particular regions as examples of how regional indicators might be included in future versions of the ROE. They are not intended to be representative of trends in other regions or the entire nation.

EPA will periodically update and revise the ROE indicators and add new indicators as supporting data become available. In the future, indicators will include information about the statistical confidence of status and trends. Updates will be posted electronically at http://www.epa.gov/roe.

Additional Information

You can find additional information about the indicators, including the underlying data, metadata, references, and peer review, at http://www.epa.gov/roe.

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

Each of the seven questions is addressed in a separate section of this chapter. However, all the questions are fundamentally connected—a fact that is highlighted throughout the chapter text and indicator summaries. All water is part of the global hydrologic cycle, and thus it is constantly in motion—whether it is a swiftly flowing stream or a slow-moving aquifer thousands of years old. A stream may empty into a larger river that ultimately discharges into coastal waters. An aquifer may be recharged by surface waters, or feed surface waters or wetlands through springs and seeps. In each case, the extent and condition of one water resource can affect the extent and condition of another type. One example of this interdependence can be found in the movement of nutrients. Together, several of the ROE indicators track nutrient levels in water bodies ranging from small wadeable streams to coastal estuaries. Additional ROE indicators describe some of the effects that may be associated with excess nutrients, such as eutrophication and hypoxia.

In addition to the links within the water cycle, there are many connections between the extent and condition of water and other components of the environment. Air (addressed in Chapter 2), land (Chapter 4), and water all are environmental media, and the condition of one medium can influence the condition of another. For example, contaminants can be transferred from air to water via deposition, or from land to water through runoff or leaching.

Chapter 5, "Human Exposure and Health," and Chapter 6, "Ecological Condition," examine the relationships between human life, ecosystems, and some of the environmental conditions that can affect them. Humans and ecosystems depend on water, so stressors that affect the extent and condition of water—such as droughts, pathogens, and contaminants—may ultimately affect human health or ecological condition.

3.1.1 Overview of the Data

The indicators in this chapter reflect several different methods of collecting and analyzing data on the extent and condition of water resources; in some cases, indicators employ a combination of methods. Some of the indicators in this chapter are based on probabilistic surveys, with sample or monitoring locations chosen to be representative of a large area (e.g., an EPA Region or the nation as a whole). Examples of probabilistic surveys include EPA's Wadeable Streams Survey and National Coastal Assessment, and the U.S. Fish and Wildlife Service's Wetlands Status and Trends Survey. Other indicators reflect targeted sampling or monitoring—for example, collecting water samples in an area prone to hypoxia in order to ascertain the extent and duration of a particular hypoxic event. In some cases, data are based on regulatory reporting, which may in turn reflect probabilistic or targeted sampling. For example, the ROE indicator on drinking water is based on review of monitoring conducted by water systems, with results reported by the states to EPA, as required by federal law.

One of the challenges in assessing the extent and condition of water resources is that a single data collection method is rarely perfect for every combination of spatial and temporal domains. In general, there is an inherent tradeoff in representing trends in water resources. For example, a probabilistic survey may provide an accurate representation of national trends, but the resolution may be too low to definitively characterize the resource at a smaller scale. In some cases, results can be disaggregated to the scale of EPA Regions or ecoregions without losing precision. However, these indicators are generally not designed to inform the reader about the condition of his or her local water bodies, for example, or the quality of locally harvested fish.

Likewise, it is often convenient to compare trends in terms of annual averages—particularly where it is not practical to collect data every day of the year. However, averaging and periodic sampling can obscure or overlook extreme events, such as spikes in water contaminants after a pesticide application or a large storm. Thus, representative extent or condition data cannot depict the full range of variations and extremes—some of which may be critical to ecosystems or to humans—that occur in smaller areas or on smaller time scales.

This chapter presents only data that meet the ROE indicator definition and criteria (see Box 1-1, p. 1-3). Note that non-scientific indicators, such as administrative and economic indicators, are not included in this definition. Thorough documentation of the indicator data sources and metadata can be found online at http://www.epa.gov/roe. All indicators were peer-reviewed during an independent peer review process (again, see http://www.epa.gov/roe for more information). Readers should not infer that the indicators in this chapter reflect the complete state of knowledge. Many other data sources, publications, and site-specific research projects have contributed substantially to the current understanding of status and trends in water, but are not included in this report because they do not meet the ROE indicator criteria.

3.1.2 Organization of This Chapter

The remainder of this chapter is organized into seven sections corresponding to the seven questions that EPA seeks to answer about trends in water. Each section introduces a question and discusses its importance, presents the ROE indicators used to help answer the question, and discusses what the indicators, taken together, say about the question. The ROE indicators include National Indicators as well as several Regional Indicators that meet the ROE definition and criteria and help to answer a question at a smaller geographic scale. Each section concludes by highlighting the major challenges to answering the question and identifying important information gaps.

Table 3-1 lists the indicators used to answer the seven questions in this chapter and shows the locations where the indicators are presented.

Table 3-1. Water—ROE Questions and Indicators

Question	Indicator Name	Section	Page
What are the trends in the extent and condition of fresh surface waters and their effects on human health and the environment?	High and Low Stream Flows (N)	3.2.2	3-8
	Streambed Stability in Wadeable Streams (N)	3.2.2	3-11
	Lake and Stream Acidity (N)	2.2.2	2-42
	Nitrogen and Phosphorus in Wadeable Streams (N)	3.2.2	3-13
	Nitrogen and Phosphorus in Streams in Agricultural Watersheds (N)	3.2.2	3-15
	Nitrogen and Phosphorus Loads in Large Rivers (N)	3.2.2	3-17
	Pesticides in Streams in Agricultural Watersheds (N)	3.2.2	3-19
	Benthic Macroinvertebrates in Wadeable Streams (N)	3.2.2	3-21
What are the trends in the extent and condition of ground water and their effects on human health and the environment?	Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds (N)	3.3.2	3-27
What are the trends in the extent and condition of wetlands and their effects on human health and the environment?	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-32
What are the trends in the extent and condition of coastal waters and their effects on human health and the environment?	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-32
	Trophic State of Coastal Waters (N/R)	3.5.2	3-38
	Coastal Sediment Quality (N/R)	3.5.2	3-42
	Coastal Benthic Communities (N/R)	3.5.2	3-44
	Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
	Submerged Aquatic Vegetation in the Chesapeake Bay (R)	3.5.2	3-46
	Hypoxia in the Gulf of Mexico and Long Island Sound (R)	3.5.2	3-48
What are the trends in the quality of drinking water and their effects on human health?	Population Served by Community Water Systems with No Reported Violations of Health-Based Standards (N/R)	3.6.2	3-54
What are the trends in the condition of recreational waters and their effects on human health and the environment?	No ROE indicators		
What are the trends in the condition of consumable fish and shellfish and their effects on human health?	Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
	Contaminants in Lake Fish Tissue (N)	3.8.2	3-63

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

3.2 What Are the Trends in the Extent and Condition of Fresh Surface Waters and Their Effects on Human Health and the Environment?

3.2.1 Introduction

Though lakes, ponds, rivers, and streams hold less than one thousandth of a percent of the water on the planet, they serve many critical functions for the environment and for human life. These fresh surface waters sustain ecological systems and provide habitat for many plant and animal species. They also support a myriad of human uses, including drinking water, irrigation, wastewater treatment, livestock, industrial uses, hydropower, and recreation. Fresh surface waters also influence the extent and condition of other water resources, including ground water, wetlands, and coastal systems downstream.

The *extent* of fresh surface waters reflects the influence and interaction of many stressors. It can be affected by direct withdrawal for drinking, irrigation, industrial processes, and other human use, as well as by the withdrawal of ground water, which replenishes many surface waters. Hydromodifications such as dam construction can create new impoundments and fundamentally alter stream flow. Land cover can affect drainage patterns (e.g., impervious pavement may encourage runoff or flooding). Weather patterns—e.g., the amount of precipitation, the timing of precipitation and snowmelt, and the conditions that determine evaporation rates—also affect the extent of fresh surface waters. Changing climate could also affect the extent of fresh surface water that is available.

The *condition* of fresh surface waters reflects a range of characteristics. Physical characteristics include attributes such as temperature and clarity. Chemical characteristics include attributes such as salinity, nutrients, and chemical contaminants (including contaminants in sediments, which can impact water quality and potentially enter the aquatic food web). Biological characteristics include diseases, pathogens, and—in a broader sense—the status of plant and animal populations and the condition of their habitat. In addition to their effects on the environment, many of these characteristics can ultimately affect human health, mainly through drinking water, recreational activities (e.g., health effects in swimmers due to pathogens and harmful algal blooms), or consumption of fish and shellfish. Because these three topics are complex and encompass many types of water bodies, each is addressed in greater detail in its own section of this report (see Sections 3.6, 3.7, and 3.8, respectively).

Like extent, the condition of fresh surface waters can be influenced by a combination of natural and anthropogenic stressors, such as:

- **Point source pollution,** including contaminants discharged directly into water bodies by industrial operations, as well as nutrients and contaminants in sewage. Even treated sewage contains nutrients that affect the chemical composition of the water.
- **Nonpoint source pollution,** which largely reflects contaminants, nutrients, and excess sediment in runoff from urban and suburban areas (e.g., stormwater) and agricultural land. Other sources include recreational activities (e.g., boating and marinas) and acid mine drainage. Nonpoint source pollution can be influenced by land cover (e.g., impervious surfaces that encourage runoff) and land use (e.g., certain forestry techniques and agricultural practices that encourage runoff and erosion). Nonpoint sources tend to be more variable than point sources. For example, pesticide concentrations in streams reflect the location and timing of pesticide application.
- **Air deposition.** Acidic aerosols, heavy metals, and other airborne contaminants may be deposited directly on water or may wash into water bodies after deposition on land. For example, mercury emitted to the air from combustion at power plants can be transported and deposited in lakes and reservoirs.
- **Invasive species.** Invasives are non-indigenous plant and animal species that can harm the environment, human health, or the economy.[1] Invasive species can crowd out native species and alter the physical and chemical condition of water bodies.
- **Natural factors.** Precipitation determines the timing and amount of runoff and erosion, while other aspects of weather and climate influence heating, cooling, and mixing in lakes—which affect the movement of contaminants and the cycling of nutrients. The mineral composition of bedrock and sediment helps determine whether a water body may be susceptible to acidification.

The condition of fresh surface waters also may be influenced by extent. Stream flow patterns influence contaminant and sediment loads, while changes in the shape of water bodies—e.g., eliminating deep pools or creating shallow impoundments—can change water temperature. The extent of surface waters also represents the extent of habitat—a key aspect of biological condition. Some plant and animal communities are sensitive to water level (e.g., riparian communities), while

[1] National Invasive Species Council. 2005. Five year review of Executive Order 13112 on invasive species. Washington, DC: U.S. Department of the Interior.

others may be adapted to particular seasonal fluctuations in flow. Stressors that affect extent may ultimately affect the condition of freshwater habitat—for example, hydromodifications that restrict the migration of certain fish species.

3.2.2 ROE Indicators

Eight ROE indicators characterize either the extent or the condition of fresh surface waters (Table 3-2). One of these indicators presents information about stream flow patterns, an aspect of surface water extent. The other seven indicators characterize various aspects of condition, including the physical condition of sediments, the condition of benthic communities, and the chemical condition of the water itself. Several of these indicators track concentrations of nutrients, which can impact many different types of water bodies if present in excess (e.g., through eutrophication). Supporting data come from several national monitoring programs: EPA's Environmental Monitoring and Assessment Program (EMAP), EPA's Wadeable Streams Assessment, EPA's Temporally Integrated Monitoring of Ecosystems (TIME) and Long-Term Monitoring (LTM) projects, and three programs administered by the U.S. Geological Survey (USGS) (the National Water Quality Assessment [NAWQA] program, the National Stream Quality Accounting Network [NASQAN], and the USGS stream gauge network).

Table 3-2. ROE Indicators of Trends in the Extent and Condition of Fresh Surface Waters and Their Effects on Human Health and the Environment

National Indicators	Section	Page
High and Low Stream Flows	3.2.2	3-8
Streambed Stability in Wadeable Streams	3.2.2	3-11
Lake and Stream Acidity	2.2.2	2-42
Nitrogen and Phosphorus in Wadeable Streams	3.2.2	3-13
Nitrogen and Phosphorus in Streams in Agricultural Watersheds	3.2.2	3-15
Nitrogen and Phosphorus Loads in Large Rivers	3.2.2	3-17
Pesticides in Streams in Agricultural Watersheds	3.2.2	3-19
Benthic Macroinvertebrates in Wadeable Streams	3.2.2	3-21

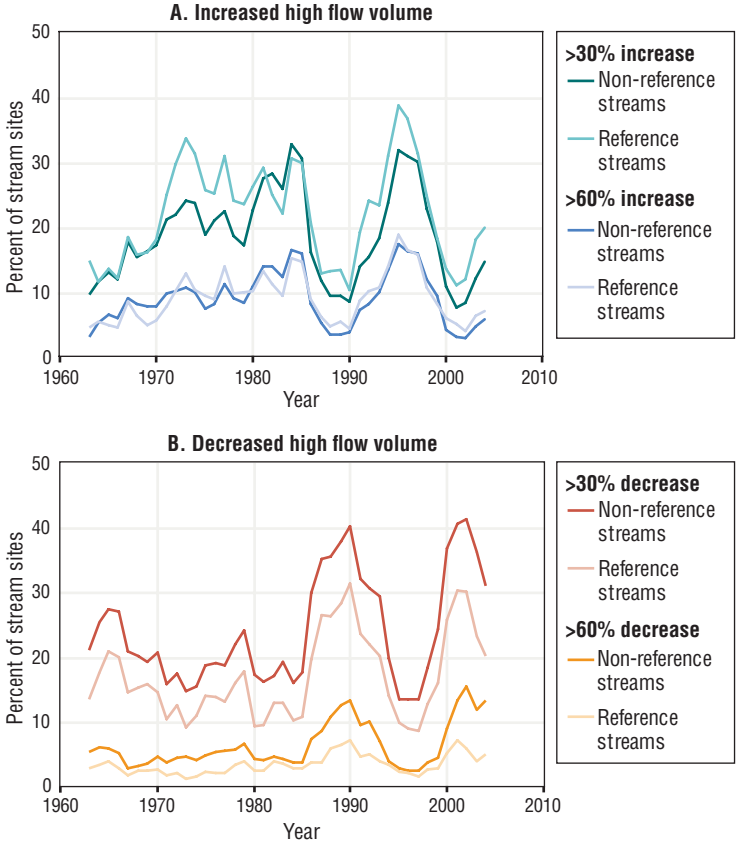
INDICATOR | High and Low Stream Flows

Flow is a critical aspect of the physical structure of stream ecosystems (Poff and Allan, 1995; Robinson et al., 2002). High flows shape the stream channel and clear silt and debris from the stream, and some fish species depend on high flows for spawning. Low flows define the smallest area available to stream biota during the year. In some cases, the lowest flow is no flow at all—particularly in arid and semi-arid regions where intermittent streams are common. Riparian vegetation and aquatic life in intermittent streams have evolved to complete their life histories during periods when water is available; however, extended periods of no flow can still impact their survival (Fisher, 1995). Changes in flow can be caused by dams, water withdrawals, ground water pumping (which can alter base flow), changes in land cover (e.g., deforestation or urbanization), and weather and climate (Calow and Petts, 1992).

This indicator, developed by the Heinz Center (in press), describes trends in stream flow volumes based on daily flow data collected by the U.S. Geological Survey's (USGS's) nationwide network of stream flow gauging sites from 1961 to 2006.

The first part of this indicator describes trends in high flow volume, low flow volume, and variability of flow in streams throughout the contiguous 48 states, relative to a baseline period of 1941-1960. Data were collected at two sets of USGS stream gauging stations: a set of approximately 700 "reference" streams that have not been substantially affected by dams and diversions and have had little change in land use over the measurement period, and a separate set of approximately 1,000 "non-reference" streams that reflect a variety of conditions (the exact number of sites with sufficient data varies from one metric to another). The indicator is based on each site's annual 3-day high flow volume, 7-day low flow volume, and variability (computed as the difference between the 1st and 99th percentile 1-day flow volumes in a given year, divided by the median 1-day flow). Annual values for each metric were examined using a rolling 5-year window to reduce the sensitivity to anomalous events. For each site, the median value for the 5-year window was compared to the median value for the 1941-1960 baseline period. The indicator shows the proportion of sites where high flow, low flow, or variability of flow was more than 30 percent higher or 30 percent lower than the baseline. It also shows differences of more than 60 percent.

Exhibit 3-1. Changes in high flow in rivers and streams of the contiguous U.S., 1961-2006, compared with 1941-1960 baseline[a,b]



[a]**Coverage:** 1,719 stream gauging sites (712 reference, 1,007 non-reference) in the contiguous U.S. with flow data from 1941 to 2006. Reference streams have not been substantially affected by dams and diversions; non-reference streams may or may not have been affected in this way.

[b]Based on the annual 3-day high flow. For each stream site, the median high flow was determined over a rolling 5-year window, then compared against the baseline. Results are plotted at the midpoint of each window. For example, the value for 2002-2006 is plotted at the year 2004.

Data source: *Heinz Center, 2007*

This indicator also examines no-flow periods in streams in grassland and shrubland areas of the contiguous 48 states. Data represent 280 USGS "reference" and "non-reference" stream gauging sites in watersheds with at least 50 percent grass or shrub cover, as defined by the 2001 National Land Cover Database (NLCD) (MRLC Consortium, 2007). The indicator reports the percentage of these streams with at least one no-flow day in a given year, averaged over a rolling 5-year window. Results are displayed for all grassland/shrubland streams, as well as for three specific ecoregion divisions (Bailey, 1995). This indicator also reports on the duration of no-flow periods. For a subset of 163 grassland/

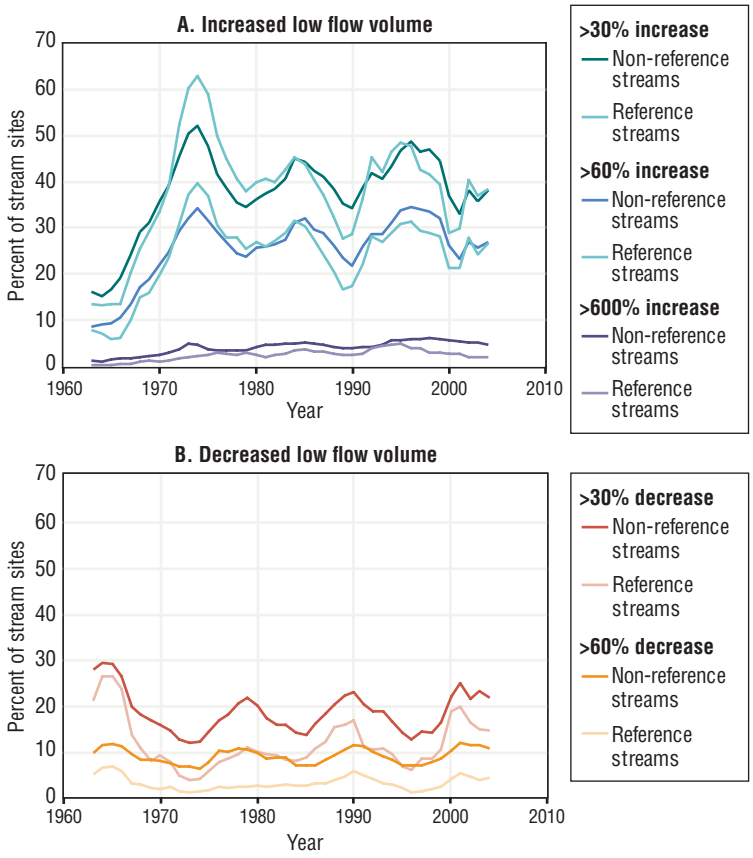
shrubland streams that had at least one no-flow day during the study period, the duration of the maximum no-flow period in each year was averaged over a rolling 5-year window and compared with the average no-flow duration for the same site during the 1941-1960 baseline period. A no-flow period more than 14 days longer than the baseline was described as a "substantial increase"; a no-flow period more than 14 days shorter than the baseline was classified as a "substantial decrease."

What the Data Show

In an average year during the period of record, roughly 20 percent of streams had increases in high flow volume of more than 30 percent, relative to the 1941-1960 baseline (Exhibit 3-1, panel A). A similar percentage had decreases of more than 30 percent (Exhibit 3-1, panel B). Large fluctuations in high flow volume are apparent over time, with both sets of trends suggesting relatively wet periods in the early 1980s and mid-1990s and relatively dry periods around 1990 and the early 2000s. Reference and non-reference stream sites show similar patterns, although larger decreases in high flow volume were more common in the non-reference streams.

Since the early 1960s, more streams have shown increases in low flow volumes than have shown decreases, relative to the 1941-1960 baseline period (Exhibit 3-2). Among the many streams with larger low flows are a few (2 to 4 percent in an average year) with increases of more than 600 percent. Fluctuations over time are apparent, and while not as pronounced as the shifts in high flow (Exhibit 3-1), they generally tend to mirror the same relatively wet and dry periods. Reference and non-reference streams show similar low flow patterns over time, but reference sites are less likely to have experienced decreases in low flow.

Exhibit 3-2. Changes in low flow in rivers and streams of the contiguous U.S., 1961-2006, compared with 1941-1960 baseline[a,b]



[a]**Coverage:** 1,609 stream gauging sites (673 reference, 936 non-reference) in the contiguous U.S. with flow data from 1941 to 2006. Reference streams have not been substantially affected by dams and diversions; non-reference streams may or may not have been affected in this way.

[b]Based on the annual 7-day low flow. For each stream site, the median low flow was determined over a rolling 5-year window, then compared against the baseline. Results are plotted at the midpoint of each window. For example, the value for 2002-2006 is plotted at the year 2004.

Data source: *Heinz Center, 2007*

Except for a few brief periods in the mid-1960s and again around 1980, decreased flow variability has been much more common than increased variability (Exhibit 3-3). Reference and non-reference streams have shown similar patterns in variability over time, although reference streams were slightly less likely to experience changes overall.

In areas with primarily grass or shrub cover, roughly 15 to 20 percent of stream sites typically have experienced periods of no flow in a given year (Exhibit 3-4). Overall, the number of streams experiencing no-flow periods has declined slightly since the 1960s. Streams in the California/Mediterranean ecoregion have shown the greatest decrease in no-flow frequency, but they still experience more no-flow periods than streams in the other two major grassland/shrubland ecoregion divisions. Among grassland/shrubland streams that have experienced at least one period of no flow since 1941, more streams have shown a substantial decrease in the duration of no-flow periods (relative to the 1941-1960 baseline) than a substantial increase (Exhibit 3-5).

Indicator Limitations

- The 1941-1960 baseline period was chosen to maximize the number of available reference sites and should

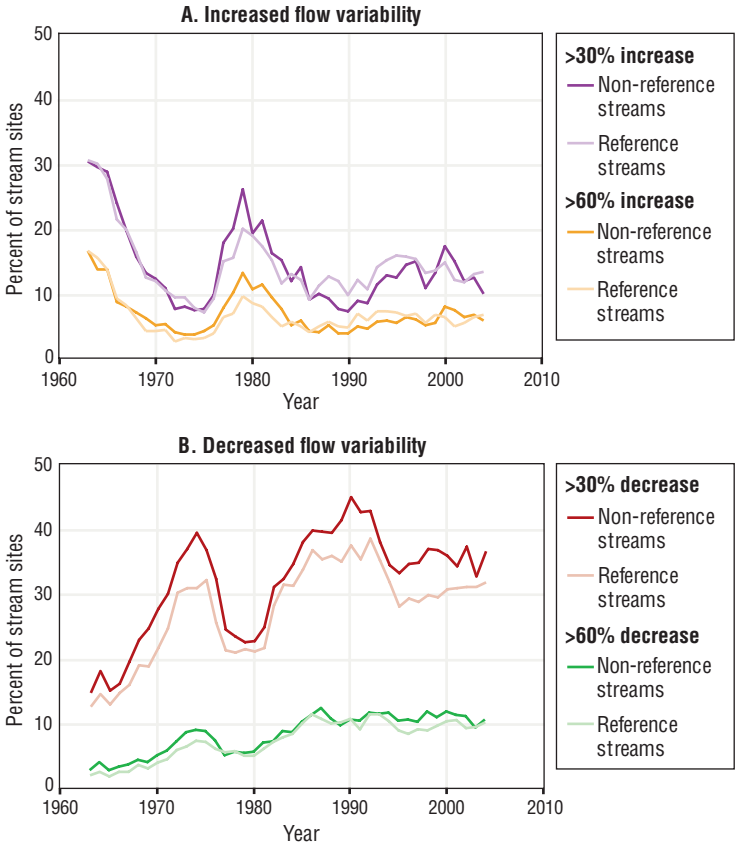
provide a sufficiently long window to account for natural variability (Heinz Center, in press); however, it does not necessarily reflect "undisturbed" conditions. Many dams and waterworks had already been constructed by 1941, and other anthropogenic changes (e.g., urbanization) were already widespread.

- Although the sites analyzed here are spread widely throughout the contiguous U.S., gauge placement by USGS is not a random process. Gauges are generally placed on larger, perennial streams and rivers, and changes seen in these larger systems may differ from those seen in smaller streams and rivers.
- This indicator does not characterize trends in the timing of high and low stream flows, which can affect species migration, reproduction, and other ecological processes.

Data Sources

The data presented in this indicator were provided by the Heinz Center (2007), which conducted this analysis for a forthcoming update to its report, *The State of the Nation's Ecosystems* (Heinz Center, in press). Underlying stream flow measurements can be obtained from the USGS National Water Information System database (USGS, 2007) (http://waterdata.usgs.gov/nwis).

Exhibit 3-3. Changes in flow variability in rivers and streams of the contiguous U.S., 1961-2006, compared with 1941-1960 baseline[a,b]



[a]**Coverage:** 1,754 stream gauging sites (733 reference, 1,021 non-reference) in the contiguous U.S. with flow data from 1941 to 2006. Reference streams have not been substantially affected by dams and diversions; non-reference streams may or may not have been affected in this way.

[b]Based on the annual range of 1-day flows. For each stream site, the median variability was determined over a rolling 5-year window, then compared against the baseline. Results are plotted at the midpoint of each window. For example, the value for 2002-2006 is plotted at the year 2004.

Data source: *Heinz Center, 2007*

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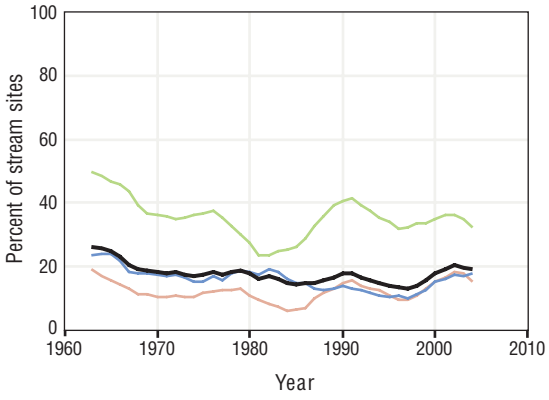
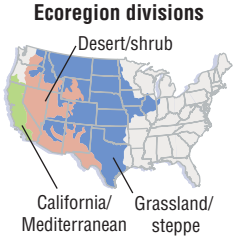
INDICATOR | High and Low Stream Flows *(continued)*

Exhibit 3-4. Percent of grassland/shrubland streams in the contiguous U.S. experiencing periods of no flow, by ecoregion, 1961-2006[a,b]





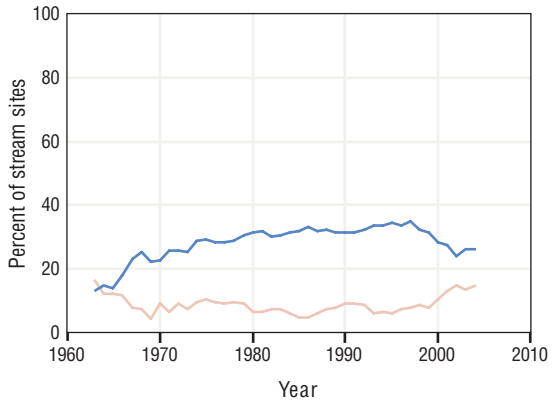
[a]**Coverage:** 280 stream gauging sites in watersheds containing 50 percent or greater grass/shrub cover, with flow data from 1941 to 2006. Grass/shrub cover refers to classes 52 and 71 of the 2001 National Land Cover Database (NLCD).

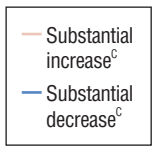
[b]Streams were classified based on annual data, then the percentage of streams in each category was averaged over a rolling 5-year window. Results are plotted at the midpoint of each window. For example, the average for 2002-2006 is plotted at the year 2004.

[c]Ecoregions based on Bailey (1995).

Data source: *Heinz Center, 2007*

Exhibit 3-5. Changes in the maximum duration of no-flow periods in intermittent grassland/shrubland streams of the contiguous U.S., 1961-2006, compared with 1941-1960 baseline[a,b]





[a]**Coverage:** 163 stream gauging sites in watersheds containing 50 percent or greater grass/shrub cover, with flow data from 1941 to 2006 and at least one no-flow day during this period. Grass/shrub cover refers to classes 52 and 71 of the 2001 National Land Cover Database (NLCD).

[b]For each stream site, the duration of the maximum no-flow period in each year was averaged over a rolling 5-year window. Results are plotted at the midpoint of each window. For example, the value for 2002-2006 is plotted at the year 2004.

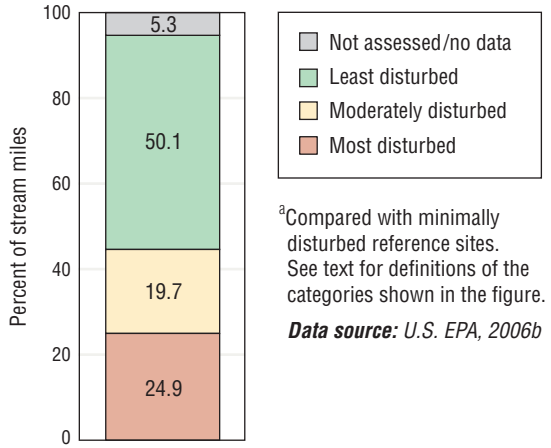
[c]A substantial increase means the no-flow period was more than 14 days longer than the average duration during the 1941-1960 baseline period; a substantial decrease means the no-flow period was more than 14 days shorter.

Data source: *Heinz Center, 2007*

INDICATOR | Streambed Stability in Wadeable Streams

Streams and rivers adjust their channel shapes and particle sizes in response to the supply of water and sediments from their drainage areas, and this in turn can affect streambed stability. Lower-than-expected streambed stability is associated with excess sedimentation, which may result from inputs of fine sediments from erosion—including erosion caused by human activities such as agriculture, road building, construction, and grazing. Unstable streambeds may also be caused by increases in flood magnitude or frequency resulting from hydrologic alterations. Lower-than-expected streambed stability may cause stressful ecological conditions when, for example, excessive amounts of fine, mobile sediments fill in the habitat spaces between stream cobbles and boulders. When coupled with increased stormflows, unstable streambeds may also lead to channel incision and arroyo formation, and can negatively affect benthic invertebrate communities and fish spawning (Kaufmann et al., 1999). The opposite condition—an overly stable streambed—is less common, and generally reflects a lack of small sediment particles. Overly stable streambeds can result from reduced sediment supplies or

Exhibit 3-6. Streambed stability in wadeable streams of the contiguous U.S., 2000-2004[a]



[a]Compared with minimally disturbed reference sites. See text for definitions of the categories shown in the figure.

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

stream flows, or from prolonged conditions of high sediment transport without an increase in sediment supply.

This indicator is based on the Relative Bed Stability (RBS), which is one measure of the interplay between sediment supply and transport. RBS is the ratio of the observed mean streambed particle diameter to the "critical diameter," the largest particle size the stream can move as bedload during storm flows. The critical diameter is calculated from field measurements of the size, slope, and other physical characteristics of the stream channel (Kaufmann et al., 1999). A high RBS score indicates a coarser, more stable bed—i.e., streambed particles are generally much larger than the biggest particle the stream could carry during a storm flow. A low RBS score indicates a relatively unstable streambed, consisting of many fine particles that could be carried away by a storm flow. Expected values of RBS are based on the statistical distribution of values observed at reference sites that are known to be relatively undisturbed. RBS values that are substantially lower than the expected range are considered to be indicators of ecological stress.

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). The WSA is based on a probabilistic design, so the results from representative sample sites can be used to make a statistically valid statement about streambed stability in wadeable streams nationwide.

Crews sampled 1,392 randomized sites throughout the U.S. using standardized methods (U.S. EPA, 2004). Western sites were sampled between 2000 and 2004; eastern and central sites were all sampled in 2004. Sites were sampled between mid-April and mid-November. At each site, crews measured substrate particle size, streambed dimensions, gradient, and stream energy dissipators (e.g., pools and woody debris), then used these factors to calculate the RBS.

Because streambed characteristics vary geographically, streams 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). In each ecoregion, a set of relatively undisturbed sites was sampled in order to determine the range of RBS values that would be expected among "least disturbed" streams. Next, the RBS for every site was compared to the distribution of RBS values among the ecoregion's reference sites. If the observed RBS for a sample site was below the 5th or the 10th percentile of the regional reference distribution (depending on the ecoregion), 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. Any stream with an RBS above the 25th percentile of the reference range was labeled "least disturbed," indicating a high probability that the site is similar to the relatively undisturbed reference sites. Streams falling between the 5th and 25th percentiles were classified as "moderately disturbed." Note that the "least disturbed" category may include some streams with higher-than-expected RBS values, which represent overly stable streambeds. Because it is more difficult to determine whether overly stable streambeds are "natural" or result from anthropogenic factors, this indicator only measures the prevalence of *unstable* streambeds (i.e., excess sedimentation).

What the Data Show

Roughly 50 percent of wadeable stream miles are classified as "least disturbed" with respect to streambed condition; that is, their streambed stability is close to or greater than what would be expected (Exhibit 3-6). Conversely, 25 percent of the nation's wadeable streambeds are significantly less stable than regional reference conditions for streambed stability ("most disturbed"), and an additional 20 percent are classified as "moderately disturbed." Approximately 5 percent of the nation's stream length could not be assessed because of missing or inadequate sample data.

Indicator Limitations

- Samples were taken one time from each sampling location during the index period (April-November). Although the probability sampling design results in unbiased estimates for relative streambed stability in wadeable streams during the study period, RBS values may be different during other seasons and years because of variations in hydrology.

INDICATOR | Streambed Stability in Wadeable Streams *(continued)*

- 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

Aggregate data for this indicator were provided by EPA's Wadeable Streams Assessment (U.S. EPA, 2006b). 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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INDICATOR | Nitrogen and Phosphorus in Wadeable Streams

Nitrogen and phosphorus are essential elements in aquatic ecosystems. Both nutrients are used by plants and algae for growth (U.S. EPA, 2005). Excess nutrients, however, can lead to increased algal production, and excess nutrients in streams can also affect lakes, larger rivers, and coastal waters downstream. In addition to being visually unappealing, excess algal growth can contribute to the loss of oxygen needed by fish and other animals, which in turn can lead to altered biological assemblages. Sources of excess nutrients include municipal sewage and septic tank drainfields, agricultural runoff, excess fertilizer application, and atmospheric deposition of nitrogen (Herlihy et al., 1998).

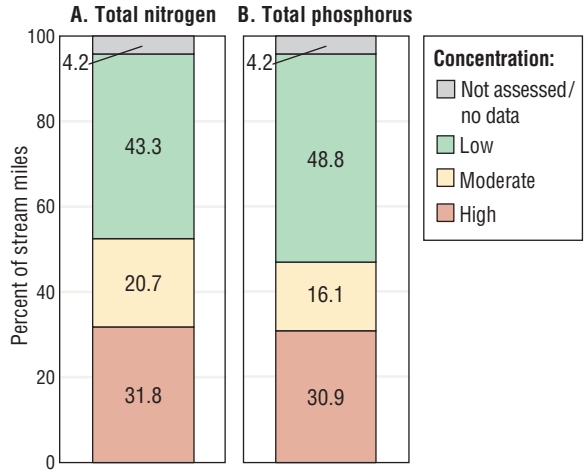
This indicator measures total phosphorus and total nitrogen based on data collected for EPA's Wadeable Streams Assessment (WSA). Wadeable streams—streams, creeks, and small rivers that are shallow enough to be sampled using methods that involve wading into the water—represent a vital linkage between land and water. They typically include waters classified as 1st through 4th order in the Strahler Stream Order classification system (Strahler, 1952). The WSA is based on a probabilistic design, so the results from representative sample sites can be used to make a statistically valid statement about nitrogen and phosphorus concentrations in all of the nation's wadeable streams.

Crews sampled 1,392 randomized sites across the United States using standardized methods. Western sites were sampled between 2000 and 2004; eastern and central sites were all sampled in 2004. All sites were sampled between mid-April and mid-November. At each site, a water sample was collected at mid-depth in the stream and analyzed following standard laboratory protocols (U.S. EPA, 2004a,b).

Because naturally occurring nutrient levels vary from one geographic area to another, streams 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). In each ecoregion, a set of relatively undisturbed sites was sampled in order to determine the range of nutrient concentrations that would be considered "low." Next, observed nitrogen and phosphorus concentrations from all sites were compared to the distribution of concentrations among the ecoregion's reference sites. If the observed result was above the 95th percentile of the ecoregion's reference distribution, the concentration was labeled "high." This threshold was used because it offers a high degree of confidence that the observed condition is statistically different from the condition of the reference streams. Concentrations below the 75th percentile of the reference range were labeled

INDICATOR | Nitrogen and Phosphorus in Wadeable Streams *(continued)*

Exhibit 3-7. Nitrogen and phosphorus in wadeable streams of the contiguous U.S., 2000-2004[a]



[a]Compared with minimally disturbed reference sites. See text for definitions of the categories shown in the figure.

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

"low," indicating a high probability that the site is similar to the relatively undisturbed reference sites. Concentrations falling between the 75th and 95th percentiles were labeled "moderate."

What the Data Show

Nationwide, 43.3 percent of wadeable stream miles had low total nitrogen concentrations, while high nitrogen concentrations were found in 31.8 percent of stream miles (Exhibit 3-7). The results for total phosphorus are similar to those for nitrogen, with low concentrations in 48.8 percent of stream miles and high concentrations in 30.9 percent (Exhibit 3-7). The concentrations associated with the regional thresholds vary because of natural differences among the ecoregions. Approximately 4 percent of the nation's wadeable stream length could not be assessed because of missing or inadequate sample data.

Indicator Limitations

- Samples were taken one time from each sampling location during the index period (April-November). Although the probability sampling design results in an unbiased estimate for total nitrogen and phosphorus concentrations in wadeable streams during the study period, concentrations may be different during other seasons.
- 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.
- Not all forms of nitrogen and phosphorus are equally bioavailable, and the ratio of nitrogen to phosphorus can affect the biomass and type of species of algae in streams. The forms of nitrogen and phosphorus and the nitrogen:phosphorus ratios may vary somewhat between the regional reference sites and the WSA streams.

Data Sources

Aggregate data for this indicator were provided by the WSA (U.S. EPA, 2006b). 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).

References

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U.S. EPA. 2004b. Wadeable Streams Assessment: Water chemistry laboratory manual. EPA/841/B-04/008. <http://www.epa.gov/owow/monitoring/wsa/WRS_lab_manual.pdf>

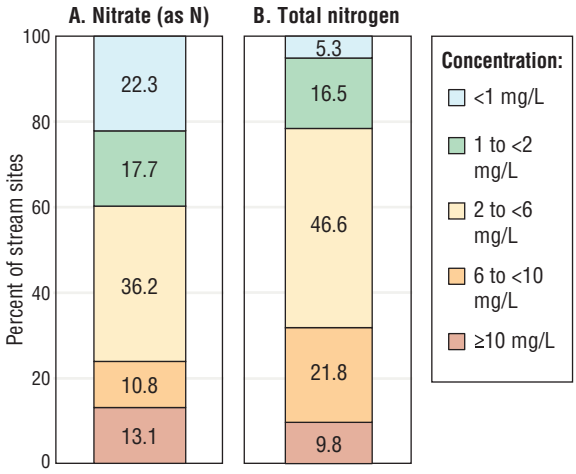
INDICATOR | Nitrogen and Phosphorus in Streams in Agricultural Watersheds

Nitrogen is a critical nutrient that is generally used and reused by plants within natural ecosystems, with minimal "leakage" into surface or ground water, where nitrogen concentrations remain very low (Vitousek et al., 2002). When nitrogen is applied to the land in amounts greater than can be incorporated into crops or lost to the atmosphere through volatilization or denitrification, however, nitrogen concentrations in streams can increase. The major sources of excess nitrogen in predominantly agricultural watersheds are fertilizer and animal waste; other sources include septic systems and atmospheric deposition. The total nitrogen concentration in streams consists of nitrate, the most common bioavailable form; organic nitrogen, which is generally less available to biota; and nitrite and ammonium compounds, which are typically present at relatively low levels except in highly polluted situations. Excess nitrate is not toxic to aquatic life, but increased nitrogen may result in overgrowth of algae, which can decrease the dissolved oxygen content of the water, thereby harming or killing fish and other aquatic species (U.S. EPA, 2005). Excess nitrogen also can lead to problems in downstream coastal waters, as discussed further in the N and P Loads in Large Rivers indicator (p. 3-17).

Phosphorus also is an essential nutrient for all life forms, but at high concentrations the most biologically active form of phosphorus (orthophosphate) can cause water quality problems by overstimulating the growth of algae. In addition to being visually unappealing and causing tastes and odors in water supplies, excess algal growth can contribute to the loss of oxygen needed by fish and other animals. Elevated levels of phosphorus in streams can result from fertilizer use, animal wastes and wastewater, and the use of phosphate detergents. The fraction of total phosphorus not in the orthophosphate form consists of organic and mineral phosphorus fractions whose bioavailability varies widely.

This indicator reports nitrogen and phosphorus concentrations in stream water samples collected from 1992 to 2001 by the U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program, which surveys the condition of streams and aquifers in study units throughout the contiguous U.S. Specifically, this indicator reflects the condition of 129 to 133 streams draining watersheds where agriculture is the predominant land use (the exact number of sites with available data depends on the analyte), according to criteria outlined in Mueller and Spahr (2005). These watersheds are located in 36 of the 51 NAWQA study units (i.e., major river basins). Sites were chosen to avoid large point sources of nutrients (e.g., wastewater treatment plants). At each stream site, samples were collected 12 to 25 times each year over a 1-to-3-year period; this indicator is based on a flow-weighted annual average of those samples. Related indicators report the concentrations of nitrogen and phosphorus in small wadeable streams, regardless of land use (p. 3-13), and nitrate concentrations in ground water in agricultural watersheds (p. 3-15).

Exhibit 3-8. Nitrogen in streams in agricultural watersheds of the contiguous U.S., 1992-2001[a,b]



[a]**Coverage:** Nitrate data from 130 stream sites; total nitrogen data from 133 stream sites. Stream sites are in watersheds where agriculture is the predominant land use. These watersheds are within 36 major river basins studied by the USGS NAWQA program.

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

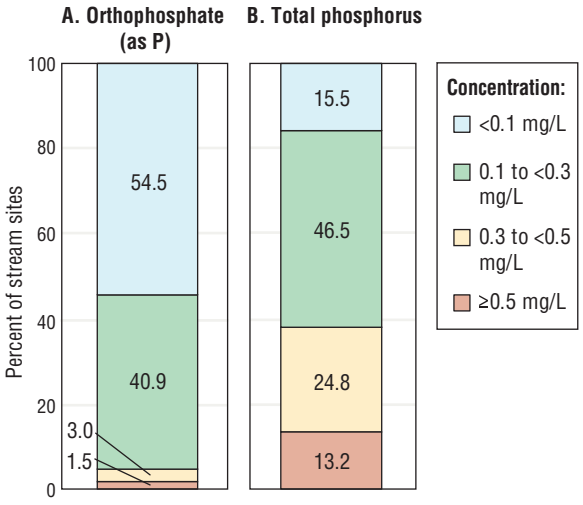
Data source: *Mueller and Spahr, 2005*

For nitrogen, the indicator reports the percentage of streams with average concentrations of nitrate and total nitrogen in one of five ranges: less than 1 milligram per liter (mg/L); 1-2 mg/L; 2-6 mg/L; 6-10 mg/L; and 10 mg/L or more. This indicator measures nitrate as N, i.e., the fraction of the material that is actually nitrogen. Measurements actually include nitrate plus nitrite, but because concentrations of nitrite are typically insignificant relative to nitrate, this mixture is simply referred to as nitrate. Naturally occurring levels of nitrate and total nitrogen vary substantially across the country, and statistical analyses of water quality data suggest that appropriate reference levels range from 0.12 to 2.2 mg/L total N, such that some streams in the lowest category (less than 1 mg/L) may still exceed recommended water quality criteria (U.S. EPA, 2002).

Concentrations of total phosphorus and orthophosphate (as P) are reported in four ranges: less than 0.1 mg/L, 0.1-0.3 mg/L, 0.3-0.5 mg/L, and 0.5 mg/L or more. There is currently no national water quality criterion for either form to protect surface waters because the effects of phosphorus vary by region and are dependent on physical factors such as the

INDICATOR | Nitrogen and Phosphorus in Streams in Agricultural Watersheds *(continued)*

Exhibit 3-9. Phosphorus in streams in agricultural watersheds of the contiguous U.S., 1992-2001[a,b]



[a]**Coverage:** Orthophosphate data from 132 stream sites; total phosphorus data from 129 stream sites. Stream sites are in watersheds where agriculture is the predominant land use. These watersheds are within 36 major river basins studied by the USGS NAWQA program.

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

Data source: *Mueller and Spahr, 2005*

size, hydrology, and depth of rivers and lakes. Nuisance algal growths are not uncommon in rivers and streams below the low reference level (0.1 mg/L) for phosphorus in this indicator, however (Dodds and Welch, 2000), and statistical analyses of water quality data suggest that more appropriate reference levels for total P range from 0.01 to 0.075 mg/L, depending on the ecoregion (U.S. EPA, 2002). Some streams in the lowest category may exceed these recommended water quality criteria.

What the Data Show

Average flow-weighted nitrate concentrations were 2 mg/L or above in about 60 percent of stream sites in these predominantly agricultural watersheds (Exhibit 3-8). About 13 percent of stream sites had nitrate concentrations of at least 10 mg/L (the slightly smaller percentage of streams with total N above 10 mg/L is an artifact of the flow-weighting algorithm). Nearly half of the streams sampled had total nitrogen concentrations in the 2-6 mg/L range, and 78 percent had concentrations of 2 mg/L or above.

Nearly half of the streams in agricultural watersheds had average annual flow-weighted concentrations of orthophosphate (as P) of at least 0.1 mg/L (Exhibit 3-9). Approximately 85 percent of the streams had concentrations of total phosphorus of 0.1 mg/L or above, while 13 percent had at least 0.5 mg/L total phosphorus.

Indicator Limitations

- These data represent streams draining agricultural watersheds in 36 of the major river basins (study units) sampled by the NAWQA program in the contiguous U.S. While they were chosen to be representative of agricultural watersheds across the United States, they are the result of a targeted sample design, and may not be an accurate reflection of the distribution of concentrations in all streams in agricultural watersheds in the U.S.
- This indicator does not provide information about trends over time, as the NAWQA program has completed only one full sampling cycle to date. Completion of the next round of sampling will allow trend analysis, using the data presented here as a baseline.

Data Sources

Summary data for this indicator were provided by USGS's NAWQA program. These data have been published in Mueller and Spahr (2005), along with the individual sampling results on which the analysis is based.

References

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INDICATOR | Nitrogen and Phosphorus Loads in Large Rivers

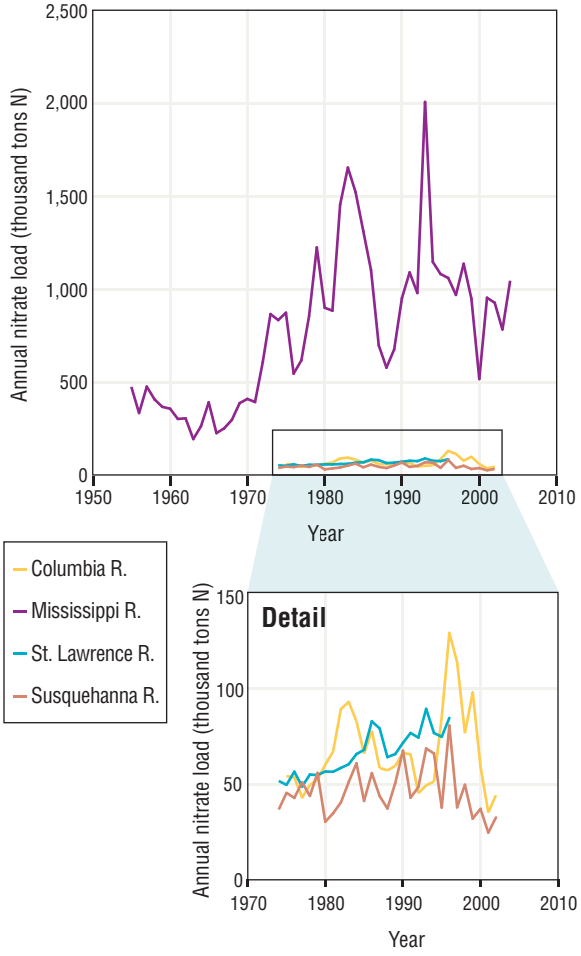
Nitrogen is a critical nutrient for plants and animals, and terrestrial ecosystems and headwater streams have a considerable ability to capture nitrogen or to reduce it to N_2 gas though the process of denitrification. Nitrogen cycling and retention is thus one of the most important functions of ecosystems (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 measurements of nitrate plus nitrite. As nitrite concentrations are typically very small relative to nitrate, this mixture is simply referred to as nitrate.

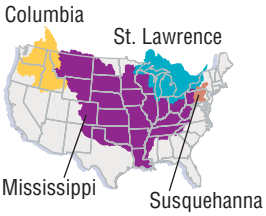
Exhibit 3-10. Nitrate loads in four major U.S. rivers, 1955-2004[a]



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

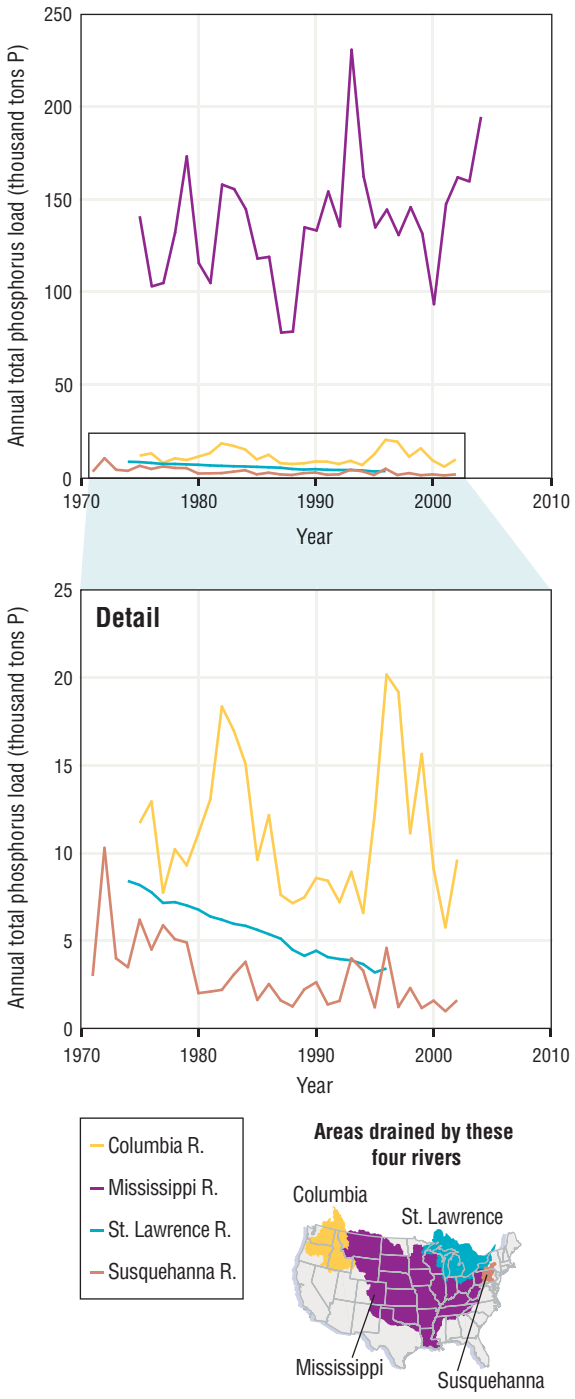
Data source: *USGS, 2007a*

Areas drained by these four rivers



INDICATOR | Nitrogen and Phosphorus Loads in Large Rivers *(continued)*

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



Data source: *USGS, 2007a*

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.

INDICATOR | Nitrogen and Phosphorus Loads in Large Rivers *(continued)*

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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INDICATOR | Pesticides in Streams in Agricultural Watersheds

Pesticides are chemicals or biological agents that kill plant or animal pests and may include herbicides, insecticides, fungicides, and rodenticides. More than a billion pounds of pesticides (measured as pounds of active ingredient) are used in the United States each year to control weeds, insects, and other organisms that threaten or undermine human activities (Aspelin, 2003). About 80 percent of the total is used for agricultural purposes. Although pesticide use has resulted in increased crop production and other benefits, pesticide contamination of streams, rivers, lakes, reservoirs, coastal areas, and ground water can cause unintended adverse effects on aquatic life, recreation, drinking water, irrigation, and other uses. Water also is one of the primary pathways by which pesticides are transported from their application areas to other parts of the environment (USGS, 2000).

This indicator is based on stream water samples collected between 1992 and 2001 as part of the U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program, which surveys the condition of streams and aquifers in study units throughout the contiguous United States. Of the streams sampled for pesticides, this indicator focuses on 83 streams in watersheds where agriculture represents the predominant land use, according to criteria outlined in Gilliom et al. (2007). These 83 streams are located in 36 of the 51 NAWQA study units (i.e., major river basins). From each site, NAWQA collected 10 to 49 water samples per year over a 1-to-3-year

INDICATOR | Pesticides in Streams in Agricultural Watersheds *(continued)*

period to analyze for 75 different pesticides and eight pesticide degradation products, which together account for approximately 78 percent of the total agricultural pesticide application in the United States by weight during the study period (Gilliom et al., 2007). This indicator reports on two variables: (1) the number of stream sites in which pesticides or degradation products were detected and (2) the number of stream sites where the annual time-weighted average concentration of one or more of these compounds exceeds standards for aquatic life. A related indicator discusses pesticide concentrations in ground water in agricultural watersheds (p. 3-19).

Several types of water quality benchmarks for aquatic life were used. Where available, data were compared with EPA's acute and chronic ambient water-quality criteria for the protection of aquatic life (AWQC-ALs). The acute AWQC-AL is the highest concentration of a chemical to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. The chronic AWQC-AL is the highest concentration to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. An exceedance was identified if a single sample exceeded the acute AWQC-AL or if a 4-day moving average exceeded the chronic AWQC-AL (per EPA's definition of the chronic AWQC-AL). Results were also compared with aquatic life benchmarks derived from toxicity values presented in registration and risk-assessment documents developed by EPA's Office of Pesticide Programs. These benchmarks included acute and chronic values for fish and invertebrates, acute values for vascular and nonvascular plants, and a value for aquatic community effects. An exceedance was identified if a single sample exceeded any acute benchmark or if the relevant moving average exceeded a chronic benchmark. Altogether, aquatic life benchmarks were available for 62 of the pesticides and degradation products analyzed. More information about the derivation and application of aquatic life guidelines for this indicator can be found in Gilliom et al. (2007).

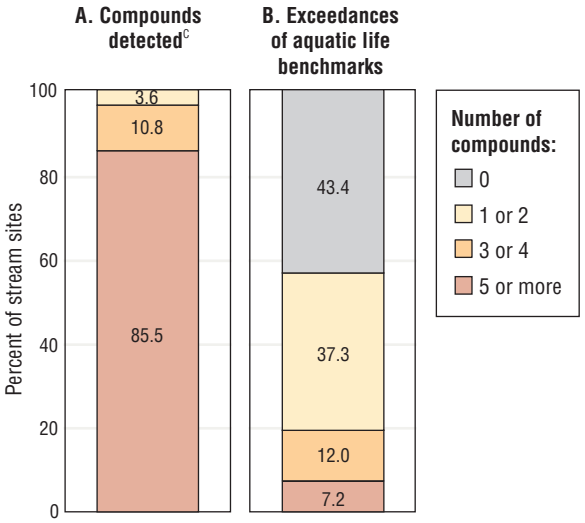
What the Data Show

Of the streams sampled, all had at least one pesticide detection and 86 percent had five or more compounds present, which suggests that pesticides frequently occur as mixtures (Exhibit 3-12). In 57 percent of the streams sampled, at least one pesticide was detected at a concentration that exceeded one or more aquatic life benchmarks (Exhibit 3-12). Approximately 7 percent of the streams (six of the 83 streams sampled) had five or more pesticides at concentrations above aquatic life benchmarks.

Indicator Limitations

- These data represent streams draining agricultural watersheds in 36 of the study units (major river basins) sampled by the NAWQA program in the contiguous United States. While they were chosen to be representative of agricultural watersheds across the nation, they are the result of a targeted sampling design, and may not be an accurate reflection of the distribution of concentrations in all streams in the nation's agricultural watersheds.
- This indicator does not provide information about trends over time, as the NAWQA program has completed only one full sampling cycle to date. Completion of the next round of sampling will allow trend analysis, using the data presented here as a baseline.
- Aquatic life benchmarks do not currently exist for 21 of the 83 pesticides and pesticide degradation products analyzed. Current standards and guidelines do not account for mixtures of pesticide chemicals and seasonal pulses of high concentrations.
- The pesticide benchmarks used here are designed to be fully protective of aquatic health. Other indicators, such as Coastal Sediment Quality (p. 3-42), use aquatic life thresholds that are less protective. Thus, these indicators are not necessarily comparable to one another.
- This indicator does not provide information on the magnitude of pesticide concentrations, only whether they exceed or fall below benchmarks.

Exhibit 3-12. Pesticides in streams in agricultural watersheds of the contiguous U.S., 1992-2001[a,b]



[a]**Coverage:** 83 stream sites in watersheds where agriculture is the predominant land use. These watersheds are within 36 major river basins studied by the USGS NAWQA program.

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

[c]All streams had at least one compound detected.

Data source: *Gilliom et al., 2007*

INDICATOR | Pesticides in Streams in Agricultural Watersheds

Data Sources

Summary data for this indicator were provided by USGS's NAWQA program, based on supporting technical data published in conjunction with Gilliom et al. (2007). Overall pesticide occurrence was determined from individual site results in Appendix 6 of Gilliom et al. (2007) (http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/), while exceedances were calculated from a separate supporting data file (http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/figures/descriptions/6_05_exceeddata.txt).

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INDICATOR | Benthic Macroinvertebrates in Wadeable Streams

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.

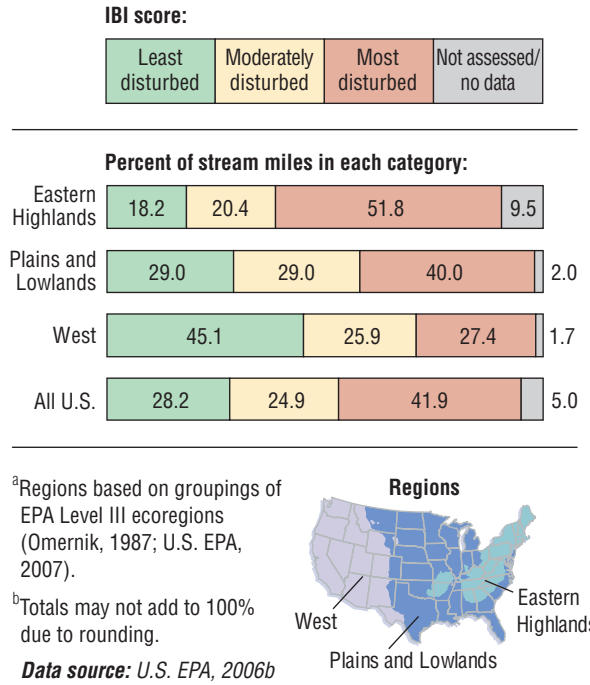
For this analysis, the 48 contiguous states were divided into nine broad ecoregions (U.S. EPA, 2006b), which were defined by the WSA based on groupings of EPA Level III ecoregions (Omernik, 1987; U.S. EPA, 2007). Benthic community condition was determined using two different approaches, each reflecting 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).

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

INDICATOR | Benthic Macroinvertebrates in Wadeable Streams *(continued)*

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*

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

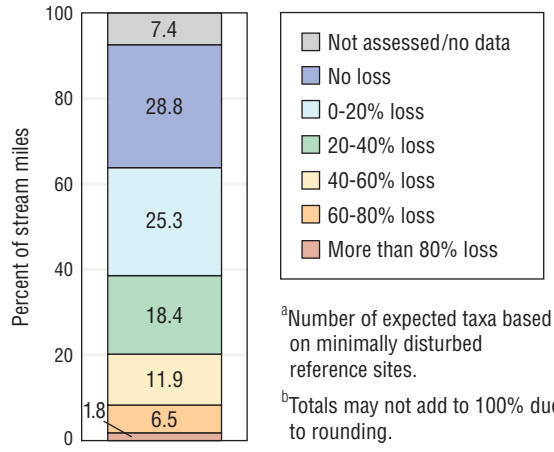
Based on the IBI, slightly more than one-quarter of wadeable stream miles nationwide (28.2 percent) were classified as "least disturbed" with respect to benthic macroinvertebrate condition, while 41.9 percent were in the "most disturbed" category (Exhibit 3-13). Of the three major stream regions in the 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.
- 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

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*

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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3.2.3 Discussion

What These Indicators Say About Trends in the Extent and Condition of Fresh Surface Waters and Their Effects on Human Health and the Environment

Although the indicators do not characterize the extent of all fresh surface waters, they do provide information about flow patterns in streams. As the Stream Flows indicator (p. 3-8) shows, substantial shifts in the volume of high and low flows have occurred over time, with large fluctuations between relatively "wet" and "dry" periods. In general, since the 1960s, more streams have experienced increases in base flow volume than have experienced decreases, compared to the prior 20 years. At the same time, overall flow variability appears to have decreased somewhat. These shifts are particularly important in intermittent streams, where life forms may be quite sensitive to changes in patterns of flow and no flow. Although intermittent streams can be found throughout the country, the Stream Flows indicator focuses on those that occur in grassland and shrubland areas, many of which are arid or semi-arid and thus especially sensitive to water stress. As this indicator shows, no-flow periods have generally decreased in number and duration since the 1960s, although a few grassland/shrubland streams have experienced substantial increases.

Factors that influence stream flow can include weather and climate, land cover, hydromodifications such as dams, and water withdrawals. Decreases in flow volume were somewhat less prevalent within a subset of relatively unmodified "reference" streams. Nonetheless, trends in the "reference" streams were highly similar to trends in the general population of streams overall, suggesting that dams, diversions, and land cover changes are not the major causes of the observed changes in stream flow over the last half-century.

The physical condition of lakes and streams is in part a function of the interaction between sediment and water. As the Streambed Stability indicator (p. 3-11) shows, about one-fourth of the nation's wadeable streams show significant evidence of excess fine sediments, which can diminish habitat. In some cases, excess sedimentation can reflect the influence of human stressors like erosion. Excess sedimentation also can be a symptom of broader changes in physical condition, such as hydromodifications that alter flow and sediment transport.

The ROE indicators provide a mixed picture of the chemical condition of fresh surface waters. Acidity in lakes and streams has decreased in three of the four sensitive areas studied (Lake and Stream Acidity indicator, p. 2-42), while excess nutrients are present in many streams, ranging from small wadeable streams to the nation's largest rivers (three N and P indicators, pp. 3-13, 3-15, and 3-17). In agricultural areas, more than half of monitoring sites have at least one pesticide at levels that exceed guidelines for aquatic health (Pesticides in Agricultural Streams indicator, p. 3-19). These indicators reflect the influence of many stressors. For example, the two Agricultural Streams indicators (pp. 3-15 and 3-19) demonstrate how chemicals applied to the land can ultimately affect surface waters. Conversely, efforts to reduce human stressors can result in improved water condition. For example, areas with declines in acidity correspond with areas of decreased acid deposition (Lake and Stream Acidity indicator, p. 2-42), while declining phosphorus loads in at least one river may be related to detergent bans and improved sewage treatment (N and P Loads in Large Rivers indicator, p. 3-17). The indicators also are influenced by natural stressors (e.g., year-to-year variability in nutrient loads due to variations in precipitation).

One ROE indicator presents direct information on the biological condition of fresh surface waters. About 40 percent of the nation's wadeable stream miles exhibit a substantial loss (more than 20 percent) of macroinvertebrate taxa—approximately equal to the number of stream miles considered "most disturbed" when other metrics of benthic community condition are considered (Benthic Macroinvertebrates in Wadeable Streams indicator, p. 3-21). Benthic macroinvertebrate communities are particularly sensitive to physical and chemical stressors, and thus the condition of these assemblages can provide information about the extent to which these stressors may be causing measurable harm. In addition, several other ROE indicators provide information about stressors that are known to affect biological condition. For example, the ROE indicators show a portion of streams with excess sedimentation, pesticides above aquatic life guidelines, nutrients at levels that could encourage eutrophication, and substantial changes in high and low stream flows.

Limitations, Gaps, and Challenges

Although the ROE indicators provide valuable information about the extent and condition of fresh surface waters, there are a few general limitations to their ability to depict trends over space and time. For example, trends in condition may be tied to the location and timing of intermittent stressors (e.g., pesticide application), so indicators that assess national condition using samples that are spread out over time and space may obscure local conditions and extreme events. Some indicators are also restricted to specific study areas. For example, the two Agricultural Streams indicators (pp. 3-15 and 3-19) do not characterize non-agricultural watersheds, and the Lake and Stream Acidity indicator (p. 2-42) does not include localized acidification in the West.

In addition to the challenges inherent in assessing fresh surface waters, there are challenges in interpreting what the indicators say. Ecological responses to freshwater stressors are complex and may depend on the species that inhabit a particular area. In some cases—e.g., the three indicators from the Wadeable Streams Assessment—data must be adjusted to account for variations in regional reference conditions. It can also be difficult to link effects to specific stressors, as many indicators reflect the interplay of multiple human and natural factors. For example, local bedrock can contribute high levels of nutrients to some rivers, while precipitation variability can drive trends in nutrient loads, potentially obscuring trends in anthropogenic stressors.

There are no ROE indicators for a few key aspects of the extent and condition of fresh surface waters. The following information would help to better answer this question:

- Information on the extent of different types of fresh surface waters, stressors to extent (e.g., water usage and extent of snowpack), and associated effects on ecological systems.
- Nationally consistent information to characterize stressors to fresh surface water condition—specifically pollutant loadings from point and nonpoint sources.
- Information on the condition of large rivers. The N and P Loads in Large Rivers indicator (p. 3-17) describes nutrient loads at the mouth, but does not address conditions upstream.
- Indicators on the condition of ponds, reservoirs, and lakes, including the Great Lakes. A nationally consistent indicator of lake trophic state could bring together several aspects of condition (e.g., physical, chemical, and biological parameters) related to eutrophication—a problem facing many of the nation's lakes.
- Indicators of salinity, of particular importance in arid regions.
- Information on the extent and condition of riparian zones and lake shoreline (the land-water interface), where much biological activity occurs.
- Information about toxic contaminants in freshwater sediments. Sediment contaminants can accumulate through the food web, and may ultimately impact the health of humans who consume fish and shellfish.
- Information on the condition of fish communities, which can be affected by many different stressors.

In addition, there are currently no ROE indicators that explicitly link human health effects to the extent or condition of fresh surface waters. As described in Chapter 1, this type of information gap largely reflects the difficulty of determining exact causation between stressors and effects.

3.3 What Are the Trends in the Extent and Condition of Ground Water and Their Effects on Human Health and the Environment?

3.3.1 Introduction

A large portion of the world's fresh water resides underground, stored within cracks and pores in the rock that makes up the Earth's crust. The U.S. Geological Survey estimates that there are approximately 1 million cubic miles of ground water within one-half mile of the Earth's surface—30 times the volume of all the world's fresh surface waters.[2] Many parts of the U.S. rely heavily on ground water for human uses (e.g., drinking, irrigation, industry, livestock), particularly areas with limited precipitation (e.g., the Southwest), limited surface water resources, or high demand from agriculture and growing populations (e.g., Florida). Half of the U.S. population (51 percent) relies on ground water for domestic uses.[3]

Ecological systems also rely on ground water. For example, some wetlands and surface waters are fed by springs and seeps, which occur where a body of ground water—known as an aquifer—reaches the Earth's surface. While the contribution of ground water to stream flow varies widely among streams, hydrologists estimate that the average contribution of ground water is 40 to 50 percent in small- and medium-sized streams. The ground water contribution to all stream flow in the U.S. may be as large as 40 percent.[4]

The extent of ground water refers to the amount available, typically measured in terms of volume or saturated thickness of an aquifer. The condition of ground water reflects a combination of physical, biological, and chemical attributes. Physical properties reflect patterns of flow—i.e., the volume, speed, and direction of ground water flow in a given location. Biologically, ground water can contain a variety of organisms, including bacteria, viruses, protozoans, and other pathogens. Ground water can also contain a variety of chemicals, which may occur naturally or as a result of human activities. Chemicals that may occur in ground water include nutrients, metals, radionuclides, salts, and organic compounds such as petroleum products, pesticides, and solvents. These chemicals may be dissolved in water or—in the case of insoluble organic contaminants—exist as undissolved plumes.

[2] U.S. Geological Survey. 1999. Ground water (general interest publication). Reston, VA. <http://capp.water.usgs.gov/GIP/gw_gip/>

[3] Ibid.

[4] Alley, W.M, T.E. Reilly, and O.L. Franke. 1999. Sustainability of ground-water resources. Circular 1186. Denver, CO: U.S. Geological Survey.

Many stressors can affect the extent of ground water, including patterns of precipitation and snowmelt and human activities that change or redistribute the amount of ground water in an aquifer. One major way humans influence ground water extent is by withdrawing water for drinking, irrigation, or other uses (e.g., ground water extracted to lower the water table for mining operations). Other human activities can increase ground water levels, such as surface irrigation runoff recharging a shallow aquifer, or water pumped directly into the ground in order to store surface waters for future use, or to aid in oil and gas extraction. Human activities can affect ground water extent indirectly, too; for example, impervious paved surfaces may prevent precipitation from recharging ground water. In some cases, changes in ground water extent may be caused by a combination of these human and natural factors—for example, droughts that require humans to withdraw more water from the ground (e.g., for irrigation), while at the same time providing less precipitation for recharge. Some aquifers are more susceptible than others to changes in extent. For example, some deep aquifers may take thousands of years to recharge, particularly if they lie below highly impermeable confining layers.

Aquifer depletion—i.e., decreased extent—can adversely affect the humans and ecosystems that directly or indirectly depend on ground water. Less ground water available for human or ecological use can result in lower lake levels or—in extreme cases—cause perennial streams to become intermittent or totally dry, thus harming aquatic and riparian plants and animals that depend on regular surface flows. An area with a high water table may have plant communities that tap ground water directly with their roots, so even a slight lowering of the aquifer could affect native species—which in turn could benefit invasive species.[5] In addition, lower water table levels may lead to land subsidence and sinkhole formation in areas of heavy withdrawal, which can damage buildings, roads, and other structures and can permanently reduce aquifer recharge capacity by compacting the aquifer medium (soil or rock). Finally, changes in the ground water flow regime can lead to consequences such as salt water intrusion, in which saline ground water migrates into aquifers previously occupied by fresh ground water.

Although aquifer depletion can have serious effects, the opposite, far less common problem—too much ground water—can also be detrimental. Too much ground water discharge to streams can cause erosion and can alter the balance of aquatic plant and animal species, as has been reported in association with some mining sites.[6]

Like extent, condition is influenced by both natural sources and human activities. Some ground water has high levels of naturally occurring dissolved solids (salinity), or metals such as arsenic that can be present as a result of natural rock formations. Land use can affect the condition of ground water; for example, pesticides, fertilizers, and other chemicals applied to the land can leach into ground water, while waste from livestock and other animals can contribute contaminants such as nutrients, organic matter, and pathogens. Shallow and unconfined aquifers are particularly susceptible to this type of contamination. In addition, landfills may leach metals, solvents, and other contaminants into ground water (particularly older landfills that do not have liners and leachate collection systems). Mining operations can mobilize toxic metals, acidic compounds, and other substances that can impact the condition of ground water. Finally, chemical or biological contaminants may enter aquifers as a result of unintentional releases, including chemical spills on land, leaks from storage tanks, sewers or septic systems, and unplugged abandoned wells that allow a direct route of entry for contaminants.

Stressors that affect ground water condition ultimately affect the condition of water available for drinking, irrigation, or other human needs. In some cases, treatment may be needed to ensure that finished drinking water does not pose risks to human health. Because drinking water can come from many different types of water bodies, and because of the many complex issues associated with treatment and regulation of drinking water, this topic is addressed in greater detail in its own section of this report, Section 3.6. The condition of ground water also can affect ecological systems. For example, many fish species depend on cold, clear spring-fed waters for habitat or spawning grounds.[7,8] In some cases, aquifers themselves may constitute ecosystems. For example, caves and sinkholes are home to many types of aquatic fauna, including invertebrates and fish adapted to life underground.[9] Ground water can also affect the condition of other environmental media. For example, volatile ground water contaminants can potentially migrate into indoor air via soil vapor intrusion.

In many ways, extent and condition are intertwined. For example, stressors that affect extent—such as withdrawal or injection—can also alter physical parameters of the ground water flow regime, such as velocity and direction of flow. These physical alterations can affect patterns of discharge to surface waters, as well as the movement of water and contaminants within the ground (e.g., salt water intrusion).

[5] Grantham, C. 1996. An assessment of ecological impacts of ground water overdraft on wetlands and riparian areas on the United States. EPA/813/S-96/001. Washington, DC: U.S. Environmental Protection Agency.

[6] United States Department of the Interior. 2002. Hydrologic impacts of mining. Chapter 1. In: Permitting hydrology, a technical reference document for determination of probable hydrologic consequence (PHC) and cumulative hydrologic impact assessments (CHIA). Washington, DC. Accessed November 8, 2003. <http://www.osmre.gov/pdf/phc2.pdf>

[7] Prichard, D., J. Anderson, C. Correll, J. Fogg, K. Gebhardt, R. Krapf, S. Leonard, B. Mitchell, and J. Stasts. 1998. Riparian area management: A user guide to assessing proper functioning condition and the supporting science for lotic areas. Technical reference 1737-15. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center.

[8] Boyd, M., and D. Sturdevant. 1997. The scientific basis for Oregon's stream temperature standard: Common questions and straight answers. Portland, OR: Oregon Department of Environmental Quality.

[9] Elliott, W.R. 1998. Conservation of the North American cave and karst biota. In: Wilkens, H., D.C. Culver, and W.F. Humphreys, eds. Subterranean biota. Amsterdam, The Netherlands: Elsevier (Ecosystems of the World series). pp. 665-689. Preprint online at <http://www.utexas.edu/depts/tnhc/.www/biospeleology/preprint.htm>

3.3.2 ROE Indicators

This report presents an indicator of ground water condition based on a nationwide survey of shallow wells in watersheds where agriculture is the predominant land use (Table 3-3). The data come from the U.S. Geological Survey's National Water Quality Assessment (NAWQA) study of major river basins with agricultural activities, representing a large portion of the nation's land area. Agricultural land use is among the major sources of certain ground water contaminants such as nutrients and pesticides.

Table 3-3. ROE Indicators of Trends in the Extent and Condition of Ground Water and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds	3.3.2	3-27

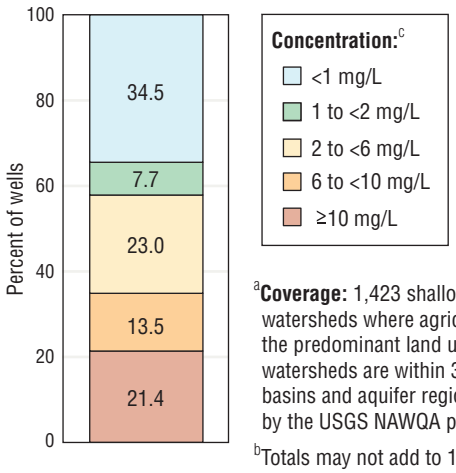
INDICATOR | Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds

Nitrogen is a critical plant nutrient, and most nitrogen is used and reused by plants within an ecosystem (Vitousek et al., 2002), so in undisturbed ecosystems minimal "leakage" occurs into ground water, and concentrations are very low. When nitrogen fertilizers are applied in amounts greater than can be incorporated into crops or lost to the atmosphere, however, nitrate concentrations in ground water can increase. Elevated nitrogen levels in ground water also might result from disposal of animal waste or onsite septic systems. Nitrate contamination in shallow ground water (less than 100 feet below land surface) raises potential concerns for human health where untreated shallow ground water is used for domestic water supply. High nitrate concentrations in drinking water pose a risk for methemoglobinemia, a condition that interferes with oxygen transport in the blood of infants (U.S. EPA, 2004).

More than a billion pounds of pesticides (measured as pounds of active ingredient) are used in the U.S. each year to control weeds, insects, and other organisms that threaten or undermine human activities (Aspelin, 2003). About 80 percent of the total is used for agricultural purposes. Although pesticide use has resulted in increased crop production and other benefits, pesticide contamination of ground water poses potential risks to human health if contaminated ground water is used as a drinking water source—especially if untreated.

This indicator reports on the occurrence of nitrate and pesticides in shallow ground water in watersheds where agriculture is the primary land use, according to criteria outlined in Gilliom et al. (2007). Ground water samples were collected by the U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program from 1992 to 2003 (pesticide sampling began in 1993). NAWQA surveyed 51 major river basins and aquifer regions across the contiguous United States during this period; the agricultural watersheds sampled were within 34 of these study units. Although agriculture is more prevalent in some parts of the country than in others, the watersheds were chosen to reflect a broad range of hydrogeologic conditions and agricultural activities. Ground water samples were collected from existing household wells where possible and new observation wells otherwise, all targeted at the uppermost aquifer and avoiding locations where ground water condition could be biased by point sources (e.g., directly

Exhibit 3-15. Nitrate in shallow ground water in agricultural watersheds of the contiguous U.S., 1992-2003[a,b]



[a]**Coverage:** 1,423 shallow wells in watersheds where agriculture is the predominant land use. These watersheds are within 34 major river basins and aquifer regions studied by the USGS NAWQA program.

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

[c]EPA's drinking water standard for nitrate is a Maximum Contaminant Level (MCL) of 10 mg/L.

Data source: *USGS, 2007a*

INDICATOR | Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds *(continued)*

downgradient from a septic system). Most of the wells sampled ground water from less than 20 feet below the water table, indicating as directly as possible the influence of land use on shallow ground water quality. To the extent feasible, the wells were intended to sample recently recharged water. Data analyses were based on one sample per well. Related indicators report concentrations of nutrients and pesticides in streams that drain agricultural watersheds (see the N and P in Agricultural Streams indicator, p. 3-15, and the Pesticides in Agricultural Streams indicator, p. 3-19).

The nitrate component of this indicator represents 1,423 wells. Results are compared with the federal drinking water standard of 10 mg/L, which is EPA's Maximum Contaminant Level (MCL) to prevent methemoglobinemia (U.S. EPA, 2006). MCLs are enforceable standards representing the highest level of a contaminant that is allowed in finished drinking water. MCLs take into account cost and best available treatment technology, but are set as close as possible to the level of the contaminant below which there is no known or expected risk to health, allowing for a margin of safety.

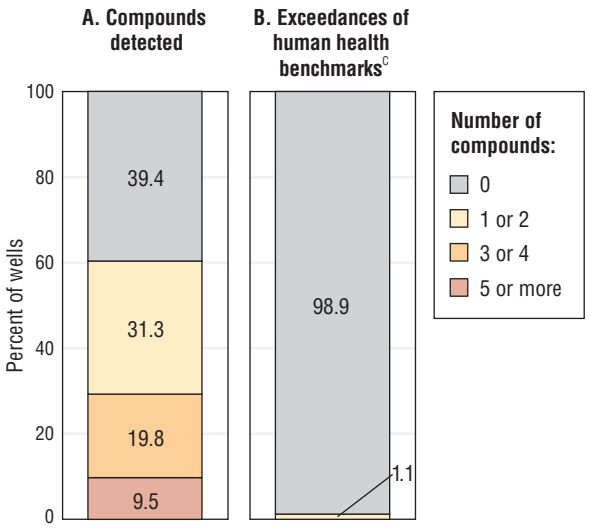
Data on 75 pesticides and eight pesticide degradation products were collected from 1,412 of the wells in the NAWQA study. These 83 chemicals account for approximately 78 percent of the total agricultural pesticide application in the United States by weight during the study period (Gilliom et al., 2007). Three types of U.S. EPA human health-related standards and guidelines were used to evaluate pesticide data: Maximum Contaminant Levels (MCLs) (as described above), Cancer Risk Concentrations (CRCs), and Lifetime Health Advisories (HA-Ls). In all three cases, the standard and guideline levels are concentrations pertaining to lifetime exposure through drinking water. The CRC is a guideline for potential carcinogens associated with a specified cancer risk of 1 in 1,000,000, based on drinking water exposure over a 70-year lifetime. The HA-L is an advisory guideline for drinking water exposure over a 70-year lifetime, considering non-carcinogenic adverse health effects. Specific standards and guidelines used for this indicator are listed in Gilliom et al. (2007), and additional information on these types of benchmarks, their derivation, and their underlying assumptions is provided in Nowell and Resek (1994). For this indicator, if a chemical had multiple benchmarks, the MCL took precedence; if no MCL was available, the lower of the CRC (at 1 in 1,000,000 cancer risk) and HA-L values was selected. An exceedance was identified if the concentration of a contaminant exceeded the relevant standard or guideline (Gilliom et al., 2007).

What the Data Show

During the study period:

- Nitrate concentrations were 2 mg/L or above in 58 percent of wells sampled in areas where agriculture is the primary land use (Exhibit 3-15). By comparison, background nitrate levels in areas with little human influence are generally expected to be below 1 mg/L (Nolan and Hitt, 2002).
- Nitrate concentrations in about 21 percent of the wells exceeded the federal drinking water standard (10 mg/L).
- About 60 percent of wells in agricultural watersheds had at least one detectable pesticide compound, and 9.5 percent had detectable levels of five or more pesticides (Exhibit 3-16). Roughly 1 percent of wells had pesticides present at concentrations exceeding human health benchmarks.

Exhibit 3-16. Pesticides in shallow ground water in agricultural watersheds of the contiguous U.S., 1993-2003[a,b]



[a]**Coverage:** 1,412 shallow wells in watersheds where agriculture is the predominant land use. These watersheds are within 34 major river basins and aquifer regions studied by the USGS NAWQA program.

[b]Samples were analyzed for 75 pesticides and eight pesticide degradation products.

[c]No wells exceeded benchmarks for more than one compound.

Data source: *Gilliom et al., 2007*

Indicator Limitations

- These data only represent conditions in agricultural watersheds within 34 of the major river basins and aquifer regions sampled by the NAWQA program from 1992 to 2003. Although sample wells were chosen randomly within each agricultural watershed, the watersheds and aquifers themselves were selected through a targeted sample design. The data also are highly aggregated and should only be interpreted as an indication of national patterns.

INDICATOR | Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds *(continued)*

- This indicator does not provide information about trends over time, as the NAWQA program has completed only one full sampling cycle to date. Completion of the next round of sampling will allow trend analysis, using the data presented here as a baseline.
- Drinking water standards or guidelines do not exist for 43 percent (36 of 83) of the pesticides and pesticide degradation products analyzed. Current standards and guidelines also do not account for mixtures of pesticide chemicals and seasonal pulses of high concentrations. Possible pesticide effects on reproductive, nervous, and immune systems, as well as on chemically sensitive individuals, are not yet well understood.
- This indicator does not provide information on the magnitude of pesticide concentrations, only whether they exceed or fall below benchmarks. It also does not describe the extent to which they exceed or fall below other reference points (e.g., Maximum Contaminant Level Goals [MCLGs] for drinking water).

Data Sources

Summary data for this indicator were provided by USGS's NAWQA program. Nitrate data have not yet been published and were provided directly by USGS (2007a); however, concentration data from individual sample sites are publicly available through NAWQA's online data warehouse (USGS, 2007b). Pesticide occurrence and exceedances were determined from individual site results in Appendix 6 of Gilliom et al. (2007) (http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/).

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Gilliom, R.J., J.E. Barbash, C.G. Crawford, P.A. Hamilton, J.D. Martin, N. Nakagaki, L.H. Nowell, J.C. Scott, P.E. Stackelberg, G.P. Thelin, and D.M. Wolock. 2007. Pesticides in the nation's streams and ground water, 1992-2001. U.S. Geological Survey circular 1291. Revised February 15, 2007. <http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/index.html> (document); <http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/supporting_info.php> (supporting technical information)

Nolan, B.T., and K.J. Hitt. 2002. Nutrients in shallow ground waters beneath relatively undeveloped areas in the conterminous United States. U.S. Geological Survey water resources investigation report 02-4289. <http://water.usgs.gov/nawqa/nutrients/pubs/wri02-4289/wri02-4289.pdf>

Nowell, L.H., and E.A. Resek. 1994. National standards and guidelines for pesticides in water, sediment, and aquatic organisms: Application to water-quality assessments. Rev. Environ. Contam. Toxicol. 140:1-164.

U.S. EPA (United States Environmental Protection Agency). 2006. Drinking water contaminants. <http://www.epa.gov/safewater/mcl.html>

U.S. EPA. 2004. Consumer factsheet on nitrates/nitrites. <http://www.epa.gov/safewater/contaminants/dw_contamfs/nitrates.html>

USGS (United States Geological Survey). 2007a. Data provided to ERG (an EPA contractor) by Nancy Baker, USGS. September 12, 2007.

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Vitousek, P., H. Mooney, L. Olander, and S. Allison. 2002. Nitrogen and nature. Ambio 31:97-101.

3.3.3 Discussion

What This Indicator Says About Trends in the Extent and Condition of Ground Water and Their Effects on Human Health and the Environment

The Nitrate and Pesticides in Ground Water indicator (p. 3-27) describes the extent to which the condition of shallow ground water may be influenced by human stressors—in this case, certain chemicals applied to land in agricultural areas. Collectively, the agricultural watersheds sampled across the nation had average nitrate concentrations that were substantially higher than the background levels one might expect in an undisturbed watershed. Nitrate concentrations exceeded EPA's MCL for nitrate in one-fifth of the wells, though this does not necessarily reflect the condition of the water people drink if it is tested and treated. Nitrate concentrations were often high enough that they could impact ecological systems upon being introduced into surface waters.[10,11] Pesticide compounds were detected

[10] Howarth, R., D. Anderson, J. Cloern, C. Elfring, C. Hopkinson, B. Lapointe, T. Malone, N. Marcus, K. McGlathery, A. Sharpley, and D. Walker. 2000. Nutrient pollution of coastal rivers, bays, and seas. Issues in ecology, number 7. Washington, DC: Ecological Society of America.

[11] Jackson, R., S. Carpenter, C. Dahm, D. McKnight, R. Naiman, S. Postel, and S. Running. 2001. Water in a changing world. Issues in ecology, number 9. Washington, DC: Ecological Society of America.

frequently (more than half of the shallow wells sampled). However, detected pesticide concentrations rarely exceeded human health-based reference points in the samples collected for this indicator.

Limitations, Gaps, and Challenges

One challenge in answering this question is that there are currently no national indicators of ground water extent. Comprehensive national data do not exist, particularly in terms of real-time water level monitoring. Statistics on water use and withdrawal might be considered a surrogate for ground water extent, but because withdrawal is but one factor that affects extent (other factors include recharge rate and flow patterns), the relationship between withdrawal and extent differs from one location to another. Thus, the issue of extent currently represents an information gap.

There are also several limitations, gaps, and challenges in addressing the issue of ground water condition. One notable limitation to the Nitrate and Pesticides in Ground Water indicator (p. 3-27) is that it does not provide information about trends over time. The indicator is also limited in its ability to represent the condition of entire aquifers. Because ground water condition is vertically heterogeneous, results from one depth do not necessarily represent other depths. This indicator characterizes the uppermost layer of shallow aquifers, which are used by many private wells. It does not provide information about the condition of deeper aquifers, which are more likely to be used for public water supplies.

The Nitrate and Pesticides in Ground Water indicator provides a representative national picture of shallow ground water condition in agricultural watersheds. At present, similar indicators do not exist for ground water in watersheds with non-agricultural land uses. Non-agricultural watersheds—particularly urban areas—reflect a different set of stressors, and to some extent a different set of chemicals (i.e., VOCs and hydrocarbons like MTBE[12]). Because many ground water stressors in urban areas are localized events such as plumes resulting from chemical spills or underground storage tank (UST) leaks, they may be harder to characterize on a national level—a potential challenge to gathering more information about ground water condition. Salt water intrusion is another issue that tends to occur locally, and for which national-scale data are not available.

[12] Delzer, G.C., and T. Ivahnenko. 2003. Occurrence and temporal variability of methyl tert-butyl ether (MTBE) and other volatile organic compounds in select sources of drinking water: Results of the focused survey. USGS series: water-resources investigations report. Report no. 2002-4084. Reston, VA: U.S. Geological Survey. <http://sd.water.usgs.gov/nawqa/pubs/wrir/wrir02_4084.pdf>

3.4 What Are the Trends in the Extent and Condition of Wetlands and Their Effects on Human Health and the Environment?

3.4.1 Introduction

The United States has many types of wetlands, which include marshes, swamps, bogs, and similar marine, estuarine, or freshwater areas that are periodically saturated or covered by water. Wetlands are an integral part of the landscape because they provide habitat for a diverse array of plants and animals, act as buffers to flooding and erosion, and serve as key links in the global water and biogeochemical cycles.

In terms of extent, wetlands currently cover 5.5 percent of the surface area of the contiguous 48 states, with freshwater wetlands accounting for nearly 95 percent of the current wetland acreage and marine and estuarine wetlands accounting for the remaining 5 percent.[13] Condition is somewhat harder to measure, as it reflects a combination of physical, chemical, and biological attributes. To be in healthy condition, however, a wetland should generally demonstrate good water quality and support native plant and animal communities, without the presence of invasive non-indigenous species. A healthy wetland should not show signs of stress related to substantial degradation or cumulative effects of smaller degradations, and should be free of modifications that restrict water flow into, through, or out of the wetland, or that alter patterns of seasonality.

Wetlands can be classified by many different attributes. First, they can be divided by degree of salinity—freshwater, marine, or estuarine. Wetlands also may be classified based on dominant vegetation type. For example, swamps are dominated by trees and shrubs, while marshes are characterized by non-woody, emergent (vertically oriented) plants like grasses and sedges. Other characteristics used to classify wetlands include soil type, water source, and the length of time a given wetland is saturated.

The structure and function of any given wetland will be governed by a combination of interrelated factors, including topography, underlying geology (e.g., mineral composition), the abundance and movement of water (hydrology), and weather and climate. These factors ultimately determine which plant and animal species will thrive in a given wetland.

All wetlands share a few basic physical, chemical, and biological attributes. By definition, all wetlands are saturated or covered

[13] Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. <http://wetlandsfws.er.usgs.gov/status_trends/>

by water at least periodically, and wetland vegetation is adapted to these conditions. Thus, wetlands are like sponges, with a natural ability to store water. Wetlands also tend to have highly developed root systems that anchor trees and other vegetation in place. This web of roots not only holds the soil in place, but also filters pollutants out of the water as it flows through.

Because of their physical, chemical, and biological properties, wetlands serve many important environmental functions. They play an important role in improving natural water quality by filtering pollutants. This function is particularly important to human health because it may affect the condition of waters used as a source of drinking water—a topic described in greater detail in Section 3.6. Wetlands also act as a buffer to protect the shoreline from erosion and storm damage. Because of their sponge-like capacity to absorb water, wetlands slow the water's momentum and erosive potential and reduce flood heights. During dry periods, the "sponge" releases water, which is critical in maintaining the base flow of many surface water systems.

Wetlands are also among the most biologically productive natural ecosystems in the world. Microbial activity in wetlands enriches the water and soil with nutrients. As the interface between terrestrial and aquatic ecological systems, wetlands provide food and habitat for many plant and animal species, including rare and endangered species. Because of these functions, wetlands support a number of human activities, including commercial fishing, shellfishing, and other industries, as well as recreation, education, and aesthetic enjoyment.

In addition, wetlands play a role in global biogeochemical cycles, particularly those driven in part by the microbial processes that occur in wetlands (e.g., the mineralization of sulfur and nitrogen from decaying plants and the methylation of mercury). Plant growth in wetlands provides a "sink" for many chemicals including atmospheric carbon. If a wetland is disturbed or degraded, these cycles can be altered and some of the chemicals may be released.

The extent of wetlands can be affected by a variety of natural stressors, such as erosion, land subsidence, changes in precipitation patterns (e.g., droughts), sea level change, hurricanes, and other types of storms. However, the vast majority of wetland losses and gains over the last few centuries have occurred as a result of human activity.[14] For years, people have drained or filled wetlands for agriculture or urban and suburban development, causing habitat loss or fragmentation as well as a decline in many of the other important functions outlined above, such as improving water quality. Conversely, other human activities may increase the extent of wetlands—for example, creating shallow ponds or re-establishing formerly drained or modified wetlands on farmlands.

Wetland extent may influence condition, as wetland loss may result in added stress to remaining wetlands. For example, if fewer wetlands are available to filter pollutants from surface waters, those pollutants could become more concentrated in remaining downgradient wetlands. Wetland loss and fragmentation also lead to decreases in habitat, landscape diversity, and the connectivity among aquatic resources (i.e., fragmented wetlands essentially become isolated wildlife refuges). Thus, stressors that affect extent may ultimately affect condition as well.

Wetland condition also reflects the influence of stressors that affect topography, hydrology, climate, water condition, and biodiversity. For example, human modifications such as pipes and channels can alter the topography, elevation, or hydrology of wetlands, while withdrawal of ground water or upstream surface waters can directly reduce inflow. Natural forces and human activities (e.g., hurricanes, sea level change, and certain agricultural and forestry practices) can also affect wetlands through increased erosion or sedimentation. Pollutants in ground water and fresh surface waters that flow into wetlands may be toxic to plants and animals, and may also accumulate in wetland sediments. In addition, invasive species can alter the composition of wetland communities. Some of the most well-known invasives in the U.S. are wetland species, including plants such as phragmites and purple loosestrife and animals such as the nutria (a South American rodent introduced to the Chesapeake and Gulf states).

Another key stressor to wetlands is conversion from one wetland type to another. Although conversion can occur naturally through plant succession (such as marshes turning into forested wetlands over time), human activities can cause more drastic changes, such as clearing trees from a forested wetland, excavating a marsh to create an open water pond, or introducing certain invasive species (e.g., the nutria, which converts tidal marsh to open water by removing vegetation). Even if wetland extent is not altered, conversion from one type to another has a major ecological impact by altering habitat types and community structure.

3.4.2 ROE Indicators

An ROE indicator describes trends in wetland extent, as well as specific activities that have contributed to recent wetland losses and gains (Table 3-4). Data were collected as part of the U.S. Fish and Wildlife Service's Wetlands Status and Trends survey, a probabilistic national survey of wetland acreage conducted approximately every 10 years for the past half-century. There is no ROE indicator for wetland condition.

Table 3-4. ROE Indicators of Trends in the Extent and Condition of Wetlands and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Wetland Extent, Change, and Sources of Change	3.4.2	3-32

[14] Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States, 1986 to 1997. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. <http://wetlandsfws.er.usgs.gov/status_trends/>

INDICATOR | Wetland Extent, Change, and Sources of Change

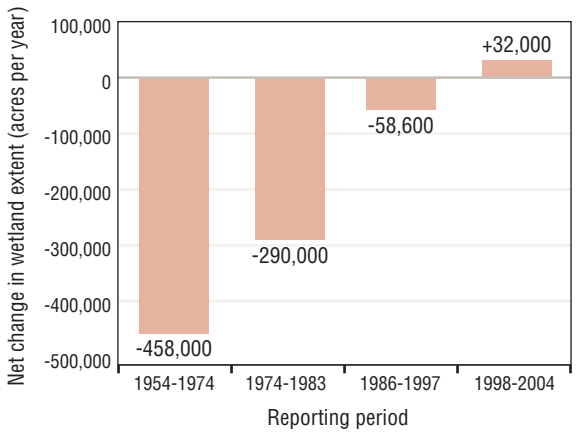
Wetlands support a variety of fish and wildlife species and contribute to the aesthetic and environmental quality of the U.S. Millions of Americans use freshwater wetlands annually for hunting, fishing, bird watching, and other outdoor activities. Coastal wetlands provide valuable nursery, feeding, breeding, staging, and resting areas for an array of fish, shellfish, mammals, and birds (Dahl, 2000). In addition, wetlands serve as ground water recharge areas and filter contaminants from surface runoff (Mitsch and Gosselink, 1986). Destruction or alteration of wetlands, therefore, can have wide-ranging biological, chemical, and hydrological impacts.

Various lines of evidence suggest that when European settlers first arrived, wetland acreage in the area that would become the contiguous 48 states was more than twice what it is today (Dahl, 1990). Since then, extensive losses have occurred due to draining and filling. In addition to the sheer loss of wetland acreage, major ecological impacts also have resulted from the conversion of one wetland type to another, such as clearing trees from a forested wetland or excavating a shallow marsh to create an open water pond. These types of conversions change habitat types and community structure in watersheds and impact the animal communities that depend on them (Dahl, 2000).

This indicator presents data from the U.S. Fish and Wildlife Service's Wetlands Status and Trends survey. Conducted approximately every 10 years, this survey provides an estimate of the extent of all wetlands in the contiguous U.S., regardless of land ownership. The Status and Trends survey uses a probabilistic design, based initially on stratification of the 48 contiguous states by state boundaries and 35 physiographic subdivisions. Within these subdivisions are located 4,375 randomly selected 4-square-mile (2,560-acre) sample plots. These plots are examined with the use of aerial imagery. Although the imagery ranges in scale and type, most are 1:40,000 scale, color infrared from the National Aerial Photography Program. Field verification is conducted to address questions of image interpretation, land use coding, and attribution of wetland gains or losses; plot delineations are also completed. In the 1980s to 1990s analysis, 21 percent of the sample plots were field-verified; in the most recent analysis, 32 percent were field-verified (Dahl, 2000, 2006). The Fish and Wildlife Service used the Cowardin et al. (1979) definition of wetlands, which is part of the draft national standard for wetland mapping, monitoring, and data reporting as determined by the Federal Geographic Data Committee.

This indicator shows trends in the total extent of wetlands, as well as the extent of several types of freshwater and intertidal wetlands. In this analysis, freshwater wetlands include forested, shrub, emergent, and non-vegetated wetlands (e.g., shallow ponds). Intertidal wetlands include marine areas (e.g., tidal flats and sandbars) and estuarine areas (vegetated or not) that are exposed and flooded by the tides. Data on wetland extent are described from several Status and Trends analyses: 1950s–1970s, 1970s–1980s, 1980s–1990s, and 1998–2004 (Frayer et al., 1983; Dahl and Johnson, 1991; Dahl, 2000, 2006). For the most recent period, the indicator also describes sources of wetland loss or gain, which the survey divided into five distinct land use categories along with an "other" category reflecting all other land use types (Dahl, 2006).

Exhibit 3-17. Average annual change in wetland acreage in the contiguous U.S., 1954-2004



Data source: *Dahl, 2006*

What the Data Show

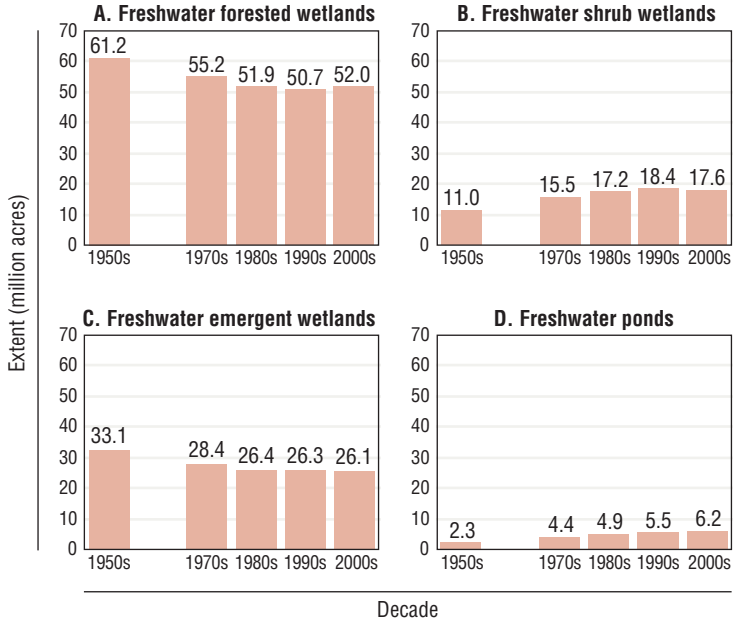
Total wetland acreage declined over the last 50 years, but the rate of loss appears to have slowed over time. From the 1950s to the 1970s, an average of 458,000 acres was lost per year (Exhibit 3-17). By the 1986–1997 period, the loss rate had declined to 58,600 acres per year; and in the most recent study period, 1998–2004, wetland area increased at a rate of 32,000 acres per year (Exhibit 3-17).

Gains and losses have varied by wetland type. Freshwater forested wetlands, which make up more than half of all freshwater wetlands, lost acreage from the 1950s to the 1990s but have shown gains over the last decade (Exhibit 3-18, panel A). Freshwater emergent wetlands have continued to lose acreage, although the rate of loss has slowed recently (panel C). Among freshwater categories, forested wetlands have sustained the greatest absolute losses since the 1950s, about 9 million acres, while emergent wetlands have shown the largest percentage loss (about 21 percent). Conversely, the extent of freshwater shrub wetlands increased until the 1990s but declined thereafter,

suggesting that some of the gains and losses in specific categories may reflect conversion rather than outright wetland loss or gain (Dahl, 2006; Exhibit 3-18, panel B). Shallow freshwater ponds, meanwhile, have increased steadily throughout the last 50 years, with current acreage more than twice what it was in the 1950s, although still much less in absolute terms than the other wetland types (panel D). These wetlands account for a large percentage of the recent gains illustrated in Exhibit 3-17 (Dahl, 2006).

Since the 1950s, intertidal wetland acreage has decreased by about 700,000 acres, or 12 percent (Exhibit 3-19, panel A). This category includes marine, estuarine vegetated, and estuarine non-vegetated wetlands. Both estuarine types lost acreage overall, with estuarine vegetated wetlands, the predominant type, losing over 400,000 acres (panel B). Long-term trends, however, indicate that losses of intertidal wetlands have slowed over time, with estuarine non-vegetated wetlands actually gaining acreage over the last decade (panel C).

Exhibit 3-18. Extent of selected freshwater wetlands in the contiguous U.S., 1950s-2000s[a]



[a]Based on mid-decade surveys. No analysis was conducted for the 1960s.

Data source: *Dahl, 2006*

Between 1998 and 2004, urban development, rural development, silviculture, and conversion to deepwater (e.g., the disappearance of coastal wetlands or flooding to create reservoirs) all contributed to losses in wetland acreage (Exhibit 3-20). However, the net change in wetland acreage during this period was positive, due largely to wetland creation and restoration on agricultural lands (70,770 acres) and on lands classified as "other" (349,600 acres). This "other" category includes conservation lands, areas in transition from one land use to another, and other lands that do not fall into the major land use categories as defined in Dahl (2006).

Indicator Limitations

- Different methods were used in some of the early schemes to classify wetland types. As methods and spatial resolution have improved over time, acreage data have been adjusted, resulting in changes in the overall wetland base over time, thus reducing the accuracy of the trend.
- Ephemeral waters and effectively drained palustrine wetlands observed in farm production are not recognized as wetland types by the Status and Trends survey and are therefore not included in the indicator.
- Forested wetlands are difficult to photointerpret and are generally underestimated by the survey.
- The aerial imagery used for this survey generally does not allow detection of small, isolated patches of wetland less than about an acre.
- Alaska and Hawaii are not included in the Status and Trends survey.
- This survey does not include Pacific coast estuarine wetlands such as those in San Francisco Bay, Puget Sound, or Coos Bay, Oregon.

Data Sources

Data for this indicator were obtained from Dahl (2006). Historical trends are based on data originally presented in earlier Fish and Wildlife Service reports (Dahl, 2000; Dahl and Johnson, 1991; Frayer et al., 1983).

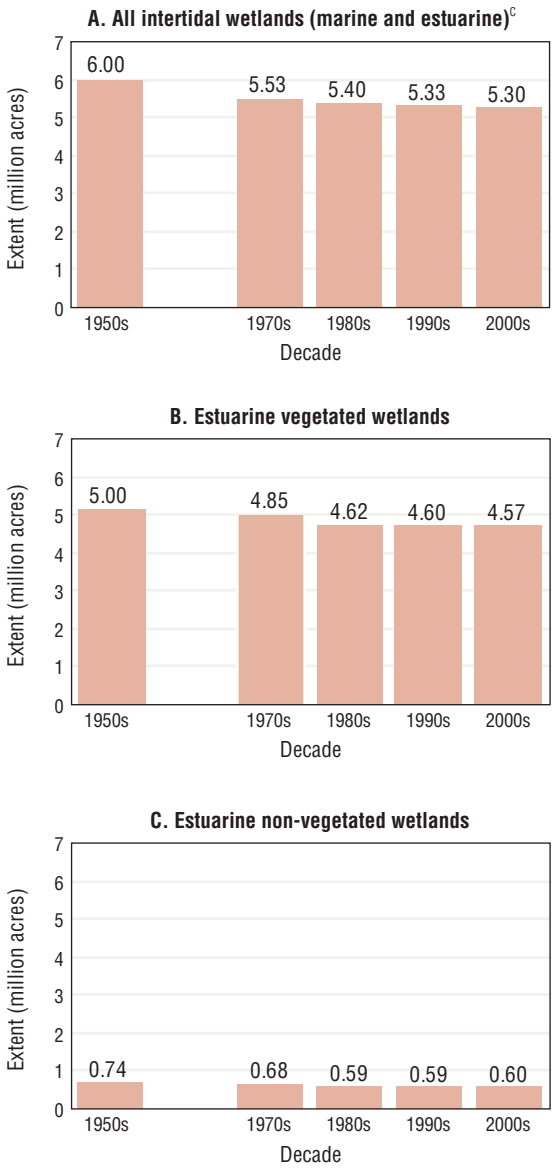
References

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. <http://library.fws.gov/FWS-OBS/79_31.pdf>

Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. <http://wetlandsfws.er.usgs.gov/status_trends/>

INDICATOR | Wetland Extent, Change, and Sources of Change *(continued)*

Exhibit 3-19. Extent of marine and estuarine wetlands in the contiguous U.S., 1950s-2000s[a,b]



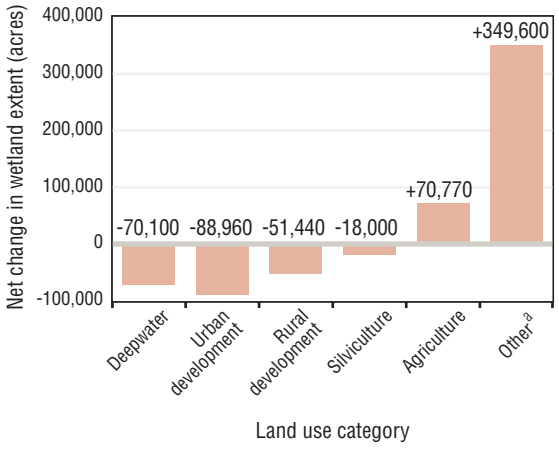
[a]Based on mid-decade surveys. No analysis was conducted for the 1960s.

[b]Surveys did not include Pacific coast estuarine wetlands.

[c]Panel A is the sum of panel B, panel C, and marine wetland acreage.

Data source: *Dahl, 2006*

Exhibit 3-20. Sources of wetland gain and loss in the contiguous U.S., 1998-2004



[a]"Other" includes lands that do not fit into any of the other five categories, such as conservation land and land in transition between different uses.

Data source: *Dahl, 2006*

Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. <http://wetlandsfws.er.usgs.gov/status_trends/>

Dahl, T.E. 1990. Wetlands losses in the United States 1780s to 1980s. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. <http://wetlandsfws.er.usgs.gov/status_trends/>

Dahl, T.E., and C.E. Johnson. 1991. Status and trends of wetlands in the conterminous United States, mid-1970s to mid-1980s. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. <http://wetlandsfws.er.usgs.gov/status_trends/>

Frayer, W.E., T.J. Monahan, D.C. Bowden, and F.A. Graybill. 1983. Status and trends of wetlands and deepwater habitats in the conterminous United States, 1950s to 1970s. Ft. Collins, CO: Colorado State University. <http://wetlandsfws.er.usgs.gov/status_trends/>

Mitsch, W.J., and J.G. Gosselink. 1986. Wetlands. New York, NY: Van Nostrand Reinhold Company Inc.

3.4.3 Discussion

What This Indicator Says About Trends in the Extent and Condition of Wetlands and Their Effects on Human Health and the Environment

Wetland extent in the contiguous 48 states is substantially lower than it was prior to widespread European settlement and it generally continued to decline over the last 50 years (Wetlands indicator, p. 3-32). The rate of loss of wetlands overall and for most types of wetlands has slowed over time, however, and since 1998 the overall extent of wetlands has actually increased. Not all types of wetlands have experienced the same rate of losses or overall percent losses. For example, freshwater shrub wetlands actually increased over the last 50 years—providing evidence of wetland conversion, most likely from forested wetlands to shrub. The nation has also seen a steady increase in acreage of freshwater ponds, which account for a substantial portion of the recent gains in overall wetland acreage.

This indicator also confirms the role of many of the stressors described in Section 3.4.1. Over the last decade, development, forestry, and conversion to deepwater (e.g., marsh to open water) have led to losses in wetland extent, while agricultural areas have experienced overall gains in wetland acreage. The other source of new wetland acreage is from the "other" land use category, which reflects the growing importance of constructed and restored wetlands, including ponds associated with golf courses and residential development.

While this indicator does not directly quantify the condition of the nation's wetlands, it suggests that the condition of many wetlands may be impacted. As discussed in Section 3.4.1, extent can be a partial surrogate for condition because wetland loss can increase the stress on those wetlands that remain, while decreasing their connectivity. Thus, the overall decline in extent over the last 50 years suggests the potential for substantial ecological impacts such as habitat loss and increased flood impacts. Changes in the extent of different *types* of wetlands also suggest changes in condition. Shallow ponds, which constitute a large fraction of the recent gains in wetland acreage, will not perform the same range and type of environmental functions as the vegetated wetlands that disappeared between the 1950s and the 1990s, some of which continue to be lost. Similarly, evidence of wetland conversion indicates that even if extent is no longer declining rapidly, changes in wetland structure and function are still occurring. In the past, studies have shown that wetlands that have been created to mitigate wetland losses have not yet provided the same functions and values of the wetlands that were lost.[15,16]

Limitations, Gaps, and Challenges

By relying on aerial imagery and statistical surveying techniques, the Wetlands indicator (p. 3-32) provides a national estimate using a logistically plausible number of samples. However, a limitation to this survey is that it may omit or undercount certain types of wetlands, including forested wetlands—which are difficult to photointerpret—and ephemeral or well-drained agricultural wetlands, which are not necessarily obvious to the surveyor but are particularly threatened by development. This indicator also does not include wetland parcels smaller than about 1 acre, which become more critical as larger wetlands are fragmented into smaller pieces.

Wetland condition poses a larger challenge for assessment. While the Wetlands indicator (p. 3-32) provides information that can be used to infer potential wetland condition, it does not explicitly measure condition—in part because condition is difficult to quantify. Condition is made up of many different attributes, and each wetland has its own unique baseline condition and function, with a unique hydrologic setting and combination of plant and animal species. Some studies have quantified regional changes in specific stressors; however, national indicators would have to bring together many regional datasets and cover many different aspects of condition in order to be truly comprehensive. The lack of such national-scale information is currently a gap in addressing the question of wetland condition. Potential human health effects associated with wetland extent and condition are also difficult to quantify, and there are no ROE indicators on this topic.

Another information gap concerns the spatial patterns of wetland change, which are not documented in the existing national data. Are most large wetlands being left intact? Are human activities threatening to fragment larger wetlands into smaller pieces that are less connected and more isolated, and therefore less able to perform the desired ecological functions? Data on patterns of wetland loss—e.g., fragmentation and edge effects—would be a useful complement to the existing data on overall losses and gains.

3.5 What Are the Trends in the Extent and Condition of Coastal Waters and Their Effects on Human Health and the Environment?

3.5.1 Introduction

Coastal waters are one of the nation's most important natural resources, valued for their ecological richness as well as for the many human activities they support. As the interface between

[15] National Research Council. 2001. Compensating for wetland losses under the Clean Water Act. Washington, DC: National Academies Press. <http://www.nap.edu/books/0309074320/html/>

[16] Mack, J.J., and M. Micacchion. 2006. An ecological assessment of Ohio mitigation banks: Vegetation, amphibians, hydrology, and soils. Ohio EPA Technical Report WET/2006-1. Columbus, OH: Ohio Environmental Protection Agency. <http://www.epa.state.oh.us/dsw/wetlands/WetlandBankReport.html>

terrestrial environments and the open ocean, coastal waters encompass many unique habitats, such as estuaries, coastal wetlands, seagrass meadows, coral reefs, mangrove and kelp forests, and upwelling areas.[17,18] Coastal waters support many fish species for at least part of their life cycle, offering some of the most productive fisheries habitats in the world. These waters also provide breeding habitat for 85 percent of U.S. waterfowl and other migratory birds (largely in coastal wetlands),[19] and support many other organisms with high public visibility (e.g., marine mammals, corals, and sea turtles) or unique ecological significance (e.g., submerged aquatic vegetation). For humans, coastal waters provide opportunities for tourism and recreation, and they contribute to the economy through transportation, fisheries, and mining and utilities.[20] Lands adjacent to the coast are highly desirable places for people to live, and represent the most densely developed areas in the nation.[21]

Extent and condition are two key variables in assessing coastal waters and their ability to serve ecological and human needs. The *extent* of coastal waters—i.e., the spatial area—is particularly important in terms of the extent of specific types of coastal waters, such as coastal wetlands or coral reefs. The *condition* of coastal waters reflects a group of interrelated physical, chemical, biological, and ecological attributes. For example, nutrient levels should be sufficient to support the food web but not so high as to cause eutrophication, while toxic chemical contaminants in water and sediment may pose a threat to aquatic organisms or accumulate in the food web. Of particular concern to human health are contaminants in consumable fish and shellfish—a topic discussed separately in Section 3.8. Other key aspects of condition include levels of pathogens and organisms that produce biotoxins—which may pose a risk to human health through aquatic recreation or contaminated fish and shellfish, and which may impact the environment by injuring native populations. Also important is the degree to which native plant and animal populations are healthy and their habitats intact.

Many factors can affect the extent of coastal waters. For example, the extent of coastal wetlands may be influenced by natural events such as erosion or storms, or by human activities such as draining or filling wetlands for development. Natural processes can change the shape of a coastline, with wave action eroding some areas while building up sediment in others, and rivers depositing sediments at their mouth. Human stressors can alter these patterns—for example, through the construction of seawalls or barriers or through the channeling of rivers, which can lead to subsidence in coastal areas that would otherwise be naturally replenished by sediments.

Changes in extent may in turn affect the condition of coastal waters. For example, beach erosion and coastal wetland loss can also affect contaminant and sediment levels, nutrient cycling, and the condition of spawning and feeding grounds for fish, shellfish, and other coastal species. As described in Section 3.4.1, the loss of some wetlands can also affect the condition of the wetlands that remain.

Other stressors to the condition of coastal waters include nutrients, pathogens, and chemical contaminants, which may pose risks to ecological systems or to human health. Nutrients and pathogens occur naturally, but their abundance can be increased by human activities along the coast or in upstream watersheds that ultimately discharge to coastal waters. Major sources include urban and suburban storm water, agricultural runoff, and sewage discharge or overflows. Chemical contaminants may come from these same sources, as well as from industrial activities that discharge treated wastewaters and from atmospheric deposition of airborne pollutants.

Several other stressors can affect the quality of habitat and the status of native plant and animal populations. For example, many species are sensitive to temperature and salinity, which can be influenced by changes in weather patterns or the condition of freshwater inputs. Salinity is particularly important in estuaries, where species may depend on a steady, reliable flow of fresh water. Another factor affecting the status of native communities is the presence and abundance of non-indigenous species—particularly invasive species that can kill or crowd out native populations, or otherwise alter coastal watersheds. Populations of fish, shellfish, marine mammals, and other species used by humans may also be affected by overharvesting.

In many cases, stressors that affect coastal condition are interrelated. For example, excess nutrients can cause algal blooms (and subsequent decay) that result in low dissolved oxygen and reduced water clarity—the chain of events known as eutrophication. Temperature and salinity can also influence algal blooms. Some algae, such as "red tide," produce toxins that pose risks to humans.

[17] U.S. Environmental Protection Agency. 2004. National coastal condition report II. EPA/620/R-03/002. <http://www.epa.gov/owow/oceans/nccr/2005/index.html>

[18] Although the Laurentian Great Lakes are included in EPA's Coastal Condition Report because they fall under the "Great Waters" designation, in the ROE they are covered in the question on fresh surface waters, Section 3.2.

[19] U.S. Environmental Protection Agency. 2004. National coastal condition report II. EPA/620/R-03/002. <http://www.epa.gov/owow/oceans/nccr/2005/index.html>

[20] National Oceanic and Atmospheric Administration. 2005. Economic statistics for NOAA. May 2005. Fourth edition. U.S. Department of Commerce. <http://www.publicaffairs.noaa.gov/pdf/economic-statistics2005.pdf>

[21] National Oceanic and Atmospheric Administration. 2004. Population trends along the coastal United States: 1980-2008. Coastal trends report series. Silver Spring, MD: U.S. Department of Commerce, National Ocean Service.

3.5.2 ROE Indicators

Five National Indicators and two Regional Indicators characterize the extent and condition of coastal waters (Table 3-5). National Indicators describe sediment quality, benthic community condition, contamination in fish tissue, and several aspects of coastal water quality, as well as trends in the extent of marine and estuarine wetlands. The Regional Indicators characterize trends in the extent of areas with low dissolved oxygen (i.e., hypoxia) and the extent of submerged aquatic vegetation (SAV). These Regional Indicators reflect conditions in three important and unique coastal water bodies: the Gulf of Mexico, Long Island Sound, and the Chesapeake Bay.

The National Indicator on wetland extent is based on data gathered from aerial and ground surveys conducted as part of the U.S. Fish and Wildlife Service's Wetlands Status and Trends study, a long-term statistical sampling effort. The other four National Indicators are derived from EPA's second National Coastal Condition Report, which involved probabilistic surveys designed to represent 100 percent of estuarine acreage in the contiguous 48 states and Puerto Rico. In addition to national totals, these four indicators present data by EPA Region. The Regional Indicator on trends in hypoxia reflects data from two long-term water sampling programs, while the indicator on SAV is based on aerial imagery.

Table 3-5. ROE Indicators of Trends in the Extent and Condition of Coastal Waters and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Wetland Extent, Change, and Sources of Change	3.4.2	3-32
Trophic State of Coastal Waters (N/R)	3.5.2	3-38
Coastal Sediment Quality (N/R)	3.5.2	3-42
Coastal Benthic Communities (N/R)	3.5.2	3-44
Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
Regional Indicators	**Section**	**Page**
Submerged Aquatic Vegetation in the Chesapeake Bay	3.5.2	3-46
Hypoxia in the Gulf of Mexico and Long Island Sound	3.5.2	3-48

N/R = National Indicator displayed at EPA Regional scale

INDICATOR | Trophic State of Coastal Waters

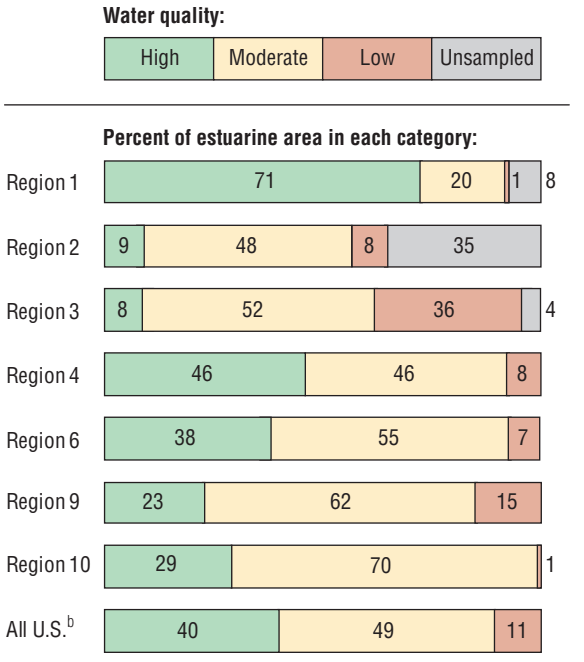
While the presence of many water pollutants can lead to decreases in coastal water quality, four interlinked components related to trophic state are especially critical: nutrients (nitrogen and phosphorus), chlorophyll-*a*, dissolved oxygen, and water clarity. "Trophic state" generally refers to aspects 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).

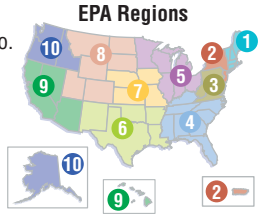
The overall water quality index is a compilation of the five components. For each site, the index is rated high if none of the five components received a score that would

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



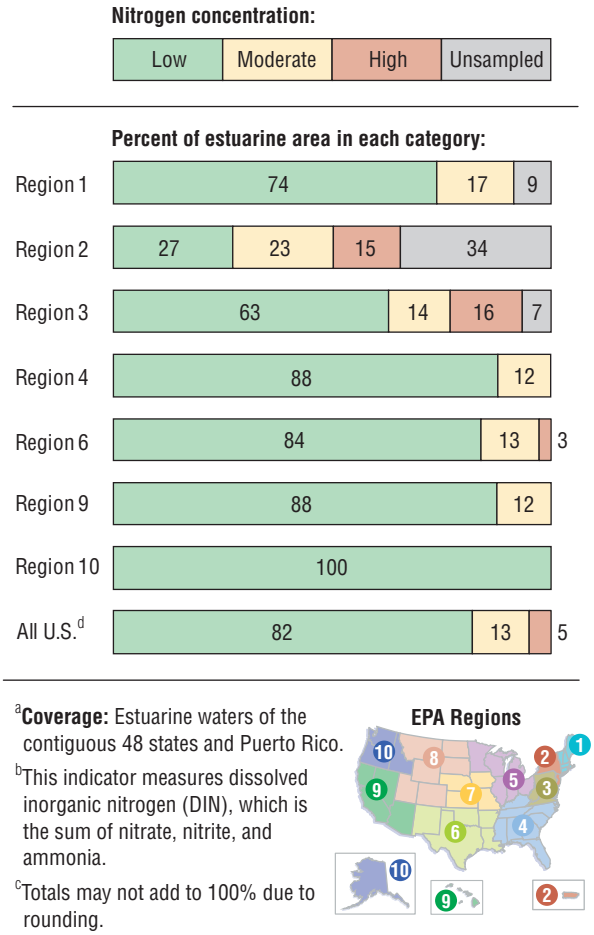
[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico. Does not include the hypoxic zone in offshore Gulf Coast waters.

[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.

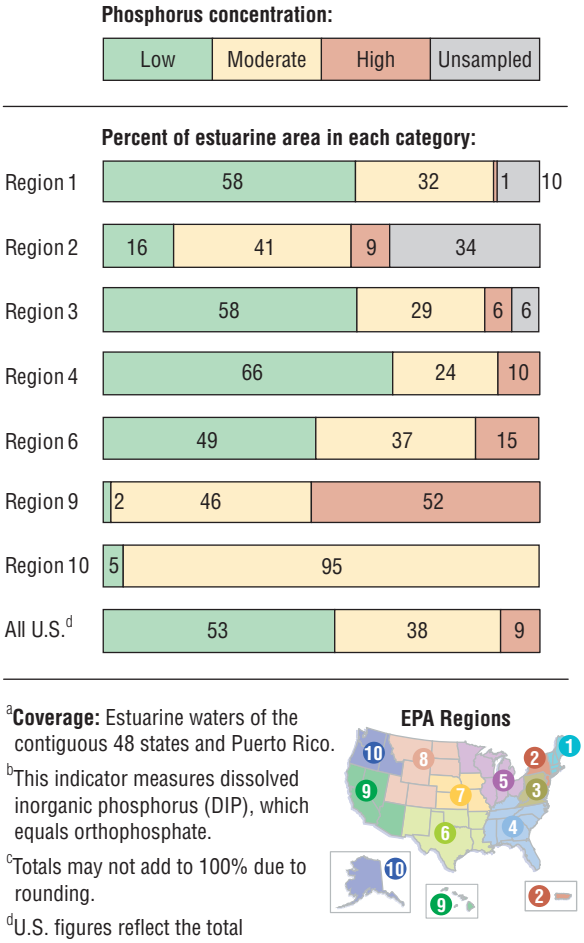
[b]This indicator measures dissolved inorganic nitrogen (DIN), which is the sum of nitrate, nitrite, and ammonia.

[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*

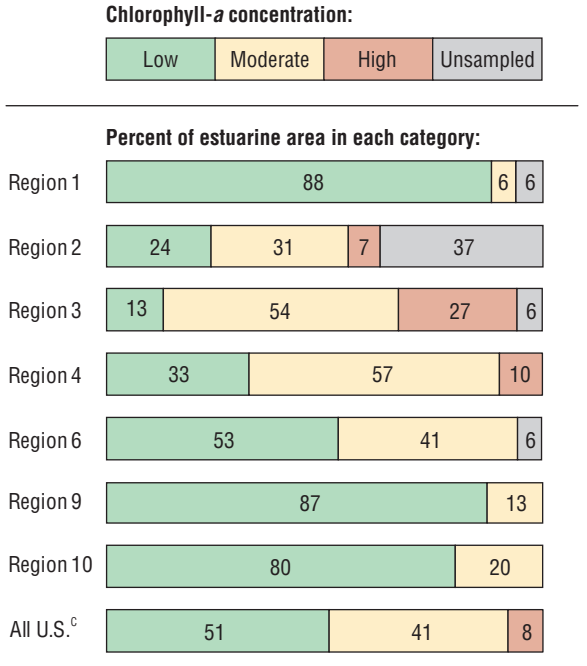
be considered environmentally unfavorable (high nitrogen, phosphorus, or chlorophyll-*a* levels or low dissolved oxygen or water clarity), and no more than one component was rated moderate. Overall water quality is low if more than two components received the most unfavorable rating. All other sites 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, p. 3-48).

INDICATOR | Trophic State of Coastal Waters *(continued)*

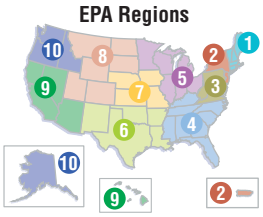
Exhibit 3-24. Chlorophyll-*a* concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a,b]



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

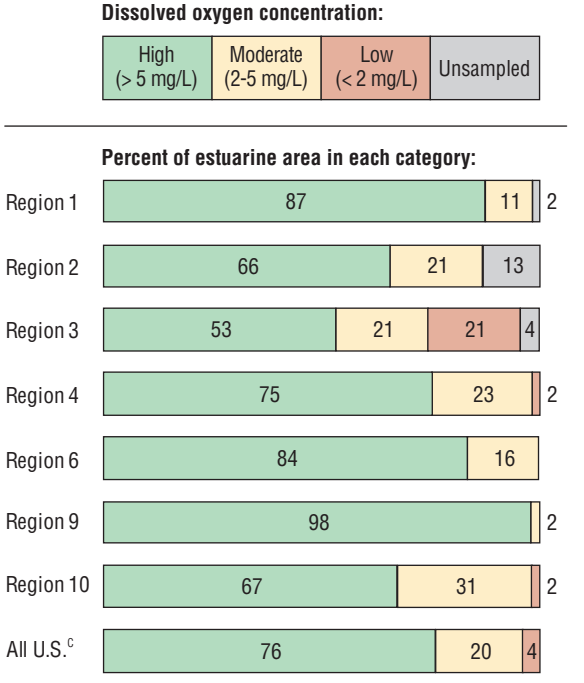
[b]Totals may not add to 100% due to rounding.

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



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

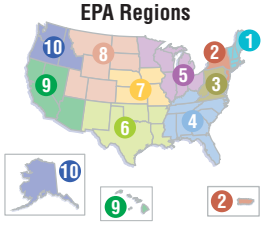
Exhibit 3-25. Dissolved oxygen levels in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a,b]



[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*

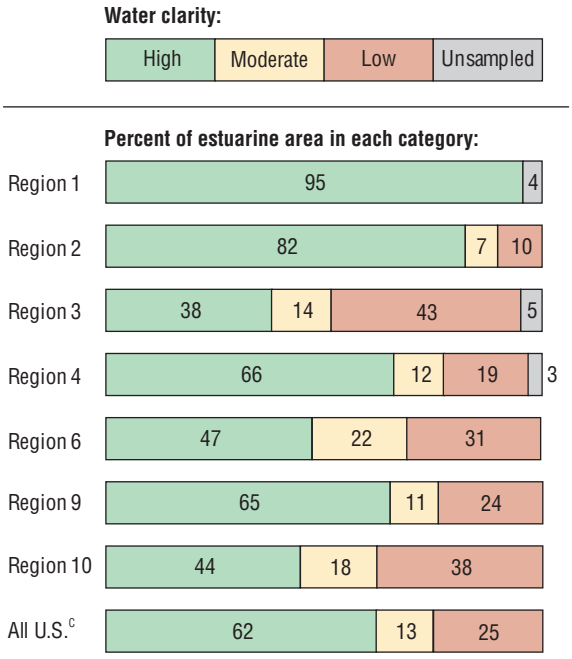
Nitrogen concentrations were low in 82 percent of estuarine area and high in 5 percent nationwide, and were low in a majority of the estuarine area in all but one EPA Region (Exhibit 3-22). Regions 2 and 3 had the largest percentage of area with high concentrations (15 percent and 16 percent, respectively); 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.

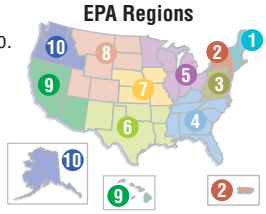
Exhibit 3-26. Water clarity in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a,b]



[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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INDICATOR | Coastal Sediment Quality

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.

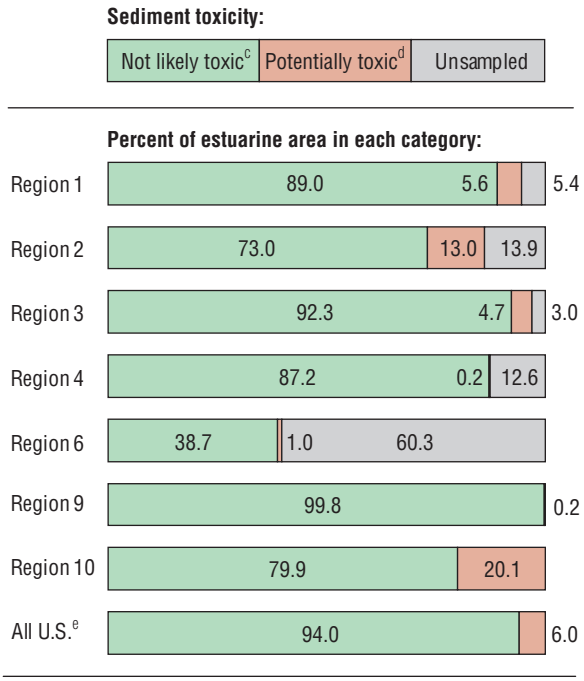
This indicator presents data on sediment toxicity and contaminant levels. The data are from probabilistic surveys conducted as part of EPA's National Coastal Assessment (NCA) and presented in EPA's second National Coastal Condition Report (U.S. EPA, 2004b). The survey was designed to provide a national 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]

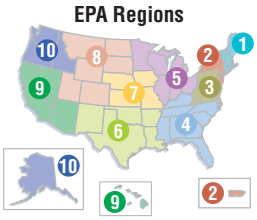


[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

[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, p. 3-44).

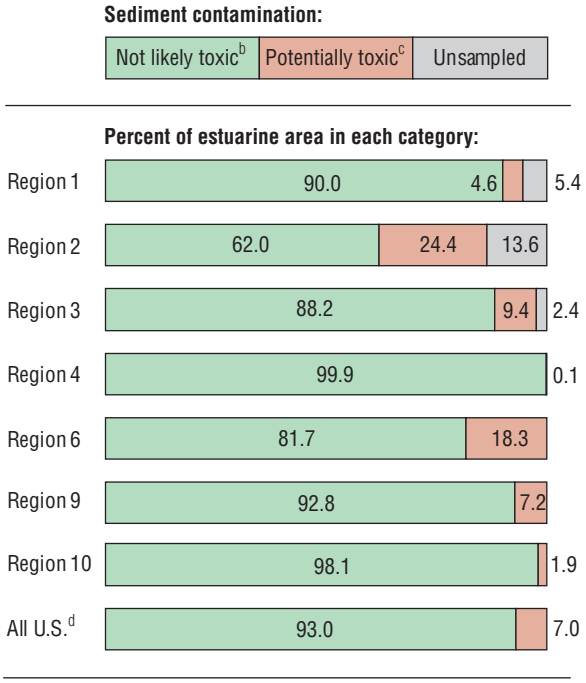
What the Data Show

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.

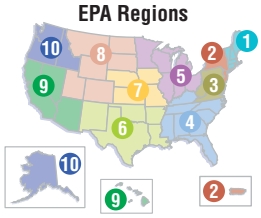
Exhibit 3-28. Sediment contamination in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a]



[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 (p. 3-27) uses thresholds intended to be protective of aquatic life with a margin of safety, instead of

INDICATOR | Coastal Sediment Quality *(continued)*

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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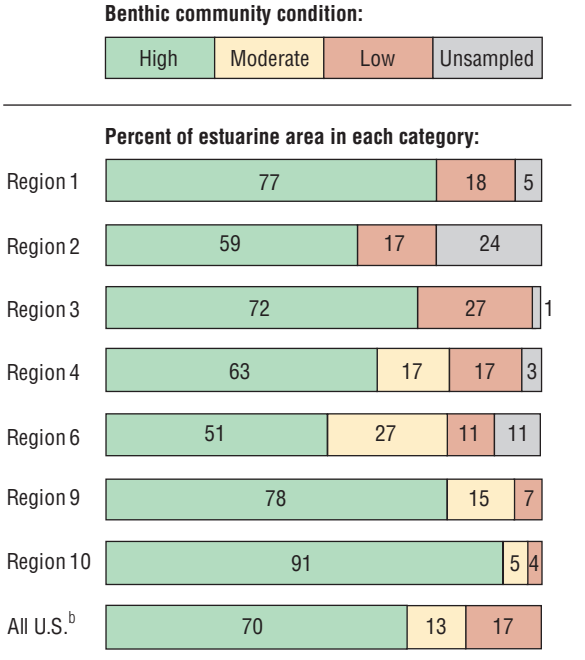
INDICATOR | Coastal Benthic Communities

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

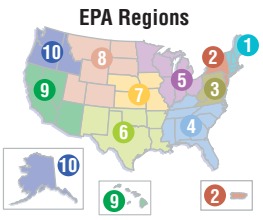
Exhibit 3-29. Coastal benthic communities index for the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000 [a]



[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*



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.

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 Benthic Communities *(continued)*

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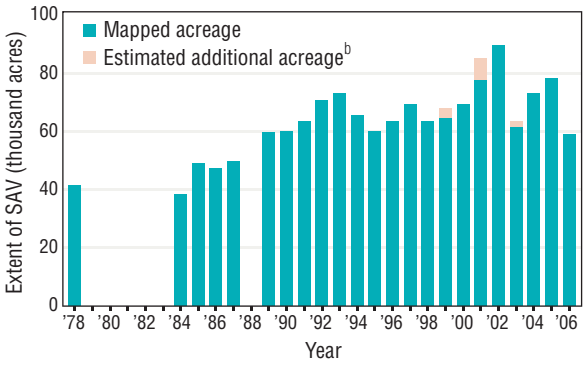
INDICATOR | Submerged Aquatic Vegetation in the Chesapeake Bay

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.

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*

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).

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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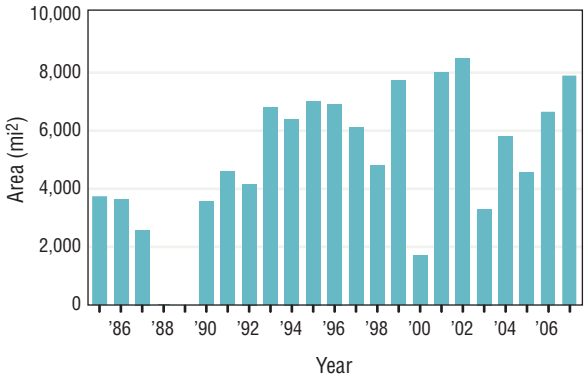
INDICATOR | Hypoxia in the Gulf of Mexico and Long Island Sound

Nutrient pollution is one of the most pervasive problems facing U.S. coastal waters, with more than half of the nation's estuaries experiencing one or more symptoms of eutrophication (Bricker et al., 1999; NRC, 2000; U.S. Commission on Ocean Policy, 2004). One symptom is low levels of dissolved oxygen (DO), or hypoxia. Hypoxia can occur naturally, particularly in areas where natural physical and chemical characteristics (e.g., salinity or mixing parameters) limit bottom-water DO. The occurrence of hypoxia in shallow coastal and estuarine areas appears to be increasing, however, and is most likely accelerated by human activities (Jickells, 1998; Vitousek et al., 1997).

This indicator tracks trends in hypoxia in the Gulf of Mexico and Long Island Sound, which are prime examples of coastal areas experiencing hypoxia. For consistency, this indicator focuses on occurrences of DO below 2 milligrams per liter (mg/L), but actual thresholds for "hypoxia" and associated effects can vary over time and space. Hypoxia often is defined as a concentration of DO below saturation, and because saturation levels vary with temperature and salinity, the concentration that defines hypoxia will vary seasonally and geographically. Effects of hypoxia on aquatic life also vary, as some organisms are more sensitive to low DO than others. As a general rule, however, concentrations of DO above 5 mg/L are considered supportive of marine life, while concentrations below this are potentially harmful. At about 3 mg/L, bottom fishes may start to leave the area, and the growth of sensitive species such as crab larvae is reduced. At 2.5 mg/L, the larvae of less sensitive species of crustaceans may start to die, and the growth of crab species is more severely limited. Below 2 mg/L, some juvenile fish and crustaceans that cannot leave the area may die, and below 1 mg/L, fish totally avoid the area or begin to die in large numbers (Howell and Simpson, 1994; U.S. EPA, 2000).

The Gulf of Mexico hypoxic zone on the Texas-Louisiana Shelf is the largest zone of coastal hypoxia in the Western Hemisphere (CAST, 1999). It exhibits seasonally low oxygen levels as a result of complicated interactions involving excess nutrients carried to the Gulf by the Mississippi and Atchafalaya Rivers; physical changes in the river basin, such as channeling, construction of dams and levees, and loss of natural wetlands and riparian vegetation; and the stratification in the waters of the northern Gulf caused by the interaction of fresh river water and the salt water of the Gulf (CENR, 2000; Rabalais and Turner, 2001). Increased nitrogen and phosphorus inputs from human activities throughout the basin support an overabundance of algae, which die and fall to the sea floor, depleting oxygen in the water as they decompose. Fresh water from the rivers entering the Gulf of Mexico forms a layer of fresh water above the saltier Gulf waters and prevents re-oxygenation of oxygen-depleted water along the bottom.

Exhibit 3-31. Extent of dissolved oxygen less than 2.0 mg/L in Gulf of Mexico bottom waters in mid-summer, 1985-2007[a]



[a]Only 15 square miles were affected in 1988. No data were collected in 1989.

Data source: *LUMCON, 2007a,b*

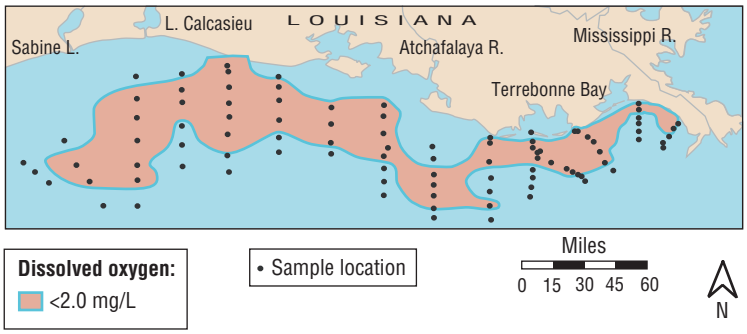
In Long Island Sound, seasonally low levels of oxygen usually occur in bottom waters from mid-July though September, and are more severe in the western portions of the Sound, where the nitrogen load is higher and stratification is stronger, reducing mixing and re-oxygenation processes (Welsh et al., 1991). While nitrogen fuels the growth of microscopic plants that leads to low levels of oxygen in the Sound, temperature, wind, rainfall, and salinity can affect the intensity and duration of hypoxia.

Data for the two water bodies are presented separately because they are collected through two different sampling programs, each with its own aims and technical approach. The Gulf of Mexico survey is conducted by the Louisiana Universities Marine Consortium (LUMCON) and is designed to measure the extent of bottom-water hypoxia in the summer, with samples collected during a cruise that generally occurs over a 5-day period in mid- to late July (LUMCON, 2007b). Samples are collected day and night along several transects designed to capture the overall extent of the hypoxic zone. The number of locations varies from 60 to 90 per year, depending on the length of the sampling cruise, the size of the hypoxic zone, logistical constraints, and the density of station locations. Long Island Sound sampling is conducted by the Connecticut Department of Environmental Protection's Long Island Sound Water Quality Monitoring Program, and is designed to determine both the maximum extent and the duration of hypoxia (Connecticut DEP, 2007). Sampling is performed every month from October to May and every 2 weeks from June to September at a set of fixed locations throughout the Sound. All Long Island Sound samples are collected during the day.

What the Data Show

The size of the midsummer bottom-water hypoxia area (<2 mg/L DO) in the Northern Gulf of Mexico has varied considerably since 1985, ranging from 15 square miles in 1988 (a drought year in the Mississippi Basin) to approximately 8,500 square miles in 2002 (Exhibit 3-31). The unusually low areal extent in 2000 also was associated with very low discharge from the Mississippi River (see the N and P Loads in Large Rivers indicator, p. 3-17). In the latest year of sampling, 2007, the hypoxic zone measured 7,900 square miles, roughly the size of New Jersey (Exhibits 3-31 and 3-32). Over the full period of record (1985-2007), the area with DO less than 2 mg/L has averaged approximately 5,200 square miles.

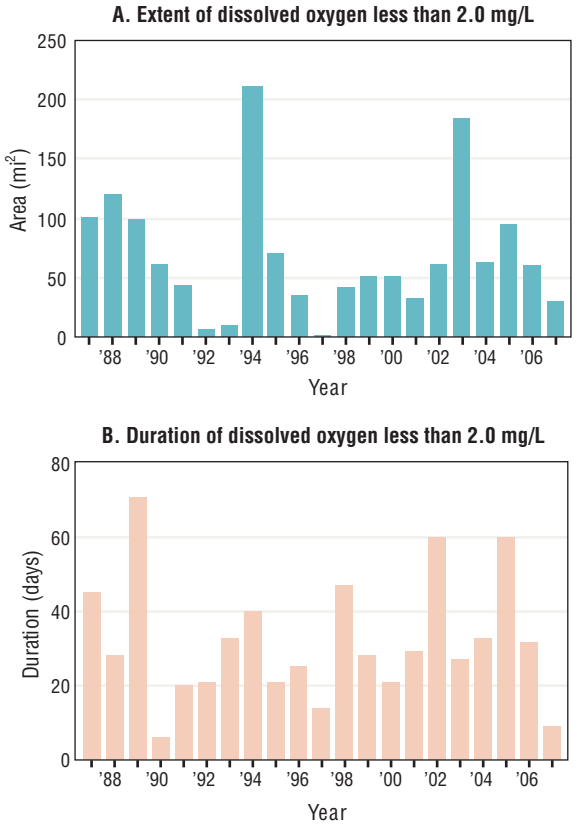
Exhibit 3-32. Dissolved oxygen less than 2.0 mg/L in Gulf of Mexico bottom waters, July 21-28, 2007



Data source: *LUMCON, 2007b*

The maximum extent and duration of hypoxic events (<2 mg/L DO) in Long Island Sound also has varied considerably since the 1980s (Exhibit 3-33). Since 1987, the largest area of DO less than 2 mg/L was 212 square miles, which occurred in 1994; the smallest area, 2 square miles, occurred in 1997 (panel A). The shortest hypoxic event was 6 days in 1990 and the longest was 71 days, in 1989 (panel B). In 2007, the latest year for which data are available, the maximum area and duration of DO less than 2 mg/L in Long Island Sound were 31 square miles and 9 days, respectively, with the lowest DO levels occurring in the western end of the Sound (Exhibits 3-33 and 3-34). Between 1987 and 2007, the average annual maximum was 68 square miles and 32 days.

Exhibit 3-33. Maximum extent and duration of dissolved oxygen less than 2.0 mg/L in Long Island Sound bottom waters, 1987-2007



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

Indicator Limitations

Gulf of Mexico:

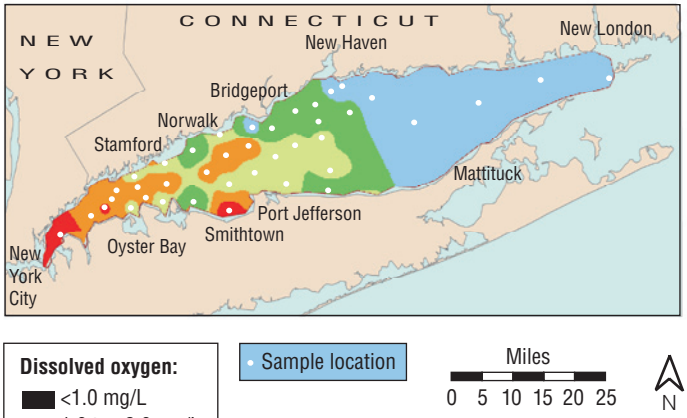
- This indicator is based on a survey conducted over a 5-day period when hypoxia is expected to be at its maximum extent. The indicator does not capture periods of hypoxia or anoxia (no oxygen at all) occurring at times other than the mid-summer surveys.
- Because the extent of hypoxia is measured through a single mid-summer sampling cruise, duration cannot be estimated.
- This indicator does not track vertical extent of hypoxia or anoxic volume.
- Surveys usually end offshore from the Louisiana-Texas state line; in years when hypoxia extends onto the upper Texas coast, the spatial extent of hypoxia is underestimated.

Long Island Sound:

- Hypoxic or anoxic periods that may occur between the 2-week surveys are not captured in the indicator.
- Samples are taken in the daytime, approximately 1 meter off the bottom. This indicator does not capture oxygen conditions at night (which may be lower because of the lack of photosynthesis) or conditions near the sediment-water interface.

INDICATOR | Hypoxia in the Gulf of Mexico and Long Island Sound *(continued)*

Exhibit 3-34. Dissolved oxygen in Long Island Sound bottom waters, July 30-August 1, 2007



Data source: *Connecticut DEP, 2007*

Data Sources

Maps and summary data from the 2007 Gulf of Mexico survey are published online (LUMCON, 2007b). Data from prior years were provided by LUMCON (2007a).

Data on the extent and duration of hypoxia in Long Island Sound have not been published, but were compiled by EPA's Long Island Sound Office (U.S. EPA, 2007). Concentration maps are available online (Connecticut DEP, 2007)—including the 2007 map shown in Exhibit 3-34.

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3.5.3 Discussion

What These Indicators Say About Trends in the Extent and Condition of Coastal Waters and Their Effects on Human Health and the Environment

Extent

Although the ROE indicators do not characterize the extent of all coastal waters, the Wetlands indicator (p. 3-32) shows that at least one type of coastal system has experienced changes in extent over the last half-century. The number of acres of marine and estuarine wetlands has decreased overall since the 1950s, although the rate of loss has slowed in recent years. While the indicator does not identify the exact stressors responsible for the decline in marine and estuarine wetlands, it does list several factors that have led to overall wetland loss, including development and conversion to deepwater. Section 3.4 provides further detail on how human activities can affect wetland extent, including human activities that exacerbate natural processes (e.g., storm damage). Ultimately, trends in wetland extent affect ecological systems, as described further below.

Condition

Together, these indicators cover much of the spectrum of "condition," including three of the broad themes introduced in Section 3.5.1: nutrients, toxic chemical contaminants, and the condition of native populations and their habitat. As described in Section 3.5.1, excess nutrients can cause algal blooms that result in low dissolved oxygen and reduced water clarity, which in turn can harm plant and animal communities. For example, the Trophic State of Coastal Waters indicator (p. 3-38) shows elevated levels of nutrients and chlorophyll-a (a surrogate for algal abundance) in a small but substantial portion of the nation's estuarine areas. These results are consistent with indicators that show evidence of eutrophication, such as decreased water clarity and hypoxia. The SAV in Chesapeake Bay indicator (p. 3-46) in turn offers an example of an ecological effect linked to eutrophication. Nutrient stressors cannot be attributed entirely to human activities; for example, the Gulf of Mexico hypoxic zone results in part from natural mixing parameters, and trends in the extent of hypoxic zones show large year-to-year variations related to factors like climate (Hypoxia in Gulf of Mexico and Long Island Sound indicator, p. 3-48). However, as the spatial distribution of hypoxia in Long Island Sound suggests, the nation's coastal waters can experience eutrophic effects that are very closely related to human activities (e.g., runoff from impervious surfaces or combined sewer overflows in an urban area). Further, as the SAV in Chesapeake Bay indicator (p. 3-46) shows, present conditions may be quite different from historical reference conditions.

Overall, levels of toxic chemical contaminants are low in most of the nation's estuarine sediments, but as the Coastal Sediment Quality indicator (p. 3-42) shows, condition can vary greatly from one region to the next. In some EPA Regions, as much as 20 percent of estuarine area has sediments that either exceed contamination reference standards or fail a screening test for benthic toxicity. Other indicators discuss the extent to which toxic contaminants may be entering and affecting the food web. For example, benthic communities—which are most directly impacted by contaminants in sediment—show evidence of disturbance in roughly one-third of U.S. estuaries (e.g., losses of pollution-sensitive species) (Coastal Benthic Communities indicator, p. 3-44). Fish tissues had at least one contaminant above human health guidelines in 22 percent of estuarine sampling sites (Coastal Fish Tissue indicator, p. 3-61), suggesting that bioaccumulation of certain toxic compounds is widespread and, in some instances, could pose risks to human health. This indicator suggests the importance of atmospheric deposition of mercury as a stressor to coastal water condition, as well as historical activities that released PCBs and DDT into upstream and coastal waters.

In ecological terms (populations, communities, and habitat), trends in the condition of coastal waters vary. Benthic communities in most of the nation's estuaries are intact in terms of species diversity (Coastal Benthic Communities indicator, p. 3-44), which is critical because these organisms are a fundamental link in the coastal food web. Other populations, however, may be substantially lower than historical levels as a result of human stressors—for example, the Chesapeake Bay's SAV, which is vulnerable to changes in water clarity (SAV in Chesapeake Bay indicator, p. 3-46). SAV is ecologically important because it is not just a plant population; it also provides habitat and facilitates nutrient cycling, much like wetlands do. SAV has recently shown increases in extent, which may translate into increased habitat and breeding grounds for various species. However, coastal habitat still continues to be threatened by human stressors. As the Hypoxia in Gulf of Mexico and Long Island Sound indicator (p. 3-48) shows, large areas of some of the nation's coastal water bodies are unsuitable for fish and shellfish populations for at least a portion of the year.

Limitations, Gaps, and Challenges

Although the seven indicators discussed here provide a good overview of many important aspects of coastal extent and condition, there are a few key limitations to their temporal and spatial coverage. For example, the four indicators derived from the National Coastal Condition Report do not provide information about trends over time, as there are insufficient data from previous surveys to compare with recent data to examine potential trends.[22] Another temporal limitation is that many surveys are conducted during an index period, not over a full year; thus, they may not capture phenomena that occur outside the sampling window.[23] Spatially, the National

[22] U.S. Environmental Protection Agency. 2004. National coastal condition report II. EPA/620/R-03/002. <http://www.epa.gov/owow/oceans/nccr/2005/index.html>

[23] Ibid.

Indicators are limited because they do not include data from Alaska, Hawaii, and most U.S. territories. Alaska contains 75 percent of the bays, sounds, and estuarine surface area in the United States, while Hawaii, the Caribbean, and the Pacific territories represent a set of unique estuarine subsystems (i.e., coral reefs and tropical bays) that are not common in the contiguous 48 states.

One challenge in assessing coastal waters is that some aspects of condition vary naturally from one area to another. For example, some rivers naturally carry a heavy load of sediments or nutrients into coastal waters, while benthic community structure may depend on climate, depth, and geology. To assess coastal waters with respect to natural background conditions, several of the ROE indicators use different reference conditions for different regions.

To assess the extent and condition of coastal waters more fully, it would help to have more information in several key areas, including:

- More information about the extent of coastal waters—e.g., an indicator on coastal subsidence.
- Nationally consistent data on coastal water pollutants beyond those associated with trophic state—for example, organics, toxics, metals, and pathogens.
- Consistent data on the occurrence of harmful algal blooms, which can be caused by many different species of algae.
- A National Indicator of invasive species, which are often transported from one area to another along shipping routes or via aquaculture. Little information exists on a national level, in part because of a lack of standard invasion metrics.
- Comprehensive information on the condition of the nation's coral reefs—a unique and fragile habitat—and the status of coastal fish and shellfish communities.[24]

3.6 What Are the Trends in the Quality of Drinking Water and Their Effects on Human Health?

3.6.1 Introduction

The average American consumes 1 to 2 liters of drinking water per day, including water used to make coffee, tea, and other beverages.[25] Virtually all drinking water in the United States comes from fresh surface water and ground water. Large-scale water supply systems tend to rely on surface water resources such as lakes, rivers, and reservoirs; these include the systems serving many large metropolitan areas. Smaller systems are more likely to use ground water, particularly in regions with limited surface water resources. Slightly more than half of the nation's population receives its drinking water from ground water, i.e., through wells drilled into aquifers[26] (including private wells serving about 15 percent of U.S. households[27]). If drinking water contains unsafe levels of contaminants, this contaminated water can cause a range of adverse human health effects. Among the potential effects are gastrointestinal illnesses, nervous system or reproductive effects, and chronic diseases such as cancer.

Surface waters and aquifers can be contaminated by various agents, including microbial agents such as viruses, bacteria, or parasites (e.g., *E. coli, Cryptosporidium,* or *Giardia*); chemical contaminants such as inorganic metals, volatile organic compounds (VOCs), and other natural or manmade compounds; and radionuclides, which may be manmade or naturally occurring. Contaminants also can enter drinking water between the treatment plant and the tap (for example, lead can leach into water from old plumbing fixtures or household or street-side pipes).

Drinking water contaminants can come from many sources:

- **Human activities that contaminate the source.** Aquifers and surface waters that provide drinking water can be contaminated by many sources, as discussed in Sections 3.2 and 3.3. For example, chemicals from disposal sites or underground storage facilities can migrate into aquifers; possible contaminants include organic solvents (e.g., some VOCs), petroleum products, and heavy metals. Contaminants can also enter ground water or surface water as a result of their application to the land. Pesticides and fertilizer compounds (e.g., nitrate) can be carried into lakes and streams by rainfall runoff or snowmelt, or percolate through the ground and enter aquifers. Industrial wastes can contaminate drinking water sources if injected into containment wells or discharged into surface waters, as can mine waste (e.g., heavy metals) if not properly contained.
- **Natural sources.** As ground water travels through rock and soil, it can pick up naturally occurring contaminants such as arsenic, other heavy metals, or radionuclides. Some aquifers are naturally unsuitable for drinking because the local geology happens to include high levels of certain contaminants.
- **Microbial pathogens.** Human wastes from sewage and septic systems can carry harmful microbes into drinking water sources, as can wastes from animal feedlots and wildlife. Major contaminants include *Giardia, Cryptosporidium,* and *E. coli* O157:H7. Coliform bacteria from human and animal wastes also may be found in drinking water if the water is not properly finished; these bacteria may indicate that other harmful pathogens are present as well.

[24] U.S. Environmental Protection Agency. 2004. National coastal condition report II. EPA/620/R-03/002. <http://www.epa.gov/owow/oceans/nccr/2005/downloads.html>

[25] U.S. Environmental Protection Agency. 1997. Exposure factors handbook. Volume I—general factors. EPA/600/P-95/002Fa. <http://rais.ornl.gov/homepage/EFH_Final_1997_EPA600P95002Fa.pdf>

[26] U.S. Geological Survey. 1999. Ground water (general interest publication). <http://capp.water.usgs.gov/GIP/gw_gip/>

[27] U.S. Environmental Protection Agency. 2002. The clean water and drinking water infrastructure gap analysis. EPA/816/R-02/020. <http://www.epa.gov/safewater/gapreport.pdf>

- **Treatment and distribution.** While treatment can remove many chemical and biological contaminants from the water, it may also result in the presence of certain disinfection byproducts that may themselves be harmful, such as trihalomethanes. Finished water can also become contaminated after it enters the distribution system, either from a breach in the system or from corrosion of plumbing materials, particularly those containing lead or copper. After water leaves the treatment plant, monitoring for lead in drinking water is done at the tap, and monitoring for microbial contaminants (as well as disinfection byproducts) occurs within the distribution system.

Chemical exposure through drinking water can lead to a variety of long- and short-term effects. Potential health effects of exposure to certain metals, solvents, and pesticides can include chronic conditions such as cancer, which can develop over long periods of time (up to 70 years). Higher doses over shorter periods of time can result in a variety of biological responses, including toxicity, mutagenicity, and teratogenicity (birth defects). Short-term results might include cosmetic effects (e.g., skin discoloration), unpleasant odors, or more severe problems such as nervous system or organ damage and developmental or reproductive effects. The effects of some drinking water contaminants are not yet well understood. For example, certain disinfection byproducts have been associated with cancer, developmental, and reproductive risks, but the extent of this association is still uncertain.

Consuming water with pathogenic microbes can cause life-threatening diseases such as typhoid fever or cholera—rare in the U.S. today—as well as more common waterborne diseases caused by organisms such as *Giardia, Cryptosporidium, E. coli,* and *Campylobacter.* Health consequences of the more common illnesses can include symptoms such as gastrointestinal distress (stomach pain, vomiting, diarrhea), headache, fever, and kidney failure, as well as various infectious diseases such as hepatitis.

A number of factors determine whether the presence of contaminants in drinking water will lead to adverse health effects. These include the type of contaminant, its concentration in the water, individual susceptibility, the amount of contaminated water consumed, and the duration of exposure.

Disinfection of drinking water—the destruction of pathogens using chlorine or other chemicals—has dramatically reduced the incidence of waterborne diseases such as typhoid, cholera, and hepatitis, as well as gastrointestinal illness, in the United States. Other processes required depend on the physical, microbiological, and chemical characteristics and the types of contaminants present in the source water (e.g., filtration to remove turbidity and biological contaminants, treatment to remove organic chemicals and inorganic contaminants such as metals, and corrosion control to reduce the presence of corrosion byproducts such as lead at the point of use).

3.6.2 ROE Indicators

This section presents an indicator that tracks trends in the total population served by community water systems for which states report no violations of health-based drinking water standards (Table 3-6). Data for this indicator come from EPA's Safe Drinking Water Information System, Federal Version. This system houses all data submitted by states, EPA Regions, and the Navajo Nation Indian Tribe on the community water systems they oversee.

Table 3-6. ROE Indicators of Trends in the Quality of Drinking Water and Their Effects on Human Health

National Indicators	Section	Page
Population Served by Community Water Systems with No Reported Violations of Health-Based Standards (N/R)	3.6.2	3-54

N/R = National Indicator displayed at EPA Regional scale

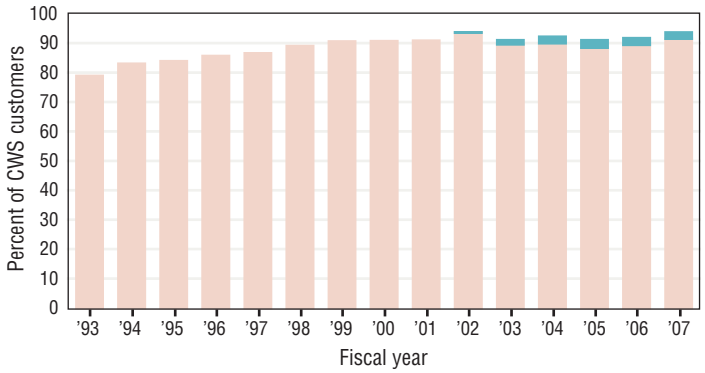
INDICATOR | Population Served by Community Water Systems with No Reported Violations of Health-Based Standards

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.

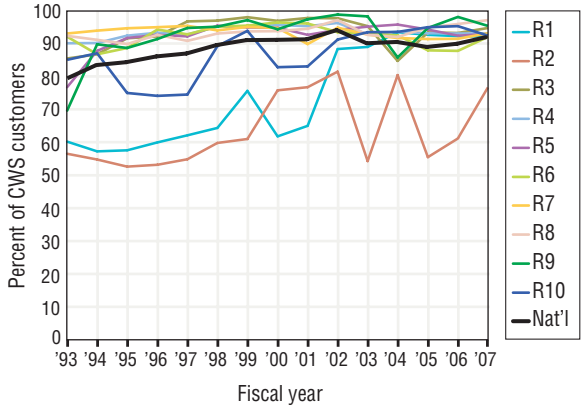
Data source: *U.S. EPA, 2007*

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.

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

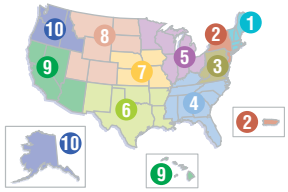
Exhibit 3-36. U.S. population served by community water systems with no reported violations of EPA health-based standards, by EPA Region, fiscal years 1993-2007[a,b]



[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*



EPA Regions

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*

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 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

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

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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3.6.3 Discussion

What This Indicator Says About Trends in the Quality of Drinking Water and Their Effects on Human Health

Most Americans served by community water systems (CWS) are served by facilities with no reported violations (Drinking Water indicator, p. 3-54). Since 1993, the percentage of Americans served by CWS for which states reported no health-based violations has increased, although there has been some reversal nationally since the percentage peaked in 2002. While there have been noticeable differences among EPA Regions over the period of record, most Regions have been consistently above 90 percent since 1993. Only one Region has been consistently below the national average, though according to the data source, this result is due largely to one large metropolitan water system that is under a legal settlement to upgrade its treatment technology. As this result suggests, while the nation has thousands of CWS, a substantial percentage of the population depends on the quality of a small number of large metropolitan water systems.

Limitations, Gaps, and Challenges

As noted in the indicator description, a challenge in assessing national drinking water quality is that there are inherent limitations in using reporting data. Some violations may be unreported, particularly if monitoring is inadequate—leading to undercounting. Other violations may be overlooked because CWS may purchase water from other CWS and not test it for

all contaminants themselves. Conversely, the data could also overstate the portion of the population receiving water in violation of standards, because a violation could be as short as an hour or a day and could be limited to water received by only a small portion of a system's customers.

Other challenges relate to the interpretation of the Drinking Water indicator (p. 3-54). For example, trends can be confounded by the fact that water quality standards and treatment requirements change over time. Thus, an apparent increase in violations over time may result from new or more stringent MCLs rather than simply a decline in the quality of drinking water, as these new requirements may also affect some systems' compliance with existing standards.

As described in the indicator summary, the indicator does not address the quality of drinking water other than that obtained from CWS. Information that would provide a more complete characterization of drinking water quality includes National Indicators for:

- **Trends in drinking water quality from CWS that *did* have reported violations.** The Drinking Water indicator does not explain the nature of every reported violation, nor does it show how many contaminants may be above standards, the identity of the contaminants, the extent to which standards were exceeded, or the duration of the violations (some of which, especially in larger systems, were only a very few hours in length).
- **The quality of drinking water from other public water systems.** There is no ROE indicator for drinking water quality from transient and non-transient non-community water systems, which are required to monitor quality and report violations to state authorities, but are regulated only for certain contaminants.
- **The quality of drinking water from non-public water supplies.** Private wells, cisterns, and other non-public water supplies are not subject to federal regulation. Some private supplies are treated, and some people do test their private water for common contaminants. However, no national infrastructure, and few if any systematic state efforts, currently exist to collect data on trends in the quality of these supplies. Bottled water is regulated by the U.S. Food and Drug Administration (FDA), which is required by law to apply standards that are no less stringent or protective of public health than EPA's, but there is no ROE indicator on the quality of bottled water.

In addition to these gaps, there are no ROE indicators to identify trends in health effects of interest, such as waterborne disease occurrence. Data are very limited for endemic waterborne illness as well as for acute waterborne disease outbreaks.

3.7 What Are the Trends in the Condition of Recreational Waters and Their Effects on Human Health and the Environment?

3.7.1 Introduction

The nation's rivers, lakes, and coastal waters are used for many different forms of recreation. Some recreational activities take place in or on the water, such as swimming, boating, white-water rafting, and surfing. Other activities may not involve contact with the water yet may still require water—or be enhanced by proximity to water. Examples include a picnic at the beach, hiking, nature viewing (e.g., bird watching), and hunting (especially waterfowl). People also engage in fishing and shellfishing as recreational activities.

In the questions on fresh surface waters and coastal waters (Sections 3.2 and 3.5), condition is defined as a combination of physical, chemical, and biological attributes of a water body. For recreational waters, condition is more specific, focusing on those physical, chemical, and biological attributes that determine a water body's ability to support recreational activities. The particular attributes necessary to support recreation vary widely, depending on the nature of the activity in question. In a more general sense, however, the components of recreational condition fall into two main categories:

- Attributes that determine whether recreational activities can be enjoyed without unacceptable risk to human health—primarily pathogens and chemical contaminants that can affect the health of humans who are exposed during contact activities such as swimming.
- Attributes associated with ecological systems that support recreation—e.g., the status of fish and bird communities, as well as chemical and physical characteristics that may affect these populations and their habitat. These attributes also contribute to the aesthetic qualities important for recreational activities.

Many stressors affecting the condition of recreational waters fall into the broad category of contaminants. This category includes chemical contaminants, various pathogens (viruses, bacteria, and other parasites or protozoans) that can cause infectious disease, and pollutants such as trash or debris. These stressors can come from a variety of point sources and non-point sources, and can be discharged or washed directly into

recreational waters or carried downstream to lakes or coastal areas. Among the major sources are storm water and sediment runoff, direct discharge (e.g., from industrial facilities and sewer systems), atmospheric deposition, and recreational activities themselves (e.g., outboard motor exhaust and overboard discharge of sanitary wastes). Some chemicals and pathogens occur naturally, but their abundance may be influenced by other human stressors such as land use and land cover (e.g., paved surfaces and forestry and irrigation practices, which can influence runoff patterns) or by natural stressors such as weather and climate. Land use and land cover can influence recreational condition in other ways as well.

In terms of human health, the stressors that pose the greatest potential risks are chemical and biological contaminants. People can be exposed to these contaminants if they swim in contaminated waters or near storm water or sewage outfall pipes—especially after a rainfall event. Boating also may pose risks of exposure, although to a lesser extent. For toxic chemical contaminants, the main routes of exposure are through dermal (skin) contact or accidental ingestion. For pathogens, the main route of exposure is by swallowing water, although some infections can be contracted simply by getting polluted water on the skin or in the eyes. In some cases, swimmers can develop illnesses or infections if an open wound is exposed to contaminated water.

Effects of exposure to chemical and biological contaminants range from minor illnesses to potentially fatal diseases. The most common illness is gastroenteritis, an inflammation of the stomach and the intestines that can cause symptoms such as vomiting, headaches, and diarrhea. Other minor illnesses include ear, eye, nose, and throat infections. While unpleasant, most swimming-related illnesses are indeed minor, with no long-term effects. However, in severely contaminated waters, swimmers can sometimes be exposed to serious and potentially fatal diseases such as meningitis, encephalitis, hepatitis, cholera, and typhoid fever.[28] Children, the elderly, and people with weakened immune systems are most likely to develop illnesses or infections after coming into contact with contaminated water.

From an ecological perspective, stressors to recreational waters can affect habitat, species composition, and important ecological processes. For example, changes in land cover (e.g., the removal of shade trees) may cause water temperature to rise above the viable range for certain fish species. Hydromodifications such as dams may create some recreational opportunities (e.g., boating), but they also may impede the migration of fish species such as salmon. Chemical and biological contaminants may harm plants and animals directly, or they may disrupt the balance of the food web. For example, acid deposition may lead to acidification in lakes, while excess nutrients can lead to eutrophic conditions such as low levels of dissolved oxygen, which in turn can harm fish and shellfish populations. Beyond their obvious effects on activities like fishing and nature viewing, stressors such as these also can be detrimental to recreational activities in a more aesthetic sense, as the presence of dead fish or visibly unhealthy plants may diminish one's enjoyment of recreation in or near the water.

Ultimately, ecological effects can also impact human health. For example, eutrophic conditions can encourage harmful algal blooms—some of which can produce discomfort or illness when people are exposed through ingestion or skin or eye contact. One well-known type of harmful algal bloom is "red tide," which in humans can cause neurotoxic shellfish poisoning and respiratory irritation.[29]

3.7.2 ROE Indicators

At this time, no National Indicators have been identified to quantify the condition of recreational waters. Individual states monitor certain recreational waters for a set of indicator bacteria and report monitoring results to EPA. However, the methodology and frequency of data collection vary among states, so the data are not necessarily comparable.

Challenges and information gaps for developing reliable National Indicators of recreational water condition are described in more detail in Section 3.7.3 below.

3.7.3 Discussion

Limitations, Gaps, and Challenges

Several challenges exist in assessing the condition of the nation's recreational waters. Foremost is the lack of a comprehensive national system for collecting data on pathogen levels at beaches, a key concern in assessing the suitability of recreational waters with respect to human health. In addition, data on the types and extent of health effects associated with swimming in contaminated water are limited. The number of occurrences is likely under-reported because individuals may not link common symptoms (e.g., gastrointestinal ailments, sore throats) to exposure to contaminated recreational waters.

Another challenge to answering this question is the breadth of the subject. "Recreation" encompasses a wide range of activities, involving different types of water bodies and entailing varying concepts of condition. While the recreational condition of a whitewater stream with a native salmon population will be determined largely by flow levels and condition of fish habitat, for example, the recreational condition of a beach will be assessed more in terms of levels of pathogens and chemical contaminants.

Gaps in assessing the condition of the nation's recreational waters include National Indicators of pathogen levels in recreational waters (rivers, lakes, and coastal beaches), the magnitude of specific stressors—particularly contaminant loadings (biological and chemical)—to recreational waters, harmful algal blooms in recreational waters, and the condition of recreational fish and shellfish populations.

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3.8 What Are the Trends in the Condition of Consumable Fish and Shellfish and Their Effects on Human Health?

3.8.1 Introduction

Fish and shellfish caught through commercial, recreational, or subsistence fishing are an important part of a healthful diet for many people. Fish and shellfish contain high-quality protein and other essential nutrients, are low in saturated fat, and contain omega-3 fatty acids. Most fish consumed in the United States comes from commercial fisheries, and is purchased in supermarkets or fish markets. Fishing also is one of the most popular outdoor recreational activities in the country, with more than 34 million people per year fishing recreationally[30]—many of whom eat at least some of the fish they catch. In addition, subsistence fishers—people who rely on fish as an affordable food source or for whom fish are culturally important—consume fish and shellfish as a major part of their diets. Commercial, recreational, and subsistence fisheries all have substantial economic value for the nation, regions, and local communities.

Americans consume fish and shellfish caught in the nation's lakes, rivers, and estuaries and in deep ocean fisheries, as well as farmed fish and shellfish.[31] Some of these fish and shellfish contain elevated levels of chemical or biological contaminants. This question addresses the condition of consumable fish and shellfish caught or farmed in the United States—whether, and the extent to which, these organisms contain contaminants that could affect the health of people who consume them.

According to recent surveys, the average American consumes close to 13 grams of fish and shellfish per day (prepared weight), which amounts to slightly more than one 3-ounce serving per week.[32] However, many Americans consume substantially more fish and shellfish than the national average; some of the highest consumption rates are among tribal and ethnic populations who fish for subsistence. Concern about fish and shellfish safety is higher for these groups as well as for children, pregnant and nursing women (because of possible effects on the fetus or infant), and other population subgroups who may be more vulnerable to the health effects of certain chemical or biological contaminants (e.g., elderly or immunosuppressed individuals).

Chemical contaminants of greatest concern in consumable fish and shellfish tend to be those that are persistent, bioaccumulative, and toxic (called PBTs). These chemicals can persist for long periods in sediments and then enter the food web when ingested by bottom-dwelling (benthic) organisms. Benthic organisms are eaten by small fish, which in turn are eaten by larger fish, which may be consumed by humans or wildlife. PBTs that are common in fresh and coastal waters include:

- **Mercury.** This highly toxic metal is present in waters all over the globe—a result of long-range transport and deposition of airborne mercury as well as direct inputs to water.[33] Mercury in water bodies can be methylated by certain bacteria in bottom sediments to form methylmercury, which is more toxic and bioavailable than other forms of mercury.[34] It also is biomagnified through aquatic food webs, so that it becomes particularly concentrated in larger and longer-lived predators such as bass, tuna, swordfish, and some sharks. Exposure to high levels of methylmercury can cause reproductive and other effects in wildlife;[35] in humans, exposure to elevated levels is primarily associated with developmental and neurological health effects.[36]
- **Polychlorinated biphenyls (PCBs) and the pesticide DDT.** Though PCBs and DDT are no longer manufactured or used in the U.S., they persist in historical deposits in watersheds and near-shore sediments, which can continue to contaminate fish and shellfish. These chemicals are also circulated globally as a result of use in other parts of the world. Levels of PCBs and DDT are a concern in some bottom-feeding fish and shellfish, as well as in some higher-level predators. These chemicals have been linked to adverse health effects such as cancer, nervous system damage, reproductive disorders, and disruption of the immune system in both humans and wildlife.

Other chemical contaminants that may be present in fish and shellfish include other pesticides, metals (such as arsenic), and dioxins and furans.[37]

Biological contamination also can affect the condition of fish and shellfish—particularly the latter. For example, shellfish contaminated with pathogens from human and animal fecal wastes can cause gastrointestinal illness and even death in individuals with compromised immune systems. Sources of

[30] U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2002. 2001 national survey of fishing, hunting, and wildlife-associated recreation.

[31] According to the National Oceanic and Atmospheric Administration's Fisheries of the United States—2006, imports of edible seafood made up 83 percent of U.S. per capita consumption in 2006. See <http://www.st.nmfs.noaa.gov/st1/fus/fus06/08_perita2006.pdf>

[32] U.S. Environmental Protection Agency. 2002. Estimated per capita fish consumption in the United States. EPA/821/C-02/003. <http://www.epa.gov/waterscience/fish/consumption_report.pdf>

[33] U.S. and global sources of mercury are described in more detail in Section 2.2, which includes an indicator of domestic mercury emissions.

[34] U.S. Environmental Protection Agency. 1997. Mercury study report to Congress. Volume III: Fate and transport of mercury in the environment. EPA/452/R-97/005. <http://www.epa.gov/mercury/report.htm>

[35] U.S. Environmental Protection Agency. 1997. Mercury study report to Congress. Volume V: Health effects of mercury and mercury compounds. EPA/452/R-97/007. <http://www.epa.gov/mercury/report.htm>

[36] National Research Council. 2000. Toxicological effects of methylmercury. Washington, DC: National Academies Press.

[37] U.S. Environmental Protection Agency. In progress. National study of chemical residues in lake fish tissue. <http://www.epa.gov/waterscience/fishstudy>

fecal contamination in shellfish include urban runoff, wildlife, wastewater treatment systems and treatment plants, agricultural runoff, and boating and marinas.

Marine biotoxins produced by certain types of algae can contaminate fish and shellfish as well. These toxins not only can harm fish and fish communities—sometimes resulting in massive fish kills or losses to aquaculture operations—but they also can make their way through the food web to affect seabirds, marine mammals, and humans. Mollusks such as mussels, clams, oysters, whelks, and other shellfish can carry biotoxins that have common symptoms such as irritation of the eyes, nose, throat, and tingling of the lips and tongue. Consumption of contaminated seafood can cause a range of other health effects in humans, depending on the organism involved, including gastrointestinal illness, amnesia, memory loss, paralysis, and even death.[38,39]

The growth of aquaculture, or fish farming, may affect the levels of certain contaminants in consumable fish and shellfish. Dense colonies can increase stress and disease transmission among fish, in some cases requiring the administration of antibiotics.[40] Studies have also found higher levels of certain contaminants in farmed fish than in their wild counterparts, possibly due to differences in diet. For example, several studies have found higher concentrations of PCBs, organochlorine pesticides, and polybrominated diphenyl ethers (PBDEs) in farmed salmon.[41]

Overharvesting also can affect the condition of fish and shellfish—not only the species being harvested, but also the species that prey on them—by disrupting the food web. Because of depleted food sources, predators can become more susceptible to disease (such as infection of rockfish by mycobacterial lesions). These infections are often confined to internal organs and may not be apparent to anglers, although in some cases they are associated with external sores as well. Some types of mycobacteria can also infect humans who handle diseased fish if the infection comes into contact with an open wound. The slow-developing infections are usually not severe in humans, but in some cases they can cause major health problems, especially in people with compromised immune systems.

3.8.2 ROE Indicators

Two ROE indicators characterize levels of chemical contaminants in edible fish and shellfish species (Table 3-7). One indicator reports levels and occurrence of contaminants in fish in estuarine areas; the other, in freshwater lakes and reservoirs. Both indicators are based on nationwide probabilistic surveys.

The coastal fish indicator is based on an index originally presented in EPA's second National Coastal Condition Report. The underlying data were collected between 1997 and 2000 as part of EPA's Environmental Monitoring and Assessment Program (EMAP). EMAP's probabilistic coastal surveys are designed to be representative of 100 percent of estuarine acreage in the contiguous 48 states. This indicator presents results by EPA Region.

The other indicator describes contamination of fish in inland lakes. This indicator is derived from fish samples collected and analyzed for EPA's National Study of Chemical Residues in Lake Fish Tissue, a probabilistic survey designed to estimate the national distribution of the mean levels of selected PBT chemical residues in fish tissue from lakes and reservoirs.

Note that this question does not rely on information about fish and shellfish consumption advisories. While many states and tribes issue fish consumption advice and develop fish advisory programs, there is great variability in how monitoring is conducted, how decisions are made to place waters under advisory, and what specific advice is provided when contamination is found in fish. Further, trends in the number of advisories over time may reflect changes in the frequency and intensity of monitoring.[42] Thus, fish advisories cannot provide a consistent national metric for trends in the condition of consumable fish and shellfish.

Table 3-7. ROE Indicators of Trends in the Condition of Consumable Fish and Shellfish and Their Effects on Human Health

National Indicators	Section	Page
Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
Contaminants in Lake Fish Tissue	3.8.2	3-63

N/R = National Indicator displayed at EPA Regional scale

[38] Baden D., L.E. Fleming, and J.A. Bean. 1995. Marine toxins. In: DeWolff, F.A., ed. Handbook of clinical neurology: Intoxications of the nervous system. Part II: Natural toxins and drugs. Amsterdam, The Netherlands: Elsevier. pp. 141-175.

[39] Van Dolah, F.M. 2000. Marine algal toxins: Origins, health effects, and their increased occurrence. Environ. Health Persp. 108(Suppl 1):133-141.

[40] Barton, B.A., and G.K. Iwama. 1991. Physiological changes in fish from stress in aquaculture with emphasis of the response and effects of corticosteroids. Annu. Rev. Fish Dis. 1:3-26.

[41] Easton, M.D.L., D. Luszniak, and E.Von der Geest. 2002. Preliminary examination of contaminant loadings in farmed salmon, wild salmon and commercial salmon feed. Chemosphere 46(7):1053-1074.

[42] U.S. Environmental Protection Agency. 2005. Fact sheet: National listing of fish advisories. EPA/823/F-05/004. <http://www.epa.gov/waterscience/fish/advisories/2004/fs2004.pdf>

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).

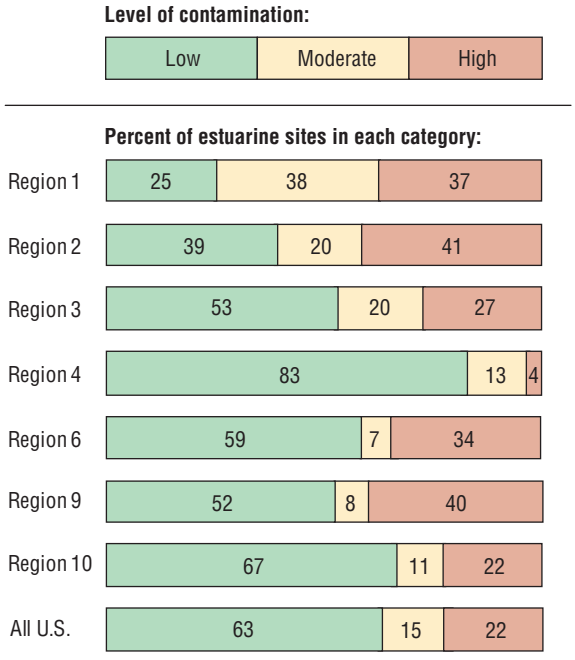
This indicator, derived from an indicator presented in EPA's second National Coastal Condition Report (U.S. EPA, 2004), is based on National Coastal Assessment (NCA) fish tissue survey data from 653 estuarine sites throughout the United States. The survey was designed to provide a national picture of 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]

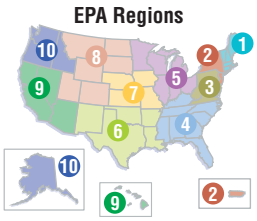


[a]**Coverage:** Estuarine waters of the contiguous 48 states.

[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,

INDICATOR | Coastal Fish Tissue Contaminants *(continued)*

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*

INDICATOR | Coastal Fish Tissue Contaminants *(continued)*

References

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Mikac, N., M. Picer, P. Stegnar, and M. Tusek-Nidari. 1985. Mercury distribution in a polluted marine area, ratio of total mercury, methyl mercury and selenium in sediments, mussels and fish. Water Res. 19:1387-1392.

Schmidt, C.J., and W.G. Brumbaugh. 1990. National contaminant biomonitoring program: Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish 1976-1984. Arch. Environ. Con. Toxicol. 19:731-747.

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Windom, H.L., and D.R. Kendall. 1979. Accumulation and biotransformation of mercury in coastal and marine biota. In: Nriagu, J.O., ed. Biogeochemistry of mercury in the environment. Amsterdam, The Netherlands: Elsevier. pp. 303-323.

INDICATOR | Contaminants in Lake Fish Tissue

Lakes and reservoirs provide important sport fisheries and other recreational opportunities, and lake ecosystems provide critical habitat for aquatic species and support wildlife populations that depend on aquatic species for food. Lakes and reservoirs occur in a variety of landscapes and can receive contaminants from several sources, including direct discharges into the water, atmospheric deposition, and agricultural or urban runoff. A group of contaminants of particular concern are the persistent, bioaccumulative, and toxic (PBT) chemicals. These contaminants are highly toxic, long-lasting chemicals that can accumulate in fish, reaching levels that can affect the health of people and wildlife that eat them.

PBT contaminants can originate from a variety of sources. A primary source of one of the most important PBTs, mercury, is combustion at coal-fired power plants and other industrial operations (see the Mercury Emissions indicator, p. 2-46); mercury emitted to the air can then be transported and deposited in lakes and reservoirs. Among other important PBTs, most uses of DDT became illegal in the U.S. effective in 1973; production of PCBs in the U.S. ceased in 1977 and most uses were phased out by 1979 (although they are still emitted as a byproduct of other manufacturing processes); chlordane was banned in 1988; and quantifiable emissions of dioxin-like compounds from all known sources have decreased in the U.S. by an estimated 89 percent between 1987 and 2000 (U.S. EPA, 2006a).

This indicator is based on tissue samples of predator and bottom-dwelling fish species collected and analyzed for EPA's National Study of Chemical Residues in Lake Fish Tissue. The data generated from this probabilistic survey (Olsen et al., 1998, in press; Stevens and Olsen, 2003, 2004) are designed to estimate the national distribution of the mean levels of PBT chemicals in fish tissue from lakes (not including the Great Lakes) and reservoirs of the contiguous 48 states. The indicator consists of statistical distributions of the concentrations of 15 PBT chemicals or chemical groups in predator and bottom-dwelling fish tissue, including mercury, arsenic (total inorganic), dioxins/furans, total PCBs, and 11 organochlorine pesticides. Fourteen of these chemicals or chemical groups also appear in the Coastal Fish Tissue indicator (p. 3-61).

Fish samples were collected from 500 lakes and reservoirs over a 4-year period (2000-2003). Sampling locations were selected from the estimated 147,000 target lakes and reservoirs in the contiguous 48 states based on an unequal probability survey design. The lakes and reservoirs were divided into six size categories, and varying probabilities were assigned to each category in order to achieve a similar number of lakes in each size category. The lakes and reservoirs ranged from 1 hectare (about 2.5 acres) to 365,000 hectares (about 900,000 acres), were at least 1 meter (3 feet) deep, and had permanent fish populations.

INDICATOR | Contaminants in Lake Fish Tissue *(continued)*

Exhibit 3-40. Lake fish tissue PBT contaminant concentration estimates for predators (fillets) in the contiguous U.S., 2000-2003[a]

Contaminant	Number of samples	Number of samples above MDL[b]	Percentiles for fillet tissue concentrations (ppm)[c]						
			5th	10th	25th	50th (median)	75th	90th	95th
Mercury	486	486	0.059	0.089	0.177	0.285	0.432	0.562	0.833
Total PCBs	486	486	0.000351	0.000494	0.001000	0.002161	0.008129	0.018159	0.033161
TEQ dioxins/furans only	486	395	*	*	*	6×10^{-9}	46×10^{-9}	109×10^{-9}	318×10^{-9}
Total inorganic arsenic	486	2	*	*	*	*	*	*	*
Total chlordane	486	96	*	*	*	*	*	0.003617	0.008266
Total DDT	486	378	*	*	*	0.00147	0.00694	0.01966	0.03057
Dicofol	486	15	*	*	*	*	*	*	*
Dieldrin	486	24	*	*	*	*	*	*	0.001193
Total endosulfan	486	18	*	*	*	*	*	*	*
Endrin	486	3	*	*	*	*	*	*	*
Heptachlor epoxide	486	6	*	*	*	*	*	*	*
Hexachlorobenzene	485	0	*	*	*	*	*	*	*
Lindane (gamma-BHC)	486	28	*	*	*	*	*	*	0.000994
Mirex	486	10	*	*	*	*	*	*	*
Toxaphene	486	0	*	*	*	*	*	*	*

[a]**Coverage:** Lakes and reservoirs of the contiguous 48 states. Each sample reported here is a composite sample from one lake.

[b]MDL = method detection limit; MDLs are available online at http://www.epa.gov/waterscience/fishstudy.

[c]* = less than MDL

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

Because no predator or bottom-dwelling species occurs in all 500 lakes and reservoirs, the study focused on 12 target predator species and six target bottom-dwelling species in order to minimize the effect of sampling different species. These species were chosen because they are commonly consumed in the study area, have a wide geographic distribution, and potentially accumulate high concentrations of PBT chemicals. Sampling teams applied consistent materials and methods nationwide. From each lake or reservoir, teams collected composite samples of five adult fish of similar size for one predator species (e.g., bass or trout) and one bottom-dwelling species (e.g., carp or catfish) (U.S. EPA, 2000). Fillets were analyzed for predators, and whole bodies were analyzed for bottom-dwelling fish. Fillet data represent the edible part of the fish most relevant to human health, while whole-body data are more relevant to wildlife consumption. A single laboratory prepared fish tissue samples for analysis in a strictly controlled environment, and tissue samples were sent to four analytical laboratories. The same laboratory analyzed tissue samples for each chemical group (e.g., PCBs or organochlorine pesticides), using the same standard analytical method, for the duration of the study. Concentrations of dioxins and furans were reported on a toxic equivalency quotient (TEQ) basis, which adjusts for the different toxicities of the various dioxin and furan compounds.

What the Data Show

Mercury, PCBs, dioxins and furans, and DDT are widely distributed in lakes and reservoirs in the contiguous 48 states (Exhibits 3-40 and 3-41). Mercury and PCBs were detected in 100 percent of both predator and bottom-dweller composite samples. Dioxins and furans were detected in 81 percent of the predator composite samples and 99 percent of the bottom-dweller composite samples, and DDT was detected in 78 percent of the predator composites and 98 percent of the bottom-dweller composites. One chemical analyzed in this study (hexachlorobenzene) was not detected in any of the fish tissue samples.

Exhibit 3-41. Lake fish tissue PBT contaminant concentration estimates for bottom-dwellers (whole fish) in the contiguous U.S., 2000-2003[a]

Contaminant	Number of samples	Number of samples above MDL[b]	Percentiles for whole-body tissue concentrations (ppm)[c]						
			5th	10th	25th	50th (median)	75th	90th	95th
Mercury	395	395	0.019	0.020	0.039	0.069	0.124	0.220	0.247
Total PCBs	395	395	0.001579	0.002308	0.005146	0.013876	0.070050	0.130787	0.198324
TEQ dioxins/furans only	395	393	19×10^{-9}	59×10^{-9}	165×10^{-9}	406×10^{-9}	1067×10^{-9}	1770×10^{-9}	2006×10^{-9}
Total inorganic arsenic	395	36	*	*	*	*	*	*	0.037
Total chlordane	395	197	*	*	*	0.001653	0.009313	0.025964	0.030931
Total DDT	395	388	0.00108	0.00182	0.00423	0.01268	0.03535	0.15392	0.21863
Dicofol	395	8	*	*	*	*	*	*	*
Dieldrin	395	73	*	*	*	*	*	0.003436	0.024613
Total endosulfan	395	23	*	*	*	*	*	*	*
Endrin	395	14	*	*	*	*	*	*	*
Heptachlor epoxide	395	25	*	*	*	*	*	*	0.000676
Hexachlorobenzene	395	0	*	*	*	*	*	*	*
Lindane (gamma-BHC)	395	31	*	*	*	*	*	0.000729	0.001541
Mirex	395	19	*	*	*	*	*	*	0.001866
Toxaphene	395	1	*	*	*	*	*	*	*

[a]**Coverage:** Lakes and reservoirs of the contiguous 48 states. Each sample reported here is a composite sample from one lake.

[b]MDL = method detection limit; MDLs are available online at http://www.epa.gov/waterscience/fishstudy.

[c]* = less than MDL

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

Median concentrations in predator fillets (i.e., half of the lakes and reservoirs had fish with higher values) were as follows: mercury, 0.285 ppm; total PCBs, 2.161 ppb; dioxins and furans, 0.006 ppt [TEQ]; and total DDT, 1.47 ppb (Exhibit 3-40). Median concentrations in whole, bottom-dwelling fish were lower for mercury (0.069 ppm), but higher for total PCBs (13.88 ppb), dioxins and furans (0.406 ppt [TEQ]), and total DDT (12.68 ppb) (Exhibit 3-41).

Indicator Limitations

- Survey data are not available for Alaska, Hawaii, or Puerto Rico.
- The Great Lakes, the Great Salt Lake, and lakes without permanent fish populations are not included in the target population.
- Because the distribution of sampling sites was based on the frequency of occurrence of lakes and reservoirs, contaminants in lakes and reservoirs in arid states (e.g., Arizona, New Mexico, and Nevada) are not well-represented.
- Due to the inaccessibility of some target lakes (e.g., landowner denial of access), the results are representative of the sampled population of lakes (approximately 80,000) rather than the original target population of 147,000 lakes.
- The indicator does not compare contaminant data to human health thresholds; EPA has not yet finalized that portion of the analysis.
- Trend data are not yet available, as this is the first time that a national lake fish tissue survey has been conducted using a probabilistic sampling design. These data will serve as a baseline for future surveys.

Data Sources

The data for Exhibits 3-40 and 3-41 were obtained from EPA's National Lake Fish Tissue Study. A report on the findings of this study was still in progress at the time this ROE went to press; however, partial results have been published in U.S. EPA (2006b) (http://www.epa.gov/waterscience/fishstudy/results.htm), along with information about how to obtain more detailed results on CD.

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U.S. EPA. 2000. Field sampling plan for the national study of chemical residues in lake fish tissue. EPA/823/R-02/004. <http://www.epa.gov/waterscience/fish/study/data/fieldplan.pdf>

3.8.3 Discussion

What These Indicators Say About Trends in the Condition of Consumable Fish and Shellfish and Their Effects on Human Health

The ROE indicators provide baseline information about consumable fish in inland lakes, reservoirs, and coastal areas. The data were collected from a variety of species, reflecting many parts of the food web. The results for fish in estuarine sites along the Atlantic, Gulf, and Pacific coasts of the contiguous 48 states (Coastal Fish Tissue indicator, p. 3-61) varied substantially among the seven coastal EPA Regions. Fish from the coastal waters of the Southeast (EPA Region 4) generally had low contamination scores, while several other Regions had a substantial proportion with high contamination. PCBs, mercury, DDT, and PAHs appeared to be the contaminants responsible for the most high contamination scores.

The results for lake fish (Lake Fish Tissue indicator, p. 3-63) suggest that several chemical contaminants are widely distributed in the nation's lakes and reservoirs, including mercury, dioxins and furans, PCBs, and DDT. However, some of the other chemicals in this screening—including certain pesticides—were detected rarely or not at all. There were some notable differences between predators and bottom-dwellers, which may be a result of how each type of fish was analyzed—fillets for predators and whole fish for bottom dwellers.

Limitations, Gaps, and Challenges

As explained in Section 3.8.2, both of the ROE indicators have important limitations. For example, like the other coastal indicators from EPA's second National Coastal Condition Report (presented in Section 3.5), the Coastal Fish Tissue indicator (p. 3-61) does not display trend data. It is also limited spatially, as adequate data for Alaska, Hawaii, the Caribbean, and the Pacific territories are not available. The lack of data from Alaska is especially notable because more than half of the nation's commercial fish and shellfish catch comes from Alaskan waters.[43]

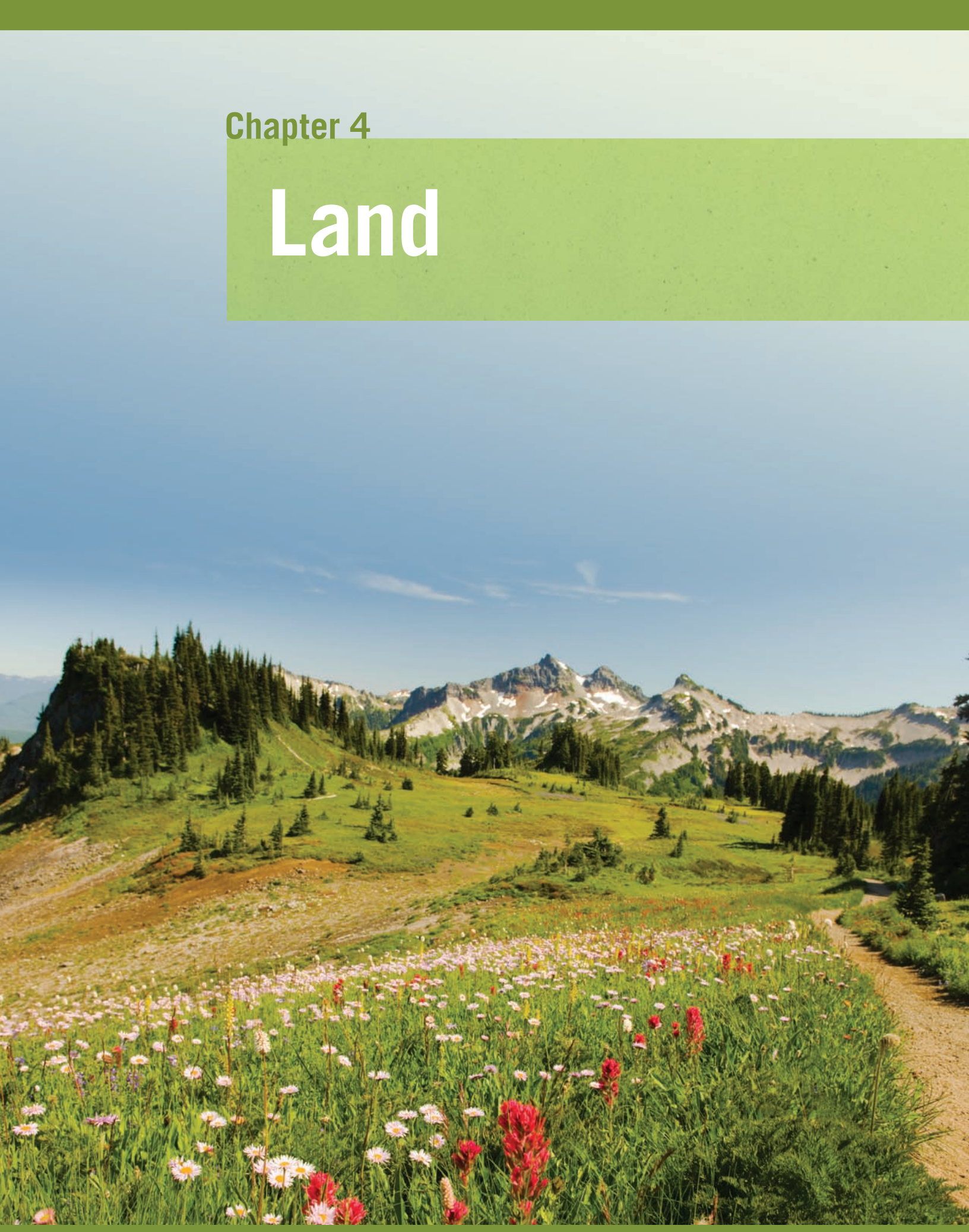
The Lake Fish Tissue indicator (p. 3-63) is also limited temporally and spatially, with no trend data and no coverage outside the contiguous 48 states. Further, unlike the coastal survey, the lake fish survey was not designed to produce results by region, and it also does not compare contaminant levels to any health-based guidelines. Thus, while both indicators present meaningful data, the results cannot easily be compared.

The Coastal Fish Tissue and Lake Fish Tissue indicators (pp. 3-61 and 3-63) do provide some information about contamination and safety of fish and shellfish. However, to fully assess the condition of the nation's fish and shellfish, more data are needed—particularly on a national level, because many issues have been studied locally or regionally, but have not yet been studied in nationally representative surveys. In addition to the limitations of the indicators described above, information gaps for answering this question include nationally consistent indicators of pathogens in fish and shellfish (in both fresh water and coastal waters) and indicators of the biological and chemical condition of fish and shellfish commercially farmed in the U.S. There are also no ROE indicators to describe the effects of fish and shellfish condition on human health. As noted in Chapter 1, it is often difficult to explicitly connect an observed effect to a particular stressor (e.g., the condition of fish and shellfish that people consume), even though there may be scientific evidence to suggest a possible association.

[43] National Oceanic and Atmospheric Administration. 2007. Fisheries of the United States—2006. <http://www.st.nmfs.noaa.gov/st1/fus/fus06/fus_2006.pdf>

Chapter 4

Land



Contents

4.1 Introduction

The land within the boundaries of the U.S., covering nearly 2.3 billion acres, provides food, fiber, and shelter for all Americans, as well as terrestrial habitat for many other species. Land is the source of most extractable resources, such as minerals and petroleum. Land produces renewable resources and commodities such as livestock, vegetables, fruit, grain, and timber; it also supports other uses, such as residential, industrial, commercial, and transportation uses. Additionally, land and the ecosystems that it is part of provide services such as trapping chemicals as they move through soil, storing and breaking down chemicals and wastes, and filtering and storing water. The use of land, what is applied to or released on it, and its condition change constantly: there are changes in the types and amounts of resources that are extracted, the distribution and nature of cover types, the amounts and types of chemicals used and wastes managed, and perceptions of the land's value.

Numerous agencies and individuals have responsibilities for managing and protecting land in the U.S., in terms of resources associated with land (e.g., timber, minerals) and land uses (e.g., wilderness designations, regulatory controls). Between 30 and 40 percent of the nation is owned or managed by public agencies.[1] The other 60 to 70 percent is managed by private owners, under a variety of federal, state, and local laws. Local governments have primary responsibilities for regulating land use, while state and federal agencies regulate chemicals and waste that are frequently used on, stored on, or released to land. EPA is interested in land because human activities on land such as food and fiber production, land development, manufacturing, or resource extraction can involve the creation, use, or release of chemicals and pollutants that can affect the environment and human health.

EPA works with other federal agencies, states, and partners to protect land resources, ecosystems, environmental processes, and uses of land through regulation of chemicals, waste, and pollutants, and through cleanup and restoration of contaminated lands. The complexities of responsibilities underscore the challenges of collecting data and assessing trends on the state of land.

This chapter addresses critical land questions by describing national trends in naturally occurring and human uses of land, stressors that affect land, and associated exposures and effects among humans and ecological systems. ROE indicators are presented to address five fundamental questions about the state of the nation's land:

- **What are the trends in land cover and their effects on human health and the environment?** "Land cover" refers to the actual or physical presence of vegetation or other materials (e.g., rock, snow, buildings) on the surface

EPA's 2008 Report on the Environment (ROE): Essentials

ROE Approach

This 2008 Report on the Environment:

- Asks questions that EPA considers important to its mission to protect human health and the environment.
- Answers these questions, to the extent possible, with available indicators.
- Discusses critical indicator gaps, limitations, and challenges that prevent the questions from being fully answered.

ROE Questions

The air, water, and land chapters (Chapters 2, 3, and 4) ask questions about trends in the condition and/or extent of the environmental medium; trends in stressors to the medium; and resulting trends in the effects of the contaminants in that medium on human exposure, human health, and the condition of ecological systems.

The human exposure and health and ecological condition chapters (Chapters 5 and 6) ask questions about trends in aspects of health and the environment that are influenced by many stressors acting through multiple media and by factors outside EPA's mission.

ROE Indicators

An indicator is derived from actual measurements of a pressure, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain. This excludes indicators such as administrative, socioeconomic, and efficiency indicators.

Indicators based on one-time studies are included only if they were designed to serve as baselines for future trend monitoring.

All ROE indicators passed an independent peer review against six criteria to ensure that they are useful; objective; transparent; and based on data that are high-quality, comparable, and representative across space and time.

Most ROE indicators are reported at the national level. Some national indicators also report trends by region. EPA Regions were used, where possible, for consistency and because they play an important role in how EPA implements its environmental protection efforts.

Several other ROE indicators describe trends in particular regions as examples of how regional indicators might be included in future versions of the ROE. They are not intended to be representative of trends in other regions or the entire nation.

EPA will periodically update and revise the ROE indicators and add new indicators as supporting data become available. In the future, indicators will include information about the statistical confidence of status and trends. Updates will be posted electronically at http://www.epa.gov/roe.

Additional Information

You can find additional information about the indicators, including the underlying data, metadata, references, and peer review, at http://www.epa.gov/roe.

[1] Lubowski, R.N., M. Vesterby, S. Bucholtz, A. Baez, and M.J. Roberts. 2006. Major uses of land in the United States, 2002. Economic Information Bulletin No. (EIB-14). U.S. Department of Agriculture, Economic Research Service. <http://www.ers.usda.gov/publications/eib14/>

of the land (it differs from land use—see the next question). It is important from the perspective of understanding land as a resource and its ability to support humans and other species. Changes in land cover can affect other media (e.g., air and water).

- **What are the trends in land use and their effects on human health and the environment?** "Land use" refers to the economic and cultural activities practiced by humans on land. Land use can have effects on both human health and the environment, particularly as land is urbanized or used for agricultural purposes.
- **What are the trends in wastes and their effects on human health and the environment?** Numerous types of waste are generated as part of most human activities. Trends in waste include trends in types and quantities of, and mechanisms for, managing wastes. Waste trends reflect the efficiency of use and reuse of materials and resources and potential for land contamination.
- **What are the trends in chemicals used on the land and their effects on human health and the environment?** Various chemicals are produced or used on land for many purposes. The quantity and diversity of chemicals and the potential for interactions among them have created challenges in understanding the full effects of their use. Pesticides, fertilizers, and toxic chemicals are examples of chemicals applied or released on land.
- **What are the trends in contaminated land and their effects on human health and the environment?** Contaminated lands are those lands that have been affected by human activities or natural events such as manufacturing, mining, waste disposal, volcanoes, or floods that pose a concern to human health or the environment. The worst-contaminated lands are tracked and their cleanups overseen by EPA.

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

4.1.1 Overview of the Data

Data are collected by many agencies with varying responsibilities for managing and protecting land and its resources. Several different sources and types of data are used to develop the indicators that address the questions in this chapter. They include:

- **Satellite imagery.** Data used in the land cover question are derived from analysis of satellite data.[2] A set of data on U.S. land cover called the National Land Cover Database is currently available for the period around 2001. Analyses are currently underway to compare these data with earlier land cover data, to provide a better understanding of trends. Multiple agencies, including EPA, have jointly funded satellite data processing efforts and are working together to derive a common classification approach for the data.
- **National surveys.** The data used in the land use question are primarily derived from two national surveys: the National Resources Inventory (NRI)[3] conducted by the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service and the Forest Inventory and Analysis (FIA)[4] conducted by the USDA Forest Service. These surveys are collected over specific areas for specific USDA purposes; the NRI data are collected only on non-federal lands, and FIA data address only forest and timberlands. These limitations contribute to the need to rely on multiple data sets for national estimates.
- **Regulatory data.** The data used for most of the chemical, waste, and contaminated land questions are derived from self-reporting or government-collected measurements to address regulatory requirements. For example, the chemical release information reported under the chemical question is derived from the Toxics Release Inventory based on industry reporting. These data, in general, represent only a small sample of the total picture of waste, chemicals, and land contamination. State and local governments collect additional data, but the lack of consistency in approaches makes compilation of national data difficult.

This chapter presents only data that meet the ROE indicator definition and criteria (see Box 1-1, p. 1-3). Note that non-scientific indicators, such as administrative and economic indicators, are not included in this definition. Thorough documentation of the indicator data sources and metadata can be found online at http://www.epa.gov/roe. All indicators were peer-reviewed during an independent peer review process (again, see http://www.epa.gov/roe for more information). Readers should not infer that the ROE indicators included reflect the complete state of knowledge on the nation's land. Many other data sources, publications, and site-specific research projects have contributed to the current understanding of land trends, but are not used in this report because they did not meet some aspect of the ROE indicator criteria.

4.1.2 Organization of This Chapter

The remainder of this chapter is organized into five sections corresponding to the five questions that EPA seeks to answer about land. Each section introduces a question and its importance, presents the ROE indicators to help answer the question, and discusses what the ROE indicators, taken together,

[2] Multi-Resolution Land Characteristics Consortium. 2007. National Land Cover Database 2001 (NLCD 2001). Accessed November 28, 2007. <http://www.mrlc.gov/mrlc2k_nlcd.asp>

[3] U.S. Department of Agriculture, Natural Resources Conservation Service. 2007. National Resources Inventory, 2003 annual NRI: Land use. <http://www.nrcs.usda.gov/technical/nri/2003/nri03landuse-mrb.html>

[4] Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2004. Forest resources of the United States, 2002. USDA Forest Service. <http://ncrs.fs.fed.us/pubs/gtr/gtr_nc241.pdf>

say about the question. Several of the National Indicators also provide information organized by EPA Regions, and one Regional Indicator addresses specific issues at a sub-EPA Region scale. Each section concludes by highlighting the major challenges to answering the question and identifying important information gaps.

Table 4-1 lists the indicators used to answer the five questions in this chapter and shows where the indicators are presented.

4.2 What Are the Trends in Land Cover and Their Effects on Human Health and the Environment?

4.2.1 Introduction

Land cover—the surface components of land that are physically present and visible—provides a means to examine landscape patterns and characteristics. Patterns and landscape characteristics are important in understanding the extent, availability, and condition of lands; ecological system extent, structure, and condition; and the potential for dispersion and effects of chemicals and other pollutants in and on the environment. Land cover represents a starting point from which a variety of monitoring activities can be performed. EPA considers land cover information to be critically important for a number of reasons, including the ability to assess nonpoint sources of pollution, understanding landscape variables for ecological analyses, assessing the behavior of chemicals, and analyzing the effects of air pollution.

Land cover, in its naturally occurring condition, integrates and reflects a given site's climate, geology and soils, and available biota over a time span of decades or longer. Land cover can be affected on shorter time scales by naturally occurring disturbances (e.g., storms, floods, fires, volcanic eruptions, insects, landslides) and human activities. Land cover represents the results of both naturally occurring conditions and disturbances and human activities such as population change, industrial and urban development, deforestation or reforestation, water diversion, and road-building. Depending on one's perspective, the changes wrought by natural processes and human activities can be perceived as improvements or degradations of the state of land cover.

Table 4-1. Land—ROE Questions and Indicators

Question	Indicator Name	Section	Page
What are the trends in land cover and their effects on human health and the environment?	Land Cover (N/R)	4.2.2	4-7
	Forest Extent and Type (N/R)	6.2.2	6-8
	Land Cover in the Puget Sound/Georgia Basin (R)	4.2.2	4-10
What are the trends in land use and their effects on human health and the environment?	Land Use (N/R)	4.3.2	4-14
	Urbanization and Population Change (N/R)	4.3.2	4-19
What are the trends in wastes and their effects on human health and the environment?	Quantity of Municipal Solid Waste Generated and Managed (N)	4.4.2	4-24
	Quantity of RCRA Hazardous Waste Generated and Managed (N)	4.4.2	4-26
What are the trends in chemicals used on the land and their effects on human health and the environment?	Fertilizer Applied for Agricultural Purposes (N/R)	4.5.2	4-30
	Toxic Chemicals in Production-Related Wastes Combusted for Energy Recovery, Released, Treated, or Recycled (N)	4.5.2	4-33
	Pesticide Residues in Food (N)	4.5.2	4-37
	Reported Pesticide Incidents (N)	4.5.2	4-39
What are the trends in contaminated land and their effects on human health and the environment?	Current Human Exposures Under Control at High-Priority Cleanup Sites (N)	4.6.2	4-44
	Migration of Contaminated Ground Water Under Control at High-Priority Cleanup Sites (N)	4.6.2	4-47

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

Land cover is also important because it affects other environmental variables including water quality, watershed hydrology, habitat and species composition, climate, and carbon storage. Land cover influences the mass and energy exchanges between the surface and the atmosphere and thus influences weather and climate.[5] Land cover is also a primary ingredient of ecological structure and function, with changes affecting species habitat and distribution. Land cover changes in watersheds can alter hydrologic regimes, runoff patterns, and flood buffering.[6]

4.2.2 ROE Indicators

The question of trends in and effects of land cover is addressed by two National Indicators and one Regional Indicator (Table 4-2). Nationwide land cover information is derived from two data collection programs: the National Land Cover Database (NLCD) and the Forest Inventory and Analysis (FIA). The NLCD is described in more detail in the Land Cover indicator summary (p. 4-7), and the FIA is described in the Forest Extent and Type indicator summary (p. 6-8).

The classification approach used in the Land Cover indicator is primarily based on the use of satellite data processing. Where satellite data were not available or processed, survey data have been included to develop the national statistics. The classification approach used in the Land Cover in Puget Sound/Georgia Basin indicator (p. 4-10), while also based on satellite data, is different from the Land Cover National Indicator, and is described in the Regional Indicator discussion. More detailed definitions of land cover types are included in the box within the text of the Land Cover indicator (p. 4-7).

Data for the Land Cover in Puget Sound/Georgia Basin indicator are derived from the NOAA Coastal Change Analysis Program and Landsat satellite data of both the U.S. and Canadian portions of the Puget Sound/Georgia Basin. This indicator depicts two cover classes: forest and urban.

The data presented in the Forest Extent and Type indicator are derived from national surveys of forest land and timberland in the U.S. These data reflect total extent of forest land both nationally and by EPA Region, as well as trends in many species types on timberland.

Table 4-2. ROE Indicators of Trends in Land Cover and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Land Cover (N/R)	4.2.2	4-7
Forest Extent and Type (N/R)	6.2.2	6-8
Regional Indicators	**Section**	**Page**
Land Cover in the Puget Sound/Georgia Basin	4.2.2	4-10

N/R = National Indicator displayed at EPA Regional scale

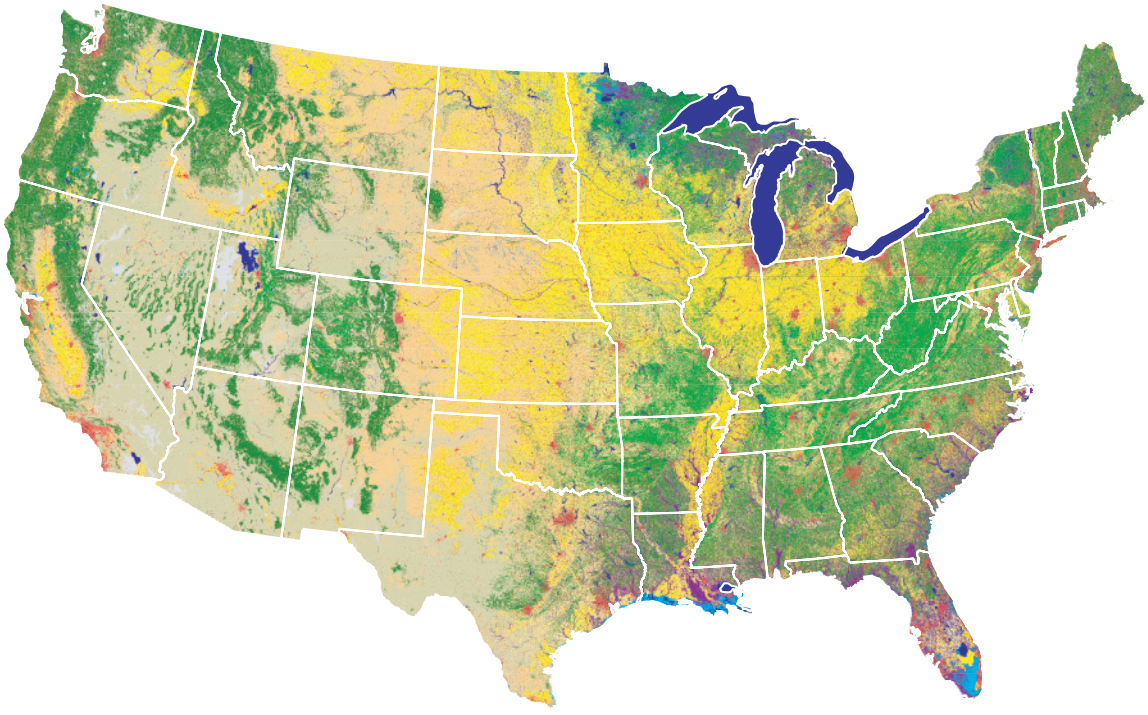
[5] Marland, G., R.A. Pielke, Sr., M. Apps, R. Avissar, R.A. Betts, K.J. Davis, et al. 2003. The climatic impacts of land surface change and carbon management, and the implications for climate-change policy. Clim. Pol. 3:149-157.

[6] de Sherbinin, A. 2002. Land-use and land-cover change: A CIESIN thematic guide. Palisades, NY: Center for International Earth Science Information Network of Columbia University. <http://sedac.ciesin.columbia.edu/tg/guide_main.jsp>

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 (p. 6-8), and wetland acreage is discussed in greater detail in the Wetlands indicator (p. 3-32).

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

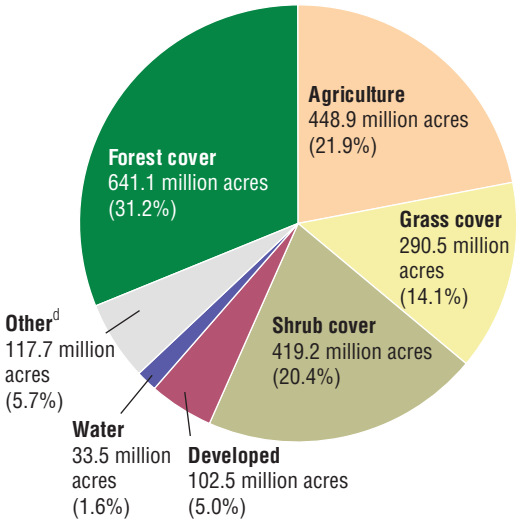
Exhibit 4-1. Land cover of the contiguous U.S., based on 2001 NLCD [a]



[a] See box on p. 4-9 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.

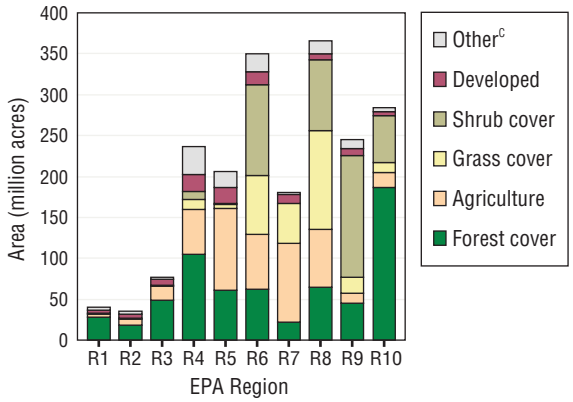
[b]See box on p. 4-9 for definitions of land cover categories.

[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]

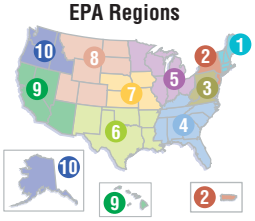


[a]**Coverage:** All land area of the contiguous 48 states (excluding water), plus forest land in Alaska and Hawaii.

[b]See box on p. 4-9 for definitions of land cover categories.

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

EPA Regions



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

resolution, comprising approximately 27 billion cells covering 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

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.

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.

- 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

INDICATOR | Land Cover *(continued)*

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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INDICATOR | Land Cover in the Puget Sound/Georgia Basin

Changes in land use and corresponding changes in land cover can alter the basic functioning and resilience of ecological systems. Watersheds, for example, experience a cascade of effects among critical physical, chemical, and biological processes when land cover changes (NWP, 1995; Thom and Borde, 1998). For instance, removal of vegetation can increase erosion, leading to impacts on soil and water quality, and increases in developed land typically result in a corresponding increase in impervious surfaces with consequences for runoff, among other issues. While individual impacts to a landscape may appear as small changes, the combined impacts of particular land uses or land management practices on watersheds can have substantial effects on water quality, species composition, and flooding patterns (PSAT, 2002, 2004). Such combined impacts are often referred to as "cumulative effects." As a result of their potential to broadly and substantially influence environmental condition, land cover and use are important factors to monitor.

This indicator compares changes in two land cover metrics for the Puget Sound and Georgia Basin in Washington state and part of British Columbia, Canada. The metrics include percent change of urban and forest land cover. Data cover the period from 1995 to 2000 for the U.S. portion of the basin and from 1992 to 1999 for the Canadian side of the basin. The metrics represent the change in total urban or forested land area divided by total land area in the watershed. Forest and urban land cover are two of the most important factors affecting the condition of watersheds in the Puget Sound Basin (Alberti and Marzluff, 2004; Alberti, 2005). In contrast to the nationwide land cover indicator, which is based on NLCD data, this indicator relies on data derived from four assembled USGS Landsat scenes covering the U.S. portion of the Puget Sound Basin

and from a combined scene covering the Canadian land area. The land cover data for all USGS 6th field watersheds in the basin were produced from NOAA Coastal Change Analysis Program (C-CAP) data and from Canadian Baseline Thematic Mapping (BTM) data. The USGS Hydrologic Unit Codes and Canadian watershed groupings provide topographically delineated watersheds, which are aggregated, or "nested," into larger sub-basin and basin units.

What the Data Show

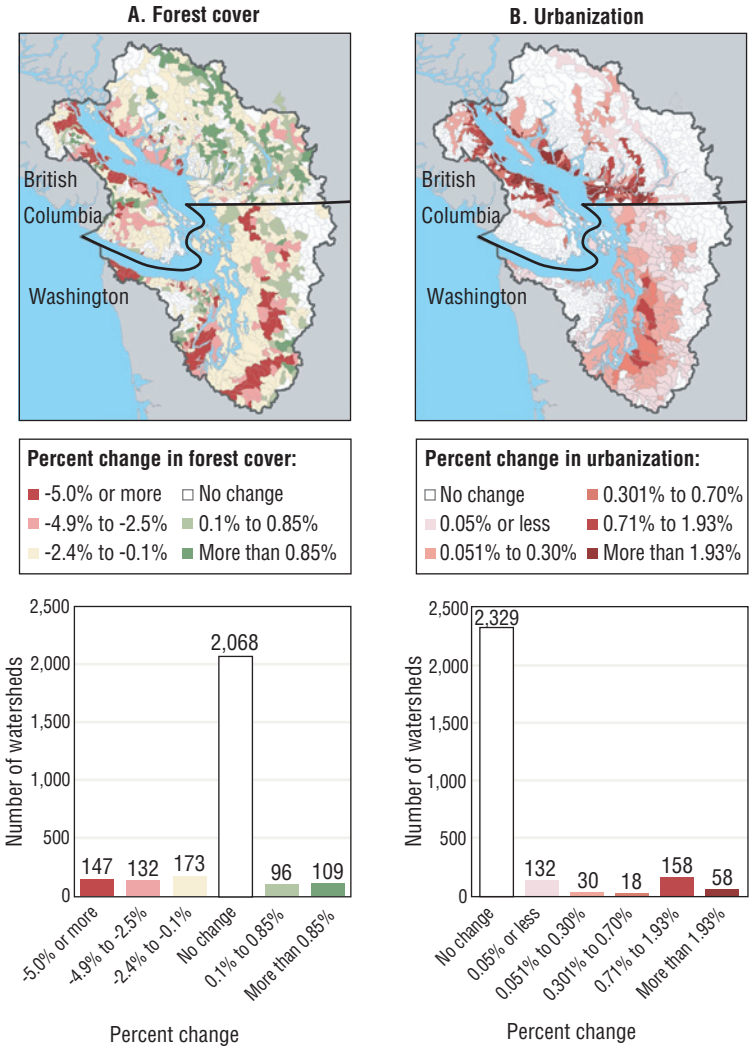
Forest Cover

Little or no change in forest cover was observed in 2,068 watersheds (76 percent) of the 2,725 watersheds assessed (Exhibit 4-4, panel A). However, 279 watersheds (10 percent) saw at least 2.5 percent of their mature forest cover converted to some other land cover, often bare ground, immature vegetation, or industrial/urban uses. At the same time, another group of 205 watersheds (8 percent), generally those at higher elevations, indicated a net increase in forest cover as young stands or cleared areas have re-grown into more mature forest cover classes.

Urbanization

During the same period, little or no change in urban land cover was observed in approximately 90 percent of the 2,725 assessed watersheds within the basin (Exhibit 4-4, panel B). However, urbanization increased across many low-elevation watersheds and shoreline areas, with 158 watersheds (6 percent) expanding the urban portion of the watershed by between 0.7 and 1.93 percent, and another 58 watersheds (2 percent) showing increases of more than 1.93 percent. Research has shown that as a watershed's drainage area becomes paved or otherwise impervious, there is a high potential for physical, chemical, and biological impairments to both water quality conditions and other aquatic resources (NWP, 1995; Alberti and Marzluff, 2004).

Exhibit 4-4. Land cover change in watersheds of the Puget Sound/Georgia Basin, 1992-2000[a,b]



[a]**Coverage:** 2,725 watersheds within the Puget Sound/Georgia Basin, located in the state of Washington and the Canadian province of British Columbia. U.S. watersheds are 12-digit Hydrologic Unit Code (HUC12) watersheds.

[b]U.S. data reflect changes from 1995 to 2000, while Canadian data reflect changes from 1992 to 1999.

Data source: *British Columbia Integrated Land Management Bureau, 2001; CommEn Space, 2005; NOAA, 2006*

Indicator Limitations

- While the U.S. C-CAP data and the Canadian BTM data have similar and overlapping time periods, as currently presented, the U.S. data reflect change from 1995 to 2000 and the Canadian data reflect change from 1992 to 1999.
- The size of the data pixels and the minimum mapping unit size affect the classification of certain features such as narrow riparian corridors, and can affect the percentages in the indicators.

INDICATOR | Land Cover in the Puget Sound/Georgia Basin *(continued)*

Data Sources

The full analysis has not been published as a data set, but it is based on publicly available data sets compiled by CommEn Space (http://www.commenspace.org). Raw data for the U.S. portion of this indicator are available from C-CAP (NOAA, 2006), and Canadian data are available from the British Columbia Integrated Land Management Bureau (2001). Additional technical background is provided by U.S. EPA (2006).

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4.2.3 Discussion

What These Indicators Say About Trends in Land Cover and Their Effects on Human Health and the Environment

The most recently available 2001 data are presented for the Land Cover indicator (p. 4-7). As of the writing of the ROE, the data are available for two points in time, 1992 and 2001, but cannot be compared. Work is ongoing to develop a comparison database. The data show that the largest extent of a cover type nationwide is forest land, followed by agriculture, shrubland, grassland, and developed land.

The Land Cover in Puget Sound/Georgia Basin indicator (p. 4-10) shows that land cover in the majority of the approximately 2,700 sub-watersheds that constitute the Puget Sound and Georgia Basin did not change appreciably during the time periods covered by the indicator. The data in this Regional Indicator allow for discrimination of patterns of watersheds where land cover has changed even in the relatively short interval of 5 years. For example, forest cover tended to decrease in coastal and mid-elevation watersheds, while showing a net increase at higher elevations. Developed land cover increased somewhat in approximately 8 percent of the sub-watersheds, mainly in watersheds at low elevations and along the shore. These and related trends may have consequences for human health and ecologic conditions in the areas where land cover is changing. For example, increases in developed land cover may be associated with increases in impervious surface area, which can cause changes in surface water runoff quantity and quality to the point where detrimental effects on aquatic resources may occur.[7]

The Forest Extent and Type indicator (p. 6-8) provides trend data for forest land cover, and shows that the total amount of forest land in the U.S. has remained relatively constant over recent years. On a regional basis, however, there have been shifts, including increases in forest cover over the last century in EPA Regions 1, 2, 3, and 5 and decreases in Regions 6 and 9. The species composition of forest cover has also shifted.[8]

Limitations, Gaps, and Challenges

The current lack of trend data is a key limitation of the Land Cover indicator (p. 4-7) as well as a gap in the data. The changing availability of technology since the 1970s, such as satellites and computing capacity to process large volumes of data, has provided new tools in the effort to track trends in

[7] U.S. Environmental Protection Agency. 2005. Estimating and projecting impervious cover in the southeastern United States. EPA/600/R-05/061. Athens, GA. <http://www.epa.gov/athens/publications/reports/Exum600R05061EstimatingandProjectingImpervious.pdf>

[8] These changes and their effects on the environment are described in Chapter 6.

land cover. The use of these tools continues to be constrained due to complexities in land cover and costs of processing. This is one reason that trend data for national land cover using satellite data are not currently available.

Another gap is the lack of indicators for human health effects related to trends in land cover. While land cover extent may represent a measure of ambient conditions and is a critical input to many other analyses (e.g., models of the water cycle, carbon cycle, ecological system function), it provides limited insight in answering the question of effects on human health.

There are several challenges related to addressing the question of trends in land cover. Two critical challenges are (1) that land cover characteristics can vary depending on the scale of mapping or measurement and (2) that the classification systems used to describe land cover vary by agency and by the agencies' needs. The variability of species and structure within land cover types can be important in how land cover is affected by pollutants or the type of habitat that is provided. While mapping or measuring the details of species and structure of forest or shrubland is possible on a local basis, it is very difficult to do consistently on a national scale. There are many different types or categories of land cover that can be defined at very different levels of detail, and different classification schema often make comparability among data sets and across time frames difficult. The major sources of data used to track land cover are based on national surveys using unique classifications that have been maintained over time to allow valid comparisons of important characteristics to be made. At the same time, technology is changing what can be measured, mapped, and classified. Data that can be collected from ground surveys or in some cases inferred from aerial photos—such as understory species—are seen differently in automated satellite data processing. Coordinating, integrating, and using data collected at a variety of scales and based on diverse data sources and classifications are challenges in tracking trends in and effects of land cover.

4.3 What Are the Trends in Land Use and Their Effects on Human Health and the Environment?

4.3.1 Introduction

Land use represents the economic and cultural activities that are practiced at a place, such as agricultural, residential, industrial, mining, and recreational uses. Land use changes occur constantly and at many scales, and can have specific and cumulative effects on air and water quality, watershed function, generation of waste, extent and quality of wildlife habitat, climate, and human health. Land use differs from land cover in that some uses are not always physically obvious (e.g., land used for producing timber but not harvested for many years or land used for grazing but without animals will not be visible). Public and private lands frequently represent very different uses. Urban development seldom occurs on public lands, while private lands are infrequently protected for wilderness uses.

EPA is concerned about the use of land because of the potential effects of land use and its byproducts on the environment. For example, land development creates impervious surfaces through construction of roads, parking lots, and other structures. Impervious surfaces contribute to nonpoint source water pollution by limiting the capacity of soils to filter runoff. Impervious surface areas also affect peak flow and water volume, which heighten erosion potential and affect habitat and water quality. Increased storm water runoff from impervious surfaces can deliver more pollutants to water bodies that residents may rely on for drinking and recreation.[9] Storm runoff from urban and suburban areas contains dirt, oils from road surfaces, nutrients from fertilizers, and various toxic compounds. Point source discharges from industrial and municipal wastewater treatment facilities can contribute toxic compounds and heated water. Impervious surfaces also affect ground water aquifer recharge.

Some land development patterns, in particular dispersed growth such as "suburbanization," can contribute to a variety of environmental concerns. For example, increased air pollution due to increased vehicle use can result in increased concentrations of certain air pollutants in developed areas that may exacerbate human health problems such as asthma.[10] Another potential effect of land development is the formation of "heat islands," or domes of warmer air over urban and suburban areas, caused by the loss of trees and shrubs and the absorption of more heat by pavement, buildings, and other sources. Heat islands can affect local, regional, and global climate, as well as air quality.[11]

Agricultural land uses can affect the quality of water and watersheds. The types of crops planted, tillage practices, and various irrigation practices can limit the amount of water available for other uses. Livestock grazing in riparian zones can change landscape conditions by reducing stream bank vegetation and increasing water temperatures, sedimentation, and nutrient levels. Runoff from pesticides, fertilizers, and nutrients from animal manure can also degrade water quality. Additionally, agricultural land uses may result in loss of native habitats or increased wind erosion and dust, exposing humans to particulate matter and various chemicals.[12]

Some land uses can accelerate or exacerbate the spread of invasive species. Certain land use practices, such as overgrazing, land conversion, fertilization, and the use of agricultural chemicals,

[9] U.S. Environmental Protection Agency. 2005. Estimating and projecting impervious cover in the southeastern United States. EPA/600/R-05/061. Athens, GA. <http://www.epa.gov/athens/publications/reports/Exum600R05061EstimatingandProjectingImpervious.pdf>

[10] Schwartz J. 2004. Air pollution and children's health. Pediatrics 113:1037-1043.

[11] U.S. Environmental Protection Agency. 2003. Cooling summertime temperatures: Strategies to reduce urban heat islands. EPA/430/F-03/014. Washington, DC. <http://www.epa.gov/heatisland/resources/pdf/HIRIbrochure.pdf>

[12] Schenker, M. 2000. Exposures and health effects from inorganic agricultural dusts. Environ. Health Persp. 108(Suppl 4):661-664. <http://ehp.niehs.nih.gov/members/2000/suppl-4/661-664schenker/schenker-full.html>

can enhance the growth of invasive plants.[13] These plants can alter fish and wildlife habitat, contribute to decreases in biodiversity, and create health risks to livestock and humans. Introduction of invasive species on agricultural lands can reduce water quality and water availability for native fish and wildlife species.

Research is beginning to elucidate the connections between land use changes and infectious disease. For example, fragmentation of forest habitat into smaller patches separated by agricultural activities or developed land increases the "edge effect" and promotes the interaction among pathogens, vectors, and hosts.[14]

In some cases, changes in land use may have positive effects, such as increasing habitat as a result of deliberate habitat restoration measures; and reclamation of lands for urban/suburban development as a result of cleanup of previously contaminated land.

4.3.2 ROE Indicators

The question of trends in land use is addressed by two ROE indicators: Land Use and Urbanization and Population Change (Table 4-3). The primary information sources for these indicators are the National Resources Inventory prepared by the U.S. Department of Agriculture's Natural Resources Conservation Service, the Forest Inventory and Analysis conducted by the Forest Service, the Census of Agriculture from the National Agricultural Statistics Service, and population data collected by the U.S. Census Bureau. The box on pages 4-16 and 4-17 provides definitions of the categories used in the indicators.

Table 4-3. ROE Indicators of Trends in Land Use and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Land Use (N/R)	4.3.2	4-14
Urbanization and Population Change (N/R)	4.3.2	4-19

N/R = National Indicator displayed at EPA Regional scale

INDICATOR | Land Use

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 page 4-16.

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.

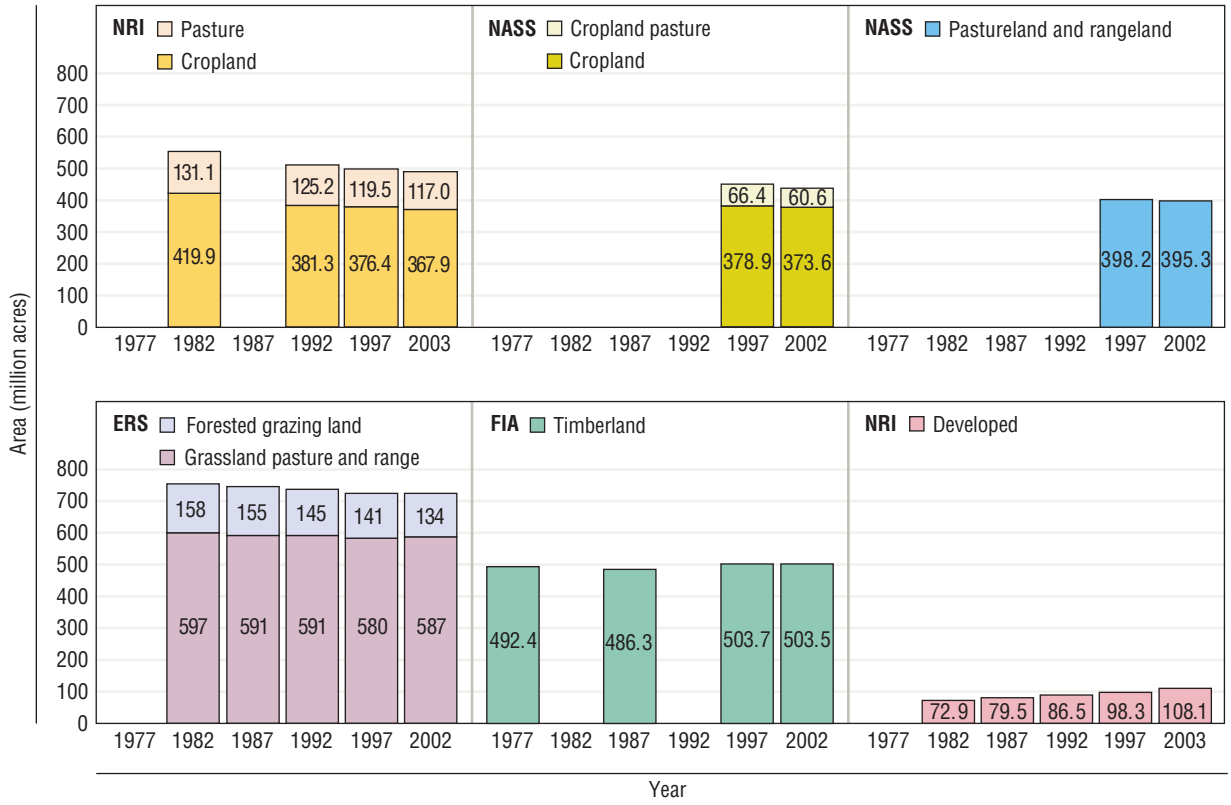
The Forest Inventory and Analysis (FIA) surveys conducted by the USDA Forest Service were used to track trends in forest and timberlands. The FIA surveys include both private and public land in all 50 states. The FIA previously assessed forest and timberland acreage every 10 years, but the data are now 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 rangeland (typically "unimproved" grazing land) are available from the USDA Economic Research Service (ERS) for 5-year intervals from 1982 through 2002.

[13] Westbrooks, R.G. 1998. Invasive plants: Changing the landscape of America: Fact book. Washington, DC: Federal Interagency Committee for the Management of Noxious and Exotic Weeds.

[14] Patz, J.A., P. Daszak, G.M. Tabor, A.A. Aguirre, M. Pearl, J. Epstein, N.D. Wolfe, A.M. Kilpatrick, J. Foufopoulos, D. Molyneux, D.J. Bradley, and Members of the Working Group on Land Use Change and Disease Emergence. 2004. Unhealthy landscapes: Policy recommendations on land use change and infectious disease emergence. Environ. Health Persp. 112(10):1092-1098.

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



[a]See box on p. 4-16 for definitions of land use categories.

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

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 cropland 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[15] 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.

[15] 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.

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.

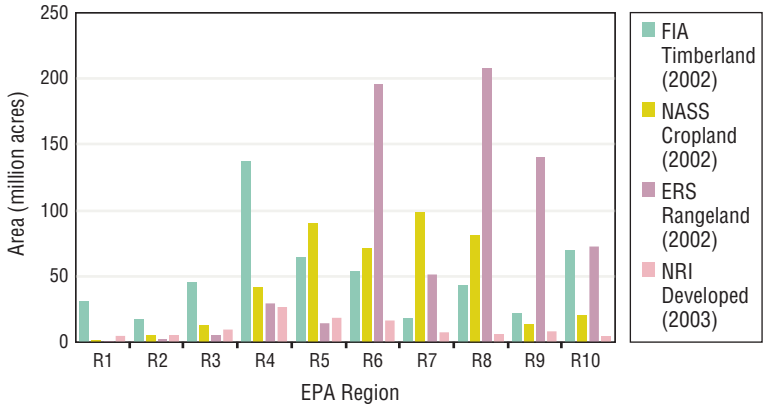
Forest lands are managed by a complex array of interests to meet multiple purposes, including providing habitat for a variety of species, recreation, and timber production. While forest is a land *cover* classification, timberland is a land *use* classification that reflects forest land capable of producing 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 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

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



[a]See box on p. 4-16 for definitions of land use categories.

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

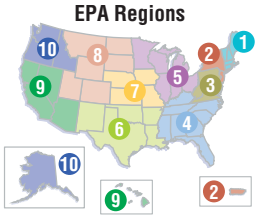
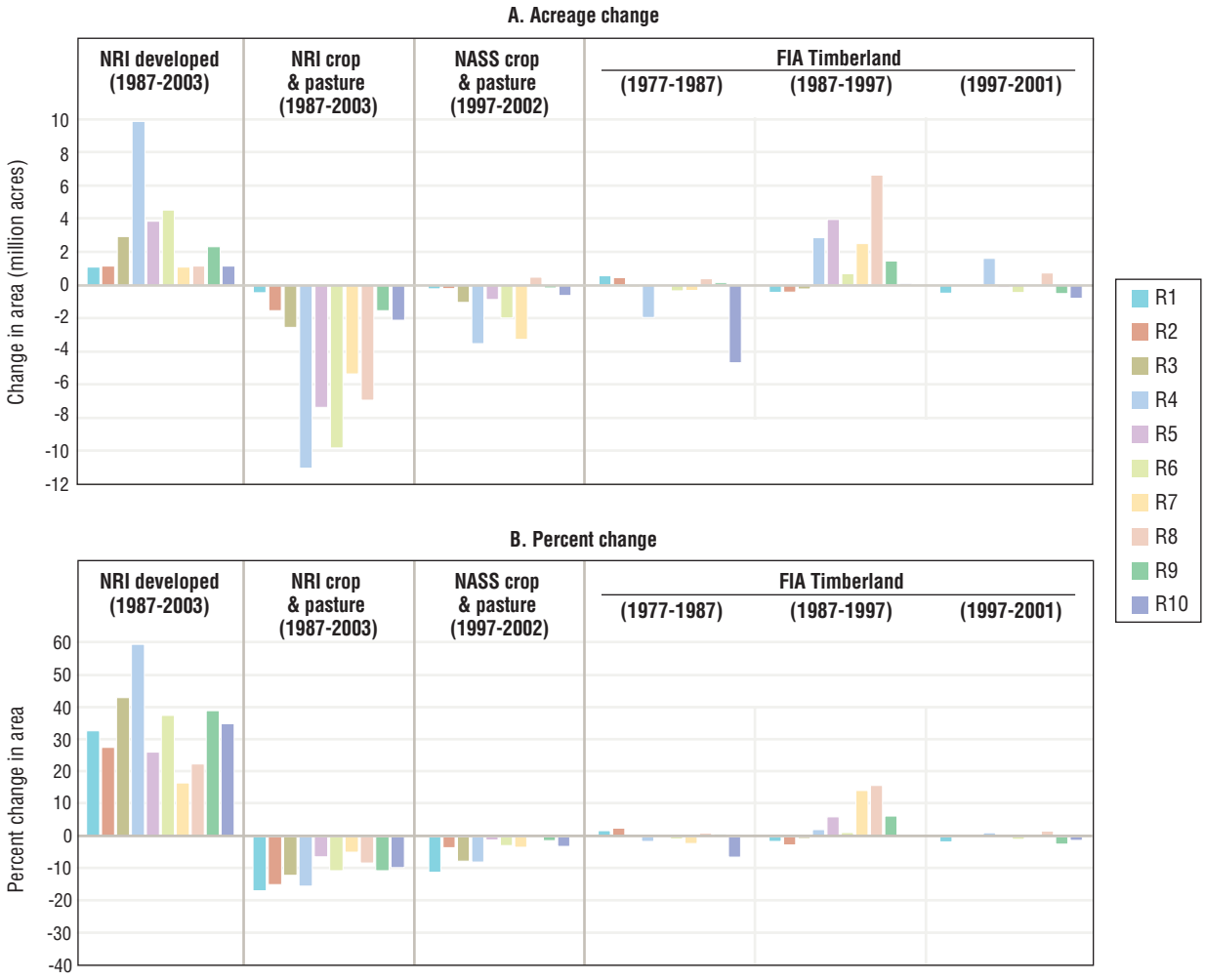
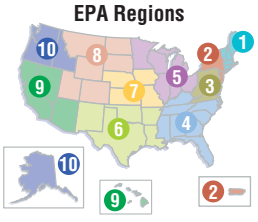


Exhibit 4-7. Changes in land use in the U.S. by EPA Region, 1977-2003[a]



[a]See box on p. 4-16 for definitions of land use categories.

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



Alaska, the NRI data likely offer a reasonable approximation of national trends in these categories.

- 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).

INDICATOR | Land Use *(continued)*

- 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).

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Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2004. Forest resources of the United States, 2002. USDA Forest Service. <http://ncrs.fs.fed.us/pubs/gtr/gtr_nc241.pdf>

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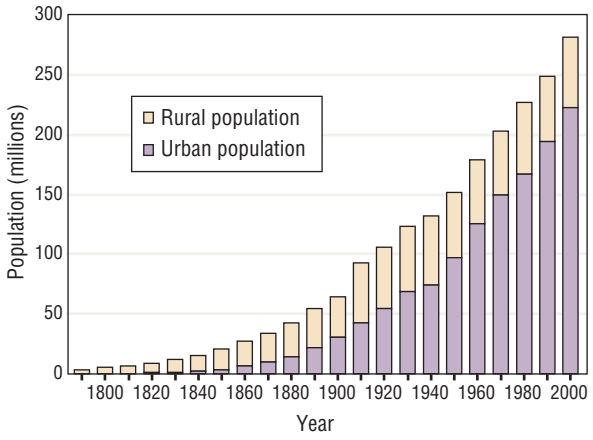
USDA NRCS. 2004. National resources inventory: 2002 annual NRI. <http://www.nrcs.usda.gov/technical/NRI/2002/glossary.html>

INDICATOR | Urbanization and Population Change

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

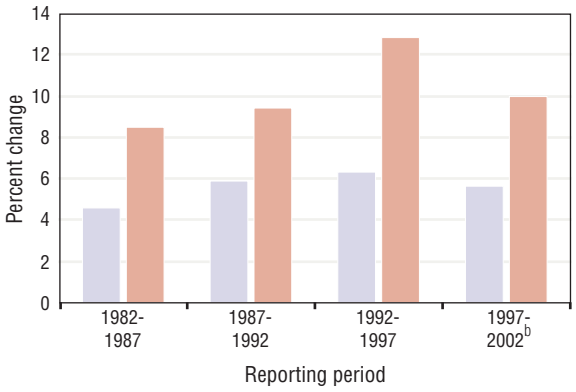
Exhibit 4-8. Population and urbanization in the U.S., 1790-2000[a]



[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]

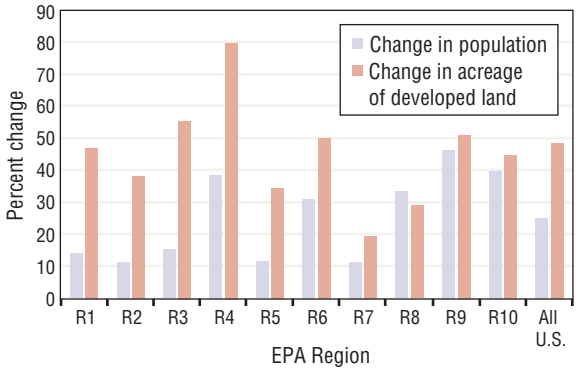


[a]**Coverage:** Contiguous 48 states (excluding the District of Columbia) and Hawaii.

[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.

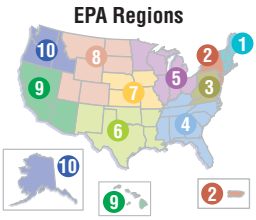
Data source: *U.S. Census Bureau, 1996, 2002b, 2006; USDA NRCS, 2000, 2004*

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*



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.

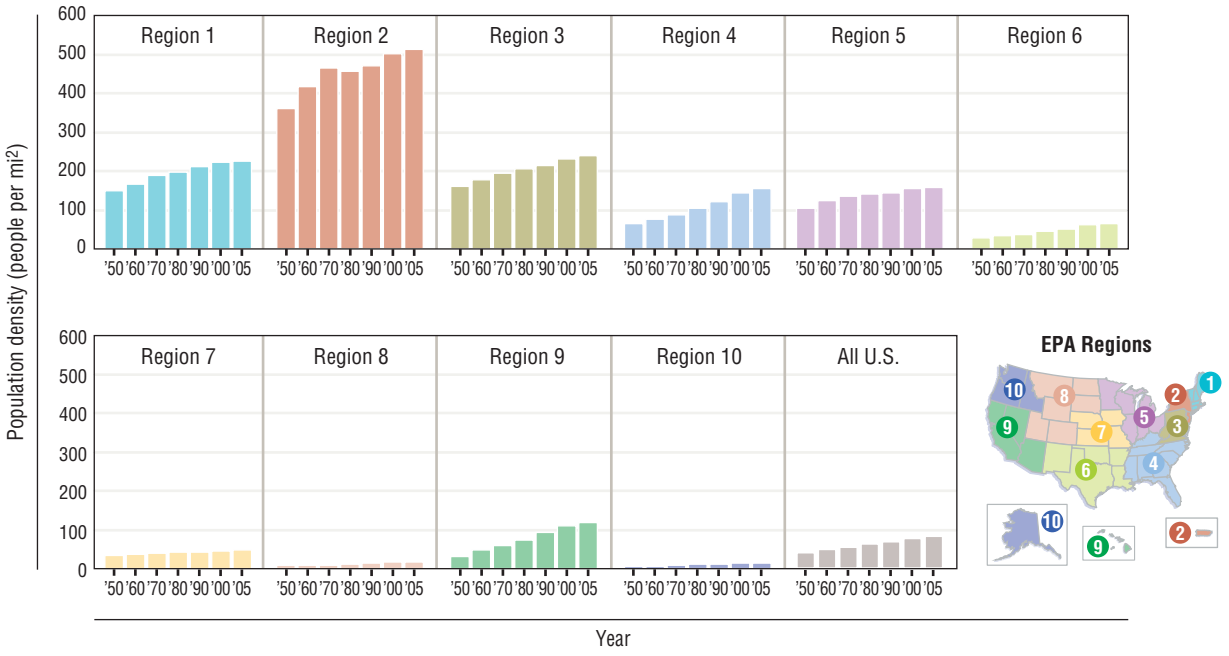
The rates of population and developed land growth over 5-year intervals increased between 1982 and 1997, before declining slightly between 1997 and 2002. Over all four 5-year increments, the amount of developed land increased at nearly twice the rate of the population (Exhibit 4-9). Between 1982 and 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). 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 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.

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*

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.
- 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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4.3.3 Discussion

What These Indicators Say About Trends in Land Use and Their Effects on Human Health and the Environment

The indicators point out that the development of land for human residential and commercial purposes is occurring at a rapid pace. In the 21-year period between 1982 and 2003, the acreage of developed land increased by more than 48 percent from its 1982 level. Population in a similar time frame grew at only half the rate of land development (25 percent), indicating that more land is being developed per capita now than 25 years ago. Across EPA regions, such rates of change in developed land and population vary both independently and with respect to each other. Over a similar 20-year time frame (1982–2002), the extent of cropland and pastureland has slowly declined, with larger decreases in those regions experiencing either increased land development or reforestation.

Limitations, Gaps, and Challenges

There is generally a lack of comprehensive data on the types and rates of land use and land cover change, and even less systematic evidence on the causes and consequences of these changes. On a global scale, the National Research Council identified land use dynamics as one of the grand challenges for environmental research.[16]

Two examples of land uses not addressed by the indicators, that can have effects in different ways on condition and extent of land, are the formal protection or reservation of land for habitat or natural resources, and mining and extraction activities. Some data are collected locally and for federal lands (e.g., National Park acreage) or tracked for economic indicators, but the national picture of the extent of land reservation and mining is not generally available.

A key challenge in answering the land use question is that estimates of the extent of various land uses differ across data sources and each source uses different classifications, measurement approaches, methodologies for analysis and interpretation,

[16] National Research Council, Committee on Grand Challenges in Environmental Sciences. 2001. Grand challenges in environmental sciences. Washington, DC: National Academies Press.

and sampling time frames. The data are collected by many different agencies that manage land for many different purposes. The data collection efforts currently in place are derived from specific interests, such as tracking changes in the extent of agricultural land or farmland, or understanding how much land is used for timber production. These data collection efforts tend to develop and use their own classifications and categorization, making it difficult to integrate and use the data over time, across inventories, or as a national picture.

Another challenge is understanding the effects that trends in land use have on human health. No indicators are available, as effects have not been shown or quantified on a national basis. Urban and landscape planners have conducted site-specific studies on individual land uses, but little is known about overall national trends in land use and potential impacts on human health.

An additional challenge is that a variety of state, county, and municipal laws, regulations, and practices govern the use of land, but aside from regulations addressing protection of species and their habitats, there are no national land use regulations that apply to all non-federal lands. There are also relatively few state-level efforts to organize land use data; most activities occur over specific local, usually urbanizing, geographic areas. This means that land use records are not maintained statewide or nationally, as they are in other nations, which contributes to challenges in tracking and monitoring land use changes. It also means that strategies to plan land use across jurisdictions are difficult to develop.

Finally, a challenge in developing data to determine trends is the difficulty of actually delineating land use. Land use is generally a function of laws, policies, or management designations that may not always be possible to infer from examining the ground via surveys. Analysis of zoning maps or property records at the local level may be necessary.

4.4 What Are the Trends in Wastes and Their Effects on Human Health and the Environment?

4.4.1 Introduction

Every resident, organization, and human activity in the U.S. generates some type of waste. Many different types of wastes are generated, including municipal solid waste, agricultural and animal waste, medical waste, radioactive waste, hazardous waste, industrial non-hazardous waste, construction and demolition debris, extraction and mining waste, oil and gas production waste, fossil fuel combustion waste, and sewage sludge (see the glossary in Appendix A for detailed descriptions of these wastes). In general, waste generation represents inefficient use of materials. These materials, some of which are hazardous, must be managed through reuse, recycling, storage, treatment, and disposal. Hazardous wastes are either specifically listed as hazardous by EPA or a state, or exhibit one or more of the following characteristics: ignitability, corrosivity, reactivity, or toxicity. Generation and management of hazardous wastes have the potential to contaminate land, air, and water and negatively affect human health and environmental conditions. Tracking trends in the quantity, composition, and effects of these materials provides insight into the efficiency with which the nation uses (and reuses) materials and resources and provides a means to better understand the effects of wastes on human health and ecological condition.

The amount of waste produced is influenced by economic activity, consumption, and population growth. Affluent societies, such as the U.S., generally produce large amounts of municipal solid waste (e.g., food wastes, packaged goods, disposable goods, used electronics) and commercial and industrial wastes (e.g., demolition debris, incineration residues, refinery sludges). Among industrialized nations, the U.S. generates the largest amounts of municipal solid waste per person on a daily basis.[17]

Current approaches to waste management evolved primarily due to health concerns and odor control. Waste often was deposited outside developed areas on nearby lands, frequently wetlands. Excavation of land specifically for deposition of wastes followed, often accompanied by burning of wastes to reduce volume, a practice eventually determined to be a contributor to degraded air quality in urban areas. Burning of wastes occurred at multiple levels, from backyard burning to large, open-burning dumps of municipal solid wastes to onsite burning of commercial and industrial wastes. Land disposal created problems such as ground water contamination, methane gas formation and migration, and disease vector hazards.

The amount of land being used to manage the many types of waste generated is not known. Most municipal solid wastes and hazardous wastes are managed in land disposal units. Land disposal of hazardous wastes includes landfills, surface impoundments, land treatment, land farming, and underground injection. Modern landfill facilities are engineered with containment systems and monitoring programs. Waste management practices prior to the Resource Conservation and Recovery Act (RCRA) regulations left legacies of contaminated lands in many cases, which are addressed in Section 4.6 of this chapter.

Landfills represent one of the largest human-related sources of methane gas in the U.S. Between 1997 and 2003, landfills accounted for slightly more than one-fourth of the estimated methane emissions attributed to human activity.[18] Methane gas is released as wastes decompose, as a function of the total amount and makeup of the wastes as well as management

[17] Clark, R., and E. Capponi, eds. 2005. OECD in figures 2005: Statistics on the member countries. Organization for Economic Cooperation and Development (OECD) Observer. Paris, France.

[18] U.S. Environmental Protection Agency. 2006. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2004. EPA/430/R-06/002. <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html>

[19] More information on air emissions related to waste management practices, including nitrogen oxides (NO_x) and carbon monoxide (CO), is included in Chapter 2.

facility location, design, and practices.[19] EPA is interested because gas emissions can be affected by recycling and changing product use. For example, recycling aluminum or office paper can reduce environmental effects (e.g., by reducing the need to mine bauxite or harvest trees), and it will also create positive environmental benefits, such as reductions in energy consumption and greenhouse gases (e.g., emissions associated with the production of products from virgin materials).[20]

Although data do not exist to directly link trends in waste with effects on human health and the environment, the management of waste may result in waste and chemicals in waste entering the environment. Hazardous waste, by definition, has the potential to negatively affect human health and the environment, which is why it is so strictly regulated. The effects associated with waste vary widely and are influenced by the substances or chemicals found in waste and how they are managed. For chemicals found in waste, EPA has been tracking a list of Priority Chemicals. These Priority Chemicals are documented contaminants of air, land, water, plants, and animals. Between 1991 and 2001, quantities of 17 of the Priority Chemicals were reduced by more than 50 percent.[21,22]

4.4.2 ROE Indicators

The ROE indicators for this question focus on the national trends in the amount of municipal solid waste and hazardous waste generated and their management practices (Table 4-4). Municipal solid waste trends are presented for more than four decades. Trends in the generation and management of municipal solid waste are based on estimations from a materials flow or mass balance approach since 1960. Changes in the amount of RCRA hazardous waste generated and managed are based on mandated biennial submissions from generators and treatment, storage, and disposal facilities.

Table 4-4. ROE Indicators of Trends in Wastes and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Quantity of Municipal Solid Waste Generated and Managed	4.4.2	4-24
Quantity of RCRA Hazardous Waste Generated and Managed	4.4.2	4-26

INDICATOR | Quantity of Municipal Solid Waste Generated and Managed

Municipal solid waste (also called trash or garbage) is defined at the national level as wastes consisting of everyday items such as product packaging, grass clippings, furniture, clothing, bottles and cans, food scraps, newspapers, appliances, consumer electronics, and batteries. These wastes come from homes, institutions such as prisons and schools, and commercial sources such as restaurants and small businesses. EPA's definition of municipal solid waste (MSW) does not include municipal wastewater treatment sludges, industrial process wastes, automobile bodies, combustion ash, or construction and demolition debris. Once generated, MSW must be collected and managed, including reuse, recovery for recycling (which includes composting), combustion, and landfill disposal. Many wastes that are disposed in landfills represent a loss of materials that could be reused, recycled, or converted to energy to displace the use of virgin materials.

Prior to the 1970s, MSW disposal generally consisted of depositing wastes in open or excavated landfills, accompanied by open burning to reduce waste volumes. Often industrial wastes were co-disposed with municipal garbage and refuse in urban and rural landfills. Historically, environmental problems associated with landfills have included ground water contamination, emissions of toxic fumes and greenhouse gases, land contamination, and increases in vector populations (e.g., rodents, flies, mosquitoes). Wastes have the potential to cause various types of environmental concerns depending on the way in which they are disposed. When mismanaged, potentially hazardous ingredients in some products can migrate into the environment, possibly posing harm to human health and biota; stockpiled scrap tires may ignite, often burning for months and causing air pollution; waste piles can create habitats for pests and disease vectors such as rodents and

[20] U.S. Environmental Protection Agency. 2006. Solid waste management and greenhouse gases: A life-cycle assessment of emissions and sinks. Third edition. Washington, DC. <http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html>

[21] U.S. Environmental Protection Agency. 2005. National Priority Chemicals Trends Report (1999-2003). EPA/530/R-05/022.

[22] U.S. Environmental Protection Agency. 2007. National Priority Chemicals Trends Report (2000-2004). EPA/530/R-07/001. <http://www.epa.gov/epaoswer/hazwaste/minimize/trends.htm#report>

mosquitoes; and the physical presence of a waste management area can disrupt an ecosystem. Most wastes generated in the U.S. are disposed in landfills, which are subject to federal or state requirements to minimize environmental impacts. MSW landfills are discrete areas of land or excavations that receive trash/garbage, as well as various other types of wastes that are not included in this indicator, such as non-hazardous sludges, hazardous wastes from small quantity generators, non-hazardous industrial wastes, municipal wastewater treatment sludges, and construction and demolition debris.

This indicator shows trends in the national generation and management of MSW on an annual basis from 1960 to 2006. The information presented on MSW consists of estimates generated annually using a materials flow methodology and mass balance approach that relies on production data (by weight) for materials and products that eventually enter the waste stream. These data are collected from industry associations, businesses, and government agencies.

What the Data Show

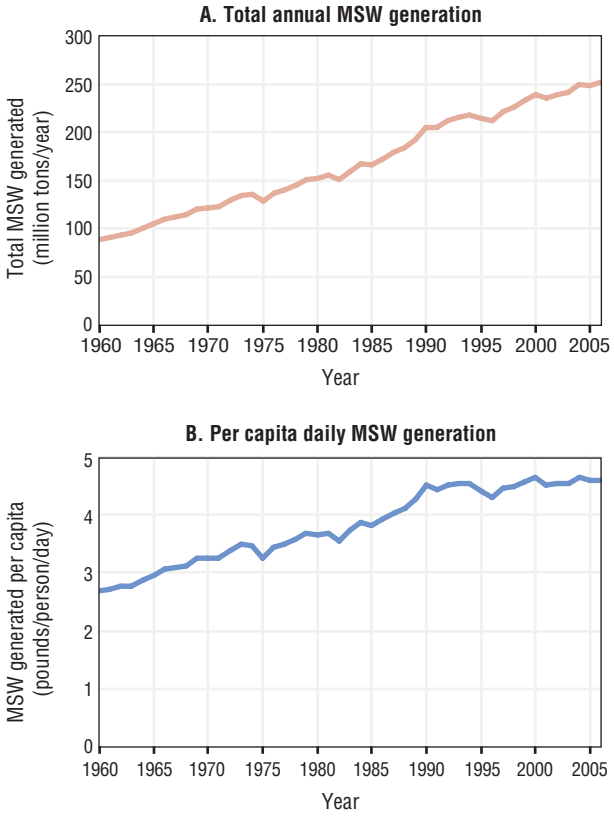
The quantity of MSW generated grew steadily from 88 million tons (MT) in 1960 to over 251 MT in 2006, an increase of 185 percent (Exhibit 4-12, panel A). During this time, the U.S. population increased by 66 percent. On a per capita basis, MSW generation increased from 2.7 pounds per person per day in 1960 to 4.6 pounds per person per day in 2006 (panel B).

Of the 88 MT of MSW generated in 1960, 6 percent was recovered through recycling and 94 percent was landfilled (Exhibit 4-13). MSW quantities sent to landfills or other disposal peaked in 1990 at 142 MT and then began to decline as recycling and combustion increased. The quantity of MSW disposed in landfills has averaged about 135 MT annually since 2000, a 4.9 percent decrease from 1990. In 2006, of the 251 MT generated, 32.5 percent was recycled (including composting), 13 percent combusted with energy recovery, and 55 percent landfilled. Since 1990, the percentage of MSW generated that was sent to landfills dropped from 69 to 55 percent, the percentage recycled rose from 14 to 24 percent, the percentage composted rose from 2 to 8 percent, and the percentage combusted with energy-recovery ranged from 13 to 15 percent.

Indicator Limitations

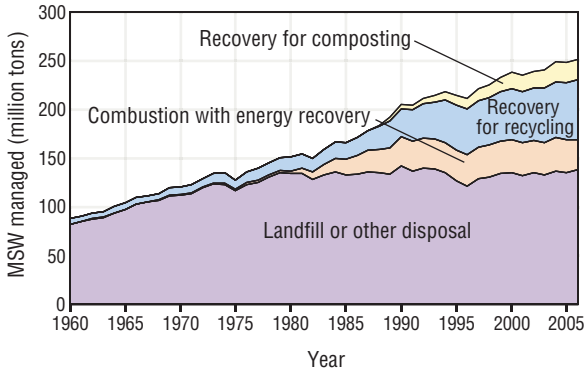
- The data in this indicator are derived from economic statistics on materials generation and estimates of the life cycle of goods, rather than on direct measurements of wastes disposed of. As a result of this methodology and especially of differences in definitions, the figures reported in this indicator do not match estimates of

Exhibit 4-12. Municipal solid waste generation in the U.S., 1960-2006



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

Exhibit 4-13. Municipal solid waste management in the U.S., 1960-2006



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

INDICATOR | Quantity of Municipal Solid Waste Generated and Managed *(continued)*

MSW reported elsewhere (e.g., *BioCycle,* which includes construction and demolition debris, industrial wastes, agricultural wastes, etc., in its estimates). However, the waste categories in this indicator are rigorously defined and consistent from year to year, therefore allowing for reliable long-term trend analyses.

- The data presented on landfills represent the amount of waste disposed in landfills, but do not indicate the capacity or volume of landfills or the amount of land used for managing MSW. Land used for recycling facilities and waste transfer stations also is not included in this indicator. Data to describe the amount of land used or total capacity of landfills are not available nationally.
- The data also do not indicate the status or effectiveness of landfill management or the extent to which contamination of nearby lands does or does not occur.

Data Sources

Exhibits 4-12 and 4-13 are derived from data published in U.S. EPA (2007). The report provides tables with numerical values for certain key years during the period of record (1960, 1970, 1980, 1990, 1995, 2000, 2002, and 2004–2006). However, the full 44-year data set is not publicly available.

References

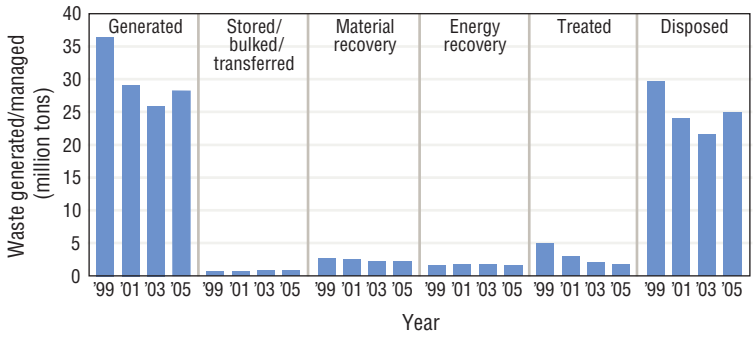
U.S. EPA (United States Environmental Protection Agency). 2007. Municipal solid waste generation, recycling, and disposal in the United States: Facts and figures for 2006. <http://www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm>

INDICATOR | Quantity of RCRA Hazardous Waste Generated and Managed

Hazardous waste is waste with a chemical composition or other property that makes it capable of causing illness, death, or some other harm to humans and other life forms when mismanaged or released into the environment. Uncontrolled dumping of wastes, including hazardous industrial wastes, was commonplace in history, with numerous entities handling and disposing of these materials. Landfills and surface impoundments containing these materials were unlined and uncovered, resulting in contaminated ground water, surface water, air, and soil. Even with tight control of hazardous wastes from generation to disposal, the potential exists for accidents that could result in the release of hazardous wastes and their hazardous constituents into the environment. Through the Resource Conservation and Recovery Act (RCRA) and the subsequent 1984 Hazardous and Solid Waste Amendments, Congress sought to better control waste management and disposal and to conserve valuable materials and energy resources.

Facilities that treat, store, or dispose of hazardous wastes are termed RCRA treatment, storage, and disposal facilities (TSDFs). Some hazardous waste generators treat, store, and dispose of their hazardous waste onsite, while others ship their waste to TSDFs. Most hazardous wastes are eventually disposed in landfills, surface impoundments (which eventually become landfills), land application units, or by deep well injection. All hazardous wastes disposed of must meet certain treatment standards required by the Land Disposal Restrictions prior to disposal.

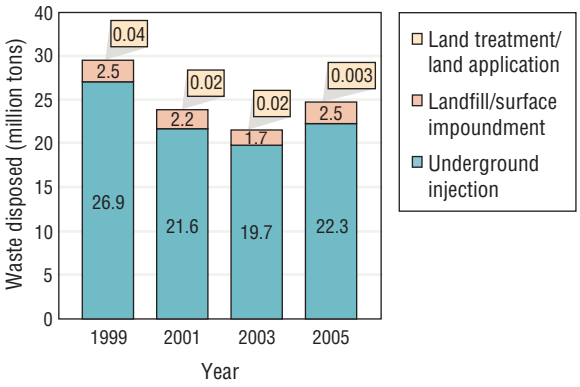
Exhibit 4-14. RCRA hazardous waste generation and management in the U.S., 1999-2005[a]



[a]Individual management practice quantities do not add up to the total quantity generated. See text for details.

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

Exhibit 4-15. RCRA hazardous waste disposal to land in the U.S. by practice, 1999-2005



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

EPA, in partnership with the states, collects extensive data on the RCRA hazardous waste generation and management practices of TSDFs and large quantity generators (businesses that generate more than 2,200 pounds of RCRA hazardous waste, 2.2 pounds of RCRA acute hazardous waste, or 220 pounds of spill cleanup material contaminated with RCRA acute hazardous waste in 1 month). These data are collected every 2 years; this indicator tracks changes in RCRA hazardous wastes generated and managed for the years 1999, 2001, 2003, and 2005.

What the Data Show

Between 1999 and 2005, the quantity of RCRA hazardous wastes generated decreased by 22 percent from 36.1 million tons (MT) to 28.0 MT (Exhibit 4-14). Included in the amount generated are material recovery, energy recovery, treatment, and wastes disposed by deep well injection. Due to RCRA hazardous waste regulations and data collection procedures, the individual management categories discussed below cannot be added together to obtain the total quantity generated. For example, under RCRA, all hazardous waste must be treated to meet technology-based land disposal treatment standards before it is placed in or on the ground, unless it meets those standards as generated. To minimize double-counting, the quantities of waste stored, bulked, transferred, or disposed by landfill, land treatment, or land application after treatment are not included in the total quantity generated, but are shown in the "Disposed" section of Exhibit 4-14 (along with wastes disposed by deep well injection).

In addition to the 36.1 MT of RCRA waste generated in 1999, 0.7 MT were stored/bulked/transferred for some time prior to final disposition (at which time they would be included in wastes recovered, treated, or disposed) (Exhibit 4-14). In 2005, the number stored/bulked/transferred rose to 0.8 MT.

Looking at management activities prior to disposal, in 1999, 7 percent of RCRA hazardous waste was sent to material recovery activities such as metal or solvent recovery, while 8 percent fell into this category in 2005 (Exhibit 4-14). The proportion of RCRA hazardous waste sent for energy recovery increased from 4 percent of RCRA wastes generated in 1999 to 6 percent in 2005. The proportion sent to treatment declined from 14 percent in 1999 to 7 percent in 2005.

The quantity of RCRA hazardous wastes ultimately disposed dropped between 1999 and 2005, from 29.5 MT to 24.9 MT; however, the proportions of waste in the three disposal categories remained fairly stable (Exhibit 4-15). In the four reporting cycles shown, the percentage of disposed RCRA hazardous wastes deep-well injected ranged from 90 to 92 percent of all waste disposed on land. The proportion disposed in landfills or surface impoundments that became landfills ranged between 8 and 10 percent. The land application and land treatment categories represent a very small percentage of disposal and dropped from 0.1 percent in 1999 to 0.01 percent of the RCRA hazardous waste disposed in 2005.

Indicator Limitations

- Data are not collected from small quantity generators, but some wastes coming from these sources *are* included in the RCRA hazardous waste management data from treatment, storage, and disposal facilities that receive the wastes.
- Data are limited to wastes referred to as "RCRA hazardous waste" which are either specifically listed as hazardous or meet specific ignitability, corrosivity, reactivity, or toxicity criteria found in the U.S. Code of Federal Regulations Title 40, Part 261. Materials that are not wastes, whether hazardous or not, are not regulated by RCRA, and therefore are not included in the data summarized here.
- States have the authority to designate additional wastes as hazardous under RCRA, beyond those designated in the national program. State-designated hazardous wastes are not tracked by EPA or reflected in the aggregated information presented.
- The comparability of year-to-year amounts of RCRA hazardous waste generated and managed can be influenced by factors such as delisting waste streams (i.e., determining that a particular listed waste stream coming from a particular facility is not hazardous) or removing the hazardous characteristic of a waste stream.

INDICATOR | Quantity of RCRA Hazardous Waste Generated and Managed *(continued)*

- The data summarized and shown in Exhibits 4-14 and 4-15 were derived from the data and information collected and reported in the Biennial RCRA Hazardous Waste Report Forms (U.S. EPA, 2007a). As a result of methodology and criteria used to derive the results for these two exhibits, the quantities presented in this indicator do not match those individual generation or management quantities presented in each reporting cycle of the National Biennial Reports. The National Biennial Reports are prepared for individual reporting cycles and may not be comparable between reporting cycles due to different reporting requirements or methods of aggregation in each cycle.
- Most hazardous waste generated in the U.S. is in the form of wastewater. The majority of these wastewaters are sent untreated to publicly owned treatment works (POTWs), treated and sent to a POTW, or discharged directly to surface waters through a National Pollutant Discharge Elimination System (NPDES) permit. Hazardous wastewaters generated and subsequently sent to POTWs or discharged through a NPDES permit are not included in this indicator. Any materials generated from these processes, such as sludge, that are considered hazardous waste are managed under hazardous waste regulations.

Data Sources

This indicator is based on the publicly available data sets compiled by EPA. The data sets compiled from individual reporting facilities for this indicator can be found in National Biennial RCRA Hazardous Waste Data Files in EPA's RCRAInfo national database (U.S. EPA, 2007b) (http://www.epa.gov/epaoswer/hazwaste/data/index.htm#rcra-info; ftp://ftp.epa.gov/rcrainfodata).

Exhibits 4-14 and 4-15 are derived from reported data stored in these data files of the RCRAInfo national database. The versions of data sets from each reporting cycle to derive the results for this indicator were downloaded from the FTP site between February 2007 and August 2007. The analyses based on the data sets downloaded were conducted in October 2007.

References

U.S. EPA (United States Environmental Protection Agency). 2007a. Biennial RCRA hazardous waste report instructions and forms. Accessed December 2007. <http://www.epa.gov/epaoswer/hazwaste/data/br05/forms.htm>

U.S. EPA. 2007b. RCRAInfo national database. Accessed December 2007. <ftp://ftp.epa.gov/rcrainfodata>

4.4.3 Discussion

What These Indicators Say About Trends in Wastes and Their Effects on Human Health and the Environment

The indicators show that municipal solid waste generation in the U.S. continued to rise between 1960 and 2006, in absolute terms. On a per capita basis, rates rose from 1960 to 1990; however, since 1990, the daily per capita generation of municipal solid waste has been relatively constant, showing that the total increase in waste may be primarily a function of population growth. Hazardous waste, which is generated primarily through industrial processes, decreased in the time period shown from 1999 to 2005, although there was a small rise between 2003 and 2005.

Materials recovery, or recycling, is an important component of waste management, as it takes materials that might be considered waste and removes them from the waste disposal path to generate reusable marketable materials. Recycling efforts related to municipal solid waste have increased over the last four decades, showing the steepest increases between 1980 and 2000. Municipal solid waste recycling efforts have been steady since 2000, with nearly a third of all municipal solid waste being recycled or composted.

Recycling (material recovery and energy recovery) of hazardous wastes has remained relatively constant over the time span represented by the indicators, although there has been a slight decrease in the amount of waste sent for materials recovery.

While recycling and composting have increased over the past several decades, most wastes are disposed. Disposal of municipal solid wastes in landfills saw a rise in absolute amount from 1960 to 1990, with declines since then. Landfill as a percentage of total waste generated, however, has seen a steady decline from 1960 to 2006. Similarly, most hazardous wastes are also land-disposed, although they are required to meet strict standards for protecting human health and the environment prior to disposal.

Limitations, Gaps, and Challenges

While numerous waste-related data collection efforts exist at the local, state, and national levels, none of these efforts result in nationally consistent or comprehensive data to provide a full understanding of the amount and locations of waste generation and management.

The two types of waste addressed in the indicators represent only a small percentage of the total amount of waste generated in the U.S.—the national amounts and percentage of total waste are unknown. Quantities of "end-of-stream" wastes, such as municipal solid waste, provide an indication

of changing trends in consumption and economic activities, but do not provide information on the other amounts of waste generated by upstream activities, including resource extraction and manufacturing. EPA is interested in better understanding the comparative amounts of the various types of waste generated, but national data are dated, inconsistent, or generally not available in common units to develop a comprehensive picture of the waste generated in the U.S.

The amount of waste generated and managed may describe ambient conditions in terms of wastes in the environment, but does not provide any indication of the effects on human health or environmental condition. There have been changes in the management of wastes over the past few decades, designed to reduce hazardous and potential exposures, but data that more concretely measure the overall exposure (and thus effects on human health and the environment caused by wastes and waste management practices) are still lacking.

4.5 What Are the Trends in Chemicals Used on the Land and Their Effects on Human Health and the Environment?

4.5.1 Introduction

Many chemicals and chemical products are considered essential to modern life because of the benefits they provide. Some break down quickly, while others persist for long periods of time in the environment and may bioaccumulate in the food chain (e.g., persistent, bioaccumulative, and toxic chemicals [PBTs]).

Introduction of chemicals into the environment occurs through acts of nature (e.g., volcanoes, hurricanes), spills on land, emissions to air, and discharges to water. Chemicals can be released through large- and small-scale industrial and manufacturing activity, in the production and storage of food and consumer products, in efforts to manage or eradicate insect-borne diseases (e.g., West Nile virus, Lyme disease), or through personal actions such as the use and improper disposal of household products (e.g., lawn care materials, pharmaceuticals, cleaning products, batteries, paint, automotive products) or wastes. Deliberate application of chemicals to the land is widespread in agricultural production to increase crop yields and control fungi, weeds, insects, and other pests.

Tracking trends in the use and disposition of chemicals in the U.S. is important to better understand the potential for those chemicals to affect human health and the environment. Many chemicals pose little known hazard to human health or environmental condition, while others pose risk. Many chemicals are recognized as carcinogens.[23] The effects of chemicals on human health and other ecological receptors through environmental exposure can be acute and very toxic, subtle and cumulative over time, or nonexistent. Chemicals can be of concern because of their pervasiveness, potential to accumulate, possibilities of interaction, and often long-term unknown effects on people and the environment (e.g., cancer, mercury in fish). Humans and wildlife may be affected by certain chemicals through direct exposure, including accidental ingestion or inhalation, accumulation and uptake through the food chain, or dermal contact.

Similarly, ecosystems and environmental processes may be compromised or contaminated through the migration and accumulation of chemicals (e.g., via uptake by plants, fugitive dust and volatilization, and migration to water supplies). For example, excessive nutrient loading from over-fertilization can result in runoff that causes adverse effects in aquatic ecosystems.[24] Widespread exposure to, or misuse of, pesticides can harm non-targeted plants and animals (including humans), as well as lead to development of pesticide-resistant pest species.

It is difficult to make generalizations about the effects of chemicals and chemical usage, not only because there are thousands of chemicals, but also because individual chemicals have unique ways of being absorbed and handled by living organisms. The risks associated with chemicals are dependent on many factors, including exposure and toxicity—which can be acute or chronic, and can occur at multiple stages of the chemical life cycle. Different stages in the life cycle of chemicals, such as manufacturing, transport, application or use, runoff, or accumulation, pose different hazards to humans and the environment.

4.5.2 ROE Indicators

The amounts and types of chemicals applied or released to land through agricultural fertilizers are examined as a National Indicator displayed at EPA Regional scale. Three other National Indicators are examined, including toxic chemicals in production-related wastes, pesticide residues in food, and occurrences of pesticide-related incidents reported to poison control centers (Table 4-5).

Trends in the amount of fertilizer used are based on sales data provided by major crop-producing states through a survey conducted each year since 1960. Acreage estimates are from an agricultural census of the 48 contiguous states conducted every 5 years since 1954. Trends in the quantities of Toxics Release Inventory-reported chemical releases are based on annual reports required since 1998 from facilities that meet certain size and usage criteria. Trends in the detection of pesticide residues in food are derived from randomly sampled data collected daily since 1993 from participating states for over 50 different commodities. Trends in reported pesticide incidents are from a pesticide surveillance system that collects data annually from poison control centers around the nation.

[23] U.S. Department of Health and Human Services. 2005. Report on carcinogens. Eleventh edition. Washington, DC: Public Health Service, National Toxicology Program.

[24] Boesch, D.F., D.M. Anderson, R.A. Horner, S.E. Shumway, P.A. Tester, and T.E. Whitledge. 1997. Harmful algal blooms in coastal waters: Options for prevention, control, and mitigation. NOAA Coastal Ocean Program Decision Analysis Series No. 10.

Table 4-5. ROE Indicators of Trends in Chemicals Used on the Land and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Fertilizer Applied for Agricultural Purposes (N/R)	4.5.2	4-30
Toxic Chemicals in Production-Related Wastes Combusted for Energy Recovery, Released, Treated, or Recycled	4.5.2	4-33
Pesticide Residues in Food	4.5.2	4-37
Reported Pesticide Incidents	4.5.2	4-39

N/R = National Indicator displayed at EPA Regional scale

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.

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).

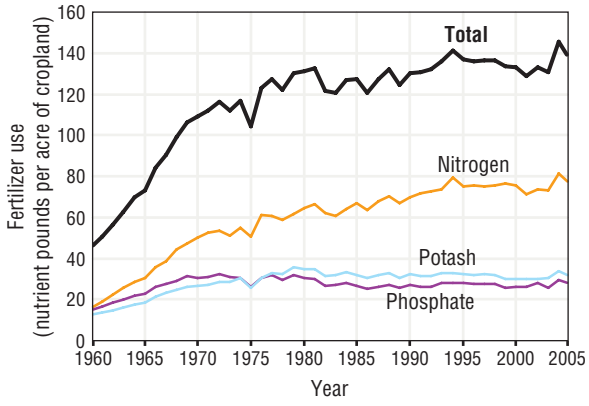
Soybeans were the fastest-growing crop in total acreage, increasing from 57.8 million acres in 1990 to 75.5 million acres in 2006 (USDA NASS, 2007c). The majority of soybean acreage (80 percent) is concentrated in the upper Midwest in EPA Regions 5 and 7. Soybeans require the least fertilizer per acre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

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 (pp. 4-7 and 4-14, respectively) 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.

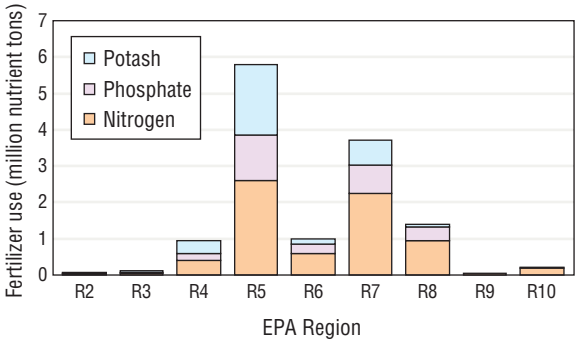
Exhibit 4-16. Commercial fertilizer use in the U.S., 1960-2005[a]



[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*

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.

EPA Regions

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

INDICATOR | Fertilizer Applied for Agricultural Purposes *(continued)*

- 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 | Toxic Chemicals in Production-Related Wastes Combusted for Energy Recovery, Released, Treated, or Recycled

Toxic chemicals are contained in waste materials produced by a wide variety of industrial activities, in both public (e.g., sewage treatment plants) and private facilities. These chemical wastes are really a composite matrix of various chemicals, some of which may be hazardous or toxic, and therefore are subject to reporting under the Toxics Release Inventory (TRI) program. Some of these chemicals are released onsite or offsite to air, water, or land (including surface impoundments and underground injection wells). The rest are treated, recycled, or combusted for energy recovery. Reductions in the quantities of TRI chemicals are desirable from both environmental and economic perspectives. TRI chemicals have known toxic properties, rendering them potentially hazardous to workers in both production and waste management facilities, and more generally to ecosystems and human health. As elements of overall business strategies, companies target waste reduction in ways that reduce costs and increase profits.

This indicator tracks trends in the amounts of toxic chemicals in production-related wastes that contain reported TRI chemicals which are either released to the environment or treated, recycled, or combusted for energy recovery. Toxic chemicals in non-production-related waste, such as might be associated with catastrophic events and remedial actions (cleanup), are not included in this indicator because they are not directly related to routine production practices.

TRI contains information on more than 650 chemicals and chemical categories from nine industry sectors, including manufacturing operations, certain service businesses, and federal facilities. Facilities are required to report to TRI if they employ 10 or more employees, are covered by a North American Industry Classification System code corresponding to a TRI-covered Standard Industrial Classification code, and manufacture more than 25,000 pounds, and/or process more than 25,000 pounds, and/or otherwise use more than 10,000 pounds of a TRI-listed non-persistent, bioaccumulative, toxic (non-PBT) chemical during a calendar year. In addition, EPA has lowered the TRI reporting thresholds for certain PBT chemicals (i.e., to 100 pounds or 10 pounds, except for dioxin and dioxin-like compounds, which have a threshold of 0.1 gram) and added certain other PBT chemicals to the TRI list of toxic chemicals. These PBT chemicals are of particular concern not only because they are toxic but also because they remain in the environment for long periods of time, are not readily destroyed, and build up or accumulate in body tissue (U.S. EPA, 2002b). EPA currently requires reporting of 16 PBT chemicals and four PBT chemical compound categories (U.S. EPA, 2007b). In 2005, 23,500 facilities reported to TRI (U.S. EPA, 2007d).

TRI is national in coverage and includes all U.S. territories. Because the reporting requirements for TRI have varied somewhat between 1998 and 2005 (the most recent year for which annual data reports are available in TRI), chemicals that were reported consistently from year to year over this period are presented separately in this indicator. Facilities that manufacture, process, or otherwise use PBT chemicals have lower reporting thresholds as established in 2000 and 2001; hence these data are depicted separately in the exhibits. Similarly, metal mining sector land releases are analyzed separately because a 2003 court decision altered the scope of TRI reporting of these quantities (U.S. EPA, 2007a).[25]

What the Data Show

In 2005 the quantities of TRI non-PBT chemicals associated with production-related wastes tracked in this indicator totaled 23.6 billion pounds (Exhibit 4-18, panel A). These quantities have decreased by more than 4 billion pounds (15.7 percent) since 1998. The decrease was gradual over time with the exception of the year 2000, which saw an increase of 4.3 billion pounds from the previous year. The 2000 increase is attributed to a few facilities that reported large amounts of onsite treatment and onsite recycling (U.S. EPA, 2002a). The amount of TRI non-PBT chemicals reported as treated varied between 1998 to 2005, from a high of nearly 13 billion pounds in the year 2000 to a low of 8 billion pounds in 2002. In 2005, the amount treated was 8.6 billion pounds or 2.9 percent more than in 1998. The amount of TRI non-PBT chemicals recycled declined by 1 billion pounds (11.6 percent) from 1998 to 2005, varying from a high of 9.6 billion pounds in 2000 to the low of 8.2 billion pounds in 2005. TRI non-PBT chemicals managed through energy recovery processes showed a decline of 0.62 billion pounds (17.2 percent) in the 8-year period, fluctuating between 3.0 and 3.7 billion pounds. Some of the year-to-year fluctuations may reflect changes in aggregate production levels in the national economy.

Reported PBT chemicals totaled 1.13 billion pounds in 2005, having declined by 0.18 billion pounds (13.9 percent) over recent years since 2001 (Exhibit 4-18, panel B). The amount of PBT chemicals recycled declined by 26.6 percent between 2001 and 2005 (0.22 billion pounds).

Excluding metal mining and PBT chemical releases, approximately 3.1 billion pounds of toxic chemicals were

[25] The metal mining sector consists of facilities that fall within Standard Industrial Classification Code 10 and must report to TRI in accordance with Section 313 of the Emergency Planning and Community Right to Know Act.

INDICATOR | Toxic Chemicals in Production-Related Wastes Combusted for Energy Recovery, Released, Treated, or Recycled *(continued)*

released offsite or onsite to air, land, or water in 2005. The 3.1 billion pounds of releases in 2005 are 18.6 percent less than the amount reported in 1998 (Exhibit 4-19, panel A). The remaining 19.6 billion pounds of non-PBT chemicals from all TRI sectors except metal mining were managed (onsite or offsite) through treatment, recycling, and energy recovery processes and represent an 8 percent decline from 1998.

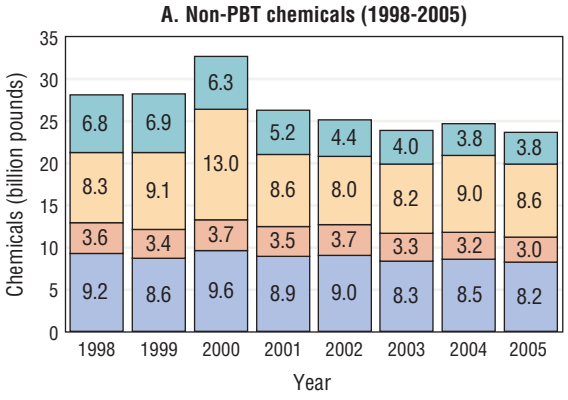
Excluding metal mining releases, nearly 0.082 billion (82 million) pounds of PBTs were released offsite or onsite to air, land, or water in 2005 (Exhibit 4-19, panel B). The remaining approximately 0.725 billion (725 million) pounds were managed (onsite or offsite) through treatment, recycling, and energy recovery processes. The amounts of reported PBT releases (excluding metal mining) have fluctuated, ranging from approximately 110 million pounds in 2003 to 79 million pounds in 2004 and 83 million pounds in 2005.

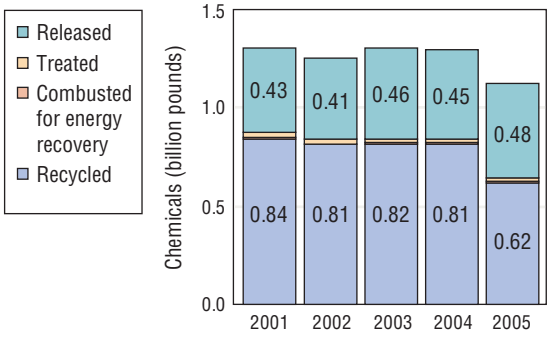
Between 1998 and 2005 there were also distinct trends in media-specific and offsite releases of non-PBT toxic chemicals (Exhibit 4-19, panel A). All of these releases exclude metal mining. Air releases declined by 28.1 percent (585 million pounds) between 1998 and 2005. Releases to surface waters decreased by 2 percent (nearly 6 million pounds) and land releases dropped by nearly 18 percent (183 million pounds). Offsite releases, which cannot be apportioned by medium in TRI, rose by 72 million pounds or 18 percent from 1998 to 2005.

PBT chemicals (also excluding metal mining) released to air increased nearly 108 percent (3 million pounds) (Exhibit 4-19, panel B). PBT releases to land decreased 24 percent (14 billion pounds) and to water 22 percent (0.035 million pounds). Offsite PBT releases increased nearly 8 percent (2.3 million pounds).

Excluding PBT chemicals, the metal mining sector accounted for 35 percent of the total production-related wastes released to the environment over the 8-year period from 1998 through 2005, releasing approximately 14 billion pounds of total production-related wastes (Exhibit 4-20, panel A) compared to 27 billion pounds reported by all other industry sectors (Exhibit 4-19, panel A). Nearly all of the production-related wastes managed by metal mining facilities were releases to land. There is a downward trend for the quantities of total releases reported by the metal mining sector from 2001 to 2005 (Exhibit 4-20, panel A). In 2001, the metal mining industry reported nearly 2 billion pounds in total releases, and in 2005, only 0.77 billion pounds were reported. Part of this trend can be attributed to the court decision (*Barrick Goldstrike Mines, Inc., v. EPA*) in 2003, in which the court determined that non-PBT chemicals present in the waste rock below concentrations of 1 percent (or 0.1 percent for Occupational Safety and Health Administration defined carcinogens) are eligible for

Exhibit 4-18. Quantities of toxic chemicals combusted for energy recovery, released, recycled, and treated in the U.S., as reported to EPA's Toxics Release Inventory, 1998-2005[a,b,c]





	2001	2002	2003	2004	2005
Released	0.43	0.41	0.46	0.45	0.48
Treated	0.02	0.03	0.02	0.02	0.02
Combusted for energy recovery	0.01	0.01	0.004	0.01	0.01
Recycled	0.84	0.81	0.82	0.81	0.62
Total	**1.31**	**1.25**	**1.30**	**1.29**	**1.13**

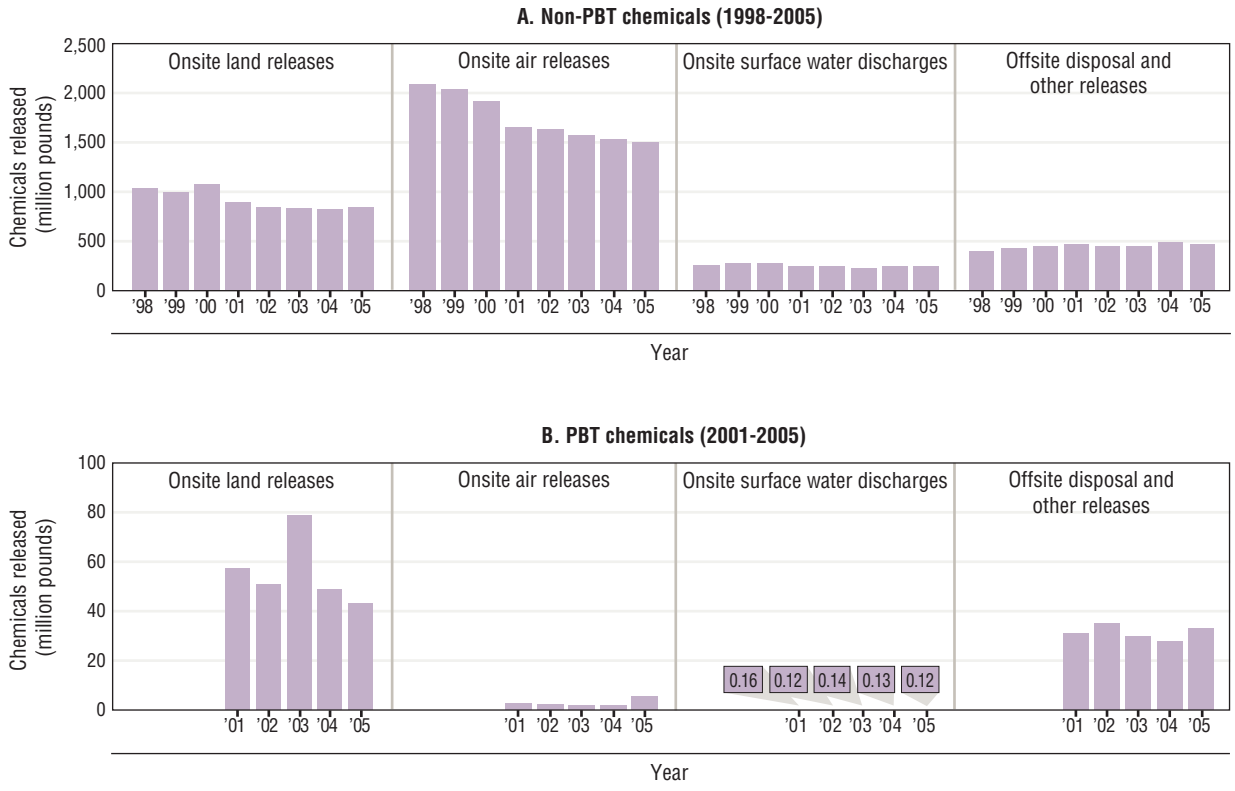
[a]**Coverage:** Production-related waste from facilities required to report to TRI, including more than 650 chemicals and chemical categories. Persistent, bioaccumulative, and toxic (PBT) chemicals are presented separately because reporting thresholds were changed partway through the period of record.

[b]Some waste quantities may be double-counted when waste has been transferred from one TRI facility (which has counted waste as offsite disposal or as other releases) to another TRI facility (which has counted transferred waste as onsite disposal or as releases to air, land, or water).

[c]Percentages reported in the "What the Data Show" section are based on the original data, which include more significant figures than shown in this exhibit.

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

Exhibit 4-19. Quantities of toxic chemicals released in the U.S., by type of release (excluding metal mining), as reported to EPA's Toxics Release Inventory, 1998-2005[a,b]



[a]**Coverage:** Production-related waste from facilities required to report to TRI, including more than 650 chemicals and chemical categories. Persistent, bioaccumulative, and toxic (PBT) chemicals are presented separately because reporting thresholds were changed partway through the period of record.

[b]Some waste quantities may be double-counted when waste has been transferred from one TRI facility (which has counted waste as offsite disposal or as other releases) to another TRI facility (which has counted transferred waste as onsite disposal or as releases to air, land, or water).

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

the *de minimis* exemption. For TRI reporting purposes, the *de minimis* exemption allows facilities to disregard certain minimal concentrations of non-PBT chemicals in mixtures or other trade name products when making threshold determinations and release and other waste management calculations (U.S. EPA, 2007a,c).

The 1.8 billion pounds of released PBT chemicals associated with metal mining make up 80 percent of all PBT chemicals released between 2001 and 2005 (Exhibit 4-20, panel B). Nearly all of these (99.9 percent) are associated with releases to land. Releases of PBTs by the metal mining sector were 16.6 percent higher (56.7 million pounds) in 2005 than in 2001.

Indicator Limitations

- TRI data reflect only "reported" chemicals, and not all chemicals with the potential to affect human health and the environment. TRI does not cover all toxic chemicals or all industry sectors. The following are not included in this indicator: (1) toxic chemicals that are not on the list of approximately 650 toxic chemicals and toxic chemical categories, (2) wastes from facilities within industrial categories that are not required to report to TRI, and (3) releases from small facilities with fewer than 10 employees or that manufactured or processed less than the threshold amounts of chemicals.

INDICATOR | Toxic Chemicals in Production-Related Wastes Combusted for Energy Recovery, Released, Treated, or Recycled *(continued)*

- TRI chemicals vary widely in toxicity, meaning that some low-volume releases of highly toxic chemicals might actually pose higher risks than high-volume releases of less toxic chemicals. The release or disposal of chemicals also does not necessarily result in the exposure of people or ecosystems.
- Vanadium releases were measured beginning in 2001; because the overall amounts were small relative to the other wastes, they are included in the 2001 to 2005 data for non-PBTs.
- National trends in toxic chemicals in wastes released to the environment are frequently influenced by a dozen or so large facilities in any particular reporting category. These trends may not reflect the broader trends in the more than 23,000 smaller facilities that report to TRI each year.
- Some facilities report offsite transfers for release to other TRI-covered facilities that report these quantities as onsite releases. This double-counting of release quantities is taken into account in the case of release for all sectors in total, but not for releases within individual sectors. This may cause some discrepancy in certain release numbers for specific sectors when compared with release data on all sectors.

Data Sources

This indicator is based on data and information from EPA's TRI Explorer database (U.S. EPA, 2007e), an online tool that allows users to generate customized reports on toxic releases reported to TRI and other online resources (U.S. EPA, 2005).

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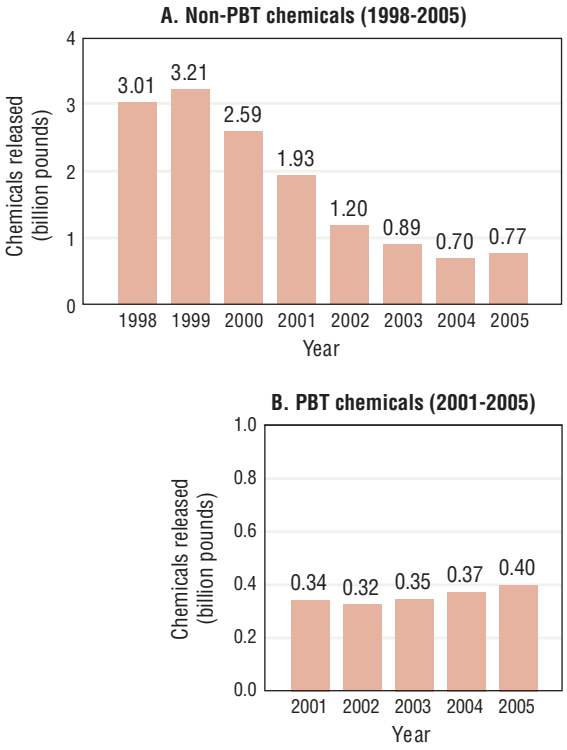
U.S. EPA. 2005. 2003 TRI public data release ereport. EPA/260/R-05/001. <http://www.epa.gov/tri/tridata/tri03/index.htm>

Exhibit 4-20. Quantities of toxic chemicals released in the U.S. by the metal mining sector, as reported to EPA's Toxics Release Inventory, 1998-2005[a,b,c]



[a]**Coverage:** Production-related waste from facilities required to report to TRI, including more than 650 chemicals and chemical categories. Persistent, bioaccumulative, and toxic (PBT) chemicals are presented separately because reporting thresholds were changed partway through the period of record.

[b]Some waste quantities may be double-counted when waste has been transferred from one TRI facility (which has counted waste as offsite disposal or as other releases) to another TRI facility (which has counted transferred waste as onsite disposal or as releases to air, land, or water).

[c]Percentages reported in the "What the Data Show" section are based on the original data, which include more significant figures than shown in this exhibit.

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

U.S. EPA. 2002a. 2000 Toxics Release Inventory (TRI) public data release report. EPA/260/R-02/003. <http://www.epa.gov/tri/tridata/tri00/index.htm>

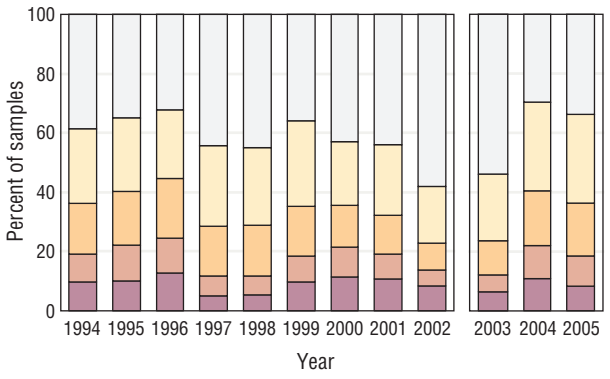
U.S. EPA. 2002b. 2000 Toxics Release Inventory (TRI) public data release report, Executive Summary. EPA/260/S-02/001 <http://www.epa.gov/tri/tridata/tri00/press/execsummary_final.pdf>

INDICATOR | Pesticide Residues in Food

Pesticides are substances or mixtures of substances intended for preventing, destroying, repelling, or mitigating plant or animal pests and may include herbicides, insecticides, fungicides, and rodenticides. More than a billion pounds of pesticides are used in the U.S. each year to control weeds, insects, and other organisms that threaten or undermine human activities (Aspelin, 2003). Some of these compounds can be harmful to human health if sufficient quantities are ingested, inhaled, or otherwise contacted (see the Urinary Pesticide indicator, p. 5-22). Potential health effects and primary exposure routes vary by chemical. The most common routes of exposure for the general population are ingestion of a treated food source and contact with applications in or near residential sites. Pesticides may also be harmful in the environment when non-target organisms are exposed (U.S. EPA, 2007).

This indicator represents data from the U.S. Department of Agriculture's Pesticide Data Program (PDP), which measures residue levels for hundreds of pesticides and their metabolites in fruits, vegetables, grains, meat, and dairy products from across the country, sampling different combinations of commodities each year. The analysis examines pesticides currently on the market and also includes continued testing for some persistent and bioaccumulative pesticides that have been banned since the 1970s, such as aldrin/dieldrin, heptachlors, and DDT and its metabolites. PDP data collection began in 1991 and includes both domestic and foreign-produced commodities. Results are published in annual reports, which include statistics on the number of pesticide residues detected, the number of residues exceeding the tolerance established by EPA for a given pesticide-commodity pair (Code of Federal Regulations, Title 40, Part 180), and the number of residues detected for which no tolerance has been established. This indicator depicts data from 1994 to 2005; data from before 1994 are considered less reliable. Between 1994 and 2005, the number of food samples analyzed per year ranged from 5,771 (1996) to 13,693 (2005), with a general increase over time.

Exhibit 4-21. Pesticide detections in food in the U.S., 1994-2005[a,b]



[a] **Coverage:** Based on a survey of fruits, vegetables, grains, meat, and dairy products across the U.S., with different combinations of commodities sampled in different years. Samples were analyzed for more than 290 pesticides and their metabolites.

[b] Data from 2003 to 2005 are not comparable to prior years due to a difference in how detects were counted. Prior to 2003, each compound detected was counted as a separate "residue." Beginning in 2003, parent compounds and their metabolites were combined to report the number of "pesticides." For example, a sample with positive detections for endosulfan I, endosulfan II, and endosulfan sulfate would have been counted as three residues in 2002. In 2003, this sample would have been counted as one pesticide detection.

Data source: *USDA Agricultural Marketing Service, 1996-2006a,b*

What the Data Show

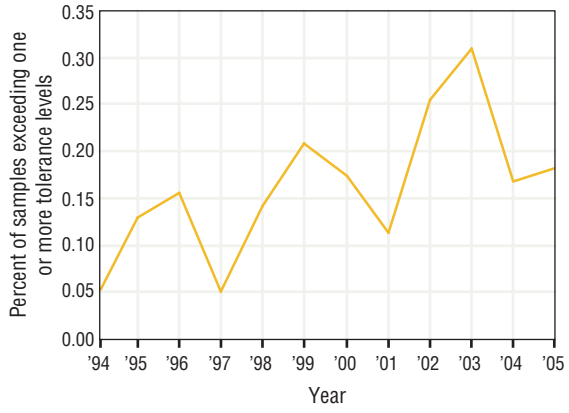
The percent of samples with no detectable pesticide residues generally increased during the period from 1994 to 2002 (Exhibit 4-21). Samples with no detects accounted for 38.5 percent of samples analyzed in 1994 and rose to 57.9 percent of samples in 2002. Data for 2003 and thereafter cannot be compared directly to the previous years' data due to a change in the way that detects are counted. Data for 2004 and 2005 show a lower percentage of samples with no detects than 2003 data, going from 53.9 percent of samples in 2003 to 29.5 percent in 2004 and 33.7 percent in 2005. The largest jump in detects in the 2003-2004 time frame was in those samples with detection of one pesticide or metabolite. These trends in number of detections have occurred at the same time that analytical limits of detection for various compounds have been decreasing, allowing the instruments to pick up ever smaller concentrations.

Exhibit 4-22 illustrates the percentage of samples in which at least one pesticide residue was detected at a concentration exceeding the tolerance established by EPA for a given pesticide-commodity pair. The percentage of samples exceeding EPA tolerance values increased from 0.05 percent in 1994 to 0.31 percent in 2003. Compared to 2003, the last 2 years of data show a drop in exceedances, with 0.17 percent in 2004 and 0.18 percent in 2005.

Indicator Limitations

- As Exhibit 4-21 explains, pesticide detection data from 2002 and earlier cannot be compared directly with data gathered after 2002. (Before 2003, each compound detected was counted separately; beginning in 2003, measurement of a parent compound and/or any of its metabolites was counted as a single detect.)

Exhibit 4-22. Pesticides exceeding EPA tolerance levels in food in the U.S., 1994-2005[a]



[a]**Coverage:** Based on a survey of fruits, vegetables, grains, meat, and dairy products across the U.S., with different combinations of commodities sampled in different years. Samples were analyzed for more than 290 pesticides and their metabolites.

Data source: *USDA Agricultural Marketing Service, 1996-2006a,b*

- The PDP does not sample all commodities over all years, so some gaps in coverage exist. Differences in the percent of detections for any given pesticide class might not be due to an increase (or decrease) in the predominance of detectable residues. Instead, these differences might simply reflect the changing nature and identity of the commodities selected for inclusion in any given time frame.
- The indicator measures pesticide residue related to dietary intake, which does not directly correlate to toxicological effects in humans or effects on the environment.

Data Sources

Data for this indicator were obtained from a series of annual summary reports published by the PDP (USDA Agricultural Marketing Service, 1996-2006). These reports are all available from http://www.ams.usda.gov/science/pdp/. The Food and Drug Administration also collects data (not reported here) on pesticide residues in cooked food that may be a source of chemicals in human diets. These data are available at http://www.cfsan.fda.gov/~dms/pesrpts.html.

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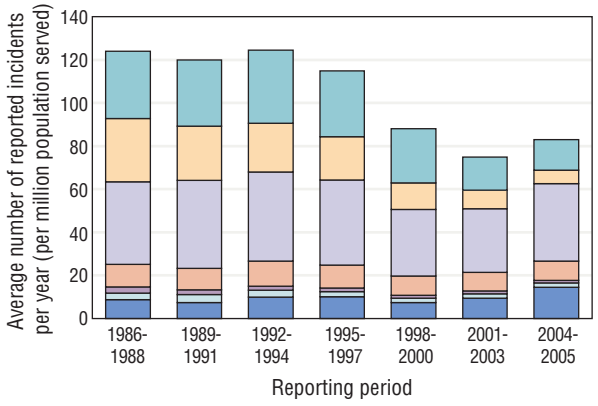
Although pesticides play a role in protecting human health, food, and crops, they pose a risk of poisoning when not used and/or stored properly. The American Association of Poison Control Centers (AAPCC) collects statistics on poisonings and represents the single largest source of information on acute health effects of pesticides resulting in symptoms and requiring health care (Calvert et al., 2001). The data include incidents related to individual pesticides and to mixtures of products (about 8 percent of reports). The data also include intentional exposures (suicide attempts and malicious use), which account for less than 3 percent of reports. The AAPCC uses the Toxic Exposure Surveillance System (TESS) to collect information on all reported incidents.

This indicator is based on data from TESS-published reports for the years 1986 through 2005. During this period, at least 50 percent of the U.S. population was covered by poison control centers (PCCs) reporting to the national database. Annual reports of incidents were divided by the percent of U.S. population served to estimate the total incidents nationwide, and divided by the total U.S. population to develop the incidence rate. Only calls with known outcomes are reported here; this may introduce some bias, because the percent of all reported pesticide incidents with a known outcome declined from 71 percent in 1986-1988 to just 41 percent in 2004-2005. The 2004-2005 data are averaged over 2 years; all other data are grouped into 3-year periods and presented as average annual rates to facilitate identification of trends.

Exhibit 4-23. Reported pesticide incidents per million U.S. population by type of pesticide, 1986-2005[a,b]



[a]This indicator tracks pesticide incidents reported to poison control centers (PCCs) that report to the AAPCC national database. The rate of reported incidents is calculated based on the population served by these PCCs.

[b]The 2004-2005 data are averaged over 2 years. All other data are averaged over 3-year intervals.

Data source: *Lai et al., 2006; Litovitz et al., 1987-2002; Watson et al., 2003-2005*

What the Data Show

Between the 1986-1988 and 2001-2003 periods, there was an overall 40 percent decline in reported pesticide incidents in the U.S. In 2004-2005, however, there was a slight rise compared to 2001-2003, primarily in the "other insecticides" and "all other pesticides" categories (Exhibit 4-23). The single largest decline occurred for the category of organophosphate (OP) insecticides, which saw nearly a 79 percent drop in reported incidents between 1986-1988 and 2004-2005. Part of the decline in reported OP-related incidents may be due to the substitution of other, less toxic insecticides for some of the OPs over time.

Indicator Limitations

- Misclassification of incidents may occur when incidents reported over the phone are not verified by laboratory tests. For example, a child found holding a pesticide container may not have actually been exposed, but if a call is received by a PCC poison specialist who determines that the reported symptoms were consistent with the toxicology, dose, and timing of the incident, the call will be registered as an incident. About 13 percent of calls to PCCs arise from health care professionals, but the majority are calls made by victims or their relatives or caretakers. Although some misclassification can be expected to occur, it is assumed to be non-differential among the different types of pesticides.
- Only calls with known outcomes are reported in this indicator. This may introduce some bias, because the percent of all reported pesticide incidents with known outcomes declined from 71 percent in 1986-1988 to just 41 percent in 2004-2005.
- The data collection process is standardized for PCCs, but is a passive system. Under-reporting of incidents is a serious shortcoming. Studies show that medical facilities generally report between 24 and 33 percent of incidents from all substances to PCCs (Chafee-Bahamon et al., 1983; Harchelroad et al., 1990; Veltri et al., 1987).
- Data are collected by multiple poison centers, with follow-up likely performed in different ways.

Data Sources

This indicator is based on summary data from annual reports published by the TESS (Litovitz et al., 1987-2002; Watson et al., 2003-2005; Lai et al., 2006) (available from http://www.aapcc.org/poison1.htm). Annual data from

these reports were grouped into 3-year periods, with the exception of 2004–2005 where only 2 years of data were grouped together, and incidence rates were calculated from the population served by participating PCCs; population figures can also be found in the annual reports. Only summary data are publicly available; raw data from individual cases are considered confidential.

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4.5.3 Discussion

What These Indicators Say About Trends in Chemicals Used on the Land and Their Effects on Human Health and the Environment

These indicators provide information on aspects of chemical use and effects. Data are presented on the amounts and types of chemical usage for two large sectors of the U.S. economy—agriculture and manufacturing. The disposition of pesticides in food and the number of reported pesticide incidents are examined. Two indicators describe stressors to the environment from chemical usage.

The amount of chemicals deliberately applied to agricultural land as commercial fertilizer has increased over the last 40 years (Agricultural Fertilizer indicator, p. 4-30). Per acre total fertilizer use has nearly tripled since 1960, with peak usage occurring in 2004. Total nitrogen use has more than quadrupled over the same period. While fertilizers themselves are not inherently harmful, when applied improperly or in quantities above the level taken up by crops, streamside vegetation, or soil biota, they have the potential to contaminate ground water and surface water in agricultural watersheds and estuaries. Fertilizer usage in recent years, for major crops, appears concentrated in the states surrounding the Mississippi River.

The Toxics Release Inventory (TRI) data (Toxic Chemicals in Wastes indicator, p. 4-33) show a small but steady decline in the quantities of TRI chemicals released to all media between 1998 and 2005, with the exception of offsite releases (persistent, bioaccumulative, and toxic or otherwise), which increased slightly.

Residues of potentially harmful substances used in food production, such as some pesticides, are assessed under food protection programs. While national-level indicators on the use and application of pesticides and pesticide loads in soil are lacking, the Pesticide Residues in Food indicator (p. 4-37) is an indirect measure of ambient conditions, providing insight into potential exposures from the most widely used pesticide products on the market. The indicator shows that between 2003 and 2005 (after a change in sampling technique), pesticide residues were detected in 46 percent of the food commodities tested in 2003 and in 66 to 71 percent of the food commodities tested in 2004 and 2005. Currently available technology used in the U.S. Department of Agriculture's Pesticide Data Program sampling can detect pesticide residues at concentrations that are orders of magnitude lower than those determined to have potential human health effects. Therefore, the number of pesticide detections that exceed federally established tolerance levels is perhaps more relevant. Results over the years suggest less than 1 percent of commodities tested were above tolerance levels.

Similarly, the Pesticide Incidents indicator (p. 4-39) provides information on the potential for human exposure to toxic substances through misuse. Reported incidents of pesticide exposure, which represent accidental exposure to a pesticide that is readily available to the public, declined between 1986 and 2003, then rose slightly in 2004-2005. The largest decline occurred in organophosphate compounds, a group of insecticides that are acutely toxic to humans (and other vertebrates) but do not accumulate in the environment, unlike other toxic materials (or compounds containing them) such as chromium, arsenic, and heavy metals.

Limitations, Gaps, and Challenges

While chemicals in soil or on plants may be an initial pathway into the environment, it is the movement and concentration of chemicals through the food chain that are often of greatest concern, as well as exposures from other media such as contaminated water or air. The indicators provide information on a relatively small universe of toxic chemicals and only limited information on the potential exposures humans may experience as a consequence of chemical use.

Fertilizer use in agriculture has been identified as one of the principal uses of chemicals responsible for nutrient loading into non-targeted water bodies and for nonpoint source loading of nutrients within agricultural watersheds.[26] Actual fertilizer use data are not available nationally. The Agricultural Fertilizer indicator (p. 4-30) is supported by sales data that do not consider mitigating factors (e.g., slow-release formulations) or agricultural practices that reduce runoff. The cost of fertilizer accounts for a relatively high percentage of agricultural costs, so it is generally assumed that purchased products eventually are applied in agricultural operations. Agricultural sources of fertilizer, however, are only estimated to be 85 percent of all sources, with the remaining being primarily professional lawn care, consumer retail, and golf courses. The usage patterns associated with these nonagricultural sources are unknown. Additionally, the urban and suburban watersheds, where these non-tracked uses occur, are also locations where nutrient runoff may result from other sources such as turf runoff, septic systems, and sewage treatment plants.

The indicators do not provide information related to the land application of sludges[27] that may contain toxic metals and other persistent bioaccumulative substances. Sludges may be applied as fertilizer on agricultural or forest land in accordance with EPA requirements, but the implications for wildlife, aquatic organisms, and movement through the food chain are unknown. Additionally, the indicators reported provide only limited information on the potential exposures that target organisms other than humans may experience as a consequence of chemical use.

TRI data include information on a range of chemical categories such as arsenic, cyanide, dioxin, lead, mercury, and nitrate compounds, but do not reflect a comprehensive total of toxic releases nationwide. They do not include all toxic chemicals with the potential to affect human health and the environment, nor do they include all sources of potential releases. Facilities report release and other waste management data using various techniques, which include estimations based on emission factors, mass balancing approaches, engineering calculations, and actual monitoring. Estimation techniques and factors considered may vary widely, making it difficult to ensure the accuracy of reporting. TRI data only represent a portion of the chemical life cycle (e.g., wastes as a result of production) and do not take into account amounts of chemicals incorporated into industrial and/or consumer products that also have the potential to affect the environment and human health when they are used, discarded, or recycled.

There is no existing reporting system that provides information on the volume, distribution, and extent of pesticide use in the U.S. Estimates are developed based on information available through a variety of reports from multiple governmental and non-governmental entities on pesticide sales, crop profiles, and expert surveys. The Pesticide Residues in Food indicator (p. 4-37) provides information on one aspect of the potential for human exposure from pesticides (dietary intake from the commercial food supply), but does not provide a complete picture of all the ways in which humans can be exposed to pesticides, which include contaminated drinking water, pesticide drift, and dermal contact.

4.6 What Are the Trends in Contaminated Land and Their Effects on Human Health and the Environment?

4.6.1 Introduction

There are many settings for contaminated lands, ranging from abandoned buildings in inner cities to large areas contaminated with toxic materials from past industrial or mining activities. Contaminated lands include sites contaminated by improper handling or disposal of toxic and hazardous materials and wastes, sites where toxic materials may have been deposited as a result of wind or flood, and sites where improper handling or accidents resulted in release of toxic or hazardous materials that are not wastes.

Land contamination can result from a variety of intended, accidental, or naturally occurring activities and events such as manufacturing, mineral extraction, abandonment of mines, national defense, waste disposal, accidental spills, illegal dumping, leaking underground storage tanks, hurricanes, floods, pesticide use, and fertilizer application. Sites are categorized in a variety of ways, often based on the level and type of contamination and the regulations under which they are monitored and cleaned up. Box 4-1 provides an overview of the common types of contaminated sites. With the exception of accidental spills and contamination that result from naturally occurring and other unanticipated events, most land contamination is the result of historical activities that are no longer practiced. Hazardous material and waste management and disposal are now highly regulated.

[26] Howarth, R.W., D. Walker, and A. Sharpley. 2002. Sources of nitrogen pollution to coastal waters of the United States. Estuaries 25:656-676.

[27] Sludges are the nutrient-rich organic materials resulting from sewage and wastewater treatment processes. Sludges contain many of the nutrients required for improved plant growth (nitrogen, phosphorus, and potassium) and other organic matter that can improve overall soil condition and increase productivity.

Contaminated soils can leach toxic chemicals into nearby ground or surface waters, where these materials can be taken up by plants and animals, contaminate a human drinking water supply, or volatilize and contaminate the indoor air in overlying buildings. In dry areas, contamination in soil can be further distributed through wind-borne dusts. Once soil contamination migrates to waterways, it may also accumulate in sediments, which can be very difficult to remediate and may affect local ecosystems and human health. Humans can be harmed by contact with toxic and hazardous materials on a contaminated site via exposure to contaminated land, air, surface water, and ground water. When contaminated lands are not properly managed, humans and wildlife can be exposed to contaminants through inhalation, ingestion, or dermal contact. The risks of human exposure are site-specific and difficult to generalize at the national level. Potential effects may be acute or chronic.

Some contaminated sites pose little risk to human health and the environment, because the level of contamination is low and the chance of exposure to toxic or hazardous contaminants is also low. Other contaminated sites are of greater concern because of the chemicals that may be present and their propensity to persist in or move through the environment, exposing humans or the environment to hazards. These sites must be carefully managed through containment or cleanup to prevent hazardous materials from causing harm to humans, wildlife, or ecological systems, both on- and offsite.

Nationally, there are thousands of contaminated sites of varying size and significance. Many sites, particularly the largest

Box 4-1. Categorizing Contaminated Lands

Superfund National Priorities List sites: These sites are seriously contaminated and include industrial facilities, waste management sites, mining and sediment sites, and federal facilities such as abandoned mines; nuclear, biological, chemical, and traditional weapons productions plants; and military base industrial sites (e.g., used for aircraft and naval ship maintenance).

Resource Conservation and Recovery Act (RCRA) Cleanup Baseline facilities: The RCRA Cleanup Baseline is a priority subset of a broader universe of facilities that are subject to cleanup under RCRA due to past or current treatment, storage, or disposal of hazardous wastes and have historical releases of contamination.

Underground storage tanks/leaking underground storage tanks: Businesses, industrial operations, gas stations, and various institutions store petroleum and hazardous substances in large underground storage tanks that may fail due to faulty materials, installation, operating procedures, or maintenance systems, causing contamination of soil and ground water.

Accidental spill sites: Each year, thousands of oil, gas, and chemical spills occur on land and in water from a variety of types of incidents, including transportation (e.g., rail, barges, tankers, pipeline) and facility releases.

Sites contaminated by natural disasters or terrorist activities: Disasters of any sort, naturally occurring or caused by humans, have the potential to contaminate lands and cause problems at already-contaminated sites.

Land contaminated with radioactive and other hazardous materials: Many sites spanning a large area of land in the U.S. are contaminated with radioactive and other hazardous materials as a result of activities associated with nuclear weapons production, testing, and research.

Brownfields: Brownfields are real property where expansion, redevelopment, or reuse may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant. Brownfields are often found in and around economically depressed neighborhoods.

Military bases and defense sites: Some of the millions of acres of land used by the Department of Defense are contaminated from releases of hazardous substances and pollutants; discarded munitions, munitions constituents, and unexploded ordnance; and building demolition and debris.

Low-level area-wide contamination: Some soil contamination problems involve low to moderate levels of contamination that encompass large geographic areas ranging in size from several hundred acres to many square miles. Low-level, area-wide contamination can occur from emissions related to past industrial operations (e.g., smelters), widespread agricultural pesticide applications, combustion of gasoline, and deterioration of lead-based paint.

Past waste management sites and illegal dumping sites: Prior to the 1970s, solid waste was typically placed in unlined landfills that were not adequately designed to prevent adverse environmental impacts to ground water or surface water. Separately, illegal dumping of materials such as construction waste, abandoned automobiles, appliances, household waste, and medical waste, has occurred for decades and still occurs because of convenience and the cost of legal disposal.

Abandoned and inactive mine lands: Abandoned and inactive mines may not have been properly cleaned up, and may have features ranging from exploration holes to full-blown, large-scale mine openings, pits, waste dumps, and processing facilities.

and most severely contaminated, are tracked at the national level, but many others are tracked only at state or local levels. The number and status of contaminated sites changes frequently as sites are newly contaminated (e.g., via spills or hurricanes), discovered, documented, and cleaned up.

4.6.2 ROE Indicators

The ROE indicators for this question focus on the trends in reducing potential threats to human health associated with site contamination at some lands contaminated by a variety of industrial and other activities and from current and past waste management activities (Table 4-6). The indicators address sites on the Superfund National Priorities List and facilities on the Resource Conservation and Recovery Act Cleanup Baseline where human exposure to contamination and migration of contaminated ground water have been documented to be within acceptable established health-based levels.

Trends in the spread of contaminated ground water and potential human exposure to contaminants in excess of health-based standards are assessed through site-specific monitoring and modeling data collected by site personnel. Site data and conditions are generally reviewed and confirmed by federal and/or state program managers annually, or more frequently if site conditions warrant.

Table 4-6. ROE Indicators of Trends in Contaminated Land and Their Effects on Human Health and the Environment

National Indicators	Section	Page
Current Human Exposures Under Control at High-Priority Cleanup Sites	4.6.2	4-44
Migration of Contaminated Ground Water Under Control at High-Priority Cleanup Sites	4.6.2	4-47

INDICATOR | Current Human Exposures Under Control at High-Priority Cleanup Sites

The EPA Superfund and Resource Conservation and Recovery Act (RCRA) Programs conduct a number of activities to address the nation's most severely contaminated lands. The Programs investigate and collect data on potentially contaminated sites to determine whether they are contaminated and require cleanup. When a potentially hazardous waste site is reported to EPA, trained inspectors determine whether the site presents a hazard to human health and the environment. Sites that pose the greatest threat are placed on the Superfund National Priorities List (NPL) or RCRA Cleanup Baseline. For RCRA, "sites" are more commonly referred to as RCRA Corrective Action Facilities.

One of the priorities for both the NPL and RCRA Cleanup Baseline sites is safeguarding against human exposures to site contamination. EPA and state officials determine whether there is a reasonable expectation that humans are exposed to site contamination and if interim actions are needed to reduce or eliminate all current human exposure in excess of health-based standards. Such activities may include removing and/or isolating contaminated media, providing alternative water supplies, and restricting access or other land use controls. Exposure at levels below the standards is considered protective (i.e., under control). Although these standards may vary from state to state, EPA believes that they fall within an acceptable range for gauging whether human health is protected (U.S. EPA, 2005b). Determinations of human exposure at levels of concern are based on site-specific characterization information and monitoring data (usually many analytical samples) pertaining to relevant environmental media (e.g., soil, indoor air, outdoor air, ground water, and surface water), current human activity patterns, and actions taken to prevent human exposure. All potential exposure routes are assessed, including inhalation, dermal contact, and ingestion of the contaminated media or food affected by contaminated media (U.S. EPA, 1999, 2005b).

This indicator describes the numbers of NPL Indicator Baseline sites and RCRA Cleanup Baseline sites for which government officials have determined that (1) humans are *not* exposed to contamination in excess of health-based standards (i.e., exposure is under control); (2) humans are reasonably expected to be exposed to contamination in excess of health-based standards; or (3) insufficient information exists to make a finding of exposure to contamination in excess of health-based standards. The intention of the indicator is not to capture an "action" or "administrative determination" on the part of EPA, but to characterize

environmental conditions relevant to the risk to human health from contaminants at RCRA Cleanup Baseline and NPL Indicator Baseline sites.

What the Data Show

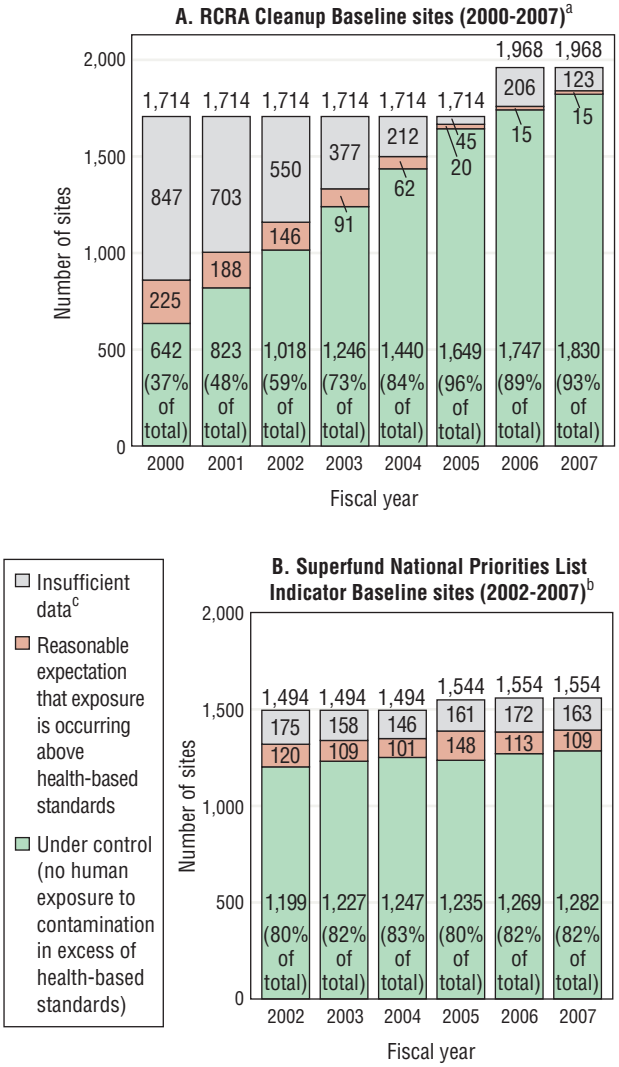
In 2007, there were 1,968 sites on the RCRA Cleanup Baseline (U.S. EPA, 2007a). Of these, the percentage of sites where human exposure to contamination was under control increased from 37 percent (642 sites out of 1,714) in fiscal year (FY) 2000 to 93 percent (1,830 sites out of 1,968) in FY 2007 (Exhibit 4-24, panel A). This increase represents a combination of sites where mitigation has prevented exposure to contaminants and sites where there are sufficient data to show that exposure to contaminated media was not a problem, regardless of mitigation. The percentage of sites where officials had reasonable expectations that humans were exposed to contamination in excess of health-based standards has decreased from 13 percent (225 sites out of 1,714) in FY 2000 to less than 1 percent (15 sites out of 1,968) in FY 2007.

As of September 2007, there were 1,554 sites on the NPL that were categorized as "Final" or "Deleted" (U.S. EPA, 2007b,c). These are referred to as the Superfund NPL Indicator Baseline. The Superfund NPL Indicator Baseline sites where human exposure to contamination was under control increased as a percentage of the total: 80 percent (1,199 of 1,494 sites) in 2002 and 82 percent (1,282 of 1,554 sites) in 2007 (Exhibit 4-24, panel B). As of the end of FY 2007, officials determined that there were reasonable expectations that humans were exposed to contamination in excess of health-based standards at 7 percent (109 out of 1,554) of the NPL Indicator Baseline sites. This is a decrease from 2002, when the percentage was 8 percent (120 out of 1,494). In 2007, there was insufficient information to confirm whether humans were exposed to contamination in excess of health-based standards at 10 percent (163 out of 1,554) of the sites.

Indicator Limitations

- The NPL does not represent all of the contaminated or potentially contaminated sites listed in the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) database, which contains information on thousands of hazardous waste sites, potential hazardous waste sites, and remedial activities across the nation. A small percentage (less than 1 percent) of the total number of final and deleted NPL sites are excluded from the Indicator Baseline for reasons of consistency.

Exhibit 4-24. Status of current human exposures under control at high-priority cleanup sites in the U.S., fiscal years 2000-2007



[a]The RCRA Cleanup Baseline changed in 2006 from 1,714 to 1,968 sites.

[b]The Superfund NPL Indicator Baseline changed in 2005 from 1,494 to 1,544 sites and in 2006 from 1,544 to 1,554 sites.

[c]For RCRA Cleanup Baseline sites and Superfund NPL Indicator Baseline sites, "insufficient data" includes sites officially classified as "insufficient data" or "no status."

Data source: *U.S. EPA, 2005a, 2006, 2007a,b,c*

INDICATOR | Current Human Exposures Under Control at High-Priority Cleanup Sites *(continued)*

- The indicator results are presented for the 1,714 RCRA Cleanup Baseline sites tracked from 2000 to 2005 and the 1,968 sites tracked in 2006 and 2007, and not the entire group of approximately 3,476 hazardous waste management facilities currently believed to be subject to RCRA Corrective Action requirements (e.g., initial assessments and if needed more thorough investigations and cleanups) (see http://www.epa.gov/epaoswer/hazwaste/ca/lists/2020scc.pdf).
- The indicator does not typically make measurements of exposure biomarkers among potentially exposed individuals at the NPL Indicator Baseline or RCRA Cleanup Baseline sites, but relies on environmental measures at or near the point of exposure and activities that should prevent exposure to contaminants.
- Concentrations of toxic and hazardous contaminants that must not be exceeded to designate a site as having/not having human exposures to contamination in excess of health-based standards vary from state to state, although they fall within a range determined to be acceptable to EPA (U.S. EPA, 2005a,b).
- The indicator is based on certification by a responsible official that the criteria necessary to designate a site as having/not having human exposures to contamination in excess of health-based standards have been met (U.S. EPA, 1999, 2005a,b). The trend in the number of sites may be underestimated to the extent that certification lags behind the potential human exposure to contamination or certification is delayed due to insufficient or outdated information.
- This approach may not take into account certain risks (e.g., endocrine disruptors) where specific risk levels (e.g., to human health) may not have been established.
- Some new sites (e.g., those created with the "reportable quantity" spill response program) as well as other known sites (e.g., spills) are not included in this indicator.

Data Sources

Data for this indicator were provided by EPA's Office of Solid Waste and Emergency Response (OSWER). A list showing the current status of every RCRA baseline site is published online (U.S. EPA, 2007a). A discussion of NPL indicators is available (U.S. EPA, 2005a); information on the current status of any individual NPL site can be queried using EPA's CERCLIS database (U.S. EPA, 2006) (http://cfpub.epa.gov/supercpad/cursites/srchsites.cfm). Data for previous years are not publicly accessible, however, and must be requested from OSWER.

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INDICATOR | Migration of Contaminated Ground Water Under Control at High-Priority Cleanup Sites

The EPA Superfund and Resource Conservation and Recovery Act (RCRA) Programs conduct a number of activities to address the nation's most severely contaminated lands. The Programs investigate and collect data on potentially contaminated sites to determine whether they are contaminated and require cleanup. When a potentially hazardous waste site is reported to EPA, trained inspectors determine whether the site presents a hazard to human health and the environment. Sites that pose the greatest threat are placed on the National Priorities List (NPL) or RCRA Cleanup Baseline.

One of the priorities for both the NPL and RCRA Cleanup Baseline sites is preventing the continued spread of contaminated ground water, often referred to as "plumes" of contaminated ground water. Protecting the ground water is especially important in areas where it is the primary source for drinking water and irrigation, or a potential source for future water supplies.

EPA and state officials determine that the migration of contaminated ground water is under control (i.e., not continuing to spread in concentrations above levels of concern) when ongoing monitoring shows that the contaminant plume is not expanding or negatively impacting surface waters (U.S. EPA, 1999). Preventing further migration of contaminated ground water may result from an action taken, such as installation of a "pump and treat" or subsurface barrier system, or because of natural attenuation of the contaminants. A determination of whether migration has been prevented is based on monitoring data (usually from hundreds of analytical samples) collected from ground water wells located within and surrounding the spatial extent of the ground water plume (U.S. EPA, 1999, 2005c).

This indicator describes the percentage of NPL Indicator Baseline sites and RCRA Cleanup Baseline sites where government officials have determined that contaminated ground water is not continuing to spread in concentrations above levels of concern (e.g., that exceed the appropriate drinking water standards). This indicator covers both "Final" and "Deleted" NPL Indicator Baseline sites, and all 1,968 RCRA Cleanup Baseline sites. The percentage of sites where ground water contamination continues to spread is also noted, as well as the number of sites where there are insufficient data to make a finding. The intention of the indicator is not to capture an "action" or "administrative determination" on the part of EPA, but to convey the underlying pressure on the environment and potential for human health effects resulting from contaminated ground water.

What the Data Show

In 2007, there were 1,968 sites on the RCRA Cleanup Baseline. Of the high-priority RCRA Cleanup Baseline sites, the percentage of sites where contaminated ground water has been determined to be under control increased from 32 percent (554 out of 1,714 sites) in fiscal year (FY) 2000 to 79 percent (1,548 out of 1,968 sites) in FY 2007 (Exhibit 4-25, panel A). This increase represents a combination of sites where mitigation has halted the spread of contaminated ground water and sites where sufficient data have been collected to show that contaminated ground water migration was not continuing, regardless of mitigation activities. The percentage of sites where officials have determined that contaminated ground water was spreading above levels of concern decreased from 18 percent (306 out of 1,714 sites) in FY 2000 to less than 5 percent (94 out of 1,968 sites) in FY 2007. These sites, and the remaining 326 sites for which there are still insufficient data to make a determination at the end of FY 2007, tend to be very complex sites where the appropriate data have yet to be collected due to high costs or technical difficulties.

Ground water has not been an issue at all Superfund NPL sites. Of those Final and Deleted NPL Indicator Baseline sites where ground water contamination is present, the percentage where contaminated ground water has been determined to be under control increased from 61 percent (772 of 1,275 sites) in FY 2002 to 70 percent (977 of 1,392 sites) (Exhibit 4-25, panel B). As of the end of FY 2007, contaminated ground water was confirmed to be spreading above levels of concern at 15 percent (213) of these NPL sites, while the remaining 15 percent (202 sites) had insufficient data to confirm whether contaminated ground water is spreading above levels of concern. These percentages do not include NPL Indicator Baseline sites classified as "non-ground water" sites.

Indicator Limitations

- The NPL does not represent all of the contaminated or potentially contaminated sites listed in the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) database, which contains information on thousands of hazardous waste sites, potential hazardous waste sites, and remedial activities across the nation. A small percentage (less than 1 percent) of the total number of final and deleted NPL sites are excluded from the NPL Indicator Baseline for reasons of consistency.
- The indicator covers the 1,714 RCRA Cleanup Baseline sites tracked from 2000 to 2005 and the 1,968 sites tracked in 2006 and 2007, and not the entire group of 3,746 hazardous waste management sites currently believed to be subject to RCRA Corrective Action requirements (i.e., initial assessments, and if needed more thorough investigations and cleanups).

INDICATOR | Migration of Contaminated Ground Water Under Control at High-Priority Cleanup Sites *(continued)*

- The extent to which people have been affected, or could be affected, by the contaminated ground water at NPL or RCRA Cleanup Baseline sites is not considered in this indicator, but is addressed in the Current Human Exposures Under Control at High-Priority Cleanup Sites indicator (p. 4-44).
- The indicator does not address ground water contaminated at other types of sites, such as sites with leaking underground storage tanks and other sites being addressed solely by state cleanup programs.
- Concentrations of toxic and hazardous contaminants in ground water that must not be exceeded to designate a site as under control vary somewhat from state to state, though they fall within a range determined to be acceptable to EPA (U.S. EPA 2005a,c).
- This indicator is based on the certification by a responsible official that the criteria necessary to designate whether contaminated ground water is continuing to spread above levels of concern have been met (U.S. EPA, 1999, 2005a,b). Trends in the number of sites where the spread of contaminated ground water has been shown to occur above levels of concern may be underestimated to the extent that certification lags behind the migration of contaminated ground water or certification is delayed due to insufficient or outdated information.

Data Sources

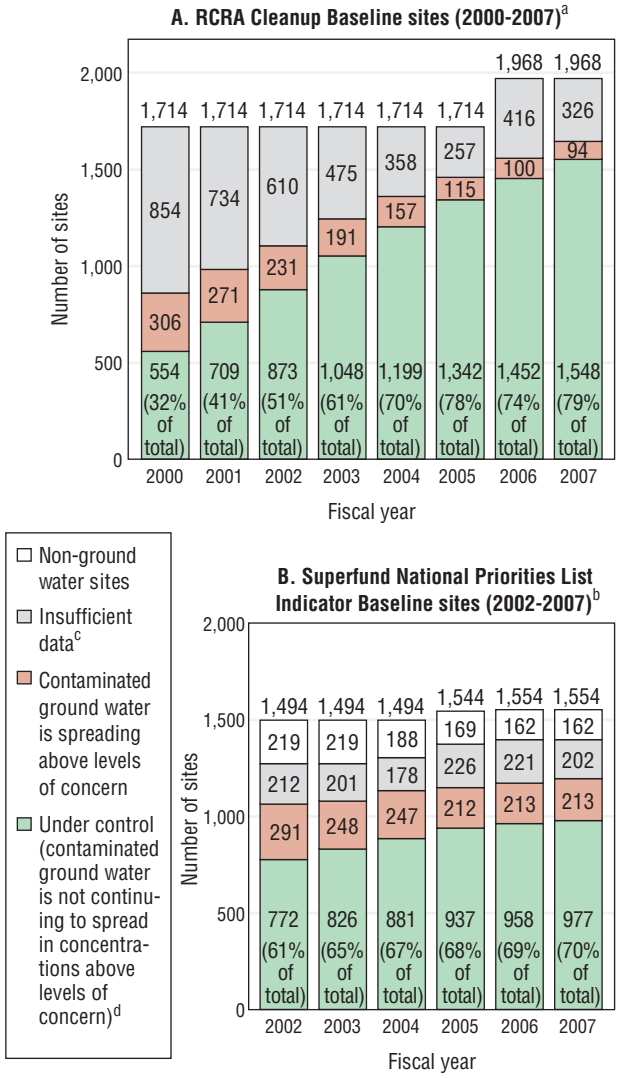
Data for this indicator were provided by EPA's Office of Solid Waste and Emergency Response (OSWER). A list showing the current status of every RCRA baseline site is published online (U.S. EPA, 2007). A summary of the status of Superfund NPL sites is available online (U.S. EPA, 2005c); information on the current status of any individual NPL site can be queried using EPA's CERCLIS database (U.S. EPA, 2006) (http://cfpub.epa.gov/supercpad/cursites/srchsites.cfm). Data for previous years are not publicly accessible, however, and must be requested from OSWER.

References

U.S. EPA (United States Environmental Protection Agency). 2007. Facilities on the RCRA 2008 GPRA corrective action baseline. Report generated 10/25/2007. <http://www.epa.gov/epaoswer/hazwaste/ca/lists/base08st.pdf>

U.S. EPA. 2006. CERCLIS database. Accessed September 14, 2006. <http://cfpub.epa.gov/supercpad/cursites/srchsites.cfm>

Exhibit 4-25. Status of migration of contaminated ground water under control at high-priority cleanup sites in the U.S., fiscal years 2000-2007



[a]The RCRA Cleanup Baseline changed in 2006 from 1,714 to 1,968 sites.

[b]The Superfund NPL Indicator Baseline changed in 2005 from 1,494 to 1,544 sites and in 2006 from 1,544 to 1,554 sites.

[c]For RCRA Cleanup Baseline sites and Superfund NPL Indicator Baseline sites, "insufficient data" includes sites officially classified as "insufficient data" or "no status."

[d]For calculating the percentage of Superfund NPL Indicator Baseline sites in the "under control" category, the total does not include "non-ground water" sites.

Data source: *U.S. EPA, 2005c, 2006, 2007*

U.S. EPA. 2005a. Draft Superfund environmental indicators guidance manual: Long-term human health revisions. <http://www.epa.gov/superfund/accomp/ei/eiguidance.pdf>

U.S. EPA. 2005b. Frequently asked questions—human exposure under control (HE) and migration of contaminated groundwater under control (GM) environmental indicators. <http://www.epa.gov/superfund/accomp/ei/ei_faqs.pdf>

U.S. EPA. 2005c. Migration of contaminated ground water under control. Accessed December 13, 2005. <http://www.epa.gov/superfund/accomp/ei/gw.htm>

U.S. EPA. 1999. Interim-final guidance for RCRA corrective action environmental indicators. <http://www.epa.gov/epaoswer/hazwaste/ca/eis/ei_guida.pdf>

4.6.3 Discussion

What These Indicators Say About Trends in Contaminated Lands and Their Effects on Human Health and the Environment

The indicators provide insights into trends in protecting humans and ground water from the nation's most contaminated lands. In 2007, 93 percent of the facilities on the Resource Conservation and Recovery Act (RCRA) Cleanup Baseline sites showed that human exposure to contamination in excess of health-based standards was being prevented, while ground water was not spreading above levels of concern at 79 percent of the facilities. Similarly in 2007, the Superfund National Priorities List (NPL) Indicator Baseline sites showed that human exposure to contamination in excess of health-based standards has been prevented at 82 percent of the sites, and ground water has been prevented from spreading above levels of concern at 70 percent of the sites with ground water contamination.

Limitations, Gaps, and Challenges

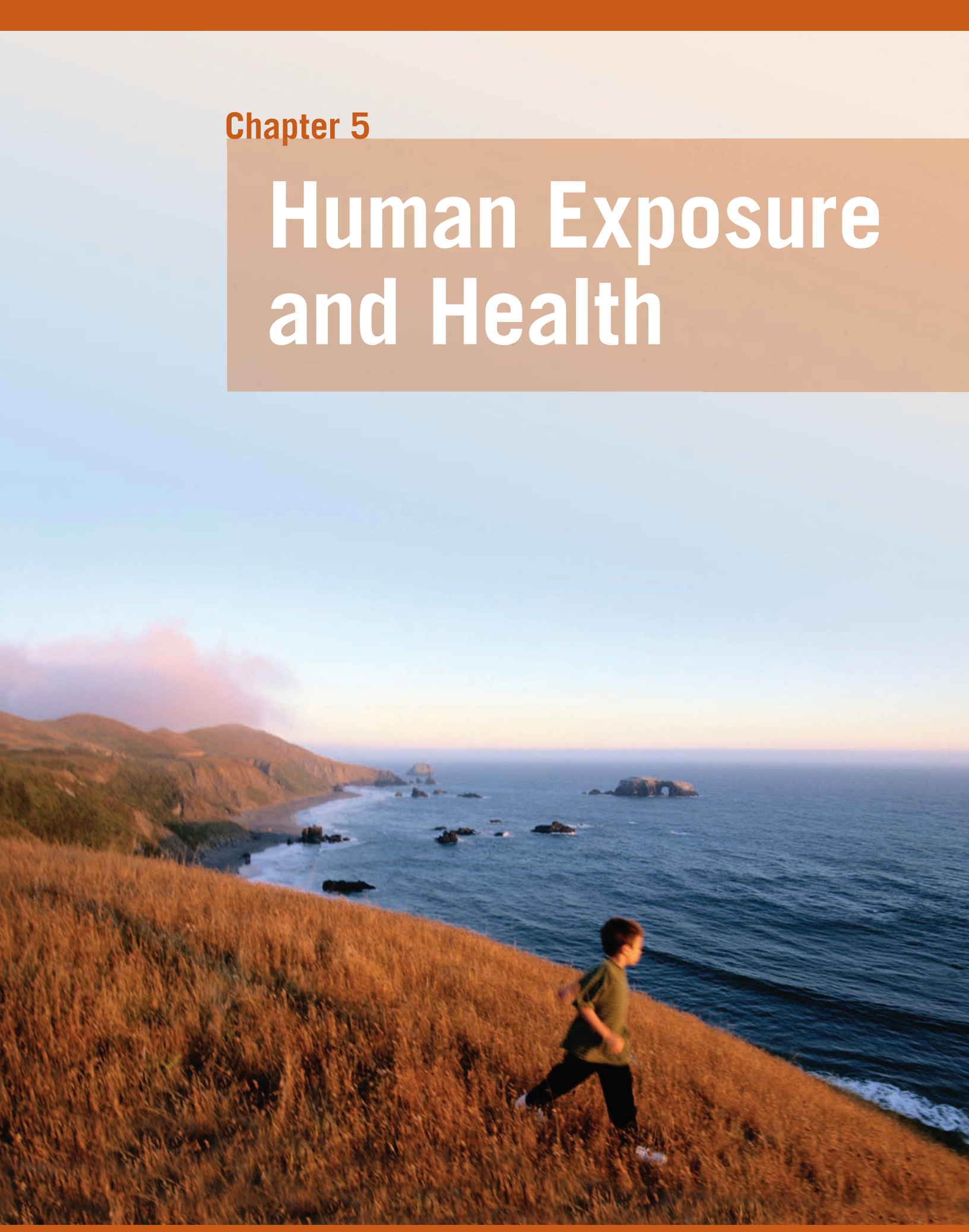
The two ROE indicators are limited in their ability to address the question. Currently, there is no single information source that tracks the extent of contaminated land nationwide. A substantial amount is known about thousands of the most contaminated sites on the Superfund NPL Indicator Baseline sites and facilities on the RCRA Cleanup Baseline, which have been the focus of in-depth studies and resource-intensive cleanup operations. Although these facilities are some of the most seriously contaminated sites in the country, they do not reflect the full universe of contaminated sites or even the full universe of seriously contaminated sites. EPA would like to have information on other sites that require extensive cleanup, including sites contaminated with radioactive materials from historical nuclear weapons production, sites with leaking underground storage tanks, smaller accidental spill sites, and other cleanup sites managed by a variety of local, state, and federal authorities. Collectively, these contaminated sites outnumber the combined Superfund NPL Indicator Baseline sites and RCRA Cleanup Baseline facilities.

EPA would also like to have information on the actual or potential acreage of contaminated land and is developing data for sites subject to Agency cleanup programs. Additionally, EPA would like to better understand the types of contamination from all sources nationally. Even where national data on contaminated sites are available, the affected area and the types and severity of contamination vary widely from site to site, making accurate trend analysis, aggregation, and generalization difficult or impossible. There is no comprehensive data source to determine the extent of these lands, populations that may be affected, and the potential for contamination to have harmful human health or ecological effects. Further, EPA is interested in knowing how much previously contaminated land has been returned to productive uses. Data associated with the use of previously contaminated land could help answer the question of trends and effects of contaminated land and the question of trends and effects of land use.

Current gaps in data on contaminated lands stem from a variety of factors and challenges, including the multi-jurisdictional responsibilities for identifying, managing, and cleaning up contaminated lands; a focus in most contaminated lands data sets on measures of regulatory compliance and associated activities; high costs to identify, inventory, study, and clean up large, complicated sites; and complexity in the effects of contaminated lands on human health and the environment, including unique site characteristics and the inability to generalize information over large geographic areas.

Chapter 5

Human Exposure and Health



Contents

5.1 Introduction

The health of the human population can be influenced by many factors, one of which is exposure to environmental contamination. Protecting human health from the effects of environmental contaminants is therefore an integral part of EPA's mission. Protecting, sustaining, or restoring the health of people and communities is central to EPA's various research and regulatory programs. In fulfilling its mission, EPA examines the human health impacts of contamination (physical, chemical, biological, or radiological) in air, in water, and on the land. Thorough study of adverse health effects associated with environmental contaminants enables the Agency to evaluate harmful levels of exposure and issue guidelines for the safe production, handling, and management of hazardous substances.

As described in Chapters 2 through 4, people can be exposed to environmental contaminants in a variety of ways, and many contaminants are known to be or suspected of causing human disease. Identifying (1) the extent to which human exposures may be occurring or may have occurred and (2) measures of health outcomes possibly influenced by environmental exposures is important in determining where further study or public health interventions may be necessary. For example, the presence or patterns of elevated levels of environmental contaminants, as measured in human tissue through biomonitoring, is of interest. Similarly, a high or increasing rate of a particular cancer for which a hazardous substance in the environment may be a contributing factor is of interest. In addition, tracking exposures and health condition across segments of the population such as gender, race or ethnicity, or geographic location helps to identify differences across subgroups and guide public health decisions and strategies.

In this chapter, EPA seeks to assess trends in human exposure and disease or conditions that may be associated with environmental factors on a national scale. Biomonitoring and health outcome indicators are presented to address three fundamental questions:

- **What are the trends in human exposure to environmental contaminants, including across population subgroups and geographic regions?** Data on trends in exposure levels provide an opportunity to evaluate the extent to which environmental contaminants are present in human tissue, independent of the occurrence of specific diseases or conditions. To address this question, this chapter focuses on biomonitoring indicators (or biomarkers of exposure) for environmental contaminants such as lead, mercury, and pesticides.
- **What are the trends in health status in the United States?** Here the report uses several general health outcome indicators (life expectancy, infant mortality, and general mortality) to provide a broad picture of health in the U.S. Trends in these indicators provide a general context for understanding trends in specific diseases and conditions that may in part be linked with the environment.
- **What are the trends in human disease and conditions for which environmental contaminants may be a risk factor, including across population subgroups and geographic regions?** This question looks at the occurrence of diseases and conditions that are known that are influenced by many stressors acting through multiple media and by factors outside EPA's mission.

EPA's 2008 Report on the Environment (ROE): Essentials

ROE Approach

This 2008 Report on the Environment:

- Asks questions that EPA considers important to its mission to protect human health and the environment.
- Answers these questions, to the extent possible, with available indicators.
- Discusses critical indicator gaps, limitations, and challenges that prevent the questions from being fully answered.

ROE Questions

The air, water, and land chapters (Chapters 2, 3, and 4) ask questions about trends in the condition and/or extent of the environmental medium; trends in stressors to the medium; and resulting trends in the effects of the contaminants in that medium on human exposure, human health, and the condition of ecological systems.

The human exposure and health and ecological condition chapters (Chapters 5 and 6) ask questions about trends in aspects of health and the environment

ROE Indicators

An indicator is derived from actual measurements of a pressure, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain. This excludes indicators such as administrative, socioeconomic, and efficiency indicators.

Indicators based on one-time studies are included only if they were designed to serve as baselines for future trend monitoring.

All ROE indicators passed an independent peer review against six criteria to ensure that they are useful; objective; transparent; and based on data that are high-quality, comparable, and representative across space and time.

Most ROE indicators are reported at the national level. Some national indicators also report trends by region. EPA Regions were used, where possible, for consistency and because they play an important role in how EPA implements its environmental protection efforts.

Several other ROE indicators describe trends in particular regions as examples of how regional indicators might be included in future versions of the ROE. They are not intended to be representative of trends in other regions or the entire nation.

EPA will periodically update and revise the ROE indicators and add new indicators as supporting data become available. In the future, indicators will include information about the statistical confidence of status and trends. Updates will be posted electronically at http://www.epa.gov/roe.

Additional Information

You can find additional information about the indicators, including the underlying data, metadata, references, and peer review, at http://www.epa.gov/roe.

or suspected to be caused (to some degree) or exacerbated by exposures to environmental contaminants. This chapter uses a spectrum of indicators for health outcomes—such as cancer, asthma, and birth outcomes—to address this question. Both morbidity and mortality statistics are considered.

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

This chapter is not intended to be exhaustive in addressing these questions, nor is it intended to be a risk assessment or epidemiological study. Rather, it provides an overview of selected indicators of human exposure and disease over space and time, based on key data sources with sufficiently robust design and quality assurance.

The indicators used here are based on data sets representative of the national population; they are not based on data from targeted populations or tied to specific exposures or releases. Therefore, these data sets cannot and should not be used to draw conclusions about linkages or causal relationships between a particular health outcome and contaminant; nor is it possible to directly link the health outcome or biomonitoring indicators to any of the indicators of emissions or ambient pollutants in air, land, or water presented in earlier chapters of this report. Though the chapter does not assess quantitative relationships between the measures of environmental contaminants and diseases, it does present some qualitative discussion of the research that has examined some of these relationships to help explain why EPA has included particular indicators. Sections 5.1.1 and 5.1.2 detail important principles guiding the selection and interpretation of exposure and health indicators used in this report.

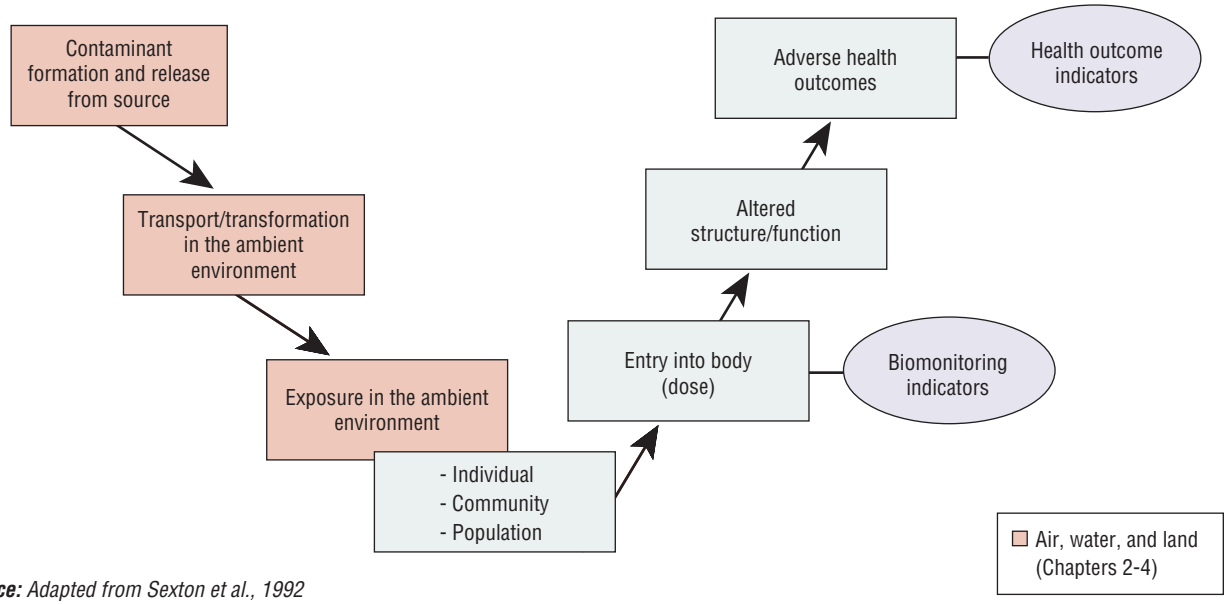
5.1.1 The Environmental Public Health Paradigm

The relationship among and between environmental contamination, exposure, and disease is complex. Development of disease is multi-faceted. Relationships between environmental exposures and various health outcomes can only be established through well-designed epidemiological, toxicological, and clinical studies. An understanding of these factors provides critical context for this chapter.

The environmental public health paradigm shown in Exhibit 5-1[1] illustrates the broad continuum of factors or events that may be involved in the potential development of human disease following exposure to an environmental contaminant. This series of events serves as the conceptual basis for understanding and evaluating environmental health. The exhibit illustrates that for adverse health effects (clinical disease or death) to occur, many things have to happen. A contaminant must be released from its source, reach human receptors (via air, water, or land), enter the human body (via inhalation, ingestion, or skin contact), and be present within the body at sufficient doses within individuals to cause biological changes that may ultimately result in an observed adverse health effect.

The paradigm, however, is a linear, schematic depiction of a process that is complex and multi-factorial. Exposure to an environmental contaminant is rarely the sole cause of an adverse

Exhibit 5-1. Environmental public health paradigm



Source: *Adapted from Sexton et al., 1992*

[1] Adapted from: Sexton, K., S.G. Selevan, D.K. Wagener, and J.A. Lybarger. 1992. Estimating human exposures to environmental pollutants: Availability and utility of existing databases. Arch. Environ. Health 47(6):398-407.

health outcome. Environmental contaminant exposure is just one of several factors that can contribute to disease occurrence or to the severity of a preexisting disease. Among the other factors are diet, exercise, alcohol consumption, individual genetic makeup, medications, and other pre-existing diseases. Asthma, for example, can be triggered by environmental insult, but environmental exposures are not the "cause" of all asthma attacks. In addition, different contaminants can be a risk factor for the same disease. Taking the same example, outdoor air pollution and certain indoor air pollutants, such as environmental tobacco smoke, can both exacerbate asthma symptoms. Further, susceptibility to disease is different for each person; some individuals may experience effects from certain ambient exposure levels while others may not.

Each block in Exhibit 5-1 can have indicators associated with it. As shown, aspects of Chapters 2 through 4 may address contaminant formation, release, transport, and transformation in the environment. Those chapters present indicators for the presence of contaminants or other stressors affecting air, water, and land, sometimes at locations in which people may be exposed. Measurements of ambient exposure levels are different than the biomonitoring indicators (biomarkers of exposures) introduced in this chapter. Other types of biomarkers exist (e.g., biomarkers of susceptibility and biomarkers of effect); because national-scale data do not exist for these biomarkers, they are not covered in this chapter at this time.

The presence of a contaminant in the environment or within human tissue alone does not mean disease will occur. Furthermore, identification of diseases for which environmental contaminants are risk factors does not mean exposure has occurred or contributed to that disease. However, extensive and collaborative data collection and research efforts across the scientific community continue to strengthen our understanding of the relationships between environmental exposures and disease. This chapter uses indicators that are tied into the environmental public health paradigm as one tool for discerning notable trends in exposure and health. First, EPA presents biomonitoring indicators to illustrate the general extent to which people are being exposed to environmental contaminants. Second, indicators of overall health status and specific diseases and conditions are used to identify potential morbidity/mortality patterns, again recognizing that environmental exposures are only one factor that could influence reported trends.

5.1.2 Establishing Linkages Between Environmental Contaminants and Health Outcomes

EPA uses the results of scientific research to help identify linkages between exposure to environmental contaminants and certain diseases, conditions, or other health outcomes. EPA relies on the possible linkages established through these types of studies to identify environmental contaminants and health outcomes of potential Agency interest (e.g., the indicators used in this chapter). Examples include radon and lung cancer; arsenic and cancer in several organs; lead and nervous system disorders; disease-causing bacteria (such as *E. coli* O157:H7) and gastrointestinal illness and death; and particulate matter and aggravation of cardiovascular and respiratory diseases. Such relationships between exposure and disease have been established through well-designed epidemiological studies with a defined or specified population (e.g., geographic location, susceptible populations, occupational exposures) and known environmental exposures.

The causes of many diseases and other health conditions are not well established. In some cases, environmental contaminants are considered important risk factors. In other cases, available data suggest that environmental exposures are important, but proof is lacking. Developing evidence that environmental contaminants cause or contribute to the incidence of adverse health effects can therefore be challenging, particularly for those effects occurring in a relatively small proportion of the population or effects with multiple causes. In cases where exposure to an environmental contaminant results in a relatively modest increase in the incidence of a disease or disorder, a large sample size for the study would be needed to detect a true relationship. In addition, there may be factors related to both the exposure and the health effect—confounding factors—that can make it difficult to detect a relationship between exposure to environmental contaminants and disease. In many cases, findings from studies in humans and/or laboratory animals may provide suggestive (rather than conclusive) evidence that exposures to environmental contaminants contribute to the incidence of a disease or disorder.

To reiterate, however, the national-scale ROE indicators do not directly link exposure with outcome and cannot be used to demonstrate causal relationships. However, when combined with other information, such as environmental monitoring data and data from toxicological, epidemiological, or clinical studies, these indicators can be an important key to better understanding the relationship between environmental contamination and health outcomes.

5.1.3 Overview of the Data

EPA draws on many resources and partnerships with other federal, state, and local agencies for the health data and statistical reports that underlie the biomonitoring and health outcome indicators used in this chapter. This chapter uses three key types of data sources, each with its own strengths and limitations:

- **Data collected from living human subjects.** This includes both questionnaire-based information (e.g., the National Center for Health Statistics' [NCHS's] National Health Interview Survey, a nationwide survey to collect data on personal and demographic characteristics, illnesses, and other topics) and biological specimens (such as NCHS's National Health and Nutrition Examination Survey, which collects and measures some chemicals in blood and urine samples). This chapter focuses on data collection activities that have a national focus and use a probability-based sampling design.

- **Vital statistics data.** Vital statistics of interest for health include births, deaths, and fetal deaths. Vital statistics data used in this chapter include NCHS's National Vital Statistics System.
- **Data from surveillance activities.** These include data from active surveillance activities such as the National Cancer Institute's Surveillance, Epidemiology, and End Results Program, which collects and publishes cancer incidence and survival data from population-based cancer registries. It also includes data from more passive collection systems, such as the Centers for Disease Control and Prevention's (CDC's) National Notifiable Disease Surveillance System, which provides information about diseases that health providers must report to state or local public health officials.

This chapter also takes advantage of several published documents that present and summarize in one place the findings from many data collection activities (e.g., NCHS's Healthy People 2010 Database). In addition, it uses some databases that provide a single point of access to a variety of reports and numeric public health data and ways to conduct analyses of those data (e.g., CDC WONDER, CDC's Wide-ranging OnLine Data for Epidemiologic Research).

The data sources used provide statistics across time, geographic areas, and/or subpopulations such as age groups, races, and ethnicities. Identifying possible differences among population subgroups, as well as evidence of whether any differences are narrowing or widening, may reveal trends needing study or intervention. This type of trend analysis is consistent with national public health goals aimed at eliminating health disparities across various groups (e.g., racial and ethnic groups, low-income populations).[2] It addresses a continuing concern that minority and/or economically disadvantaged communities frequently may be exposed disproportionately to environmental contaminants. Statistics for populations that may be particularly susceptible to environmental contaminants, such as children and pregnant women, are also examined. However, the type and level of subpopulation breakdown varies across data sets, sometimes making consistent presentation of this information difficult. Standards according to which federal agencies report race and ethnicity statistics were revised in 1997. The revised standards, which became effective in 2003, expand the race and ethnicity categories for which data are collected and are aimed at increasing comparability of data among federal data systems. As vital records used to support federal data systems continue to be revised and come into compliance with the 1997 requirements, future data reporting and comparisons will be more straightforward.

This chapter presents health statistics, including race and ethnicity subgroup categorization, as reported within the original data source documents or databases. The presentation of observed changes—temporally, spatially, or across subgroups—is descriptive, not quantitative. No statistical testing was performed (e.g., tests of statistical significance).

This chapter presents only data that meet the ROE indicator definition and criteria (see Box 1-1, p. 1-3). Note that non-scientific indicators, such as administrative and economic indicators, are not included in this definition. Thorough documentation of the indicators data sources and metadata can be found online at http://www.epa.gov/roe. All indicators were peer-reviewed during an independent peer review process (again, see http://www.epa.gov/roe for more information). Readers should not infer that the indicators included reflect the complete state of the knowledge on trends in health and exposure related to environmental exposures. Many other data sources, publications, site-specific research projects, and epidemiological studies have contributed greatly to the current understanding of health and exposure trends, but are not used because they do not meet some aspect of the ROE indicator criteria.

5.1.4 Organization of This Chapter

The rest of this chapter is organized into sections corresponding to the three questions EPA seeks to answer about trends in human health and exposure. Each section introduces the question and its importance, presents the ROE indicators selected to help answer the question, and discusses what the indicators, taken together, say about the question. The ROE indicators primarily include National Indicators, but in some cases National Indicators are broken down by EPA Region to help to answer the ROE question at a smaller geographic scale. Each section concludes by highlighting the major challenges to answering the question and identifying important information gaps.

Table 5-1 lists the indicators used to answer the three questions in this chapter and shows the locations where the indicators are presented.

[2] U.S. Department of Health and Human Services. 2000. Healthy people 2010: Understanding and improving health. Second edition. Washington, DC: U.S. Government Printing Office. <http://www.health.gov/healthypeople/>

Table 5-1. Human Exposure and Health—ROE Questions and Indicators

Question	Indicator Name	Section	Page
What are the trends in human exposure to environmental contaminants, including across population subgroups and geographic regions?	Blood Lead Level (N)	5.2.2	5-10
	Blood Mercury Level (N)	5.2.2	5-12
	Blood Cadmium Level (N)	5.2.2	5-13
	Blood Persistent Organic Pollutants Level (N)	5.2.2	5-15
	Blood Cotinine Level (N)	2.4.2	2-76
	Urinary Pesticide Level (N)	5.2.2	5-22
	Urinary Phthalate Level (N)	5.2.2	5-26
What are the trends in health status in the United States?	General Mortality (N)	5.3.2	5-33
	Life Expectancy at Birth (N)	5.3.2	5-35
	Infant Mortality (N)	5.3.2	5-36
What are the trends in human disease and conditions for which environmental contaminants may be a risk factor, including across population subgroups and geographic regions?	Cancer Incidence (N)	5.4.2	5-43
	Childhood Cancer Incidence (N)	5.4.2	5-46
	Cardiovascular Disease Prevalence (N) and Mortality (N/R)	5.4.2	5-48
	Chronic Obstructive Pulmonary Disease Prevalence (N) and Mortality (N/R)	5.4.2	5-52
	Asthma Prevalence (N)	5.4.2	5-55
	Infectious Diseases Associated with Environmental Exposures or Conditions (N)	5.4.2	5-59
	Birth Defects Prevalence and Mortality (N)	5.4.2	5-62
	Low Birthweight (N)	5.4.2	5-65
	Preterm Delivery (N)	5.4.2	5-67

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

5.2 What Are the Trends in Human Exposure to Environmental Contaminants, Including Across Population Subgroups and Geographic Regions?

5.2.1 Introduction

Understanding the extent to which human populations are being exposed to environmental contaminants helps identify those contaminants of potential public health concern and populations who may be disproportionately exposed to contaminants or uniquely vulnerable. For example, children may have disproportionately heavy exposures to environmental contaminants because they drink more water, breathe more air, and eat more food per pound or kilogram of body weight than adults; further, children may be more vulnerable to some environmental contaminants depending on the stage of development during which exposure occurs.[3,4] Evaluating exposure across certain race or ethnic groups, or other potentially susceptible subgroups, identifies possible variations in exposures. Tracking the levels of environmental contaminants in a population also enables an assessment of how exposures to those contaminants are changing in that population over time.

Referring back to the environmental public health paradigm presented in Section 5.1.1, measurements of human exposure to environmental contaminants can be made in the ambient environment (air, water, land), at the point of human contact, or after contact and contaminant entry into the human body has occurred. Box 5-1 further distinguishes the different types of exposure measures. In answering this question, the focus is on human biomonitoring, which involves the

[3] Landrigan, P.J., C.A. Kimmel, A. Correa, and B. Eskenazi. 2004. Children's health and the environment: Public health issues and challenges for risk assessment. Environ. Health Perspect. 112(2):257-265.

[4] World Health Organization. 2006. Principles for evaluating health risks in children associated with exposure to chemicals. Environmental Health Criteria 237.

measurement of human tissues or excreta for direct or indirect evidence of exposure to chemical, biological, or radiological substances. The ambient contaminant measurements presented in the media chapters are not considered here, nor can they be directly linked with biomonitoring data presented to answer this question.

Historically, human exposure has been defined as the amount of a chemical, physical, or biological contaminant at the outer boundary of the body available for exchange or intake via inhalation, ingestion, or skin or eye contact.[5] As such, human exposure to environmental contaminants has been estimated primarily through measurements of contaminant concentrations in air, water, or soil, combined with estimates of the frequency and duration of human contact with the contaminated media. These resulting exposure estimates have provided a valuable foundation for many of the regulatory and non-regulatory actions that have been taken to limit exposure to ambient contaminants. However, developments in data collection techniques and analytical methods have improved the capability to characterize human exposure via biomonitoring, which provides measurements of contaminants within the human body.

For a few environmental contaminants, particularly lead and some other metals, biomonitoring has been used for exposure characterization for a number of years. More recently, techniques for biomonitoring have been expanded to include many additional environmental contaminants. These measurements provide a tool that complements ambient measurements in characterizing human exposure to environmental contaminants. However, concentrations of environmental contaminants reported at a national level in blood, urine, or any other type of tissue cannot be used to extrapolate directly to a particular source.

The use of biological markers (or biomarkers) builds on the more traditional exposure assessment approach, providing more information on the extent to which a contaminant enters, remains, and acts in the body. Biomarker information attempts to determine the extent to which a contaminant is present in the body after entering through portals of entry such as the eyes, skin, stomach, intestines, or lungs. Given the complex set of factors that govern contaminants that are absorbed and distributed in the body, a direct measurement of the levels of a contaminant or related "marker" in the body offers more information about exposure than measured ambient levels alone.

In general, a biomarker reports the level of a substance or a marker (i.e., the product of an interaction between an agent and some target molecule or cell) present in samples collected from the body or produced by the body. *Biomarkers of exposure* measure concentrations of a contaminant, its metabolite(s), or reaction product(s) in the body fluids or tissue, most commonly blood or urine. Measurements can also be taken from a variety of other body compartments, such as feces, breast milk, hair, nails, exhaled air, and tissues obtained through biopsy or autopsy. The exposure measure used to answer this question focuses on biomarkers of exposure. Biomarkers of exposure do not predict whether biological alterations and potential health effect will result. Whether a particular exposure ultimately results in an adverse health outcome depends on a host of factors, as is described in Section 5.1.

Box 5-1. Measuring Human Exposure

Various approaches can be used to measure or estimate the levels of human exposures. No approach is best suited to all environmental contaminants, and each approach has strengths and weaknesses. Available biomonitoring data are used to answer the question on trends in human exposure to environmental contaminants.

Ambient contaminant measurements: Historically, human exposures have been estimated using environmental measurements of ambient contaminant concentrations. One limitation of ambient measurements is that the presence of a contaminant in the environment may not be fully informative regarding the extent to which individuals are exposed. In some cases, emissions data are used to model or estimate ambient concentrations.

Models of exposure: This approach combines knowledge of environmental contaminant concentrations with information on people's activities and locations (e.g., time spent working, exercising outdoors, sleeping, shopping) to account for the contact with contaminants. This approach requires knowledge of contaminant levels where people live, work, and play, as well as knowledge of their day-to-day activities. Since model output is not a direct measure of environmental conditions or exposure, it is not considered to be a true indicator of exposure.

Personal monitoring data: With personal monitoring, the monitoring device is worn by individuals as they engage in their normal day-to-day activities. This approach is most commonly used in workplace environments. Personal monitoring data provide valuable insights into the source of contaminants to which people are actually being exposed. However, a challenge with personal monitoring (as with biomonitoring) is ensuring that sufficient sampling is conducted to be representative of the population being studied. No national-scale personal monitoring data are available.

Biomonitoring data: Several environmental contaminants, notably heavy metals and some pesticides and other persistent organic pollutants, can accumulate in the body. These substances or their metabolites can be measured in human tissues or fluids such as blood or urine. These residues reflect the amount of contaminant that gets into or is present in the body, but by themselves do not provide information on how the person came into contact with the contaminant.

[5] Aldrich, T., J. Griffith, C. Cooke. 1993. Environmental epidemiology and risk assessment. New York, NY: Van Nostrand Reinhold.

5.2.2 ROE Indicators

The answer to the question on trends in human exposure relies on national-scale biomonitoring data collected as part of the Centers for Disease Control and Prevention's (CDC's) National Health and Nutrition Examination Survey (NHANES), primarily data collected from 1999 through 2002. As part of the survey, blood and urine samples are routinely collected to measure certain contaminants (or their metabolites) of public health concern. NHANES is conducted annually, but the data are combined and reported for a 2-year time period to provide more stable population estimates and to obtain adequate sample sizes for many subgroup analyses. CDC continues to process 2003–2004 and 2005–2006 survey data; raw data for the 2003–2004 survey are available for some data sets, but CDC-synthesized data and reports were not available in time for inclusion in the ROE. The chemicals in CDC's current suite of biomarkers were chosen based largely on scientific data that suggest exposure in the U.S. population, the seriousness of known or suspected health effects associated with some levels of exposure, the availability and adequacy of analytical methods, and logistical and cost considerations.[6]

Seven individual or groups of contaminants from NHANES are considered, including metals, persistent organic pollutants, pesticides, and phthalates (Table 5-2). The data presented represent data from NHANES in its entirety or a subset of the original data, with emphasis on those compounds for which CDC was able to calculate geometric means.[7] The levels of detection (LOD) presented in the indicators' exhibits vary from chemical to chemical. A chemical's LOD is the level at which the measurement has a 95 percent probability of being greater than zero. Percentile estimates that are less than the LOD for the chemical analysis are reported as "<LOD." In cases where the proportion of results below the LOD was greater than 40 percent, geometric means were not calculated and the results were reported as "NC," or not calculated.

Blood measurements for chemicals that can concentrate in lipid (e.g., dioxins, furans, PCBs, organochlorine pesticides) are presented per gram of total lipid as well as per whole weight of blood. Because these compounds are lipophilic, they concentrate in the body's lipid stores, including the lipid in blood. Blood levels reported per gram of total lipid represent the amount of these chemicals that is stored in body fat. (Blood levels per whole weight of blood are included to facilitate comparison with studies investigating exposure to these chemicals that report results in these units.) For chemicals measured in urine, levels are reported as volume in urine and per gram of creatinine. Expressing the result per gram of creatinine helps adjust for the effects of urinary dilution. For example, if one person consumed more fluids than another person, that individual's urine output is likely higher and more dilute than that of the other person.[8]

Table 5-2. ROE Indicators of Trends in Human Exposure to Environmental Contaminants

National Indicators	Section	Page
Blood Lead Level	5.2.2	5-10
Blood Mercury Level	5.2.2	5-12
Blood Cadmium Level	5.2.2	5-13
Blood Persistent Organic Pollutants Level	5.2.2	5-15
Blood Cotinine Level	2.4.2	2-76
Urinary Pesticide Level	5.2.2	5-22
Urinary Phthalate Level	5.2.2	5-26

[6] Centers for Disease Control and Prevention. 2005. Third national report on human exposure to environmental chemicals. NCEH publication no. 05-0570. <http://www.cdc.gov/exposurereport/report.htm>

[7] Geometric means are calculated by taking the log of each concentration, then calculating the mean of those log values, and finally taking the antilog of that mean. A geometric mean provides a better estimate of central tendency and is influenced less by high values than is the arithmetic mean. This type of distribution is common when measuring environmental chemicals in blood or urine. See Centers for Disease Control and Prevention. 2005. Third national report on human exposure to environmental chemicals. NCEH publication no. 05-0570. <http://www.cdc.gov/exposurereport/report.htm>

[8] Centers for Disease Control and Prevention. 2005. Third national report on human exposure to environmental chemicals. NCEH publication no. 05-0570. <http://www.cdc.gov/exposurereport/3rd/>

INDICATOR | Blood Lead Level

Lead is a naturally occurring metal found in small amounts in rock and soil. Lead has been used industrially in the production of gasoline, ceramic products, paints, metal alloys, batteries, and solder. While lead arising from the combustion of leaded gasoline was a major source of exposure in past decades, today lead-based paint and lead-contaminated dust from paint are the primary sources of lead exposure in the home. Lead levels can be measured in blood or urine.

Lead is a neurotoxic metal that affects areas of the brain that regulate behavior and nerve cell development (NRC, 1993). Its adverse effects range from subtle responses to overt toxicity, depending on how much lead is taken into the body and the age and health status of the person (CDC, 1991). Lead is one of the few pollutants for which biomonitoring and health effect data are sufficient to clearly evaluate environmental management efforts to reduce lead in the environment.

Infants, children, and fetuses are more vulnerable to the effects of lead because the blood-brain barrier is not fully developed in them (Nadakavukaren, 2000). Thus, a smaller amount of lead will have a greater effect on children than on adults. In addition, ingested lead is more readily absorbed into a child's bloodstream, while adults absorb only 10 percent. Because of lead's adverse effects on cognitive development, the Centers for Disease Control and Prevention

Exhibit 5-2. Blood lead concentrations for the U.S. population age 1 year and older by selected demographic groups, 1999-2002

			Geometric mean and selected percentiles for blood lead concentrations (µg/dL)[a]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Total, age 1 year and older	1999-2000	7,970	1.7	1.6	2.4	3.8	4.9
	2001-2002	8,945	1.5	1.4	2.2	3.4	4.4
Sex							
Male	1999-2000	3,913	2.0	1.8	2.9	4.4	6.0
	2001-2002	4,339	1.8	1.7	2.7	3.9	5.3
Female	1999-2000	4,057	1.4	1.3	1.9	3.0	4.0
	2001-2002	4,606	1.2	1.1	1.8	2.6	3.6
Race and ethnicity[b]							
Black, non-Hispanic	1999-2000	1,842	1.9	1.7	2.8	4.2	5.7
	2001-2002	2,219	1.7	1.6	2.5	4.2	5.7
Mexican American	1999-2000	2,742	1.8	1.8	2.7	4.2	5.8
	2001-2002	2,268	1.5	1.5	2.2	3.6	5.4
White, non-Hispanic	1999-2000	2,716	1.6	1.6	2.4	3.6	5.0
	2001-2002	3,806	1.4	1.4	2.1	3.1	4.1
Age group							
1-5 years	1999-2000	723	2.2	2.2	3.3	4.8	7.0
	2001-2002	898	1.7	1.5	2.5	4.1	5.8
6-11 years	1999-2000	905	1.5	1.3	2.0	3.3	4.5
	2001-2002	1,044	1.3	1.1	1.6	2.7	3.7
12-19 years	1999-2000	2,135	1.1	1.0	1.4	2.3	2.8
	2001-2002	2,231	0.9	0.8	1.2	1.9	2.7
20+ years	1999-2000	4,207	1.8	1.7	2.5	3.9	5.2
	2001-2002	4,772	1.6	1.6	2.2	3.6	4.6

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

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

Data source: *CDC, 2005*

(CDC) have defined an elevated blood lead level as equal to or greater than 10 micrograms per deciliter (µg/dL) for children under 6 years of age (CDC, 2005).

This indicator is based on data collected by the National Health and Nutrition Examination Survey (NHANES). NHANES is a series of surveys conducted by CDC's National Center for Health Statistics that is designed to collect data on the health and nutritional status of the civilian, non-institutionalized U.S. population using a complex, stratified, multistage, probability-cluster design. CDC began monitoring blood lead in 1976 as part of NHANES II, which covered the period from 1976 through 1980. Blood lead was also monitored in NHANES III, which covered the period between 1988 and 1994. CDC's National Center for Environmental Health conducted the laboratory analyses for the biomonitoring samples. Beginning in 1999, NHANES became a continuous and annual national survey, visiting 15 U.S. locations per year and surveying and reporting for approximately 5,000 people annually.

What the Data Show

The overall geometric mean blood lead levels among all participants age 1 year and older from NHANES 1999-2000 and 2001-2002 were 1.7 µg/dL and 1.5 µg/dL, respectively (Exhibit 5-2). Adults 20 years and older had a geometric mean lead level of 1.6 µg/dL during the 2001-2002 NHANES. For this same period, males and females had geometric mean lead levels of 1.8 µg/dL and 1.2 µg/dL, respectively. For non-Hispanic blacks, Mexican Americans, and non-Hispanic whites during 2001-2002, the geometric mean lead levels were 1.7, 1.5, and 1.4 µg/dL, respectively. The geometric mean blood levels among every age, race, and ethnic group, as well as for both males and females, declined in the most recent 2001-2002 survey. Of all age groups, children age 1 to 5 had the highest geometric mean lead level, at 1.7 µg/dL. However, this age group also showed the largest decline between 1999-2000 and 2001-2002 (2.2 µg/dL to 1.7 µg/dL). Children age 6 to 11 and 12 to 19 had reported geometric mean lead levels of 1.3 and 0.9 µg/dL, respectively, for the 2001-2002 survey.

Blood lead levels have declined steadily since NHANES surveillance of blood lead levels across the U.S. began in 1976. NHANES II (1976-1980) reported a geometric mean blood lead level of 14.9 µg/dL among children age 1 to 5, the population at the highest risk for lead exposure and effects; just over 88 percent of this high-risk population had blood lead levels greater than or equal to 10 µg/dL (CDC, 2004a). Data collected from 1991 to 1994 as part of NHANES III (phase 2) showed that the geometric mean blood lead level for children age 1 to 5 was 2.7 µg/dL, with 4.4 percent of children age 1 to 5 having blood lead levels greater than or equal to 10 µg/dL (CDC, 2005). Children age 1 to 5 whose blood was sampled as part of the 1999-2002 survey had a geometric mean blood lead level of 1.9 µg/dL, with 1.6 percent of the children having blood lead levels greater than or equal to 10 µg/dL (CDC, 2005). (Data not shown.)

Indicator Limitations

- Because the data from NHANES 1999-2000 and 2001-2002 represent only two survey periods, changes in estimates between the two time periods do not necessarily reflect a trend. Earlier data sets are available (e.g., NHANES III), but the data are not directly comparable to NHANES 1999-2002. As CDC releases additional survey results (e.g., 2003-2004), it will become possible to more fully evaluate trends (CDC, 2002, 2004b).

Data Source

Data used for this indicator were extracted from two CDC reports that present results of the ongoing NHANES (CDC, 2004a, 2005). The underlying laboratory data supporting CDC's reports are available online in SAS® transport file format at http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm.

References

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CDC. 2004b. NHANES analytic guidelines. June 2004 version. <http://www.cdc.gov/nchs/data/nhanes/nhanes_general_guidelines_june_04.pdf>

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NRC (National Research Council). 1993. Measuring lead exposure in infants, children, and other sensitive populations. Washington, DC: National Academies Press.

INDICATOR | Blood Mercury Level

Mercury is a naturally occurring metal. However, through many industrial processes (e.g., chemical manufacturing operations, coal combustion), mercury is widespread and persistent in the environment. It is found in elemental form and in various organic compounds and complexes. Methylmercury (an organic form) can accumulate in the food chain in aquatic systems and lead to high concentrations in predatory fish. Consumption of contaminated fish is the major source of human exposure to methylmercury in the U.S. (NRC, 2000).

The human health effects of mercury are diverse and depend on the forms of mercury encountered and the severity and length of exposure. Fetuses and children may be more susceptible to mercury than adults, with concern for the occurrence of developmental and neurological health effects (NRC, 2000). Prenatal exposures interfere with the growth and migration of neurons and have the potential to cause irreversible damage to the developing central nervous system.

This indicator quantifies the blood mercury levels (includes organic and inorganic) among U.S. women age 16 to 49 and children age 1 to 5, using data from the 1999-2002 National Health and Nutrition Examination Survey (NHANES). NHANES does not report blood mercury data for adult males. NHANES is a series of surveys conducted by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics that is designed to collect data on the health and nutritional status of the civilian, non-institutionalized U.S. population using a complex, stratified, multistage, probability-cluster design. CDC's National Center for Environmental Health conducted the laboratory analyses for the biomonitoring

Exhibit 5-3. Blood mercury concentrations for U.S. women age 16-49 years and children (male and female) age 1-5 years by selected demographic groups, 1999-2002

			Geometric mean and selected percentiles for mercury concentrations (µg/L)[a]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Women age 16-49 years							
Total, women age 16-49 years	1999-2000	1,709	1.0	0.9	2.0	4.9	7.1
	2001-2002	1,928	0.8	0.7	1.7	3.0	4.6
Race and ethnicity							
Black, non-Hispanic	1999-2000	370	1.4	1.3	2.6	4.8	5.9
	2001-2002	436	1.1	1.1	1.8	3.2	4.1
Mexican American	1999-2000	579	0.8	0.9	1.4	2.6	4.0
	2001-2002	527	0.7	0.7	1.1	2.1	3.5
White, non-Hispanic	1999-2000	588	0.9	0.9	1.9	5.0	6.9
	2001-2002	806	0.8	0.8	1.5	3.0	4.6
Children age 1-5 years							
Total, children age 1-5 years	1999-2000	705	0.3	0.3	0.5	1.4	2.3
	2001-2002	872	0.3	0.3	0.7	1.2	1.9
Sex							
Male	1999-2000	387	0.3	0.2	0.5	1.1	2.1
	2001-2002	440	0.3	0.3	0.6	1.3	1.7
Female	1999-2000	318	0.4	0.2	0.8	1.6	2.7
	2001-2002	432	0.3	0.3	0.7	1.3	2.6
Race and ethnicity							
Black, non-Hispanic	1999-2002	424	0.5	0.5	0.9	1.5	2.4
Mexican American	1999-2002	526	0.4	0.3	0.6	1.4	1.9
White, non-Hispanic	1999-2002	447	0.3	0.2	0.5	1.2	1.8

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

Data source: *CDC, 2004a, 2005*

INDICATOR | Blood Mercury Level *(continued)*

samples. Beginning in 1999, NHANES became a continuous and annual national survey. Data for 1999–2000 and 2001–2002 are presented here as a baseline, with the intent of reporting trends across time as more data become available in the future.

What the Data Show

Exhibit 5-3 presents the geometric mean and four percentiles of blood mercury for selected populations sampled during NHANES 1999–2000 and 2001–2002. For women age 16–49 years there was a small decline in geometric mean blood mercury levels from 1999–2000 and 2001–2002 (1.0 and 0.8 micrograms per liter [µg/L], respectively). Decreases occurred for each of the four percentiles, but were most pronounced at the 90th and especially 95th percentiles. Of women tested between 1999 and 2002, 5.7 percent had mercury levels measured between 5.8 and 58 µg/L (data not shown). For children age 1 to 5, the geometric mean remained the same at 0.3 µg/L.

When the geometric means are stratified across three racial/ethnic groups, black, non-Hispanic women age 16 to 49 had the highest levels during both the 1999–2000 and 2001–2002 surveys (1.4 and 1.1 µg/L, respectively), followed by white non-Hispanics (0.9 and 0.8 µg/L, respectively), and Mexican Americans (0.8 and 0.7 µg/L, respectively). Among children age 1 to 5, black non-Hispanics have the highest geometric mean between 1999 and 2002 (0.5 µg/L), followed by Mexican Americans (0.4 µg/L) and white non-Hispanics (0.3 µg/L) (CDC, 2004a).

Indicator Limitations

- Because the data from NHANES 1999–2000 and 2001–2002 represent only two survey periods, changes in estimates between the two time periods do not necessarily reflect a trend. As CDC releases additional survey results (e.g., 2003–2004) it will become possible to more fully evaluate trends (CDC, 2002, 2004b).
- Generally recognized guidelines for blood levels of mercury have not been established.

Data Sources

Data used for this indicator were extracted from two CDC reports that present results of the ongoing NHANES (CDC, 2004a, 2005). The underlying laboratory data supporting CDC's reports are available online in SAS® transport file format at http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm.

References

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NRC (National Research Council). 2000. Toxicological effects of methylmercury. Washington, DC: National Academies Press.

INDICATOR | Blood Cadmium Level

Cadmium is a metal that is usually found in nature combined with oxygen, chlorine, or sulfur. Cadmium enters the environment from the weathering of rocks and minerals that contain cadmium. Exposure to cadmium can occur in occupations such as mining or electroplating, where cadmium is produced or used. Cadmium exposure can also occur from exposure to cigarette smoke (CDC, 2005).

Cadmium and its compounds are toxic to humans and animals. Once absorbed into the human body, cadmium can accumulate in the kidneys and remain in the body for decades. Chronic exposure to cadmium can result in serious kidney damage. Osteomalacia, a bone disorder similar to rickets, is also associated with long-term ingestion of cadmium. Acute airborne exposure, as occurs from welding on cadmium-alloy metals, can result in swelling (edema) and scarring (fibrosis) of the lungs (CDC, 2005).

This indicator reflects blood cadmium concentrations in micrograms per liter (µg/L) for the U.S. population, age 1 year and older, as measured in the 1999–2002 National Health and Nutrition Examination Survey (NHANES). NHANES is a series of surveys conducted by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics that is designed to collect data on the health and nutritional status of the civilian, noninstitutionalized U.S. population using a complex, stratified, multistage, probability-cluster design. CDC's National Center for Environmental Health conducted the laboratory analyses for the biomonitoring samples. Beginning in 1999,

INDICATOR | Blood Cadmium Level *(continued)*

NHANES became a continuous and annual national survey; biomonitoring for certain environmental chemicals also was implemented. Data for 1999–2000 and 2001–2002 are presented here as a baseline, with the intent of reporting trends across time as more data become available in the future.

What the Data Show

Exhibit 5-4 presents the geometric means and selected percentiles for blood cadmium among participants age 1 year and older from NHANES 1999–2000 and 2001–2002. During the 2001–2002 survey, the overall geometric mean blood cadmium level was not calculated because of the high number of samples that were below the method's limit of detection. However, the blood cadmium levels at the four different percentiles (50th, 75th, 90th, and 95th) are very similar across the two survey periods, with levels ranging between 0.3 and 1.4 µg/L. The blood cadmium measurements were similar among males and females, as well as among the racial or ethnic groups sampled across both time periods.

During the 1999–2000 survey, the overall geometric mean among participants age 20 or older was slightly higher (0.5 µg/L) than the geometric mean among the 12–19 age group (0.3 µg/L). Compared to participants in the other age groups, those older than 20 years had higher cadmium levels for each of the four selected percentiles

Exhibit 5-4. Blood cadmium concentrations for the U.S. population age 1 year and older by selected demographic groups, 1999-2002

			Geometric mean and selected percentiles for cadmium concentrations (µg/L)[a, b, c]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Total, age 1 year and older	1999-2000	7,970	0.4	0.3	0.6	1.0	1.3
	2001-2002	8,945	NC	0.3	0.4	0.9	1.3
Sex							
Male	1999-2000	3,913	0.4	0.4	0.6	1.0	1.3
	2001-2002	4,339	NC	0.3	0.4	0.9	1.4
Female	1999-2000	4,057	0.4	0.3	0.6	1.0	1.3
	2001-2002	4,606	NC	0.3	0.5	1.0	1.4
Race and ethnicity[d]							
Black, non-Hispanic	1999-2000	1,842	0.4	0.3	0.6	1.0	1.4
	2001-2002	2,219	NC	<LOD	0.4	1.0	1.4
Mexican American	1999-2000	2,742	0.4	0.4	0.4	0.7	1.1
	2001-2002	2,268	NC	<LOD	0.3	0.6	1.0
White, non-Hispanic	1999-2000	2,716	0.4	0.4	0.5	1.0	1.3
	2001-2002	3,806	NC	<LOD	0.5	0.9	1.4
Age group							
1-5 years	1999-2000	723	NC	<LOD	0.3	0.4	0.4
	2001-2002	898	NC	<LOD	<LOD	<LOD	0.3
6-11 years	1999-2000	905	NC	<LOD	0.3	0.4	0.4
	2001-2002	1,044	NC	<LOD	<LOD	<LOD	0.4
12-19 years	1999-2000	2,135	0.3	0.3	0.3	0.8	1.1
	2001-2002	2,231	NC	<LOD	0.3	0.4	0.8
20+ years	1999-2000	4,207	0.5	0.4	0.6	1.0	1.5
	2001-2002	4,772	NC	0.3	0.6	1.1	1.6

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

[b]LOD = below the limit of detection (LOD) of the analytical method (cadmium LOD = 0.04 µg/L).

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

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

Data source: *CDC, 2005*

INDICATOR | Blood Cadmium Level *(continued)*

during both survey periods. During the 1999-2000 survey, approximately half of all participants under the age of 12 had non-detectable blood cadmium concentrations. This proportion increased to about 90 percent during the 2001-2002 survey.

Indicator Limitations

- Because the data from NHANES 1999-2000 and 2001-2002 represent only two survey periods, changes in estimates between the two time periods do not necessarily reflect a trend. As CDC releases additional survey results (e.g., 2003-2004), it will become possible to more fully evaluate trends (CDC, 2002, 2004).
- Generally recognized guidelines for blood levels of cadmium have not been established.

Data Sources

Data used for this indicator were extracted from the CDC report that presents results of the ongoing NHANES (CDC, 2005). The underlying laboratory data supporting CDC's report are available online in SAS® transport file format at http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm.

References

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CDC. 2002. NHANES 1999-2000 addendum to the NHANES III analytic guidelines. Updated August 30, 2002. <http://www.cdc.gov/nchs/data/nhanes/guidelines1.pdf>

INDICATOR | Blood Persistent Organic Pollutants Level

Persistent organic pollutants (POPs) are manmade organic chemicals that remain in the environment for years or decades. POPs are of special concern because they often remain toxic for decades or longer after release to the environment. The more persistent a toxic chemical is, the greater the probability for human exposure over time. Because they circulate globally long after being released into the environment, POPs are often detected in locations far from the original source (U.S. EPA, 2004a).

One of the major sources of POPs exposure among the general population is food. Food contamination begins with contaminated soil and/or plants, but is of greatest concern to humans as the POPs move up the food chain into animals. Because POPs typically accumulate in fatty tissue and are slow to be metabolized, they bioconcentrate (i.e., increase in concentration) with each trophic level. Therefore, foods such as dairy products, eggs, animal fats, and some types of fish are more likely to contain greater concentrations of POPs than fruits, vegetables, and grains. POPs have been linked to adverse health effects such as cancer, nervous system damage, reproductive disorders, and disruption of the immune system in both humans and animals (U.S. EPA, 2004a).

This indicator presents data from the Centers for Disease Control and Prevention's (CDC's) National Health and Nutrition Examination Survey (NHANES) 1999-2000 and 2001-2002. NHANES is a series of surveys conducted by CDC's National Center for Health Statistics that is designed to collect data on the health and nutritional status of the civilian, non-institutionalized U.S. population using a complex, stratified, multistage, probability-cluster design. CDC's National Center for Environmental Health conducted the laboratory analyses for the biomonitoring samples. Beginning in 1999, NHANES became a continuous and annual national survey; biomonitoring for certain environmental chemicals also was implemented. These data are presented here as a baseline, with the intent of reporting trends over larger time periods in the future. Blood levels of POPs or their metabolites were measured in NHANES participants age 12 or older. This indicator includes the following three broad classes of POPs:

- Organochlorine pesticides
- Polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzo-p-furans (furans)
- Polychlorinated biphenyls (PCBs)

Organochlorine pesticides were first introduced in the 1940s. Because of their environmental persistence, EPA banned most uses of these chemicals during the 1970s and 1980s. However, many other countries still produce and/or use organochlorines. These fat-soluble chemicals are most commonly absorbed through fatty foods. These pesticides are associated with effects to the central nervous system at acute exposure levels and potential carcinogenic effects with long-term exposure (Reigart and Roberts, 1999). This indicator includes eight organochlorine pesticides that

Exhibit 5-5. Blood concentrations of selected organochlorine pesticides and metabolites for the U.S. population age 12 years and older, lipid-adjusted and whole weight, 1999-2002

			Geometric mean and selected percentiles for organochlorine pesticide metabolite concentrations (ng/g)[a,b,c]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Aldrin							
Lipid-adjusted	2001-2002	2,275	NC	<LOD	<LOD	<LOD	<LOD
Whole weight	2001-2002	2,275	NC	<LOD	<LOD	<LOD	<LOD
Chlordane							
Oxychlordane							
Lipid-adjusted	1999-2000	1,661	NC	<LOD	20.6	34.4	44.8
	2001-2002	2,249	11.4	11.1	21.7	36.3	49.7
Whole weight	1999-2000	1,661	NC	<LOD	0.13	0.26	0.31
	2001-2002	2,249	0.07	0.07	0.14	0.25	0.35
trans-Nonachlor							
Lipid-adjusted	1999-2000	1,933	18.3	17.8	31.9	55.1	79.4
	2001-2002	2,286	17.0	17.9	33.7	56.3	78.2
Whole weight	1999-2000	1,933	0.11	0.11	0.21	0.37	0.54
	2001-2002	2,286	0.10	0.11	0.22	0.39	0.59
DDT/DDE							
p,p'-DDE							
Lipid-adjusted	1999-2000	1,964	260	226	537	1,150	1,780
	2001-2002	2,298	295	250	597	1,400	2,320
Whole weight	1999-2000	1,964	1.54	1.31	3.49	7.49	11.6
	2001-2002	2,298	1.81	1.57	3.97	8.81	15.4
p,p'-DDT							
Lipid-adjusted	1999-2000	1,679	NC	<LOD	<LOD	<LOD	28.0
	2001-2002	2,305	NC	<LOD	<LOD	<LOD	26.5
Whole weight	1999-2000	1,679	NC	<LOD	<LOD	<LOD	0.17
	2001-2002	2,305	NC	<LOD	<LOD	<LOD	0.18
o,p'-DDT							
Lipid-adjusted	1999-2000	1,669	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,279	NC	<LOD	<LOD	<LOD	<LOD
Whole weight	1999-2000	1,669	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,279	NC	<LOD	<LOD	<LOD	<LOD
Dieldrin							
Lipid-adjusted	2001-2002	2,159	NC	<LOD	<LOD	15.2	20.3
Whole weight	2001-2002	2,159	NC	<LOD	<LOD	0.11	0.15
Endrin							
Lipid-adjusted	2001-2002	2,187	NC	<LOD	<LOD	<LOD	5.1
Whole weight	2001-2002	2,187	NC	<LOD	<LOD	<LOD	0.02

See notes at end of table.

Continued

Exhibit 5-5 (continued)**.** Blood concentrations of selected organochlorine pesticides and metabolites for the U.S. population age 12 years and older, lipid-adjusted and whole weight, 1999-2002

			Geometric mean and selected percentiles for organochlorine pesticide metabolite concentrations (in ng/g)[a,b,c]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Heptachlor							
Heptachlor epoxide							
Lipid-adjusted	1999-2000	1,589	NC	<LOD	<LOD	15.3	23.9
	2001-2002	2,259	NC	<LOD	<LOD	14.8	21.6
Whole weight	1999-2000	1,589	NC	<LOD	<LOD	0.11	0.18
	2001-2002	2,259	NC	<LOD	<LOD	0.10	0.15
Hexachlorobenzene (HCB)							
Lipid-adjusted	1999-2000	1,702	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,277	NC	<LOD	<LOD	<LOD	<LOD
Whole weight	1999-2000	1,702	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,277	NC	<LOD	<LOD	<LOD	<LOD
Mirex							
Lipid-adjusted	1999-2000	1,853	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,257	NC	<LOD	<LOD	15.8	57.1
Whole weight	1999-2000	1,853	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,257	NC	<LOD	<LOD	0.10	0.41

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

[b]<LOD = below the limit of detection (LOD) of the analytical method (see CDC, 2005, for chemical-specific LODs).

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

Data source: *CDC, 2005*

were measured in NHANES 1999-2000 and 2001-2002; data for three of these pesticides (aldrin, dieldrin, and endrin) first became available with the release of results from NHANES 2001-2002 (CDC, 2005).

- **Aldrin and dieldrin.** These two pesticides were widely used from the 1950s until 1970, when EPA prohibited most agricultural uses. However, they continued to be used to control termites until that use was prohibited in 1987. Aldrin rapidly converts to dieldrin in the environment or after being ingested or absorbed into the body. Dieldrin is more persistent and often accumulates in fatty tissues (CDC, 2005).
- **Chlordane and heptachlor.** EPA banned these pesticides in 1988. Within the body, chlordane is metabolized to oxychlordane and *trans*-nonachlor, and heptachlor is metabolized to heptachlor epoxide (CDC, 2003). Chlordane was commonly used against termites and on some agricultural crops and heptachlor was used primarily against soil insects and termites (Ritter et al., n.d.).
- **DDT.** Dichlorodiphenyltrichlorethane, or DDT, was banned in the U.S. in 1973 but is still produced in other countries, where it is used primarily to control mosquitoes. In the body or the environment, DDT breaks down to DDE (dichlorodiphenyldichloroethane), a more persistent chemical. DDT or DDE in the human body may reflect either a relatively recent exposure or cumulative past exposures (CDC, 2005).
- **Endrin.** Endrin is a stereoisomer (i.e., a molecule that is a mirror image of another molecule with the same molecular formula) of dieldrin. Endrin production was discontinued in 1986, primarily because of its persistence in the environment. Unlike many other organochlorine pesticides, endrin does not readily accumulate in body tissues and is metabolized and eliminated from the body relatively quickly (CDC, 2005).
- **Hexachlorobenzene** (HCB) was commonly used as a pesticide until 1965. HCB was also used in the past as a fungicide to protect wheat seeds, and for a variety of industrial purposes, including rubber, aluminum,

Exhibit 5-6. Blood concentrations of selected polychlorinated dibenzo-p-dioxins (dioxins), polychlorinated dibenzofurans (furans), and dioxin-like polychlorinated biphenyls (PCBs) for the U.S. population age 20 years and older, lipid-adjusted and whole weight, 1999-2002[a,b]

			Geometric mean and selected percentiles for dioxin, furan, and PCB concentrations[c,d,e]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Dioxins (pg/g)							
1,2,3,4,6,7,8,9-OCDD							
Lipid-adjusted	1999-2000	1,254	NC	<LOD	445	704	948
	2001-2002	1,171	346	333	571	939	1,260
Whole weight	1999-2000	1,254	NC	<LOD	2.80	4.57	6.20
	2001-2002	1,171	2.23	2.17	3.86	6.46	9.11
1,2,3,4,6,7,8-HpCDD							
Lipid-adjusted	1999-2000	1,237	NC	<LOD	61.9	92	119
	2001-2002	1,220	39	40.2	68.7	115	147
Whole weight	1999-2000	1,237	NC	<LOD	0.39	0.61	0.80
	2001-2002	1,220	0.25	0.27	0.44	0.78	1.03
1,2,3,6,7,8-HxCDD							
Lipid-adjusted	1999-2000	1,237	NC	<LOD	36.1	62.8	75.6
	2001-2002	1,234	34.6	39.2	60.7	95.2	127
Whole weight	1999-2000	1,237	NC	<LOD	0.23	0.40	0.52
	2001-2002	1,234	0.22	0.25	0.41	0.66	0.87
Furans (pg/g)							
1,2,3,4,6,7,8-HpCDF							
Lipid-adjusted	1999-2000	1,109	NC	<LOD	<LOD	14.2	18.4
	2001-2002	1,219	9.6	10.3	14.5	21.3	27.1
Whole weight	1999-2000	1,109	NC	<LOD	<LOD	0.09	0.11
	2001-2002	1,219	0.06	0.06	0.09	0.13	0.18
PCBs (units vary)							
PCB 126 (pg/g)							
Lipid-adjusted	1999-2000	1,238	NC	<LOD	30.8	57.1	89.5
	2001-2002	1,226	22.7	24.5	40.8	69.3	108
Whole weight	1999-2000	1,238	NC	<LOD	0.20	0.38	0.59
	2001-2002	1,226	0.15	0.16	0.27	0.48	0.73
PCB 169 (pg/g)							
Lipid-adjusted	1999-2000	1,240	NC	<LOD	<LOD	36.4	47.8
	2001-2002	1,223	17.9	19	33.1	50.0	60.7
Whole weight	1999-2000	1,240	NC	<LOD	<LOD	0.24	0.30
	2001-2002	1,223	0.12	0.13	0.22	0.34	0.42

See notes at end of table.

Continued

Exhibit 5-6 (continued)**.** Blood concentrations of selected polychlorinated dibenzo-p-dioxins (dioxins), polychlorinated dibenzofurans (furans), and dioxin-like polychlorinated biphenyls (PCBs) for the U.S. population age 20 years and older, lipid-adjusted and whole weight, 1999-2002[a,b]

			Geometric mean and selected percentiles for dioxin, furan, and PCB concentrations[c,d,e]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
PCBs (units vary)							
PCB 138 & 158 (ng/g)							
Lipid-adjusted	1999-2000	1,261	NC	<LOD	<LOD	54.7	72.8
	2001-2002	1,545	23.3	23.9	44.6	73.8	99.5
Whole weight	1999-2000	1,261	NC	<LOD	<LOD	0.36	0.49
	2001-2002	1,545	0.15	0.15	0.29	0.51	0.68
PCB 153 (ng/g)							
Lipid-adjusted	1999-2000	1,258	NC	<LOD	<LOD	83.2	122
	2001-2002	1,549	32.6	35	62.8	99.5	132
Whole weight	1999-2000	1,258	NC	<LOD	<LOD	0.56	0.79
	2001-2002	1,549	0.21	0.22	0.41	0.67	0.90
PCB 180 (ng/g)							
Lipid-adjusted	1999-2000	1,257	NC	<LOD	41	65.5	83.8
	2001-2002	1,547	23	26.4	46.7	74	90.7
Whole weight	1999-2000	1,257	NC	<LOD	0.27	0.44	0.56
	2001-2002	1,547	0.15	0.17	0.30	0.49	0.64

[a]The 1999-2000 subsample included those aged 12-19 years and aged 20 years and older. The 2001-2002 subsample does not include the 12-19 year-old age group. To enable comparisons, this table presents results for the 20 and older age group only.

[b]This table only includes individual congeners detected with sufficient frequency to calculate a geometric mean.

[c]<LOD = below the limit of detection (LOD) of the analytical method (see CDC, 2005, for chemical-specific LODs).

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

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

Data source: *CDC, 2005*

and dye production and wood preservation (U.S. EPA, 2004b). EPA canceled registered use in 1984; however, HCB is still formed as a byproduct during manufacturing of other chemicals and pesticides (U.S. EPA, 2004b).

- **Mirex** has not been produced or used in the U.S. since 1978. It was used primarily in the southern U.S. to control fire ants. The primary source of exposure is dietary, most often through consumption of fish (U.S. EPA, 2004c).

Dioxins and furans are similar classes of chlorinated aromatic chemicals, usually generated as pollutants or byproducts. In the environment, dioxins and furans occur as a mixture of about 20 compounds (termed "congeners"). The half-lives of these congeners range from roughly 3 to 19 years (CDC, 2005). Human exposure occurs primarily through food; other sources of exposure include industrial accidents, burning of PCBs contaminated with dioxins and furans, burning of many plastics such as PVC, and spraying or unintended releases of contaminated herbicides such as Agent Orange. The detection of dioxins and furans in human blood can reflect either recent or past exposures (CDC, 2005).

Researchers continue to study the potential adverse health effects associated with dioxins and furans. Studies of individual congeners have shown immunotoxic, developmental/reproductive, and other systemic effects. The effects of individual congeners in humans are difficult to determine, since exposures are more likely be to mixtures of several congeners. The dioxin congener TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) is the most toxic form of dioxin and is classified as a known human carcinogen (IARC, 1997). Uncertainties remain, however, about the levels and mechanisms involved in producing harmful effects in humans.

INDICATOR | Blood Persistent Organic Pollutants Level *(continued)*

PCBs are chlorinated aromatic hydrocarbons used in a variety of industries as electrical insulating and heat exchange fluids. PCBs are composed of mixtures of up to 209 different chlorinated congeners. U.S. production of PCBs peaked in the early 1970s; PCBs were banned in 1979. Sources of exposure for the general population include releases from waste sites and fires involving transformers, ingestion of foods contaminated by PCBs, and migration from packaging materials. PCBs typically accumulate in fatty tissues (ATSDR, 2000).

The detection of PCBs in human blood can reflect either recent or past exposures. PCBs with higher degrees of chlorination persist in the human body from several months to years after exposure. Coplanar and mono-ortho substituted PCBs exhibit health effects similar to dioxins. The human health effects of PCBs include changes in liver function, elevated lipids, and gastrointestinal cancers (CDC, 2005).

What the Data Show

Organochlorine Pesticides

Exhibit 5-5 presents the lipid-adjusted and whole weight geometric means and four percentile values for selected organochlorine pesticide metabolites measured in blood. The overall geometric mean for *p,p'*-DDE (a metabolite for DDT) during the 1999-2000 survey was 260 nanograms per gram (ng/g), compared to 295 ng/g in 2001-2002. During the most recent survey (2001-2002), the geometric mean for *trans*-nonachlor (a component of technical-grade chlordane) was 17 ng/g, compared with 18.3 ng/g in 1999-2000. Aldrin, dieldrin, endrin, heptachlor epoxide (the metabolite for heptachlor), HCB, and mirex were not measured with sufficient frequency above the limit of detection to calculate a geometric mean.

Geometric mean blood concentrations of *p,p'*-DDE were compared among demographic groups after adjustment for the covariates of race/ethnicity, age, and gender. For samples collected between 1999 and 2002, the 12-19 year age group had less than half the blood *p,p'*-DDE level compared to the 20 years or older age group (CDC, 2005). The lipid-adjusted geometric mean level in Mexican Americans was 652 ng/g during the most recent survey, more than two and one-half times higher than levels in non-Hispanic whites and two times higher than levels in non-Hispanic blacks. It is unknown whether differences in geometric mean blood *p,p'*-DDE concentrations between different age groups or racial/ethnic groups represent differences in exposure, body size relationships, or metabolism (CDC, 2005) (data not shown).

Dioxins and Furans

In the U.S., quantifiable emissions of dioxin-like compounds from all known sources have decreased by an estimated 90 percent between 1987 and 2000 (U.S. EPA, 2006). Values reported in NHANES 1999-2000 and 2001-2002 support that estimated decline (CDC, 2005). For example, among the entire NHANES 1999-2000 sample population, TCDD (generally considered the most toxic dioxin) was detected less than 1 percent of the time (CDC, 2003). During 2001-2002, only a small number of the dioxin and furan congeners analyzed were detected frequently enough for geometric means to be calculated (Exhibit 5-6). TCDD continued to be among the list of congeners analyzed in NHANES 2001-2002, though only the 95th percentiles for women and non-Hispanic blacks could be characterized: 6.4 and 7.4 picograms per gram (pg/g) TCDD lipid-adjusted, respectively (data not shown). From NHANES 1999-2000, none of the six dioxin or nine furan congeners measured in the blood were detected with sufficient frequency to calculate a geometric mean.

In general, the more highly chlorinated dioxin and furan congeners were the main contributors to the human body burden. The higher concentrations of these congeners in human samples are a result of their greater persistence in the environment, bioaccumulation in the food chain, resistance to metabolic degradation, and greater solubility in body fat (CDC, 2005).

PCBs

During the NHANES 1999-2000 subsample period, none of the three coplanar and 25 other PCB congeners were measured in blood with sufficient frequency above the limit of detection to calculate a geometric mean. The frequency of detection of the eight mono-ortho substituted PCBs ranged from 2 to 47 percent (CDC, 2003). Coplanar PCB congeners 169 and 126, which exhibit dioxin-like toxicity, had a detection rate above 5 percent (CDC, 2003). In the 2001-2002 survey, a total of 12 dioxin-like PCB compounds, three coplanar PCBs and nine mono-ortho-substituted PCBs, were measured in blood. A total of 25 non-dioxin-like PCBs were also included in the 2001-2002 NHANES analysis. However, only two coplanar PCBs and three non-dioxin-like PCB compounds were detected with sufficient frequency to calculate a geometric mean (Exhibit 5-6). Although some PCB congeners were detected with greater frequency during the 2001-2002 survey compared to 1999-2000, this may, in part, be attributed to improved limits of detection in NHANES 2001-2002 (CDC, 2005). After adjusting for a number of covariates (e.g., age, gender, blood cotinine, and lipid level), there were some differences observed in the concentrations of different PCB congeners between different demographic subgroups. However, it is unknown whether these differences represent differences in exposure, pharmacokinetics, or the relationship of dose per body weight (CDC, 2005).

Indicator Limitations

- Because the data from NHANES 1999-2000 and 2001-2002 represent only two survey periods, changes in estimates between the two time periods do not necessarily reflect a trend. As CDC releases additional survey results (e.g., 2003-2004), it will become possible to more fully evaluate trends (CDC, 2002, 2004).
- Generally recognized reference levels for organochlorine pesticides and dioxin, furan, and PCB congeners in blood have not yet been established.

Data Sources

Data used for this indicator were extracted from the CDC report that presents results of the ongoing National Health and Nutrition Examination Survey (CDC, 2005). The underlying laboratory data supporting CDC's report are available online in SAS® transport file format at http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm.

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INDICATOR | Urinary Pesticide Level

Pesticides are chemicals or biological agents that kill plant or animal pests. They include herbicides, insecticides, fungicides, and rodenticides. More than a billion pounds of pesticides are used in the U.S. each year to control weeds, insects, and other organisms that threaten or undermine human activities (Aspelin, 2003). Some of these compounds can be harmful to humans if ingested, inhaled, or otherwise contacted in sufficient quantities. The primary routes of exposure for the general population are ingestion of a treated food source and contact with applications in or near residential sites. Herbicide exposure can also result from contaminated water. Those who manufacture, formulate, and/or apply these chemicals can also be occupationally exposed.

This indicator reports the results of human biomonitoring for three classes of non-persistent insecticides and three classes of herbicides, which can be measured through metabolites that result from the chemical breakdown of the pesticide within the body. Measurement of non-persistent pesticide metabolites in urine typically reflects recent exposure (i.e., in the last few days) due to the short time these metabolites remain within the body (CDC, 2005).

The three classes of insecticides covered by this indicator are carbamates, organophosphates, and pyrethroids. Carbamate insecticides have a wide variety of uses, which include applications on agricultural crops, residential lawns and gardens, and golf courses. Carbamate insecticides do not persist long in the environment, so they have a low potential for bioaccumulation. Organophosphates are used to control a broad spectrum of insects. Although organophosphates are still used for insect control on many food crops, most residential uses are being phased out in the U.S. Pyrethroids are synthetic analogues of pyrethrins, which are natural chemicals found in chrysanthemum flowers. All three groups are neurotoxicants that act by overstimulating the nervous systems of exposed organisms. Symptoms of exposure to pesticides in these classes include muscle weakness or paralysis, difficulty breathing, difficulty concentrating, impaired coordination, and memory loss (CDC, 2005).

The three herbicide classes discussed here are licensed for both commercial and restricted use. Restricted use products can only be applied by certified applicators or under the supervision of such an applicator (U.S. EPA, 2003). The

Exhibit 5-7. Urine concentrations of selected carbamate pesticide metabolites for the U.S. population age 6-59 years, 1999-2002

	Survey years	Sample size	Geometric mean and selected percentiles for carbamate metabolite concentrations[a,b,c]				
			Geometric mean	50th	75th	90th	95th
1-Naphthol[d]							
µg/L of urine	1999-2000	1,998	1.70	1.22	2.72	6.20	12.0
µg/g of creatinine	1999-2000	1,998	1.52	1.25	3.00	6.80	11.6
2-Isopropoxyphenol							
µg/L of urine	1999-2000	1,917	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,503	NC	<LOD	<LOD	<LOD	<LOD
µg/g of creatinine	1999-2000	1,917	NC	<LOD	<LOD	<LOD	<LOD
	2001-2002	2,502	NC	<LOD	<LOD	<LOD	<LOD
Carbofuranphenol							
µg/L of urine	1999-2000	1,994	NC	<LOD	<LOD	<LOD	0.74
	2001-2002	2,530	NC	<LOD	<LOD	<LOD	<LOD
µg/g of creatinine	1999-2000	1,994	NC	<LOD	<LOD	<LOD	0.78
	2001-2002	2,529	NC	<LOD	<LOD	<LOD	<LOD

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

[b]<LOD = below the limit of detection (LOD) of the analytical method (see CDC, 2005, for chemical-specific LODs).

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

[d]1-Naphthol was not included in CDC, 2005.

Data source: *CDC, 2003, 2005*

Exhibit 5-8. Urine concentrations of selected organophosphate pesticide metabolites for the U.S. population age 6-59 years, 1999-2002

			Geometric mean and selected percentiles or organophosphate pesticide metabolite concentrations[a,b,c]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Dimethylphosphate							
µg/L of urine	1999-2000	1,949	NC	0.74	2.80	7.90	13.0
	2001-2002	2,519	NC	<LOD	3.25	8.22	13.4
µg/g of creatinine	1999-2000	1,949	NC	0.81	2.93	8.46	16.1
	2001-2002	2,518	NC	<LOD	3.00	7.83	12.7
Dimethylthiophosphate							
µg/L of urine	1999-2000	1,948	1.82	2.70	10.0	38.0	46.0
	2001-2002	2,518	NC	0.45	4.02	16.2	32.6
µg/g of creatinine	1999-2000	1,948	1.64	2.12	9.57	32.0	51.0
	2001-2002	2,517	NC	0.85	3.79	13.2	27.2
Dimethyldithiophosphate							
µg/L of urine	1999-2000	1,949	NC	<LOD	2.30	12.0	19.0
	2001-2002	2,518	NC	<LOD	0.89	2.49	4.95
µg/g of creatinine	1999-2000	1,949	NC	<LOD	1.86	10.1	21.7
	2001-2002	2,517	NC	<LOD	0.67	2.60	5.80
Diethylphosphate							
µg/L of urine	1999-2000	1,949	1.03	1.20	3.10	7.50	13.0
	2001-2002	2,520	NC	<LOD	2.76	6.33	11.4
µg/g of creatinine	1999-2000	1,949	0.92	0.92	2.73	7.94	12.1
	2001-2002	2,519	NC	<LOD	2.39	5.23	8.53
Diethylthiophosphate							
µg/L of urine	1999-2000	1,949	NC	0.49	0.76	1.30	2.20
	2001-2002	2,519	0.46	0.57	1.48	2.46	3.94
µg/g of creatinine	1999-2000	1,949	NC	0.25	0.71	1.70	2.64
	2001-2002	2,518	0.45	0.52	1.33	2.84	4.61
Diethyldithiophosphate							
µg/L of urine	1999-2000	1,949	NC	0.08	0.20	0.47	0.87
	2001-2002	2,516	NC	<LOD	<LOD	0.61	0.83
µg/g of creatinine	1999-2000	1,949	NC	0.07	0.20	0.55	0.86
	2001-2002	2,515	NC	<LOD	<LOD	0.58	1.01

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

[b]<LOD = below the limit of detection (LOD) of the analytical method (see CDC, 2005, for chemical-specific LODs).

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

Data source: *CDC, 2005*

Exhibit 5-9. Urine concentrations of selected pyrethroid pesticide metabolites for the U.S. population age 6-59 years, 2001-2002

	Survey years	Sample size	Geometric mean and selected percentiles of pyrethroid pesticide metabolite concentrations[a,b,c]				
			Geometric mean	50th	75th	90th	95th
4-Fluoro-3-phenoxybenzoic acid							
µg/L of urine	2001-2002	2,539	NC	<LOD	<LOD	<LOD	<LOD
µg/g of creatinine	2001-2002	2,538	NC	<LOD	<LOD	<LOD	<LOD
cis-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid							
µg/L of urine	2001-2002	2,539	NC	<LOD	0.16	0.49	0.89
µg/g of creatinine	2001-2002	2,538	NC	<LOD	0.22	0.44	0.78
trans-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid							
µg/L of urine	2001-2002	2,525	NC	<LOD	0.41	1.20	2.50
µg/g of creatinine	2001-2002	2,524	NC	<LOD	0.72	1.45	2.55
cis-3-(2,2-Dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid							
µg/L of urine	2001-2002	2,539	NC	<LOD	<LOD	<LOD	<LOD
µg/g of creatinine	2001-2002	2,538	NC	<LOD	<LOD	<LOD	<LOD
3-Phenoxybenzoic acid							
µg/L of urine	2001-2002	2,539	0.32	0.28	0.69	1.69	3.32
µg/g of creatinine	2001-2002	2,538	0.32	0.28	0.58	1.46	3.10

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

[b]<LOD = below the limit of detection (LOD) of the analytical method (see CDC, 2005, for chemical-specific LODs).

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

Data source: *CDC, 2005*

herbicide groups are chlorphenoxy acids, triazines, and chloroacetanilides. Symptoms of acute high-dose exposure to these herbicides can include skin and mucosal irritation as well as burning sensations in the nasopharynx and chest if inhaled (Reigart and Roberts, 1999).

This indicator presents pesticide urinary metabolite data collected as part of the Centers for Disease Control and Prevention's (CDC's) National Health and Nutrition Examination Survey (NHANES). NHANES is a series of surveys conducted by CDC's National Center for Health Statistics that is designed to collect data on the health and nutritional status of the civilian, non-institutionalized U.S. population using a complex, stratified, multistage, probability-cluster design. CDC's National Center for Environmental Health conducted the laboratory analyses for the biomonitoring samples. Beginning in 1999, NHANES became a continuous and annual national survey; biomonitoring for certain environmental chemicals also was implemented. Data for 1999-2000 and 2001-2002 are presented here as a baseline, with the intent of reporting trends over larger time periods in the future. Carbamates, organophosphates, and herbicides were measured as part of NHANES 1999-2000; urinary levels of pyrethroids were added during the NHANES 2001-2002 survey. This indicator presents data for a subsample of survey participants age 6 to 59 years. NHANES also measured levels of a class of persistent pesticides, the organochlorine pesticides, which are not discussed here but can be found under the Blood Persistent Organic Pollutants Level indicator (p. 5-15).

What the Data Show

Carbamates

Exhibit 5-7 presents the geometric means and four percentile values for unadjusted and creatinine-adjusted urinary concentrations of the carbamate pesticide metabolites. Of the three metabolites presented, only 1-naphthol was detected with sufficient frequency to calculate a geometric mean, which was 1.70 micrograms per liter (µg/L) and 1.52 micrograms per gram (µg/g) (creatinine-adjusted).

Organophosphates

NHANES 1999-2000 and 2001-2002 measured urinary concentrations of dialkyl phosphates, which are the primary

metabolites of many organophosphate compounds. Exhibit 5-8 presents the geometric means and four percentile values for urinary concentrations and creatinine-adjusted urinary concentrations of these metabolites. Only three of the six urinary dialkyl phosphates presented (dimethylthiophosphate, diethylphosphate, and diethylthiophosphate) were measured with sufficient frequency above the limit of detection to calculate a geometric mean. The geometric means for those metabolites were 1.82 µg/L (1.64 µg/g creatinine), 1.03 µg/L (0.92 µg/g creatinine), and 0.46 µg/L (0.45 µg/L creatinine), respectively.

Pyrethroids

Pyrethroid (parent and metabolite) compounds were not included in the NHANES 1999-2000 list of analytes measured in urine. During the 2001-2002 NHANES, however, five pyrethroid urinary metabolites were measured in urine samples from a subgroup of participants. Only one of these metabolites, 3-phenoxybenzoic acid, was measured with sufficient frequency above the limit of detection to calculate a geometric mean. The geometric mean concentration of this metabolite measured in urine was 0.32 µg/L (Exhibit 5-9).

Herbicides

During the 1999-2000 survey, none of the direct metabolites of the three primary classes of herbicide were detected in urine with sufficient frequency above the limit of detection to calculate a geometric mean; therefore, data are not displayed. The metabolites 2,4,5-trichlorophenoxyacetic acid and atrazine mercapturate were detected in only 1.2 percent and 3.3 percent, respectively, of the subsample (CDC, 2003). The minor metabolite 2,4-dichlorophenol had a geometric mean of 1.1 µg/L measured in urine; however, this metabolite can also be a result of metabolism of several other chemicals or a byproduct in the manufacture of chemicals. The findings from the 2001-2002 survey were generally consistent with earlier findings showing these metabolites to be frequently near or below the limits of detection. Unlike the 1999-2000 results, 2,4-dichlorophenol samples collected during 2001-2002 were not detected with sufficient frequency above the detection limit to calculate a geometric mean. However, the reported concentrations of this metabolite at the 75th, 90th, and 95th percentile were higher during the 2001-2002 survey than during the 1999-2000 survey (CDC, 2005). (Data not shown.)

Indicator Limitations

- Because the data from NHANES 1999-2000 and 2001-2002 represent only two survey periods, changes in estimates between the two time periods do not necessarily reflect a trend. As CDC releases additional survey results (e.g., 2003-2004) it will become possible to more fully evaluate trends (CDC, 2002, 2004).
- Urine creatinine concentrations were used to adjust the urinary concentrations of pesticides and metabolites of pesticides and phthalates in subsets of adults participating in NHANES. Traditionally, this approach has been used in population groups without much diversity. However, the inclusion of multiple demographic groups (e.g., children) in NHANES may increase the variability in the urinary creatinine levels when comparing across these different study populations (Barr et al., 2004).
- Generally recognized reference levels for carbamate, organophosphate, herbicide, and pyrethroid metabolites in urine have not yet been established.
- Some metabolites may result from sources other than pesticide exposure. For example, 1-naphthol in the urine may reflect multiple sources of exposure, and is therefore not just an indicator of carbamate pesticide exposure.

Data Sources

Data used for this indicator were extracted from two CDC publications that present results of the ongoing NHANES (CDC, 2003, 2005). The underlying laboratory data supporting CDC's report are available online in SAS® transport file format at http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm.

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INDICATOR | Urinary Pesticide Level *(continued)*

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INDICATOR | Urinary Phthalate Level

Phthalates are industrial chemicals added to many consumer products such as food packaging, plastics (plastic bags, garden hoses, recreational toys, medical tubing, plastic clothes, etc.), adhesives, detergents, personal-care products (such as soap, shampoo, nail polish, etc.), and many others. Exposure can occur through food that has been in contact with phthalate containing packaging, as well as direct contact with products that contain phthalates.

Acute high-dose exposure to di-2-ethylhexyl phthalate, for example, may be associated with mild gastrointestinal disturbances, nausea, and vertigo (U.S. EPA, 2005). Chronic exposure to phthalate compounds has been associated with damage to the liver and testes, cancer, and birth defects in animal studies. However, the extent to which these effects occur in humans is the subject of ongoing research; whether detected levels in humans are a health concern is not yet known (CDC, 2005; Kavlock et al., 2002a-g).

This indicator is based on data collected by the National Health and Nutrition Examination Survey (NHANES). NHANES is a series of surveys conducted by the Centers for Disease Control and Prevention's (CDC's) National Center for Health Statistics that is designed to collect data on the health and nutritional status of the civilian, non-institutionalized U.S. population using a complex, stratified, multistage, probability-cluster design. CDC's National Center for Environmental Health conducted the laboratory analyses for the biomonitoring samples. Beginning in 1999, NHANES became a continuous and annual national survey; biomonitoring for certain environmental chemicals also was implemented. Metabolites of phthalates are measured in urine as a biomarker of phthalate exposure in the population. Data for 1999-2000 and 2001-2002 are presented here as a baseline, with the intent of reporting trends across time as more data become available in the future.

What the Data Show

Exhibit 5-10 presents the geometric means and four percentiles for urinary concentrations and creatinine-adjusted urinary concentrations of 12 selected metabolites of phthalates among a subsample of participants age 6 years and older from the most current NHANES (2001-2002). Seven of the 12 phthalates were also measured in the 1999-2000 survey and are also presented in the table. Mono-ethyl phthalate (the metabolite for diethyl phthalate, an industrial solvent used in many products including those containing fragrances) was the phthalate detected in the highest concentration during both surveys (1999-2000 and 2001-2002), with creatinine-adjusted geometric mean concentrations of 163 and 167 micrograms per gram (μg/g) of creatinine, respectively.

In addition, other phthalate compounds such as mono-n-butyl phthalate (a metabolite for dibutyl phthalate, an industrial solvent used in cosmetics, printing inks, insecticides), mono-benzyl phthalate (a metabolite for benzylbutyl phthalate, an industrial solvent used in adhesives, vinyl flooring, and car care products), and mono-2-ethyl-hexyl phthalate (a metabolite for di-2-ethylhexyl phthalate, used to produce flexible plastics) were detected in urine samples. Mono-cyclohexyl phthalate, mono-n-octyl phthalate, and mono-isononyl phthalate were not measured with sufficient frequency above the limit of detection to calculate a geometric mean for those samples collected between 1999 and 2002.

During the 1999-2000 and 2001-2002 surveys, the geometric mean levels for mono-ethyl phthalate, mono-n-butyl phthalate, mono-benzyl phthalate, and mono-2-ethylhexyl phthalate among specified demographic subgroups were compared after adjustment for the covariates of race/ethnicity, age, gender, and urinary creatinine. For those age 6-11 years compared to the older age groups (12-19 years and 20+ years), urinary mono-ethyl phthalate levels were found to be lower, but urinary mono-butyl, mono-benzyl, and mono-2-ethylhexyl phthalates were higher (CDC, 2005). Females tended to have a higher level than males for mono-ethyl, mono-butyl, and mono-benzyl phthalates. Non-Hispanic blacks had higher levels of mono-ethyl phthalate than non-Hispanic whites or Mexican Americans. (Data not shown.)

Indicator Limitations

- Because the data from NHANES 1999-2000 and 2001-2002 represent only two survey periods, changes in estimates between the two time periods do not necessarily reflect a trend. As CDC releases additional survey results (e.g., 2003-2004), it will become possible to more fully evaluate trends (CDC, 2002, 2004).

Exhibit 5-10. Urine concentrations of selected phthalate metabolites in the U.S. population age 6 years and older, 1999-2002[a]

			Geometric mean and selected percentiles of phthalate metabolite concentrations[b,c,d]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Mono-methyl phthalate							
µg/L of urine	2001-2002	2,782	1.15	1.50	3.30	6.00	9.80
µg/g of creatinine	2001-2002	2,772	1.08	1.33	2.62	5.00	7.97
Mono-isobutyl phthalate							
µg/L of urine	2001-2002	2,782	2.71	2.60	5.70	11.9	17.9
µg/g of creatinine	2001-2002	2,772	2.53	2.44	4.50	8.02	12.0
Mono-(2-ethyl-5-hydroxyhexyl) phthalate							
µg/L of urine	2001-2002	2,782	20.0	20.1	43.6	91.3	192
µg/g of creatinine	2001-2002	2,772	18.8	16.6	32.3	70.8	147
Mono-(2-ethyl-5-oxohexyl) phthalate							
µg/L of urine	2001-2002	2,782	13.5	14.0	29.6	59.9	120
µg/g of creatinine	2001-2002	2,772	12.6	11.2	21.3	45.1	87.5
Mono-3-carboxypropyl phthalate							
µg/L of urine	2001-2002	2,782	2.75	3.00	5.70	10.0	14.6
µg/g of creatinine	2001-2002	2,772	2.57	2.45	4.07	7.25	11.4
Mono-ethyl phthalate							
µg/L of urine	1999-2000	2,536	179	164	450	1,260	2,840
	2001-2002	2,782	178	169	465	1,230	2,500
µg/g of creatinine	1999-2000	2,536	163	141	360	898	1,950
	2001-2002	2,772	167	147	388	975	1,860
Mono-n-butyl phthalate							
µg/L of urine	1999-2000	2,541	24.6	26.0	51.6	98.6	149
	2001-2002	2,782	18.9	20.4	40.4	73.6	108
µg/g of creatinine	1999-2000	2,541	22.4	21.9	38.9	68.3	97.5
	2001-2002	2,772	17.8	17.4	30.4	52.4	81.3
Mono-benzyl phthalate							
µg/L of urine	1999-2000	2,541	15.3	17.0	35.3	67.1	103
	2001-2002	2,782	15.1	15.7	38.0	80.8	122
µg/g of creatinine	1999-2000	2,541	14.0	13.3	25.1	50.1	77.4
	2001-2002	2,772	14.1	13.5	26.6	55.1	90.4
Mono-cyclohexyl phthalate							
µg/L of urine	1999-2000	2,541	NC	<LOD	<LOD	<LOD	1.00
	2001-2002	2,782	NC	<LOD	<LOD	0.40	0.40
µg/g of creatinine	1999-2000	2,541	NC	<LOD	<LOD	<LOD	3.00
	2001-2002	2,772	NC	<LOD	<LOD	0.59	0.85

See notes at end of table.

Continued

Exhibit 5-10 (continued)**.** Urine concentrations of selected phthalate metabolites in the U.S. population age 6 years and older, 1999-2002[a]

			Geometric mean and selected percentiles of phthalate metabolite concentrations[b,c,d]				
	Survey years	Sample size	Geometric mean	50th	75th	90th	95th
Mono-2-ethylhexyl phthalate							
µg/L of urine	1999-2000	2,541	3.43	3.20	7.60	14.8	23.8
	2001-2002	2,782	4.27	4.10	9.80	22.8	38.9
µg/g of creatinine	1999-2000	2,541	3.12	3.08	5.88	10.8	18.5
	2001-2002	2,772	3.99	3.89	7.94	18.2	32.8
Mono-n-octyl phthalate							
µg/L of urine	1999-2000	2,541	NC	<LOD	<LOD	1.60	2.90
	2001-2002	2,782	NC	<LOD	<LOD	<LOD	<LOD
µg/g of creatinine	1999-2000	2,541	NC	<LOD	<LOD	2.40	3.51
	2001-2002	2,772	NC	<LOD	<LOD	<LOD	<LOD
Mono-isononyl phthalate							
µg/L of urine	1999-2000	2,541	NC	<LOD	<LOD	<LOD	3.50
	2001-2002	2,782	NC	<LOD	<LOD	<LOD	<LOD
µg/g of creatinine	1999-2000	2,541	NC	<LOD	<LOD	<LOD	4.29
	2001-2002	2,772	NC	<LOD	<LOD	<LOD	<LOD

[a]1999-2000 data are not available for mono-methyl phthalate, mono-isobutyl phthalate, mono-(2-ethyl-5-hydroxyhexyl) phthalate, mono-(2-ethyl-5-oxohexyl) phthalate, and mono-3-carboxypropyl phthalate.

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

[c]<LOD = below the limit of detection (LOD) of the analytical method (see CDC, 2005, for chemical-specific LODs).

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

Data source: *CDC, 2005*

- Urine creatinine concentrations were used to adjust the urinary concentrations of phthalates and metabolites of phthalates in subsets of adults participating in NHANES. Traditionally, this approach has been used in population groups without much diversity. However, the inclusion of multiple demographic groups (e.g., children) in NHANES may increase the variability in the urinary creatinine levels when comparing across these different study populations (Barr et al., 2004).
- Differences in the excretion of various phthalates may be due to differences in either exposure or toxicokinetics. The low detection rates for some of the long alkyl chain phthalates metabolites may be due to significantly less metabolism to the monoester metabolite.
- It is unknown whether differences between ages, genders, or races/ethnicities represent differences in exposure, body-size relationships, or metabolism.
- Generally recognized reference levels for phthalate metabolites in urine have not been established.

Data Sources

Data used for this indicator were extracted from the CDC report that presents results of the ongoing NHANES (CDC, 2005). The underlying laboratory data supporting CDC's report are available online in SAS® transport file format at http://www.cdc.gov/nchs/about/major/nhanes/datalink.htm.

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5.2.3 Discussion

What These Indicators Say About Trends in Human Exposure to Environmental Contaminants

The biomonitoring indicators presented in this section provide an overall representation of the levels of selected contaminants, or metabolites of contaminants, in human blood and urine across the U.S. population. Measurable levels of many of these contaminants appear in at least some subset of the populations tested. Together, these indicators help us understand the extent to which exposure to individual substances has or has not occurred on a national scale. As stated previously, the presence of a contaminant in human tissue does not by itself mean that the contaminant has caused or will cause adverse effects in that person.

Lead, mercury, cadmium, persistent organic pollutant metabolites, and cotinine were reported at varying levels in sampled blood and the metabolites of pesticides and phthalates in the urine of a subset of those tested. Based on the available data, some notable changes in blood levels were reported over time, primarily for the metals. Compared to historical data collected by the Centers for Disease Control and Prevention (CDC), blood lead levels have been steadily declining since the 1980s. The same general observation is true for blood cotinine (see Section 2.4).

Most blood mercury levels in children and women tested were reported below 5.8 micrograms per liter (µg/L)—levels believed not to be associated with harmful health effects. However, nearly 6 percent of women tested showed blood mercury between 5.8 and 58 µg/L. The latter level is considered a general lower bound for neurological effects in developing fetuses and children of exposed mothers.[9]

Current National Health and Nutrition Examination Survey (NHANES) data sets provide some information about variability of biomarkers across age, gender, race, or ethnicity. Such analysis is only possible, however, for those chemicals frequently measured above the level of detection. For example, blood lead levels are highest among children; cadmium levels

[9] Centers for Disease Control and Prevention. 2005. Third national report on human exposure to environmental chemicals. NCEH publication no. 05-0570. <http://www.cdc.gov/exposurereport/report.htm>

are reported highest in the most recent survey in those 20 years and older. Blood mercury levels are reported for children age 1-5 years and women of child-bearing age only, with the highest levels reported in the latter group. In most cases where disparities are observed, it is unknown whether the differences observed represent differences in exposure, pharmacokinetics (absorption, distribution, metabolism, and excretion), or the relationship of dose per body weight.[10]

Limitations, Gaps, and Challenges

Available national-level data provide information on the general magnitude of exposures that are occurring for this subset of contaminants. Further, they serve as a firm foundation or baseline for future analysis. However, available indicator data answer only a part of the question. At this point in time, most of the biomonitoring indicators alone do not (1) enable an extensive assessment of temporal trends; (2) identify and explain possible differences among some subpopulations; (3) provide information on the geographic distribution of the population of concern, or any particular "hot spots" that may exist; (4) reveal exposure conditions; (5) provide information for all contaminants of potential interest; (6) consider exposure to multiple contaminants; or (7) provide perspective as to whether measured levels are elevated or likely to cause harmful effects. These are the most notable limitations, challenges, and data gaps of EPA interest in answering the question of trends in exposure to environmental contaminants.

Temporal Trends

The relatively short time frame of the indicator data set limits the analysis of temporal trends, but these indicators can serve as a baseline for future analysis. Most of the indicators presented to answer this question reflect data from only one or two NHANES sampling periods (1999-2000 and 2001-2002). Only as additional NHANES reports are released every 2 years will meaningful temporal trend analysis be possible. However, CDC has been monitoring blood lead and cotinine since approximately 1976; for these contaminants, more meaningful temporal trend analysis is possible.

Subgroup Analysis

The adequacy of data for subgroup evaluations varies by indicator. The NHANES data sets presented in this chapter contain a sufficiently large sample size to provide reliable age, gender, race, and ethnicity subgroup analyses. In some cases, however, the numbers of observations were insufficient to meet statistical reliability or confidentiality requirements for reporting estimates for all race or ethnicity categories.[11] The benefits of such analyses have been demonstrated in earlier NHANES subgroup comparisons of blood lead levels (e.g., children age 1-5 years, children living in urban or low-income areas), which have allowed resources to be targeted to higher risk or susceptible populations. However, not all ages are represented for all biomarkers in NHANES. Further, in cases where a small percentage of samples had detectable concentrations of the measured contaminant, subgroup comparisons are impossible or less meaningful.

Geographic Trends

The data currently available do not allow for reliable regional subgroup analyses, because the number of geographic regions sampled each year is relatively small. Although the NHANES sampling scheme is designed to obtain a cross-section of data from various regions across the U.S., the data set is not sufficiently representative to allow inferences about regional levels of the selected biomonitoring indicators.

Exposure Conditions

Biomonitoring data alone do not provide information on when or how exposure to a particular contaminant occurred. Many different exposure scenarios (e.g., acute high exposure versus long-term low-level exposures) can lead to the same concentration measured in the body. The measure does not necessarily identify the source(s) of that contaminant or how a person was exposed (e.g., exposure via drinking water versus food versus inhalation; environmental versus non-environmental source). Biomarkers of exposure integrate exposures across multiple exposure routes. Additional information on ambient conditions would be needed to determine what exposures contribute to concentrations in people's bodies. For example, lead in children's blood may come from exposure to airborne sources, contaminated water or food, or contaminated soil or dust. In addition, some biomarkers are not specific to a particular contaminant, making interpretation of the data and their significance uncertain. Lastly, some environmental contaminants are also produced in trace amounts by normal metabolic processes (e.g., formaldehyde and acetone), so their presence cannot always be attributed to external exposure.[12,13]

Other Environmental Contaminants

There are still many contaminants for which no biomonitoring indicators exist, and others that are simply not feasible to analyze using current technology or data collection methods. For example, although it is possible to measure the amount of radiation that a person is exposed to using a dosimeter, biomarkers are not yet feasible for national estimates of exposure to radon. Similar issues of feasibility exist with other contaminants, including most criteria air pollutants (e.g., ozone, nitrogen dioxide, carbon monoxide, and particulate matter), biological agents (e.g., molds, certain infectious agents such

[10] Centers for Disease Control and Prevention. 2005. Third national report on human exposure to environmental chemicals. NCEH publication no. 05-0570.<http://www.cdc.gov/exposurereport/report.htm>

[11] National Center for Health Statistics. 2006. Health, United States, 2006, with chartbook on trends in the health of Americans. DHHS publication no. 2006-1232. Hyattsville, MD Watson, W.P., and A. Mutti. 2004. Role of biomarkers in monitoring exposures to chemicals: Present position, future prospects. Biomarkers 9(3):211-242.

[12] Watson, W.P., and A. Mutti. 2004. Role of biomarkers in monitoring exposures to chemicals: Present position, future prospects. Biomarkers 9(3):211-242.

[13] Bates, M.N., J.W. Hamilton, J.S. LaKind, P. Langenberg, M. O'Malley, and W. Snodgrass. 2005. Workgroup report: Biomonitoring study design, interpretation, and communication—lessons learned and path forward. Environ. Health Perspect. 113(11):1615-1621.

as bacteria or viruses, and dust mites), byproducts from the disinfection of drinking water (e.g., chlorine or chlorine-containing compounds), and several contaminants commonly found in air and drinking water at Superfund sites (e.g., trichloroethylene and tetrachloroethylene, among others). In many cases, biomonitoring for these contaminants is either cost-prohibitive or not yet technologically feasible. However, biomonitoring methods are constantly evolving. For example, CDC has added a number of environmental contaminants to its biomonitoring efforts, which will be included in future reports. These include arsenic, polybrominated compounds, and perfluorinated compounds (e.g., perfluorooctane sulfonate and perfluorooctanoic acid), among others.[14]

In addition, researchers continue to evaluate whether certain chemicals, referred to as endocrine disruptors, may contribute to adverse health effects in humans and may impact the health of future generations. Information about the magnitude and pattern of human exposure to endocrine disruptors is being collected for only a small subset of chemicals that compose this group (e.g., PCBs, DDT and its metabolites); wider testing will be challenging because there are still many compounds that have not yet been classified as endocrine disruptors, but may someday be identified as such. Moreover, understanding the specific window of vulnerability during different stages of development will be critical in evaluating the potential harmful effects of these chemicals.

Multiple Contaminants

Current biomonitoring indicators do not consider the effects of exposures to multiple contaminants. Specifically, biomarker measurements that are collected in NHANES do not provide any perspective on how different classes of contaminants interact with one another once they enter the body and to what extent associated responses are additive, antagonistic, or synergistic.

Clinical Reference or Comparison Levels

For most available biomonitoring indicators, no general scientific consensus exists as to how to interpret measured levels of contaminants in blood and urine. For example, are measured levels associated with some clinical effect or elevated above some "safe" or "background" level? Tracking trends in exposure over time, combined with trends in ambient measurements and health outcome measurements, is a key part of establishing such reference values. Establishing background or reference ranges (distributions) will help in identifying people with unusually high exposure or the percentage of the populations with contaminant exposures above established levels of concern.

5.3 What Are the Trends in Health Status in the United States?

5.3.1 Introduction

An overarching goal of public health agencies is to increase quality and years of healthy life and to eliminate health disparities. Tracking historical trends in general health status can help identify where interventions have improved the health of a population or where interventions may be needed (e.g., exploring causative factors and preventive measures). For example, a key concern for EPA is what possible environmental exposures could be contributing to the diseases or conditions that are the leading causes of death in the U.S.

The topics covered under this question are broad and not intended to represent specific diseases or conditions related to the environment. Environmental contaminants from air, water, and land can influence the overall health of a nation. As described in Section 5.1, however, many factors other than the environment influence the health of a population, such as socio-demographic attributes, behavioral and genetic risk factors, level of preventive care, and quality of and access to health care. Though no consensus exists on the relative contribution of environmental exposures, tracking overall health in the U.S. provides important context for the next section of this chapter, which examines specific acute and chronic diseases and conditions that may be linked more specifically with exposures to environmental contaminants.

As defined by the World Health Organization, health is a state of complete physical, mental, and social well-being, and not the mere absence of disease or infirmity.[15] The health status of a population can be measured by a wide range of factors: birth and death rates, life expectancy, quality of life, morbidity from specific diseases, risk factors, use of ambulatory care and inpatient care, accessibility of health personnel and facilities, financing of health care, health insurance coverage, and many other factors.[16]

While no single set of measures can completely characterize the health of a large and diverse population, CDC and other health agencies worldwide consistently have viewed life expectancy and mortality data as indicators of overall population health because they represent the cumulative effects of social and physical environmental factors, behavioral and genetic risk factors, and the level and quality of health care. These data include the leading causes of mortality (among both infants and

[14] Department of Health and Human Services. 2003. Candidate chemicals for possible inclusion in future releases of the national report on human exposure to environmental chemicals. Federal Register 68(189):56296-56298. September 30.

[15] World Health Organization. 1946. Preamble to the constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 states (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.

[16] U.S. Department of Health and Human Services. 2000. Healthy people 2010: Understanding and improving health. Second edition. Washington, DC: U.S. Government Printing Office. <http://www.health.gov/healthypeople/>

the general population), which provide a broad perspective on the diseases and conditions that are having the greatest impact on the nation's health. Infant mortality is a particularly useful measure of health status, because it indicates both the current health status of the population and predicts the health of the next generation.[17] It reflects the overall state of maternal health as well as the quality and accessibility of primary health care available to pregnant women and infants.

Tracking health status using such indicators provides information on changing or emerging trends. At the beginning of the 20th century, the population of the U.S. was characterized by a low standard of living, poor hygiene, and poor nutrition; communicable diseases and acute conditions were major causes of most premature deaths. Over the course of the century, public health measures such as improved sanitation and drinking water treatment led to a dramatic decrease in deaths due to infectious diseases and a marked increase in life expectancy. As the population has aged, chronic diseases such as heart disease and cancer have become the leading causes of death.[18] These diseases may require a different approach to prevention, detection, and treatment compared to the infectious and acute illnesses more common in the past.

5.3.2 ROE Indicators

Other agencies such as CDC routinely assess the state of the nation's health. EPA has drawn on the comprehensive data collection efforts and assessments conducted by these agencies in addressing this question. Three indicators are used to assess the trends in health status in the U.S. (Table 5-3). *Life expectancy at birth* is the number of years a newborn would expect to live if that person experienced the mortality schedule existing at the time of birth. *Infant mortality* is the number of infants who die before their first birthday. *General mortality* represents the number of all deaths nationwide and provides information on the leading causes of death. Mortality is also tracked using years of potential life lost, or the number of years "lost" by people in a population who die prematurely of a stated cause. These indicators are interrelated—e.g., declines in mortality result in increased life expectancy, and shifts in life expectancy are often used to describe changes in mortality; changes in infant mortality are reflected in general mortality as well.

Where possible, the indicators for this question track health status among subpopulations (e.g., by gender, race, ethnicity). Generally, differences in mortality and life expectancy between black and white Americans have been tracked for the past several decades, in some cases as far back as the 1930s. A broader spectrum of race and ethnic group breakdowns is available for these indicators in more recent years, including American Indian/Alaska Native, Asian or Pacific Islander, and Hispanic origin. Subpopulation data are presented to the extent practicable under "What the Data Show" and/or within indicator exhibits.

Table 5-3. ROE Indicators of Trends in Health Status in the United States

National Indicators	Section	Page
General Mortality	5.3.2	5-33
Life Expectancy at Birth	5.3.2	5-35
Infant Mortality	5.3.2	5-36

[17] National Center for Health Statistics. 2001. Healthy people 2000 final review. Hyattsville, MD: Public Health Service. <http://www.cdc.gov/nchs/data/hp2000/hp2k01-acc.pdf>

[18] Ibid.

Overall mortality is a key measure of health in a population. Three measures of mortality are "all cause" mortality, cause-specific mortality, and years of potential life lost (YPLL). "All cause" mortality counts the total number of deaths due to any cause within a specified year, whereas cause-specific mortality statistics count the number of deaths due to a particular cause in a specified year. YPLL is defined as the number of years between the age at death and a specified age; that is, the total number years "lost" by persons in the population who die prematurely of a stated cause. Ranking the causes of death can provide a description of the relative burden of cause-specific mortality (NCHS, 2005).

This indicator is based on mortality data recorded in the National Vital Statistics System, which registers virtually all deaths nationwide from death certificate data. YPLL is calculated by subtracting the age at death from a selected age (e.g., 65, 75, 85), then summing the individual YPLLs across each cause of death (CDC, 2007). Sixty-five was selected as the age for this indicator to focus on deaths more likely to be attributable to preventable causes and less influenced by increasing age. The temporal coverage of the data is from 1933 to 2004 and data are collected from all 50 states and the District of Columbia.

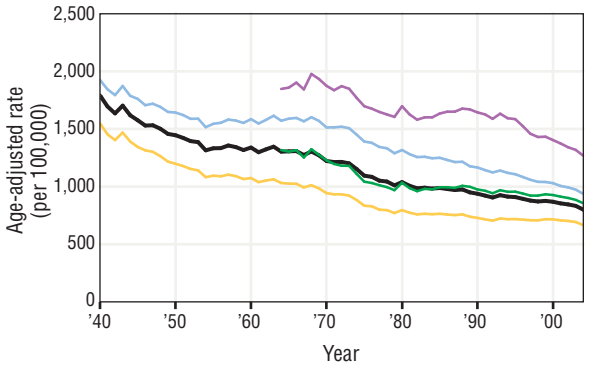
What the Data Show

An increase in the number of deaths in the U.S. has been observed over the last few decades, reflecting the increase in the size and aging of the population. However, the age-adjusted all cause mortality rates have declined yearly since 1980 (except in years of influenza outbreaks in 1983, 1985, 1988, 1993, and 1999) with the most recent available rate of 800.8 deaths per 100,000 people in 2004. Exhibit 5-11 provides some historical perspective on trends in the age-adjusted mortality rates between 1940 and 2003, showing that age-adjusted rates were nearly twice as high in 1940 as they were in 2000. The largest decline in "all cause" mortality rates since 1990 has occurred among black males compared with white males and black and white females.

The rank order of the leading causes of death has remained generally the same since 1999. The one difference is Alzheimer's disease, which was the eighth leading cause of death between 1999 and 2003 but became the seventh leading cause in 2004, displacing influenza and pneumonia. Exhibits 5-12 and 5-13 present the leading causes of mortality and YPLL for 2004, respectively. The three leading causes of death were heart disease, cancer, and stroke, accounting for about 60 percent of all deaths. The YPLL ranking is different, with unintentional injuries, cancer, and heart disease as the leading three causes.

During 2004, heart disease was the leading cause of death across the reported racial and ethnic groups, except for Asians or Pacific Islanders for whom cancer (malignant neoplasms) was the leading cause of death. In addition, diabetes was ranked as the fourth leading cause of death among blacks and American Indians/Alaska Natives (both sexes), which was a higher ranking than for most of the other racial and ethnic groups. (Data not shown.)

Exhibit 5-11. Age-adjusted "all cause" mortality rates in the U.S., 1940-2004[a,b]



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

[b]Mortality rates were not generally reported for black males and black females prior to 1964.

Data source: *NCHS, 2001, 2007*

Indicator Limitations

- Cause of death rankings denote the most frequently occurring causes of death among those causes eligible to be ranked. The rankings do not necessarily denote the causes of death of greatest public health importance. Further, rankings of cause-specific mortality could change depending on the defined list of causes that are considered and, more specifically, the types of categories and subcategories that are used for such rankings (NCHS, 2005).
- Mortality rates are based on underlying cause of death as entered on a death certificate by a physician. Incorrect coding and low rates of autopsies that confirm the cause of death may occur. Additionally, 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 as a result of these uncertainties, as well as the underreporting of some causes of death.

Data Sources

Mortality rates were obtained from vital statistics reports published by CDC's National Center for Health Statistics (NCHS, 2001, 2007). Data in the NCHS reports are based

in part on unpublished work tables, available on the NCHS Web site at http://www.cdc.gov/nchs/deaths.htm. Leading cause of death and YPLL data were extracted from CDC's Web-Based Injury Statistics Query and Reporting System (WISQARS) (CDC, 2007) (http://www.cdc.gov/ncipc/wisqars/). The underlying data in WISQARS come from CDC/NCHS annual mortality data files.

References

CDC (Centers for Disease Control and Prevention). 2007. National Center for Injury Prevention and Control. Web-Based Injury Statistics Query and Reporting System (WISQARS) [online]. Leading causes of death and years of potential life lost (YPLL) reports, 1999–2004. Accessed October 2, 2007. <http://webappa.cdc.gov/sasweb/ncipc/leadcaus.html> <http://webappa.cdc.gov/sasweb/ncipc/ypll10.html>

CDC. n.d. CDC WONDER: Help page for compressed mortality file. Accessed October 2007. <http://wonder.cdc.gov/wonder/help/cmf.html>

NCHS (National Center for Health Statistics). 2007. Deaths: Final data for 2004. National Vital Statistics Reports 55(19). <http://www.cdc.gov/nchs/data/nvsr/nvsr55/nvsr55_19.pdf>

NCHS. 2005. Deaths: Leading causes for 2002. National Vital Statistics Reports 53(17). <http://www.cdc.gov/nchs/data/nvsr/nvsr53/nvsr53_17.pdf>

NCHS. 2001. Age-adjusted death rates; trend data based on the year 2000 standard population. National Vital Statistics Reports 49(9). <http://www.cdc.gov/nchs/data/nvsr/nvsr49/nvsr49_09.pdf>

Exhibit 5-12. Leading causes of death in the U.S., 2004

Cause of death	Number of deaths	Percent of all deaths[a]
Heart disease	652,486	27.2
Cancer (malignant neoplasms)	553,888	23.1
Stroke (cerebrovascular)	150,074	6.3
Chronic lower respiratory diseases	121,987	5.1
Accidents (unintentional injuries)	112,012	4.7
Diabetes mellitus	73,138	3.1
Alzheimer's disease	65,965	2.8
Influenza and pneumonia	59,664	2.5
Nephritis	42,480	1.8
Septicemia	33,373	1.4
All other causes	532,548	22.2

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

Data source: *CDC, 2007*

Exhibit 5-13. Years of potential life lost (YPLL) before age 65 in the U.S., 2004

Cause of death	YPLL	Percent of all YPLL[a]
Accidents (unintentional injuries)	2,219,044	19.1
Cancer (malignant neoplasms)	1,877,690	16.2
Heart disease	1,413,158	12.2
Perinatal period	922,191	7.9
Suicide	687,395	5.9
Homicide	565,979	4.9
Congenital anomalies	486,853	4.2
HIV	261,784	2.3
Stroke (cerebrovascular)	245,074	2.1
Liver disease	231,132	2.0
All other causes	2,702,330	23.3

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

Data source: *CDC, 2007*

INDICATOR | Life Expectancy at Birth

Life expectancy at birth is often used to appraise the overall health of a given population (NCHS, 2006a). Changes in life expectancy over time are commonly used to describe trends in mortality. Life expectancy is the average number of years at birth a person could expect to live if current mortality trends were to continue for the rest of that person's life.

This indicator is based on data from the National Vital Statistics System, which registers virtually all deaths and births nationwide. The temporal coverage of the data is from 1933 to 2004 and data are collected from all 50 states and the District of Columbia.

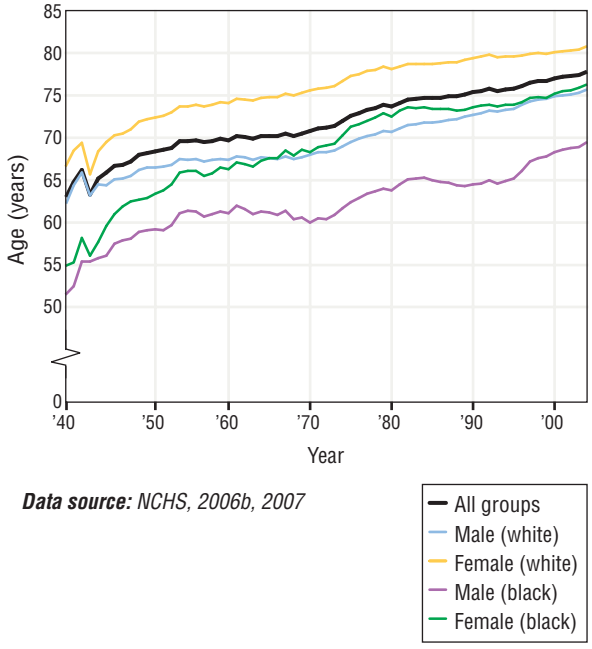
What the Data Show

Exhibit 5-14 presents the historical trends in life expectancy at birth for the entire population as well as by gender and race (black and white) between 1940 and 2004, showing an upward trend in life expectancy in the U.S. over time. Life expectancy at birth has increased throughout the 20th and now into the 21st century. The overall life expectancy was the highest ever reported in 2004 at 77.8 years, increasing from 77.4 in 2003.

Life expectancy continues to increase for both males (73.9 years in 1999 to 75.2 years in 2004) and females (79.4 years in 1999 to 80.4 years in 2004). The gap in life expectancy between males and females widened from 2.0 years to 7.8 years between 1900 and 1979. Recently, this gap narrowed for the year 2000 (a difference of 5.4 years between males and females) and remained relatively constant through 2004 (a difference of 5.2 years between males and females). (Data not shown.)

The increase in life expectancy among blacks reported for 1999 (71.4 years) continued, with a reported life expectancy of 73.1 years in 2004. The difference in life expectancy between the black and white populations was 5.2 years in 2004. In 2004, white females continued to have the highest life expectancy at 80.8 years, followed by black females at 76.3 years, white males at 75.7 years, and black males at 69.5 years (Exhibit 5-14).

Exhibit 5-14. Life expectancy in the U.S. by race and sex, 1940-2004



Data source: *NCHS, 2006b, 2007*

Indicator Limitations

- Life expectancy at birth is strongly influenced by infant and child mortality rates. It is important to consider such influences when making comparisons among subgroups, since differences in life expectancy among certain subgroups may be mostly attributed to differences in prenatal care and other important determinants of infant and child mortality.

Data Sources

The annual life expectancy data used for this indicator were obtained from life tables published by CDC's National Center for Health Statistics (NCHS, 2006b). NCHS also publishes life expectancy data in its annual "deaths: final data" reports (e.g., NCHS, 2007); however, these reports generally provide year-by-year breakdowns beginning in 1975. NCHS life table reports provide annual data back to before 1940. Life table methodologies used to calculate life expectancies are presented in each of these NCHS reports.

References

NCHS (National Center for Health Statistics). 2006a. Health, United States, 2006, with chartbook on trends in the health of Americans. DHHS Publication No. 2006-1232. Hyattsville, MD.

NCHS. 2006b. United States life tables, 2003. National Vital Statistics Reports 54(14). Table 12. <http://www.cdc.gov/nchs/data/nvsr/nvsr54/nvsr54_14.pdf>

NCHS. 2007. Deaths: Final data for 2004. National Vital Statistics Reports 55(19). Table 8. <http://www.cdc.gov/nchs/data/nvsr/nvsr55/nvsr55_19.pdf>

INDICATOR | Infant Mortality

Infant mortality is a particularly useful measure of health status because it both indicates current health status of the population and predicts the health of the next generation (NCHS, 2001). Infant mortality in the U.S. is defined as the death of an infant from time of live birth to the age of 1 year. It does not include still births. Overall infant mortality is composed of neonatal (less than 28 days after birth) and postneonatal (28 days to 11 months after birth) deaths.

This indicator presents infant mortality for the U.S. based on mortality data from the National Vital Statistics System (NVSS) based on death certificate data. 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

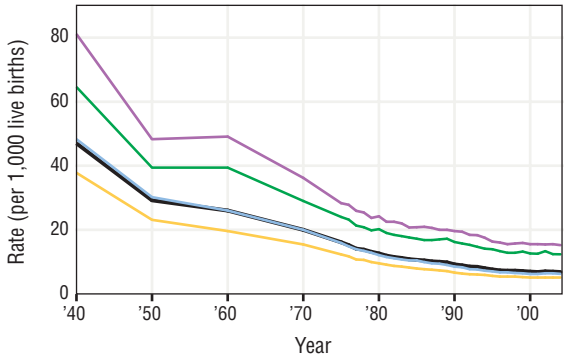
In 2004, a total of 27,936 deaths occurred in children under 1 year of age, 89 fewer deaths than in 2003. Exhibit 5-15 presents the national trends in infant mortality between 1940 and 2004 for all infant deaths as well as infant deaths by gender and race (black and white). A striking decline has occurred during this time period, with overall infant mortality rates dropping from nearly 50 deaths per 1,000 live births in 1940 to just under seven deaths per 1,000 live births in 2004. Beginning around 1960, the infant mortality rate has decreased or remained level each successive year through 2004, except for 2002. From 2000 to 2004, infant mortality rates ranged from 6.8 (2001 and 2004) to nearly 7.0 (2002) per 1,000 live births. Infant mortality rates were highest among black males and lowest among white females, although this gap has been decreasing over time.

The infant mortality rate for blacks decreased from 14.6 per 1,000 live births in 1999 to 13.8 per 1,000 live births in 2004. However, this is still twice the rate compared to white infants, which ranged from approximately 5.7 to 5.8 per 1,000 live births between 1999 and 2004. Infant mortality rates among Hispanic infants have changed little since 1999. In 2004, the infant mortality rate for Hispanic infants was 5.6 per 1,000 live births (NCHS, 2007a). (Data not shown.)

In the U.S. in 2004, the 10 leading causes of infant mortality accounted for nearly 69 percent of all infant deaths, with the subgroup consisting of congenital anomalies (i.e., congenital malformations, deformations, and chromosomal abnormalities) having the highest rate at nearly 1.4 per 1,000 live births. This category alone accounts for approximately 20 percent of all infant deaths in 2004 (Exhibit 5-16).

Congenital anomalies were generally ranked highest among the different racial groups. However, the leading cause of infant mortality among blacks was short gestation and low birthweight, followed by congenital anomalies. There were few differences in the leading causes of infant mortality between Hispanics and non-Hispanics. In addition, the Centers for Disease Control and Prevention (CDC) report a substantial difference in the leading causes of death during the neonatal versus the postneonatal periods. Disorders related to short gestation and low birthweight were the leading cause of death for neonates and sudden infant death syndrome was the leading cause of death for postneonates, based on 2003 data (NCHS, 2007b). (Data not shown.)

Exhibit 5-15. Infant mortality rates in the U.S. by race and sex, 1940-2004[a,b]



[a]Race was reported based on the race of the child (1940-1979) or the race of the mother (1980-2004).

[b]Annual infant mortality rates are not available prior to 1975 in published sources. Trends presented from 1940-1974 are based on data published for 1940, 1950, 1960, and 1970.

Data source: *NCHS, 2007*

Indicator Limitations

- Cause of death rankings denote the most frequently occurring causes of death among those causes eligible to be ranked. The rankings do not necessarily denote the causes of death of greatest public health importance. Further, rankings of cause-specific mortality could change depending on the defined list of causes that are considered and, more specifically, the types of categories and subcategories that are used for such rankings (NCHS, 2005).
- Mortality rates are based on underlying cause of death as entered on a death certificate by a physician. Incorrect coding and low rates of autopsies that confirm the cause of death may occur. Additionally, 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 as a result of these uncertainties, as well as the underreporting of some causes of death.

Exhibit 5-16. Leading causes of infant death in the U.S., 2004[a]

Cause of death	Number of deaths	Percent of all infant deaths[b]
Congenital malformations, deformations, and chromosomal abnormalities	5,622	20.1
Disorders related to short gestation and low birthweight	4,642	16.6
Sudden infant death syndrome (SIDS)	2,246	8.0
Newborn affected by maternal complications of pregnancy	1,715	6.1
Accidents (unintentional injuries)	1,052	3.8
Newborn affected by complications of placenta, cord, and membranes	1,042	3.7
Respiratory distress of newborn	875	3.1
Bacterial sepsis of newborn	827	3.0
Neonatal hemorrhage	616	2.2
Circulatory system disease	593	2.1
All other causes	8,706	31.2

[a]"Infant deaths" are those occurring before the age of 1.

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

Data source: *CDC, 2007*

Data Sources

Infant mortality data were obtained from a published report by CDC's National Center for Health Statistics (NCHS, 2007a), which provides annual natality data back to 1975 and decadal data for 1940, 1950, 1960, and 1970. Data in the NCHS report are based in part on unpublished work tables, available on the NCHS Web site at http://www.cdc.gov/nchs/deaths.htm. Leading cause of infant death data were extracted from CDC's Web-Based Injury Statistics Query and Reporting System (WISQARS) (CDC, 2007) (http://www.cdc.gov/ncipc/wisqars/), with supporting documentation from NVSS reports (NCHS, 2007). The underlying data in WISQARS come from CDC/NCHS annual mortality data files.

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CDC. n.d. CDC WONDER: Help page for compressed mortality file. Accessed October 2007. <http://wonder.cdc.gov/wonder/help/cmf.html>

NCHS (National Center for Health Statistics). 2007. Deaths: Final data for 2004. National Vital Statistics Reports 55(19). <http://www.cdc.gov/nchs/data/nvsr/nvsr55/nvsr55_19.pdf>

NCHS. 2005. Deaths: Leading causes for 2002. National Vital Statistics Reports 53(17). <http://www.cdc.gov/nchs/data/nvsr/nvsr53/nvsr53_17.pdf>

NCHS. 2001. Healthy people 2000 final review. Hyattsville, MD: Public Health Service. <http://www.cdc.gov/nchs/data/hp2000/hp2k01-acc.pdf>

5.3.3 Discussion

What These Indicators Say About Trends in Health Status in the United States

ROE indicators used to answer this question show that the overall health of the nation has continued to improve. The three leading causes of death across all age groups—heart disease, cancer, and stroke—remain unchanged since 1999. In contrast, a ranking by years of potential life lost, which weighs deaths at an earlier age more heavily, places unintentional injuries, cancer, and heart disease as the top three (General Mortality indicator, p. 5-33). Although men and women in many other countries have longer life expectancies, general mortality rates in the U.S. continue to decline, and life expectancy continues a long-term upward trend (Life Expectancy indicator, p. 5-35). See Box 5-2 for an overview of health status in the U.S. compared to the rest of the world.

The decline in the all cause mortality rate since 1940 has been driven largely by declines in deaths from heart disease, stroke, and unintentional injuries. These trends have been linked in part to the resources devoted to health education, public health programs, health research, and health care, and the impact of these efforts on controlling disease. For example, public campaigns about smoking and the use of cholesterol-lowering drugs have contributed to a decline in the death rate from heart disease. Efforts to improve motor vehicle safety as well as safety in homes and workplaces have helped to lower death rates from unintentional injuries. New medical treatments have resulted in a decline in the death rate from HIV.[19]

Infant Mortality (p. 5-36), like the other two indicators, shows a long-term decline, likely due to widespread application of advances in medical knowledge (such as the introduction of synthetic surfactant for preterm infants and widespread public education about infant sleep position).[20] However, infant mortality in the U.S. remains among the highest in the industrialized world. In 2003 and 2004, the infant mortality rates decreased after increasing in 2002 for the first time since 1958. The 2002 rise in infant mortality was attributed to an increase in neonatal deaths (infants less than 28 days old), particularly deaths of infants within the first week of life.[21]

Despite a generally improving picture of the nation's health, racial and ethnic disparities in health status persist. For example, though the nation's infant mortality rate has decreased, the infant death rate for black infants is still more than double that of whites. In 2004, the gap in life expectancy between the black and white populations is 5.2 years, though this gap has been narrowing.[22] Differences in death rates also exist between black and white populations. Observed differences are believed to be the result of a complex interaction of genetic variations, environmental factors, and specific health behaviors.[23]

Box 5-2. Worldwide Comparisons in Health Status

The following comparisons are based on the most current statistics for each of the three indicators used to study U.S. health status. The World Health Organization (WHO) calculates its statistics to ensure comparability across data sets; the statistics may not fully match those generated by individual countries and reported in other reports.

Life expectancy: According to the WHO, in 2004, the U.S. ranked 35th in terms of life expectancy for males and females of the 192 WHO member states.[a] Japan reports the highest life expectancy (82 years, compared to the U.S life expectancy of 78 years reported by WHO).

Leading causes of death: The leading causes of death reported in the U.S. continue to be heart disease, cancer, and stroke. Worldwide, as reported for 2002, cardiovascular diseases accounted for the largest percentage of deaths, followed by infectious and parasitic diseases and cancer.[b]

Infant mortality: In 2003, the United States ranked 28th among the 37 countries, territories, cities, or geographic areas with at least 1 million population considered to have completed counts of live births and infant deaths as indicated in the United Nations Demographic Yearbook.[c] The U.S. infant mortality rate for the same time period (6.9 per 1,000 live births) was approximately 2 to 3 times higher than the lowest rates reported worldwide (e.g., in Hong Kong the rate was 2.3, in Singapore 2.5, in Japan 3.0, and in Sweden 3.1, per 1,000 live births).

[a] World Health Organization. 2006. World Health Report. See Statistical Annex Table 1. <http://www.who.int/entity/whr/2006/annex/annex1.xls>

[b] World Health Organization. 2005. Incidence, prevalence, mortality, YLL, YLD and DALYs by sex, cause and region, estimates for 2002 as reported in the World Health Report 2004. <http://www.who.int/healthinfo/bodgbd2002revised/en/index.html>

[c] National Center for Health Statistics. 2006. Health, United States, 2006, with chartbook on trends in the health of Americans. Hyattsville, Maryland. DHHS Publication No. 2006-1232. Table 25. <http://www.cdc.gov/nchs/data/hus/hus05.pdf>

[19] National Center for Health Statistics. 2006. Health, United States, 2006, with chartbook on trends in the health of Americans. DHHS publication no. 2006-1232. Hyattsville, MD. p. 3.

[20] National Center for Health Statistics. 2001. Healthy people 2000 final review. Hyattsville, MD: Public Health Service. p. 206. <http://www.cdc.gov/nchs/data/hp2000/hp2k01-acc.pdf>

[21] National Center for Health Statistics. 2005. Health, United States, 2005, with chartbook on trends in the health of Americans. DHHS publication no. 2005-1232. Hyattsville, MD. p. 66.

[22] Ibid. pp. 11-12.

[23] U.S. Department of Health and Human Services. 2000. Healthy people 2010: Understanding and improving health. Second edition. Washington, DC: U.S. Government Printing Office. <http://www.health.gov/healthypeople/>

Differences also exist between men and women. Based on 2004 data, men have a life expectancy 5.2 years less than that of women and have higher death rates for each of the 10 leading causes of death. However, women have shown increased death rates over the past decade in areas where men have experienced improvements, such as lung cancer.[24]

Limitations, Gaps, and Challenges

The indicators are important and widely accepted measures of population health status. However, the selected indicators cannot be expected to fully answer the question on trends in general U.S. health status. Limitations and information gaps are highlighted here.

The indicators provide a broad measure of health status and include many variables that are not related to the environment. No conclusions, therefore, can or should be drawn about the role of exposure to environmental contaminants using these indicators alone. While declining mortality rates and increasing life expectancy suggest improving health status, these indicators do not address other aspects of health, such as morbidity, perceived well-being, or quality of life.

The use of mortality data presents some limitations, largely related to uncertainties associated with the use of death certificate data. First, correct coding of the underlying cause of death and confirmation by autopsy may not occur. Second, uncertainties in intercensal population estimates can affect conclusions about trends in data sets. In addition, improved data on the health status of population subgroups—particularly across race and ethnic groups—would allow better characterization of potential trends across different groups. Accurate identification of health disparities will require improved data collection and the use of standardized data. For example, problems of race and Hispanic-origin classification can affect Hispanic death rates and the comparison of rates across the Hispanic and non-Hispanic populations.[25]

5.4 What Are the Trends in Human Disease and Conditions for Which Environmental Contaminants May Be a Risk Factor, Including Across Population Subgroups and Geographic Regions?

5.4.1 Introduction

As discussed throughout this report, numerous human diseases and conditions have been linked with exposures to environmental contaminants, some more strongly than others. Identifying diseases that might be associated with environmental contaminants, and determining the existing data sources available for them, is a key part of the effort to better characterize links between environmental exposures and adverse health outcomes.

Tracking overall rates of disease in the nation, independent of exposure, enables the evaluation of disease patterns and emerging trends. It may identify diseases, conditions, and possible risk factors that warrant further study or intervention and can help identify where policies or interventions have been successful. Because the U.S. has a diverse population, an important component of such an analysis is identifying disparities among people of differing races and ethnicities, genders, education and income levels, and geographic locations.

EPA has selected those human diseases and conditions with well-established associations with exposures to environmental contaminants and for which national data are available, recognizing again that in most cases risk factors are multi-factorial and that the development of a particular disease or condition depends on the magnitude, duration, and timing of the exposure. The diseases and conditions addressed in this question are associated with the contaminant sources covered by the questions in the three media chapters (Chapters 2, 3, and 4) of this report. As described in Section 5.1, however, this question is not intended to tie human diseases and conditions to specific changes in the environment being measured at the national level. Covered health outcomes fall into the following five broad categories: cancer, cardiovascular disease, respiratory

[24] National Center for Health Statistics. 2006. Health, United States, 2006, with chartbook on trends in the health of Americans. DHHS publication no. 2006-1232. Hyattsville, MD. pp. 11-12.

[25] National Center for Health Statistics. 2006. Deaths: Final data for 2003. National Vital Statistics Reports 54(13). <http://www.cdc.gov/nchs/data/nvsr/nvsr54/nvsr54_13.pdf>

disease, infectious disease, and birth outcome. The reasons for the inclusion of each are highlighted below.

Cancer

The term "cancer" refers to diseases in which abnormal cells divide without control, losing their ability to regulate their own growth, control cell division, and communicate with other cells. Cancer is the second leading cause of death in the U.S. (General Mortality indicator, p. 5-33). More than one in three people will develop cancer and nearly one in four will die of it.[26,27] In response, scientists continue to explore the role that the exposure to environmental contaminants may play, along with other possible risk factors, in the initiation and development of cancer. Some environmental contaminant exposures are known risk factors for certain types of cancers. Examples include radon and lung cancer and arsenic and skin cancer. Though many types of cancer are suspected of being related to ambient environmental exposures, associations are not always clear because the etiology of cancer is complex and influenced by a wide range of factors. Many factors can increase individual cancer risk, such as age, genetics, existence of infectious diseases, and socioeconomic factors that can affect exposure and susceptibility.

Childhood cancers are dissimilar from cancers in adults and are therefore tracked separately. They affect different anatomic sites and may be of embryonic origin. Though overall cancer incidence rates are lower in children than in adults, childhood cancers are the third leading cause of death in children age 1-19 years.[28] Children may be particularly susceptible to exposures *in utero* or during early childhood because their systems are rapidly developing and affected by evolving hormonal systems.[29] As with many adult cancers, the causes of childhood cancers are unknown for the most part; environmental influences may be a factor and have been the subject of extensive research. Environmental exposures are difficult to evaluate because cancer is rare in children and because of challenges in identifying past exposure levels, particularly during potentially important time periods such as *in utero* or maternal exposures prior to conception.[30]

Cardiovascular Disease

More than one-fourth of the U.S. population lives with a cardiovascular disease, with more than 6 million hospitalizations each year.[31] Coronary heart disease and stroke, two of the major types of cardiovascular disease, rank as the first and third leading causes of death, respectively (General Mortality indicator, p. 5-33), and are leading causes of premature and permanent disabilities. Known risk factors include smoking, high blood pressure, high blood cholesterol, diabetes, physical inactivity, and poor nutrition. Outdoor air pollution and environmental tobacco smoke are also known risk factors for cardiovascular disease. Particulate matter, for example, has been demonstrated to be a likely causal factor in both cardiovascular disease morbidity and mortality. Collective evidence from recent studies suggests excess risk associated with short-term exposures to particulate matter and hospital admissions or emergency department visits for cardiovascular effects.[32,33] Environmental tobacco smoke has been shown to be a risk factor for coronary heart disease morbidity and mortality and may contribute to stroke, though evidence is more limited.[34,35]

Respiratory Disease

Chronic obstructive pulmonary disease (COPD) and asthma are two prevalent chronic respiratory diseases in the U.S. Epidemiological and clinical studies have shown that ambient and indoor air pollution are risk factors in several respiratory health outcomes, including reported symptoms (nose and throat irritation), acute onset or exacerbation of existing disease (e.g., asthma), and deaths.[36,37] The relationship between environmental tobacco smoke and diseases of the respiratory tract has been studied extensively in humans and in animals; environmental tobacco smoke has been shown to produce a variety of upper and lower respiratory tract disorders.[38]

[26] American Cancer Society. 2005. Cancer facts and figures 2005. Atlanta. <http://www.cancer.org/downloads/STT/CAFF2005f4PWSecured.pdf>

[27] National Toxicology Program. 2004. Report on carcinogens. Eleventh edition. U.S. Department of Health and Human Services, Public Health Service. <http://ntp.niehs.nih.gov/ntp/roc/toc11.html>

[28] National Center for Health Statistics. 2004. Deaths: Final data for 2002. National Vital Statistics Reports 53(5). <http://www.cdc.gov/nchs/data/nvsr/nvsr53/nvsr53_05.pdf>

[29] Anderson, L.M., B.A. Diwan, N.T. Fear, and E. Roman. 2000. Critical windows of exposure for children's health: Cancer in human epidemiological studies and neoplasms in experimental animal models. Environ. Health. Perspect. 108(Suppl 3):573-594.

[30] National Cancer Institute. 2005. National Cancer Institute research on childhood cancers. Accessed November 2007. <http://www.cancer.gov/cancertopics/factsheet/sites-types/childhood>

[31] Centers for Disease Control and Prevention. 2005. Preventing heart disease and stroke. Addressing the nation's leading killers—at a glance. Revised August 2005.

[32] U.S. Environmental Protection Agency. 2005. Review of the National Ambient Air Quality Standards for particulate matter: Policy assessment of scientific and technical information. OAQPS Staff Paper.

[33] U.S. Environmental Protection Agency. 2004. Air quality criteria for particulate matter. Volumes I (EPA/600/P-99/002aF) and II (EPA/600/P-99/002bF). National Center for Environmental Assessment—RTP Office, Office of Research and Development.

[34] National Cancer Institute. 1999. Smoking and tobacco control monograph 10: Health effects of exposure to environmental tobacco smoke. <http://cancercontrol.cancer.gov/tcrb/monographs/10/m10_complete.pdf>

[35] U.S. Department of Health and Human Services. 2006. The health consequences of involuntary exposure to tobacco smoke: A report of the Surgeon General. Atlanta, GA. Centers for Disease Control and Prevention, Coordinating Center for Health Promotion, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health. <http://www.surgeongeneral.gov/library/secondhandsmoke/report/>

[36] U.S. Environmental Protection Agency. 2005. Review of the National Ambient Air Quality Standards for particulate matter: Policy assessment of scientific and technical information. OAQPS Staff Paper.

[37] U.S. Environmental Protection Agency. 2007. Review of the National Ambient Air Quality Standards for ozone: Policy assessment of scientific and technical information. OAQPS Staff Paper.

[38] State of California. 2005. Proposed identification of environmental tobacco smoke as a toxic air contaminant. Part B: Health effects assessment for environmental tobacco smoke. As approved by the Scientific Review Panel on June 24, 2005. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. <http://www.arb.ca.gov/regact/ets2006/ets2006.htm>

COPD is a group of diseases characterized by airflow obstruction, resulting in breathing-related symptoms and encompasses chronic obstructive bronchitis and emphysema.[39,40] COPD is the fourth leading cause of death in the U.S. and is the leading cause of hospitalization in U.S. adults, particularly in older adults. It represents a major cause of morbidity, mortality, and disability.[41] Air pollution may be an important contributor to COPD, though approximately 80 to 90 percent of COPD deaths is generally attributed to smoking.[42]

Asthma continues to receive attention in both children and adults. Asthma prevalence increased nearly 74 percent during 1980-1996.[43] During 2001-2003, an average annual 20 million people in the U.S. had asthma.[44] Environmental contaminants such as dust mites, pets, mold, and other allergens are considered important triggers for asthma.[45] In addition, the relationship between environmental tobacco smoke and diseases of the respiratory tract has been studied extensively in humans and in animals; environmental tobacco smoke has been shown to produce a variety of upper and lower respiratory tract disorders.[46]

Infectious Disease

Infectious diseases are acute illnesses caused by bacteria, protozoa, fungi, and viruses. Food and water contaminated with pathogenic microorganisms are the major environmental sources of gastrointestinal illness. Though well-established systems for reporting food- and waterborne cases exist, data reported through these largely voluntary programs must be interpreted with caution because many factors can influence whether an infectious disease is recognized, investigated, and reported. Changes in the number of cases reported could reflect actual changes or simply changes in surveillance and reporting. In addition, many milder cases of gastrointestinal illnesses go unreported or are not diagnosed, making it difficult to estimate the number of people affected every year.

The discovery of bacterial contamination of drinking water as the cause of many cases of gastrointestinal illness represents one of the great public health success stories of the 20th century. Waterborne diseases such as typhoid fever and cholera were major health threats across the U.S. at the beginning of the 20th century. Deaths due to diarrhea-like illnesses, including typhoid, cholera, and dysentery, represented the third largest cause of death in the nation at that time. These types of diarrheal deaths dropped dramatically once scientists identified the bacteria responsible, elucidated how these bacteria were transmitted to and among humans in contaminated water supplies, and developed effective water treatment methods to remove pathogens from water supplies.

In addition to being of food- or waterborne origin, infectious disease can be airborne, arthropod-borne (spread by mosquitoes, ticks, fleas, etc.), or zoonotic (spread by rodents, dogs, cats, and other animals). Legionellosis can be contracted from naturally occurring bacteria found in water and spread through poorly maintained artificial water systems (e.g., air conditioning, ventilation systems). Arthropod-borne diseases, including Lyme disease, Rocky Mountain spotted fever, and West Nile virus, can be contracted from certain ticks and mosquitoes that acquire bacteria or viruses by biting infected mammals or birds.

Birth Outcomes

Birth defects are structural or functional anomalies that present at birth or in early childhood. Birth defects cause physical or mental disability and can be fatal. They affect approximately one out of 33 babies born each year in the U.S. and remain the leading cause of infant mortality (Infant Mortality indicator, p. 5-36). Serious, adverse effects on health, development, and functional ability may be experienced by individuals born with birth defects.[47] Birth defects have been linked with a variety of possible risk factors that can affect normal growth and development—genetic or chromosomal aberrations, as well as environmental factors such as exposure to chemicals; exposure to viruses and bacteria; and use of cigarettes, drugs, or alcohol by the mother. The causes of most birth defects are unknown, but research continues to show the possible influence of environmental exposures (e.g., prenatal exposure to high levels of contaminants such as mercury or PCBs). The relationship between exposure to lower concentrations of environmental contaminants and birth defects, however, is less clear.

Low birthweight delivery and preterm birth are considered important risk factors for infant mortality and birth defects. Low birthweight infants have a significantly increased risk of infant death, and those who survive are more likely to experience long-term developmental disabilities.[48] Multiple birth babies have a low birthweight rate of more than 50 percent,

[39] Mannino, D.M. 2002. COPD epidemiology, prevalence, morbidity and mortality, and disease heterogeneity. Chest 121:121S-126S.

[40] Barnes, P.J. 2000. Chronic obstructive pulmonary disease. Review article. N. Engl. J. Med. 343(4):269-280.

[41] Mannino, D.M., D.M. Homa, L.J. Akinbami, E.S. Ford, and S.C. Redd. 2002. Chronic obstructive pulmonary disease surveillance—United States, 1971-2000. In: Surveillance Summaries. MMWR 51(SS06):1-16.

[42] American Lung Association. 2004. Chronic obstructive pulmonary disease (COPD) fact sheet. Accessed February 7, 2005. <http://www.lungusa.org/site/pp.asp?c=dvLUK9O0E&b=35020>

[43] Mannino, D.M., D.M. Homa, L.J. Akinbami, J.E. Moorman, C. Gwynn, S.C. Redd. 2002. Surveillance for asthma—United States, 1980-1999. In: Surveillance Summaries. MMWR 51(SS-1):1-13.

[44] Moorman, J.G., R.A. Rudd, C.A. Johnson, M. King, P. Minor, C. Bailey, M.R. Scalia, L.J. Akinbami. 2007. National surveillance for asthma—United States, 1980-2004. In: Surveillance Summaries. MMWR 56(SS08):1-14.

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

[46] State of California. 2005. Proposed identification of environmental tobacco smoke as a toxic air contaminant. Part B: health effects assessment for environmental tobacco smoke. As approved by the Scientific Review Panel on June 24, 2005. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. <http://www.arb.ca.gov/regact/ets2006/ets2006.htm>

[47] Centers for Disease Control and Prevention. 2006. Improved national prevalence estimates for 18 selected major birth defects—United States, 1999-2001. MMWR 54(51&52):1301-1305.

[48] National Center for Health Statistics. 2005. Health, United States, 2005, with chartbook on trends in the health of Americans. DHHS publication no. 2005-1232. Hyattsville, MD. p. 11.

compared to approximately 6 percent among singletons, among whom the low birthweight rate rose only 1 percent from 1989 to 1998.[49] To eliminate the effect that multiple births may have on birth outcomes, this report presents data for singleton births only.

Environmental exposures are being investigated for possible associations with birth outcomes such as low birthweight, preterm births, and infant mortality. Some of the risk factors for low birthweight infants born at term include maternal smoking, weight at conception, and nutrition and weight gain during pregnancy.[50] Specific examples of known or suspected environmental contaminant influences on birth outcomes include environmental tobacco smoke, lead, and air pollution. The most robust evidence exists for environmental tobacco smoke and lead.[51] Environmental tobacco smoke is associated with increased risk of low birthweight, preterm delivery, and sudden infant death syndrome.[52] Several studies have identified lead exposure as a risk factor for preterm delivery.[53] Associations between air pollution and fetal growth and infant mortality have been documented. Recent studies report significant associations between PM_{10} concentration averaged over a month or a trimester of gestation and the risk of intrauterine growth reduction and low birthweight.[54] Growing evidence shows exposure-response relationships between maternal exposures to air pollutants (e.g., sulfur dioxide and particulates) and preterm birth.[55,56] Research continues, however, in establishing causal relationships between air pollution and low birthweight and preterm birth. Researchers also continue to examine possible associations between other contaminants as birth outcome risk factors, such as pesticides, polycyclic aromatic hydrocarbons, and others.

5.4.2 ROE Indicators

EPA has selected indicators of health outcomes for which environmental exposures may be a risk factor and for which nationally representative data are available. Nine indicators were selected to address the question (Table 5-4)—two for cancer (including the leading sites of cancer in adults and children), one for cardiovascular disease (including coronary heart disease, stroke, and hypertension), two related to respiratory disease (including asthma and chronic lung conditions such as bronchitis and emphysema), one for infectious diseases (composed of multiple diseases and conditions), and three for birth outcomes.

Table 5-4. ROE Indicators of Trends in Human Disease and Conditions for Which Environmental Contaminants May Be a Risk Factor

National Indicators	Section	Page
Cancer Incidence	5.4.2	5-43
Childhood Cancer Incidence	5.4.2	5-46
Cardiovascular Disease Prevalence and Mortality (N/R)	5.4.2	5-48
Chronic Obstructive Pulmonary Disease Prevalence and Mortality (N/R)	5.4.2	5-52
Asthma Prevalence	5.4.2	5-55
Infectious Diseases Associated with Environmental Exposures or Conditions	5.4.2	5-59
Birth Defects Prevalence and Mortality	5.4.2	5-62
Low Birthweight	5.4.2	5-65
Preterm Delivery	5.4.2	5-67

N/R = National Indicator displayed at EPA Regional scale

[49] National Center for Health Statistics. 2001. Healthy people 2000 final review. Hyattsville, MD: Public Health Service. p. 208. <http://www.cdc.gov/nchs/data/hp2000/hp2k01-acc.pdf>

[50] U.S. Department of Health and Human Services. 2000. Healthy people 2010: Understanding and improving health. Second edition. Washington, DC: U.S. Government Printing Office. <http://www.health.gov/healthypeople/>

[51] Behrman, R.E., and A. Stith Butler, eds. 2007. Preterm birth: Causes, consequences, and prevention. Committee on Understanding Premature Birth and Assuring Healthy Outcomes. Institute of Medicine of the National Academies. Washington, DC: National Academies Press.

[52] State of California. 2005. Proposed identification of environmental tobacco smoke as a toxic air contaminant. Part B: Health effects assessment for environmental tobacco smoke. As approved by the Scientific Review Panel on June 24, 2005. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. <http://www.arb.ca.gov/regact/ets2006/ets2006.htm>

[53] Agency for Toxic Substances and Disease Registry. 2005. Toxicological profile for lead (update). Draft for public comment. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

[54] U.S. Environmental Protection Agency. 2005. Review of the National Ambient Air Quality Standards for particulate matter: Policy assessment of scientific and technical information. OAQPS Staff Paper.

[55] Behrman, R.E., and A. Stith Butler, eds. 2007. Preterm birth: Causes, consequences, and prevention. Committee on Understanding Premature Birth and Assuring Healthy Outcomes. Institute of Medicine of the National Academies. Washington, DC: National Academies Press.

[56] Sram, R.J., B. Binkova, J. Dejmek, and M. Bobak. 2005. Ambient air pollution and pregnancy outcomes: A review of the literature. Environ. Health Perspect. 113(4):375-382.

The indicators used to answer this question are drawn from the Centers for Disease Control and Prevention's vital statistics and surveillance data, including the CDC WONDER Mortality Database, the Summary of Notifiable Diseases, the National Center for Health Statistics' National Vital Statistics Reports and VitalStats Database, and the National Health Interview Survey, as well as the National Cancer Institute's Surveillance, Epidemiology, and End Results Database. The time frames covered generally range back to the 1970s for mortality and incidence data and to the mid-1990s for prevalence data.

In answering this question, both disease morbidity (incidence or prevalence) and mortality (resulting death) statistics are used. Depending on the health outcome of interest, both measures can provide useful insights about trends in disease. Both morbidity and mortality statistics are influenced by a number of factors, however, such as the accuracy of reporting mechanisms and issues related to access to, quality of, and advances in medical care. An overall understanding of the disease measures and associated statistics used to answer this question is important (see Box 5-3).

Where possible, the indicators provide breakouts of population subgroups, such as race, ethnicity, age, and gender. Subpopulation data are presented to the extent practicable under "What the Data Show," within text or shown in indicator figures. For cardiovascular and respiratory diseases, mortality statistics are provided for each of the 10 EPA Regions. For cancer, data for the most frequently diagnosed cancer sites in adults and children, along with overall cancer rates, are used to answer the question.

Box 5-3. Morbidity and Mortality Measures

Both morbidity and mortality can be measured using occurrences or rates. Occurrences represent frequency counts, while rates enable a comparison across populations. Rates are ratios that calculate the frequency of cases (of disease, condition, outcome) divided by the size of the defined population for a specified time period. Usually some constant (generally a multiplier of the power 10) is applied to convert the rate to a whole number.

Morbidity data are often used to describe the incidence and prevalence of a disease or condition. Both incidence and prevalence are often expressed as a rate per 1,000 persons over a particular time period. "Incidence" refers to the number of new cases of a disease or condition in a population during a specified time period. "Prevalence" refers to the total number of people with a given disease or condition in a population at a specified point in time.

Mortality is generally expressed as a rate and is defined as the proportion of the population who die of a disease or condition during a specified time period. The rate is usually calculated for a calendar year and is often expressed per 100,000 persons.

Incidence, prevalence, and mortality statistics can be used to compare the rates of disease at two or more points in time, across different populations (ages, gender, racial/ethnic groups), or between different geographic areas. In general, disease incidence, prevalence, and mortality increase with age. For this reason, when comparing different populations, the data must be adjusted to account for the age differences between the populations. The adjusted data, called "age-adjusted rates," are used where possible in answering this question. Age-adjusted rates are weighted sums of age-specific rates and calculated using standard population factors. (In this report, the 2000 U.S. standard population was used.) Unadjusted rates are referred to as "crude" rates.

INDICATOR | Cancer Incidence

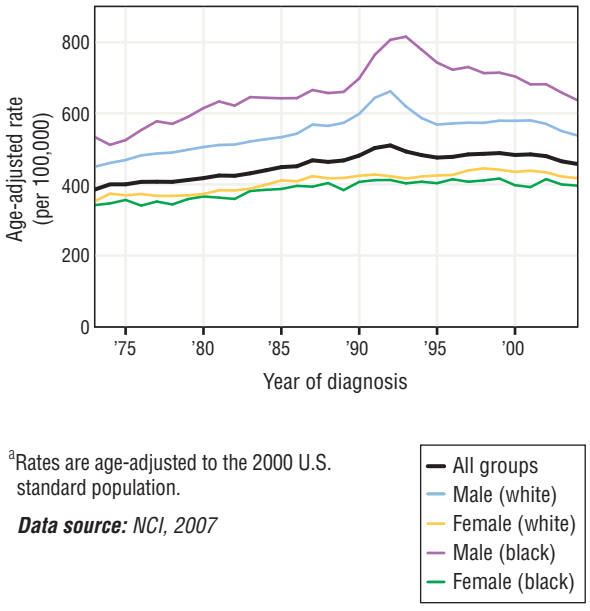
The term "cancer" is used to characterize diseases in which abnormal cells divide without control. A cancerous cell loses its ability to regulate its own growth, control cell division, and communicate with other cells. Cancer cells can invade nearby tissues and can spread through the bloodstream and lymphatic system to other parts of the body (NCI, n.d.). The risk of developing cancer increases with age. Environmental exposures, genetic predisposition, certain viruses, and socioeconomic factors may all play a role in the development and progression of the disease.

For the U.S. population, age-adjusted cancer incidence rates for all sites combined have been stable since 1992 (Edwards et al., 2005). Nevertheless, cancer continues to be the second leading cause of death in the U.S., accounting for about 23 percent of all deaths in 2004 (General Mortality indicator, p. 5-33) (NCHS, 2007). Many different types of cancer exist. These can develop in various organs and tissues within the body and contributing causal factors can vary depending on the cancer site and type. Therefore, tracking rates for individual cancer sites is more meaningful when evaluating cancer trends.

Many factors are known to contribute, or suspected of contributing, to cancer risk. Factors including individual food and beverage preferences, use of tobacco products, exposure to natural and medical radiation (including sunlight), workplace exposures, and pharmaceutical use as well as exposure to substances in the air, water and soil all may contribute individually (i.e., additively) or synergistically

INDICATOR | Cancer Incidence *(continued)*

Exhibit 5-17. Age-adjusted cancer incidence rates in the U.S., 1973-2004: All cancer sites for all ages, by race and sex[a]



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

Data source: *NCI, 2007*

(i.e., producing an effect greater than the sum of each factor acting alone) to the development of cancer (NTP, 2004). Further, the cancer hazard to any individual is dependent on the amount and duration of exposure and the individual's susceptibility to a particular substance. Only in a small number of cases is it known what specific exposures or conditions are responsible for the onset and development of cancers (NTP, 2004).

This indicator presents cancer incidence rates for the U.S. population using data collected through the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program. The SEER Program collects and publishes cancer incidence and survival data from 14 population-based cancer registries and three supplemental registries covering approximately 26 percent of the U.S. population. The 10 most commonly diagnosed cancer sites presented are based on 2004 data compiled from SEER. Site classifications (e.g., lung and bronchus, colon and rectum) were compared to the American Cancer Society's "leading sites" classification to ensure consistency in how data are presented (ACS, 2004).

What the Data Show

Although a slow steady increase in cancer incidence occurred between 1973 and 1992, peaking in 1992 with an age-adjusted cancer incidence of 510 cases per 100,000,

Exhibit 5-18. Age-adjusted cancer incidence rates in the U.S., 2004: Ten leading cancer sites by sex[a]

Percent of all cancers	Rate[b]	Male	Female	Rate[b]	Percent of all cancers
29.9	159.5	Prostate	Breast	124.3	30.7
13.8	73.6	Lung and bronchus	Lung and bronchus	50.2	12.4
10.6	56.7	Colon and rectum	Colon and rectum	41.7	10.3
6.8	36.3	Urinary bladder	Corpus uteri	23.9	5.9
4.6	24.7	Non-Hodgkin's lymphoma	Non-Hodgkin's lymphoma	17.1	4.2
4.5	24.1	Melanoma of the skin	Melanoma of the skin	16.5	4.1
3.3	17.8	Kidney and renal pelvis	Thyroid	14.4	3.6
2.9	15.5	Oral cavity and pharynx	Ovary	12.6	3.1
2.9	15.4	Leukemia	Pancreas	9.8	2.4
2.5	13.3	Pancreas	Urinary bladder	9.1	2.2
18.2	NC[c]	All other sites	All other sites	NC[c]	21.1

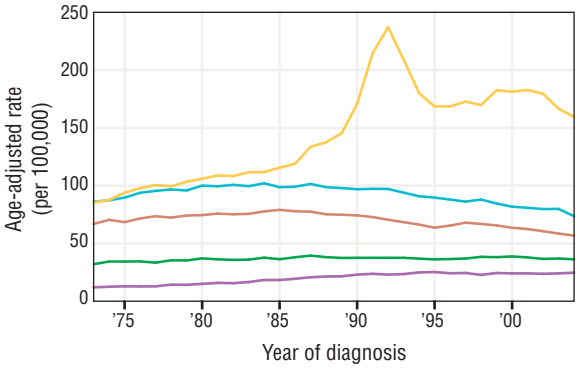
[a]Excludes basal and squamous cell skin cancers and in situ carcinoma, except urinary bladder.

[b]Rates are per 100,000 and age-adjusted to the 2000 U.S. standard population.

[c]NC = not calculated

Data source: *NCI, 2007*

Exhibit 5-19. Age-adjusted cancer incidence rates in the U.S., 1973-2004: Top five cancers in males of all ages[a]

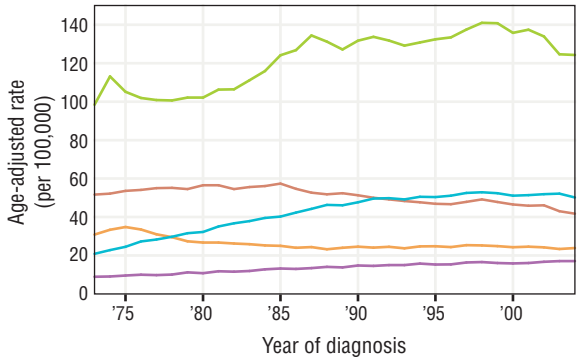


[a]Rates are age-adjusted to the 2000 U.S. standard population.

Data source: *NCI, 2007*

- Colon and rectum
- Lung and bronchus
- Non-Hodgkin's lymphoma
- Prostate
- Urinary bladder

Exhibit 5-20. Age-adjusted cancer incidence rates in the U.S., 1973-2004: Top five cancers in females of all ages[a]



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

Data source: *NCI, 2007*

- Breast
- Colon and rectum
- Corpus uteri
- Lung and bronchus
- Non-Hodgkin's lymphoma

overall incidence rates appear to have stabilized over the last 10 years (Exhibit 5-17). Some differences exist in incidence rates across age, gender, and racial groups. During 2004, those age 65 and older had the highest incidence rates (2,102.4 cases per 100,000) compared to all other age categories (data not shown). Total (all sites combined) cancer incidence rates are higher for males compared to females and for black males compared to white males (Exhibit 5-17). The age-adjusted cancer incidence rate in 2004 for black males was 637.2 cases per 100,000 compared to 537.9 cases per 100,000 for white males; among females, the age-adjusted cancer incidence rate in 2004 was 417.9 cases per 100,000 for white females compared to 396.6 cases per 100,000 among black females.

Exhibit 5-18 shows the differences between the top 10 cancer sites in males and females. For both, the top three cancers represent over half of all newly identified cancer cases in 2004. Among the most notable differences is the rate of urinary bladder cancer among males (36.3 cases per 100,000), which is nearly four times that of females (9.1 cases per 100,000). Melanoma of the skin is also higher among males (24.1 cases per 100,000) than females (16.5 cases per 100,000). Thyroid cancer appears as the seventh leading cancer in females (14.4 cancers per 100,000), but is not among the top 10 for males (5.1 cases per 100,000).

Among males, prostate cancer incidence rates increased dramatically between 1986 and the early 1990s, with a decline in rates between 1992 and 1995. This increase is likely due to the introduction of serum prostate-specific antigen testing for the early detection and screening of prostate cancer (Hankey et al., 1999). The other four leading cancers (colon and rectum, lung and bronchus, urinary bladder, and non-Hodgkin's lymphoma) have either been relatively stable or have showed a small decline over the last decade (Exhibit 5-19).

Recent trends (i.e., since 1995) among the less prevalent site-specific cancers in males show small increases in the incidence rates for melanoma of the skin (melanoma), which ranged from 20.2 (1995) to 24.2 (2001) cases per 100,000, and cancers of the kidney and renal pelvis (kidney), which ranged from 15.1 (1997) to 17.8 (2003, 2004) cases per 100,000. Overall, slightly decreasing rates were observed for leukemia, which ranged from 17.6 (1995) to 15.4 (2004) cases per 100,000, and cancers of the oral cavity and pharynx (oral cavity), which ranged from 17.7 (1996) to 15.3 (2001, 2003) cases per 100,000. (Data not shown.)

As shown in Exhibit 5-20, among females, breast cancer remains the leading cancer and rates have generally increased for much of the reporting period. While lung cancer among males has slowly declined over the past decade, the rate among women has generally increased over time and is the second leading cancer among men and women in 2004. The incidence rate of colon cancer among women increased between 1973 and 1985 and has slowly declined since. The incidence of uterine (corpus uteri) cancer in females was relatively stable since 1986, with a small decrease in more recent years, ranging from 25.4 (1997) to 23.3 (2003) cases per 100,000. The incidence rate of non-Hodgkin's lymphoma has exhibited a slow increase since 1973.

INDICATOR | Cancer Incidence *(continued)*

Recent trends in cancer incidence rates among the less prevalent site-specific cancers in females showed increases for melanoma, which ranged from 13.7 (1995) to 16.5 (2004) cases per 100,000 and thyroid cancer, which ranged from 8.9 (1995) to 14.4 (2004) cases per 100,000. Incidence rates decreased for cancers of the ovary, which ranged from 14.7 (1997) to 12.6 (2004) cases per 100,000. (Data not shown.)

Indicator Limitations

- SEER data cover approximately 26 percent of the U.S. population, though it is designed to be representative of the entire U.S. population.
- Incidence data generated from SEER are updated annually. There may be changes in the numerator (e.g., revised counts of newly identified cases) or denominator (i.e., revised population counts) numbers that result in small changes in the overall incidence rates for the same year, depending on when a query is run within the SEER database. For example, the SEER database queried in 2005 generating incidence rates for the year 2000 may provide different incidence rates than the database queried in 2004 for the year 2000.

Data Sources

Cancer incidence data for this indicator were obtained by querying the National Cancer Institute's SEER Program database through the Cancer Query Systems Web-based interface (NCI, 2007), available at http://www.seer.cancer.gov/canques/incidence.html.

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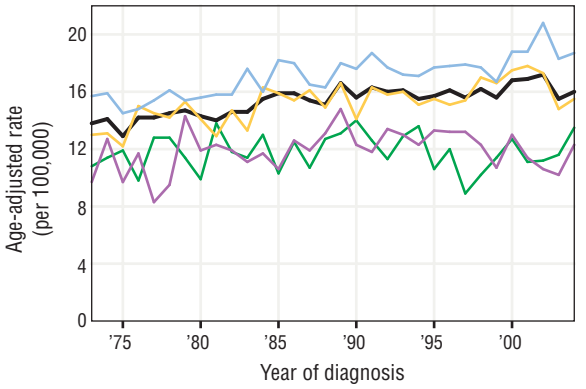
INDICATOR | Childhood Cancer Incidence

The term "cancer" is used to characterize diseases in which abnormal cells divide without control. A cancerous cell loses its ability to regulate its own growth, control cell division, and communicate with other cells. If left unchecked, cancer cells can invade nearby tissues and can spread through the bloodstream and lymphatic system to other parts of the body. The cellular changes caused by cancer cells are complex and occur over a period of time. This may be accelerated in children. The classification of cancers in children differs from the classification used for adult cancers. The International Classification of Childhood Cancer classifies childhood cancer based on tumor morphology rather than, as for adults, the site of the tumor (NCI, 2004).

The causes of childhood cancers are largely unknown. Only a small percentage of cases can be explained by a few conditions such as specific chromosomal/genetic abnormalities (e.g., Down's syndrome) and ionizing radiation exposure (NCI, 2005). Environmental exposures have long been suspected of increasing the risk of certain childhood cancers. Researchers continue to examine environmental influences on childhood cancer (NCI, 2005).

This indicator presents incidence rates for childhood cancers using data collected through the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program. The SEER Program collects and publishes cancer incidence and survival data from 14 population-based cancer

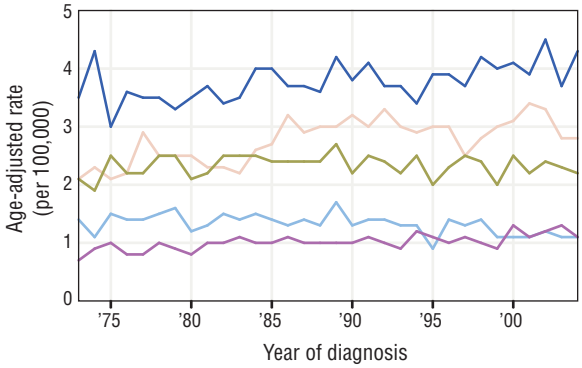
Exhibit 5-21. Age-adjusted cancer incidence rates in the U.S., 1973-2004: All cancer sites for ages 0-19, by race and sex[a]



[a]Rates are age-adjusted to the 2000 U.S. standard population, age 0-19 years.

Data source: *NCI, 2007*

Exhibit 5-22. Age-adjusted cancer incidence rates in the U.S., 1973-2004: Top five cancers for ages 0-19[a]



[a]Rates are age-adjusted to the 2000 U.S. standard population, age 0-19 years.

Data source: *NCI, 2007*

registries and three supplemental registries covering approximately 26 percent of the U.S. population.

What the Data Show

In general, overall childhood (ages 0-19 years) cancer incidence for the U.S. has increased slightly between 1973 and 2004 (Exhibit 5-21), increasing over time from an age-adjusted incidence rate of 13.8 per 100,000 in 1973 to a high of 17.2 per 100,000 in 2002. A rate of 16.0 per 100,000) was reported in 2004. Males generally had higher rates than females, although for some years the reverse was true. Incidence among black females and males age 0-19 years was lower than among white females and males. In 2004, black females and males age 0-19 years had overall incidence rates of 13.5 and 12.3 per 100,000, respectively, compared to white females and males with rates of 15.5 and 18.7 per 100,000 (Exhibit 5-21).

Exhibit 5-22 presents the age-adjusted incidence rates for the top five cancers among children 0-19 years of age between 1973 and 2004. In general, there are no clearly identifiable trends among any of the top five cancers over the reported time period. Leukemia continues to be the most frequently diagnosed cancer in children age 0-19 years.

Indicator Limitations

- SEER data cover approximately 26 percent of the U.S. population, though it is designed to be representative of the entire U.S. population.
- Incidence data generated from SEER are updated annually. There may be changes in the numerator (e.g., revised counts of newly identified cases) or denominator (i.e., revised population counts) numbers that result in small changes in the overall incidence rates for the same year, depending on when a query is run within the SEER database. For example, the SEER database queried in 2005 generating incidence rates for the year 2000 may provide different incidence rates than the database queried in 2004 for the year 2000.

Data Sources

Cancer incidence data for this indicator were obtained by querying the National Cancer Institute's SEER Program database through the Cancer Query Systems Web-based interface (NCI, 2007), available at http://www.seer.cancer.gov/canques/incidence.html.

References

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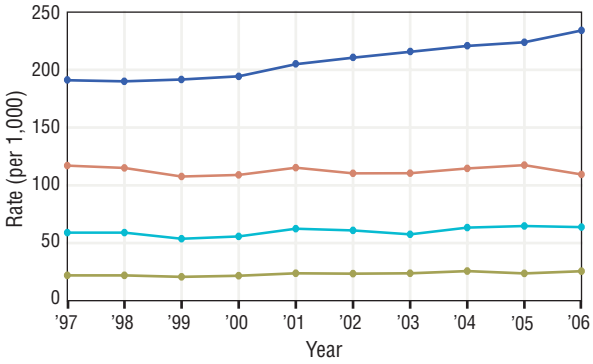
INDICATOR | Cardiovascular Disease Prevalence and Mortality

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, p. 5-33). 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.

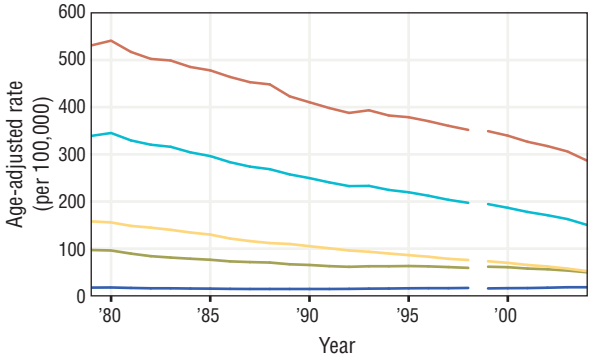
Exhibit 5-23. Cardiovascular disease prevalence in U.S. adults (age 18 and older), 1997-2006[a]



[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

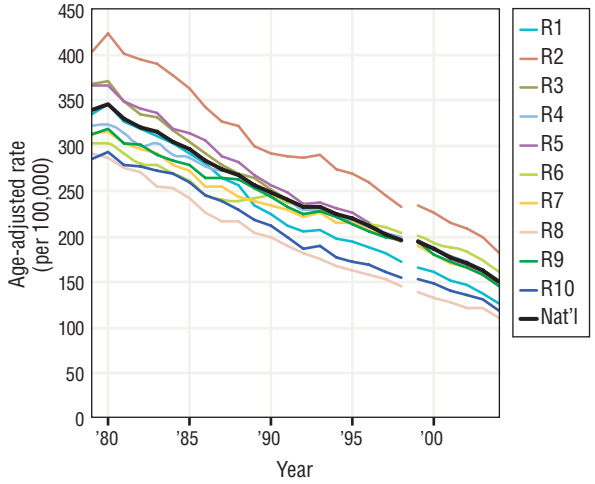
Among adults 18 years and older, the prevalence of heart disease and stroke between 1997 and 2006 has remained essentially the same (Exhibit 5-23). In contrast, the prevalence of hypertension has shown an increase from 191.6 cases per 1,000 in 1999 to 234.1 cases per 1,000 in 2006.

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 (1999-2004)].

[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.

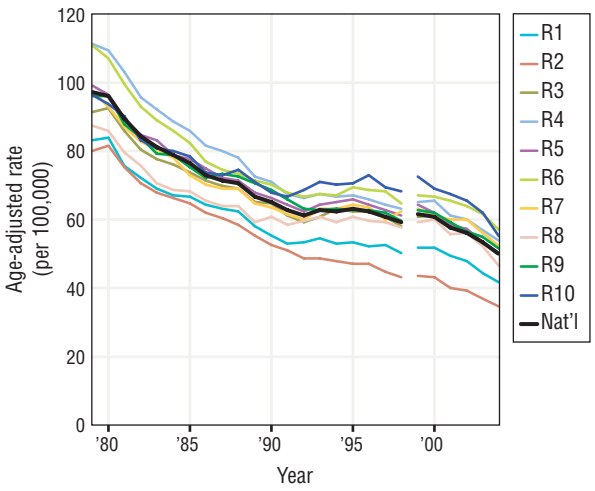
Differences exist in CVD mortality rates among gender, racial, and age groups. For example, in 2004, those age 65 and older had the highest CVD (all types), coronary heart disease, and stroke mortality (1,898.7, 990.8, and 346.2 per 100,000, respectively). For the same year, the age-adjusted CVD, coronary 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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NCHS. 2003. Summary health statistics for U.S. adults: National Health Interview Survey, 2001. Vital Health Stat. 10(218). <http://www.cdc.gov/nchs/data/series/sr_10/sr10_218.pdf>

NCHS. 2002. Summary health statistics for U.S. adults: National Health Interview Survey, 2000. Vital Health Stat. 10(215). <http://www.cdc.gov/nchs/data/series/sr_10/sr10_215.pdf>

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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 non-institutionalized 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.

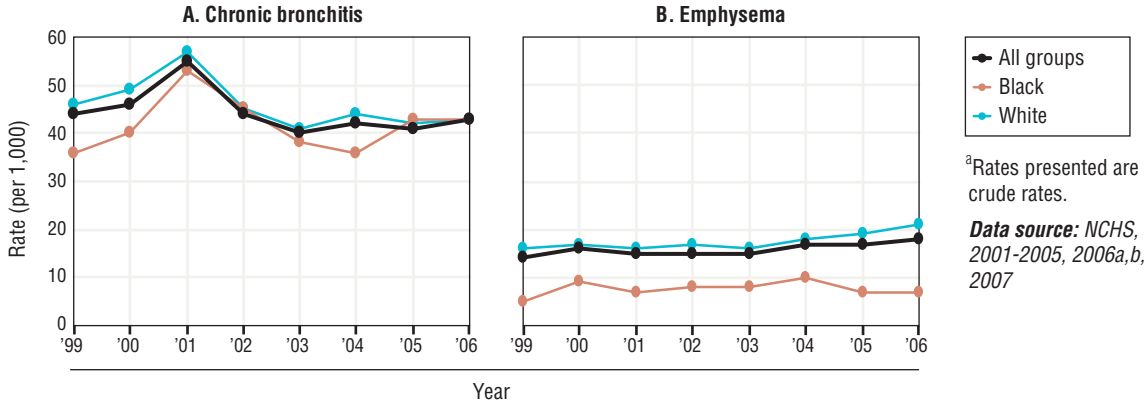
What the Data Show

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

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*

emphysema diseases than 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 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.)

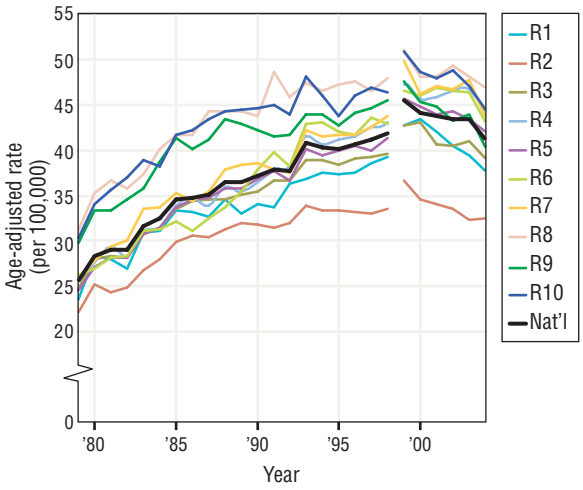
COPD Mortality

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, p. 5-33). 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.

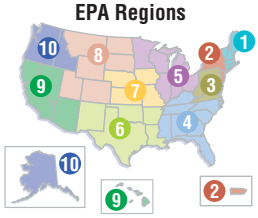
COPD age-adjusted mortality rates have been declining for males over time, with a rate of 58.7 per 100,000 in 1999 compared to 49.5 per 100,000 in 2004. For females, the rates are lower than males and have been relatively stable between 1999 and 2004 (37.7 and 36.0 per 100,000, respectively). The COPD 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

INDICATOR Chronic Obstructive Pulmonary Disease Prevalence and Mortality *(continued)*

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 | Asthma Prevalence

Asthma is a chronic respiratory disease characterized by inflammation of the airways and lungs. During an asthma attack, the airways that carry air to the lungs are constricted, and as a result, less air is able to flow in and out of the lungs (NHLBI, 2004). Asthma attacks can cause a multitude of symptoms ranging in severity from mild to life-threatening. These symptoms include wheezing, breathlessness, chest tightness, and coughing (NHLBI, 2004). Currently, there is no cure for asthma; however, people who have asthma can still lead productive lives if they control their asthma. Taking medication and avoiding contact with environmental "triggers" can control asthma.

A family history of asthma contributes to susceptibility, but mostly what causes the development of asthma is unknown. Environmental exposures such as environmental tobacco smoke, dust mites, cockroach allergen, outdoor air pollution (e.g., ozone, particulate matter), pets, and mold are considered important triggers of an asthma attack (CDC, 2003, 2004; U.S. EPA, 2005, 2007).

Statistics for lifetime diagnosis prevalence, current asthma prevalence, and asthma attack prevalence are based on national estimates 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. For this indicator, lifetime asthma diagnosis is defined as the number of adults/children who reported that they had ever been told by a doctor or other health practitioner that they had asthma. To determine current asthma prevalence, adults/children who had been told that they had asthma were asked whether they still have asthma. Asthma attack prevalence is based on the number of adults/children who reported an asthma episode or attack in the past 12 months.

What the Data Show

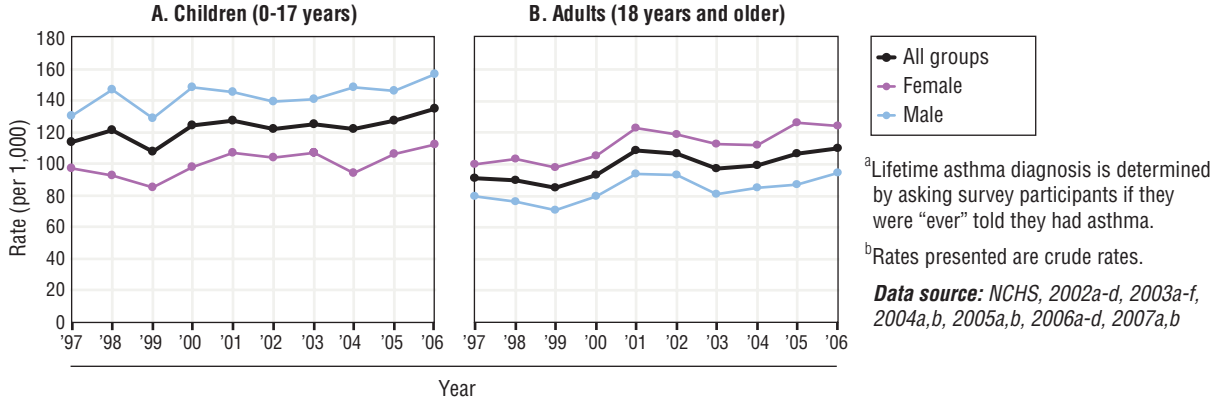
From 2003 to 2005, approximately 7.3 percent of the U.S. population reported that they currently have asthma (NCHS, 2007c). Reported asthma rates are highest in the child and adolescent population.

Adult Asthma

In adults, an increase in asthma prevalence rates (i.e., lifetime diagnosis) is evident from 1997 to 2001, with some decrease after 2001 and subsequent increase after 2003 (Exhibit 5-29, panel B). The prevalence rates range from a low of 85 cases per 1,000 in 1999 to a high of 110 cases per 1,000 in 2006. Asthma was consistently higher among adult females than males, with a range of 98 (1999) and 126 (2005) cases per 1,000 in females and 71 (1999) and 95 (2006) cases per 1,000 in males. The asthma prevalence rate also consistently decreases in older populations. In 2006, the asthma prevalence rates were 115 (ages 18-44 years), 105 (ages 45-64), 117 (ages 65-74 years), and 93 (ages 75+ years) cases per 1,000 (data not shown).

Exhibit 5-30 compares asthma rates across racial and ethnic groups for the 2003-2005 time period. As shown in panel A, the lifetime asthma diagnosis in adults was highest among American Indians/Alaska Natives (131 cases per 1,000), followed by blacks or African Americans (112 cases per 1,000), whites (100 cases per 1,000), and lowest among Asians (72 cases per 1,000). This same general pattern is seen for current asthma and asthma attack prevalence. Panel B shows that Hispanics or Latinos had lower rates across all three asthma prevalence categories than non-Hispanic whites and non-Hispanic blacks. For lifetime asthma diagnosis, 77 cases per 1,000 were reported in Hispanics or Latinos, 106 cases per 1,000 in non-Hispanic whites, and 111 cases per 1,000 in non-Hispanic blacks.

Exhibit 5-29. Estimated lifetime asthma diagnosis prevalence in children and adults in the U.S., 1997-2006[a,b]



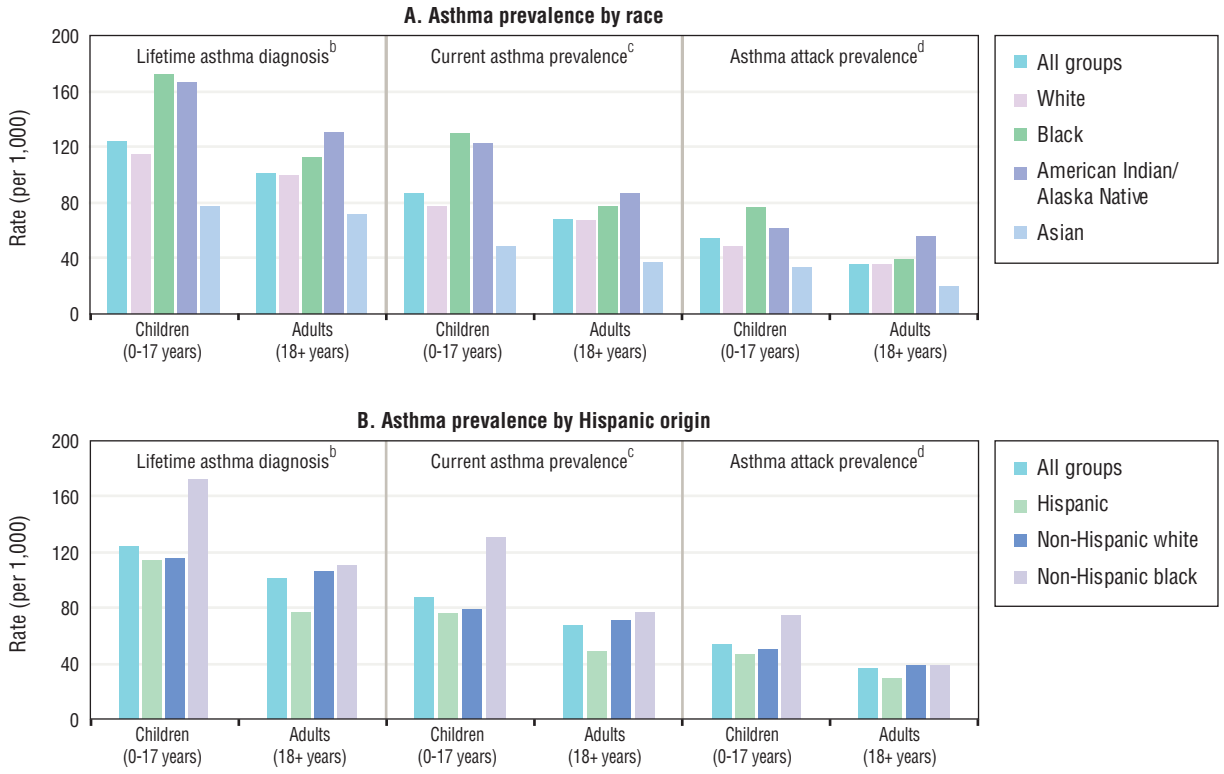
[a]Lifetime asthma diagnosis is determined by asking survey participants if they were "ever" told they had asthma.

[b]Rates presented are crude rates.

Data source: *NCHS, 2002a-d, 2003a-f, 2004a,b, 2005a,b, 2006a-d, 2007a,b*

INDICATOR | Asthma Prevalence *(continued)*

Exhibit 5-30. Asthma prevalence in the U.S. by race and Hispanic origin, 2003-2005[a]



[a]Rates presented for age 0-17 are crude rates; rates presented for age 18 and older are age-adjusted.

[b]Lifetime asthma diagnosis is determined by asking survey participants if they were "ever" told that they had asthma.

[c]Current asthma prevalence is determined by asking if the survey participant still has asthma.

[d]Asthma attack prevalence is determined by asking if the survey participant has had an asthma attack within the past 12 months.

Data source: *NCHS, 2007c*

Childhood Asthma

In 2006, almost 10 million children within the U.S. (age 0-17 years) were reported as ever having a diagnosis of asthma and nearly 4 million reported experiencing an asthma episode or attack during the previous 12 months. As shown in Exhibit 5-31, asthma prevalence rates increased approximately 4 percent per year between 1980 and 1996. Rates in subsequent years (1997-2006), reported in three categories, show no sharp upward or downward change through most of the time period, although an increase in current and lifetime reported asthma rates was observed in 2005 and 2006. Lifetime asthma diagnosis rates range from a low of 108 cases per 1,000 in 1999 to a high of 135 cases per 1,000 in 2006. Since tracking began in 2001, current asthma prevalence has ranged from approximately 83.4 cases per 1,000 (2002) to 93 cases per 1,000 (2006). Between 1997 and 2006, asthma attack prevalence rates have varied, with the lowest rate of 52.0 per 1,000 occurring in 2005 and the highest rate of 57.7 cases per 1,000 occurring in 2002. Male children consistently had higher rates of asthma prevalence than female children (Exhibit 5-29, panel A).

The overall pattern of asthma prevalence across races in children during 2003-2005 is similar to that seen in adults (Exhibit 5-30). One notable exception is that asthma prevalence in black or African American children was higher than asthma prevalence in American Indian/ Alaska Native children, the reverse of what was observed in the adult population. For example, reported lifetime asthma diagnosis was highest among black or African American children (172 cases per 1,000), followed by American Indians/Alaska Natives (166 cases per 1,000), whites (114 cases per 1,000), and Asians (78 cases per 1,000). Hispanic children had lower asthma prevalence rates for all three categories than non-Hispanic white and non-Hispanic black children.

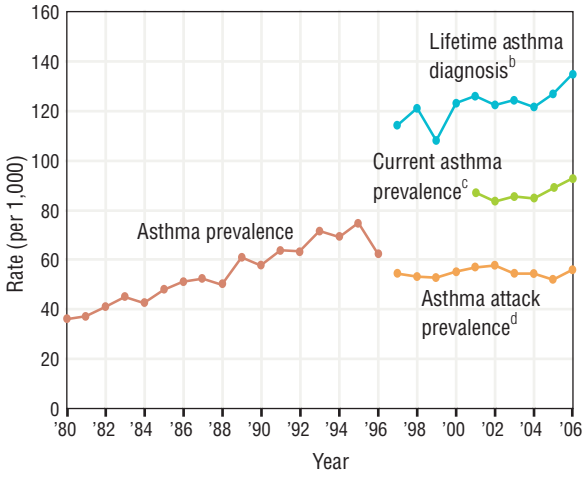
Indicator Limitations

- The NHIS questionnaire underwent major changes in 1997, and the data presented focus on surveys conducted from 1997 to the most currently available release (2004). The redesigned NHIS is different in content, format, and mode of data collection from earlier versions of the survey. Due to changes in methodology, comparisons between 1997–2004 NHIS estimates and pre-1997 NHIS data may not be valid.
- Prevalence data reported in the NHIS are based on self-reported responses to specific questions pertaining to airway-related illnesses, and are subject to the biases associated with self-reported data. Self-reported data may underestimate the disease prevalence being measured if, for whatever reason, the respondent is not fully aware of his/her condition.
- Except where otherwise noted, 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.

Data Sources

Asthma prevalence data were obtained from annual reports published by NCHS (NCHS, 2002a–d; 2003a–f; 2004a,b; 2005a,b; 2006a–d; 2007a,b), which summarize health statistics compiled from the NHIS (http://www.cdc.gov/nchs/products/pubs/pubd/series/ser.htm#sr10). Race and ethnicity data were obtained from CDC's online "Health Data for All Ages" (NCHS, 2007c) (http://www.cdc.gov/nchs/health_data_for_all_ages.htm). The data used by CDC to create the asthma tables in "Health Data for All Ages" originate from the NHIS. The pre-1997 data also originate from the NHIS, as compiled by NCHS in Akinbami (2006).

Exhibit 5-31. Asthma prevalence in U.S. children (0-17 years), 1980-2006[a]



[a]Due to changes in NHIS questions in 1997, asthma prevalence data collected from 1980-1996 are not directly comparable to the data collected from 1997-2004.

[b]Lifetime asthma diagnosis is determined by asking survey participants if they were "ever" told their child has asthma.

[c]Current asthma prevalence is determined by asking if the child still has asthma.

[d]Asthma attack prevalence is determined by asking if the child has had an asthma attack within the past 12 months.

Data source: *Adapted from Akinbami, 2006; NCHS, 2007b*

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INDICATOR | Asthma Prevalence *(continued)*

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NCHS. 2003d. Summary health statistics for U.S. children: National Health Interview Survey, 2000. Vital Health Stat. 10(213). <http://www.cdc.gov/nchs/data/series/sr_10/sr10_213.pdf>

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INDICATOR | Infectious Diseases Associated with Environmental Exposures or Conditions

Infectious diseases are human illnesses caused by viruses, bacteria, parasites, fungi, and other microbes. They can be spread by direct contact with an infected person or animal, through ingestion of contaminated food or water, by insects like mosquitoes or ticks (disease vectors), or by contact with contaminated surroundings like animal droppings or contaminated air. Demographic and environmental factors such as population growth, increased urbanization, and alteration of habitats of disease-carrying insects and animals (e.g., irrigation, deforestation) may promote the spread of infectious diseases (CDC, 1998a). The three broad infectious disease categories included here are those whose appearance and spread may be influenced to some extent by environmental conditions and change. They include gastrointestinal (GI) disease, arthropod-borne disease, and legionellosis.

- **Gastrointestinal diseases.** Eight notifiable GI diseases caused by microorganisms are discussed below: cholera, cryptosporidiosis, *Escherichia coli (E. coli)* O157:H7, giardiasis, hepatitis A, salmonellosis, shigellosis, and typhoid fever. The major environmental source of gastrointestinal illness is water or food that is contaminated with pathogenic microorganisms. The primary means of transmission for these eight diseases is through ingestion of contaminated food/water or through contact with and accidental ingestion of fecal matter (CDC, 2005a).
- **Arthropod-borne diseases.** Three arthropod-borne diseases are included: Lyme disease (transmission of *Borrelia burgdorferi* by ticks), Rocky Mountain spotted fever (transmission of *Rickettsia rickettsii* by ticks), and West Nile virus (transmitted by mosquitoes). Certain ticks and mosquitoes (arthropods) can carry bacteria and viruses that cause disease in humans. The arthropods acquire the bacteria or viruses when they bite an infected mammal or bird. Some studies indicate that spread of vector-borne disease may be influenced by land use and/or other environmental change (CDC, 2004). In recent years, both Lyme disease and West Nile virus have spread across the U.S. (CDC, 1993, 2000, 2004). Surveillance for Lyme disease was initiated by the Centers for Disease Control and Prevention (CDC) in 1982 (CDC, 1993).
- **Legionellosis.** Legionellosis, or Legionnaires' disease, is a serious and sometimes fatal form of pneumonia. It is caused by *Legionella* bacteria, which are found naturally in the environment and thrive in warm water and warm damp places. They are commonly found in lakes, rivers, creeks, hot springs, and other bodies of water. This bacterium has been associated with outbreaks in the U.S. linked to poorly maintained artificial water systems (e.g., air conditioning and industrial cooling systems) and air ventilation systems. Infection results from inhalation of contaminated water sprays or mists (CDC, 2003a).

This indicator reflects occurrence of these notifiable diseases as reported by health departments to the National Notifiable Diseases Surveillance System (NNDSS). A notifiable disease is one for which regular, frequent, and timely information regarding individual cases is considered necessary for the prevention and control of the disease (CDC, 2005b). Data are collected by all 50 states, five territories, New York City, and the District of Columbia, based on a list of recommended nationally notifiable infectious diseases, and compiled nationally. The temporal coverage of the data varies by disease. The number of states reporting may also vary. For example, in 1995, when cryptosporidiosis was first nationally reported, only 27 states reported; 45 states reported this disease by 1997.

What the Data Show

Gastrointestinal Diseases

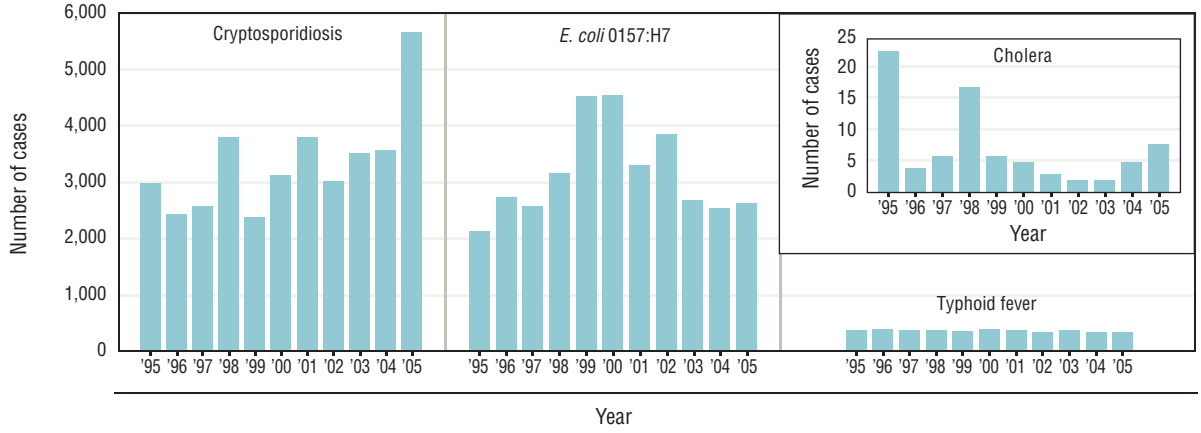
Exhibits 5-32 and 5-33 present the number of reported cases for each of the eight notifiable GI diseases from 1995-2005. In comparison to the other GI diseases, the number of newly identified cholera cases reported each year is low. From 1995 to 2005, just 81 laboratory-confirmed cases of cholera were reported to CDC, with eight cases being reported in 2005, the most current reporting year. Of these 81 total cases, 51 (63 percent) were acquired outside the U.S. The number of newly identified cases of typhoid fever was relatively stable from 1995 to 2005, ranging between a low of 321 cases in 2002 and a high of 396 cases in 1996. In 2005, 324 cases of typhoid fever were reported. Hepatitis A has continued to decline, with 31,582 cases reported in 1995 compared to 4,488 cases in 2005. The number of reported cryptosporidiosis cases increased in 2005 (5,659 cases). Fewer shigellosis cases were reported in 2004 and 2005 than in preceding years. No notable changes in the number of cases were observed for *E. coli* O157:H7, giardiasis (only 4 years of reporting data available), and salmonellosis.

Arthropod-Borne Diseases

Exhibit 5-34 presents the number of reported cases for three arthropod-borne diseases. Lyme disease is the most commonly reported arthropod-borne disease in the U.S., with 23,305 cases reported in 2005, just under the record number reported in 2002 (23,763 cases). CDC began surveillance of Rocky Mountain spotted fever in 1970. The number of new cases of Rocky Mountain spotted fever reported from 1995 to 2005 has fluctuated, ranging between a low of 365 cases in 1998 and a high of 1,936 cases in 2005. Cases of West Nile virus were first documented in the U.S. in 1999. A total of 80 cases were reported in 1999 (62 cases) and 2000 (18 cases) (data not shown). West Nile virus became nationally reportable in 2002, and the number of reported cases rose from 2,840 in

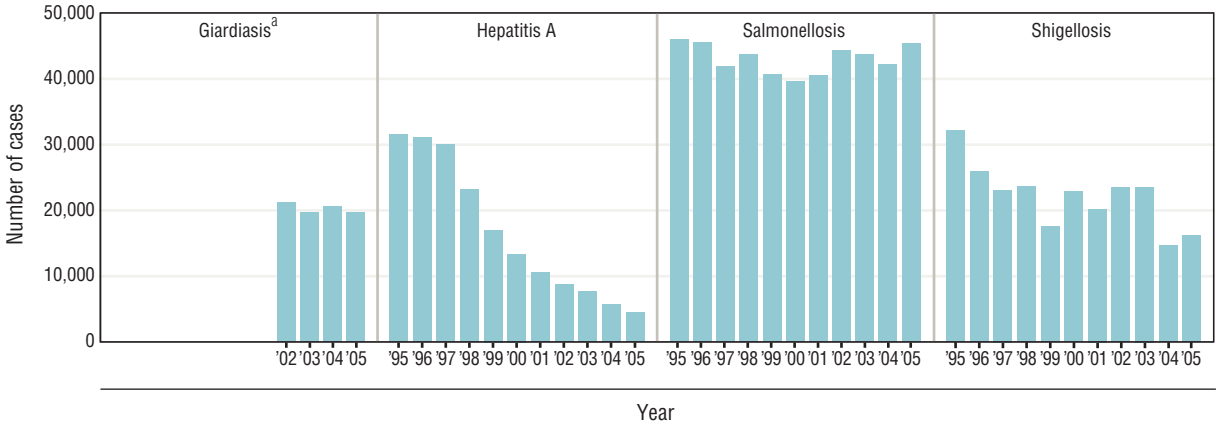
INDICATOR | Infectious Diseases Associated with Environmental Exposures or Conditions *(continued)*

Exhibit 5-32. Number of reported cases of gastrointestinal diseases in the U.S., 1995-2005 (part 1)



Data source: *CDC, 1996, 1997, 1998b, 1999, 2001, 2002, 2003b, 2004, 2005b, 2006, 2007*

Exhibit 5-33. Number of reported cases of gastrointestinal diseases in the U.S., 1995-2005 (part 2)



[a]Giardiasis was not on CDC's list of nationally notifiable infectious diseases prior to 2002.

Data source: *CDC, 1996, 1997, 1998b, 1999, 2001, 2002, 2003b, 2004, 2005b, 2006, 2007*

2002 to 2,866 in 2003. In 2004, the number of reported cases decreased to 1,142; the number increased to 1,309 reported cases in 2005.

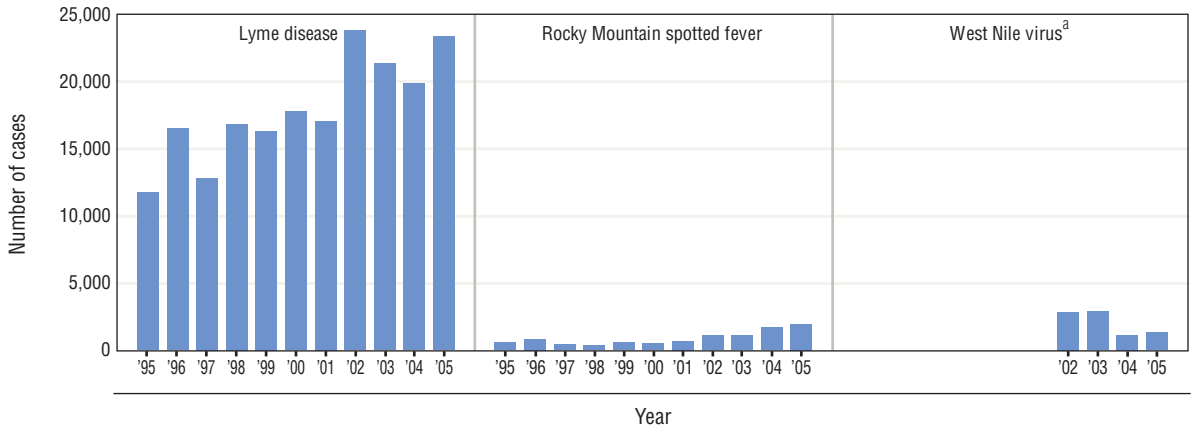
Legionellosis

Exhibit 5-35 presents the number of reported cases of legionellosis within the U.S. population from 1995 to 2005. From 1995 to 2002, the number of new cases of legionellosis was relatively stable, ranging from a low of 1,108 cases in 1999 to 1,355 cases in 1998. However, an increased number of new cases was reported in 2003 (2,232), 2004 (2,093), and 2005 (2,301).

Indicator Limitations

- State health departments report cases of notifiable diseases to CDC; policies for reporting can vary by disease or reporting jurisdiction.
- Disease reporting likely underestimates the actual number of cases for a given time period because reporting nationally notifiable diseases to CDC is voluntary. Additionally, the completeness of reporting likely varies by disease. The degree of completeness of data reporting is influenced by many factors such as the diagnostic facilities available, the control measures in effect, public awareness of a specific

Exhibit 5-34. Number of reported cases of arthropod-borne diseases in the U.S., 1995-2005



[a]West Nile virus was not on CDC's list of nationally notifiable infectious diseases prior to 2002.

Data source: *CDC, 1996, 1997, 1998b, 1999, 2001, 2002, 2003b, 2004, 2005b, 2006, 2007*

disease, and the interests, resources, and priorities of state and local officials responsible for disease control and public health surveillance (CDC, 2007).

- Factors such as changes in case definitions for public health surveillance, introduction of new diagnostic tests, or discovery of new disease entities can cause changes in disease reporting that are independent of the true incidence of disease (CDC, 2004).
- Prior to 2005, only confirmed "neuroinvasive" cases of West Nile virus—the most severe form of the condition—were reported (CDC, 2005c). Beginning in 2005, non-neuroinvasive domestic arboviral diseases for the six domestic arboviruses listed were added to the list of nationally notifiable diseases; these included West Nile fever, a non-neuroinvasive form of West Nile virus (CDC, 2007). In order to maintain reporting consistency, only neuroinvasive cases are presented for this indicator.

Data Sources

The data for this indicator were obtained from CDC annual reports that summarize data on nationally notifiable infectious diseases reported to CDC by state health agencies across the country (CDC, 1996, 1997, 1998b, 1999, 2001, 2002, 2003b, 2004, 2005b, 2006, 2007). Data are collected and compiled from reports sent by state health departments to the NNDSS, which is operated by CDC. The NNDSS is neither a single surveillance system nor a method of reporting. Certain NNDSS data are reported to CDC through separate surveillance information systems and through different reporting mechanisms; however, these data are aggregated and compiled for publication purposes (CDC, 2007).

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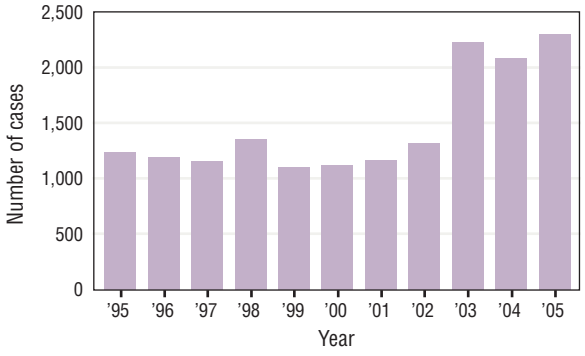
Exhibit 5-35. Number of reported cases of legionellosis in the U.S., 1995-2005



Data source: *CDC, 1996, 1997, 1998b, 1999, 2001, 2002, 2003b, 2004, 2005b, 2006, 2007*

INDICATOR | Infectious Diseases Associated with Environmental Exposures or Conditions *(continued)*

CDC. 2006. Summary of notifiable diseases—United States, 2004. MMWR 53(53). <http://www.cdc.gov/mmwr/PDF/wk/mm5353.pdf> See Table 1.

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CDC. 2005c. West Nile virus statistics, surveillance, and control: 2005 West Nile virus activity in the United States. Accessed October 16, 2005. <http://www.cdc.gov/ncidod/dvbid/westnile/surv&controlCaseCount05_detailed.htm>

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INDICATOR | Birth Defects Prevalence and Mortality

Birth defects are structural or functional anomalies causing physical or mental disability, some of which can be fatal. Although birth defects are the leading cause of infant mortality (deaths occurring to those under 1 year of age) in the U.S., the cause is unknown for approximately 70 percent of all cases (Infant Mortality indicator, p. 5-36) (CDC, 2005). Many different factors may be associated with the development of birth defects, such as genetic and/or chromosomal aberrations, *in utero* exposure to viruses or bacteria, uncontrolled maternal diabetes, maternal cigarette smoke, maternal use of drugs and alcohol during pregnancy, and prenatal exposure to chemicals. All of these factors may influence normal infant growth or development, resulting in different types of birth defects (NICHD, 2006).

This indicator presents birth defects prevalence at birth and mortality rates among infants in the U.S. as recorded in the National Vital Statistics System, which registers virtually all births and deaths nationwide. Data collection began in 1933 and is available through 2004. Birth defects data are collected on death certificates from all 50 states and the District of Columbia and recorded on birth certificates for 49 states and the District of Columbia. Reported race and ethnicity data are based on the race and ethnicity of the mother.

What the Data Show

Exhibit 5-36 presents the prevalence of live births with identified specific congenital anomalies (i.e., birth defects) between 1999 and 2004. The most frequently occurring

Exhibit 5-36. Prevalence of live births in the U.S. with specific birth defects (congenital anomalies), 1999-2004[a]

	1999	2000	2001	2002	2003	2004
Overall rate	1,170.2	1,164.2	1,178.8	1,170.6	1,103.4	1,111.8
Central nervous system anomalies						
Anencephalus	11.0	10.7	9.9	9.9	11.4	10.9
Spina bifida/meningocele	20.1	20.7	19.9	20.0	18.7	19.3
Hydrocephalus	21.5	23.7	22.5	22.5	22.2	22.4
Microcephalus	5.9	7.2	5.6	5.5	5.6	6.9
Other central nervous system anomalies	20.0	20.7	24.8	22.2	21.1	21.5
Circulatory/respiratory anomalies						
Heart malformations	119.8	124.9	122.5	129.9	128.9	137.7
Other circulatory/respiratory anomalies	140.6	138.1	139.6	131.7	126.1	135.3
Gastrointestinal anomalies						
Rectal atresia/stenosis	9.0	8.4	9.0	8.3	7.8	8.7
Tracheo-esophageal fistula/esophageal atresia	13.3	12.1	12.0	10.8	10.8	11.8
Omphalocele/gastroschisis	30.2	29.7	31.8	30.3	32.5	31.9
Other gastrointestinal anomalies	29.8	29.9	34.2	36.1	33.0	33.9
Urogenital anomalies						
Malformed genitalia	76.3	84.2	88.4	86.6	79.7	80.8
Renal agenesis	13.7	13.8	14.8	15.4	14.0	13.6
Other urogenital anomalies	99.0	99.3	102.8	101.8	90.2	89.5
Chromosomal anomalies						
Cleft lip/palate	80.9	82.1	80.6	78.5	75.9	77.7
Polydactyly/syndactyly/adactyly	87.9	87.2	82.4	82.2	76.4	74.8
Clubfoot	55.7	57.2	58.6	59.6	57.6	55.7
Diaphragmatic hernia	13.1	10.8	11.4	12.1	11.4	10.4
Other musculoskeletal/integumental anomalies	239.9	217.0	226.4	228.9	208.2	211.1
Down's syndrome	45.5	46.9	45.5	46.7	46.5	47.9
Other chromosomal anomalies	36.9	39.7	36.2	31.6	30.1	29.3

[a]Rates are per 100,000 live births.

Data source: *NCHS, 2001, 2002a,b, 2003, 2005, 2006; CDC, 2007a*

types of birth defects were various musculoskeletal/integumental anomalies, circulatory/respiratory system anomalies, and heart malformations. In 2004, heart malformations occurred at a rate of 137.7 per 100,000 live births, which was highest among the specific anomalies listed (i.e., categories that do not include "other"). The overall rate of birth defects (i.e., all birth defects combined) has been relatively stable between 1999 and 2002, with a noticeable decline in 2003 and 2004. Blacks have a consistently higher rate of birth defects than whites during this time period, with a rate of 1,337.5 (blacks) compared with 1,064.0 (whites) birth defects per 100,000 live births in 2004 (data not shown).

Rates for certain types of anomalies differ widely with maternal age. For example, in 2004 as in past years, infants of the youngest mothers (under 20 years of age) have the highest rates for omphalocele/gastroschisis, a defect or abnormality of the anterior abdominal wall (87.1 per 1,000 live births); infants of mothers age 35 years and over have the highest rates for Down's syndrome (348.3 per 1,000 live births). (Data not shown.)

INDICATOR | Birth Defects Prevalence and Mortality *(continued)*

Birth defects continue to be the leading cause of infant mortality, accounting for 5,622 (20.1 percent) of the 27,936 infant deaths in 2004 (Exhibit 5-16, Infant Mortality indicator, p. 5-37). Between 1979 and 1998, a decline in the national birth defects mortality rate has been observed, ranging from 255.4 per 100,000 live births in 1979 to 157.6 per 100,000 live births in 1998. From 1999 to 2004, the birth defects mortality rates were 144.2 (1999), 150.9 (2000), 136.7 (2001), 139.4 (2002), 140.4 (2003), and 137.9 (2004) per 100,000 live births. (Data not shown.)

Birth defects mortality was consistently higher among black infants than white infants. In 2004, for example, mortality attributed to birth defects among black male and female infants was 169.9 and 155.6 per 100,000 infants, respectively; among white male and female infants, it was 134.3 and 134.7 per 100,000 infants, respectively. (Data not shown.)

Indicator Limitations

- Because some birth defects are not recognized immediately, they are often underreported on both birth and death certificates (Friis and Sellers, 1999). Many anomalies are hard to detect at birth, which limits early ascertainment and complete reporting. The most serious and/or apparent anomalies are more likely to be identified and reported prior to hospital discharge (Honein et al., 2001).
- The lack of uniform reporting on birth certificates introduces additional uncertainty. For example, race information may be missing or incomplete. Also, beginning in 2003, two states began using a revised "standard certificate of live birth;" therefore, a subset of anomaly data was excluded because of the lack of comparability with other data sets (NCHS, 2005).
- The congenital anomalies reported on birth certificates are rare events. Since a small change in the number of anomalies reported can result in a relatively large change in rates, caution should also be used in comparing yearly rates for a specific anomaly.
- The birth defects anomaly groupings that include "other" (e.g., other musculoskeletal anomalies) include a large number of non-specific birth defects and should be considered separately from the specific birth defects listed.
- Birth defects mortality rates are based on underlying cause of death as entered on a death certificate by a physician. Incorrect coding and low rates of autopsies that confirm the cause of death may occur. Additionally, 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 underreporting of some birth defects 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. The relatively large difference between birth defects mortality rates reported from 1979 through 1998 and those reported beginning in 1999 may be due to some changes in the criteria used to report birth defects mortality during the switch from ICD-9 to ICD-10.

Data Sources

The birth defects rate data used for this indicator are from National Vital Statistics Reports published by the CDC's National Center for Health Statistics (NCHS, 2001, 2002a,b, 2003, 2005, 2006). CDC's "VitalStats"—a collection of vital statistics products including tables, data files, and reports that allow users to access and examine vital statistics and population data interactively—were used to obtain specific anomaly data for 2004 (CDC, 2007a). The birth defects mortality data were obtained from a published report by the National Center for Health Statistics (NCHS, 2007) and from CDC's compressed mortality files (underlying cause of death), accessed via CDC WONDER (CDC, 2007b), at http://wonder.cdc.gov.

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INDICATOR | Birth Defects Prevalence and Mortality *(continued)*

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NCHS. 2005. Births: Final data for 2003. National Vital Statistics Reports 54(2). <http://www.cdc.gov/nchs/data/nvsr/nvsr54/nvsr54_02.pdf> See Table 49.

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INDICATOR | Low Birthweight

The term "low birthweight" (LBW) is typically used for any infant weighing less than 2,500 grams at birth. Weight is a critical health measure because LBW children are more prone to death and disability than their counterparts.

The etiology of LBW for term-LBW (born after 37+ weeks of gestation) infants and preterm-LBW (born after less than 37 weeks of gestation) infants differs. For term-LBW infants, underlying causes include factors such as maternal smoking, weight at conception, and gestational weight gain, whereas for preterm-LBW infants, the etiology largely remains unexplained (CDC, 1994). Various exposures have been implicated as risk factors for term-LBW (e.g., maternal smoking, maternal exposure to lead, diethylstilbestrol, occupational exposures) (Sram et al., 2005; Kiely et al., 1994). The potential effect of air pollution on LBW continues to be researched (e.g., particulate matter, carbon monoxide, ozone).

This indicator presents the percentage of LBW infants born in the U.S. based on natality data reported to the National Vital Statistics System (NVSS). 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.

The data presented are based on singleton births only. This was done to eliminate the effect of multiple births. The data are presented across three maternal age groups (under 20 years, 20-39 years, and 40 years and older). Additionally, the data are stratified and reported for preterm (less than 37 weeks) and full-term (37 weeks and over) births because of the strong association between birthweight and gestational age.

What the Data Show

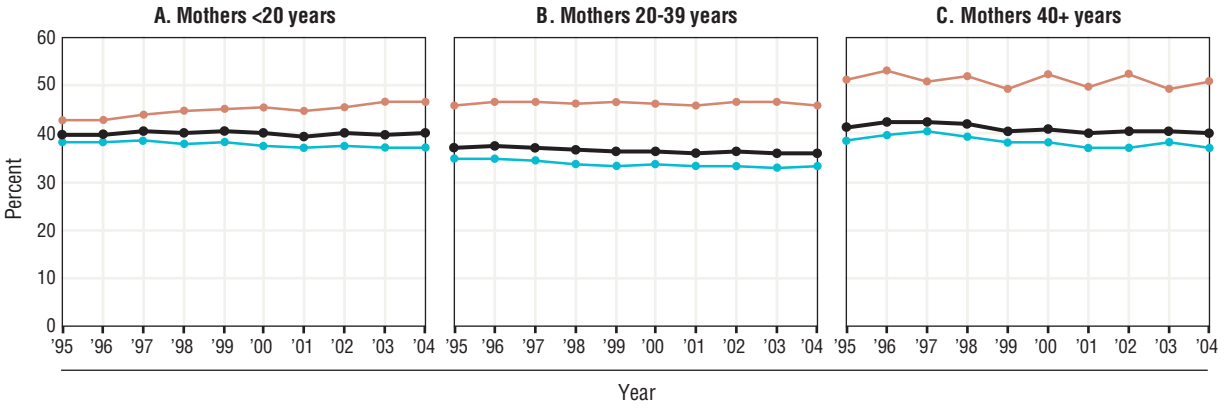
As expected, the percent of total LBW deliveries among preterm births is much higher than the percent of total LBW deliveries among full-term births across each of the three maternal age categories (Exhibits 5-37 and 5-38).

In general, small differences in the percent of LBW babies among maternal age categories are evident for both pre- and full-term births. For example, in 2004, the frequency of LBW babies among full-term births for mothers less than 20 years old (4.0 percent) is almost 1 percent higher than for mothers who are 40 years and older (3.2 percent) and about 1.4 percent higher than for mothers who are in the 20-39 age group (2.4 percent) (Exhibit 5-38).

Among the full-term births, black women had consistently higher frequencies of LBW babies compared to any of the other racial groups reported from 1995 and 2004. This racial pattern is evident in 2004 for all three maternal age groups, and the difference is most apparent in the 40 and older age group (6.2 percent for blacks and 2.7 percent for whites) (Exhibit 5-38).

The percentages of term-LBW babies among the other two racial groups reported in 2004, Native Americans and Asians/Pacific Islanders, were 4.1 percent and 3.3 percent, respectively, for the 40 and older age group. In 2004, some

Exhibit 5-37. Percent of low birthweight infants (<2,500 grams) born preterm in the U.S. by mother's race and age, 1995-2004[a,b]

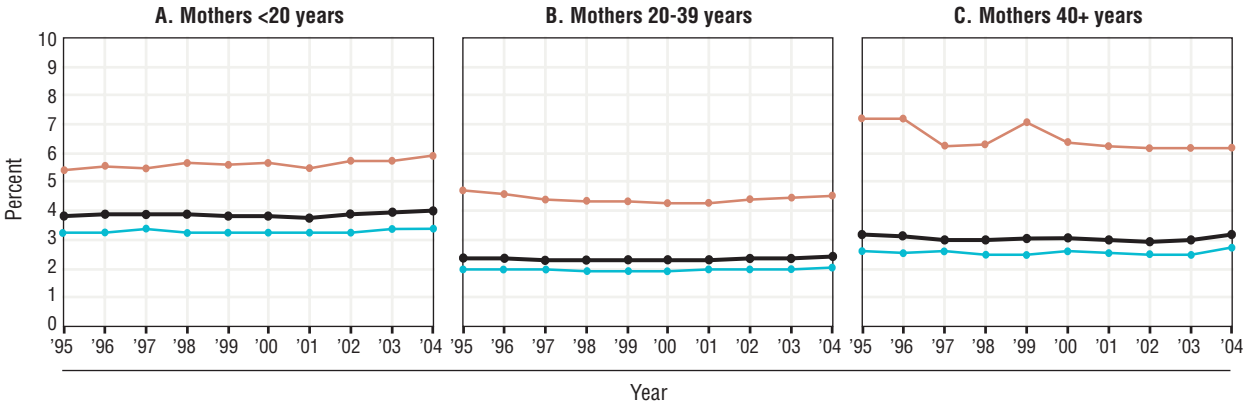


[a]Preterm births are births occurring at <37 weeks gestation.

[b]Data represent singleton births only.

Data source: *CDC, 2007*

Exhibit 5-38. Percent of low birthweight infants (<2,500 grams) born full-term in the U.S. by mother's race and age, 1995-2004[a,b]



[a]Full-term births are births occurring at ≥ 37 weeks gestation.

[b]Data represent singleton births only.

Data source: *CDC, 2007*

variation in the frequency of term-LBW was reported for Native Americans and Asian/Pacific Islanders among the three different age groups reported (under 20 years, 20-39 years, and 40 years and older), with Asian/Pacific Islanders showing the highest percentage of LBW babies (4.7 percent) among the under 20 year age group and Native Americans showing the highest percentage of LBW babies (4.1 percent) among women 40 years and older. Hispanic women and non-Hispanic women had similar frequencies of LBW babies. For example, in 2004, the percent of LBW babies for Hispanic women was 2.4 percent compared to 2.7 percent for non-Hispanic women. (Data not shown.)

Indicator Limitations

- Complete reporting of natality indicators such as LBW may vary due to differences in the reporting requirements established by each state. In some states, the number of LBW babies may be underreported.

INDICATOR | Low Birthweight *(continued)*

Data Source

The data used for this indicator were public-use natality data (1995-2002 and 2003-2004) obtained from the Centers for Disease Control and Prevention's National Center for Health Statistics, Division of Vital Statistics, available via CDC WONDER (CDC, 2007), at http://wonder.cdc.gov.

References

CDC (Centers for Disease Control and Prevention). 2007. CDC Wide-ranging OnLine Data for Epidemiologic Research (WONDER). Natality public-use data. Accessed October 2007. <http://wonder.cdc.gov/natality.html>

CDC. 1994. Increasing incidence of low birthweight—United States, 1981-1991. MMWR 43:335-339. <http://www.cdc.gov/mmwr/preview/mmwrhtml/00030918.htm>

Kiely, J.S., K.M. Brett, S. Yu, and D.L. Rowley. 1994. Low birthweight and intrauterine growth retardation. In: Wilcox, L.S., and J.S. Marks, eds. From data to action: CDC's public health surveillance for women, infants, and children. CDC's maternal and child health monograph 1994. Atlanta, GA: Centers for Disease Control and Prevention.

Sram R.J., B. Binkova, J. Dejmek, and M. Bobak. 2005. Ambient air pollution and pregnancy outcomes: A review of the literature. Environ. Health Perspect. 113(4):375-382.

INDICATOR | Preterm Delivery

Preterm delivery is defined as delivery prior to 37 weeks of gestation (a typical pregnancy lasts 40 weeks). The shorter the gestational age of an infant, the more likely (s)he is to suffer adverse effects. Preterm birth along with low birthweight is the second leading cause of infant death (Infant Mortality indicator, p. 5-36) (NCHS, 2004, 2006), and accounts for nearly half of all congenital neurological defects, such as cerebral palsy, and more than two-thirds of infant deaths (Goldenberg and Rouse, 1998; NCHS, 2006).

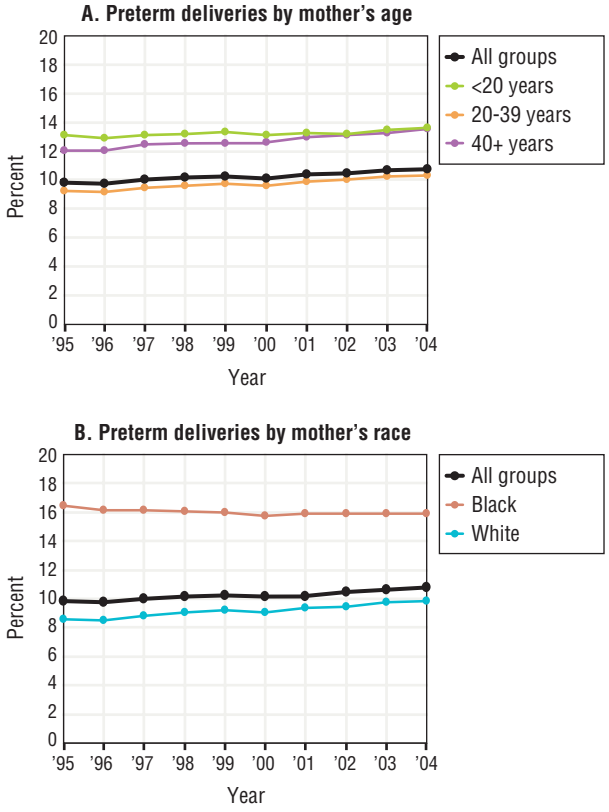
The determinants of preterm births are not fully known and the causes are often multi-factorial. Maternal high-risk conditions (e.g., infertility problems, vaginal spotting, inadequate maternal weight gain), previous history, socioeconomic status, smoking, alcohol consumption before third trimester, and multiple gestation pregnancy are known risk factors for preterm delivery. Environmental contaminants (e.g., lead, environmental tobacco smoke, air pollution) continue to be studied to better understand the strength of the associations with preterm delivery.

This indicator presents the proportion of U.S. infants born prior to 37 weeks of gestation, based on natality data reported to the National Vital Statistics System (NVSS). 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. The data presented here on preterm delivery were based on singleton births only. This was done to eliminate the effect of multiple births. The data are presented across three maternal age groups (under 20 years, 20-39 years, and 40 years and older).

What the Data Show

The proportion of infants defined as preterm has risen 18 percent since 1990 (NCHS, 2006). A small overall increase in preterm births has been observed from 1995 (9.8 percent)

Exhibit 5-39. Preterm deliveries in the U.S. by mother's age and race, 1995-2004[a,b]



[a]Preterm deliveries are births occurring at <37 weeks gestation.

[b]Data represent singleton births only.

Data source: *CDC, 2007*

INDICATOR | Preterm Delivery *(continued)*

to 2004 (10.8 percent). The largest percent increase between 1995 and 2000 has occurred among mothers in the 40 and over age group, with the percent of preterm births ranging from 12.0 (1995) to 13.5 percent (2004). The next largest percent increase was observed in the 20–39 year old maternal group, ranging from 9.2 percent (1996) to 10.3 percent (2004), with little overall change over time among those under 20 years of age (Exhibit 5-39, panel A).

In 1995, the percent of preterm births was almost twice as high among black mothers as among white mothers (16.4 versus 8.5 percent) (Exhibit 5-39, panel B). From 1995 to 2004, preterm delivery among black mothers decreased slightly: from 16.4 percent in 1995 to 15.9 percent in 2001, where the percentage has remained the same through 2004. During the same time, preterm delivery among white mothers increased slightly, rising from 8.5 percent in 1995 to 9.9 percent in 2004, resulting in a slight narrowing of the difference in the preterm birth rate between black and white mothers. Preterm delivery for Hispanic mothers ranged from 10.1 (1995) to 10.9 percent (2004), compared to 9.7 (1996) and 10.7 (2004) percent for non-Hispanic mothers between 1995 and 2004. (Data not shown.)

Indicator Limitations

- The primary measure used to determine the gestational age of the newborn is the interval between the first day of the mother's last normal menstrual period (LMP) and the date of birth. This measurement is subject to error for reasons such as imperfect maternal recall or misidentification of the LMP because of postconception bleeding, delayed ovulation, or intervening early miscarriage. When the LMP and date of birth are clearly inconsistent with the infant's birthweight or plurality, then a "clinical estimate of gestation" is used. Problems with reporting gestational age persist and may occur more frequently among some subpopulations and among births with shorter gestations (NCHS, 2006).

Data Source

The data used for this indicator were public-use natality data (1995–2002 and 2003–2004) obtained from the Centers for Disease Control and Prevention's National Center for Health Statistics, Division of Vital Statistics, available via CDC WONDER (CDC, 2007), at http://wonder.cdc.gov.

References

CDC (Centers for Disease Control and Prevention). 2007. CDC Wide-ranging OnLine Data for Epidemiologic Research (WONDER). Natality data query. Accessed October 2007. <http://wonder.cdc.gov/natality.html>

Goldenberg, R.L. and D.J. Rouse. 1998. Prevention of premature birth. New Engl. J. Med. 339:313–320.

NCHS (National Center for Health Statistics). 2006. Births: Final data for 2004. National Vital Statistics Reports 55(1). <http://www.cdc.gov/nchs/data/nvsr/nvsr55/nvsr55_01.pdf>

NCHS. 2004. Infant mortality statistics from the 2002 period linked birth/infant death data set. National Vital Statistics Reports 53(10).

5.4.3 Discussion

What These Indicators Say About Trends in Human Disease and Conditions for Which Environmental Contaminants May Be a Risk Factor

The indicators selected to answer this question represent diseases and conditions that affect multiple systems of the human body and are associated with a number of risk factors, some of which include exposures to contaminants that may be found in the air, water, and land. Some indicators represent chronic conditions (e.g., various cancers, heart and lung disease), some are primarily acute in nature (e.g., infectious diseases), and others represent conditions of the developing fetus and neonate. Understandably, no striking trends are evident across the broad categories of diseases represented by the indicators. However, some changes in disease rates or occurrence were observed for individual indicators. These relate largely to disease patterns observed over time and to differences observed across age groups, gender, and racial and ethnic groups.

Generally, the occurrence of many chronic diseases in adults is increasing with the aging of the population (Cancer indicator, p. 5-43; Cardiovascular Disease indicator, p. 5-48; Chronic Obstructive Pulmonary Disease indicator, p. 5-52). However, while overall cancer incidence rates showed a steady increase from the mid-1970s to the mid-1990s, rates have held relatively steady between 1997 and 2004. With the exception of prostate cancer in males and breast cancer in females, site-specific cancer rates also have remained fairly constant. Similarly, prevalence rates for cardiovascular disease and chronic obstructive pulmonary disease have shown no striking changes between 1997 and 2006, with the exception of an overall increase in the prevalence of hypertension during this time period. Prevalence rates for adult asthma have fluctuated from 1997 to 2006, with an overall increase during that time period (Asthma indicator, p. 5-55).

No distinct upward or downward patterns were revealed between 1995 and 2005 for most of the acute infectious gastrointestinal diseases presented in this report. An exception is the decrease in hepatitis A cases, which has been attributed to childhood vaccination for this disease.[57] Other observable shifts in acute infectious diseases, such as an increase of cryptosporidiosis in 2005, are difficult to interpret because of acknowledged uncertainties in the completeness of disease reporting in a given year.[58] Generally increased reported occurrence of arthropod-borne diseases and legionellosis bears watching (Infectious Diseases indicator, p. 5-59).

Review of diseases in children and birth outcomes revealed the following overall trends. Childhood cancer incidence has increased slightly since 1975, with boys having a higher incidence rate than girls. Leukemia and brain and other nervous system cancers remain the leading cancer sites in children (Childhood Cancer indicator, p. 5-46). Prevalence rates for childhood asthma remain at historically high levels following increases from 1980 through the late 1990s (Asthma indicator, p. 5-55).[59] A wide range of birth defects continues to be reported each year, but with no notable shifts in prevalence observed for specific types of defects from 1999 to 2004. Heart malformations and other circulatory/respiratory anomalies and musculoskeletal/integumental anomalies remain the most prevalent types of birth defects based on birth certificate data (Birth Defects indicator, p. 5-62). Among full-term singleton births, the percentage of low birthweight infants has not varied from 1995 to 2004. Age of mother showed the greatest influence, with the greatest number of low birthweight infants born to younger mothers (less than 20 years old) (Low Birthweight indicator, p. 5-65). The highest rate of preterm births is also seen in these younger mothers, though nearly comparable and rising preterm birth rates are seen among mothers over the age of 40 (Preterm Delivery indicator, p. 5-67).

Some differences were observed across racial and ethnic groups. Observations are reported for the most recently available annual data set. Overall, cancer incidence is higher among black males than for any other racial group. Less disparity was observed between cancer incidence in white and black women. With childhood cancers, higher rates have been consistently reported in whites than in blacks (Cancer indicator, p. 5-43, Childhood Cancer indicator, p. 5-46). For cardiovascular disease (p. 5-48), prevalence rates were generally reported highest among whites and American Indians/Alaska Natives, followed by blacks or African Americans and Asians. Asthma rates were generally reported highest among blacks or African Americans in children and American Indians/Alaska Natives in adults, followed by whites and Asians (Asthma indicator, p. 5-55).

The percentage of preterm and low birthweight infants is consistently higher among blacks than whites (1.5 to nearly 3 times higher). This observation is seen across all maternal age groups (Preterm Delivery indicator, p. 5-67; Low Birthweight indicator, p. 5-65). When available, reported disease rates were generally lower (Asthma indicator, p. 5-55; Cardiovascular Disease indicator, p. 5-48; Chronic Obstructive Pulmonary Disease indicator, p. 5-52) or comparable (Preterm Delivery indicator, p. 5-67; Low Birthweight indicator, p. 5-65) in Hispanic versus non-Hispanic populations.

Limitations, Gaps, and Challenges

In answering this question, EPA reviewed general trends in morbidity and mortality of several diseases that may be related, at least in part, to contaminants in the environment to which people may be exposed. The indicators presented in this section provide an overall picture of specific disease rates or occurrence across the nation, including among some population subgroups. ROE indicator data sets, however, do not enable extensive analysis of disease trends within or across geographic regions, nor do they allow fully consistent reporting of trends across racial and ethnic groups. In addition, there are other diseases or conditions of potential interest for which no national scale data are currently available, or for which the strength of associations with environmental contaminants are still being evaluated. Specific limitations, data gaps, and challenges related to answering the question on trends in disease are highlighted below.

Geographic Patterns

Mortality data sets enable some analysis at the EPA regional level, but underlying data for most ROE indicators selected to answer this question do not currently enable meaningful analysis of geographic trends across the nation. The regional analyses presented in this report for cardiovascular disease and chronic obstructive pulmonary disease mortality reveal no discernable patterns.

Other Diseases and Conditions for Which Environmental Contaminants May Be Risk Factors

Additional data are needed to prompt or enable EPA to track other diseases and conditions with potential environmental risk factors (direct or indirect), particularly those for which unexplained increases are being noted. Examples of diseases or conditions with suggestive or growing evidence that environmental contaminants are a risk factor follow. The extent to which national-level indicators meeting ROE criteria are available to track these diseases and conditions varies.

Behavioral and neurodevelopmental disorders in children continue to receive attention. These include disabilities of the functioning brain that affect a child's behavior, motor skills, memory, or ability to learn. Examples include attention-deficit/hyperactivity disorder (ADHD), dyslexia and other learning disabilities, cerebral palsy, mental retardation, and autism. Considerable evidence exists that lead and methylmercury are associated with mental retardation and impairment of mental function and attention.[60] While the role of other

[57] Centers for Disease Control and Prevention. 2007. Summary of notifiable diseases—United States, 2005. MMWR 54(53):9. <http://www.cdc.gov/mmwr/PDF/wk/mm5453.pdf>

[58] Ibid.

[59] Akinbami, L.J. 2006. The state of childhood asthma, United States, 1980-2005. Advance data from vital and health statistics. Number 381. Hyattsville, MD: National Center for Health Statistics. <http://www.cdc.gov/nchs/data/ad/ad381.pdf>

[60] Mendola, P., S.G. Selevan, S. Gutter, and D. Rice. 2002. Environmental factors associated with a spectrum of neurodevelopmental deficits. Ment. Retard. Dev. Disabil. Res. Rev. 8(3):188-197.

environmental contaminants in contributing to some of these disorders is not fully known or understood (e.g., for ADHD), the weight of evidence suggesting relationships between behavioral and neurodevelopmental effects from exposure to polychlorinated biphenyls (PCBs), environmental tobacco smoke, and other contaminants continues to grow.[61,62] The National Health Interview Survey (NHIS) tracks ADHD and mental retardation, though the accurate reporting of these types of disorders is complicated by difficulties in diagnoses and possible underreporting (e.g., institutionalized children are excluded from the NHIS survey population).

As the U.S. population continues to age, more individuals are afflicted with neurodegenerative disorders such as Parkinson's disease and Alzheimer's disease. For example, Alzheimer's disease is the seventh leading cause of death in the nation (General Mortality indicator, p. 5-33). Such diseases are characterized by the progressive loss of neural cells, which lead to central nervous system dysfunction (e.g., memory loss, cognitive deficits, personality changes, motor control abnormalities). The etiology of these disorders is multifactorial, but in many cases the etiology is unknown. Ongoing research is exploring the role, if any, of environmental contaminant exposure (e.g., heavy metals, pesticides). Thus far, findings are largely inconclusive due to conflicting results.[63]

Diabetes was reported as the sixth leading cause of death in the U.S. in 2004 (General Mortality indicator, p. 5-33). Two types of diabetes exist. Diabetes mellitus (type 2), the most common form, is characterized by the body's resistance to insulin action and a relative deficiency of insulin. Known risk factors for diabetes mellitus include factors such as age, obesity, family history, physical inactivity, and dietary glycemic load. Type 1 diabetes results from decreased insulin production by the pancreas as part of an autoimmune response. Onset typically occurs before adulthood and believed to be triggered by genetic predisposition and possible environmental factors. Diabetes itself is a risk factor for the development of many other acute and chronic conditions. Epidemiological research has been conducted to evaluate possible associations between environmental contaminant exposure and diabetes; however, findings are inconclusive. Occupational and environmental exposures to contaminants such as arsenic, PCBs, dioxins, and nitrates have been examined.[64,65] Other endocrine and metabolic disorders, such as thyroid disorders, continue to be studied. Research continues to evaluate the extent to which various environmental contaminants are capable of disrupting endocrine function in humans (e.g., phthalates, persistent organic pollutants).

Reproductive function is another condition of interest to EPA. Scientists are studying whether environmental contaminants may cause alterations in reproductive function and contribute to conditions such as ovarian failure, decreased sperm counts, infertility, sub-fecundity, and possibly early onset of puberty. For example, components of cigarette smoke and other environmental contaminants have been studied in association with possible effects on female reproductive function.[66] Other contaminants under study include pesticides, dioxins, various metals, and solvents.

Renal disease is of interest because of the vital function of the kidneys in maintaining human health and the range of complex factors that lead to kidney dysfunction and disease. The kidneys can be seriously affected by a number of primary diseases such as hypertension and diabetes. Nephritis and nephritic syndrome were reported as the ninth leading cause of death in 2004 (General Mortality indicator, p. 5-33). EPA is interested because the kidney is known to be the target of some environmental contaminants. For example, as evidenced through occupational exposure, poisoning, and other experimental studies, exposure to heavy metals such as lead, cadmium, and mercury has been shown to be nephrotoxic.[67,68] The U.S. Renal Data System is a national data system that collects, analyzes, and distributes morbidity and mortality information about end-stage renal disease in the U.S.

Infectious diseases represent a continuing threat in the U.S. and worldwide. CDC continues to monitor infectious diseases and implement preventive strategies for infectious diseases whose incidence has increased within the past two decades or threatens to increase in the near future.[69] Infectious diseases of EPA interest may shift over time, making tracking of these diseases more of a challenge. An area of research interest for arthropod-borne diseases, and a potential issue for zoonotic diseases, is whether their incidence may change with changes in environmental condition such as land use, local weather conditions, or other environmental disturbances.

Other Data Collection Systems

To better answer the question, expanded national-level health data collection systems are needed, as well as integration of systems that collect health data. For example, the birth certificate data currently used to track birth defects on a national level have limitations (see Birth Defects indicator, p. 5-62).

[61] Schantz, S.L., J.J. Widholm, and D.C. Rice. 2003. Effects of PCB exposure on neuropsychological function in children. Review. Environ. Health Perspect. 111(3):357-376.

[62] State of California. 2005. Proposed identification of environmental tobacco smoke as a toxic air contaminant. Part B: Health effects assessment for environmental tobacco smoke. As approved by the Scientific Review Panel on June 24, 2005. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. <http://www.arb.ca.gov/regact/ets2006/ets2006.htm>

[63] Brown, R.C., A.H. Lockwood, and B.R. Sonawane. 2005. Neurodegenerative disorders: An overview of environmental risk factors. Environ. Health Perspect. 113(9):1250-1256.

[64] Longnecker, M.P., and J.L. Daniels. 2001. Environmental contaminants as etiologic factors for diabetes. Environ. Health Perspect. 109(Suppl 6):871-876.

[65] Remillard, R.B., and N.J. Bunce. 2002. Linking dioxins to diabetes: Epidemiology and biologic plausibility. Review. Environ. Health Perspect. 110(9):853-858.

[66] Mlynarcikova, A., M. Fickova, and S. Scsukova. 2005. Ovarian intrafollicular processes as a target for cigarette smoke components and selected environmental reproductive disruptors. Review. Endocr. Regul. 39(1):21-32.

[67] Klaassen, C.D., ed. 2001. Casarett and Doull's toxicology: The basic science of poisons. Sixth edition. New York, NY: McGraw-Hill.

[68] Jarup, L. 2003. Hazards of heavy metal contamination. Review. Br. Med. Bull. 68:167-182.

[69] Centers for Disease Control and Prevention. 1998. Preventing emerging diseases. A strategy for the 21st century. Atlanta, GA: U.S. Department of Health and Human Services.

CDC recognizes the need for continuing efforts to improve birth defects surveillance, and recently released improved national prevalence estimates for major birth defects looking at data reported through the National Birth Defects Prevention Network.[70] Also, as noted above, systems do not exist at the state or national level to track many of the diseases or conditions that may be related to environmental hazards. Existing environmental hazard, exposure, and disease tracking systems are not linked together.

Some efforts are underway to begin tracking exposure and health outcomes together. For example, CDC's "environmental public health tracking network" involves the collection and integration of data from environmental hazard monitoring and from human exposure and health outcome surveillance; CDC's goal is to build a national tracking network (http://www.cdc.gov/nceh/tracking/). In addition, CDC has initiated the "environmental public health indicator project," which identifies indicators of environmental hazards and health effects that state health departments can use to develop comprehensive environmental public health programs (http://www.cdc.gov/nceh/indicators/default.htm). Such programs will help bridge some existing gaps in knowledge between disease trends and environmental condition. These efforts also will enhance data collection efforts at the community level (state and local) and help ensure better temporal and spatial congruence between environmental, surveillance, and biomonitoring programs.

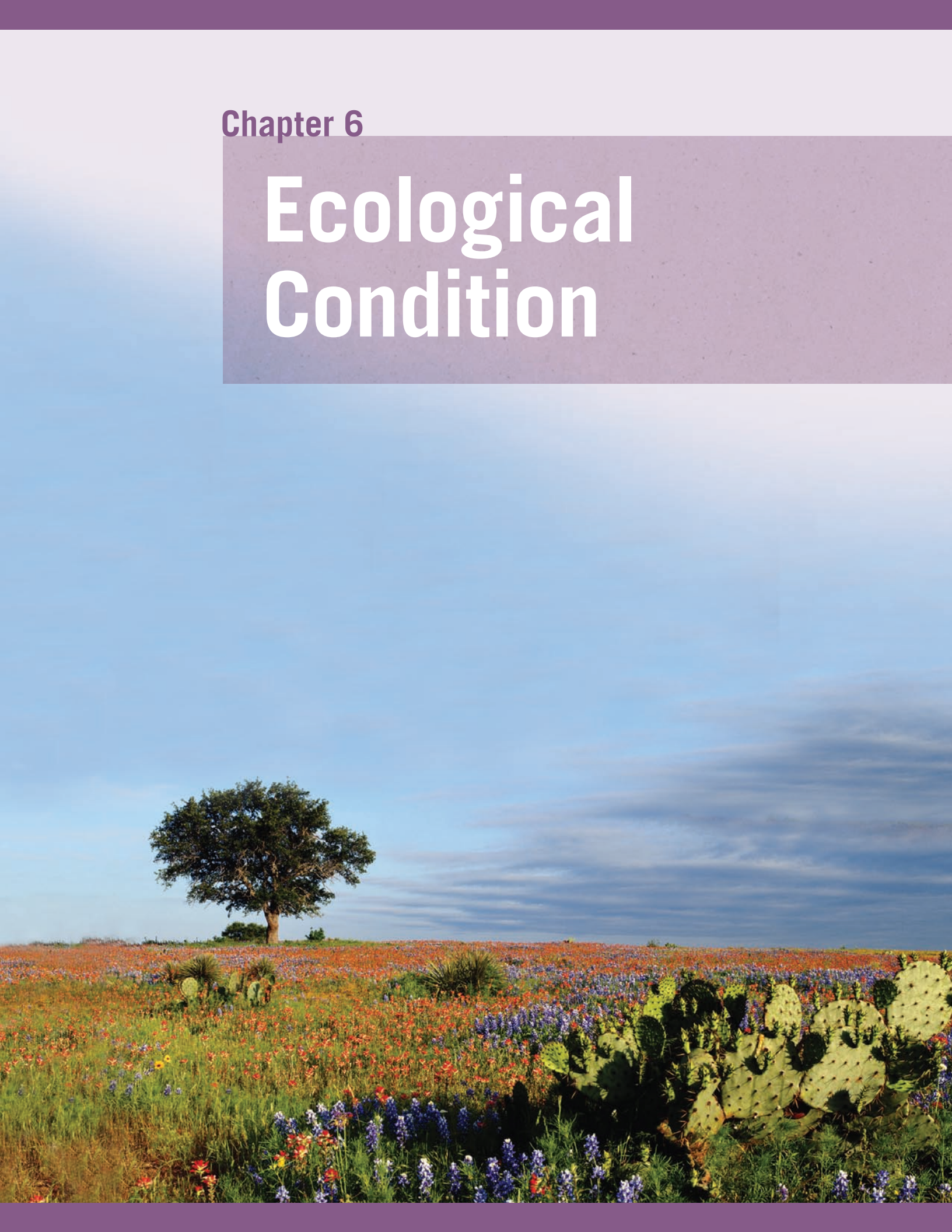
Lastly, data collection systems that collect data at different scales are available that may support future trend analysis. For example, CDC and the National Cancer Institute (NCI) have been combining forces to build a database of U.S. cancer statistics with data from CDC's National Program of Cancer Registries and NCI's Surveillance, Epidemiology, and End Results Program (http://apps.nccd.cdc.gov/uscs/). Cancer incidence data are available for 47 states, including six metropolitan areas, and the District of Columbia, and represent approximately 96 percent of the U.S. population.[71] Another example is asthma estimate data from CDC's state-based Behavioral Risk Factor Surveillance System.

[70] Centers for Disease Control and Prevention. 2006. Improved national prevalence estimates for 18 selected major birth defects—United States, 1999-2001. MMWR 54(51&52):1301-1305.

[71] Centers for Disease Control and Prevention and National Cancer Institute. 2006. United States cancer statistics: 2003 incidence and mortality. U.S. Cancer Statistics Working Group. <http://www.cdc.gov/cancer/npcr/npcrpdfs/US_Cancer_Statistics_2003_Incidence_and_Mortality.pdf>

Chapter 6

Ecological Condition



Contents

6.1 Introduction

The term "ecological condition" refers to the state of the physical, chemical, and biological characteristics of the environment, and the processes and interactions that connect them. Understanding ecological condition is crucial, because humans depend on healthy ecological systems for food, fiber, flood control, and other benefits,[1] and many Americans attribute deep significance and important intangible benefits to ecological systems and their diverse flora and fauna.[2] As noted in the introduction to this report, this chapter focuses on critical ecosystem characteristics that are affected simultaneously by stressors in multiple media, rather than those whose trends can be definitively shown to be the results of trends in particular air, water, or land stressors. The ability to report on ecological condition remains significantly limited by the lack of indicators, but this chapter at least provides a framework for examining ecological condition.

EPA's mission, broadly stated, is "to protect human health and to safeguard the natural environment—air, water, and land—upon which life depends."[3] The translation of the mission into programs, initiatives, and research efforts continues to evolve within the Agency and is reflected in program goals, regulatory programs, and collaborative and educational efforts. EPA, other federal agencies, and state agencies collectively bear responsibility for ensuring the protection of ecological systems, including forests, public lands, oceans and estuaries, and particular species or groups of species. Trends in ecological condition provide insight into the degree to which the natural environment is being protected.

In this chapter, EPA seeks to assess trends in critical attributes of ecological condition on a national scale, using indicators to address five fundamental questions:

- **What are the trends in the extent and distribution of the nation's ecological systems?** This question examines trends in the overall extent (e.g., area and location) of different kinds of ecological systems (e.g. forests, undeveloped lands, and watersheds) and of spatial patterns in the distribution of ecological systems that affect interactions of nutrients, energy, and organisms.
- **What are the trends in the diversity and biological balance of the nation's ecological systems?** This question explores trends in the types and numbers of species that live within ecological systems. The question also examines biological balance in terms of the proportional distributions of species and the influence of interactions among native and invasive species on the stability of ecological systems.
- **What are the trends in the ecological processes that sustain the nation's ecological systems?** This question

EPA's 2008 Report on the Environment (ROE): Essentials

ROE Approach

This 2008 Report on the Environment:

- Asks questions that EPA considers important to its mission to protect human health and the environment.
- Answers these questions, to the extent possible, with available indicators.
- Discusses critical indicator gaps, limitations, and challenges that prevent the questions from being fully answered.

ROE Questions

The air, water, and land chapters (Chapters 2, 3, and 4) ask questions about trends in the condition and/or extent of the environmental medium; trends in stressors to the medium; and resulting trends in the effects of the contaminants in that medium on human exposure, human health, and the condition of ecological systems.

The human exposure and health and ecological condition chapters (Chapters 5 and 6) ask questions about trends in aspects of health and the environment that are influenced by many stressors acting through multiple media and by factors outside EPA's mission.

ROE Indicators

An indicator is derived from actual measurements of a pressure, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain. This excludes indicators such as administrative, socioeconomic, and efficiency indicators.

Indicators based on one-time studies are included only if they were designed to serve as baselines for future trend monitoring.

All ROE indicators passed an independent peer review against six criteria to ensure that they are useful; objective; transparent; and based on data that are high-quality, comparable, and representative across space and time.

Most ROE indicators are reported at the national level. Some national indicators also report trends by region. EPA Regions were used, where possible, for consistency and because they play an important role in how EPA implements its environmental protection efforts.

Several other ROE indicators describe trends in particular regions as examples of how regional indicators might be included in future versions of the ROE. They are not intended to be representative of trends in other regions or the entire nation.

EPA will periodically update and revise the ROE indicators and add new indicators as supporting data become available. In the future, indicators will include information about the statistical confidence of status and trends. Updates will be posted electronically at http://www.epa.gov/roe.

Additional Information

You can find additional information about the indicators, including the underlying data, metadata, references, and peer review at http://www.epa.gov/roe.

[1] Daily, G.C., ed. 1997. Nature's services: Societal dependence on natural ecosystems. Washington, DC: Island Press.

[2] Norton, B. 1988. Commodity, amenity, and morality: The limits of quantification in valuing biodiversity. In: Wilson, E.O., ed. Biodiversity. Washington, DC: National Academies Press. p. 521.

[3] U.S. EPA. 2007. About EPA. <http://www.epa.gov/epahome/aboutepa.htm#mission>

focuses on trends in the critical processes that sustain ecological systems, such as primary and secondary productivity, nutrient cycling, decomposition, and reproduction.

- **What are the trends in the critical physical and chemical attributes of the nation's ecological systems?** This question addresses trends in the physical and chemical attributes of ecological systems. Physical attributes can include climatological patterns, hydrology, and electromagnetic radiation, as well as major physical events that reshape ecological systems, such as fires, floods, and windstorms. This question also examines chemical attributes such as pH, oxidation-reduction potential, and nutrient levels.
- **What are the trends in biomarkers of exposure to common environmental contaminants in plants and animals?** This question examines trends in biomarkers of exposure to contaminants that are particularly important to the health of plants and animals as well as to humans who consume such organisms.

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

While the indicators of ecological condition (and those in the previous chapter, "Human Exposure and Health") may be directly influenced by pollutants, other environmental stressors, and complex interactions among these factors, the indicators are not intended to confirm direct causal relationships.

6.1.1 The Ecological Condition Paradigm

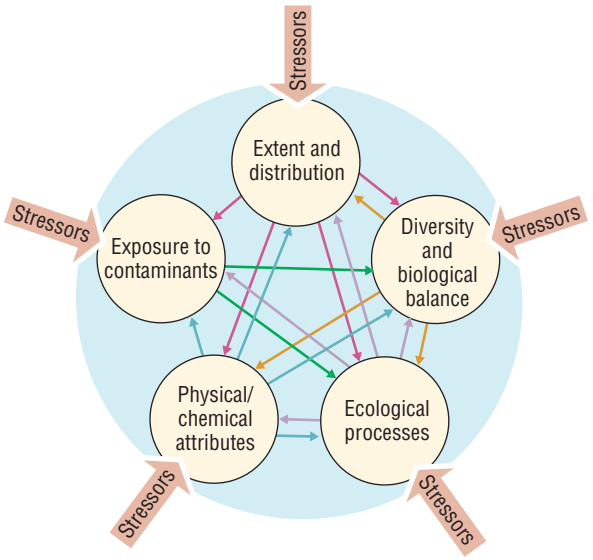
Because ecological systems are dynamic assemblages of organisms that have more or less continuously adapted to a variety of natural stressors over shorter (e.g., fire, windstorms) and longer (e.g., climate variations) periods of time, measuring ecological condition is a complicated endeavor. It is not as straightforward as monitoring water or air for temperature or concentrations of pollutants. The complexity of interactions within ecological systems makes determination of the condition of a natural system difficult.[4] In addition, people have altered natural ecological systems to increase the productivity of food, timber, fish, and game and to provide the infrastructure needed to support a modern society. How should the ecological condition of these altered ecological systems be measured and against what reference points?

Ecological systems are not necessarily naturally occurring entities with well-defined, mutually exclusive boundaries; rather, they are constructs with boundaries determined for human scientific or management purposes. Consequently there are many ways to define ecological systems, including by the predominant biota, spatial scales, and physical characteristics. These factors further complicate the definition and measurement of ecological condition. Several recent reports by experts in the field have provided guidance for current and future efforts, however.

The National Research Council (NRC) report *Ecological Indicators for the Nation*[5] provides an introduction to recent national efforts to measure ecological condition and a thoughtful discussion of the rationale for choosing indicators. EPA's Science Advisory Board (SAB) also proposed a *Framework for Assessing and Reporting on Ecological Condition*.[6] The framework identified six essential attributes of ecological systems: landscape condition, biotic condition, chemical and physical characteristics, ecological processes, hydrology and geomorphology, and natural disturbance regimes. The SAB report is organized around questions about trends in each of these attributes, consolidating the last three into a single attribute. Neither report identifies specific methodologies, network designs, or actual datasets. The SAB and NRC documents provide the foundation for the questions that are addressed within this chapter.

Exhibit 6-1 is a conceptual depiction of the events that link environmental changes and ecological outcomes in this paradigm. "Stressors," indicated by thick arrows, represent factors such as insect outbreaks or contaminants affecting the system. These stressors act directly on one or more of the "essential ecological attributes" shown in the circles in the center of the diagram. Most of these attributes can, in turn, act on and be acted on by others. The web of arrows among the indicators

Exhibit 6-1. Ecological condition paradigm



Stressors (shown as ⟵) affect ecological attributes directly and also indirectly through feedback (interaction) among the attributes (e.g., ↑).

[4] Ehrenfeld, D.H. 1992. Ecosystem health and ecological theories. In: Costanza, R., B.G. Norton, and B.D. Haskell, eds. Ecosystem health: New goals for environmental management. Washington, DC: Island Press. pp. 135-143.

[5] National Research Council. 2000. Ecological indicators for the nation. Washington, DC: National Academies Press. <http://www.nap.edu/openbook.php?isbn=0309068452>

[6] U.S. Environmental Protection Agency. 2002. A framework for assessing and reporting on ecological condition: An SAB report. EPA/SAB/EPEC-02/009. <http://www.epa.gov/sab/pdf/epec02009a.pdf>

illustrates some of the possible interactions. Effects on ecological attributes can be direct or indirect. The diagram illustrates the fact that changes in ecological structure and processes provide important feedback on the chemical and physical structure of the environment in which these changes occur. The overall changes in the attributes result in altered structure and function of ecological systems, which in turn lead to outcomes (positive or negative) about which society is concerned.

There have been other notable efforts conducted by EPA and other federal agencies and institutions to describe the ecological condition of the nation, either in total or by type of ecological systems. These efforts include both indicator-based and integrative approaches. The indicator-based approaches, such as this report, use indicators to assess ecological condition. The integrated assessments do not rely on indicators; rather, they comprehensively assess a wide range of data in order to arrive at an overall picture of the status and trends in ecological systems. Indicator approaches offer the advantage of drawing attention to important trends and do not require an extensive background in ecology, but are not able to capture the complex interactions that characterize ecological systems.

6.1.2 Overview of the Data

This chapter, like the others in this report, is not intended to be an exhaustive treatment of the condition of all ecological systems in the nation. Rather, it provides a snapshot of status or trends using the few ecological condition indicators that are available at the national level and that meet the ROE indicator criteria. Because ecological condition depends critically on the physical and chemical characteristics of land, air, and water, this chapter draws on indicators from Chapters 2 through 4 of this report. Those chapters should be consulted for the data sources of those indicators. Many of the indicators continue to be drawn from The H. John Heinz III Center for Science, Economics, and the Environment report *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States*.

Most of the data relied upon come from surveillance and monitoring surveys. The key data sources for this chapter reflect the fact that monitoring ecological condition is a multi-organizational task. Organizations in addition to EPA that are responsible for collecting the data to support indicators in this chapter include the U.S. Department of Commerce (National Oceanic and Atmospheric Administration), National Aeronautics and Space Administration, U.S. Department of Agriculture (Forest Service, Agricultural Research Service, National Agricultural Statistics Service, and Natural Resource Conservation Service), U.S. Department of Interior (U.S. Geological Survey and U.S. Fish and Wildlife Service), and NatureServe (a private research organization).

Programs such as the U.S. Department of Agriculture Forest Inventory and Analysis program and the Natural Resources Inventory have a long history because they measure aspects of the environment that are critical to multi-billion-dollar industries (e.g., timber, crops). Programs with a strictly "ecological" focus (e.g., the U.S. Geological Survey's National Water Quality Assessment Program [NAWQA], the multi-agency Multi-Resolution Land Characteristics [MRLC] Consortium, and EPA's Environmental Monitoring and Assessment Program [EMAP]) are more recent, but equally informative.

The major challenges involve adequate coverage of the diverse aspects of ecological condition. For example, there are numerous groups of animals and plants, but there are ROE indicators for only some of these. Major groups known to be undergoing changes, such as amphibians, are not captured by the ROE indicators. These challenges and limitations are described in each of the subsections.

This chapter presents only data that meet the ROE indicator definition and criteria (see Box 1-1, p. 1-3). Note that non-scientific indicators, such as administrative and economic indicators, are not included in this definition. Thorough documentation of the indicator data sources and metadata can be found online at http://www.epa.gov/roe. All indicators were peer-reviewed during an independent peer review process (again, see http://www.epa.gov/roe for more information). Readers should not infer that the indicators included reflect the complete state of knowledge on current indicators of U.S. ecological condition. Many other data sources, publications, and site-specific research projects have contributed to the current understanding of status and trends in indicators of U.S. ecological condition, but are not used in this report because they do not meet some aspect of the ROE indicator criteria.

6.1.3 Organization of This Chapter

The remainder of this chapter is organized into five sections, corresponding to the five questions EPA is seeking to answer regarding trends in ecological condition. Each section introduces the question and its importance, presents the National Indicators selected to help answer the question, and discusses what the indicators, taken together, say about the question. Some of the National Indicators presented are broken down by EPA Regions or other appropriate regions. In addition, several Regional Indicators are presented that capture regional trends of particular interest to EPA Regions. These Regional Indicators serve as models that could potentially be expanded to other EPA Regions in the future. A map showing the EPA Regions (and states within each Region) is provided in Chapter 1 (Exhibit 1-1). Each section concludes by highlighting the major challenges to answering the question and identifying important information gaps.

Table 6-1 lists the indicators used to answer the five questions in this chapter and shows the locations where the indicators are presented.

Table 6-1. Ecological Condition—ROE Questions and Indicators

Question	Indicator Name	Section	Page
What are the trends in the extent and distribution of the nation's ecological systems?	Land Cover (N/R)	4.2.2	4-7
	Forest Extent and Type (N/R)	6.2.2	6-8
	Forest Fragmentation (N/R)	6.2.2	6-11
	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-32
	Land Use (N)	4.3.2	4-14
	Urbanization and Population Change (N)	4.3.2	4-19
	Land Cover in the Puget Sound/Georgia Basin (R)	4.2.2	4-10
	Ecological Connectivity in EPA Region 4 (R)	6.2.2	6-13
	Relative Ecological Condition of Undeveloped Land in EPA Region 5 (R)	6.2.2	6-14
What are the trends in the diversity and biological balance of the nation's ecological systems?	Coastal Benthic Communities (N/R)	3.5.2	3-44
	Benthic Macroinvertebrates in Wadeable Streams (N)	3.2.2	3-21
	Bird Populations (N)	6.3.2	6-20
	Fish Faunal Intactness (N)	6.3.2	6-21
	Submerged Aquatic Vegetation in the Chesapeake Bay (R)	3.5.2	3-46
	Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest (R)	6.3.2	6-23
What are the trends in the ecological processes that sustain the nation's ecological systems?	Carbon Storage in Forests (N)	6.4.2	6-28
What are the trends in the critical physical and chemical attributes of the nation's ecological systems?	U.S. and Global Mean Temperature and Precipitation (N)	6.5.2	6-32
	Sea Surface Temperature (N)	6.5.2	6-37
	Streambed Stability in Wadeable Streams (N)	3.2.2	3-11
	High and Low Stream Flows (N)	3.2.2	3-8
	Sea Level (N)	6.5.2	6-39
	Nitrogen and Phosphorus Loads in Large Rivers (N)	3.2.2	3-17
	Nitrogen and Phosphorus in Wadeable Streams (N)	3.2.2	3-13
	Nitrogen and Phosphorus in Streams in Agricultural Watersheds (N)	3.2.2	3-15
	Lake and Stream Acidity (N)	2.2.2	2-42
	Hypoxia in the Gulf of Mexico and Long Island Sound (R)	3.5.2	3-48
What are the trends in biomarkers of exposure to common environmental contaminants in plants and animals?	Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
	Contaminants in Lake Fish Tissue (N)	3.8.2	3-63
	Ozone Injury to Forest Plants (N)	2.2.2	2-24

N = National Indicator

R = Regional Indicator

N/R = National Indicator displayed at EPA Regional scale

6.2 What Are the Trends in the Extent and Distribution of the Nation's Ecological Systems?

6.2.1 Introduction

Ecological systems,[7] ranging from forests and watersheds to wetlands and coral reefs, are the foundation of the environment. An ecological system can be defined as a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment, within its boundaries. Ecological systems are not isolated but blend into and interact with other systems. The spatial coverage and arrangement of ecological systems influence the types of animals and plants that are present; the physical, chemical, and biological processes in the system; and the resiliency of the systems to perturbations.[8] Ecological systems influence water and nutrient cycles, the building of soils, the production of oxygen, sequestration of carbon, and many other functions important for the health of the planet and people who depend on them.

This section examines trends in the extent and distribution of ecological systems. *Extent* refers to the physical coverage of an ecological system; it can be reflected as area or percent compared to a baseline or total area. *Distribution* includes the pattern or arrangement of the components of an ecological system and is dependent on the scale of analysis. For example, the national distribution of forests can be estimated by a percent coverage, but within a stand of trees the distribution may involve patterns of gaps, species, and edge/interior ratios. As noted in Section 6.1.1, ecological systems can be defined by predominant biota, spatial scales, and physical characteristics. Extent indicators typically are based on physical and biological characteristics that are observable by remote sensing, with indistinct boundaries operationally defined according to some scientific or resource management construct.[9]

As noted in Chapter 1, safeguarding the natural environment is an integral part of EPA's mission. EPA traditionally has been most concerned with maintaining the quality of air, water, and land necessary to support balanced biological communities and the processes that support them; however, the success of these efforts requires that ecological systems not be altogether lost or fragmented. The potential influences of pollutants on the extent and distribution of ecological systems are a prime concern, and, in turn, the extent and distribution of ecological systems have far-reaching influences on air and water quality.

Apparent trends in extent and distribution of ecological systems depend on the temporal and spatial scale of assessment. For this reason, both National and Regional Indicators are particularly valuable. *Temporal* changes occur naturally over long time scales, such as those associated with geological and climatological forces (e.g., glaciation). Change can also occur more quickly as a result of direct shifts in land use (e.g., forest to development and historical filling of wetlands), alterations of nutrient and hydrological cycles (e.g., dam removal), introduction of invasive species (e.g., Asian carp), pollutant exposure (e.g., acid rain), or extreme weather events, which all act over comparatively short time periods. Thus, trends can be the result of natural forces or may be accelerated by human activity.

The *spatial* scale of alterations also represents a significant factor in tracking ecological condition. Alterations that are short in duration and local in nature (e.g., seasonal droughts or a windfall in a closed forest canopy) may not have large-scale or lasting effects on ecological systems. Alterations that are chronic in nature and occur over large areas may affect entire ecosystems over long periods of time, especially if they affect soil formation, microclimate, refugia for recolonizing species, etc. Particularly relevant discussions of the importance of scale in ecological processes, monitoring, and management can be found in a number of relatively recent publications.[10,11,12]

Different regions and different ecological systems respond to stressors in different ways, resulting in unique regional distributions of species and habitats. The result is that across any slice of landscape the extent and distribution of ecological systems may shift.[13] In the case of habitat loss, large impacts may occur and the extent of coverage may be reduced or eliminated altogether. More subtle changes in ecological systems can occur that are not captured in simple metrics of extent and distribution. These changes are discussed in later sections of this chapter.

Fragmentation, the division of previously uninterrupted habitat, can have either negative or positive impacts on communities.[14] Examples of fragmentation include building highways through a forest, damming a river in a manner that limits migration of fish, or developing waterfronts in a manner that splits apart bordering marshlands. Fragmentation and the increasing area of edge habitat may force migrating species to find new transport corridors, may allow new species (e.g., competitors, pathogens, weeds) to enter areas previously

7 Likens, G. 1992. An ecosystem approach: Its use and abuse. Excellence in ecology, book 3. Oldendorf/Luhe, Germany: Ecology Institute.

8 Wilson, E.O. 1992. The diversity of life. Cambridge, MA: Belknap Press.

9 The H. John Heinz III Center for Science, Economics, and the Environment. 2005. The state of the nation's ecosystems: Measuring the lands, waters, and living resources of the United States. New York, NY: Cambridge University Press. Web update 2005. <http://www.heinzctr.org/ecosystems/forest/frgmnt.shtml>

10 Peterson, D.L., and V.T. Parker. 1998. Ecological scale: Theory and applications. New York: Columbia University Press.

11 Niemi, G., and M. McDonald. 2004. Application of ecological indicators. Annu. Rev. Ecol. Evol. Syst. 35:89-111.

12 Findlay, C.S., and L. Zheng. 1997. Determining characteristic stressor scales for ecosystem monitoring and assessment. J. Environ. Manage. 50(3):265-281.

13 The H. John Heinz III Center for Science, Economics, and the Environment. 2005. Forest pattern and fragmentation. In: The state of the nation's ecosystems: Measuring the lands, waters, and living resources of the United States. New York, NY: Cambridge University Press. Web update 2005. <http://www.heinzctr.org/ecosystems/forest/frgmnt.shtml>

14 Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. J. Wildl. Manage. 61(3):603-610.

blocked from immigration, and in some cases may actually increase biodiversity.[15] Regardless of the impact, fragmentation likely will result in shifting distributions of species.

Trends in ecological system extent and distribution are highly dependent on the evaluation scale. At one scale, coastal wetlands may appear to be uninterrupted and uniform. However, at a more refined scale, edges, patches, corridors associated with tidal creeks, and discontinuous distributions of species become evident. Defining systems in terms of local organization or predominant species facilitates discussion and analysis, but may also obscure the important linkages among systems across landscapes. Therefore, while it is helpful to discuss trends in the extent and distribution of systems such as wetlands or forests, each system is tied into global water, nutrient, carbon, and energy cycles.

The indicators discussed in this section fall into three broad categories: indicators of the extent and distribution of forests, indicators of the extent and distribution of wetlands, and indicators of land use.

6.2.2 ROE Indicators

In this question, trends in the extent and distribution of ecological systems are evaluated for a subset of systems including forests, wetlands, undeveloped lands, and developed lands.

To answer the question on extent and distribution of ecological systems, this report relies primarily on six National Indicators and three Regional Indicators (Table 6-2). Data on trends in extent and distribution of ecological systems come from a variety of sources, including satellite remote sensing, geographic information systems, and independent field studies. Information for the indicators discussed in this section is drawn from several national assessments including the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis program, the U.S. Fish and Wildlife Service's Wetlands Status and Trends Survey, the National Land Cover Dataset/Database (NLCD) for 1992 and 2001, and the USDA National Resources Inventory.

Table 6-2. ROE Indicators of Trends in Extent and Distribution of the Nation's Ecological Systems

National Indicators	Section	Page
Land Cover (N/R)	4.2.2	4-7
Forest Extent and Type (N/R)	6.2.2	6-8
Forest Fragmentation (N/R)	6.2.2	6-11
Wetland Extent, Change, and Sources of Change	3.4.2	3-32
Land Use	4.3.2	4-14
Urbanization and Population Change	4.3.2	4-19
Regional Indicators	**Section**	**Page**
Land Cover in the Puget Sound/Georgia Basin	4.2.2	4-10
Ecological Connectivity in EPA Region 4	6.2.2	6-13
Relative Ecological Condition of Undeveloped Land in EPA Region 5	6.2.2	6-14

N/R = National Indicator displayed at EPA Regional scale

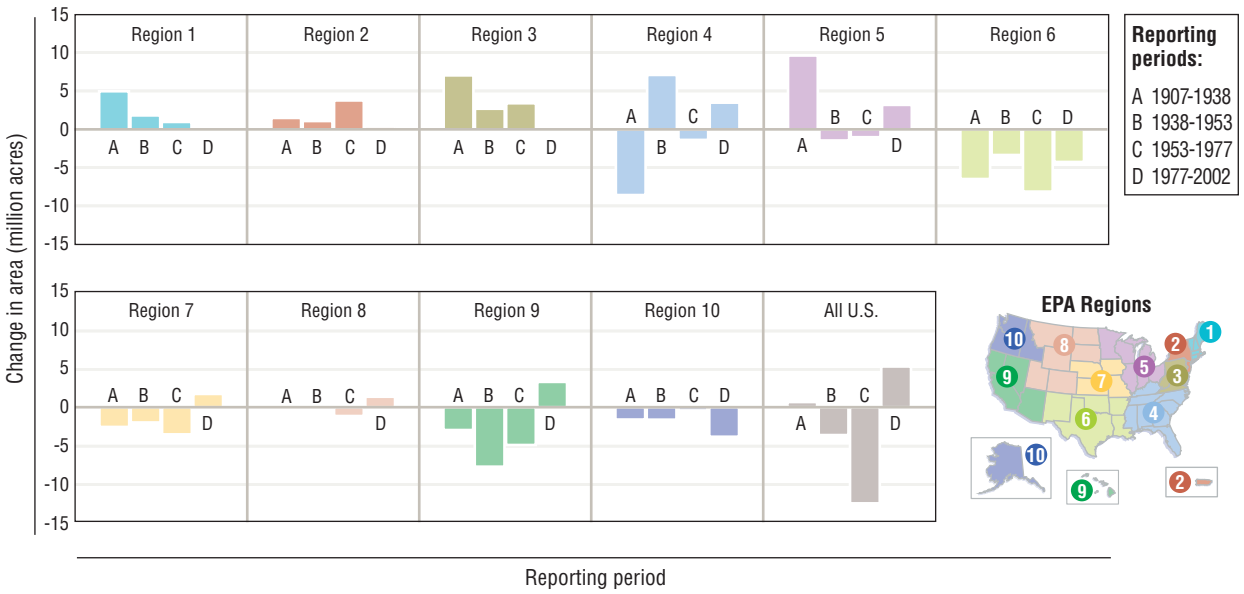
INDICATOR | Forest Extent and Type

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

[15] Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annu. Rev. Ecol. Syst. 34:487-515.

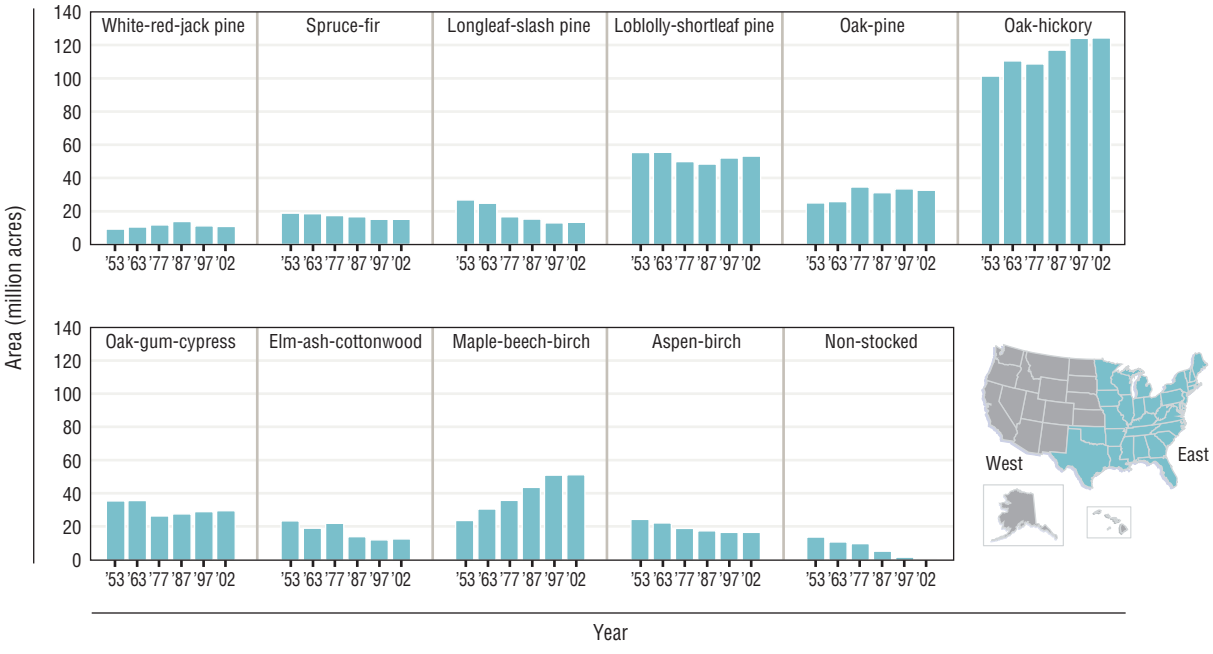
Exhibit 6-2. Changes in the extent of forest land in the U.S. by EPA Region, 1907-2002[a]



[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]

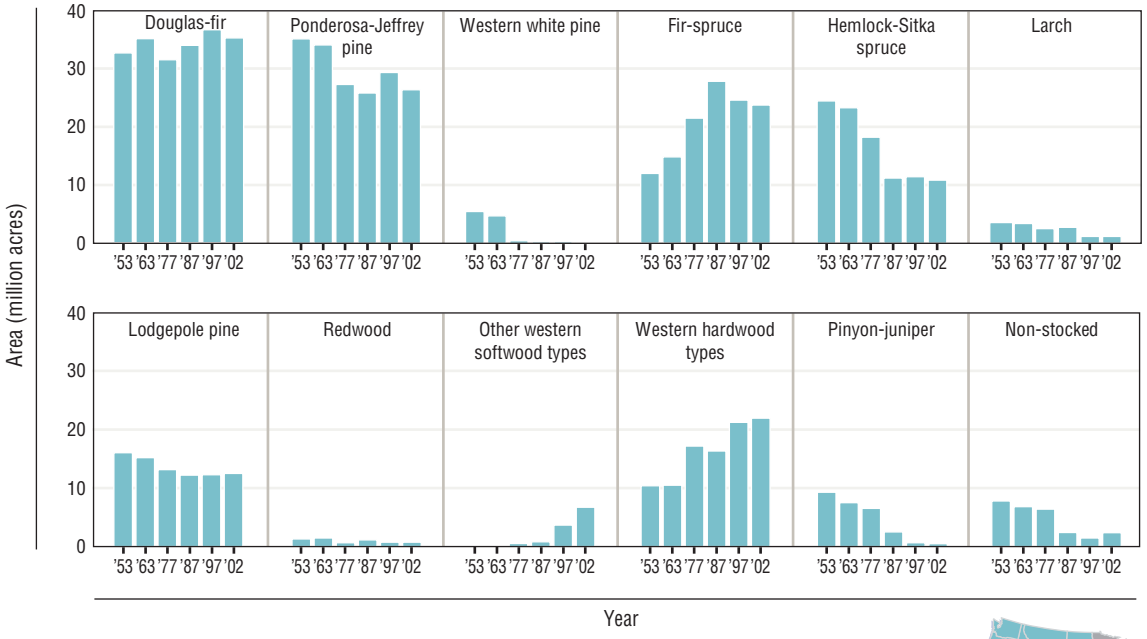


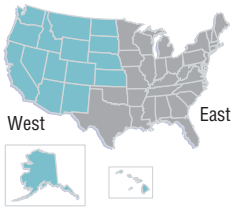
[a]**Coverage:** States in the eastern U.S., based on USDA Forest Service reporting regions (see map at right). These data cover timberland, as defined by the Forest Service's Forest Inventory and Analysis (FIA) Program. Approximately 94% of the forest land in the eastern states is timberland.

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

INDICATOR | Forest Extent and Type *(continued)*

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*

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.

INDICATOR | Forest Extent and Type *(continued)*

- 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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Smith, W.B., J.S. Vissage, D.R. Darr, and R.M. Sheffield. 2001. Forest resources of the United States, 1997. General Technical Report NC-219. St. Paul, MN: USDA Forest Service, North Central Research Station. <http://www.ncrs.fs.fed.us/pubs/gtr/gtr_nc219.pdf>

USDA Forest Service. 2005. Forest Inventory and Analysis, national FIA data base systems. Accessed 2005. <http://www.fia.fs.fed.us/tools-data/>

INDICATOR | Forest Fragmentation

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.

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

INDICATOR | Forest Fragmentation *(continued)*

Region 1 are surrounded by less than 60 percent forest, compared to almost 40 percent of the forest pixels in Region 7.

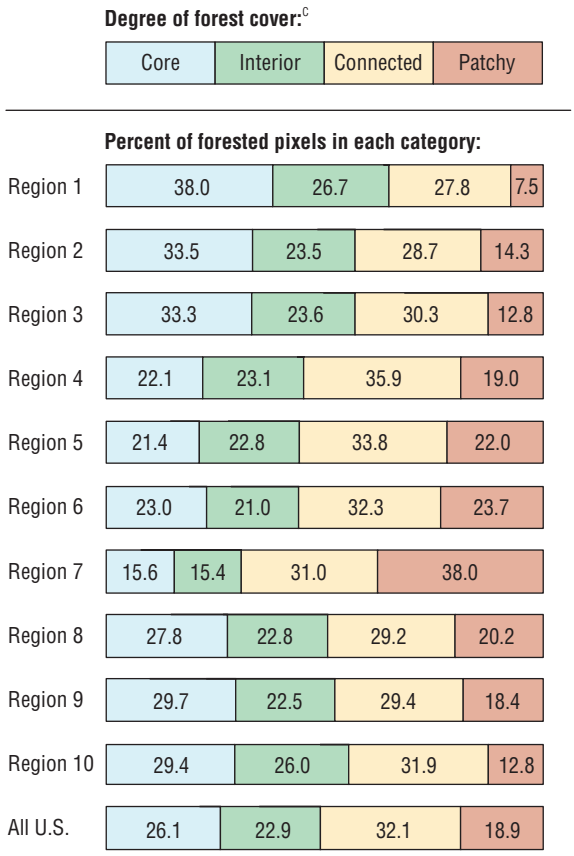
Indicator Limitations

- 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).

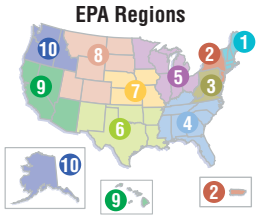
Exhibit 6-5. Forest fragmentation in the contiguous U.S. by EPA Region, based on 2001 NLCD[a,b]



[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*

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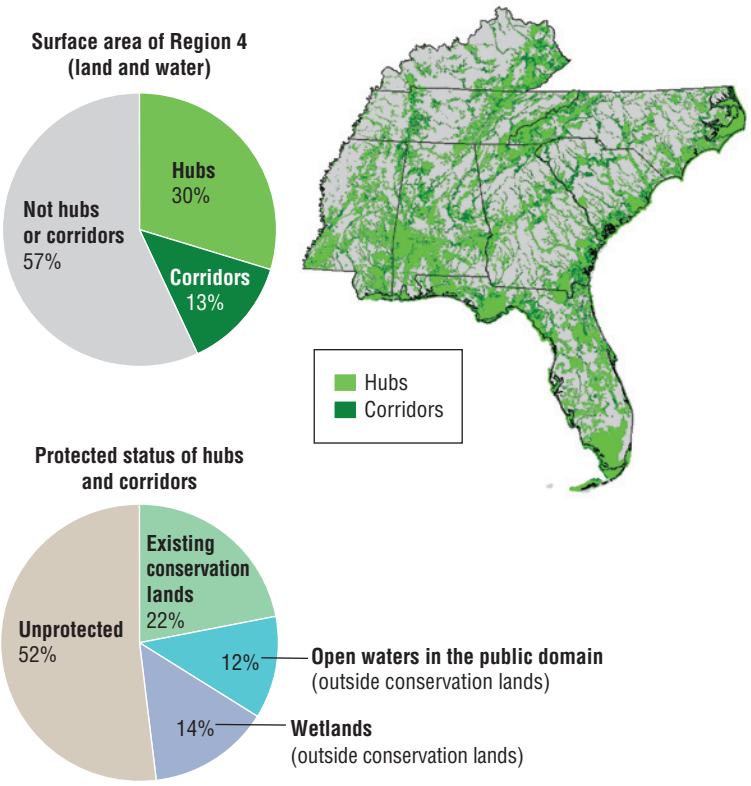
INDICATOR | Ecological Connectivity in EPA Region 4

As part of their natural functioning, ecological systems remove particulate matter and carbon dioxide from the air, purify surface and ground water, reduce flooding, and maintain biological diversity. These functions depend on a connected ecological "framework" of high-quality land consisting of central hubs interconnected by corridors that provide for the movement of energy, matter, and species across the landscape. This framework of connectivity is threatened by agricultural and silvicultural practices, road development, and "urban sprawl" that fragment the landscape. Maintaining ecological connectivity protects the entire system.

The Ecological Connectivity Indicator (ECI) developed by EPA Region 4 (Durbrow et al., 2001) consists of a framework that captures the connectivity of important natural areas and ecological systems across the landscape of the Region (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee). Four ecological aspects contribute to the functionality of the ECI infrastructure (see Carr et al., 2002, for additional details). The most important of the four, hub and corridor connectivity, forms the basis for this indicator. Hub and corridor connectivity shows the connections among critical ecological systems in the Region. Hubs are large areas of important natural ecosystems such as the Okefenokee National Wildlife Refuge in Georgia and the Osceola National Forest in Florida. Connections, referred to as "corridors," are links to support the functionality of the hubs (e.g., the Pinhook Swamp which connects the Okefenokee and Osceola hubs). The ECI framework is based on land cover data obtained from the 1992 National Land Cover Dataset (NLCD), which was constructed from satellite imagery (Landsat) showing the land area of the contiguous U.S. during different seasons (i.e., leaves-on and leaves-off) during the early 1990s. In many locations, the best available Landsat images were collected between 1991 and 1993, with data in a few locations ranging from 1986 to 1995.

Exhibit 6-6. Ecological hubs and corridors in EPA Region 4, based on 1992 NLCD



Data source: *U.S. EPA, 2002*

What the Data Show

The hub and connection framework covers 43 percent of the total land and water resources in EPA Region 4—30 percent classified as hubs and 13 percent as corridors (Exhibit 6-6). Currently, 22 percent of this framework area is protected as conservation land, 12 percent is in the public domain as open water, and an additional 14 percent is classified as wetlands, for a total of 48 percent of hub and corridor acreage being afforded some type of long-term protection.

Indicator Limitations

- Trend information is not available for this indicator. The most important data layer used in the ECI development is the NLCD from the early 1990s. Establishing trends in the indicator may be limited by the availability of comparable land cover/land use data in the future.
- Due to both the limited availability of data (ecological data not available or not in digital or geographic information system [GIS] format) and the Southeastern Ecological Framework (SEF) parameter that sets a size threshold of 5,000 acres for ecological hubs, the results do not comprehensively include each and every ecologically important area in the Southeast. The appropriate geographic scale of connectivity depends on the species and communities that are the focus of particular protection efforts (Carr et al., 2002).

INDICATOR | Ecological Connectivity in EPA Region 4 *(continued)*

Data Sources

The hub and corridor map was provided by EPA Region 4's SEF project, and is available as a GIS data layer from the SEF Web site's data page (U.S. EPA, 2002) (http://geoplan.ufl.edu/epa/data.html). The summary statistics shown in the pie charts in Exhibit 6-6 are presented in Carr et al. (2002). This analysis was based on the 1992 NLCD (USGS, 2005) (http://landcover.usgs.gov/natllandcover.php) and several additional datasets described in Carr et al. (2002); input data layers can be obtained on CD by following instructions on the SEF Web site (U.S. EPA, 2002).

References

Carr, M.H., T.D. Hoctor, C. Goodison, P.D. Zwick, J. Green, P. Hernandez, C. McCain, J. Teisinger, and K. Whitney. 2002. Final report: Southeastern Ecological Framework. Region 4. Atlanta, GA: U.S. Environmental Protection Agency. <http://geoplan.ufl.edu/epa/download/sef_report.pdf>

Durbrow, B.R., N.B. Burns, J.R. Richardson, and C.W. Berish. 2001. Southeastern Ecological Framework: A planning tool for managing ecosystem integrity. In: Hatcher, K.J., ed. Proceedings of the 2001 Georgia Water Resources Conference. Athens, GA: University of Georgia.

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INDICATOR | Relative Ecological Condition of Undeveloped Land in EPA Region 5

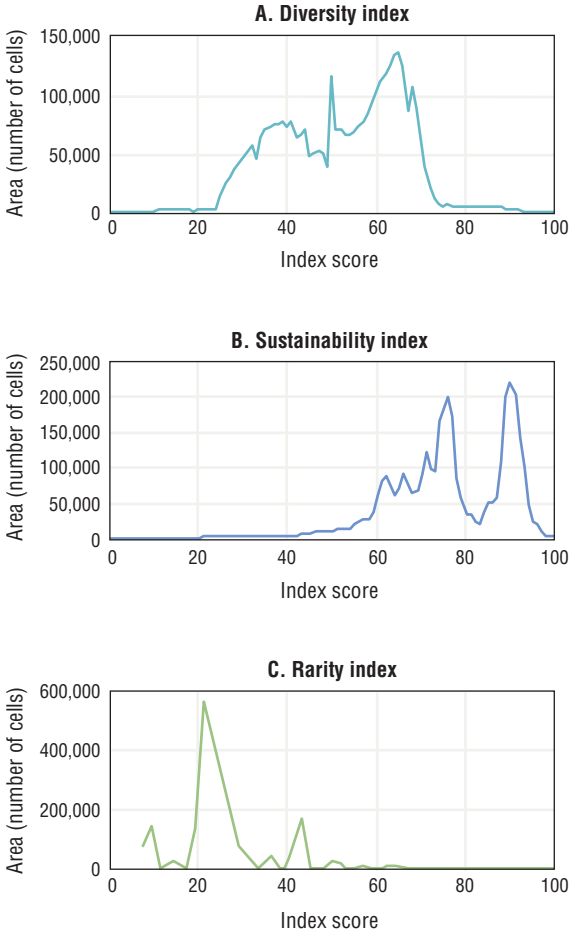
Ecological condition in the ROE is approached using questions broadly relating to landscape, biological diversity, ecological function, and the physical and chemical makeup of the environment, but no attempt is made at the national level to capture ecological condition in a small number of indices. In this indicator, the ecological condition of undeveloped land in EPA Region 5 (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin) is characterized based on three indices derived from criteria representing diversity, self-sustainability, and the rarity of certain types of land cover, species, and higher taxa (White and Maurice, 2004). In this context, "undeveloped land" refers to all land use not classified as urban, industrial, residential, or agricultural.

Geographic units referred to as cells are used to quantify geographic information. A spatially explicit model using ecological theory and geographic information system (GIS) technology was used to create 20 data layers of 300-meter by 300-meter cells. These layers originate from several sources, including water quality datasets, state Natural Heritage Program databases (for species abundance), and the 1992 National Land Cover Dataset (NLCD), which was constructed from satellite imagery (Landsat) showing the land area of the contiguous U.S. during different seasons (i.e., leaves-on and leaves-off) during the early 1990s. In many locations, the best available Landsat images were collected between 1991 and 1993, with data in a few locations ranging from 1986 to 1995. For this indicator, data layers were combined to generate three indices, which represent estimates of three criteria:

- **Ecological diversity.** The relative diversities of populations (species), communities, and ecological systems in any given location on the landscape. Four data layers were used to derive this index.
- **Ecological self-sustainability.** The potential for an ecological system to persist for years without external management; it is negatively impacted by two factors: landscape fragmentation and the presence of chemical, physical, and biological stressors. Twelve data layers were used to derive this index.
- **Rarity.** The rarity of land cover, species, and higher taxa. Four data layers were used to derive this index.

The model produces composite layers that are statistically independent. The scores for each criterion are normalized from 1 to 100 and each layer contributes equally to the final index (all of the data layers are weighted equally). In all the data layers and the resultant criteria layers, scores are normalized from 0 to 100. Zero always indicates the lowest quality, the greatest stress, or the least valuable observation, and 100 indicates the highest quality, least stress, or most valuable observation. While

Exhibit 6-7. Distribution of index scores for the relative ecological condition of undeveloped land in EPA Region 5, 1990-1992[a]



[a]**Coverage:** Undeveloped land in EPA Region 5, based on the 1992 National Land Cover Dataset (NLCD). For this analysis, "undeveloped" land is any land that the NLCD classifies as bare rock/sand/clay, deciduous forest, evergreen forest, mixed forest, shrubland, grasslands/herbaceous, woody wetlands, emergent herbaceous wetlands, or open water.

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

it has not been done for this indicator, the three composite scores can be summed to result in a final "ecological condition" score for each cell (White and Maurice, 2004). Cell counts (a measure of geographic coverage) are used to indicate the distributions of scores associated with three index scores of ecological condition of undeveloped land: diversity, sustainability, and rarity.

What the Data Show

The frequency distributions of the 1992 baseline scores are quantified and plotted for each criterion (Exhibit 6-7), and these provide a baseline against which to track future landscape trends in diversity, sustainability, and rarity. Diversity scores generally run from 20 to 80 across the region, signifying that most areas are in the moderate diversity range. More than 90 percent of the region has sustainability scores above 50, but rarity scores above 50 are seldom encountered. The highest index scores are found largely in the northern forests of Minnesota, Wisconsin, and Michigan and along the large rivers in Ohio, Indiana, and Illinois (Exhibit 6-8).

Indicator Limitations

- Trend information is not available for this indicator. Establishing trends in the indicator may be limited by the availability of comparable land cover/land use data in the future.
- Although this indicator is designed to be comparable across undeveloped land within Region 5, layers were ranked within ecoregions for some of the components in order to account for different geophysical, geochemical, or climatic features of each ecoregion.
- Aquatic systems and connectivity resulting from water flow paths are not adequately covered and small, but potentially keystone, systems are not a part of the analysis (U.S. EPA, 2005).
- The data layers that contribute to each index were weighted equally, which may not reflect the actual relative importance of each layer (U.S. EPA, 2005).
- The resolution and uncertainty of the results make comparing the ecosystem condition score for one individual cell (300 meters by 300 meters) with another inappropriate, but this is not the case for comparison

INDICATOR | Relative Ecological Condition of Undeveloped Land in EPA Region 5 *(continued)*

between larger landscapes (U.S. EPA, 2005).

- The model has not yet been field-validated to ensure that modeled results reflect actual ecosystem condition.

Data Sources

Maps and frequency distributions for the three indices were provided by EPA Region 5 (U.S. EPA, 2006). An EPA report available online contains several related maps produced by the Critical Ecosystem Assessment Model (CrEAM), along with a list of the various datasets used as inputs for the model (White and Maurice, 2004, appendices). Results from the CrEAM model are no longer available as digital map layers.

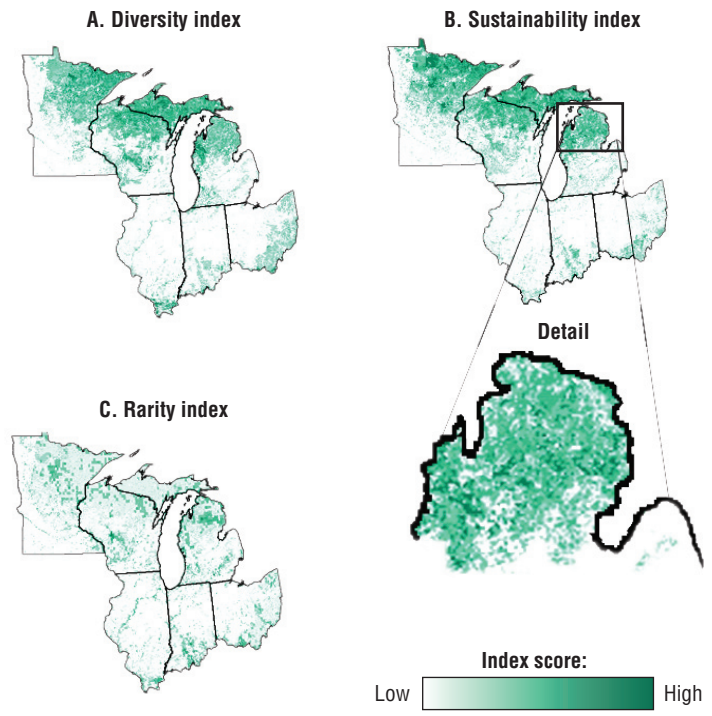
References

U.S. EPA (United States Environmental Protection Agency). 2006. Data provided to ERG (an EPA contractor) by Mary White, EPA Region 5. August 3, 2006.

U.S. EPA. 2005. SAB review of the EPA Region 5 Critical Ecosystem Assessment Model. EPA/SAB/05/011. Washington, DC. <http://yosemite.epa.gov/sab%5CSABPRODUCT.NSF/A6D38FFBCAB115E38525702A006B6A86/$File/cream_sab-05-011.pdf>

White, M.L., and C. Maurice. 2004. CrEAM: A method to predict ecological significance at the landscape scale. Chicago, IL: U.S. Environmental Protection Agency.

Exhibit 6-8. Relative ecological condition of undeveloped land in EPA Region 5, 1990-1992[a]



[a]**Coverage:** Undeveloped land in EPA Region 5, based on the 1992 National Land Cover Dataset (NLCD). For this analysis, "undeveloped" land is any land that the NLCD classifies as bare rock/sand/clay, deciduous forest, evergreen forest, mixed forest, shrubland, grasslands/herbaceous, woody wetlands, emergent herbaceous wetlands, or open water.

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

6.2.3 Discussion

What These Indicators Say About Trends in Extent and Distribution of the Nation's Ecological Systems

While ecological systems are interconnected and overlapping, it is useful to discuss trends in terms of major types of systems. As previously mentioned, there are many ways to define ecological systems, including by the predominant biota, spatial scales, and physical characteristics. Most terrestrial systems are defined by predominant vegetation types. The current extent of these types has been assessed (see the Land Cover indicator, p. 4-7). Forests form the predominant land cover in the eastern and northwestern U.S. while grasslands, shrublands, and agricultural lands are the predominant types of vegetation in the central and western parts of the country. Trends in forest and wetland ecological systems are considered below. Trends in land development also are discussed, as this influences trends in the extent of ecological systems.

Trends in Extent and Distribution of Forested Ecological Systems

At a national scale, the percentage of forest land has varied somewhat over the last century with some decreases and some recent increases (see the Forest Extent and Type indicator, p. 6-8). Over the same period, shifts in regional distribution and species composition have occurred. For example, forested ecological systems decreased in extent in EPA Regions 6 and 9 over the last century, but increased in extent in Regions 1, 2, 3, and 5. The complex of tree species within a forest can have

a strong influence on the community structure and functioning of a forested ecological system, and these assemblages can change over time. On a broad geographic scale, some forest types have more than doubled in acreage in the last 50 years—for example, maple-beech-birch in the eastern U.S. and fir-spruce in the West. At the same time, some other types of forest have decreased in acreage. These compositional changes can be as important as changes in the overall extent of forested ecological systems.

At a finer regional scale, forest cover in the Puget Sound and Georgia Basin in the Pacific Northwest also was relatively stable during the 1990s (see the Land Cover in Puget Sound/Georgia Basin indicator, p. 4-10). However, some of the forested watersheds experienced a conversion of small amounts of forest land to some other cover type. As discussed below, urbanization of low-elevation forested watersheds is a change that is receiving particular attention (see the Land Cover in Puget Sound/Georgia Basin indicator, p. 4-10).

While extent and species composition are important aspects of forested ecological systems, the spatial arrangement and contiguity of the systems also influence the functioning of the systems and the distribution of wildlife species that use forests and adjacent areas for habitat. Fragmentation of forested systems can reduce or redefine the interconnections within forests, modifying the scale of habitat and shifting distributions of wildlife species. For example, increasing fragmentation due to forest clearing, development, fires, or other activities creates more edge habitat and limits the acreage of interior habitat. Groups of wildlife species may prefer one habitat over another and move to maximize the time spent in the preferred habitat type. Nationwide, almost one-fifth of forests are highly fragmented or "patchy," although more than 30 percent of the forests in the heavily forested Regions 1, 2, and 3 are virtually unfragmented "core" forest (see the Forest Fragmentation indicator, p. 6-11).

Ecosystem connectivity, characterized by ecosystem "hubs" connected to each other by "spokes" that serve as corridors for the interaction of biota, was shown to account for about 40 percent of the land cover in EPA Region 4, the southeastern U.S. (see the Ecological Connectivity in Region 4 indicator, p. 6-13). In this indicator, connectivity includes not only forested land but also wetlands and open water.

Trends in Extent and Distribution of Wetland Ecosystems

Wetlands are ecosystems of high biological diversity and support a number of ecological functions from nursery and breeding areas to food and protection.[16] Whether inland or coastal, freshwater or marine, wetland acreage has declined over the past 50 years (see the Wetlands indicator, p. 3-32). The extent of the losses varies by type of wetland, with forested wetlands losing the most acreage and coastal wetland loss slowing somewhat.

Trends in Land Development

"Land use" refers to the visible effects of human use (see the Land Use indicator, p. 4-14). Changes in land use from forested or wetland systems to urban or agricultural environments have a direct impact on the ecological systems within which the change occurs, as well as on systems that are interconnected with the altered areas (e.g., watersheds and coastal areas). Some changes can create edge environments that are favored by certain wildlife species. Therefore, trends in land development are important considerations with respect to overall trends in the extent and distribution of ecological systems.

Changes in land use sometimes result in changes in land cover and conversion from one major ecosystem type to another, but sometimes they do not. For example, gains in agricultural productivity have caused significant changes in the extent and location of crop and pasture land uses. Some land that had been used for crops or pasture has reverted to forest. Timber production may convert cropland to forest, or it may do little more than substitute one forest type or age-class distribution for another. At the same time, growth in population has driven an increase in the extent of developed land, much of which has converted crop or pasture land to developed land.

At a national scale over the last three decades, crop and farm acreages have decreased, timberland (productive forest land) has remained fairly constant, and developed lands have increased (see the Land Use indicator, p. 4-14). Within the larger-scale trends, many subtle shifts occur at smaller scales. The increase in developed lands has received particular attention in National and Regional Indicators.

Increases in the numbers and changes in the spatial distribution of human populations explain part of the increase in developed lands. However, developed land increased by almost two times the increase in population from 1982 to 2003, suggesting that during this period people were making a proportionally greater use of the landscape (see the Urbanization and Population Change indicator, p. 4-19). Geographically, the rate of development was four times the population growth rate in the Northeast, one to three times the population growth rate in the South and Midwest, and nearly equal to the growth rate in the West. The increases in developed land suggest there were comparable decreases in other types of lands. To the extent that these other lands afford habitat to animals and plants, shifts in land use result in shifts in the extent and distribution of ecological systems. Increases in developed land also impact physical and chemical factors; for example, more runoff from impervious surfaces leads to greater loading of nutrients and contaminants, more unstable hydrology, reduced ground water inputs, and increased stream temperatures.

The degree of change in developed lands appears to be associated with types of locations that emerge as focal points for increasing stress on ecological systems. For example, in the Puget Sound and Georgia Basin area of the Pacific Northwest,

[16] Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. Washington, DC: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

forest conversion to other types of land use is occurring along the coast while older growth forests are observed at higher elevations (see the Land Cover in Puget Sound/Georgia Basin indicator, p. 4-10). Further, trends indicate that impervious surface coverage is increasing to the point where detrimental impacts to aquatic resources may occur.[17] In the Great Lakes region, most of the undeveloped lands occur in the northern forests or along the major rivers (see the Condition of Undeveloped Land in Region 5 indicator, p. 6-14). Proximity to developed areas has an obvious effect on the quality of these ecological systems. The highest quality systems make up about 3 percent of the total and are located in the most remote and/or protected areas.

Limitations, Gaps, and Challenges

While many of the indicators in this section provide baseline information, trend information is available for only a few of the major types of systems—forests and wetlands. There are no ROE indicators for other types of terrestrial or aquatic systems including grasslands, shrublands, and marine hard bottom communities such as coral reefs, or for finer-scale ecosystem classifications such as riparian zones or habitat for threatened and endangered species. Filling these gaps in information would help EPA to better evaluate trends in ecological condition.

One of the challenges in capturing meaningful changes relates to location and scale. The importance of location-specific changes is evident in some of the indices. For example, small changes in certain areas, such as near-coastal areas of the Pacific Northwest, could have disproportionately large effects on coastal waters relative to a similar change in the middle of an expansive prairie. In addition, the appearance of fragmentation in ecological systems depends on the area over which data were extracted.[18] Thus, choosing locations and assessment areas have obvious impacts on trend assessment. Conversely, the implications of trends are manifested at scales that are location- and area-specific. Important consequences of changes can be captured or missed depending on how the information is aggregated and presented.

Another challenge relates to understanding the factors underlying changes that occur over various time scales and their effects on human health and ecological condition. Principal among these is recognizing that natural cycles and natural variability bring about changes that may appear as "trends" over one time scale but will appear as cycles or variations over longer time scales. Familiar examples include population variations among predators and prey or temperature variations associated with the advance and retreat of ice ages. Distinguishing these natural cycles and variations from trends caused by human-induced perturbations is yet another challenge. In some cases the relationships may be evident, as in the influence of urbanization on watersheds or the impact of lost sand dunes on subsequent beach erosion. In other cases factors influencing changes may be difficult to discern, such as long-term shifts in major plant communities.

6.3 What Are the Trends in the Diversity and Biological Balance of the Nation's Ecological Systems?

6.3.1 Introduction

Trends in the biological diversity of the nation's ecological systems can be viewed in terms of both the numbers of species present in an ecological system and the extent to which some of the species are threatened or endangered. "Biological balance" refers to the interrelationships among organisms, including the structure of food webs and the ability of ecological systems to maintain themselves over time. Balance is a dynamic characteristic rather than a fixed state.

The biological diversity and balance within ecological systems are often used to judge the health of the system, and their reduction often represents a response to pollutants or other stressors. Restoring biodiversity and biological balance has been a focus of EPA's attention over the past three decades. Reversing declines of species such as the brown pelican (caused by pesticides) and brook trout (caused by acid rain), replacing nuisance algal blooms caused by excess nutrients with balanced communities of phytoplankton, replacing beds of sludge worms below wastewater discharges with balanced communities of benthic invertebrates, and restoring biological communities previously decimated by improper handling of toxic and hazardous wastes are well-known examples.

The significance of biological diversity also stems from the fact that, for many people, biological diversity contributes to the quality of life.[19] Everyone recognizes the importance of species as commodities (if those species produce products that can be bought and sold), and some argue that species have moral value in and of themselves.

Diversity and biological balance are also of interest because of how they may influence the functioning and stability of ecological systems.[20,21] While scientists debate the exact relationship between the diversity and the functioning and

[17] Klein, R.D. 1979. Urbanization and stream water quality impairment. Water Resour. Bull. 15(4):948-963.

[18] USDA Forest Service. 2004. National report on sustainable forests—2003. <http://www.fs.fed.us/research/sustain/>

[19] Norton, B. 1988. Commodity, amenity, and morality: The limits of quantification in valuing biodiversity. In: Wilson, E.O., ed. Biodiversity. Washington, DC: National Academies Press.

[20] Chapin III, F.S., B.H. Walker, R.J. Hobbs, D.U. Hooper, J.H. Lawton, O.E. Sala, and D. Tilman. 1997. Biotic control over the functioning of ecosystems. Science 277(5325):500-504.

[21] Wilson, E.O. 1992. The diversity of life. Cambridge, MA: Belknap Press.

stability of ecological systems, it is generally agreed that as the number of species in any particular type of ecological system declines, there is a potential loss of resilience within that system.[22] It is also recognized that these relationships are not straightforward and can vary in degree depending on the types of species introduced to or removed from a system.[23]

Diversity and balance have important time and space components. Diversity arises over time as adaptation results in new species that fill available niches in the environment. This is a dynamic process involving colonization, evolution of species adapted to new conditions, and extinction of species that are less well adapted to a changing environment. This process has occurred over thousands or millions of years over large geographic areas, punctuated occasionally by events such as large meteor impacts, periods of intense volcanism, and ice ages. Ecological systems that are stable in the short term evolve into different systems in the long term. Disturbances that reduce biological diversity or disrupt balance on a small scale may not have an effect on a larger scale or over longer time periods.

Changes (decreases and increases) in biological diversity have likely occurred throughout the history of the U.S. in response to regional land use changes, water management, intentional and unintentional introductions of species, and environmental pollution. Other changes in diversity and the composition of the biological community can be rapid and dramatic. Introduced plants and plant pathogens can rapidly transform landscapes as some species, such as the American chestnut, are lost and others, such as kudzu, thrive. Introduction of the sea lamprey to the Great Lakes led to sweeping changes in the entire food chain, from lake trout all the way down to the phytoplankton.[24] Declining sea otter populations led to loss of kelp forests, as sea urchins formerly preyed upon by otters grazed the kelp down to the sea floor.[25] The decimation of grazers such as the American Bison or predators such as grizzly bear or wolves has had cascading impacts on upland vegetation, wetlands, fish, and other species.[26] Toxic chemical pollution can create wastelands where only the most resistant species can survive, and nutrients and acid rain have had indirect effects on diversity and balance by causing sweeping changes in the chemical habitat.

Indicators of diversity and biological balance incorporate information about primary producers and invertebrate and vertebrate consumers, especially keystone species that play critical roles in structuring habitat or serve major roles as primary producers, top predators, or important prey species. Indicators of invasive species are also important with respect to assessing trends in diversity and biological balance because these species can alter the nation's ecological systems by displacing indigenous species, potentially changing the structure of biological communities.

6.3.2 ROE Indicators

Trends in diversity and balance are evaluated using four National Indicators and two Regional Indicators (Table 6-3). The focus for this question is on national- or regional-scale trends in biological diversity or balance over time spans of one to three decades. The data on biological diversity and

Table 6-3. ROE Indicators of Trends in Diversity and Biological Balance of the Nation's Ecological Systems

National Indicators	Section	Page
Coastal Benthic Communities (N/R)	3.5.2	3-44
Benthic Macroinvertebrates in Wadeable Streams	3.2.2	3-21
Bird Populations	6.2.2	6-20
Fish Faunal Intactness	6.2.2	6-21
Regional Indicators	**Section**	**Page**
Submerged Aquatic Vegetation in the Chesapeake Bay	3.5.2	3-46
Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest	6.2.2	6-23

N/R = National Indicator displayed at EPA Regional scale

[22] McCann, K.S. 2000. The diversity-stability debate. Nature 405(11):228–233.

[23] Srivastava, D.S., and M. Vellend. 2005. Biodiversity-ecosystem function research: Is it relevant to conservation? Annu. Rev. Ecol. Syst. 36:267–294.

[24] Eck, G.W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife (Alosa pseudoharengus). Can. J. Fish. Aquat. Sci. 44(Suppl. 2):53–60.

[25] Estes, J.A., and J.F. Palmisano. 1974. Sea otters: Their role in structuring nearshore communities. Science 185:1058–1060.

[26] Pritchard, J.A. 1999. Preserving Yellowstone's natural conditions: Science and the perception of nature. Lincoln, NE: University of Nebraska Press.

balance come from a variety of sources, including both systematic monitoring and ad hoc data collection.[27] Systematic probability surveys are now providing national pictures of the biological diversity of benthic communities in estuaries and in rivers and streams. The Breeding Bird Survey is a private sector effort that provides valuable national-level data on trends in bird populations.

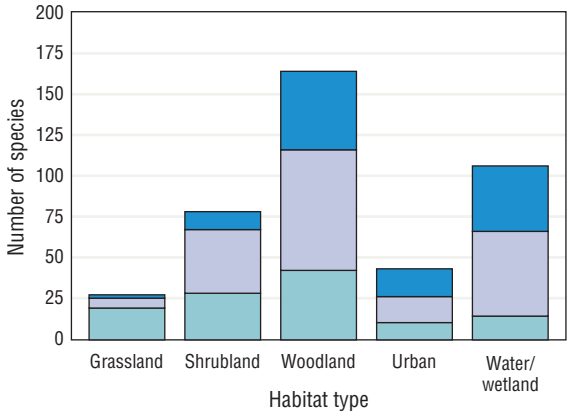
Trends involving longer-term effects associated with climate change are not included. Many issues regarding biodiversity at subregional and local scales (e.g., tall-grass prairie or the Okefenokee Swamp) that cannot be covered here are no less important.

INDICATOR | Bird Populations

Bird populations are among the most visible biological components of ecological systems, supporting a number of important ecological functions including seed dispersal, plant pollination, and pest control. Some birds migrate over entire continents, while others have more restricted ranges and habitats, but in all cases trends in bird populations and in the abundance of species integrate the influences of changes in landscape and habitat, the availability and quality of food, toxic chemicals, and climate. The North American Breeding Bird Survey (BBS) began in 1966 with approximately 600 surveys conducted in the U.S. and Canada east of the Mississippi River. Today there are approximately 3,700 active BBS routes across the continental U.S. and southern Canada (Sauer et al., 1997).

Trends have been computed for observed population sizes of 418 bird species for the 1966–2003 period (Sauer et al., 2004). The Audubon Society (2004) categorized each species according to its primary habitat: grassland, shrubland, woodland, urban, and water and wetlands. This indicator reflects the number of species with "substantial" increases or decreases in the number of observations (not a change in the number of species) for which adequate trend data exist between 1966 and 2003. Substantial increases or decreases were defined for this study as those in which the observed populations on BBS routes increased or decreased by more than two-thirds between 1966 and 2003; this designation does not necessarily imply a statistically significant trend.

Exhibit 6-9. Changes in bird populations in the contiguous U.S. and southern Canada, by habitat type, 1966-2003[a]



[a]**Coverage:** 418 bird species studied as part of the North American Breeding Bird Survey (BBS), which covers the contiguous U.S. and southern Canada.

[b]Increases or decreases are considered "substantial" if the observed population on BBS routes increased or decreased by more than two-thirds from 1966 to 2003.

Data source: *Audubon Society, 2004*

Population change:[b]
- Substantial increase
- No substantial change
- Substantial decrease

What the Data Show

The results point to dynamic changes in observed bird populations in all habitat types (Exhibit 6-9), although there were no consistent increases or decreases.

- Of 27 grassland species for which adequate data are available, only two species (7 percent) showed substantial observed population increases and 19 species (70 percent) showed substantial decreases.
- Of 78 shrubland species for which adequate data are available, 11 species (14 percent) showed substantial increases, while 28 species (36 percent) showed substantial declines.
- Of 164 woodland species for which adequate data are available, 48 species (29 percent) showed substantial observed population increases and 42 species (26 percent) showed substantial decreases.
- Of 43 primarily urban species for which adequate data are available, 17 species (40 percent) showed substantial observed population increases and 10 species (23 percent) had substantial decreases.
- Of 106 water and wetland bird species for which adequate data are available, 40 species (38 percent) showed substantial observed population increases and 14 species (13 percent) showed substantial decreases.

Indicator Limitations

- The BBS produces an index of relative abundance rather than a complete count of breeding bird populations. The

[27] There are no systematic national efforts to quantify trends in the diversity of other vertebrate, invertebrate, plant, or microbial species, but a private sector organization, NatureServe, working in concert with state Natural Heritage Programs, has done much to assimilate and integrate data from ad hoc and systematic studies to assess the status of nearly 40,000 U.S. species and to quantify populations of more than 20,000 at-risk species.

INDICATOR | Bird Populations *(continued)*

data analyses assume that fluctuations in these indices of abundance are representative of the population as a whole.

- The BBS data do not provide an explanation for the causes of observed population trends. To evaluate population changes over time, BBS indices from individual routes are combined to obtain regional and continental estimates of trends. Although some species have consistent trends throughout the history of the BBS, most do not. For example, populations of permanent resident and short-distance migrant species (birds wintering primarily in the U.S. and Canada) are adversely affected by periodic episodes of unusually harsh winter weather.
- Few species have consistent observed population trends across their entire ranges, so increases or decreases in this indicator may not reflect the situation across the entire range of the species.

Data Sources

Trend data were obtained from the Audubon Society's 2004 *State of the Birds* report (Audubon Society, 2004). Audubon's analysis used raw data from the National Breeding Bird Survey (USGS, 2004), which can be downloaded from http://www.pwrc.usgs.gov/bbs/retrieval/menu.cfm.

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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.

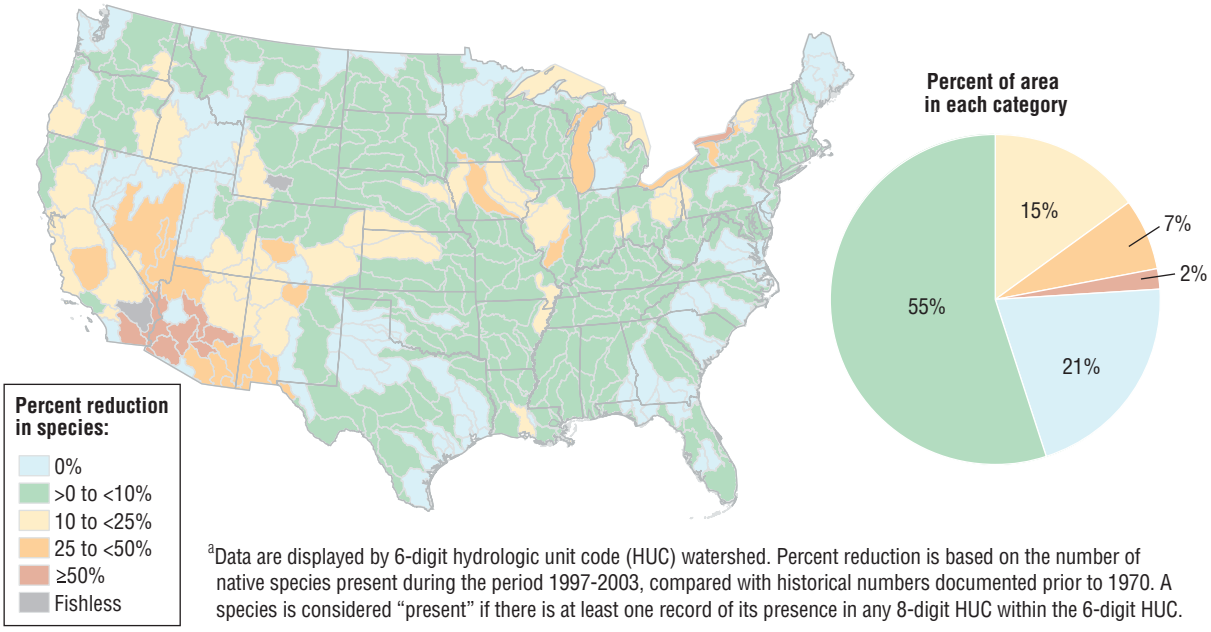
Reductions in watershed diversity may be due either to the overall extinction of a species (at least 12 U.S. freshwater fish species are known to be extinct and another three species are known only from historical records and may be extinct) or, more commonly, to the extirpation of a species from selected 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*

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).

References

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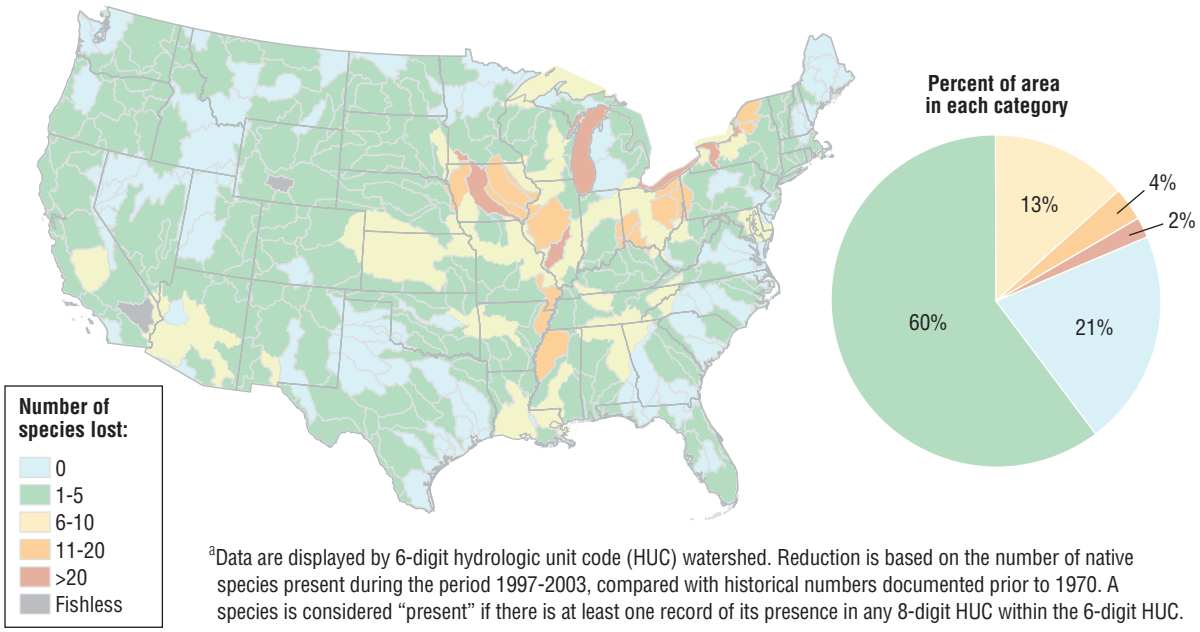
Master, L.L, S.R. Flack, and B.A. Stein. 1998. Rivers of life: Critical watersheds for protecting freshwater biodiversity. Arlington, VA: The Nature Conservancy. <http://www.natureserve.org/publications/riversOflife.jsp>

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*

NatureServe. 2006. NatureServe explorer. Accessed 2006. <www.natureserve.org/explorer>

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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>

INDICATOR | Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest

Non-indigenous species (NIS) are one of the greatest threats to aquatic ecosystems and can impact local and regional economies (Lowe et al., 2000). The number of invasive species in estuaries of the Pacific Northwest (including Puget Sound, Columbia Estuary, and Coos Bay) is rising, and these areas can become sources of invasives to other locales. Coastal waters are particularly vulnerable to NIS transported in ballast water and introduced via aquaculture (Puget Sound Action Team, 2002). It is becoming apparent that NIS are capable of impacting estuaries along the Pacific coast, even though they are rarely addressed in routine monitoring studies. One limitation is the lack of standardized invasion metrics and threshold values.

This indicator focuses on estuarine soft-bottom communities of the Columbian Biogeographic Province located along the Pacific coast from Cape Mendocino, California, north to the Strait of Juan de Fuca at the entrance to Puget Sound, Washington. It is limited to sites with salinities of 5 parts per thousand or higher. The indicator is based on the percent abundance of NIS individuals relative to the combined abundance of native and NIS individuals in a benthic grab sample.

The data for this indicator were collected by EPA's Environmental Monitoring and Assessment Program (EMAP) using a probability survey over the 1999-2001 period (Nelson et al., 2004, 2005) and by a special probabilistic study

INDICATOR | Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest *(continued)*

focusing on estuaries not exposed to ballast water or aquaculture. Probability sampling provides unbiased estimates of the percent abundance of natives and NIS in all estuaries in the study area, but because the data for the special study have not yet been statistically expanded, data for this indicator are based on stations sampled rather than area.

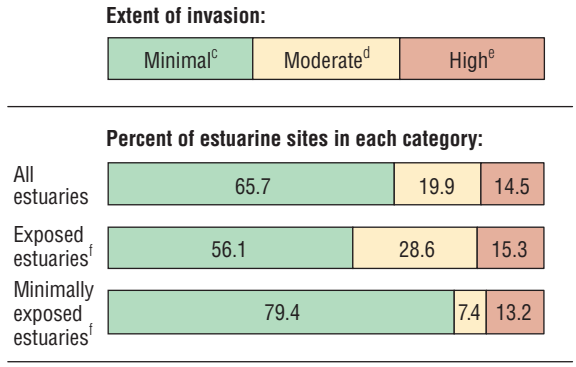
Interpretation of this indicator requires threshold values to distinguish among different levels of invasion. To determine the lowest expected level of invasion within the Columbian Biogeographic Province, EPA examined the extent of invasion in estuaries with minimal exposure to ballast water discharges and aquaculture of exotic oysters, which are the primary invasion vectors in the region. Using observed percentages of NIS at the minimally exposed estuaries as a reference, the threshold for "minimally invaded" survey sites was set at 10 percent NIS (i.e., sites were classified as minimally invaded if NIS constituted 0 to 10 percent of the individuals collected). Survey sites were classified as "highly invaded" if NIS were more abundant than native species (more than 50 percent NIS) and as "moderately invaded" if NIS constituted 10 to 50 percent of the individuals.

What the Data Show

Approximately 15 percent of the stations in the Columbian Province were highly invaded (i.e., abundance of NIS was greater than abundance of natives) and another 20 percent were moderately invaded (Exhibit 6-12). The EMAP survey showed that NIS were among the most frequently occurring anthropogenic stressors in this biogeographic region when compared to indicators of sediment contamination or eutrophication (Nelson et al., 2004).

The extent of invasion was not uniform, however, among exposed and minimally exposed estuaries. Estuaries with greater exposure to these invasion vectors were more invaded; 44 percent of the stations in the exposed estuaries were moderately to highly invaded compared to only 21 percent of the stations in minimally exposed estuaries (Exhibit 6-12). Nonetheless, the observation that 21 percent of the stations in these "pristine" estuaries were at least moderately invaded indicates that NIS can disperse widely once they are introduced into a region, so even estuaries with no direct exposure to ballast water or aquaculture are at risk of invasion.

Exhibit 6-12. Relative abundance of non-indigenous benthic species in estuaries of the Pacific Northwest, 1999-2001[a,b]



[a]**Coverage:** Soft-bottom estuaries between Cape Mendocino, CA, and the Strait of Juan de Fuca, WA (limited to sites with salinity ≥5 parts per thousand).

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

[c]**Minimally invaded:** 0-10% of benthic organisms belong to non-indigenous species

[d]**Moderately invaded:** >10-50% of benthic organisms belong to non-indigenous species

[e]**Highly invaded:** >50% of benthic organisms belong to non-indigenous species

[f]"Exposed" estuaries have been exposed to ballast water discharges from international shipping and/or aquaculture of exotic oysters. "Minimally exposed" estuaries have not.

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

Indicator Limitations

- This indicator presents baseline data only; trend information is not yet available.
- Studies in the San Francisco Estuary (Lee et al., 2003) and in Willapa Bay, Washington (Ferraro and Cole, in progress) have shown that the percent of NIS can vary substantially among different types of soft-bottom communities—e.g., unvegetated sediment versus sea grass beds. Thus, regional background values for the Columbian Province as a whole may not be appropriate for specific community types.
- This indicator represents percent NIS in individual benthic grabs of the soft-bottom community, but does not characterize the total number of NIS in the estuaries. It does not include benthic NIS not subject to grab sampling, particularly hard substrate organisms.
- The data for the indicator were only collected during a summer index period and thus do not capture seasonal variations.

INDICATOR | Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest *(continued)*

- The threshold values for "minimally invaded," "moderately invaded," and "highly invaded" are preliminary and require further research in order to establish their ecological significance. Specific values may differ in other biogeographic provinces.

Data Sources

Data for this indicator were collected by two different studies: EPA's National Coastal Assessment (NCA) and a special EPA study of minimally exposed estuaries. The complete results from these studies were not publicly available at the time this report went to press, but summary data from the 1999 NCA are available from Nelson et al. (2004, 2005), and the underlying sampling data can be obtained from EPA's NCA database (U.S. EPA, 2007) (http://www.epa.gov/emap/nca/html/data/index.html). Results from the special study of minimally exposed estuaries will be published in the near future. Until then, data for this indicator can be obtained from EPA's Western Ecology Division (U.S. EPA, 2006).

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Nelson, W.G., H. Lee II, J.O. Lamberson, V. Engle, L. Harwell, and L.M. Smith. 2004. Condition of estuaries of the western United States for 1999: A statistical summary. EPA/620/R-04/200. <http://www.epa.gov/wed/pages/publications/authored/EPA620R-04200ConditionOfEstuariesOfTheWesternUSNelson.pdf>

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U.S. EPA. 2006. Data provided to ERG (an EPA contractor) by Henry Lee, EPA Western Ecology Division. August 7, 2006.

6.3.3 Discussion

What These Indicators Say About Trends in the Diversity and Biological Balance of the Nation's Ecological Systems

Few national programs track diversity and biological balance. However, there are ROE indicators available for invertebrate communities and select vertebrates (birds and fish) and regionally for invasive species (as these can be important disruptors of ecosystem balance) and important communities of submerged aquatic vegetation (SAV). Some of these indicators show reduced or declining diversity for particular groups of animals and plants, but this is not consistent across all the ROE indicators. The particular trends of available ROE indicators are discussed below by plant and animal groupings, followed by the limitations of the available information and future challenges.

Primary Producers

Primary producers range from the microscopic plants of the oceans to the giant redwoods of California. The types of plants and the biomass they produce are fundamental to ecological systems. For example, SAV is an important biological component of aquatic systems, contributing to diversity and balance by providing habitat and food. While there is no National Indicator of trends in SAV, the SAV in Chesapeake Bay indicator (p. 3-46) provides data on trends in an important regional ecosystem. SAV has increased in the Bay over the past 25 years, but remains below its historical coverage. Contributing factors in the Bay include excessive nutrients, sediment loads, diseases, and physical disturbance.

Invertebrates

Invertebrates such as worms, insects, and crustaceans are among the most diverse group of organisms. Collectively they make up the largest component of animal biomass on the planet and are critical components of aquatic and terrestrial food webs. Trends in the composition of invertebrate communities can reflect important environmental changes.

In the nation's coastal systems, baseline measures of invertebrate biodiversity and species composition indicate that about one-fifth of estuarine area exhibits low biological condition

(see the Coastal Benthic Communities indicator, p. 3-44). Because benthic invertebrates live on or in sediments, it is not surprising that many of these areas also exhibit low sediment and/or water quality. For small streams, the benthic macroinvertebrate Index of Biological Integrity exhibits a broad distribution from low to high values (see the Benthic Macroinvertebrates in Wadeable Streams indicator, p. 3-21).

Vertebrates

The biodiversity of fish, amphibians, reptiles, birds, and mammals is influenced by available food resources, the size and arrangement of suitable habitats, influxes of new species, climate and weather, and the presence of contaminants. Vertebrates often receive much attention because they are highly visible and are often near the top of the food chain.

Among vertebrates the most reliable indicator of national trends is for birds, which have been tracked since 1966 (see the Bird Populations indicator, p. 6-20). Bird populations are in dynamic flux. There appears to be a net decline of observed populations most commonly found in grasslands and shrublands, comparable increases and decreases in observed populations in woodlands, and some gains in observed populations inhabiting urban and water/wetlands areas.

Fish are distributed throughout most of the nation's aquatic and marine ecological systems. Comparisons between current and historical species compositions (see the Fish Faunal Intactness indicator, p. 6-21) indicate that one-fifth of the watersheds of the contiguous 48 states retain their full complement of fish species, while about a quarter have experienced a loss in species of 10 percent or more. Absolute losses have occurred primarily in the Midwest and the Great Lakes, while on a percentage basis, losses have been highest in the Great Lakes and the Southwest.

Invasive Species

The infiltration of new species into areas is a natural phenomenon but can be accelerated through intentional and unintentional introductions. Introduction of species such as kudzu, zebra mussels, grass carp, starlings, and nutria have had profound effects on ecological systems.[28] Many newly introduced species may lack predators or parasites that kept these species under control in their native habitats, allowing them to out-compete resident species and even dominate entire systems. While national data are lacking, the Non-Indigenous Estuarine Species in Pacific Northwest indicator (p. 6-23) shows that in the Columbian Biogeographic Province (from California to Washington), about one-third of the stations sampled were highly or moderately invaded with non-indigenous invertebrates.

Limitations, Gaps, and Challenges

A number of additional ROE indicators would help EPA better address the question of trends in diversity and biological balance. While there are ROE indicators for the extent and distribution of vegetation types, there remain gaps with respect to indicators of plant biodiversity in terrestrial and aquatic ecological systems, including both vascular and non-vascular plants. There is no ROE indicator for threatened and endangered species. Also, there are no ROE indicators for algal blooms in coastal waters, nor are there any comparable indicators for freshwater systems—e.g., the extent of nuisance aquatic plants such as the prolific growths of Eurasian milfoil and water chestnut in lakes and ponds, which continue to create water management problems.[29,30] ROE indicators of climate-related vegetation changes also are lacking (e.g., fluctuations in the extent of kelp beds along the Pacific coast related to El Niño events).[31]

There are no ROE indicators for major groups of vertebrate biota including amphibians, reptiles, and mammals. Because amphibians live both on land and in the water, their diversity and trends in their abundance could be influenced by a wide range of stressors to air, water, and land. Recent reported declines in amphibian populations worldwide indicate that losses are attributable in some areas primarily to overharvesting, in others to loss of habitat, and in still others to unknown causes,[32] but at this time there is no National Indicator that meets the criteria for this report. There also are no ROE indicators for trends in important insect and freshwater shellfish species, coastal fish and shellfish communities, microbial communities in soil and water, or genetic diversity in plant and animal populations, which could affect their viability when stressed by contaminants or habitat alteration.

Modern transportation and international trade in biota for food have caused invasive species to remain a potentially important but poorly quantified source of stress to the diversity and balance of native species. While the Non-Indigenous Estuarine Species in Pacific Northwest indicator (p. 6-23) provides some insight into the potential importance of invasive species, the full significance of accelerated species introductions is not captured by any ROE indicator.

In addition to indicator gaps and limitations, there are challenges to developing indicators of biological diversity and balance even if the data were available. For example, establishing an appropriate time scale for assessing trends in diversity and balance poses a major challenge. Biological variation is expected at annual, decadal, and even longer time scales. Because of the limited time frames over which observations have been made, parsing normal fluctuations in diversity and balance from longer-term trends is difficult. In addition, the level of interest and care of observation can change with time, confounding the determination of actual trends.

[28] Lowe, S., M. Browne, S. Boudjelas, and M. De Poorter. 2000. 100 of the world's worst invasive alien species: A selection from the Global Invasive Species Database. Auckland, New Zealand: World Conservation Union, Invasive Species Specialist Group.

[29] Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian water-milfoil canopies. J. Aquat. Plant Manage. 29:94-99.

[30] Lake Champlain Basin Program Federal Agencies Work Group. 2005. Opportunities for federal action: Managing aquatic non-native nuisance plants and animals. <http://nh.water.usgs.gov/champlain_feds/nonnative.htm>

[31] Dayton, P.K., and M. Tegner. 1984. Catastrophic storms, El Niño, and patch stability in a southern California kelp community. Science 224(4646):283-285.

[32] Stuart, S.N., J.S. Chanson, N.A. Cox, B.E. Young, A.S.L. Rodrigues, D.L. Fischman, and R.W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. Science 306(5702):1783-1786.

Appropriate spatial scales are equally important. Regional Indicators provide helpful insights into stressors affecting diversity and biological balance in some kinds of ecological systems for which there are no National Indicators. In fact, because many ecological systems vary so much by geographic region, compilations of Regional Indicators may provide the only rational approach for identifying meaningful trends. Especially important examples for biological diversity are unique ecosystems such as the Arctic and Pacific islands. Trends in physical characteristics and processes can have far-reaching effects. For example, polar bears represent important keystone species in the nation's Arctic regions, where they are stressed by warming of coastal waters that limit the duration of ice formation. Pacific island biota are stressed by invasive species and a number of other stressors.

6.4 What Are the Trends in the Ecological Processes That Sustain the Nation's Ecological Systems?

6.4.1 Introduction

Ecological systems are sustained by a number of biological, physical, and chemical processes. Collectively, these processes produce organic matter using energy (photosynthesis and chemosynthesis), transfer carbon and nutrients (through food webs and through decomposition), drive soil formation, and enable the reproduction of organisms (e.g., through pollination of plants by insects). Ecological processes also play an important role in providing ecological services such as the provision of natural resources and regulation of air and water quality.[33]

Ecological processes influence the extent, distribution, and biodiversity of systems. If primary production declines, energy flow to higher trophic levels is diminished, potentially compromising the sustainability of animal populations dependent on plants for food. Primary production is influenced by the availability of nutrients. Decreases and increases in nutrients can affect the amounts of primary production as well as the types of plants that grow, with subsequent effects on animals. The successful reproduction of plants and animals depends on the physical and chemical regimes of their environment.

Too much primary production can also cause problems, such as those that occur in eutrophic lakes that experience an overload of nutrient inputs. Eutrophic conditions can alter the composition of animal and plant life and result in reduced oxygen levels due to decomposition of organic matter. For these reasons, management of nutrient inputs is commonly driven by the potential for excessive plant growth.

Primary production and associated carbon cycling (which form the base of food webs), nitrogen cycling (e.g., ammonification and nitrification), nutrient cycling (e.g., phosphorous and other essential elements for sustainability of carbon-based life), and hydrogen/oxygen cycles (implicating hypoxic/anoxic conditions) are fundamental ecological processes within systems. Processes related to the production, transfer, and loss of biomass and the reproduction and death rates of individuals within populations are reflected in various "end states" in time, snapshots of the outcomes of integrated processes. The standing stock of a population or the amounts and types of carbon stored within an ecological system are measures of these end states. While not processes themselves, trends in end states provide some insight into the relative balance among processes. Carbon storage in forests, discussed in this section, is an example of such an end state.

EPA has long been concerned with the impacts of human activities that can affect the rates, types, and timing of ecological processes. In particular, activities that upset the balance between primary production and respiration (e.g., biochemical oxygen demand, nutrients from fertilizers and human waste, and the effects of ultraviolet radiation) and activities that affect sediment erosion and transport are important factors in water quality management. Many pesticides, chemicals used in industry, pollutants, and waste products have the potential to interfere with species reproduction (one of the most important of ecological processes). At local and regional scales, changes in land use that alter the extent and distribution of ecological systems (Section 6.2) directly affect ecological processes within and adjacent to particular areas. Concomitant changes often occur in primary production, nutrient cycling, and erosion and sediment transport. For example, shifts from forested to urban or agricultural lands influence the amounts and types of primary producers, the infiltration of water into soils, and the storage and cycling of carbon and nutrients.

Table 6-4. ROE Indicators of Trends in the Ecological Processes That Sustain the Nation's Ecological Systems

National Indicators	Section	Page
Carbon Storage in Forests	6.4.2	6-28

[33] Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Current state and trends. Washington, DC: Island Press.

6.4.2 ROE Indicators

This section uses one National Indicator (Table 6-4) to examine trends in the ecological processes that sustain ecological systems. Information for this indicator comes from satellite remote sensing, geographic information systems, and independent field studies conducted as part of the USDA Forest Service Forest Inventory and Analysis. It is important to note that the data presented for carbon storage in forests include only forests classified as "timberland," which excludes about one-third of U.S. forest land cover. Timberland is defined as forests capable of producing at least 20 cubic feet per acre per year and not withdrawn from timber utilization by regulation or statute. This is an important distinction between previously illustrated trends in forest extent and type and the following discussion of carbon storage.

INDICATOR | Carbon Storage in Forests

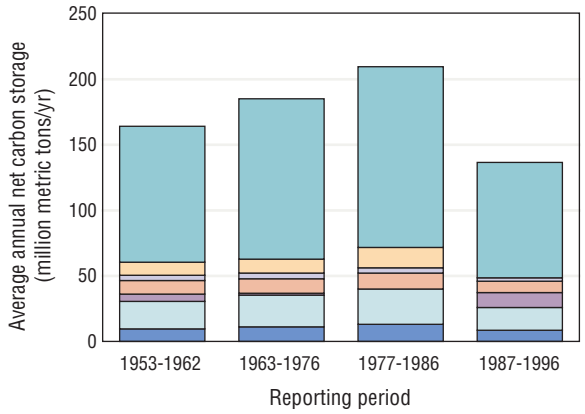
After carbon dioxide is converted into organic matter by photosynthesis, carbon is stored in forests for a period of time in a variety of forms before it is ultimately returned to the atmosphere through the respiration and decomposition of plants and animals, or harvested from forests for use in paper 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

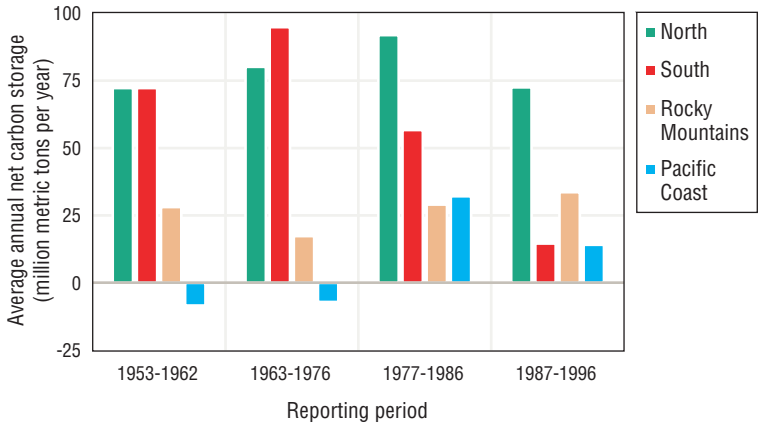
Exhibit 6-13. Average annual net carbon storage in forests of the contiguous U.S., by forest component, 1953-1996[a]



[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.

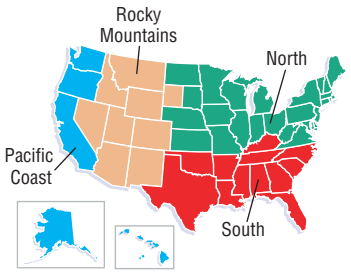
Data source: *USDA Forest Service, 2004a,b*

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*



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).

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.

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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INDICATOR | Carbon Storage in Forests *(continued)*

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USDA Forest Service. 2005. Forest Inventory and Analysis (FIA) database. Accessed 2005. <http://fia.fs.fed.us/tools-data/>

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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.

6.4.3 Discussion

What This Indicator Says About Trends in the Ecological Processes That Sustain the Nation's Ecological Systems

The ROE indicator provides data on trends in primary production and carbon cycles for terrestrial systems.[34] Primary producers capture, store, and supply solar-derived energy to other species in the system. In the forest, the energy currency is organic matter. Primary producers convert carbon dioxide into organic matter, which is then available to species throughout the ecological system as an energy resource and ultimately returns to the atmosphere (see the Carbon Storage in Forests indicator, p. 6-28). For forests, the stability of the system may depend on the balance between carbon stored in standing stock and carbon lost from the system due to harvesting. Net carbon storage has been positive for the last half-century, reflecting an overall gain in forest biomass. The rate of net storage increased between the 1950s and the 1980s, then declined through the mid-1990s. During the 1987-1996 time period, the greatest carbon storage occurred in the North and Rocky Mountain regions where there is more tree growth relative to harvesting, while the greatest decline in storage rates occurred in the South where harvesting has been increasing relative to growth. The distribution of carbon has received much attention, not only from a biological point of view but also with respect to global cycles of carbon. Increases and decreases in carbon storage suggest that other pools of carbon (e.g., within the aquatic and atmospheric environments) are also changing. The distribution of carbon among all these pools reflects a combination of processes and can also influence other chemical, physical, and biological processes.

Limitations, Gaps, and Challenges

Carbon storage trends are important for assessing the future viability of ecological systems, and they have increasing utility in evaluating global carbon cycles and potential climate change. At this time, however, ROE indicators are not available for carbon storage in systems other than forests (e.g., grasslands), and the indicator presented here is restricted to timberland (versus all forest) and does not include carbon storage in soil. Direct measurement can pose a challenge; in this case, statistical models must be employed to estimate carbon storage relationships among different components of the forest ecosystem.

A further limitation of the indicator presented here is that it provides very little insight into other ecological processes across the nation. Indicators are lacking for primary production, nutrient cycling (e.g., nitrogen fixation and denitrification), secondary production, and reproduction and growth rates of populations. Indicators also are lacking for processes such as pollination, decomposition, and removal of contaminants from air and water. EPA recognizes this as a gap in understanding trends in ecological processes. To some degree, information presented in Sections 6.2 and 6.3 gives insight into the net result of ecological processes. Trends in the extent and distribution of ecological systems and in the biodiversity and balance of those systems reflect underlying processes that produce food, cycle nutrients, and sustain populations of plants and animals. Sections 6.2 and 6.3 can be thought of as addressing "end states" that indicate the results of underlying ecological processes. Trends in these end states may or may not pick up important trends in the underlying processes because systems are dynamic and internal relationships are rarely linear. Indicators of ecosystem stability or resilience are potentially important gaps in this regard.

[34] Whitmarsh, J., and Govindjee. 1999. The photosynthetic process. In: Singhal, G.S., G. Renger, S.K. Sopory, K.D. Irrgang, and Govindjee, eds. Concepts in photobiology: Photosynthesis and photomorphogenesis. New Delhi, India: Narosa Publishers; Dordrecht, The Netherlands: Kluwer Academic Publishers. pp. 11-51.

6.5 What Are the Trends in the Critical Physical and Chemical Attributes of the Nation's Ecological Systems?

6.5.1 Introduction

Physical and chemical attributes influence and sustain ecological systems. Critical physical attributes include temperature, light, and hydrology (rainfall, soil moisture, flow rates, and sea level), as well as infrequent physical events that reshape ecological systems, such as fires, floods, and storms. Examples of critical chemical attributes include oxygen, nutrients, pH, salinity, and the presence of other chemicals in the environment.[35] Together, these attributes have driven the evolutionary history of species, and they continue to drive ecological processes, shape the conditions in which species live, and govern the very nature of ecological systems.

Species have evolved within particular physical and chemical environments. These are characterized by mean (i.e., long-term average) conditions as well as by fluctuations on time scales of a day (e.g., tidal and light/dark cycles), seasons (e.g., temperature and hydrological cycles), years (e.g., periodic climatic and fire events), and longer time scales. The occurrence of ice ages every 40,000 to 100,000 years reflects one of the longer time scales. Because critical physical and chemical attributes influence so many aspects of ecological systems, small changes in average conditions or changes in temporal variations can potentially have large effects on the extent and distribution of ecological systems and on the biodiversity of these systems.

Average conditions and the degree and periodicity of fluctuations in physical and chemical attributes vary over the surface of the globe, and species have evolved with specific niche requirements that reflect the physical and chemical states of the ecological systems in which they live. For this reason, a species that has evolved in tropical waters would have temperature requirements that are higher and narrower (the species is less able to tolerate fluctuations) than a species that has evolved in temperate waters where temperatures are lower and more variable. Reproduction and other activity patterns of species are often related to physical and chemical cues such as temperature, light, and salinity. Because species have evolved coincident with the presence (or absence) of physical disturbances, reproductive strategies may be linked with the occurrence of events that otherwise appear destructive. Thus, disturbances such as periodic fires or flooding may be essential for sustaining certain species and ecological systems where these disturbances have been present over evolutionary time scales.

Critical physical attributes reflect, in part, the influence of solar radiation. Solar radiation warms land and water masses and drives hydrologic cycles. The amount of light reaching the surface of the Earth and penetrating into its waters determines levels of photosynthesis, which is essential to the support of biological systems. Other examples of physical, chemical, and biological processes that are influenced by the amount and periodicity of light include temperature and weather conditions, photoactivation of chemicals, mutations, and the timing of reproductive cycles. Solar radiation can also have potentially harmful effects on some species. Light regimes can be influenced by changes in solar energy reaching the earth, changes in the transparency of water, and changes in sea level, which in turn can change the degree of light penetration reaching the sea floor, coral reefs, and kelp forests. The implication of climate change for changes in many aspects of ecological condition has received broad attention.[36,37]

EPA has been actively involved over its three decades in assessing and managing factors that alter the critical chemical and physical characteristics of ecological systems (e.g., temperature, pH, electrochemical [redox] potential, and the transparency of air and water). For example, the use of water for cooling purposes can result in temperature increases in receiving waters of a river, acid rain can lower the pH levels of lakes in sensitive regions, and wastewater and fertilizer can lead to low redox potentials, which affect biological communities and the cycling of both toxic and non-toxic materials. Although EPA is not directly involved in the control of hydrology—an important physical factor in the environment—hydrology greatly influences the fate and transport of pollutants in aquatic ecosystems. Changes in such factors as the amount of runoff or snowpack can affect ground water levels as well as flows into streams and rivers. Flood control efforts can alter flooding and sedimentation processes that sustain particular types of systems. Because ground water is a primary source to surface water bodies in many parts of the nation, changes in the quantity (water level) and quality of ground water influence ecological conditions not only in the hyporheic zone (below and adjacent to the stream bed) but also in surface waters. The potential impacts of climate change (whether natural or human-induced) have important consequences for virtually every aspect of ecological structure and function.

[35] Information on nutrients and potentially toxic chemicals is presented in Chapters 2, 3, and 4 of the ROE.

[36] Millennium Ecosystem Assessment Board. 2005. Living beyond our means: Natural assets and human well being. <http://www.maweb.org/documents/document.429.aspx.pdf>

[37] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. <http://www.ipcc.ch/ipccreports/ar4-wg2.htm>

Table 6-5. ROE Indicators of Trends in the Critical Physical and Chemical Attributes of the Nation's Ecological Systems

National Indicators	Section	Page
U.S. and Global Mean Temperature and Precipitation	6.5.2	6-32
Sea Surface Temperature	6.5.2	6-37
Streambed Stability in Wadeable Streams	3.2.2	3-11
High and Low Stream Flows	3.2.2	3-8
Sea Level	6.5.2	6-39
Nitrogen and Phosphorus Loads in Large Rivers	3.2.2	3-17
Nitrogen and Phosphorus in Wadeable Streams	3.2.2	3-13
Nitrogen and Phosphorus in Streams in Agricultural Watersheds	3.2.2	3-15
Lake and Stream Acidity	2.2.2	2-42
Regional Indicators	**Section**	**Page**
Hypoxia in the Gulf of Mexico and Long Island Sound	3.5.2	3-48

6.5.2 ROE Indicators

The evaluation of trends in the critical physical and chemical attributes of the nation's ecological systems relies primarily on nine National Indicators and one Regional Indicator (Table 6-5). Information comes from a variety of sources, including satellite remote sensing, geographic information systems, monitoring programs, visual surveys, and independent field studies. Indicator data in this section are drawn from a variety of programs such as EPA's Wadeable Streams Assessment (WSA), National Aeronautics and Space Administration (NASA) remote sensing, the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center and tidal gauge network, and the U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program and stream gauge network.

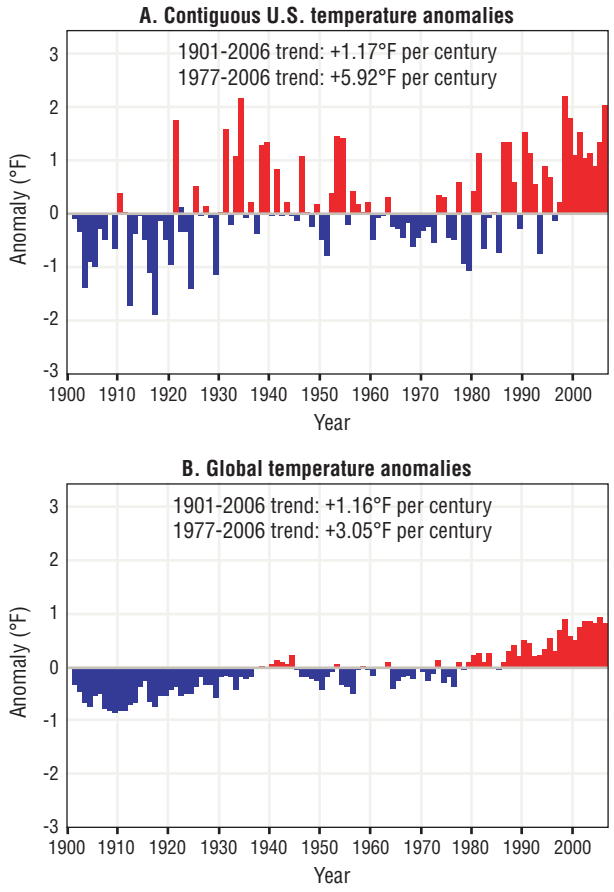
INDICATOR | U.S. and Global Mean Temperature and Precipitation

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

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*

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).

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), 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).

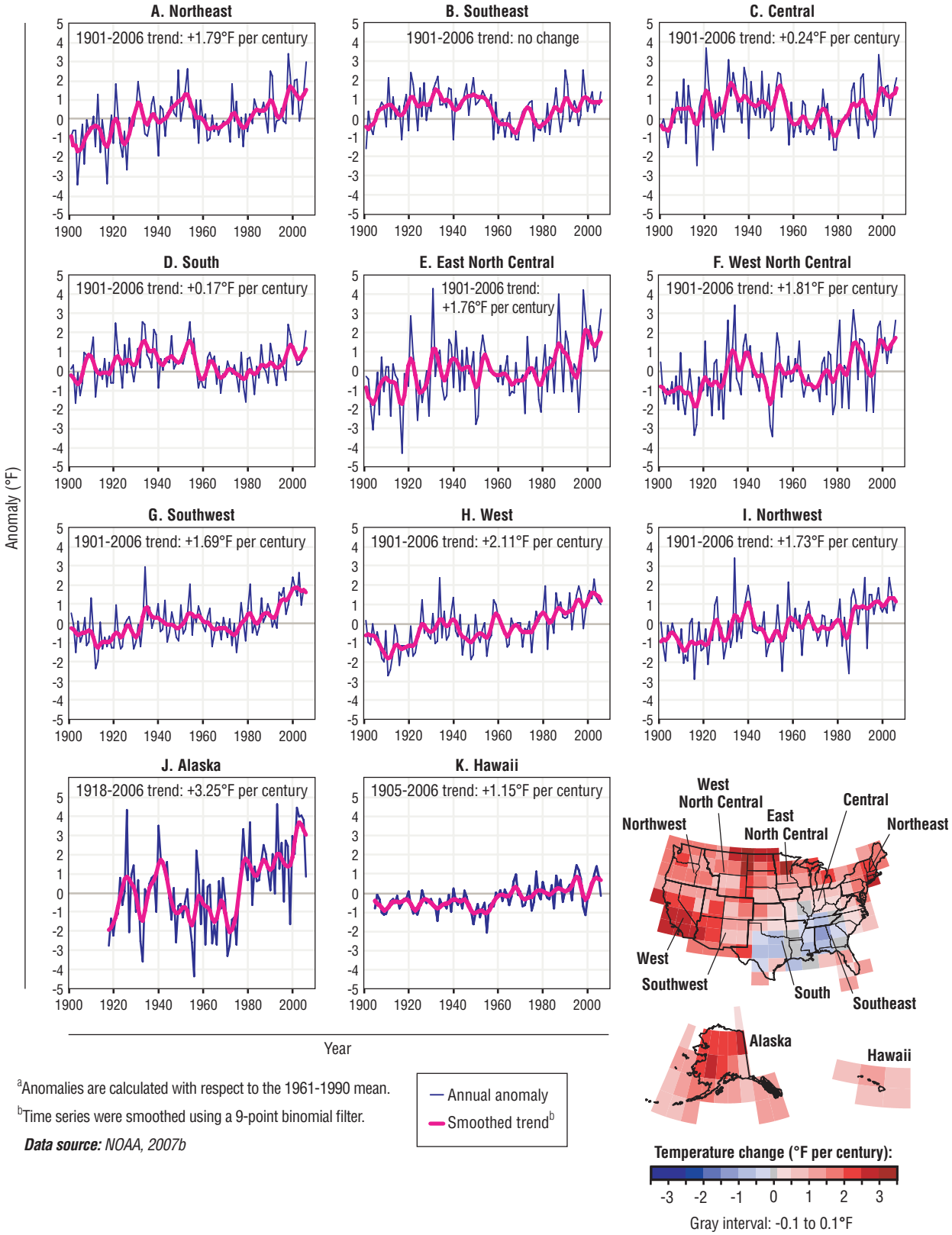
Indicator Limitations

- 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 6-16. 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*

References

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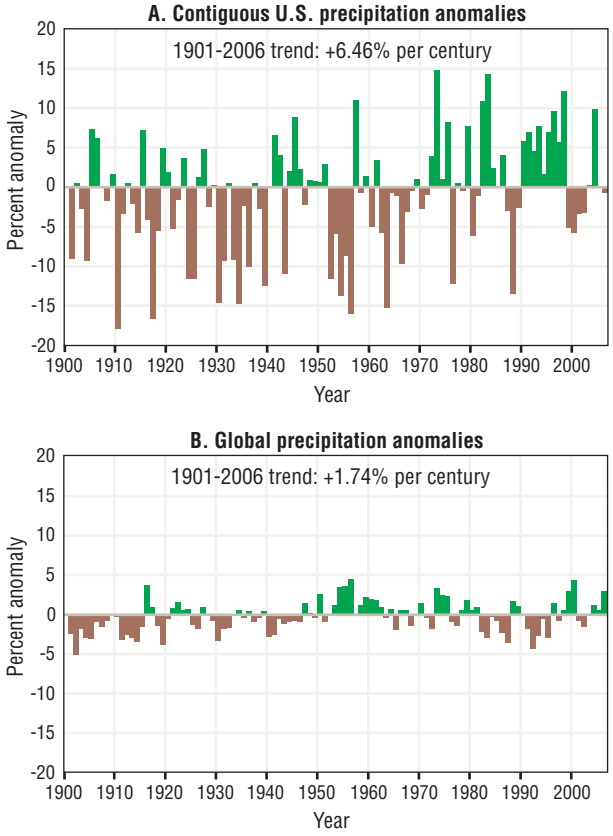
NOAA. 2007c. National Climatic Data Center. Accessed October–November 2007. <http://www.ncdc.noaa.gov/oa/ncdc.html> (NCDC home page); <http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html> (U.S. Historical Climate Network version 1); <http://www.ncdc.noaa.gov/oa/climate/research/ghcn/ghcn.html>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

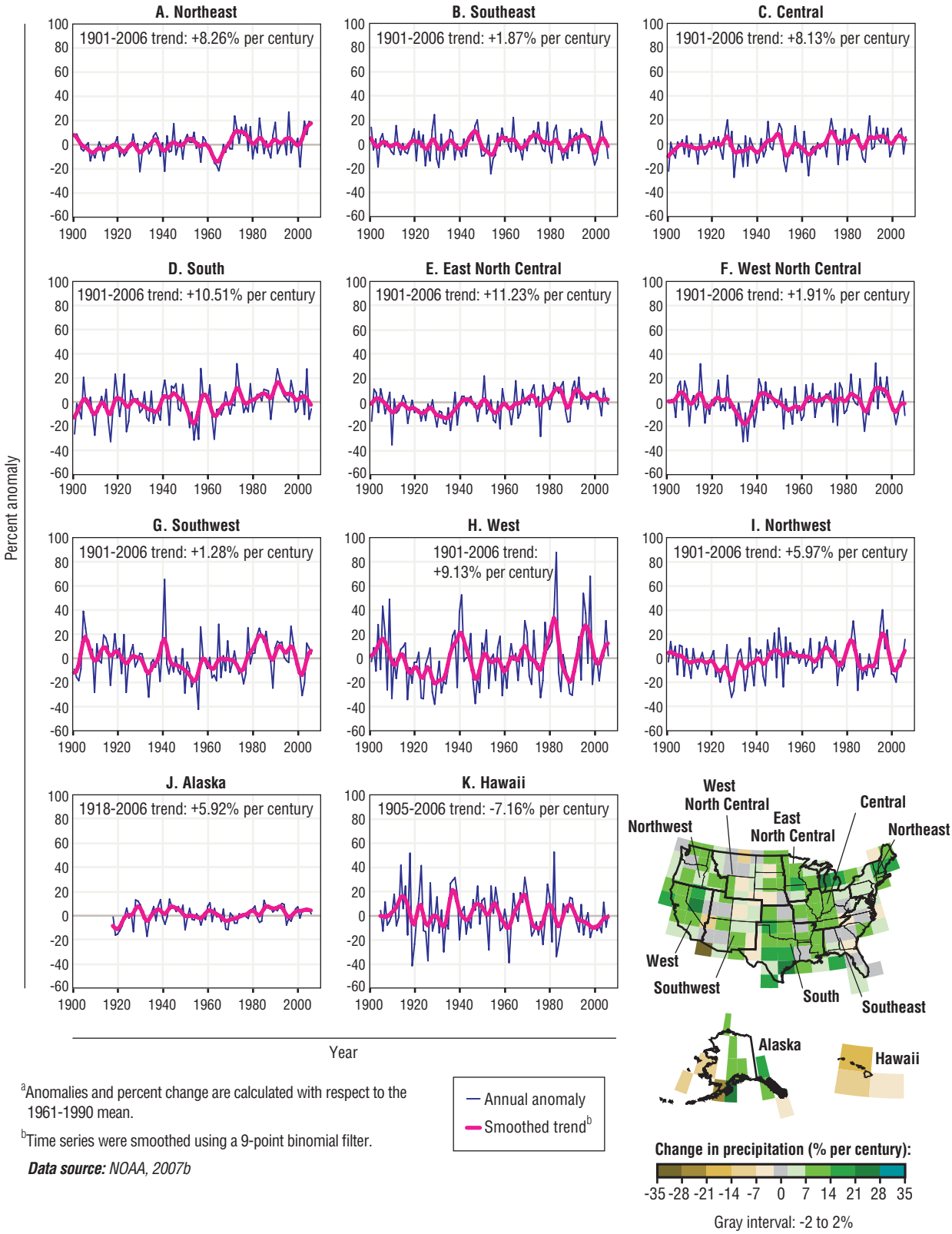
Exhibit 6-17. Annual precipitation anomalies in the contiguous U.S. and worldwide, 1901-2006[a]



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

Data source: *NOAA, 2007b*

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



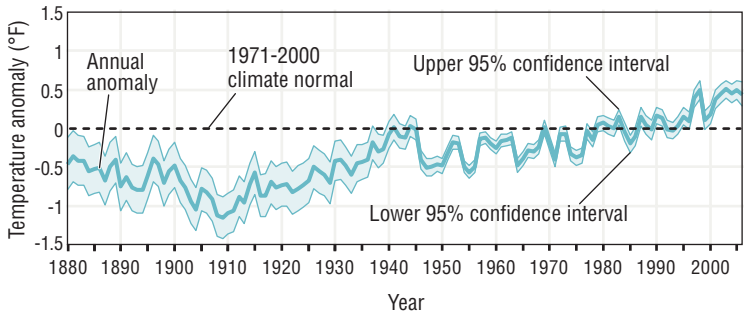
[a]Anomalies and percent change are calculated with respect to the 1961-1990 mean.

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

Data source: *NOAA, 2007b*

Sea surface temperature (SST) is a critical physical attribute of the oceans and coastal ecological systems. Water temperature directly affects biological and physical process rates, water column stability, and the presence and functioning of species of plants (e.g., algae, sea grasses, marsh plants, and mangroves) and animals (e.g., microscopic animals, larger invertebrates, fish, and mammals). Increases in temperature have been associated with the timing of breeding in sea turtles (Weishampel et al., 2004), stress and bleaching of coral reefs (Brown, 1997; Woodbridge and Done, 2004), alteration of species migration patterns, changes in ecological system extent and composition (Helmuth et al., 2002), and changes in the frequency or extent of blooms of harmful algae (Ostrander et al., 2000). On longer time scales (decades to centuries), rising SST may result in decreases in the supply of nutrients to surface waters from the deep sea, which could trigger a cascade of effects leading to decreases in primary production and declines in fish production (Pratchett et al., 2004), wetland loss, reductions in coastal storm buffering, and losses of local tourism. SST is both an indicator of, and a profound influence on, the climate system. Changes in SST may result from long-term cycles in ocean circulation, climate variability, or secular trends in climate (Committee on the Bering Sea Ecosystem et al., 1996).

Exhibit 6-19. Annual global sea surface temperature anomaly, 1880-2006[a]



[a]**Coverage:** Anomaly with respect to the 1971-2000 climate normal, which is plotted as zero.

Data source: *NOAA, 2007b*

This SST indicator, developed by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research, describes the long-term variability and change in global mean SST for the 1880-2006 period. This reconstruction provides consistent spatial and temporal data with their associated 95 percent confidence intervals. The data are compiled from in situ measurements from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) release 2 (Slutz et al., 2002) and—in recent years—from satellite imagery. Data are available from multiple sources (e.g., ship reports, buoy monitors, oceanographic profiles) from as early as 1854 (Woodruff et al., 1998). By filtering and blending data sets that use alternative measurement methods and include redundancies in space and time, this reconstruction is able to fill spatial and temporal data gaps and correct for biases in the different measurement techniques (e.g., uninsulated buckets, intakes near warm engines, uneven spatial coverage). The extended reconstructed data are shown as anomalies, or differences, from the "normal" (i.e., average) SST from 1971 to 2000. The long-term average change obtained by this method is very similar to those of the "unanalyzed" measurements and reconstructions developed by other researchers (e.g., Rayner et al., 2003).

What the Data Show

The reconstruction of SST anomalies over all latitudes indicates that the highest SSTs during the period of record occurred over the last three decades (Exhibit 6-19). Warming has occurred through most of the twentieth century and appears to be independent of measured inter-decadal and short-term variability (Smith and Reynolds, 2005). The SST warming occurred in two parts, the first between 1910 and 1940 and the second after 1970, with a roughly stationary period between 1940 and 1970. SST appears to have cooled between 1880 and 1910, although confidence intervals are wider over the early period of record. Despite that uncertainty, warming for the entire period of the indicator and for the period from 1900 forward is statistically significant.

Indicator Limitations

- The 95 percent confidence interval is wider than other methods for long-term reconstructions; in mean SSTs, this interval tends to dampen anomalies.
- The geographic resolution is coarse for ecosystem analyses but reflects long-term and global changes as well as variability.
- The reconstruction methods used to create this indicator remove almost all random "noise" in the data. However, the anomalies are also dampened when and where data are too sparse for a reliable reconstruction. The 95 percent

confidence interval reflects this "damping" effect as well as uncertainty caused by possible biases in the observations.

- Data screening results in loss of many observations at latitudes higher than 60 degrees north or south. Although the effects of screening at high latitudes are extremely small on the global average, the main effect is to lessen anomalies and widen the confidence intervals.

Data Sources

This extended reconstruction of SST, called ERSST.v3, was recently described in Smith et al. (in press). NCDC (NOAA, 2007b) provides access to monthly and annual SST and error data from this reconstruction (http://www.ncdc.noaa.gov/oa/climate/research/sst/ersstv3.php), as well as a mapping utility that allows the user to calculate average anomalies over time and space (http://nomads.ncdc.noaa.gov/#climatencdc). The ERSST.v3 reconstruction is based on in situ measurements and satellite data, both of which are available from online databases. In situ measurements are available from NOAA (2007a) (http://icoads.noaa.gov/products.html), and satellite data from NASA (2007) (http://podaac.jpl.nasa.gov/DATA_PRODUCT/SST/index.html).

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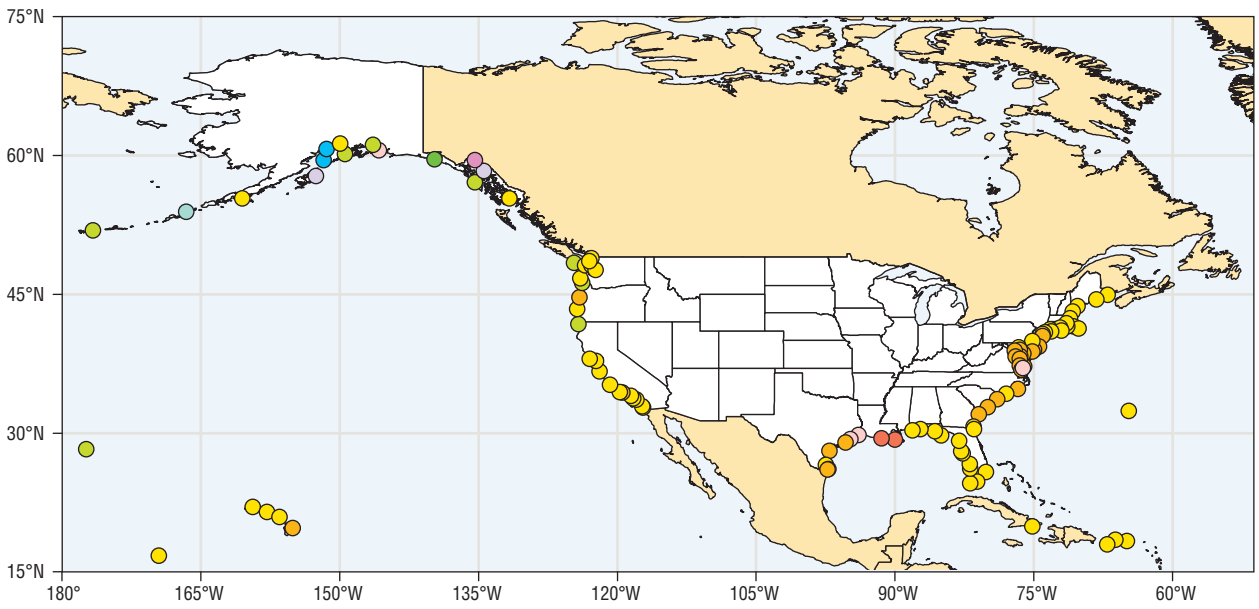
Sea level is an indicator of global and local change and a factor that affects human welfare and coastal ecosystem conditions. Coastal areas host a rich set of natural and economic resources and include some of the most developed and rapidly growing population centers in the nation. More than 100 million 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

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*

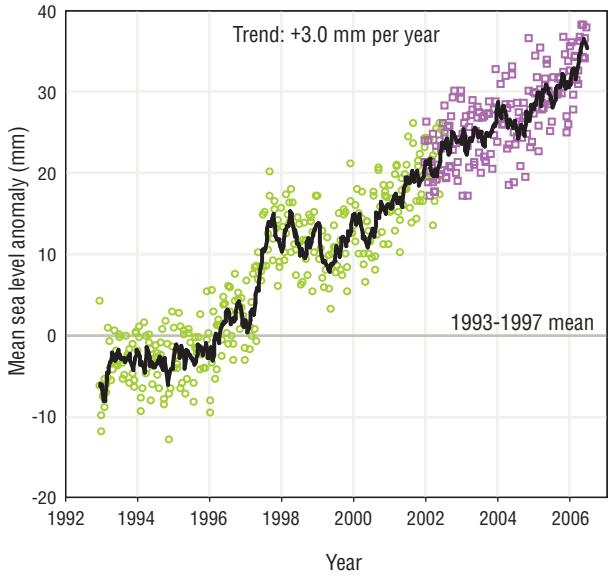
INDICATOR | Sea Level *(continued)*

an indicator of the physical and climatic stability of the global environment.

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.

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*

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.

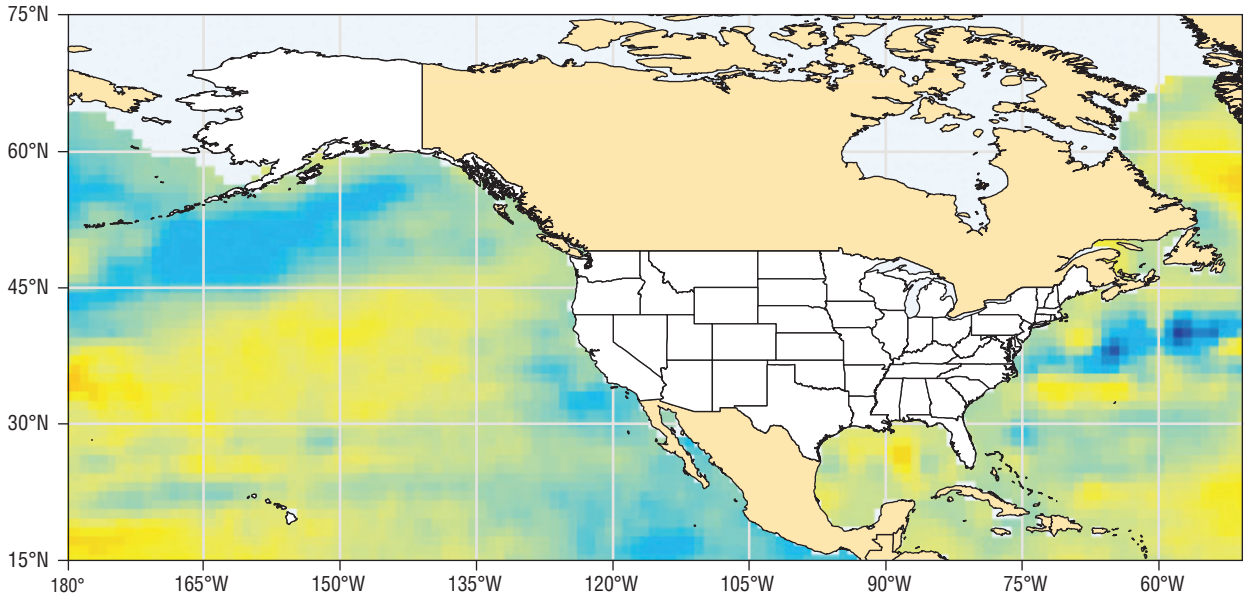
Indicator Limitations

- 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 Administration's (NOAA's) National Oceans Service (NOAA, 2006) (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml). These data were previously published in

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*

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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6.5.3 Discussion

What These Indicators Say About Trends in Critical Physical and Chemical Attributes of the Nation's Ecological Systems

Critical Physical Attributes

Information is available on trends in temperature and precipitation (see the Temperature and Precipitation indicator, p. 6-32). Across the contiguous U.S., mean temperature increased over the past century. The rate of increase in the past 30 years was higher than in the previous part of the century, amounting to more than 0.5°F per decade. Some regional trends in temperature are evident, with Alaska and the western part of the contiguous 48 states exhibiting a greater warming trend than the rest of the country. This overall warming trend is consistent with the latest findings of the Intergovernmental Panel on Climate Change (IPCC), which concluded that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."[38]

These general warming trends have occurred concurrently with rising atmospheric concentrations of greenhouse gases (see the Greenhouse Gas Concentrations indicator, p. 2-66). The IPCC confirms a connection, concluding that "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* [defined by IPCC as greater than 90 percent probability] due to the observed increase in anthropogenic greenhouse gas concentrations."[39]

Temperature changes can influence the physical aspects of ecological systems, including regional and global weather and oceanographic patterns. Observed impacts associated with warming include the global retreat of mountain glaciers, reduction in snow-cover extent, earlier spring melting of ice on rivers and lakes, and increases in sea surface temperatures

[38] 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>

[39] Ibid.

and ocean heat content.[40] For example, global sea surface temperature increased throughout the past century, with the greatest increases occurring in the past three decades (see the Sea Surface Temperature indicator, p. 6-37).

The potential ecological implications of a gradual warming trend have received much attention.[41,42,43] Virtually every ecological system in the U.S. is potentially vulnerable to changes in temperature regimes that might affect physical (and in turn, biological) conditions, including coastal and marine areas,[44,45] inland freshwater and wetland systems,[46] and terrestrial systems.[47] All species have preferred ranges of temperature for survival, growth, and reproduction as well as lower and upper thermal tolerance limits. Mean temperature, seasonal changes, and other temporal fluctuations constitute species' temperature regimes. As these regimes change, several types of stresses are placed on a species. First, a species may not be well adapted to the new regime and may not be able to sustain its population. Second, other species may be better adapted and able to extend their ranges into new areas. Finally, because temperature can affect other biological and physical attributes of systems, the ecological system itself may change in a way that is not favorable for the species.

Temperature patterns are interlinked with air and water circulation patterns, which are critical to the dispersal of organisms, the movement of nutrients, and many other processes important to sustaining ecological systems. The replenishment of water over land surfaces is particularly critical, as it is a major determinant of the sustainability of the varied ecological systems that exist along a gradient of moisture from wetlands to deserts. For example, in areas where precipitation is reduced, droughts can have a pronounced and rapid influence on vegetation.[48]

Overall, precipitation increased in the U.S. over the past century (see the Temperature and Precipitation indicator, p. 6-32). Regional differences are apparent, however, with the greatest increases in the East North Central climate region and the South, very small increases in other regions, and a decrease in Hawaii. It is difficult to assign causes to such local and regional changes in precipitation because of natural climate variability (e.g., oscillations such as El Niño and others), complex interactions between aerosols (from natural and industrial processes) and clouds, and the effects of urban and rural land use on evaporation and transpiration.

Stream flows are another physical attribute that shapes and sustains ecological systems. Whether by moving sediment under high flow regimes or fostering sedimentation in lower flow regimes, stream flows impact ecological communities by forming aquatic habitats and defining habitat boundaries. Streambed stability is an important variable in this regard (see the Streambed Stability indicator, p. 3-11). Cycles of high and low flow are particularly important for species that depend on specific conditions. For example, streambeds may require an annual high flow event to restore habitat that had been filled with debris and sediment during lower flow periods. The timing of seasonal flows also coincides with the reproductive cycles of some species. Data from stream gauges indicate that over the last half-century, high flow volumes have increased substantially in many streams compared to the previous 20 years, but they have decreased in just as many (see the Stream Flows indicator, p. 3-8). Meanwhile, low flow volume appears to have increased in many streams, while variability of flow has generally decreased—indicating a smaller difference between high and low flows. Among streams in grassland and shrubland areas, the number and duration of no-flow periods also has decreased since the 1960s. While weather patterns naturally vary from year to year, trends revealing broader shifts in high and low flows and changes in no-flow periods may forewarn of instability in ecological systems.

In many locations along the U.S. coast, sea level has risen steadily, reflecting changes in water levels as well as subsidence in land in some areas (see the Sea Level indicator, p. 6-39). These changes can alter the ecological conditions in coastal areas, especially where land elevations are low. The rise of sea levels results in increased flooding that can be exacerbated during storm events. Rising sea level also can result in increased salinity levels in coastal inland waters and soils, thereby changing the chemical condition of habitats. Freshwater ecological systems are progressively lost as they are transformed into more saline inland waters or into open coastal waters.

Critical Chemical Attributes

Dissolved oxygen is critical to the support of aerobic animals and plants. In aquatic systems, dissolved oxygen levels reflect a balance between that produced by plants, consumption by all biota, and physical mixing processes. The spatial extent and timing of reduced oxygen conditions (hypoxia) and no oxygen

[40] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. <http://www.ipcc.ch/ipccreports/ar4-wg2.htm>

[41] National Research Council. 2001. Climate change science: An analysis of some key questions. Committee on the Science of Climate Change. Washington, DC: National Academies Press.

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[46] Poff, N.L., M.M. Brinson, and J.W. Day, Jr. 2002. Aquatic ecosystems and global climate change: Potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Arlington, VA: Pew Center on Global Climate Change.

[47] Malcolm, J., and L. Pitelka, 2000. Ecosystems and global climate change: A review of potential impacts on U.S. terrestrial ecosystems and biodiversity. Washington, DC: Pew Center on Global Climate Change.

[48] Allen, C., and D. Breshears. 1998. Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. PNAS 95(25):14839-14842.

conditions (anoxia) affects the distribution and sustainability of populations of aerobic organisms. As hypoxic and anoxic areas increase in size and persistence, animals such as mollusks (snails and clams), arthropods (e.g., crabs and shrimp), and fish have proportionally less habitat within which they can thrive. For these reasons, trends in oxygen affects the sustainability of populations as well as the overall biodiversity of aquatic and marine systems.

Regional information is available on hypoxic conditions in the Gulf of Mexico and Long Island Sound (see the Hypoxia in Gulf of Mexico and Long Island Sound indicator, p. 3-48). The size of the hypoxic zones in both the Gulf of Mexico and Long Island Sound has been highly variable since the mid-1980s, with no discernable trend in either area. In both cases, there remain substantial areas in the latest year of record (2007) where low dissolved oxygen concentrations make the waters unsuitable to support most fish and shellfish species.

Nutrient levels are tightly interwoven into ecological condition. Aquatic systems are strongly influenced by nutrient levels, and nutrient inputs within a watershed may impact ecological systems far from the origin of the input (e.g., input occurs upstream, but impact occurs at the mouth of a river). Indicators focusing on the most active nutrients in aquatic systems—nitrogen and phosphorus—provide insights into trends in nutrient loads, cycles, and transport.

Nutrient loads have been examined for the Mississippi, Columbia, St. Lawrence, and Susquehanna Rivers (see the N and P Loads in Large Rivers indicator, p. 3-17). The largest of the monitored rivers, the Mississippi River, carries more than 15 times the nitrate load of the other rivers. The nutrient loads in this river more than doubled from the 1950s to the present. In contrast to the overall upward trend of nitrate loads in the Mississippi River, nitrate loads in the Columbia River nearly doubled in the 1990s compared to historical loads, but returned to historical levels by 2002. Nitrate loads increased in the St. Lawrence but did not exhibit a particular trend in the Susquehanna. Trends in phosphorus loads are variable in the Mississippi and Columbia Rivers, and show a decrease in the St. Lawrence and Susquehanna Rivers, likely due to phosphorus controls.

Baseline information on nitrogen and phosphorus concentrations is available for two sets of streams: wadeable streams and streams in agricultural watersheds. Among wadeable streams, a recent nationwide survey found that for both of these nutrients, roughly one-third of wadeable stream miles had concentrations that were substantially higher than regionally appropriate reference levels (see the N and P in Wadeable Streams indicator, p. 3-13). Agriculture-dominated watersheds are often characterized by higher loads of applied nitrogen and phosphorus fertilizers to optimize crop development. Streams located within these areas provide an indication of the extent of nutrient inputs. Baseline studies confirm that levels of nitrogen and phosphorus are elevated in many of these water bodies (see the N and P in Agricultural Streams indicator, p. 3-19).

The pH of air masses and waters is critical to biological functions, can directly affect the viability of species, and can affect the bioavailability of chemicals (both nutrients and potential toxics). There has been a decrease in wet deposition of sulfur and nitrogen compounds over the past 15 years, as discussed in Chapter 2. Associated with the decrease in deposition has been an increase in the acid neutralizing capability of water bodies (see the Lake and Stream Acidity indicator, p. 2-42). In one sensitive region, however (the Blue Ridge), fresh water bodies have yet to show recovery from acidification.

Limitations, Gaps, and Challenges

There are ROE indicators for only a few of the critical physical and chemical attributes of ecological systems. EPA would like to have ROE indicators for solar radiation over land and water as well as penetration into the nation's waters. In addition, there are no ROE indicators of disturbance regimes associated with flooding and fire. Other important gaps include water levels in lakes, the amount of snowpack or ground water available to support base flow in rivers and streams, and indicators of soil quality such as salinity or base cation saturation. Still, information is available for a few of the most critical attributes. Trends in temperature provide insight into other trends that have important biological and physical ramifications.

The indicators of trends in chemical and physical life-sustaining parameters are influenced by uncertainty. As technology changes, biases develop for data collected over long periods of time. Data collection tools may improve, creating new uncertainties when comparing recent data to historical trend data. In historical trend analyses, gaps in the record may emerge. Bridging the gaps between data series may require use of estimation or interpolation methods, or those time periods may be excluded altogether. All indicators of long-term trends are susceptible to changes in monitoring technology and historical data gaps. However, the increase in temperature and precipitation is occurring, and with the collection of additional data sets, longer-term trends can be confirmed or refuted.

Measuring trends in physical and chemical attributes is subject to a number of limitations. For the assessment of the indicator for stream flow, the U.S. Geological Survey gauging stations that generate the data for this parameter are placed on the larger tributaries and may miss trends in the smaller waterways. However, this indicator does provide valuable trend information regarding high and low flows for larger waterways. For the assessment of acidification, the focus is largely on areas where previous studies revealed an impact. This may exclude areas that are impacted to a lesser extent by acid rain.

While the large river surveys provide trend data for a watershed, it is not possible to identify the relative contributions of different land uses in the river basin. More detailed studies focus on the most common land uses contributing to nutrient runoff. Each provides useful information regarding trends in the specific system.

Information contained in the indicators represents baseline, decadal, and even century-level trends. However, for hydrologic and temperature patterns, these time periods may be too short to assess long-term changes. The field of paleoclimatology offers some promise for extending information to

larger time frames.[49] In addition, the predictive capability of forecasting the extent of dissolved oxygen deficits in regional and coastal water bodies is increasing.[50] Information is also available on the distribution of solar energy over the surface of the U.S. Over time, such information could be used to evaluate trends in this physical attribute.

6.6 What Are the Trends in Biomarkers of Exposure to Common Environmental Contaminants in Plants and Animals?

6.6.1 Introduction

Chemicals can be introduced to the environment intentionally (e.g., fertilizers, pesticides, and herbicides), or unintentionally through accidental spillage or leaks of chemicals used in home and commercial applications (e.g., in wastes from municipal and industrial operations). The extent to which the presence of mixtures of chemicals influences human health and the environment has long been a focus of EPA assessments.

Biomarkers of exposure can include measures of chemical concentrations in plant and animal tissue. Such measures provide insight into the magnitude of chemical exposure that organisms receive from their environment. Measures of biological response such as biochemical concentrations (e.g., enzymes and ligands) that respond to chemical exposures can also serve as biomarkers of exposure. Examples include histopathological anomalies such as plant tissue damage from ozone or tumors in fish exposed to sediment contaminated with polycyclic aromatic hydrocarbons (PAHs). This evaluation examines the trends in biomarkers of exposures to common environmental contaminants in plants and animals as presented in the ROE indicators. It also discusses challenges in assessing trends in these biomarkers.

Chemical stressors can have a detrimental effect on plant and animal communities. Exposure of plants and animals to chemical stressors can lead to increases in tissue concentrations of the chemical stressor in the plants and animals. Once stressor concentrations are above threshold levels, they can affect physiological systems within the plants and animals and can begin to have toxic effects on individuals within the population. These individual effects can lead to changes in plant and animal community structure when chemical stressor concentrations in the environment reach levels that can affect one or more species, or when the population numbers of a key species are detrimentally affected. Biomarkers of exposure, including concentrations of chemical stressors or key biomarkers collected over time within plant and animal tissues, can help to gauge the health of plant and animal communities over time. These biomarkers of chemical exposure, when coupled with other information (e.g., toxicity testing results), can provide a basis for estimating what levels of a chemical stress can and cannot be tolerated in the environment by plant and animal communities. These biomarkers also help explain the recovery of certain animal populations (e.g., brown pelican) that were once nearly driven to extinction by specific chemical stressors. Tissue levels of pesticides, PCBs, and mercury have been used for many years to evaluate exposures to such species as the brown pelican, bald eagle, and lake trout and a host of other fish and wildlife. The Mussel Watch program relies on sampling lower-trophic-level organisms (mussels and clams) for a broad range of chemicals to evaluate exposures in coastal areas. As these examples demonstrate, measures of bioaccumulative compounds in animal tissues provide an indication of exposure levels throughout food webs.

6.6.2 ROE Indicators

Although trends in specific contaminants of concern in environmental media (e.g., sediments or air) have been available for specific locations, the indicators to evaluate trends in biomarkers of exposure to common environmental contaminants in plants and animals are mainly focused on national or regional programs that have been measuring chemical stressor concentrations in fish tissue in lakes and coastal regions of the U.S. over less than a decade. An example of such biomonitoring efforts is summarized in the National Coastal Condition Report II,[51] which was completed as a collaborative effort between EPA, the National Oceanic and Atmospheric Administration, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey.[52]

Trends in biomarkers of exposure to common environmental contaminants in plants and animals are evaluated using three National Indicators (Table 6-6). The focus of this question is on national- or regional-scale trends in biomarkers of exposure over the period in which measurements have occurred (i.e., the last one to three decades, depending upon the biomarkers of exposure). While other subregional or local-scale efforts concerning monitoring of biomarkers of exposure cannot be covered here, they are no less important.

[49] National Oceanic and Atmospheric Administration. 2003. North American drought: A paleo perspective. <http://www.ngdc.noaa.gov/paleo/drought/drght_home.html>

[50] Longstaff, B.J., D. Jasinski, and P. Tango. 2005. Ecological forecast—summer 2005. Monitoring and Analysis Subcommittee. Chesapeake Update.

[51] U.S. Environmental Protection Agency. 2002. EMAP research strategy. EPA/620/R-02/002.

[52] Within the U.S. Geological Survey, the Biomonitoring of Environmental Status and Trends (BEST) Program is another example of a national program mandated to collect biomarkers of common contaminant exposure. Although monitoring of fish contaminant concentrations is a focus of this program, this program also monitors common pollutants in many other aquatic and terrestrial receptors, such as upper trophic level receptors (fish-eating birds like the bald eagle), and catalogues biomarker data collected from many sources into an online database.

Table 6-6. ROE Indicators of Trends in Biomarkers of Exposure to Common Environmental Contaminants in Plants and Animals

National Indicators	Section	Page
Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
Contaminants in Lake Fish Tissue	3.8.2	3-63
Ozone Injury to Forest Plants	2.2.2	2-24

N/R = National Indicator displayed at EPA Regional scale

6.6.3 Discussion

What These Indicators Say About Trends in Biomarkers of Exposure to Common Environmental Contaminants in Plants and Animals

The ROE indicators provide a baseline of recent conditions against which future trends can be assessed. Lipophilic chemicals such as polychlorinated biphenyls (PCBs), DDT, and methylmercury are present in fish tissues throughout most of the nation's freshwater lakes and coastal systems (Coastal Fish Tissue indicator, p. 3-61; Lake Fish Tissue indicator, p. 3-63), which shows widespread exposure to these bioaccumulative compounds. Some judgment concerning these levels can be made by reference to benchmarks that relate to tissue residues. For example, approximately one-fifth of estuarine fish samples were found to have at least one contaminant at levels that exceed commonly used benchmarks. Differences are apparent across EPA Regions. The contaminants most responsible for exceedances were PCBs, mercury, DDT, and PAHs.

Foliar injury from ozone pollution disrupts plant/tree physiology. Baseline data indicate that exposure of forests to ozone levels varies geographically, with more severe injury generally occurring in the eastern U.S. than in the West (Ozone Injury to Forest Plants indicator, p. 2-24). Up to 7 percent of sites had severe foliar injury in some EPA Regions, while no injury was observed at sites in Regions 8 and 10.

Limitations, Gaps, and Challenges

Few national programs involve unbiased assessment that can support indicators of trends in national conditions in biomarkers of exposure. While there are tissue-level ROE indicators for fish, there are no similar indicators for plants (either aquatic or terrestrial) or wildlife species. This represents a gap in EPA's ability to identify trends in biomarkers of exposure to common environmental contaminants in plants and animals.

Among the primary challenges relating to monitoring biomarkers of exposure are the following:

- To monitor a single biomarker of exposure on a national or regional scale requires a great deal of planning, coordination, and resources. Biomarkers are more costly and time-consuming to measure than chemical concentrations in other media (e.g., water, sediment, air), because the living things that require measurement are more difficult to collect and/or analyze for the chemical stressors.
- The biomarkers of exposure need to be clearly linked to biomarkers of effects to be useful for predicting whether the function of plant or animal communities is being affected by the concentrations of chemical in the environment. In many cases, capabilities are currently lacking to link biomarkers of exposure with biomarkers of effects. In addition, most monitoring focuses on the media within which plants and animals live (i.e., air and water), and does not address the body burden of the chemical in the plant or animal or biomarkers of effects.
- With a myriad of environmental contaminants in the environment, it is difficult to prioritize which contaminants should be monitored in biological tissues. Classically, the organochlorine pesticides (e.g., DDT), PCBs, and mercury have been monitored in fish tissues in the aquatic environment. However, in the future, new chemicals may emerge as equally or more important (see Chapter 7).

Chapter 7

7. Afterword

Next Steps

The *Report on the Environment* represents a commitment by EPA to continually improve the quality and quantity of information available to understand the condition of human health and the environment and how they are changing over time. The results of these improvements will be communicated to the public via regular updates of the ROE. Specific plans for updating the report include:

- **EPA's 2008 ROE:** Revised editions of this report will be produced at a frequency that will provide input to the Agency's strategic planning process. New editions will reflect revisions or additions to the ROE questions, updates and revisions of the indicators in this report, addition of new indicators, and revisions to the "Introduction" and "Discussion" sections that accompany each question.
- **EPA's 2008 ROE: Highlights of National Trends:** This document, which communicates key information from the ROE to the interested public, will be updated periodically.
- **Electronic version of the ROE (http://www.epa.gov/roe):** EPA will present the ROE and ROE Highlights in electronic form on the Internet so people can navigate and query the ROE content. This "e-ROE" will be updated on an ongoing basis to enable users to obtain indicator revisions as soon as they are available.

To strengthen its ability to answer the ROE questions, the Agency will work to overcome some of the important challenges identified by public comments and by EPA's Science Advisory Board in its review of the 2008 ROE.

Challenges

Throughout this report, EPA uses indicators to answer what it believes are among the most important questions about the environment and human health. For many of these questions, the answers are incomplete. Three important challenges affect EPA's ability to answer these questions:

- Synthesizing and integrating information from multiple indicators to obtain a coherent understanding of their interrelationships, as relevant to the ROE questions.
- Filling gaps and reducing limitations in the 2008 ROE indicators.
- Addressing emerging issues that suggest potential new areas of concern for which indicators are not yet available.

All three areas offer opportunities for improvement in future editions of this report.

Synthesis and Integration

Synthesizing and integrating information across multiple indicators is a major challenge for several reasons:

- There currently are no "meta-indicators" that can provide an integrated, comprehensive measure of trends in human health or the environment to answer any of the ROE questions. Instead, the available indicators provide in-depth coverage of particular aspects of the environment or health that are relevant to answer the questions.
- Differences in the spatial and temporal coverage of indicator data make it difficult to compare trends among indicators.
- In many cases, it is not clear whether a trend in one ROE indicator is directly linked to trends in other, potentially related ROE indicators.

These types of challenges preclude EPA from being able, at present, to fully respond to the individual ROE questions or to make an integrated or "bottom line" statement in response to any of the questions. EPA will strive to address these challenges in future reports by working to fill gaps and reduce indicator limitations, as described below.

Indicator Gaps and Limitations

Each ROE question focuses on a set of interrelated environmental issues (described in the "Introduction" to the question) about which there is a good scientific understanding. In general, there are ROE indicators that describe status and trends relating to some but not all of these issues. The "Discussion" section for each question describes the limitations in the current indicators and their underlying data, as well as gaps where no appropriate indicators are available to answer important parts of the questions. EPA is working to strategically analyze gaps and limitations in order to identify priorities for developing additional indicators and improving existing indicators. This work will:

- Expand EPA's ability to present indicators and supporting data at variable geographic scales. This will likely involve scaling National Indicators in a way that recognizes important natural boundaries in air, land, and water, while at the same time presenting the data in a way that is meaningful and useful to EPA's Regions and other stakeholders, and developing a strategy for the incorporation of many more regional and sub-regional indicators consistent with the hierarchical framework described above in the "Synthesis and Integration" section.
- Strengthen existing indicators, both by resolving their limitations and by incorporating statistical analysis in order to quantify the uncertainty in current status and trends.
- Identify what indicators are most needed to answer the ROE questions, taking into consideration new or emerging technologies and research needs to support future development of these indicators.
- Utilize improved research, science, and technology to develop new indicators.
- Work with the scientific community to ensure that the information reported continues to meet EPA's high standards for science. EPA's Science Advisory Board has recommended that EPA revisit the indicator criteria to achieve a better balance between inclusiveness and sound science.

Partnerships with federal, state, and non-governmental organizations to support indicator development and improvement through coordinated research, monitoring, and data sharing will be critical to fulfilling this commitment.

Emerging Issues

In this report, "emerging issues" are issues whose potential to affect human health and the environment is not well understood. Emerging issues pose different challenges to EPA's ability to answer the ROE questions than do indicator gaps and limitations. For example, many emerging issues have only recently been described in the scientific literature and popular press. Therefore, the current state of scientific understanding makes it unclear whether indicators are needed, and if so, how they should be constructed and tracked. Areas where issues potentially relevant to the ROE questions are emerging include:

- **New technologies, contaminants, or environmental effects potentially related to such contaminants.** Examples include brominated flame retardants;[1,2] residues of pharmaceuticals and personal care products;[3,4,5] air pollutants

[1] Rayne, S., M.G. Ikonomou, and B. Antcliffe. 2003. Rapidly increasing polybrominated diphenyl ether concentrations in the Columbia River system from 1992 to 2000. Environ. Sci. Technol. 37(13):2847-2854.

[2] Birnbaum, L.S., and D.F. Staskal. 2004. Brominated flame retardants: Cause for concern? Environ. Health Perspect. 112(1):9-17.

[3] Daughton, C.G., and T.A. Ternes. 1999. Pharmaceuticals and personal care products in the environment: Agents of subtle change? Environ. Health Perspect. 107(Suppl 6):907-944. <http://www.epa.gov/ppcp/pdf/errata.pdf>

[4] Koplin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, and H.T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: A national reconnaissance. Environ. Sci. Technol. 36:1202-1211. <http://pubs.acs.org/journals/esthag/36/i06/pdf/es011055j.pdf>

[5] Lindsey, M.E., M.T. Meyer, and E.M. Thurman. 2001. Analysis of trace levels of sulfonamide and tetracycline antimicrobials in groundwater and surface water using solid-phase extraction and liquid chromatography/mass spectrometry. Anal. Chem. 73(19):4640-4646.

related to the use of alternative fuels (e.g., biodiesel);[6] new chemicals and new uses for existing chemicals;[7] wastes that contain multiple materials that are challenging to separate, particularly for recycling and reuse;[8] the growing field of nanotechnology and the potential release of engineered nanomaterials (e.g., nanoparticles) to the environment;[9] and diseases and conditions for which there is emerging evidence that exposure to environmental contaminants may be a risk factor (see Section 5.4.3).

- **Issues for which the inherent complexity of the interactions between pollutants, environmental media, and ecological systems makes it unclear what should be measured.** Examples include (1) interactions between changing climate and feedback mechanisms and the effects of a wide range of pollutants on human health, water resources, ecosystems, coastal areas, and other valued resources,[10,11,12,13] including the distribution and occurrence of harmful algal blooms or other pathogens;[14] and (2) loss of genetic diversity, which may result in the loss of an entire species if that species becomes less able to adapt to changing conditions.[15]

These examples are neither definitive nor prioritized, but offered simply to illustrate the types of challenges that lie ahead.

[6] Morris, R.E., A.K. Pollack, G.E. Mansell, C. Lindhjem, Y. Jia, and G. Wilson. 2003. Impact of biodiesel fuels on air quality and human health. National Renewable Energy Laboratory. NREL/SR-540-33793. <http://www.nrel.gov/docs/fy03osti/33793.pdf>

[7] U.S. Department of Energy. 2000. Energy and environmental profile of the U.S. chemical industry. Report prepared by Energetics Incorporated. Columbia, MD. <http://www.eere.energy.gov/industry/chemicals/>

[8] U.S. Environmental Protection Agency. 2001. Electronics: A new opportunity for waste prevention, reuse, and recycling. EPA/530/F-01/006. <http://www.epa.gov/epaoswer/osw/elec_fs.pdf>

[9] Oberdörster, G., E. Oberdörster, and J. Oberdörster. 2005. Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles. Environ. Health. Perspect. 113:823-839.

[10] Foley, J. 2005. Atmospheric science: Tipping points in the tundra. Science 310(5,748):627-628.

[11] Milkov, A.V. 2004. Global estimates of hydrate-bound gas in marine sediments: How much is really out there? Earth Sci. Rev. 66(3-4):183-197.

[12] Faeth, P., and S. Greenhalgh. 2000. A climate and environmental strategy for U.S. agriculture. WRI Issue Brief, World Resources Institute, Washington, DC, November 2000.

[13] Harrison, J., and P. Matson. 2003. Patterns and controls of nitrous oxide emissions from waters draining a subtropical agricultural valley. Global Biogeochem. Cycles 17(3):1080.

[14] Daniels, N.A., and A. Shafaie. 2000. A review of pathogenic Vibrio infections for clinicians. Infect. Med. 17(10):665-685. <http://www.issc.org/client_resources/Education/PathogenicVibrioInfections.pdf>

[15] Bagley, M.J., S.E. Franson, S.A. Christ, E.R. Waits, and G.P. Toth. 2003. Genetic diversity as an indicator of ecosystem condition and sustainability: Utility for regional assessments of stream condition in the eastern United States. U.S. Environmental Protection Agency. EPA/600/R-03/056.

Appendix A: Acronyms and Glossary

This glossary provides definitions for a limited set of terms. Most of these terms are included because they have a particular usage or meaning either within EPA or in the context of this report. A few others are included to ensure understanding of intended meaning because they are key terms within this report. This glossary does not include other scientific terms for which standard definitions are readily available.

Acronyms

AAPCC	American Association of Poison Control Centers
ADHD	attention-deficit/hyperactivity disorder
ANC	acid neutralizing capacity
AQI	Air Quality Index
AQS	Air Quality System
ARMS	Agricultural Resources Management Survey
AWQC-AL	ambient water-quality criterion for the protection of aquatic life
BBS	Breeding Bird Survey
C-CAP	Coastal Change Analysis Program
CDC	Centers for Disease Control and Prevention
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFC	chlorofluorocarbon
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CWS	community water system
DDE	dichlorodiphenyldichloroethane
DDT	dichlorodiphenyltrichloroethane
DO	dissolved oxygen
ECI	Ecological Connectivity Indicator
EECl	effective equivalent troposphere chlorine
EESC	effective equivalent stratospheric chlorine
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ERS	Economic Research Service
ETS	environmental tobacco smoke
FIA	Forest Inventory and Analysis
FY	fiscal year
GHG	greenhouse gas
GI	gastrointestinal
GIS	geographic information system
GOME	Global Ozone Monitoring Experiment
GWP	global warming potential
HAP	hazardous air pollutant
HCB	hexachlorobenzene
HCFC	halogenated fluorocarbon
HFC	hydrofluorocarbon
HUC	hydrologic unit code
IBI	Index of Biological Integrity
ICD	International Classification of Diseases
IMPROVE	Interagency Monitoring of Protected Visual Environments
K	potassium
LBW	low birthweight
LOD	level of detection
LTM	Long-Term Monitoring
LUMCON	Louisiana Universities Marine Consortium
MCL	Maximum Contaminant Level

Units of Measure

km	kilometer
µeq/L	microequivalents per liter
µg/dL	micrograms per deciliter
µg/L	micrograms per liter
$\mu g/m^3$	micrograms per cubic meter
µm	micron
mm/yr	millimeters per year
MT	million tons
MtC/yr	metric tons of carbon per year
ng/g	nanograms per gram
ng/mL	nanograms per milliliter
pg/g	picograms per gram
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion

MDL	method detection limit
MMT	methylcyclopentadienyl manganese tricarbonyl
MRLC	Multi-Resolution Land Characteristics
MSA	metropolitan statistical area
N	nitrogen
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NASA	National Air and Space Administration
NASS	National Agricultural Statistics Service
NATA	National-Scale Air Toxics Assessment
NAWQA	National Water-Quality Assessment
NCA	National Coastal Assessment
NCDC	National Climatic Data Center
NCHS	National Center for Health Statistics
NCI	National Cancer Institute
NEDS	National Emissions Data System
NEI	National Emissions Inventory
NHANES	National Health and Nutrition Examination Survey
NHIS	National Health Interview Survey
NIS	non-indigenous species
NIWA	National Institute of Water and Atmospheric Research
NLCD	National Land Cover Database *or* National Land Cover Dataset
NNDSS	National Notifiable Diseases Surveillance System
NOAA	National Oceanic and Atmospheric Administration
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NPL	National Priorities List
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NVSS	National Vital Statistics System
O_3	ozone
ODS	ozone-depleting substance
O/E	observed/expected
OMB	Office of Management and Budget
OP	organophosphate
OSWER	Office of Solid Waste and Emergency Response
P	phosphorus
PAH	polycyclic aromatic hydrocarbon
PAN	peroxyacetyl nitrate
PBDE	polybrominated diphenyl ether
PBT	persistent, bioaccumulative, and toxic
PCB	polychlorinated biphenyl
PCC	Poison Control Center
PDP	Pesticide Data Program
PFC	perfluorinated carbon
PM	particulate matter
$PM_{2.5}$	particles with aerodynamic diameters less than or equal to 2.5 microns
PM_{10}	particles with aerodynamic diameters less than or equal to 10 microns
RBS	Relative Bed Stability
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
ROE	Report on the Environment
SAB	Science Advisory Board
SAV	submerged aquatic vegetation
SBUV	Solar Backscatter Ultraviolet
SEER	Surveillance, Epidemiology, and End Results
SEF	Southeastern Ecological Framework
SF_6	sulfur hexafluoride
SO_2	sulfur dioxide
SST	sea surface temperature
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
TEQ	toxic equivalency quotient
TESS	Toxic Exposure Surveillance System
TIME	Temporally Integrated Monitoring of Ecosystems
TOMS	Total Ozone Mapping Spectrometer
TRI	Toxics Release Inventory
TSDF	treatment, storage, and disposal facility
TSP	total suspended particulates
TT	Treatment Technique
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UV	ultraviolet
VOC	volatile organic compound
WBDO	waterborne disease outbreak
WISCARS	Web-Based Injury Statistics Query and Reporting System
WSA	Wadeable Streams Assessment

YPLL years of potential life lost

Glossary

A

advisory: A nonregulatory document that communicates risk information to those who may have to make risk management decisions. For example, a fish consumption advisory may recommend that people limit or avoid eating certain species of fish caught from certain lakes, rivers, or coastal waters. In some cases, advisories may include recommendations for specific groups (such as infants, children, the elderly, or women who are pregnant or may become pregnant).

agricultural and animal waste: Waste generated by the production and harvest of crops or trees or the rearing of animals. Animal waste is a subset of agricultural waste and includes waste (e.g., feed waste, bedding and litter, and feedlot and paddock runoff) from livestock, dairy, and other animal-related agricultural and farming practices.

air pollutant: Any substance in air that could, in high enough concentration, harm humans, animals, vegetation, or material. Air pollutants can include almost any natural or artificial composition of matter capable of being airborne—solid particles, liquid droplets, gases, or a combination thereof. Air pollutants are often grouped in categories for ease in classification; some of the categories are sulfur compounds, volatile organic compounds, particulate matter, nitrogen compounds, and radioactive compounds.

Air Quality Index (AQI): An index for reporting daily air quality that characterizes air pollution levels and associated health effects that might be of concern. EPA calculates the AQI for five criteria pollutants. AQI values range from 0 to 500; the higher the AQI value, the greater the level of air pollution and the greater the health concern. AQI values below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered to be unhealthy—at first for certain sensitive groups of people, then for everyone as AQI values get higher. Refer to EPA's AIRNOW Web site (http://www.epa.gov/airnow) for more information on the AQI and how it is calculated.

Air Quality System (AQS): EPA's electronic repository of ambient air monitoring data collected by EPA, state, local, and tribal air pollution control agencies from thousands of monitoring stations. The AQS contains monitoring data, descriptive information about monitoring stations, and data quality assurance and quality control information.

air toxics: Air pollutants that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects. Examples of toxic air pollutants include benzene (found in gasoline), perchloroethylene (emitted from some dry cleaning facilities), and methylene chloride (used as a solvent by a number of industries). Air toxics are also known as hazardous air pollutants.

anthropogenic: Originating from humans; not naturally occurring.

area source: A source of air pollution that is released over an area that cannot be classified as a point source. Area sources can include vehicles and other small engines, small businesses and household activities, or biogenic sources such as a forest that releases hydrocarbons.

B

baseline: A reference condition against which changes or trends are judged—usually a set of conditions that exist at a particular point in time.

benchmark: A concentration or other accepted measure against which environmental conditions are compared.

bioaccumulative compound: A compound that tends to accumulate in tissues and build up in food webs. Some bioaccumulative compounds can potentially have adverse effects on ecosystems or human health.

biogenic source: An air emissions source created by some sort of biological activity. Examples include emissions resulting from microbial activity in soils and emissions from trees and other vegetation. Emissions from biogenic sources are a subset of emissions from natural sources (see *natural source*).

biological balance: The interrelationships among organisms, including the structure of food webs and the ability of ecological systems to maintain themselves over time. Balance is a dynamic characteristic, rather than a fixed state.

biological diversity: The variety and variability among living organisms and the ecological complexes in which they occur. Though it most often refers to the numbers of species, the term can apply to levels of organization ranging from genes to ecosystems.

biomarker: A molecular or cellular indicator (or "marker") of an event or condition (exposure, effect, susceptibility) in a biological system or sample. It is the product of an interaction between a contaminant and some target molecule or cell.

biomarker of effect: A measure of disease progression, representing a measurable alteration at the molecular, cellular, or some other structural level in the body that can be recognized as a potential or established adverse health effect. Such a biomarker can indicate a biological response or health effect related to a chemical or other stressor; however, it is not always possible to link a biomarker with exposure to a single substance.

biomarker of exposure: The level of a contaminant or its metabolite collected from the body or from substances produced or excreted within biological systems. In humans, this measurement can reflect the amount of the contaminant that is stored in the body, and is sometimes referred to as the body burden. It indicates the level of exposure.

biomarker of susceptibility: A measurement of individual factors that can affect response to environmental agents. Examples include enzymes whose presence or absence may reflect a particular genetic condition.

biomonitoring: The measurement of human tissues or excreta from biological systems for direct or indirect evidence of exposure to chemical, biological, or radiological substances.

biotic environment: The biological component of an ecosystem, including plants and animals.

C

cleanup: Action taken to deal with a release (or threat of release) of a hazardous substance that could affect humans and/or the environment. This term is sometimes used interchangeably with the terms "remedial action," "removal action," "response action," and "corrective action."

climate change: A term sometimes used to refer to all forms of climatic inconsistency; because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, "climate change" has been used synonymously with "global warming." Scientists, however, tend to use "climate change" in the wider sense to also include natural changes in climate.

coastal waters: Waters at the interface between terrestrial environments and the open ocean. Many unique habitats lie in coastal waters—for example, estuaries, coastal wetlands, seagrass meadows, coral reefs, mangrove and kelp forests, and upwelling areas.

community: In ecology, an assemblage of populations of different species within a specified location in space and time. Sometimes, a particular subgrouping may be specified, such as the fish community in a lake or the soil arthropod community in a forest.

community water system: A water system that supplies drinking water to 25 or more of the same people year-round in their residences.

condition: The state of a resource, generally reflecting a combination of physical, chemical, and biological characteristics such as temperature, water clarity, chemical composition, or the status of biological communities. ROE questions address the condition of fresh surface waters, ground water, wetlands, coastal waters, recreational waters, and consumable fish and shellfish. (Also see *ecological condition*.)

construction and demolition debris: Waste materials generated during the construction, renovation, and demolition of buildings, roads, and bridges. Construction and demolition debris often contains bulky, heavy materials such as concrete, wood (from buildings), asphalt (from roads and roofing shingles), gypsum (from drywall), metals, bricks, glass, plastics, building components (doors, windows, plumbing fixtures), and trees, stumps, earth, and rock from clearing sites.

contaminant: Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

contaminated land: Land that has been polluted with hazardous materials and requires cleanup or remediation. Contaminated lands include sites contaminated as a result of improper handling or disposal of toxic and hazardous wastes, sites where improper handling or accidents released toxic or hazardous materials that are not wastes, and sites where toxics may have been deposited by wind or flooding.

criteria pollutants: A group of six widespread and common air pollutants that EPA regulates on the basis of standards set to protect public health or the environment (see *National Ambient Air Quality Standards*). The six criteria pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide.

D

deleted NPL site: A site that has been deleted from the Superfund National Priorities List because its cleanup goals have been met and there is no further need for federal action. (See *Superfund* and *National Priorities List*.)

drinking water quality: Refers to whether contaminants are present in water that people drink—including water from the tap, private wells, hauled water, untreated surface water sources, and bottled water—at levels that could affect human health.

drinking water standards: Regulations that EPA sets to control the level of contaminants in the nation's drinking water. Enforceable standards include Maximum Contaminant Levels (MCLs) and Treatment Techniques (TTs) (see separate entries for each). Drinking water standards apply to all public water systems (see *public water system*).

E

ecological condition: A term referring to the state of the physical, chemical, and biological characteristics of the environment, and the processes and interactions that connect them.

ecological connectivity: A term referring to the connected system of open space throughout an ecosystem and adjacent ecosystems. Includes the presence of ecotones, the transitional regions between ecosystems.

ecological processes: The metabolic functions of ecosystems—energy flow, elemental cycling, and the production, consumption, and decomposition of organic matter.

ecological system: A hierarchically nested area that includes all living organisms (people, plants, animals, and microorganisms), their physical surroundings (such as soil, water, and air), and the natural cycles that sustain them.

ecoregion: An area within which the ecosystems—and the type, quality, and quantity of environmental resources—are generally similar. An ecoregion can serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. Several different classification schemes have been developed, at various resolutions. For more information about EPA's ecoregion designations for North America, visit http://www.epa.gov/wed/pages/ecoregions/ecoregions.htm.

ecosystem: The interacting system of a particular biological community and its non-living environmental surroundings, or a class of such systems (e.g., forests or wetlands).

emission factor: The relationship between the amount of pollution produced by a particular source and the amount of raw material processed. For example, an emission factor for a blast furnace making iron might be pounds of particulates emitted per ton of raw materials processed.

emission inventory: A listing, by source and pollutant, of the amount of air pollutants discharged into the atmosphere. Emission inventories can be based on emissions estimates, emissions measurements, or both.

endpoint: A biological or ecological characteristic that is the basis for evaluation or measurement.

end state: Any one of a number of ecosystem characteristics observed at a point in time. The term is commonly used to represent the results of ecological processes.

EPA Region: One of ten EPA geographic divisions, each responsible for executing the Agency's programs within a specific group of states and territories. A map of the EPA Regions is provided in Chapter 1, Exhibit 1-2.

ephemeral waters: Water bodies (e.g., streams or wetlands) that contain water for brief periods, usually in direct response to a precipitation event. Ephemeral waters generally flow for a shorter time period than intermittent waters, although in some cases the terms are used interchangeably (see *intermittent waters*).

exposure: For humans, the amount of a chemical, physical, or biological contaminant at the outer boundary of the body available for exchange or intake via inhalation, ingestion, or skin or eye contact.

extent: The amount and distribution of a resource, which may be measured in terms of spatial area, volume, depth, or flow (e.g., for water resources). ROE questions address the extent of fresh surface waters, ground water, wetlands, and coastal waters.

extraction and mining waste: Soil and rock generated during the process of gaining access to the ore or mineral body, as well as water that infiltrates the mine during the extraction process. This category also includes certain wastes associated with the beneficiation of ores and minerals, including wastes from the following activities: crushing, grinding, washing, dissolution, crystallization, filtration, sorting, sizing, drying, sintering, pelletizing, briquetting, calcining to remove water and/or carbon dioxide, roasting in preparation for leaching (except where the roasting/leaching sequence produces a final or intermediate product that does not undergo further beneficiation or processing), gravity concentration, magnetic separation, electrostatic separation, floatation, ion exchange, solvent extraction, electrowinning, precipitation, amalgamation, and heap, dump, vat, tank, and in situ leaching.

F

final NPL site: A site that has been formally added to the Superfund National Priorities List. (See *Superfund* and *National Priorities List*.)

finished water: Water that has been treated and is ready to be delivered to customers.

fossil fuel combustion waste: Waste from the combustion of oil, natural gas, or petroleum coke; the combustion of coal at electric utilities and independent power-producing facilities, non-utilities, and facilities with fluidized bed combustion technology; or the combustion of mixtures of coal and other fuels (i.e., coburning of coal with other fuels) where coal is at least 50 percent of the total fuel.

G

global climate change: See *climate change.*

greenhouse gas: Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), ozone (O_3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

H

hazardous air pollutants: See *air toxics*.

hazardous waste: Waste with properties that make it dangerous or potentially harmful to human health or the environment. The universe of hazardous wastes is large and diverse. Hazardous wastes can be liquids, solids, contained gases, or sludges. They can be the byproducts of manufacturing processes or simply discarded commercial products, like cleaning fluids or pesticides. Hazardous waste is regulated under the Resource Conservation and Recovery Act (RCRA) Subtitle C (see *RCRA hazardous waste* for the regulatory definition). States can identify additional wastes as hazardous beyond those identified by EPA.

health-based standards: Standards based on contaminant concentrations in environmental media or exposure doses that are likely to be without an appreciable risk of adverse health effects in humans. (Some health-based standards allow for consideration of technological and cost limitations.)

hypoxia: The occurrence of low dissolved oxygen concentrations in water. Hypoxia is generally defined with respect to saturation; because saturation levels vary with temperature and salinity, the concentration that defines hypoxia may vary seasonally and geographically. In practice,

scientists often use a threshold of 2 parts per million, the generally accepted minimum required for most marine life to survive and reproduce.

I

impervious surface: A hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate of flow. Common impervious surfaces include rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, and gravel roads.

index: A single number, derived from two or more environmental variables, that is intended to simplify complex information. For example, the Index of Biological Integrity combines several metrics of benthic community condition into a single index score.

index period: In EPA's aquatic resource monitoring, a term used to describe the portion of the year when data are collected. The index period is often selected based on ecological considerations.

indicator: A numerical value derived from actual measurements of a stressor, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain, whose trends over time represent or draw attention to underlying trends in the condition of the environment.

industrial non-hazardous waste: Waste generated from processes associated with the production of goods and products, such as electric power generation and manufacturing of materials such as pulp and paper, iron and steel, glass, and concrete. This waste usually is not classified as municipal solid waste by the federal government, but some states may classify it as such if it enters the municipal solid waste stream.

industrial source: A term used in this report to describe air emissions sources of industrial origin. The report breaks industrial sources down into contributions from selected industries, as appropriate.

intermittent waters: Water bodies (e.g., streams or wetlands) that contain water for part of each year, due to precipitation events and some ground water contributions. Intermittent streams and wetlands typically contain water for weeks or months, while "ephemeral" streams and wetlands contain water for briefer periods—but in some cases these terms are used interchangeably (see *ephemeral waters*).

invasive species: A non-indigenous plant or animal species that can harm the environment, human health, or the economy.

L

land treatment unit: A site where physical, chemical, and biological processes occurring in the topsoil layers (e.g., naturally occurring soil microbes and sunlight) are used to treat and contain waste. Hazardous waste is applied directly to the soil surface or incorporated into the upper layers of the soil, where its constituents are degraded, transformed, or immobilized. Liner systems or leachate collection and removal systems are not required for land treatment units. Closure consists primarily of placing a vegetative cover over the unit and certifying that hazardous constituent levels in the treatment zone do not exceed background levels.

landfill: A disposal site for solid wastes spread in layers, compacted to the smallest practical volume, and covered by material (e.g., soil). Landfills are designed to isolate waste from the surrounding environment (e.g., ground water, rain, air). Landfills are subject to requirements that include installing and maintaining a final cover, operating leachate collection and removal systems, maintaining and monitoring the leak detection system, ground water monitoring, preventing storm water run-on and -off, and installing and protecting surveyed benchmarks.

M

Maximum Contaminant Level (MCL): The highest level of a contaminant that EPA allows in drinking water. MCLs are enforceable standards that ensure that drinking water does not pose either a short-term or long-term health risk. EPA sets MCLs at levels that are economically and technologically feasible. Some states set MCLs that are more strict than EPA's.

medical waste: Any solid waste generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals, excluding hazardous waste identified or listed under 40 CFR Part 261 or any household waste as defined in 40 CFR Sub-Section 261.4(b)(1).

metal mining sector: Metal mining facilities that fall within Standard Industrial Classification Code 10 and must report to the Toxics Release Inventory in accordance with Section 313 of the Emergency Planning and Community Right to Know Act.

mobile source: A term used to describe a wide variety of vehicles, engines, and equipment that generate air pollution and that move, or can be moved, from place to place. "On-road" sources are vehicles used on roads to transport passengers or freight. "Nonroad" sources include vehicles, engines, and equipment used for construction, agriculture, transportation, recreation, and many other purposes.

municipal solid waste: Waste from homes, institutions, and commercial sources consisting of everyday items such as product packaging, grass clippings, furniture, clothing, bottles and cans, food scraps, newspapers, appliances, consumer electronics, and batteries. (Excluded from this category are municipal wastewater treatment sludges, industrial process wastes, automobile bodies, combustion ash, and construction and demolition debris.)

N

National Ambient Air Quality Standards (NAAQS): Standards established by EPA that apply to outdoor air

throughout the country. The Clean Air Act established two types of national air quality standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. EPA has set NAAQS for the six *criteria pollutants*.

National Indicator: An ROE indicator for which nationally consistent data are available, and which helps to answer an ROE question at a national scale. Some National Indicators also present data broken down by EPA Region. (See *ROE indicator*.)

National Priorities List (NPL): EPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial action under Superfund. (See *Superfund*.)

natural source: A term used in this report to describe any air emissions source of natural origin. Examples include volcanoes, wild fires, wind-blown dust, and releases due to biological processes (see *biogenic source*).

non-indigenous species: A species that has been introduced by human action, either intentionally or by accident, into an area outside its natural geographical range; also called an alien, exotic, introduced, or non-native species. Certain non-indigenous species are considered "invasive." (See *invasive species*.)

non-production-related waste: Waste that is not production-related; for example, waste associated with catastrophic events and cleanup actions. Toxic chemicals in non-production-related waste must be reported to the Toxics Release Inventory (see *Toxics Release Inventory*).

non-transient non-community water system: A type of public water system that supplies water to 25 or more of the same people at least 6 months per year in places other than their residences. Some examples are schools, factories, office buildings, and hospitals that have their own water systems. (See *public water system*.)

nonpoint source: A diffuse source of pollution, having no single point of origin. This term is commonly used to describe water pollution caused by rainfall or snowmelt moving over and through the ground and carrying natural and human-made contaminants into lakes, rivers, streams, wetlands, estuaries, other coastal waters, and ground water. Atmospheric deposition and hydrologic modification are also sources of nonpoint water pollution.

non-public water system: A water system that does not provide water for human consumption through at least 15 service connections, or regularly serve at least 25 individuals, for at least 60 days per year.

nutrient: Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus but is also applied to other essential and trace elements.

O

oil and gas production waste: Gas and oil drilling muds, oil production brines, and other waste associated with exploration for, or development and production of, crude oil or natural gas.

onsite treatment: See *treatment*.

ozone-depleting substance: Any compound that contributes to stratospheric ozone depletion (see *ozone depletion*).

ozone depletion: Destruction of the stratospheric ozone layer, which shields the Earth from ultraviolet radiation harmful to life. This destruction of ozone is caused by the breakdown of certain chlorine- and/or bromine-containing compounds (chlorofluorocarbons or halons). These compounds break down when they reach the stratosphere and then catalytically destroy ozone molecules.

P

point source: A fixed location or facility that discharges pollution—for example, a factory smokestack, a ship, an ore pit, a ditch, or a pipe discharging treated industrial wastewater or treated sewage into a waterway.

pollutant: Any substance introduced into the environment that may adversely affect the usefulness of a resource or the health of humans, animals, or ecosystems. For most environmental media, this term is commonly understood to refer to substances introduced by human activities. In the case of air, the convention is to include substances emitted from natural sources as well (see *air pollutant*).

population: In ecology, a group of interbreeding organisms occupying a particular space. In other contexts, including human health, this term generally refers to the number of humans living in a designated area.

precursor: In photochemistry, any compound antecedent to a pollutant. For example, volatile organic compounds (VOCs) and nitrogen oxides react in sunlight to form ozone or other photochemical oxidants. As such, VOCs and nitrogen oxides are precursors.

primary pollutant: Any pollutant that is emitted into the atmosphere directly from its source and that retains the same chemical form. An example of a primary pollutant is dust that blows into the air from a landfill.

Priority Chemicals: A set of chemicals, found in the nation's products and wastes, that EPA targets for voluntary reduction (or recovery and recycling if they cannot be eliminated or reduced at the source). The list of Priority Chemicals is available at http://www.epa.gov/epaoswer/hazwaste/minimize/chemlist.htm.

production-related waste: The sum of a facility's production-related onsite waste releases, onsite waste management (recycling, treatment, and combustion for energy recovery), and offsite transfers for disposal, treatment,

recycling, or energy recovery. Toxic chemicals in production-related waste must be reported to the Toxics Release Inventory (see *Toxics Release Inventory*).

public water system: A system that provides water for human consumption through at least 15 service connections, or regularly serves at least 25 individuals, for at least 60 days per year. Public water systems are divided into three categories (see *community water system, non-transient non-community water system,* and *transient non-community water system*). Examples of public water systems include municipal water companies, homeowner associations, schools, businesses, campgrounds, and shopping malls.

R

radioactive waste: Waste containing substances that emit ionizing radiation. Radioactive waste is classified by regulation according to its source and/or content. The types of waste that are typically considered "radioactive waste" include high-level waste, low-level waste, mixed low-level waste, transuranic waste (i.e., elements heavier than uranium), and certain wastes from the extraction and processing of uranium or thorium ore. Spent nuclear fuel, which is produced as a result of the controlled nuclear fission process in nuclear reactors, is considered a nuclear material rather than radioactive waste.

RCRA Cleanup Baseline: A priority subset of the universe of facilities that are subject to cleanup under the Resource Conservation and Recovery Act (RCRA) due to past or current treatment, storage, or disposal of hazardous wastes, and that have historical releases of contamination.

RCRA hazardous waste: A national regulatory designation for certain wastes under the Resource Conservation and Recovery Act (RCRA). Some wastes are given this designation because they are specifically listed on one of four RCRA hazardous waste lists (see http://www.epa.gov/epaoswer/osw/hazwaste.htm). Other wastes receive this designation because they exhibit at least one of four characteristics—ignitability, corrosivity, reactivity, or toxicity.

Regional Indicator: An ROE indicator that helps to answer an ROE question on a smaller-than-national geographic scale. A Regional Indicator may cover a topic for which nationally consistent data are unavailable, or it may present an issue that is of particular concern within a certain geographic area. (See *ROE indicator.*)

risk factor: A characteristic (e.g., race, sex, age, obesity) or variable (e.g., smoking, occupational exposure level) associated with increased probability of an adverse effect.

ROE indicator: An indicator that meets the ROE criteria (see Box 1-1, p. 1-8) and has been peer-reviewed. (See *indicator.*)

S

secondary pollutant: Any pollutant that is formed by atmospheric reactions of precursor or primary emissions. An example of a secondary pollutant is ground-level ozone, which forms from chemical reactions involving airborne nitrogen oxides, airborne volatile organic compounds, and sunlight.

sewage sludge: A semi-solid residue from any of a number of air or water treatment processes. When treated and processed, sewage sludge becomes a nutrient-rich organic material called biosolids.

stratosphere: The layer of the atmosphere that starts about 6 to 9 miles above the Earth's surface at mid-latitudes and lies atop the troposphere. The stratosphere contains small amounts of gaseous ozone, which filters out about 99 percent of the incoming ultraviolet radiation.

stressor: A physical, chemical, or biological entity that can induce adverse effects on ecosystems or human health.

Superfund: A program, operated under the legislative authority of the Comprehensive Environmental Response, Compensation, and Liability Act and the Superfund Amendments and Reauthorization Act, that funds and carries out EPA solid waste emergency and long-term removal and remedial activities. These activities include establishing the National Priorities List, investigating sites for inclusion on the list, determining their priority, and conducting and/or supervising cleanup and other remedial actions. (See *National Priorities List*.)

T

toxic chemical: A chemical that can produce injury if inhaled, swallowed, or absorbed through the skin.

Toxics Release Inventory (TRI): A database containing detailed information on nearly 650 chemicals and chemical categories that over 23,000 industrial and other facilities manage through disposal or other releases, recycling, combustion for energy recovery, or treatment.

Toxics Release Inventory (TRI) chemicals: The chemicals and chemical categories that appear on the current TRI toxic chemical list. As of December 2007, the TRI toxic chemical list contains 581 individually listed chemicals and 30 chemical categories (including three delimited categories containing 58 chemicals). The list of TRI chemicals is available at http://www.epa.gov/tri/chemical/index.htm.

Toxics Release Inventory (TRI) facilities: The facilities that are required by Section 313 of the Emergency Planning and Community Right to Know Act to report to the TRI. In the 2005 reporting year, approximately 23,500 facilities reported to the TRI.

transient non-community water system: A type of public water system that provides water in a place—such as a gas station or campground—where people do not remain for long periods of time. These systems do not have to test or treat their water for contaminants that pose long-term health risks, because fewer than 25 people drink the water over a long period. They still must test their water for microbes and several chemicals. (See *public water system*.)

treatment: Any process that changes the physical, chemical, or biological character of a waste to make it less of an environmental threat. Treatment can neutralize the waste, recover energy or material resources from it, render it less hazardous, or make it safer to transport, store, or dispose of.

Treatment Technique (TT): A required process intended to reduce the level of a contaminant in drinking water.

troposphere: The layer of the atmosphere closest to the Earth's surface. The troposphere extends from the surface up to about 6 to 9 miles.

U

underground injection: The technology of placing fluids underground in porous formations of rocks, through wells or other conveyance systems. The fluids may be water, wastewater, or water mixed with chemicals. Regulations for disposing of waste this way vary depending on type of waste. RCRA hazardous waste is placed in highly regulated (Class 1) wells.

urbanization: The concentration of development in relatively small areas (cities and suburbs). The U.S. Census Bureau defines "urban" as referring to areas with more than 1.5 people per acre.

W

wadeable stream: A stream, creek, or small river that is shallow enough to be sampled using methods that involve wading into the water. Wadeable streams typically include waters classified as first through fourth order in the Strahler Stream Order classification system.

wetland: An area that is inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Appendix B:
Development of EPA's 2008 ROE

The 2008 ROE was developed by EPA's Office of Research and Development, working in collaboration with EPA's program and Regional offices as well as external partners. This appendix describes the key elements of the 2008 ROE development process.

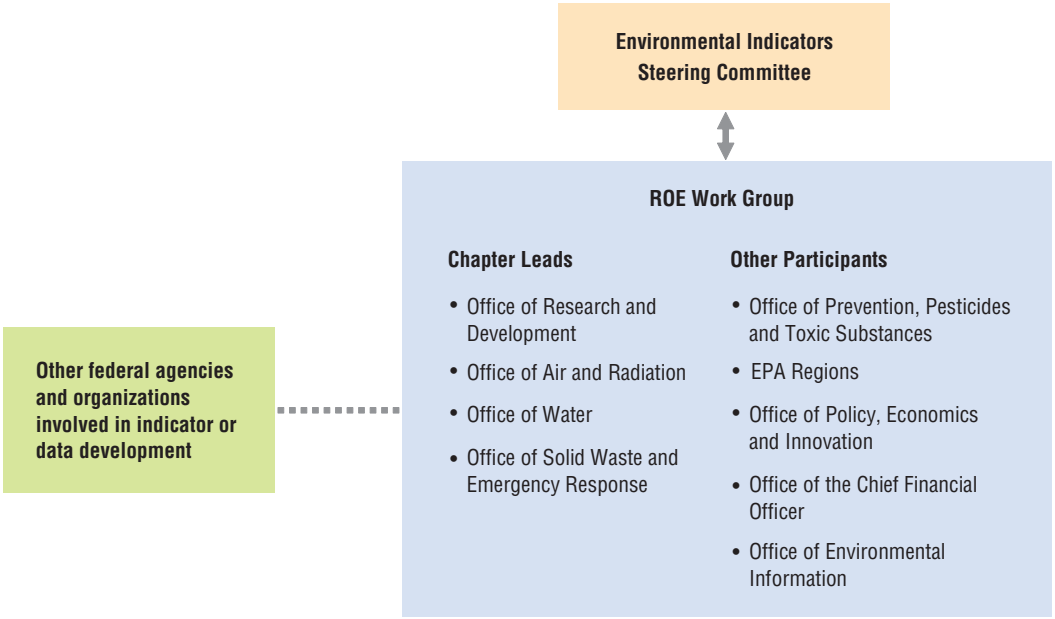
Laying the Foundation

EPA published its Draft Report on the Environment in June 2003 and invited feedback. The Agency received comments from several sources:

- The Science Advisory Board (SAB) reviewed the 2003 Draft ROE Technical Document in March 2004, issuing draft comments shortly afterwards and publishing final comments in December 2004.[1]
- Through February 2004, the public provided comments on the 2003 Draft ROE Technical Document via EPA's online public comment system.[2]
- Stakeholders commented on the 2003 Draft ROE Public Report during six dialogue sessions across the nation in 2003 and early 2004.[3]

In January 2004, the EPA Administrator requested that work begin to develop the next version of the ROE. Exhibit B-1 shows the organizational structure for development of EPA's 2008 ROE.[4] A standing ROE Work Group took the lead in all phases of development. The group included five theme leads, each responsible for development of a particular chapter of the 2008 ROE, plus representatives of EPA Regions and other relevant EPA offices. During the development process, the theme leads coordinated with other federal agencies and organizations involved in indicator development or data collection. An Environmental Indicators Steering Committee, composed of senior managers from across the Agency, oversaw development of the ROE. The Steering Committee reviewed Work Group activities and draft products.

Exhibit B-1. Organizational structure for development of EPA's 2008 ROE



[1] U.S. Environmental Protection Agency. 2004. EPA's Draft Report on the Environment (ROE) 2003: An advisory by the ROE Advisory Panel of the EPA Science Advisory Board. Science Advisory Board. EPA/SAB/05/004. <http://yosemite.epa.gov/sab/sabproduct.nsf/18246BED9FB52FE085256F6A006BC3C1/$File/SAB-05-004_unsigned.pdf>

[2] U.S. Environmental Protection Agency. 2004. E-docket for Draft Report on the Environmental Technical Document. Docket Number: OEI-2003-0030. <http://www.regulations.gov/fdmspublic/component/main?main=DocketDetail&d=EPA-HQ-OEI-2003-0030>

[3] U.S. Environmental Protection Agency. 2004. Summary report of the National Dialogue on the EPA Draft Report on the Environment 2003. Office of Environmental Information. <http://www.epa.gov/Envindicators/docs/National_Dialogue_Summary_Report.pdf>

[4] An additional organizational element, the Indicators Work Group, was added to the process as the indicators were being finalized for the July 2005 peer review. The Indicators Work Group provided coordination between the ROE Work Group and the Environmental Indicators Steering Committee.

The ROE is based on three components:

- A series of fundamental questions about the condition of the nation's air, water, and land; about human exposure and health; and about the condition of ecological systems. These are questions that the Agency considers to be of critical importance to its mission.
- An indicator definition.
- Criteria against which indicators are evaluated to ensure that they are useful, objective, transparent, and scientifically reliable.

The first step in developing the 2008 ROE was to review and refine the 2003 Draft ROE version of these components:

- **Questions.** Over 100 EPA specialists from across the Agency were convened in the five ROE theme areas: air, water, land, human exposure and health, and ecological condition. Each theme team was charged with considering feedback and refining the ROE questions. The questions were finalized after review by the Environmental Indicators Steering Committee in 2004.
- **Indicator definition and criteria.** The 2003 Draft ROE indicator definition and criteria were refined for the 2008 ROE using an iterative process that included input from EPA specialists and review by the Environmental Indicators Steering Committee. Care was taken to ensure that the criteria were consistent with requirements of EPA's Information Quality Guidelines.

Indicator Development

Once the questions, definition, and criteria were refined, the next step was to identify and develop indicators to answer the questions.

- 2003 Draft ROE indicators were screened against the 2008 ROE indicator definition and criteria. Many 2003 Draft ROE indicators were proposed for the 2008 ROE; some were withdrawn; and some were combined into other indicators (see Appendix C for details).
- Ideas for new indicators were solicited from across EPA, other federal agencies, and organizations. Newly proposed indicators were screened for their ability to meet the indicator definition and criteria and for their value in answering the ROE questions.

For each indicator that passed screening, three components were developed: text describing the indicator, a graphic or table displaying the indicator data, and a metadata form that documents the data source and quality (see Box B-1).

The 2008 ROE development team worked with staff at other departments, agencies, and private organizations that originally developed indicators or provided indicator data to ensure that indicator graphics, data, and quality assurance information were up to date and accurate. Indicators were reviewed by the Environmental Indicators Steering Committee.

Box B-1. Questions Addressed in the 2008 ROE Metadata Forms

- Describe the physical, chemical, or biological measurements upon which this indicator is based. Are these measurements widely accepted as scientifically and technically valid? Explain.
- Describe the sampling design and/or monitoring plan used to collect the data over time and space. Is it based on sound scientific principles? Explain.
- Describe the conceptual model used to transform these measurements into an indicator. Is this model widely accepted as a scientifically sound representation of the phenomenon it indicates? Explain.
- For which ROE question(s) is this indicator used? To what extent is the indicator sampling design and monitoring plan appropriate for answering the relevant question(s) in the ROE?
- To what extent does the sampling design represent sensitive populations or ecosystems?
- What, if any, are the established reference points, thresholds, or ranges of values for this indicator that unambiguously reflect the state of the environment?
- What documentation clearly and completely describes the underlying sampling and analytical procedures used?
- To what extent is the complete data set accessible, including metadata, data-dictionaries, and embedded definitions? Are there confidentiality issues that may limit accessibility to the complete data set?
- Are the descriptions of the study or survey design clear, complete, and sufficient to enable the study or survey to be reproduced? Explain.
- To what extent are the procedures for quality assurance and quality control of the data documented and accessible?
- What statistical methods, if any, have been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)? Are these methods scientifically appropriate?
- What uncertainty measurements or estimates are available for the indicator and/or the underlying data set?
- To what extent do uncertainty and variability impact the conclusions that can be inferred from the data and the utility of the indicator?
- Describe any limitations, or gaps in the data that may mislead a user about fundamental trends in the indicator over space or over the time period for which data are available.

Box B-2. Charge Questions for Peer Review of the Proposed 2008 ROE Indicators

- Indicate the extent to which you think the proposed indicator is appropriate, adequate, and useful for evaluating _____.[a]
- Indicate the extent to which you think the proposed indicator makes an important contribution to answering the specific ROE question it is intended to answer.
- To what extent do you think the indicator meets the indicator definition?
- To what extent do you think the indicator meets each of the indicator criteria?
- Do you have any suggestions for more effective graphic presentation of the data? Provide any additional comments, suggestions, or concerns regarding the indicator that you have not already noted earlier. In particular, note any limitations to the indicator.
- Select one: Overall, this indicator (1) ___ should be included in the ROE; (2) ___ should be included in the ROE with the modifications identified above; or (3) ___ should not be included in the ROE.
- Do any of the proposed indicators clearly seem to be more appropriate, adequate, or useful for evaluating _____[a] than others? Do any seem to be more important than the others for answering the question(s) they are intended to answer?
- Are there any additional *national-level* indicators that make an important contribution to answering one of the ROE questions in your topic area, but were not proposed for the ROE, that you would recommend? As you consider this question, consider the list of indicators presented in ROE03 that EPA does not intend to carry forward to the 2008 ROE, along with EPA's rationale for withdrawing them. If you disagree with EPA's rationale and feel any of these indicators should be included in the ROE, please so indicate in your response to this question, along with your rationale for why they should be included.

[a] This part of the charge varied according to theme area as follows:

- Air: "our nation's air and therefore useful for contributing to an overall picture of our nation's air"
- Water: "our nation's waters and for contributing to an overall picture of our nation's waters"
- Chemicals on land: "trends in chemicals used on land and their effects on human health and the environment"
- Land wastes: "trends in wastes and their effects on human health and the environment"
- Human health: "human health and for contributing to an overall picture of human health"
- Ecological condition: "ecological conditions and therefore useful for contributing to an overall picture of ecological conditions"

Indicator Peer Review and Public Comment

Once the full suite of proposed indicators was assembled, all indicators were independently peer-reviewed by nationally recognized experts to ensure that they were scientifically sound and properly documented, met the indicator definition and criteria, and were useful for answering the questions posed in the ROE. Two rounds of review were conducted:

- At a workshop in July 2005, 21 experts reviewed the initial set of 88 proposed indicators.
- In November 2005, nine experts reviewed 11 indicators that were new or had been substantially revised since the July 2005 review.

The peer review, organized by a contractor, was conducted following the Office of Management and Budget's (OMB's) specifications for peer review of "Highly Influential Scientific Assessments" as specified in OMB's "Final Information Quality Bulletin for Peer Review."[5] The reviewer selection criteria, list of reviewers, charge to reviewers, and reviewer comments can be found in the peer review summary report.[6] EPA announced the peer reviews in the Federal Register and also posted the proposed indicators on a Web site for public comment. Key questions addressed during the review are listed in Box B-2. After the peer review and public comment period, EPA revised and finalized the indicators. EPA's responses to reviewer and public comments are available at EPA's ROE Web site: http://www.epa.gov/roe.

ROE Review

Concurrent with indicator development, EPA's ROE team, working with specialists across the Agency, developed the text elements of the 2008 ROE. The final indicators were incorporated into the text to produce the full 2008 ROE. This draft document was reviewed internally at EPA, externally by other federal agencies and OMB, and externally by SAB (including public comment on the federal docket). EPA revised the document based on comments and, after the third review, finalized it for publication.

[5] Office of Management and Budget. 2004. Final information quality bulletin for peer review. December 16, 2004. <http://www.whitehouse.gov/omb/memoranda/fy2005/m05-03.pdf>

[6] U.S. Environmental Protection Agency. 2006. Report of the peer review of proposed ROE07 indicators. Office of Research and Development. <http://cfpub.epa.gov/eroe/index.cfm?fuseaction=main.peerReview>

Appendix C:
Comparison of Indicators Used in EPA's 2008 ROE and the 2003 Draft ROE

- Indicators new to the 2008 report are listed in **bold** font.
- Indicators in the 2003 report but withdrawn in 2008 are highlighted in gray.
- The rationale for withdrawing indicators is explained at the end of this appendix.
- Some indicators are used to answer more than one ROE question; indicators are listed in the table below only where they are first used to answer an ROE question in the 2008 report.

Air Chapter

Outdoor Air Quality	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Lead Emissions	Lead Emissions
Ambient Concentrations of Lead	Ambient Concentrations of Lead
Nitrogen Oxides Emissions	Emissions: Particulate Matter ($PM_{2.5}$ and PM_{10}), Sulfur Dioxide, Nitrogen Oxides, and Volatile Organic Compounds Emissions (Utility): Sulfur Dioxide and Nitrogen Oxides
Volatile Organic Compounds Emissions	Emissions: Particulate Matter ($PM_{2.5}$ and PM_{10}), Sulfur Dioxide, Nitrogen Oxides, and Volatile Organic Compounds
Ambient Concentrations of Ozone	Ambient Concentrations of Ozone: 8-hour and 1-hour
Ozone Injury to Forest Plants	Ozone Injury to Trees (from the ecological condition chapter)
Particulate Matter Emissions	Emissions: Particulate Matter ($PM_{2.5}$ and PM_{10}), Sulfur Dioxide, Nitrogen Oxides, and Volatile Organic Compounds
Ambient Concentrations of Particulate Matter	Ambient Concentrations of Particulate Matter: $PM_{2.5}$ and PM_{10}
Regional Haze	Visibility
Sulfur Dioxide Emissions	Emissions: Particulate Matter ($PM_{2.5}$ and PM_{10}), Sulfur Dioxide, Nitrogen Oxides, and Volatile Organic Compounds Emissions (Utility): Sulfur Dioxide and Nitrogen Oxides
Acid Deposition	Deposition: Wet Sulfate and Wet Nitrogen Atmospheric Deposition of Nitrogen (from the water chapter)

Outdoor Air Quality	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Lake and Stream Acidity	Acid Sensitivity in Lakes and Streams (from the water chapter)
Percent of Days with Air Quality Index Values Greater Than 100	Number and Percentage of Days That Metropolitan Statistical Areas (MSAs) Have Air Quality Index (AQI) Values Greater Than 100
Air Toxics Emissions	Air Toxics Emissions
Ambient Concentrations of Benzene	Ambient Concentrations of Selected Air Toxics
Concentrations of Ozone-Depleting Substances	Concentrations of Ozone-Depleting Substances (Effective Equivalent Chlorine)
Ozone Levels over North America	Ozone Levels over North America
Carbon Monoxide Emissions	
Ambient Concentrations of Carbon Monoxide	
Ambient Concentrations of Nitrogen Dioxide	
Mercury Emissions	
Ozone and Particulate Matter Concentrations for U.S. Counties in the U.S./Mexico Border Region	
Ambient Concentrations of Manganese Compounds in EPA Region 5	
Withdrawn	Worldwide and U.S. Production of Ozone-Depleting Substances (ODSs)
Withdrawn	Number of People Living in Areas with Air Quality Levels Above the NAAQS for Particulate Matter (PM) and Ozone

Greenhouse Gases	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
U.S. Greenhouse Gas Emissions	
Atmospheric Concentrations of Greenhouse Gases	

Indoor Air Quality	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
U.S. Homes Above EPA's Radon Action Level	U.S. Homes Above EPA's Radon Action Levels
Blood Cotinine Level	Blood Cotinine Level; Blood Cotinine Level in Children (from the human health chapter)
Withdrawn	Percentage of Homes Where Young Children Are Exposed to Environmental Tobacco Smoke

Water Chapter

Fresh Surface Waters	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
High and Low Stream Flows	Changing Stream Flows Number/Duration of Dry Stream Flow Periods in Grassland/Shrublands
Nitrogen and Phosphorus in Streams in Agricultural Watersheds	Nitrate in Farmland, Forested, and Urban Streams and Ground Water (partially replaced, partially withdrawn) Phosphorus in Farmland, Forested, and Urban Streams (partially replaced, partially withdrawn)
Nitrogen and Phosphorus Loads in Large Rivers	Partly new information and partly from indicator: Movement of Nitrogen (from the ecological condition chapter)
Pesticides in Streams in Agricultural Watersheds	Pesticides in Farmland Streams and Ground Water
Benthic Macroinvertebrates in Wadeable Streams	Macroinvertebrate Biotic Integrity Index for Streams
Streambed Stability in Wadeable Streams	
Nitrogen and Phosphorus in Wadeable Streams	
Withdrawn	Altered Fresh Water Ecosystems
Withdrawn	Lake Trophic State Index
Withdrawn	Percent Urban Land Cover in Riparian Areas
Withdrawn	Agricultural Lands in Riparian Areas
Withdrawn	Sedimentation Index
Withdrawn	Nitrate in Farmland, Forested, and Urban Streams and Ground Water (partially withdrawn)
Withdrawn	Phosphorus in Farmland, Forested, and Urban Streams (partially withdrawn)
Withdrawn	Phosphorus in Large Rivers
Withdrawn	Atmospheric Deposition of Mercury
Withdrawn	Chemical Contamination in Streams and Ground Water
Withdrawn	Sediment Contamination of Inland Waters
Withdrawn	Fish Index of Biotic Integrity in Streams

Ground Water	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds	Pesticides in Farmland Streams and Ground Water Nitrate in Farmland, Forested, and Urban Streams and Ground Water (partially replaced, partially withdrawn)
Withdrawn	Nitrate in Farmland, Forested, and Urban Streams and Ground Water (partially withdrawn)

Wetlands	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Wetland Extent, Change, and Sources of Change	Wetland Extent and Change Sources of Wetland Change/Loss

Coastal Waters	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Trophic State of Coastal Waters	Water Clarity in Coastal Waters Dissolved Oxygen in Coastal Waters Chlorophyll Concentrations Total Nitrogen in Coastal Waters Total Phosphorus in Coastal Waters
Coastal Sediment Quality	Sediment Contamination of Coastal Waters Sediment Toxicity in Estuaries
Coastal Benthic Communities	Benthic Community Index (for Coastal Waters) (presented in both the water and ecological condition chapters)
Submerged Aquatic Vegetation in the Chesapeake Bay	Submerged Aquatic Vegetation (changed to a Regional Indicator; from the ecological condition chapter)
Hypoxia in the Gulf of Mexico and Long Island Sound	
Withdrawn	Total Organic Carbon in Sediments
Withdrawn	Population Density in Coastal Areas

Drinking Water	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Population Served by Community Water Systems with No Reported Violations of Health-Based Standards	Population Served by Community Water Systems That Meet All Health-Based Standards

Recreational Waters	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Withdrawn	Number of Beach Days That Beaches Are Closed or Under Advisory

Consumable Fish and Shellfish	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Coastal Fish Tissue Contaminants	Chemical Contamination (from the ecological condition chapter) (partially withdrawn)
Contaminants in Lake Fish Tissue	Contaminants in Fresh Water Fish
Withdrawn	Percent of River Miles and Lake Acres Under Fish Consumption Advisories
Withdrawn	Number of Watersheds Exceeding Health-Based National Water Quality Criteria for Mercury and PCBs in Fish Tissue

Land Chapter

Land Cover	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Land Cover	Extent of Grasslands and Shrublands Extent of Forest Area, Ownership, and Management Patches of Forest, Grassland, Shrubland, and Wetland in Urban/Suburban Areas (from the ecological condition chapter) Ecosystem Extent (from the ecological condition chapter)
Land Cover in the Puget Sound/Georgia Basin	

Land Use	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Land Use	Extent of Urban and Suburban Lands Extent of Agricultural Land Uses
Urbanization and Population Change	Extent of Developed Lands (plus land chapter introduction from 2003 Draft ROE)
Withdrawn	The Farmland Landscape
Withdrawn	Sediment Runoff Potential from Croplands and Pasturelands

Wastes	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Quantity of Municipal Solid Waste Generated and Managed	Quantity of Municipal Solid Waste (MSW) Generated and Managed Number and Location of Municipal Solid Waste (MSW) Landfills
Quantity of RCRA Hazardous Waste Generated and Managed	Quantity of RCRA Hazardous Waste Generated and Managed Number and Location of RCRA Hazardous Waste Management Facilities (partially replaced, partially withdrawn)
Withdrawn	Quantity of Radioactive Waste Generated and in Inventory
Withdrawn	Number and Location of Municipal Solid Waste (MSW) Landfills (partially withdrawn)
Withdrawn	Number and Location of RCRA Hazardous Waste Management Facilities (partially withdrawn)
Withdrawn	Number and Location of Superfund National Priorities List (NPL) Sites
Withdrawn	Number and Location of RCRA Corrective Action Sites

Chemicals Used on the Land	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Fertilizer Applied for Agricultural Purposes	Fertilizer Use
Toxic Chemicals in Production-Related Wastes Combusted for Energy Recovery, Released, Treated, or Recycled	Quantity and Type of Toxic Chemicals Released and Managed Number and Location of RCRA Hazardous Waste Management Facilities (partially replaced, partially withdrawn)
Pesticide Residues in Food	Pesticide Residues in Food
Reported Pesticide Incidents	
Withdrawn	Agricultural Pesticide Use
Withdrawn	Potential Pesticide Runoff from Farm Fields
Withdrawn	Risk of Nitrogen Export
Withdrawn	Risk of Phosphorus Export
Withdrawn	Pesticide Leaching Potential (from the ecological condition chapter)

Contaminated Land	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Current Human Exposures Under Control at High-Priority Cleanup Sites	
Migration of Contaminated Ground Water Under Control at High-Priority Cleanup Sites	

Human Exposure and Health Chapter

Exposure to Environmental Contaminants	
2008 ROE Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Blood Lead Level	Blood Lead Level Blood Lead Level in Children
Blood Mercury Level	Blood Mercury Level Blood Mercury Level in Children
Blood Cadmium Level	Blood Cadmium Level
Urinary Pesticide Level	Urine Organophosphate Levels to Indicate Pesticides
Blood Persistent Organic Pollutants Level	
Urinary Phthalate Level	
Withdrawn	Urine Arsenic Level
Withdrawn	Blood Volatile Organic Compound Levels

Health Status	
ROE 2008 Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Life Expectancy at Birth	Life Expectancy
Infant Mortality	Infant Mortality
General Mortality	(partially based on "Leading Causes of Death" in the contextual information provided in the 2003 Draft ROE human health chapter)

Disease and Conditions	
ROE 2008 Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Cancer Incidence	Cancer Incidence
Childhood Cancer Incidence	Childhood Cancer Incidence
Cardiovascular Disease Prevalence and Mortality	Cardiovascular Disease Mortality Cardiovascular Disease Prevalence
Chronic Obstructive Pulmonary Disease **Prevalence** and Mortality	Chronic Obstructive Pulmonary Disease Mortality
Asthma Prevalence	Asthma Prevalence Childhood Asthma Prevalence
Infectious Diseases Associated with Environmental Exposures or Conditions (with the following new additions: **Giardiasis, Lyme Disease, Rocky Mountain Spotted Fever, West Nile Virus, Legionellosis)**	Cholera Prevalence Cryptosporidiosis Prevalence *E. coli* O157:H7 Prevalence Hepatitis A Prevalence Salmonellosis Prevalence Shigellosis Prevalence Typhoid Fever Prevalence
Birth Defects Prevalence and Mortality	Deaths Due to Birth Defects Birth Defect Incidence
Low Birthweight	Low Birthweight Incidence
Preterm Delivery	
Withdrawn	Cancer Mortality
Withdrawn	Asthma Mortality
Withdrawn	Childhood Cancer Mortality
Withdrawn	Childhood Asthma Mortality

Ecological Condition Chapter

Extent and Distributon	
ROE 2008 Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Forest Extent and Type	Extent of Area by Forest Type
Forest Fragmentation	Forest Pattern and Fragmentation
Ecological Connectivity in EPA Region 4	
Relative Ecological Condition of Undeveloped Land in EPA Region 5	
Withdrawn	Forest Age Class
Withdrawn	Extent of Ponds, Lakes, and Reservoirs
Withdrawn	Extent of Estuaries and Coastline

Diversity and Biological Balance	
ROE 2008 Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Bird Populations	
Fish Faunal Intactness	
Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest	
Withdrawn	At-Risk Native Forest Species
Withdrawn	Populations of Representative Forest Species
Withdrawn	Tree Condition
Withdrawn	At-Risk Native Grassland and Shrubland Species
Withdrawn	Population Trends of Invasive and Native Non-Invasive Bird Species
Withdrawn	At-Risk Native Fresh Water Species
Withdrawn	Non-Native Fresh Water Species
Withdrawn	At-Risk Fresh Water Plant Communities
Withdrawn	Coastal Living Habitats
Withdrawn	Shoreline Types
Withdrawn	Fish Diversity
Withdrawn	At-Risk Native Species
Withdrawn	Bird Community Index

Ecological Processes	
ROE 2008 Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Carbon Storage in Forests	Carbon Storage
Withdrawn	Forest Disturbance: Fire, Insects, and Disease

Physical and Chemical Attributes	
ROE 2008 Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
U.S. and Global Mean Temperature and Precipitation	
Sea Surface Temperature	
Sea Level	
Withdrawn	Soil Compaction
Withdrawn	Soil Erosion (Forests)
Withdrawn	Soil Erosion (Farmland)
Withdrawn	Processes Beyond the Range of Historic Variation
Withdrawn	Soil Quality Index
Withdrawn	Terrestrial Plant Growth Index
Withdrawn	Chemical Contamination (partially withdrawn)

Ecological Exposure to Contaminants	
ROE 2008 Indicator Title	**Corresponding 2003 Draft ROE Indicator Title**
Withdrawn	Animal Deaths and Deformities
Withdrawn	Fish Abnormalities
Withdrawn	Unusual Marine Mortalities

Explanation of Indicators Used in the 2003 Draft ROE But Not in the 2008 ROE

A number of indicators were included in EPA's 2003 Draft ROE that are not included in the 2008 ROE. The general reasons for these changes are described below, followed by indicator-specific explanations.

- Members of the independent scientific review panel that reviewed the draft indicators for the 2008 ROE recommended their withdrawal.
- The EPA Science Advisory Board Committee review of the 2003 Draft ROE recommended EPA develop and utilize a more precise definition of "indicator" than was used for 2003 Draft ROE.
- EPA developed a set of specific indicator criteria to provide a more precise conformance to Office of Management and Budget and EPA Information Quality Guidelines.
- The 2008 ROE introduced a Regional Pilot Project and developed and implemented a relevant process. Sub-National or Regional Indicators that were included in the 2003 Draft ROE but did not go through this pilot are not included in the 2008 ROE.

A small number of the indicators in 2003 Draft ROE did not conform to one or more of these requirements. Explanations for not including these indicators were peer-reviewed by an independent scientific panel along with the indicators in this report. Broadly speaking, the explanations for withdrawal fall into five categories, coded as follows:

- **(D) Definition.** The indicator fails to meet the improved indicator definition for the 2008 ROE.
- **(C) Criteria.** The indicator fails to meet one of the six indicator criteria that were established to conform to EPA Information Quality Guidelines.

- **(N) New indicator.** The indicator is replaced by a "new" and superior indicator that was not available for the 2003 Draft ROE.
- **(R) Regional.** The indicator is not national in scope and is not part of the 2008 ROE Regional Pilot Project.
- **(P) Peer review.** The independent peer review panel recommended withdrawing the indicator from the 2008 ROE.

The following information briefly explains the rationale for withdrawing specific indicators from the 2008 ROE. Each indicator is categorized as D, C, N, R, or P. The indicators are organized by chapter.

Air Chapter

Worldwide and U.S. Production of Ozone-Depleting Substances (ODSs)—C

This 2003 Draft ROE indicator presented estimates of the amount of ODSs produced worldwide in 1986 and 1999, and annual U.S. production from 1958 to 1993. This indicator was withdrawn because of issues concerning data reliability and relevance. Global ODC production data are not reliable with respect to comparability among reporting countries. The U.S. estimates are more reliable because of legal reporting requirements and the small number of sources. However, the data set fails to account for imports, and annual production is not a good surrogate for emissions of ODCs into the environment because the time between production and eventual entry into the environment is highly variable among the various products and recovery systems.

Number of People Living in Areas with Air Quality Levels Above the NAAQS for Particulate Matter (PM) and Ozone—C

This 2003 Draft ROE indicator conveyed how many people (based on census data) lived in counties where air pollutant levels at times were above the level of the NAAQS during the year stated. It was intended to give the reader some indication of the number of people potentially exposed to unhealthy air. Because of changing populations and air quality standards, however, this indicator masks actual trends in the levels of air pollutants. It is not a valid exposure indicator for the ROE because it is not based on measurement of an actual marker of exposure measured on or in individuals.

Percentage of Homes Where Young Children Are Exposed to Environmental Tobacco Smoke—D

This 2003 Draft ROE indicator portrayed the percentage of homes in the U.S. in which young children were exposed to tobacco smoke in 1998 versus 1957. The survey was based on a questionnaire (do children live in the home, and does someone who smokes regularly live in the home), rather than on measurements of the amount of smoke actually present or the degree to which children were exposed to the resulting smoke. This indicator violates the ROE indicator definition, which requires that indicators be based on actual measurements; furthermore, the 2008 ROE's Blood Cotinine indicator better indicates children's exposure to smoke.

Water Chapter

Altered Fresh Water Ecosystems—C

Percent Urban Land Cover in Riparian Areas—C

Agricultural Lands in Riparian Areas—C

These 2003 Draft ROE indicators were based on the percentage of land within 30 meters of the edge of a stream or lake that is classified as urban or agriculture based on 1991 satellite data (NLCD). Baseline data are incomplete, there are no reference points for the appropriate percentage of such cover, and it is not clear that the indicators could be reproduced with newer satellite data. There are no data for other alterations such as damming, channelization, etc.

Lake Trophic State Index—R, C

This 2003 Draft ROE indicator was based on phosphorus data collected in a one-time statistical sample of lakes in the northeastern U.S. during 1991-1994. It is not included in the 2008 ROE Regional Pilot Project.

Sedimentation Index—R, C, N

This 2003 Draft ROE indicator was based on data collected on freshwater streams in the Mid-Atlantic Highlands Region during a one-time 1993-1994 statistical survey. It is not included in the 2008 ROE Regional Pilot Project. The 2008 ROE's Streambed Stability in Wadeable Streams indicator provides a more complete nationwide picture of sedimentation in streams.

Nitrate in Farmland, Forested, and Urban Streams and Ground Water (partially withdrawn)—N

Phosphorus in Farmland, Forested, and Urban Streams (partially withdrawn)—N

These 2003 Draft ROE indicators were replaced by two new indicators, "Nitrogen and Phosphorus in Streams in Agricultural Watersheds" and "Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds." The NAWQA streams in forested and urban watersheds were based on a small sample size, and may not be representative of forested and urban streams in general.

Phosphorus in Large Rivers—C

The indicator was based on phosphorus concentrations in large rivers sampled periodically by the USGS National Stream Quality Accounting Network (NASQAN). Monitoring at many of the large river NASQAN sites has been discontinued. Information on phosphorus loads in four major rivers has been incorporated into the new 2008 ROE indicator, Nitrogen and Phosphorus Loads in Large Rivers.

Atmospheric Deposition of Mercury—C

This indicator was withdrawn following peer review of the indicators because trend data could not be analyzed in time to revise it.

Chemical Contamination in Streams and Ground Water—C

This 2003 Draft ROE indicator was based on data from a large number of USGS National Water Quality Assessment

(NAWQA) watersheds. The sampling and analytical protocols (including the analytes measured) are not comparable across all NAWQA watersheds.

Sediment Contamination of Inland Waters—C

This 2003 Draft ROE indicator was based on reported concentrations of sediment contaminants collected by a large number of organizations focusing particularly on places where sediment contamination is perceived to be a problem (the EPA National Sediment Inventory). The database suffers from a number of limitations: the data are heavily biased toward sites at which there is a known or suspected toxicity problem and to particular geographic areas (non-representative of the nation), the data cover different dates in different locations (making estimation of trends difficult), and the data and procedures used to assign sites to a toxicity category are not uniform from watershed to watershed. It is unsuitable for trend estimation.

Fish Index of Biotic Integrity in Streams—R, C

This 2003 Draft ROE indicator was based on fish community data collected on freshwater fish in the Mid-Atlantic Highlands Region during a one-time 1993-1996 statistical survey. Condition cannot be assessed in streams where no fish were caught, because data were insufficient to indicate whether the stream had poor quality or simply no fish. It is not included in the 2008 ROE Regional Pilot Project.

Total Organic Carbon in Sediments—R

This 2003 Draft ROE indicator was based on data collected in a survey of Mid-Atlantic estuaries during a one-time 1997-1998 statistical survey. It is not included in the 2008 ROE Regional Pilot Project. Also, total organic carbon in sediments is useful in understanding sediment toxicity, but there are unlikely to be trends in sediment total organic carbon, and therefore it would be of limited value as an ROE indicator.

Population Density in Coastal Areas—D

Discussion of population density in coastal areas was moved to the introduction of the water chapter section responding to the question, "What are the trends in the extent and condition of coastal waters and their effects on human health and the environment?"

Number of Beach Days That Beaches Are Closed or Under Advisory—D

Percent of River Miles and Lake Acres Under Fish Consumption Advisories—D

These 2003 Draft ROE indicators were based on the frequency of beach closures or fish consumption advisories as reported to EPA voluntarily by states and local government organizations. The data are not nationally or temporally consistent because of different and changing criteria for closing beaches or issuing fish consumption advisories in the different states, many of which do not involve actual water quality measurements. They are therefore administrative indicators (based on administrative action rather than actual physical measurements) and fail to meet the definition for ROE indicators.

Number of Watersheds Exceeding Health-Based National Water Quality Criteria for Mercury and PCBs in Fish Tissue—C

This 2003 Draft ROE indicator was based on voluntary reporting of mercury contamination using data that had not undergone formal QA/QC review. It is not representative of the nation, or suitable for trend monitoring.

Land Chapter

The Farmland Landscape—C

This 2003 Draft ROE indicator represented croplands and the forests, woodlots, wetlands, grasslands, and shrublands that surround or are intermingled with them, and the degree to which croplands dominate the landscape. The indicator relied on data generated using early 1990s satellite data, and it is unclear whether the definition of "farmland landscape" is sufficiently precise to be replicated independently, especially with respect to any future satellite data availability.

Sediment Runoff Potential from Croplands and Pasturelands—C

This 2003 Draft ROE indicator represented the estimated sediment runoff potential for croplands and pasturelands based on topography; weather patterns; soil characteristics; land use, land cover, and cropping patterns; and the Universal Soil Loss equation. The indicator addressed "potential" and not actual/current condition, and relied on a model (the Soil and Water Assessment Tool: http://www.brc.tamus.edu/swat) to predict ambient characteristics based on pressure/stressor measurements, which violates a fundamental ROE protocol on the use of models in indicators. Trends in this indicator would likely be associated only with trends in land cover, cropping practices, and weather (topography and soil type are unlikely to change). No reliable spatial trend data at the appropriate scale exist for either cropping practices or land cover, and consequently trends in this indicator would be difficult to calculate.

Agricultural Pesticide Use—C

Agricultural pesticide usage data, measured at the national aggregate level for all pesticides, are very difficult to interpret. From one time period to another, the mix of pesticides changes, pest pressures change, agricultural practices change, agricultural acreage changes, regulatory status of key uses changes, and many other important variables change. Moreover, the effects of pesticide usage are encountered at three levels of the product's life cycle: production, usage, and residues on foods. The geographic distribution of those effects renders difficult the interpretation of national usage levels for all pesticides, taken as a group. While it is of course possible to compare magnitudes of aggregates at different times, the real significance for the environment is in the differences in the content and geographic distribution of the aggregates, not in the magnitude of the aggregate.

Potential Pesticide Runoff from Farm Fields—C

Pesticide Leaching Potential—C

These 2003 Draft ROE indicators represented the potential movement of agricultural pesticides from the site of application

to ground and surface waters, based on estimates of pesticide leaching and runoff losses derived from soil properties, field characteristics, management practices, pesticide properties, and climate for 243 pesticides applied to 120 specific soils in growing 13 major agronomic crops. The indicators address "potential" and not actual/current condition, and rely on models to predict ambient characteristics based on measurements of pressures/stressors. This violates a fundamental ROE protocol on the use of models in indicators.

Risk of Nitrogen Export—C

Risk of Phosphorus Export—C

These 2003 Draft ROE indicators represented the potential movement of nitrogen and phosphorus from the site of application to surface waters, based on a large empirical dataset relating land use to nitrogen and phosphorus observed in receiving streams over several decades at a variety of locations. The indicators address "potential" and not actual/current conditions, and rely on statistical models to predict ambient characteristics based on measurements of pressures/stressors. This violates a fundamental ROE protocol on the use of models in indicators.

Quantity of Radioactive Waste Generated and in Inventory—C

This 2003 Draft ROE indicator was based on production and inventory data collected by the Department of Energy. Although the data continue to be collected, they are no longer publicly available post-September 11, 2001; therefore, ongoing data trends are not and will not be available for this indicator in the future. Moreover, the earlier data reflected two distinct periods in the history of waste generation in the nuclear weapons complex. The first reflected a period during which wastes and other materials were being generated as an integral part of the production of weapons-grade nuclear materials and components. The period after 1989 reflected the cessation of large-scale production of such materials and the initiation of cleanup activities and wastes from those initiatives. Thus, even before the truncation of data in the post-9/11 period, there were significant issues with the comparability of the data over time.

Number and Location of Municipal Solid Waste (MSW) Landfills—D, N

This 2003 Draft ROE indicator represents an administrative count of landfills, rather than an amount of waste produced, and therefore does not meet the 2008 ROE indicator definition. The indicator was replaced by a new and superior indicator that tracks the quantity of municipal solid waste generated and how it is managed.

Number and Location of RCRA Hazardous Waste Management Facilities (partially withdrawn)—D, N

This 2003 Draft ROE indicator, by itself, represents an administrative decision to force a cleanup, rather than an amount of waste present or removed, and therefore does not meet the 2008 ROE indicator definition. The data were combined into a new indicator, Quantity of RCRA Hazardous Waste Generated and Managed, which combines information from several 2003 Draft ROE indicators.

Number and Location of Superfund National Priorities List (NPL) Sites—D

This 2003 Draft ROE indicator represented an administrative decision to force a cleanup, rather than an amount of waste present or removed, and therefore does not meet the 2008 ROE indicator definition.

Number and Location of RCRA Corrective Action Sites—D

This 2003 Draft ROE indicator represented an administrative decision to force a cleanup, rather than an amount of waste present or removed, and therefore does not meet the 2008 ROE indicator definition.

Human Exposure and Health Chapter

Urine Arsenic Level—R

This 2003 Draft ROE indicator was based on data from EPA Region 5 only, and is not part of the 2008 ROE Regional Pilot.

Blood Volatile Organic Compound Levels—C

This 2003 Draft ROE indicator was based on a convenience sample whose representativeness cannot be determined or necessarily used as a baseline for future sampling. The indicator is based on detects only, so there is no reference level. Also, volatile organic compounds are cleared from the bloodstream rapidly (about 1 hour), so there is a significant possibility of false negatives, considering that exposure tends to be associated with occupational and indoor settings.

Cancer Mortality—P

Childhood Cancer Mortality—P

Asthma Mortality—P

Childhood Asthma Mortality—P

The independent peer review panel recommended the removal of the cancer and asthma mortality indicators because trends in these indicators are less likely to be due to changes in environmental factors than to changes in social factors such as availability/access to healthcare.

Ecological Condition Chapter

Forest Age Class—N

While forest age class has implications for biodiversity and ecological function, this indicator was withdrawn in favor of indicators of forest extent and type and forest fragmentation.

Extent of Ponds, Lakes, and Reservoirs—C

This 2003 Draft ROE indicator was based on data from the USGS National Wetlands Inventory. While these data are based on a valid statistical sampling design, the total amount of surface water is less than half the area of lakes, reservoirs, and ponds greater than 6 acres in size in the USGS National Hydrography Data Set. Until this discrepancy is resolved, the indicator may not satisfy the ROE criteria.

Extent of Estuaries and Coastline—C

This 2003 Draft ROE indicator was based on remote sensing data, but is unlikely to show trends unrelated to sea level rise and changing tides, so it is not a very useful indicator for trends.

At-Risk Native Species—C

At-Risk Native Grassland and Shrubland Species—C

At-Risk Native Forest Species—C

Populations of Representative Forest Species—C

Non-Native Fresh Water Species—C

At-Risk Native Fresh Water Species—C

At-Risk Fresh Water Plant Communities—C

The ecological condition chapter was restructured from the 2003 Draft ROE organization per the recommendation of EPA's Science Advisory Board and numerous stakeholders. As such, the chapter no longer requires that the above indicators be broken out by ecosystem. In addition, the ability to track trends of many of these indicators is questionable.

Tree Condition—C

This 2003 Draft ROE indicator was based on an ongoing statistical sample of forests across the contiguous U.S. and comprises components that relate to crown (tree canopy) condition, the ratio of dead to live wood, and the fire class. This indicator likely relates more to forest management practices than to environmental condition, and for this reason has low relevance value to EPA.

Population Trends of Invasive and Native Non-Invasive Bird Species—R

This 2003 Draft ROE indicator was based on an analysis of USGS Breeding Bird Survey data in grassland and shrubland ecosystems for 5-year periods ranging from the late 1960s to 2000. Because the ecological condition questions are no longer directed at specific ecosystem types, this appears to be a Regional Indicator. Also, it is not clear at this time that the data for this indicator will be collected in the future.

Coastal Living Habitats—C

This 2003 Draft ROE indicator was based on remote sensing data of coastal wetlands, mudflats, sea-grass beds, etc., but the only system for which a National Indicator has been developed is coastal vegetated wetlands, which already is covered in another indicator (the 2008 ROE's Wetlands indicator).

Shoreline Types—C

This 2003 Draft ROE indicator was based on NOAA's Environmental Sensitivity Index. The index is based on a standardized mapping approach, but coverage is not complete for large parts of the coastline and the data in some of the atlases are more than 15 years old. Consequently, this indicator is not appropriate for measurement of representative, national trends.

Fish Diversity—R

This 2003 Draft ROE indicator was based on a statistical sample of fish trawls in Mid-Atlantic estuaries during 1997-1998. This indicator is not part of the 2008 ROE Regional Pilot Project, and EPA's Environmental Monitoring and Assessment Program (EMAP) is no longer collecting fish samples to support this indicator.

Bird Community Index—R

This 2003 Draft ROE indicator was not national in scope or part of the ROE EPA Regional Pilot.

Forest Disturbance: Fire, Insects, and Disease—P

The independent peer review panel recommended that this indicator be withdrawn because it was "limited in many aspects of its coverage: temporally, spatially, and in types of disturbance…Ecological interpretation of disturbance patterns is difficult…For example, the lack of fire may actually represent an ecological disturbance, while fire suppression can lead to overcrowded forests that are more conducive to insect and disease outbreaks." The reviewers also commented that the data were questionable and that the interdependence among the disturbance categories could result in significant double-counting. Finally, timber harvest was not included even though it disturbs more acres than fires, insects, or disease.

Soil Compaction—C

Soil Erosion—C

These 2003 Draft ROE indicators are based on an ongoing statistical sample of soils in forests across the contiguous U.S., but the actual indicators are based on models rather than measurement. This violates a fundamental ROE protocol on the use of models in indicators.

Processes Beyond the Range of Historic Variation—C

This 2003 Draft ROE indicator was based on an analysis of recent Forest Inventory and Analysis data on climate events, fire frequency, and forest insect and disease outbreaks, which were then compared to anecdotal data for the 1800-1850 period. Because the early data are anecdotal, and because the data mostly relate to forest management practices, etc., it is proposed that this indicator has low relevance to EPA and that trend data are of questionable utility as an ROE indicator.

Soil Quality Index—R

This 2003 Draft ROE indicator was based on a survey of soils in the Mid-Atlantic region during the 1990s; that survey was not repeated and is not part of the Regional Pilot Project for the 2008 ROE.

Terrestrial Plant Growth Index—P

The independent peer review panel recommended that this indicator be withdrawn because "The results are too ambiguous and not explained, or perhaps, unexplainable…NDVI is a crude measure of growth. [Also,] The relative deviation of the Plant Growth Index (20-40%) without explanation during the period of analysis suggests that the indicator might lack the precision needed to assess national trends in productivity."

Chemical Contamination (partially withdrawn)—C

This 2003 Draft ROE indicator combined data from the NAWQA program that are not consistent in terms of sampling frequency or analytical protocols. The part of this indicator presenting contaminant levels in coastal fish as measured by EMAP was moved to a separate indicator in the water chapter of the 2008 ROE: Coastal Fish Tissue Contaminants.

Animal Deaths and Deformities—C

This 2003 Draft ROE indicator was based on data reported by a number of different organizations to USGS on incidences of death or deformities in waterfowl, fish, amphibians, and mammals. Trends are available only for waterfowl, and because data reporting is voluntary rather than systematic, the data are not adequate to determine actual trends versus trends in reporting.

Fish Abnormalities—C

This 2003 Draft ROE indicator was based on a statistical sample of fish trawls in estuaries in the Atlantic and Gulf, but the data are no longer being collected by EMAP to support this indicator.

Unusual Marine Mortalities—C

This 2003 Draft ROE indicator was based on voluntary reporting of unusual mortality events to NOAA. Because there is no systematic requirement to report, these data are not suitable to support national trends in the indicator.