

# **CHAPTER 3**

## **WATER**



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## 1 3.1 INTRODUCTION

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

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

11 In this chapter, EPA seeks to assess national trends in the extent and condition of water, stressors that  
12 influence water, and associated exposures and effects among humans and ecological systems. The ROE  
13 indicators in this chapter address seven fundamental questions about the state of the nation's waters:  
14

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

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

37 Each of the seven questions is addressed in a separate section of this chapter. However, all the questions  
38 are fundamentally connected—a fact that is highlighted throughout the chapter text and indicator  
39 summaries. All water is part of the global hydrologic cycle, and thus it is constantly in motion—whether  
40 it is a swiftly flowing stream or a slow-moving aquifer thousands of years old. A stream may empty into a  
41 larger river that ultimately discharges into coastal waters. An aquifer may be recharged by surface waters,

1 or feed surface waters or wetlands through springs and seeps. In each case, the extent and condition of  
2 one water resource can affect the extent and condition of another type. One example of this  
3 interdependence can be found in the movement of nutrients. Together, several of the ROE indicators track  
4 nutrient levels in water bodies ranging from small wadeable streams to the coastal waters. Additional  
5 ROE indicators describe some of the effects that may be associated with excess nutrients, such as  
6 eutrophication and hypoxia.

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

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

### 16 **3.1.1 Overview of the Data**

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

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

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

42 This chapter presents only data that meet the ROE indicator definition and criteria (see Chapter 1,  
43 Introduction). Note that non-scientific indicators, such as administrative and economic indicators, are not

1 included in this definition. Thorough documentation of the indicator data sources and metadata can be  
2 found online at [\[insert url\]](#). All ROE indicators were peer-reviewed during an independent peer review  
3 process (see [\[insert url\]](#) for more information). Readers should not infer that the indicators in this chapter  
4 reflect the complete state of knowledge. Many other data sources, publications, and site-specific research  
5 projects have contributed substantially to the current understanding of status and trends in water, but are  
6 not included in this report because they do not meet the ROE indicator criteria.

### 7 **3.1.2 Organization of This Chapter**

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

15 The table below shows the indicators used to answer each of the questions in this chapter and their  
16 location within this report.

17



1 **Table 3.1.1. Water—ROE Questions and Indicators**

<b>Question</b>	<b>Indicator Name</b>	<b>Section</b>	<b>Page</b>
<i>What are the trends in extent and condition of fresh surface waters and their effects on human health and the environment?</i>	High and Low Stream Flows (N)	3.2.2	3-14
	Streambed Stability in Wadeable Streams (N)	3.2.2	3-19
	Lake and Stream Acidity (N)	2.2.2	2-62
	Nitrogen and Phosphorus in Wadeable Streams (N)	3.2.2	3-22
	Nitrogen and Phosphorus in Streams in Agricultural Watersheds (N)	3.2.2	3-25
	Nitrogen and Phosphorus Discharge from Large Rivers (N)	3.2.2	3-28
	Pesticides in Streams in Agricultural Watersheds (N)	3.2.2	3-32
	Benthic Macroinvertebrates in Wadeable Streams (N)	3.2.2	3-35
<i>What are the trends in extent and condition of ground water and their effects on human health and the environment?</i>	Nitrate and Pesticides in Shallow Ground Water in Agricultural Areas (N)	3.3.2	3-44
<i>What are the trends in extent and condition of wetlands and their effects on human health and the environment?</i>	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-53
<i>What are the trends in extent and condition of coastal waters and their effects on human health and the environment?</i>	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-53
	Trophic State of Coastal Waters (N/R)	3.5.2	3-62
	Coastal Sediment Quality (N/R)	3.5.2	3-67
	Coastal Benthic Communities (N/R)	3.5.2	3-71
	Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-103
	Submerged Aquatic Vegetation in the Chesapeake Bay (R)	3.5.2	3-74
	Hypoxia in the Gulf of Mexico and Long Island Sound (R)	3.5.2	3-77
	Harmful Algal Bloom Outbreaks Along the Western Florida Coastline (R)	3.5.2	3-81
<i>What are the trends in the quality of drinking water and their effects on human health?</i>	Population Served by Community Water Systems with No Reported Violations of Health-Based Standards (N/R)	3.6.2	3-90

Question	Indicator Name	Section	Page
<i>What are the trends in the condition of recreational waters and their effects on human health and the environment?</i>	No ROE indicators		
<i>What are the trends in the condition of consumable fish and shellfish and their effects on human health?</i>	Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-103
	Contaminants in Lake Fish Tissue (N)	3.8.2	3-107

- 1 N = National Indicator
- 2 R = Regional Indicator
- 3 N/R = National Indicator displayed at EPA Regional scale
- 4

1 **3.2 WHAT ARE THE TRENDS IN EXTENT AND CONDITION OF FRESH**  
2 **SURFACE WATERS AND THEIR EFFECTS ON HUMAN HEALTH AND THE**  
3 **ENVIRONMENT?**

4 **3.2.1 Introduction**

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

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

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

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

- 31 • **Point source pollution**, including contaminants discharged directly into water bodies by  
32 industrial operations, as well as nutrients and contaminants in sewage. Even treated sewage  
33 contains nutrients that affect the chemical composition of the water.
- 34 • **Nonpoint source pollution**, which largely reflects contaminants, nutrients, and excess  
35 sediment in runoff from urban and suburban areas (e.g., stormwater) and agricultural land.  
36 Other sources include recreational activities (e.g., boating and marinas) and acid mine  
37 drainage. Nonpoint source pollution can be influenced by land use—e.g., certain forestry  
38 techniques and agricultural practices that encourage runoff and erosion. Nonpoint sources  
39 tend to be more variable than point sources. For example, pesticide concentrations in streams  
40 reflect the location and timing of pesticide application.

- 1 • **Air deposition.** Acidic aerosols, heavy metals, and other airborne contaminants may be  
2 deposited directly on water or may wash into water bodies after deposition on land. Air  
3 deposition is a major source of mercury, for example.
- 4 • **Invasive species.** Invasives are non-indigenous plant and animal species that can harm the  
5 environment, human health, or the economy.<sup>1</sup> Invasive species can crowd out native species,  
6 and also may alter the physical and chemical condition of water bodies.
- 7 • **Natural factors.** Precipitation determines the timing and amount of runoff and erosion, while  
8 other aspects of weather and climate influence heating, cooling, and mixing in lakes—which  
9 affect the movement of contaminants and the cycling of nutrients. The mineral composition  
10 of bedrock and sediment helps determine whether a water body may be susceptible to  
11 acidification.

12 The condition of fresh surface waters also may be influenced by extent. Stream flow patterns influence  
13 contaminant and sediment loads, while changes in the shape of water bodies—e.g., eliminating deep pools  
14 or creating shallow impoundments—can change water temperature. The extent of surface waters also  
15 represents the extent of habitat—a key aspect of biological condition. Some plant and animal  
16 communities are sensitive to water level (e.g., riparian communities), while others may be adapted to  
17 particular seasonal fluctuations in flow. Stressors that affect extent may ultimately affect the condition of  
18 freshwater habitat—for example, hydromodifications that restrict the migration of certain fish species.

### 19 **3.2.2 ROE Indicators**

20 Eight ROE indicators characterize either the extent or the condition of fresh surface waters (Table 3.2.1).  
21 One of these indicators presents information about stream flow patterns, an aspect of surface water extent.  
22 The other seven indicators characterize various aspects of condition, including the physical condition of  
23 sediments, the condition of benthic communities, and the chemical condition of the water itself. Several  
24 of these indicators track concentrations of nutrients, which can impact many different types of water  
25 bodies if present in excess (e.g., through eutrophication). Supporting data come from several national  
26 monitoring programs: EPA’s Environmental Monitoring and Assessment Program (EMAP), EPA’s  
27 Wadeable Streams Assessment (WSA), EPA’s Temporally Integrated Monitoring of Ecosystems (TIME)  
28 and LTM (Long-Term Monitoring) projects, and three programs administered by the U.S. Geological  
29 Survey (the National Water Quality Assessment [NAWQA] program, the National Stream Quality  
30 Accounting Network [NASQAN], and the USGS stream gauge network).

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

1 **Table 3.2.1. ROE Indicators of the Trends in Extent and Condition of Fresh Surface Waters and**  
 2 **their Effects on Human Health and the Environment**

<b>NATIONAL INDICATORS</b>	<b>LOCATION</b>
High and Low Stream Flows	3.2.2 – p. 3-14
Streambed Stability in Wadeable Streams	3.2.2 – p. 3-19
Lake and Stream Acidity	2.2.2 – p. 2-62
Nitrogen and Phosphorus in Wadeable Streams	3.2.2 – p. 3-22
Nitrogen and Phosphorus in Streams in Agricultural Watersheds	3.2.2 – p. 3-25
Nitrogen and Phosphorus Discharge from Large Rivers	3.2.2 – p. 3-28
Pesticides in Streams in Agricultural Watersheds	3.2.2 – p. 3-32
Benthic Macroinvertebrates in Wadeable Streams	3.2.2 – p. 3-35

3

## 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). The timing of high and low flows also influences many ecological processes. 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, which combines two indicators presented by The Heinz Center (2005), reports on trends in two aspects of stream flow:

- **Flow magnitude and timing:** This part of the indicator reports the percentage of streams or rivers throughout the contiguous 48 states that experienced major changes in the magnitude or the timing of average annual 1-day high flows or 7-day low flows in the 1970s, 1980s, or 1990s, compared to a 20-year baseline period between 1930 and 1949. This indicator is based on 867 USGS stream gauging sites with 20 years of continuous discharge records during the baseline period and continuous records for the three decades between 1970 and 1999.
- **No-flow periods:** This part of the indicator describes trends in no-flow periods in grassland and shrubland areas of the contiguous 48 states. These areas were selected for further analysis because they are largely arid or semi-arid, and therefore relatively water-stressed. This part of the indicator has two components. The first component reports the percentage of grassland/shrubland streams in which no-flow periods occurred during the 1950s, 1960s, 1970s, 1980s, or 1990s. The second component reports the percentage of these streams in which the duration of no-flow periods during each of these decades represents an increase or decrease of more than 50 percent compared to the 50-year (1950-1999) average for that stream. Data were collected from USGS stream gauges in watersheds where at least 50 percent of the land cover is considered grassland or shrubland per the National Land Cover Dataset (NLCD). These land cover designations generally correspond with three ecoregion types: Grassland/Steppe, California/Mediterranean, and Desert/Shrub (Bailey, 1995). The first component (percentage with no-flow periods) is based on 408 gauging sites; the second component (duration of no-flow periods) is based on 143 of these sites that had at least one no-flow day between 1950 and 1999.

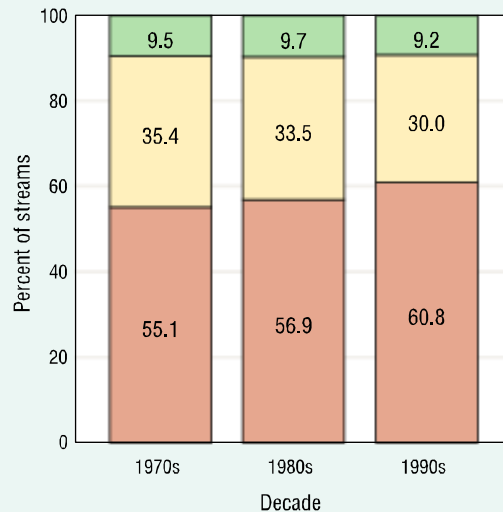
### What the Data Show

More than half of the streams and rivers showed changes of 75 percent or more in their high or low flows or a shift of 60 days or more in the timing of their high or low flows, compared to the period 1930-1949 (Exhibit 3-1). This percentage increased from 55 percent in the 1970s to 61 percent in the 1990s. About one-third of the streams showed moderate changes in flow (25-75 percent) or timing (30-60 days). Only 10 percent of the streams and rivers had minimal alterations of flow of less than 25 percent or timing of fewer than 30 days, compared to the historical baseline period.

1 Exhibit 3-2 provides more detail about the nature of  
 2 “major changes” in stream flow between the historical  
 3 reference period (1930-1949) and the 1970s-1990s  
 4 period of record. Notable trends include:

- 5 • Approximately two-thirds of streams had  
 6 major changes in the volume of low flow,  
 7 with about one-third of streams showing  
 8 substantially larger low flows throughout  
 9 the period of record (panel A) and another  
 10 one-third showing substantially smaller  
 11 low flows (panel B).
- 12 • In terms of high flow volume, more  
 13 streams showed major decreases than  
 14 major increases. In the 1970s and 1980s,  
 15 only 12 percent of streams had  
 16 substantially larger high-flow volumes  
 17 than they had from 1930 to 1949, although  
 18 this figure jumped to 31 percent in the  
 19 1990s (panel D). In contrast, throughout  
 20 the 1970s, 1980s, and 1990s, nearly 40  
 21 percent of streams exhibited smaller high  
 22 flows than they had during the reference  
 23 period (panel E).
- 24 • Between the reference period and the  
 25 1970s-1990s period of record, about 30  
 26 percent of streams showed major changes  
 27 in the timing of low flows (panel C), and  
 28 42 to 47 percent showed major changes in  
 29 the timing of high flows (panel F). The  
 30 number of streams in each of these  
 31 categories increased somewhat between  
 32 the 1970s and the 1990s.

**Exhibit 3-1. Alteration of high and low flow in rivers and streams in the contiguous U.S., 1970s-1990s, compared with 1930-1949 baseline<sup>a</sup>**



<sup>a</sup>**Coverage:** 867 stream gauging sites in the contiguous U.S. with continuous discharge measurements from 1930 to 1949 and from 1970 to 1999.

**Degree of alteration:**

- Minimal<sup>b</sup>
- Moderate<sup>c</sup>
- Major<sup>d</sup>

<sup>b</sup>**Minimal:** Less than 25% increase or decrease in flow, or less than a 30-day change in timing of low or high flow.

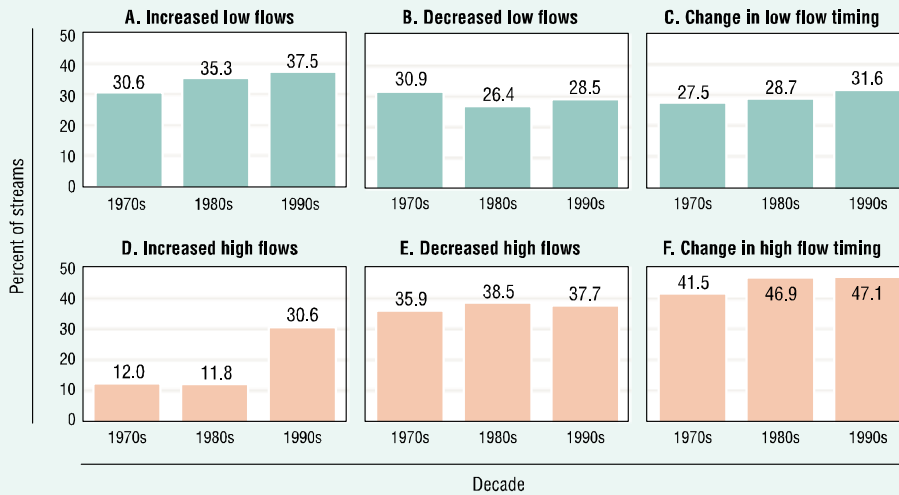
<sup>c</sup>**Moderate:** Between 25% and 75% increase or decrease in flow, or a 30- to 60-day change in timing of low or high flow.

<sup>d</sup>**Major:** More than 75% increase or decrease in flow, or more than a 60-day change in timing of low or high flow.

**Data source:** Heinz Center, 2005. Data collected by USGS, with analysis by Raff and Poff, 2001.

33 Overall, the percentage of streams and rivers in grassland and shrubland regions of the United States with  
 34 periods of no flow decreased from 24 percent in the 1950s to 14 percent in the 1990s, with some variation  
 35 by ecoregion (Exhibit 3-3). Among streams experiencing periods of no flow, the duration of these periods  
 36 also decreased between the 1950s and 1990s (Exhibit 3-4). In the 1950s, 38 percent of these streams and  
 37 rivers experienced no-flow periods that were at least 50 percent longer than their long-term average no-  
 38 flow periods during 1950-1999. By the 1990s, only 10 percent of streams fell into this category. The  
 39 percentage of streams with no-flow periods at least 50 percent shorter than their long-term average  
 40 increased from 23 percent in the 1950s to 63 percent in the 1990s, with a peak of 64 percent in the 1980s.

**Exhibit 3-2. Major changes in high and low flow in rivers and streams of the contiguous U.S., 1970s-1990s, compared with 1930-1949 baseline<sup>a, b</sup>**

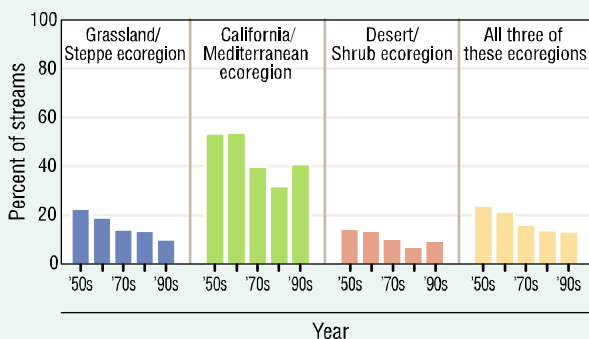


<sup>a</sup>**Coverage:** 867 stream gauging sites in the contiguous U.S. with continuous discharge measurements from 1930 to 1949 and from 1970 to 1999.

<sup>b</sup>Based on 7-day low flows and 1-day high flows. "Major" changes involve at least a 75% increase or decrease in flow or at least a 60-day shift in timing.

**Data source:** Heinz Center, 2005. Data collected by USGS, with analysis by Raff and Poff, 2001.

**Exhibit 3-3. Percentage of grassland/shrubland streams in the contiguous U.S. experiencing periods of no flow, by ecoregion, 1950s-1990s<sup>a, b</sup>**



<sup>a</sup>**Coverage:** 408 stream gauging sites within 4-digit Hydrologic Unit Code (HUC4) watersheds containing 50 percent or greater grass/shrub cover, and with continuous discharge measurements from 1950 to 1999. Grass/shrub cover refers to National Land Cover Dataset (NLCD) classes 31, 51, and 71 (<http://landcover.usgs.gov/classes.asp>).

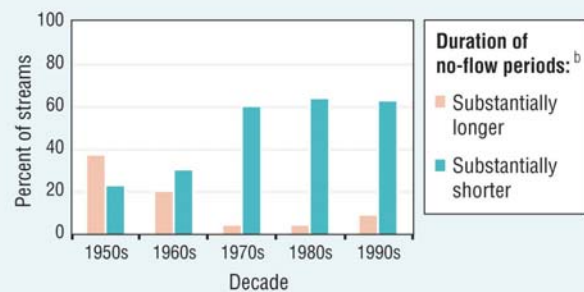
**Ecoregion divisions**



<sup>b</sup>Ecoregions based on Bailey, 1995.

**Data source:** Heinz Center, 2005. Data collected by USGS, with analysis by Raff, 2001 and Raff et al., 2001.

**Exhibit 3-4. Duration of no-flow periods in intermittent grassland/shrubland streams of the contiguous U.S., 1950s-1990s<sup>a</sup>**



<sup>a</sup>**Coverage:** Stream gauging sites within 4-digit Hydrologic Unit Code (HUC4) watersheds containing 50 percent or greater grass/shrub cover, and with continuous discharge measurements from 1950 to 1999. This analysis is limited to 143 sites that had at least one no-flow day during this period. Grass/shrub cover refers to National Land Cover Dataset (NLCD) classes 31, 51, and 71 (<http://landcover.usgs.gov/classes.asp>).

<sup>b</sup>A no-flow period is considered "substantially longer" if it is at least twice as long as the 50-year average for a given stream, and "substantially shorter" if it is 50% or less of the 50-year average. A decade without any no-flow days qualifies as "substantially shorter."

**Data source:** Heinz Center, 2005. Data collected by USGS, with analysis by Raff, 2001 and Raff et al., 2001.



1 **Indicator Limitations**

- 2 • The “magnitude and timing” component of this indicator compares stream flows in the  
3 decades from 1970 to 1999 with a baseline period, 1930-1949. Many dams and other  
4 waterworks had already been constructed by 1930, and this baseline period was characterized  
5 by low rainfall in some parts of the country. However, a similar analysis based on data from  
6 506 watersheds (USDA Forest Service, 2004) showed a tendency toward higher high- and  
7 low-flow rates in the decades of the 1940s, 1950s, and 1960s compared to the earlier period  
8 1879-1929.
- 9 • The “dry periods” component of this indicator compares stream flows in the decades from  
10 1950 to 1999 with average stream flow over the full 50-year period. Like the baseline  
11 discussed above, this long-term average does not represent the “natural state” of stream flow  
12 because it postdates anthropogenic changes such as urbanization, construction of dams, etc.
- 13 • Although the sites analyzed here are spread widely throughout the U.S., gauge placement by  
14 the USGS is not a random process. Gauges are generally placed on larger, perennial streams  
15 and rivers, and changes seen in these larger systems may differ from those seen in smaller  
16 streams and rivers.

17 **Data Sources**

18 The data presented in this indicator were originally published in Heinz Center (2005). The Heinz Center’s  
19 analysis was conducted by David Raff and N. LeRoy Poff, Colorado State University (Raff and Poff,  
20 2001; Raff et al., 2001; Raff, 2001), using stream flow data from the USGS National Water Information  
21 System database (USGS, 2005) (<http://waterdata.usgs.gov/nwis>). All data, including the 1930-1949  
22 reference data, can be downloaded from this database. Ecoregions are based on Bailey (1995).

23 **References**

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- 36 Poff, N.L., and J.D. Allan. 1995. Functional organization of stream fish assemblages in relation to  
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2 grassland and shrubland ecosystems in support of the State of the Nation's Ecosystems project for The H.  
3 John Heinz III Center. Colorado State University.
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5 State of the Nation's Ecosystems project for The H. John Heinz III Center. Colorado State University.
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7 predominantly grassland and shrubland ecosystems in support of the State of the Nation's Ecosystems  
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- 9 Robinson, C.T., K. Tockner, and J.V. Ward. 2002. The fauna of dynamic riverine landscapes. *Freshwater*  
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## 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 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 stormflows. 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 stormflow. A low RBS score indicates a relatively unstable streambed, consisting of many fine particles that could be carried away by a stormflow. 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 the U.S. 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 1<sup>st</sup> through 4<sup>th</sup> 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.

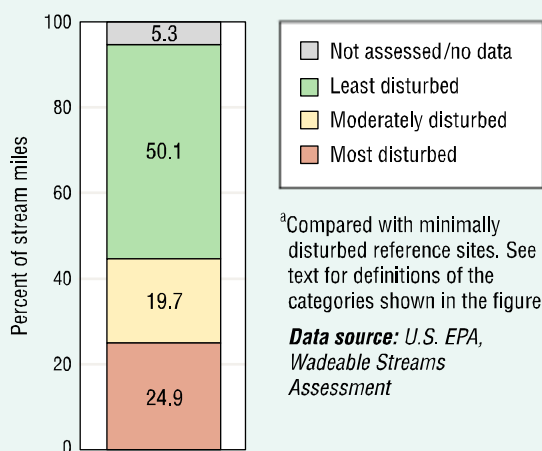
Because streambed characteristics vary geographically, streams were divided into nine ecoregions.<sup>2</sup> In each ecoregion, a set of relatively undisturbed sites was sampled in order to determine the range of RBS

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<sup>2</sup> For this analysis, the 48 contiguous states were divided into nine broad ecoregions. These “macro-level” ecoregions were defined by the WSA based on groupings of EPA Level III ecoregions (for a map of EPA Level III ecoregions, see [http://www.epa.gov/wed/pages/ecoregions/level\\_iii.htm](http://www.epa.gov/wed/pages/ecoregions/level_iii.htm)). A map of the nine WSA ecoregions will be available in the e-ROE.

1 values that would be expected among “least disturbed” streams. Next, the RBS for every site was  
 2 compared to the distribution of RBS values among the ecoregion’s reference sites. If the observed RBS  
 3 for a sample site was below the 5<sup>th</sup> or the 10<sup>th</sup> percentile of the regional reference distribution (depending  
 4 on the ecoregion), the site was classified as “most disturbed.” This threshold was used because it offers a  
 5 high degree of confidence that the observed condition is statistically different from the “least disturbed”  
 6 reference condition. Streams with an RBS above the 25<sup>th</sup> percentile of the reference range were labeled  
 7 “least disturbed,” indicating a high probability that the site is similar to the relatively undisturbed  
 8 reference sites. Streams falling between the 5<sup>th</sup> and 25<sup>th</sup> percentiles were classified as “moderately  
 9 disturbed.” Note that the “least disturbed” category may include some streams with higher-than-expected  
 10 RBS values, which represent overly stable streambeds. Because it is more difficult to determine whether  
 11 overly stable streambeds are “natural” or result from anthropogenic factors, this indicator only measures  
 12 the prevalence of *unstable* streambeds (i.e., excess sedimentation).

**Exhibit 3-5.** Streambed stability in wadeable streams of the contiguous U.S., 2000-2004<sup>a</sup>



### 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 3-5). 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.

### 29 Indicator Limitations

- 30 • Samples were taken one time from each sampling location during the index period (April–  
 31 November). Although the probability sampling design results in unbiased estimates for  
 32 relative streambed stability in wadeable streams during the study period, RBS values may be  
 33 different during other seasons and years because of variations in hydrology.
- 34 • Trend data are unavailable because this is the first time that a survey on this broad scale has  
 35 been conducted, and the survey design does not allow trends to be calculated within a single  
 36 sampling period (2000-2004). These data will serve as a baseline for future surveys.

### 37 Data Sources

38 Aggregate data for this indicator were provided by EPA’s Wadeable Streams Assessment (WSA) (U.S.  
 39 EPA, 2006b). Data from individual stream sites can be obtained from EPA’s STORET database (U.S.  
 40 EPA, 2006a) ([http://www.epa.gov/owow/streamsurvey/web\\_data.html](http://www.epa.gov/owow/streamsurvey/web_data.html)).

1   **References**

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- 5   Strahler, A.N. 1952. Dynamic basis of geomorphology. Geol. Soc. Am. Bull. 63:923-938.
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7   <[http://www.epa.gov/owow/streamsurvey/web\\_data.html](http://www.epa.gov/owow/streamsurvey/web_data.html)>
- 8   U.S. EPA. 2006b. Wadeable Streams Assessment: a collaborative survey of the nation's streams. EPA  
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- 11  U.S. EPA. 2004. Wadeable Streams Assessment: field operations manual. EPA/841/B-04/004.  
12  Washington, DC. <[http://www.epa.gov/owow/monitoring/wsa/wsa\\_fulldocument.pdf](http://www.epa.gov/owow/monitoring/wsa/wsa_fulldocument.pdf)>

## 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 the U.S. 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 1<sup>st</sup> through 4<sup>th</sup> 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 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, 2004b).

Because naturally occurring nutrient levels vary from one geographic area to another, streams were divided into nine ecoregions.<sup>3</sup> 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 95<sup>th</sup> 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 75<sup>th</sup> percentile of the reference range were labeled “low,” indicating a high probability that the site is similar to the relatively undisturbed reference sites. Concentrations falling between the 75<sup>th</sup> and 95<sup>th</sup> percentiles were labeled “moderate.”

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<sup>3</sup> For this analysis, the 48 contiguous states were divided into nine broad ecoregions. These “macro-level” ecoregions were defined by the WSA based on groupings of EPA Level III ecoregions (for a map of EPA Level III ecoregions, see [http://www.epa.gov/wed/pages/ecoregions/level\\_iii.htm](http://www.epa.gov/wed/pages/ecoregions/level_iii.htm)). A map of the nine WSA ecoregions will be available in the e-ROE.

1 **What the Data Show**

2 Nationwide, 43.3 percent of wadeable stream miles  
3 had low total nitrogen concentrations, while high  
4 nitrogen concentrations were found in 31.8 percent of  
5 stream miles (Exhibit 3-6). The results for total  
6 phosphorus are similar to those for nitrogen, with low  
7 concentrations in 48.8 percent of stream miles and  
8 high concentrations in 30.9 percent (Exhibit 3-6). The  
9 concentrations associated with the regional thresholds  
10 vary because of natural differences among the  
11 ecoregions. Approximately 4 percent of the nation's  
12 wadeable stream length could not be assessed because  
13 of missing or inadequate sample data.

14 **Indicator Limitations**

- 15 • Samples were taken one time from each  
16 sampling location during the index period  
17 (April–November). Although the  
18 probability sampling design results in an  
19 unbiased estimate for total N and P  
20 concentrations in wadeable streams during  
21 the study period, concentrations may be  
22 different during other seasons.
- 23 • Trend data are unavailable because this is the first time that a survey on this broad scale has  
24 been conducted, and the survey design does not allow trends to be calculated within a single  
25 sampling period (2000-2004). These data will serve as a baseline for future surveys.
- 26 • Not all forms of nitrogen and phosphorus are equally bioavailable, and the ratio of nitrogen  
27 and phosphorus can affect the biomass and type of species of algae in streams. The forms of  
28 N and P and the N/P ratios may vary somewhat between the regional reference sites and the  
29 WSA streams.

30 **Data Sources**

31 Aggregate data for this indicator were provided by EPA's Wadeable Streams Assessment (WSA) (U.S.  
32 EPA, 2006b). Data from individual stream sites can be obtained from EPA's STORET database (U.S.  
33 EPA, 2006a) ([http://www.epa.gov/owow/streamsurvey/web\\_data.html](http://www.epa.gov/owow/streamsurvey/web_data.html)).

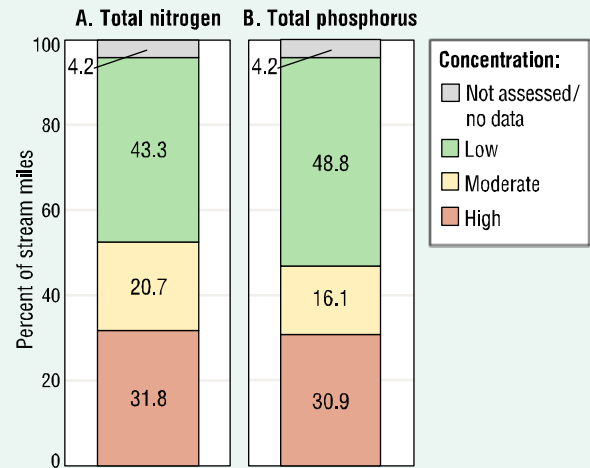
34 **References**

35 Herlihy, A.T., J.L. Stoddard, and C.B. Johnson. 1998. The relationship between stream chemistry and  
36 watershed land use data in the Mid-Atlantic region. *US Water Air Soil Pollut.* 105:377-386.

37 Strahler, A.N. 1952. Dynamic basis of geomorphology. *Geol. Soc. Am. Bull.* 63:923-938.

38 U.S. EPA. 2006a. Data from the Wadeable Streams Assessment. Accessed 2006.  
39 [<http://www.epa.gov/owow/streamsurvey/web\\_data.html>](http://www.epa.gov/owow/streamsurvey/web_data.html)

**Exhibit 3-6.** Nitrogen and phosphorus in wadeable streams of the contiguous U.S., 2000-2004<sup>a</sup>



<sup>a</sup>Compared with minimally disturbed reference sites. See text for definitions of the categories shown in the figure.

**Data source:** U.S. EPA, Wadeable Streams Assessment

- 1 U.S. EPA. 2006b. Wadeable Streams Assessment: a collaborative survey of the nation's streams. EPA
- 2 841-B-06-002. Washington, DC.
- 3 <[http://www.epa.gov/owow/streamsurvey/WSA\\_Assessment\\_Dec2006.pdf](http://www.epa.gov/owow/streamsurvey/WSA_Assessment_Dec2006.pdf)>
  
- 4 U.S. EPA. 2005. National estuary program—challenges facing our estuaries. Key management issues:
- 5 nutrient overloading. <[www.epa.gov/owow/estuaries/about3.htm](http://www.epa.gov/owow/estuaries/about3.htm)>
  
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- 7 Washington, DC. <[http://www.epa.gov/owow/monitoring/wsa/wsa\\_fulldocument.pdf](http://www.epa.gov/owow/monitoring/wsa/wsa_fulldocument.pdf)>
  
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## 1 INDICATOR: Nitrogen and Phosphorus in Streams in Agricultural Watersheds

2 Nitrogen is a critical nutrient that is generally used and reused by plants within natural ecosystems, with  
3 minimal “leakage” into surface or ground water, where nitrogen concentrations remain very low  
4 (Vitousek et al., 2002). When nitrogen is applied to the land in amounts greater than can be incorporated  
5 into crops or lost to the atmosphere through volatilization or denitrification, however, nitrogen  
6 concentrations in streams can increase. The major sources of excess nitrogen in predominantly  
7 agricultural watersheds are fertilizer and animal waste; other sources include septic systems and  
8 atmospheric deposition. The total nitrogen concentration in streams is comprised of the most common  
9 bioavailable form (nitrate), organic nitrogen which is generally less available to biota, and nitrite and  
10 ammonium compounds which are typically not present in streams except in highly polluted situations.  
11 Excess nitrate is not toxic to aquatic life, but increased nitrogen may result in overgrowth of algae which  
12 can decrease the dissolved oxygen content of the water, thereby harming or killing fish and other aquatic  
13 species (U.S. EPA, 2005). Excess nitrogen also can lead to problems in downstream coastal waters, as  
14 discussed further in the N and P Discharge from Large Rivers indicator (p. 3-28). High concentrations of  
15 nitrate in drinking water may pose a risk of methemoglobinemia, a condition that interferes with oxygen  
16 transport in the blood of infants (U.S. EPA, 2004).

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

24 This indicator reports nitrogen and phosphorus concentrations in stream water samples collected from  
25 1992 to 2001 by the U.S. Geological Survey’s National Water Quality Assessment (NAWQA) program,  
26 which surveys the condition of streams and aquifers in study units throughout the contiguous United  
27 States. Specifically, this indicator reflects the condition of streams draining 111 watersheds where  
28 agriculture is the predominant land use, according to criteria outlined in Mueller and Spahr (2005), and  
29 where data are available to characterize all four species of interest (nitrate, total nitrogen, orthophosphate,  
30 and total phosphorus). These 111 watersheds are located in 38 of the 51 NAWQA study units (i.e., major  
31 river basins). Sites were chosen to avoid large point sources of nutrients (e.g., wastewater treatment  
32 plants). At each stream site, samples were collected 12 to 25 times each year over a 1-to-3-year period;  
33 this indicator is based on a flow-weighted annual average of those samples. Related indicators report the  
34 concentrations of nitrogen and phosphorus in small wadeable streams, regardless of land use (p. 3-22),  
35 and nitrate concentrations in ground water in agricultural watersheds (p. 3-44).

36 For nitrogen, the indicator reports the percentage of streams with average concentrations of nitrate and  
37 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  
38 mg/L; and 10 mg/L or more. (This indicator measures nitrate (as N), i.e., the fraction of the material that  
39 is actually nitrogen.) The highest level (10 mg/L as N) represents the Maximum Contaminant Level  
40 (MCL) for nitrate allowed in finished drinking water in the United States (U.S. EPA, 2006). Because  
41 people are unlikely to drink untreated stream water, this concentration should be viewed as a point of  
42 reference, and not necessarily as a health risk to consumers. There is no human health guideline for total  
43 nitrogen and no comparable aquatic health guideline for either nitrate or total nitrogen because neither  
44 form represents a direct threat to organisms living in the stream.

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

9 **What the Data Show**

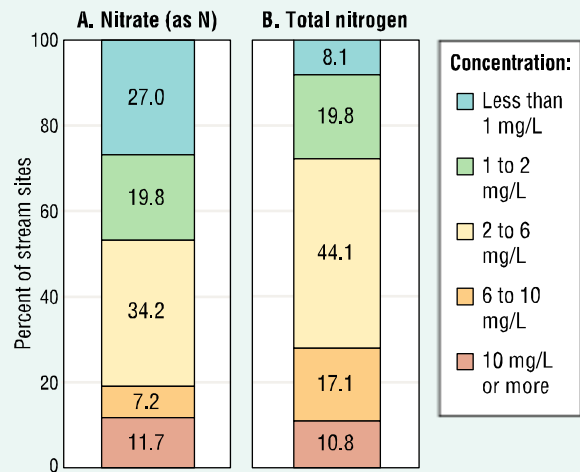
10 Average flow-weighted nitrate concentrations were  
 11 above 2 mg/L in about half of the stream sites in these  
 12 predominantly agricultural watersheds (Exhibit 3-7).  
 13 About 12 percent of stream sites had nitrate  
 14 concentrations above the federal drinking water MCL  
 15 of 10 mg/L (the slightly smaller percentage of streams  
 16 with total N above 10 mg/L is an artifact of the flow-  
 17 weighting algorithm). Nearly half of the streams  
 18 sampled had total nitrogen concentrations in the 2-6  
 19 mg/L range, and 72 percent had concentrations above  
 20 2 mg/L.

21 Almost 60 percent of the streams in agricultural  
 22 watersheds had flow-weighted concentrations of  
 23 orthophosphate (as P) of less than 0.1 mg/L. More than  
 24 three-fourths of the streams had average annual flow-  
 25 weighted concentrations of total phosphorus above 0.1  
 26 mg/L, while nearly 15 percent had total phosphorus  
 27 concentrations above 0.5 mg/L (Exhibit 3-8).

28 **Indicator Limitations**

- 29 • These data represent streams draining  
 30 agricultural watersheds in 38 of the major  
 31 river basins (study units) sampled by the  
 32 NAWQA program in the contiguous U.S.  
 33 While they were chosen to be  
 34 representative of agricultural watersheds  
 35 across the United States, they are the  
 36 result of a targeted sample design, and  
 37 may not be an accurate reflection of the  
 38 distribution of concentrations in all  
 39 streams in agricultural watersheds in the  
 40 U.S.

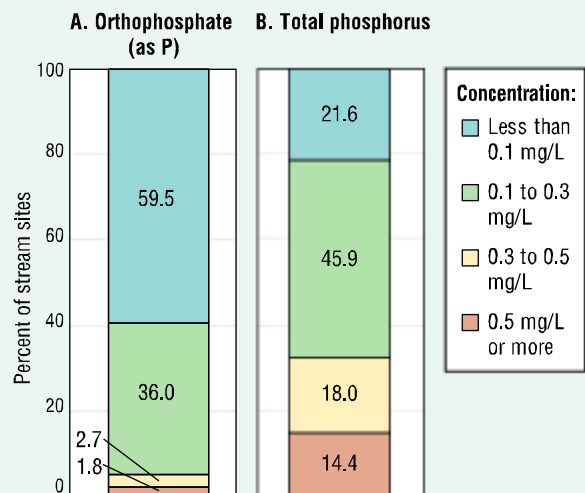
**Exhibit 3-7. Nitrogen in streams in agricultural watersheds of the contiguous U.S., 1992-2001<sup>a</sup>**



<sup>a</sup>**Coverage:** 111 watersheds in which agriculture is the predominant land use, according to criteria outlined in Mueller and Spahr, 2005. These watersheds are within 38 major river basins studied by the USGS NAWQA Program.

**Data source:** Mueller and Spahr, 2005

**Exhibit 3-8. Phosphorus in streams in agricultural watersheds of the contiguous U.S., 1992-2001<sup>a</sup>**



<sup>a</sup>**Coverage:** 111 watersheds in which agriculture is the predominant land use, according to criteria outlined in Mueller and Spahr, 2005. These watersheds are within 38 major river basins studied by the USGS NAWQA Program.

**Data source:** Mueller and Spahr, 2005

- 1           • This indicator does not provide information about trends over time, as the NAWQA program  
2           has completed only one full sampling cycle to date. Completion of the next round of  
3           sampling will allow trend analysis, using the data presented here as a baseline.
- 4           • Drinking water treatment can significantly reduce concentrations of nitrate, so the levels of  
5           contaminants reported in this indicator are not necessarily representative of the exposures to  
6           people when these waters are used as public drinking water supplies.

7   **Data Sources**

8   Summary data for this indicator were provided by the U.S. Geological Survey's National Water Quality  
9   Assessment (NAWQA) program. These data have been published in Mueller and Spahr (2005), along  
10 with the individual sampling results on which the analysis is based.

11 **References**

12 Mueller, D.K., and N.E. Spahr. 2005. Water-quality, streamflow, and ancillary data for nutrients in  
13 streams and rivers across the nation, 1992-2001: U.S. Geological Survey data series 152.

14 <<http://pubs.usgs.gov/ds/2005/152/>>

15 U.S. EPA. 2005. National estuary program—challenges facing our estuaries. Key management issues:  
16 nutrient overloading. <<http://www.epa.gov/owow/estuaries/about3.htm>>

17 U.S.EPA. 2006. List of drinking water contaminants and MCLs.

18 <<http://www.epa.gov/safewater/mcl.html>>

19 U.S. EPA. 2004. Consumer factsheet on nitrates/nitrites.

20 <[http://www.epa.gov/safewater/contaminants/dw\\_contamfs/nitrates.html](http://www.epa.gov/safewater/contaminants/dw_contamfs/nitrates.html)>

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

## INDICATOR: Nitrogen and Phosphorus Discharge from 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<sub>2</sub> gas through 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.

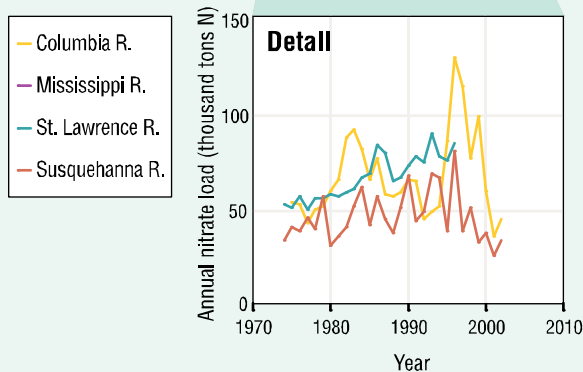
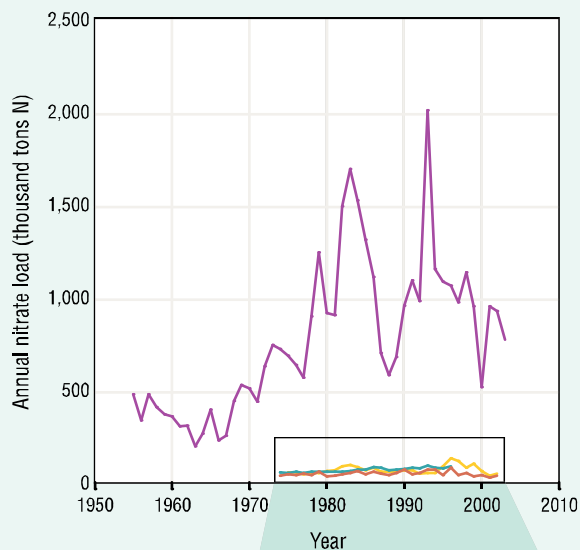
This indicator tracks trends in the discharge of nitrate and phosphorus from four of the largest rivers in the United States: the Mississippi, Columbia, St. Lawrence, and Susquehanna. While not inclusive of the entire nation, these four rivers account for approximately 55 percent of all freshwater flow entering the ocean from the contiguous 48 states, and are geographically distributed. 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 stream 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 (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.

### What the Data Show

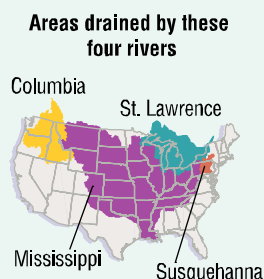
The Mississippi River, which drains more than 40 percent of the area of the lower 48 states, carries roughly 15 times more nitrate than any other U.S. river. Nitrate discharge from the Mississippi increased noticeably over much of the last half-century, rising from 200,000–500,000 tons per year in the 1950s and 1960s to an average of about 1,000,000 tons per year during the 1980s and 1990s (Exhibit 3-9). Large

**Exhibit 3-9. Nitrate discharge from four major U.S. rivers, 1955-2003<sup>a</sup>**



<sup>a</sup>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 National Water Quality Assessment (NAWQA) Program, USGS National Stream Quality Network (NASQAN), and USGS Federal-State Cooperative Program



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 nitrate load in the Columbia River increased to almost twice its historical loads during the later half of the 1990s, but by the last year of record (2002), the amount of nitrate discharged had returned to levels similar to those seen in the late 1970s (Exhibit 3-9). The St. Lawrence River showed an overall upward trend in nitrate discharge 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 both carried an average of about 66,000 tons of nitrate per year, while the Susquehanna averaged 46,000 tons. By comparison, the Mississippi carried an average of 770,000 tons per year over its period of record.

The amount of phosphorus discharged decreased in the St. Lawrence and Susquehanna Rivers over the period of record (Exhibit 3-10). There is no obvious trend in the Mississippi and Columbia Rivers, and the year-to-year variability is quite large. Nitrogen and phosphorus discharges 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 136,000; 11,000; 6,000; and 3,000 tons, respectively.

### Indicator Limitations

- 38 • The indicator does not include data from numerous coastal watersheds whose human
- 39 populations are rapidly increasing (e.g., Valigura et al., 2000).
- 40 • It does not include smaller watersheds in geologically sensitive areas, whose ability to retain
- 41 nitrogen might be affected by acid deposition (e.g., Evans et al., 2000).
- 42 • It does not include forms of nitrogen other than nitrate. Although nitrate is one of the most
- 43 bioavailable forms of nitrogen, other forms may constitute a substantial portion of the
- 44 nitrogen load. Historically, nitrate data are more extensive than data on other forms of
- 45 nitrogen.

- Not all forms of phosphorus included in the total phosphorus loads are equally capable of causing algal blooms.

#### 4 Data Sources

A previous version of this analysis was published in the Heinz Center’s report, *The State of the Nation’s Ecosystems* (Heinz Center, 2005). Updated data were provided to EPA by USGS. USGS’s analysis was based on nutrient sampling and daily stream flow data, which can be obtained from USGS’s public databases (USGS, 2006a, 2006b).

#### 12 References

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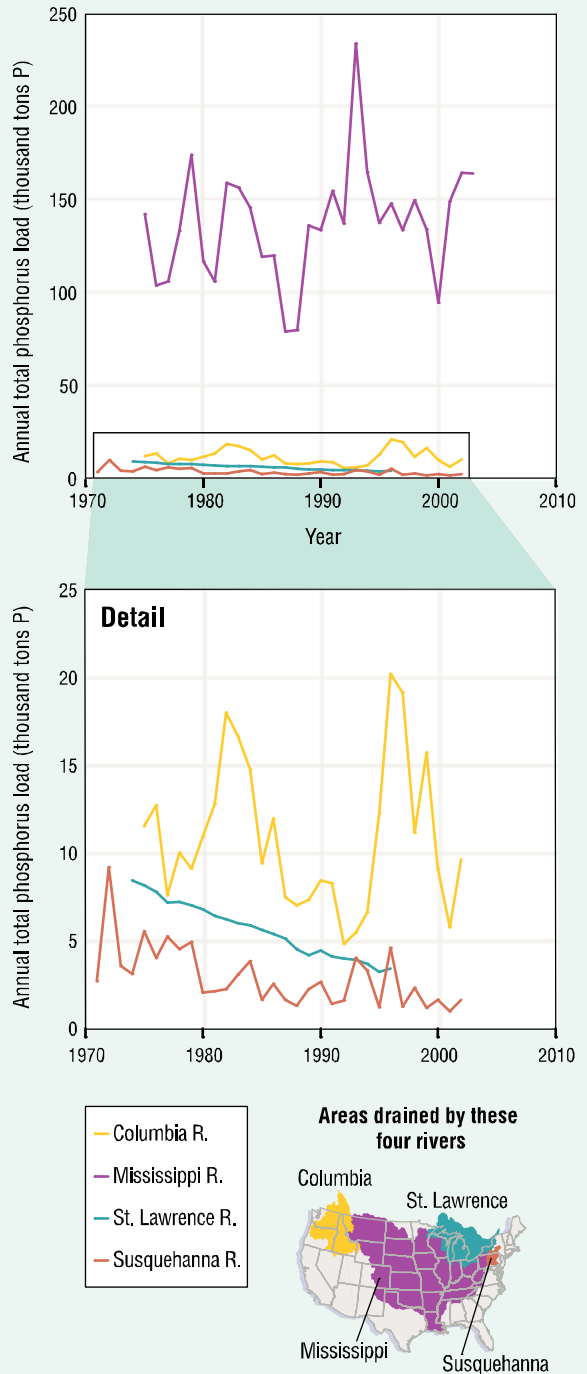
Rabalais, N.N., and R.E. Turner, eds. 2001. *Coastal hypoxia: consequences for living resources and ecosystems*. Coastal and estuarine studies 58. Washington, DC: American Geophysical Union.

Smith, S.V., D.P. Swaney, L. Talaue-McManus, J.D. Bartley, P.T. Sandhei, C.J. McLaughlin, V.C. Dupra, C.J. Crossland, R.W. Buddemeier, B.A. Maxwell, and F. Wulff. 2003. Humans, hydrology, and the distribution of inorganic nutrient loading to the ocean. *BioScience* 53:235-245.

USGS. 2006a. National Stream Quality Accounting Network (NASQAN) data. Accessed 2006. <http://water.usgs.gov/nasqan/data/index.html>

USGS. 2006b. National water information system. Accessed 2006. <http://waterdata.usgs.gov/nwis/>

**Exhibit 3-10. Total phosphorus discharge from four major U.S. rivers, 1971-2003**



**Data source:** USGS National Water Quality Assessment (NAWQA) Program, USGS National Stream Quality Network (NASQAN), and USGS Federal-State Cooperative Program

- 1 Valigura, R., R. Alexander, M. Castro, T. Meyers, H. Paerl, P. Stacey, and R. Turner, eds. 2000. Nitrogen
- 2 loading in coastal water bodies—an atmospheric perspective. Washington, DC: American Geophysical
- 3 Union.
  
- 4 Vitousek, P., H. Mooney, L. Olander, and S. Allison. 2002. Nitrogen and nature. *Ambio* 31:97-101.

## 1 INDICATOR: Pesticides in Streams in Agricultural Watersheds

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

11 This indicator is based on stream water samples collected between 1992 and 2001 as part of the U.S.  
12 Geological Survey's National Water Quality Assessment (NAWQA) program, which surveys the  
13 condition of streams and aquifers in study units throughout the contiguous United States. Of the streams  
14 sampled for pesticides, this indicator focuses on 83 streams in watersheds where agriculture represents the  
15 predominant land use, according to criteria outlined in Gilliom et al. (2006). These 83 streams are located  
16 in 36 of the 51 NAWQA study units (i.e., major river basins). From each site, NAWQA collected 10 to 49  
17 stream water samples per year over a 1-to-3-year period to analyze for 75 different pesticides and 8  
18 pesticide degradation products, which together account for approximately 78 percent of the total  
19 agricultural pesticide application in the United States by weight during the study period (Gilliom et al.,  
20 2006). This indicator reports the number of stream sites where the annual time-weighted average  
21 concentration of one or more of these pesticides or degradation products exceeds standards for aquatic or  
22 human health. A related indicator discusses pesticide concentrations in ground water in agricultural  
23 watersheds (p. 3-44).

24 Three types of U.S. EPA standards and guidelines for drinking water were used as human health  
25 benchmarks for pesticide concentrations: Maximum Contaminant Levels (MCLs), Cancer Risk  
26 Concentrations (CRCs), and Lifetime Health Advisories (HA-Ls). All of these standards/guidelines are  
27 concentrations that pertain to lifetime exposure through drinking water (CRCs relate to potential  
28 carcinogens and HA-Ls relate to non-carcinogenic adverse health effects). Gilliom et al. (2006) provides a  
29 full list of the standards and guidelines used in this assessment; see also the list of MCLs at EPA (2006).  
30 More detail on these types of benchmarks, their derivation, and their underlying assumptions is provided  
31 in Nowell and Resek (1994). If a chemical had multiple benchmarks, the MCL was used if available;  
32 otherwise, the lower of the CRC (at 1 in 1,000,000 cancer risk) and HA-L values was selected. An  
33 exceedance was identified if a yearly, time-weighted mean concentration exceeded the corresponding  
34 standard or guideline (Gilliom et al., 2006).

35 Several types of water quality benchmarks were used for aquatic life. Where available, data were  
36 compared with EPA's acute and chronic ambient water-quality criteria for the protection of aquatic life  
37 (AWQC-ALs). The acute AWQC-AL is the highest concentration of a chemical to which an aquatic  
38 community can be exposed briefly without resulting in an unacceptable effect. The chronic AWQC-AL is  
39 the highest concentration to which an aquatic community can be exposed *indefinitely* without resulting in  
40 an unacceptable effect. An exceedance was identified if a single sample exceeded the acute AWQC-AL or  
41 if a 4-day moving average exceeded the chronic AWQC-AL (per EPA's definition of the chronic AWQC-  
42 AL). Results were also compared with aquatic life benchmarks derived from toxicity values presented in  
43 registration and risk-assessment documents developed by EPA's Office of Pesticide Programs (OPP).  
44 These benchmarks included acute and chronic values for fish and invertebrates, acute values for vascular



1 and nonvascular plants, and a value for aquatic community effects. An exceedance was identified if a  
2 single sample exceeded any acute benchmark or if the relevant moving average exceeded a chronic  
3 benchmark. More information about the derivation and application of aquatic life guidelines for this  
4 indicator can be found in Gilliom et al. (2006).

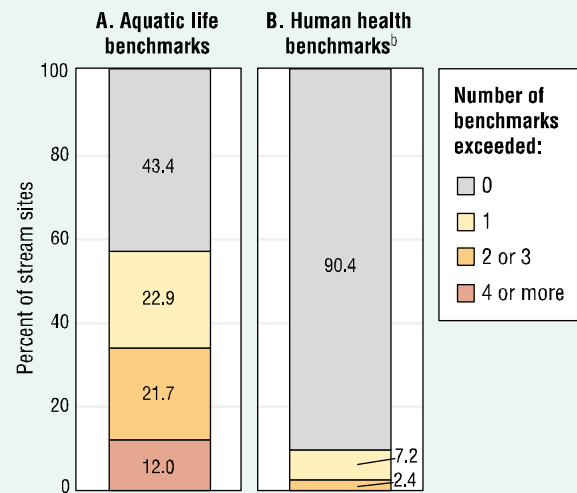
## 5 What the Data Show

6 In 57 percent of the streams sampled, at least one  
7 pesticide was detected at a concentration that exceeded  
8 one or more aquatic life benchmarks (Exhibit 3-11).  
9 Roughly 10 percent of streams contained at least one  
10 pesticide at a concentration above the corresponding  
11 benchmark for human health. For reference, NAWQA  
12 data indicate that within this set of agricultural  
13 streams, at least one pesticide was present at detectable  
14 levels more than 90 percent of the time (Gilliom et al.,  
15 2006). NAWQA data also indicate that pesticides in  
16 agricultural streams most often occur in mixtures (i.e.,  
17 more than one compound is present in the sample)  
18 (Gilliom et al., 2006). The human health and  
19 environmental impacts of pesticide contamination,  
20 particularly when the pesticides occur as mixtures, are  
21 not well understood.

## 22 Indicator Limitations

- 23 • These data represent streams draining  
24 agricultural watersheds in 36 of the study  
25 units (major river basins) sampled by the  
26 NAWQA program in the contiguous  
27 United States. While they were chosen to  
28 be representative of agricultural  
29 watersheds across the nation, they are the  
30 result of a targeted sampling design, and  
31 may not be an accurate reflection of the  
32 distribution of concentrations in all  
33 streams in the nation's agricultural watersheds.
- 34 • This indicator does not provide information about trends over time, as the NAWQA program  
35 has completed only one full sampling cycle to date. Completion of the next round of  
36 sampling will allow trend analysis, using the data presented here as a baseline.
- 37 • Drinking water treatment can significantly reduce concentrations of many pesticides, so the  
38 levels reported in this indicator are not necessarily representative of the exposures to people  
39 when these waters are used as public drinking water supplies.
- 40 • Aquatic life benchmarks do not currently exist for 21 of the 83 pesticides and pesticide  
41 degradation products analyzed, while drinking water standards or guidelines (MCLs, CRCs,  
42 and HAs) do not exist for 36 of 83. Current standards and guidelines do not account for  
43 mixtures of pesticide chemicals and seasonal pulses of high concentrations. Possible pesticide  
44 effects on reproductive, nervous, and immune systems, as well as on chemically sensitive  
45 individuals, are not yet well understood.

**Exhibit 3-11.** Pesticides in streams in agricultural watersheds of the contiguous U.S., 1992-2001<sup>a</sup>



<sup>a</sup>**Coverage:** 83 watersheds in which agriculture is the predominant land use, according to criteria outlined in Gilliom et al., 2006. These watersheds are within 36 major river basins studied by the USGS NAWQA program.

<sup>b</sup>No streams exceeded 4 or more human health benchmarks.

**Data source:** USGS, National Water Quality Assessment (NAWQA) Program

- 1           • The pesticide benchmarks used here are designed to be fully protective of human or aquatic  
2 health. Other indicators, such as Coastal Sediment Quality (p. 3-67), use aquatic life  
3 thresholds that are less protective. Thus, these indicators are not necessarily comparable to  
4 one another.
- 5           • This indicator does not provide information on the degree to which pesticide concentrations  
6 exceed or fall below benchmarks.

## 7 **Data Sources**

8 Summary data for this indicator were provided by the U.S. Geological Survey's National Water Quality  
9 Assessment (NAWQA) program. Portions of this analysis have also been published in Gilliom et al.  
10 (2006). Data from individual sample sites are available online in Appendix 6 of the same report  
11 (<http://ca.water.usgs.gov/pnsp/pubs/circ1291/appendix6/>).

## 12 **References**

- 13 Aspell, A.L. 2003. Pesticide usage in the United States: trends during the 20<sup>th</sup> century. Raleigh, NC:  
14 Center for Integrated Pest Management, North Carolina State University.  
15 <[http://www.pestmanagement.info/pesticide\\_history/index.pdf](http://www.pestmanagement.info/pesticide_history/index.pdf)>
- 16 Gilliom, R.J., J.E. Barbash, C.G. Crawford, P.A. Hamilton, J.D. Martin, N. Nakagaki, L.H. Nowell, J.C.  
17 Scott, P.E. Stackelberg, G.P. Thelin, and D.M. Wolock. 2006. Pesticides in the Nation's Streams and  
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19 <<http://ca.water.usgs.gov/pnsp/pubs/circ1291/>>
- 20 Nowell, L.H., and E.A. Resek. 1994. National standards and guidelines for pesticides in water, sediment,  
21 and aquatic organisms: application to water-quality assessments: Rev. Environ. Contam. Toxicol. 140:1-  
22 164.
- 23 U.S. EPA. 2006. List of drinking water contaminants and MCLs.  
24 <<http://www.epa.gov/safewater/mcl.html>>
- 25 USGS (U.S. Geological Survey). 2000. Pesticides in stream sediment and aquatic biota.  
26 <<http://ca.water.usgs.gov/pnsp/rep/fs09200/>>

## 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 (Karr and Dudley, 1997). 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 one 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 the U.S. 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 1<sup>st</sup> through 4<sup>th</sup> order in the Strahler Stream Order classification system (Strahler, 1952). Between 2000 and 2004, crews sampled 1,392 sites throughout the contiguous United States using standardized methods (U.S. EPA, 2004a, 2004b). 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. 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.

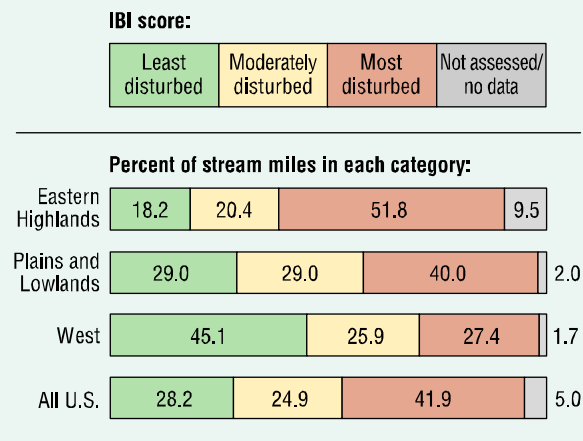
The IBI is an index that reduces complex information about community structure into a simple numerical value based on measures of taxonomic richness (number of taxa); taxonomic composition (e.g., insects vs. non-insects); taxonomic diversity; feeding groups (e.g., shredders, scrapers, or predators); habits (e.g., burrowing, clinging, or climbing taxa); and tolerance to stressors. Separate metrics were used for each of these categories in different ecoregions of the United States, based on their ability to best discriminate among streams.<sup>4</sup> Each metric was scaled against the 5<sup>th</sup>-95<sup>th</sup> 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 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 5<sup>th</sup> 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 an IBI score above the 25<sup>th</sup> percentile of the reference range were labeled "least disturbed," indicating a high probability that the

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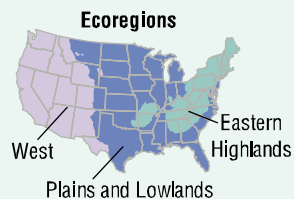
<sup>4</sup> For this analysis, the 48 contiguous states were divided into nine broad ecoregions. These "macro-level" ecoregions were defined by the WSA based on groupings of EPA Level III ecoregions (for a map of EPA Level III ecoregions, see [http://www.epa.gov/wed/pages/ecoregions/level\\_iii.htm](http://www.epa.gov/wed/pages/ecoregions/level_iii.htm)). A map of the nine WSA ecoregions will be available in the e-ROE.

**Exhibit 3-12.** Index of Biological Integrity (IBI) for benthic macroinvertebrates in wadeable streams of the contiguous U.S., by ecoregion, 2000-2004<sup>a</sup>



<sup>a</sup>Ecoregions based on Omernik, 1987.

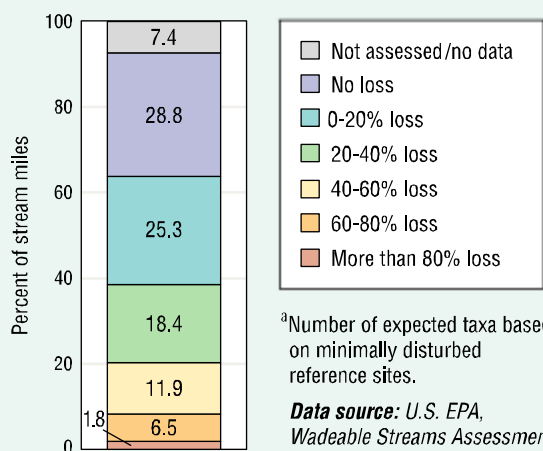
**Data source:** U.S. EPA, Wadeable Streams Assessment



site is similar to the relatively undisturbed reference sites. Streams falling between the 5<sup>th</sup> and 25<sup>th</sup> percentiles were classified as “moderately disturbed.”

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.

**Exhibit 3-13.** Percent loss of benthic macroinvertebrate taxa in wadeable streams of the contiguous U.S., relative to the number of expected taxa, 2000-2004<sup>a</sup>



### 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 3-12). Of the three major stream regions in the nation (see inset map, Exhibit 3-12), 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).

46 O/E model, the results are presented in 20 percent increments of taxa losses for the contiguous 48 states

1 (Exhibit 3-13). Nearly 40 percent (38.6 percent) of wadeable stream miles in this area have lost more than  
2 20 percent of their macroinvertebrate taxa, compared to comparable minimally disturbed reference sites,  
3 and 8.3 percent of stream miles have lost more than 60 percent of their macroinvertebrate taxa.

#### 4 **Indicator Limitations**

- 5 • Although the probability sampling design results in unbiased estimates for the IBI and O/E in  
6 wadeable streams during the April–November index period, values may be different during  
7 other seasons.
- 8 • Reference conditions for the IBI and O/E vary from one ecoregion to another in both number  
9 and quality, which limits the degree of ecoregional resolution at which this indicator can be  
10 calculated.
- 11 • Because “E” is subject to both model error and sampling error, O/E values near 1.0 (above or  
12 below) do not necessarily imply a gain or loss of species relative to the reference conditions.
- 13 • Trend data are unavailable because this is the first time that a survey on this broad scale has  
14 been conducted, and the survey design does not allow trends to be calculated within a single  
15 sampling period (2000-2004). These data will serve as a baseline for future surveys.

#### 16 **Data Sources**

17 The results shown in Exhibit 3-12 were previously published in EPA’s 2006 Wadeable Streams  
18 Assessment (WSA) report (U.S. EPA, 2006c). The data in Exhibit 3-13 are based on frequency  
19 distributions provided by the WSA program (the 2006 report also presents results from the O/E analysis,  
20 but using different categories). Data from individual stream sites can be obtained from EPA’s STORET  
21 database (U.S. EPA, 2006a) ([http://www.epa.gov/owow/streamsurvey/web\\_data.html](http://www.epa.gov/owow/streamsurvey/web_data.html)).

22 Ecoregions for the IBI metric are WSA “Mega Regions” based on groupings of EPA Level III Ecoregions  
23 (Omernik, 1987; U.S. EPA, 2006b).

#### 24 **References**

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### 1 3.2.3 Discussion

#### 2 ***What These Indicators Say About Trends in the Extent and Condition of*** 3 ***Fresh Surface Waters and Their Effects on Human Health and the*** 4 ***Environment***

5 Although the indicators do not characterize the extent of all fresh surface waters, they do provide  
6 information about flow patterns in streams (Stream Flows indicator, p. 3-14). As this indicator shows,  
7 substantial shifts in the extent and timing of high and low flows can occur from one decade to the next.  
8 These shifts are particularly important in intermittent streams, where life forms may be quite sensitive to  
9 changes in patterns of flow and no flow. Although intermittent streams can be found throughout the  
10 country, the Streams Flows indicator focuses on those that occur in grassland and shrubland areas, many  
11 of which are arid or semi-arid and thus especially sensitive to water stress. As this indicator shows, flows  
12 have generally increased over the last few decades, at least on a nationwide basis.

13 The physical condition of lakes and streams is in part a function of the interaction between sediment and  
14 water. As the Streambed Stability indicator (p. 3-19) shows, about one-fourth of the nation's wadeable  
15 streams show significant evidence of excess fine sediments, which can diminish habitat. In some cases,  
16 excess sedimentation can reflect the influence of human stressors like erosion. Excess sedimentation also  
17 can be a symptom of broader changes in physical condition, such as hydromodifications that alter flow  
18 and sediment transport.

19 The ROE indicators provide a mixed picture of the chemical condition of fresh surface waters. Acidity in  
20 lakes and streams is decreasing in some sensitive areas but holding steady in others (Lake and Stream  
21 Acidity indicator, p. 2-62), while excess nutrients are present in many streams, ranging from small  
22 wadeable streams to the nation's largest rivers (three N and P indicators, pp. 3-22, 3-25, and 3-28). In  
23 agricultural areas, a large percentage of monitoring sites have at least one pesticide at levels that exceed  
24 guidelines for aquatic health (Pesticides in Agricultural Streams indicator, p. 3-32). These indicators  
25 reflect the influence of many stressors. For example, the two Agricultural Streams indicators (pp. 3-25  
26 and 3-32) demonstrate how chemicals applied to the land can ultimately affect surface waters.  
27 Conversely, efforts to reduce human stressors can result in improved water condition. For example, areas  
28 with declines in acidity correspond with areas of decreased acid deposition (Lake and Stream Acidity  
29 indicator, p. 2-62), while declining phosphorus loads in at least one river may be related to detergent bans  
30 and improved sewage treatment (N and P Discharge from Large Rivers indicator, p. 3-28). The indicators  
31 also reveal the influence of natural stressors, such as the role of precipitation in year-to-year variability in  
32 nutrient loads.

33 The ROE indicators also provide a mixed picture of the biological condition of fresh surface waters. The  
34 indicators of extent and physical and chemical condition show a number of attributes that could  
35 potentially harm aquatic life, including substantial changes in high and low stream flows, a portion of  
36 streams with excess sedimentation, pesticides above aquatic life guidelines, and nutrients at levels that  
37 could encourage eutrophication. Benthic macroinvertebrate communities are particularly sensitive to  
38 these stressors, and thus the condition of these assemblages can provide information about the extent to  
39 which these stressors are causing measurable harm. About 40 percent of the nation's wadeable stream  
40 miles exhibit a substantial loss (>20 percent) of macroinvertebrate taxa—approximately equal to the  
41 number of stream miles considered "most disturbed" when other metrics of benthic community condition  
42 are considered (Benthic Macroinvertebrates in Wadeable Streams indicator, p. 3-35).

## 1 **Limitations, Gaps, and Challenges**

2 Although the ROE indicators provide valuable information about the extent and condition of fresh surface  
3 waters, there are a few general limitations to their ability to depict trends over space and time. For  
4 example, trends in condition may be tied to the location and timing of intermittent stressors (e.g.,  
5 pesticide application), so indicators that assess national condition using samples that are spread out over  
6 time and space may obscure local conditions and extreme events. Some indicators are also restricted to  
7 specific study areas. For example, the two Agricultural Streams indicators (pp. 3-25 and 3-32) do not  
8 characterize non-agricultural watersheds, and the Lake and Stream Acidity indicator (p. 2-62) does not  
9 include localized acidification in the West.

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

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

- 20 • Information on the extent of different types of fresh surface waters, stressors to extent (e.g.,  
21 water usage), and associated effects on ecological systems.
- 22 • Nationally consistent information to characterize stressors to fresh surface water condition—  
23 specifically pollutant loadings from point and nonpoint sources.
- 24 • Information on the condition of large rivers. The N and P Discharge from Large Rivers  
25 indicator (p. 3-28) describes nutrient loads at the mouth, but does not address conditions  
26 upstream.
- 27 • Information on the condition of lakes. A nationally consistent indicator of lake trophic state  
28 could bring together several aspects of condition (e.g., physical, chemical, and biological  
29 parameters) related to eutrophication—a problem facing many of the nation’s lakes.
- 30 • Information about toxic contaminants in freshwater sediments. Sediment contaminants can  
31 accumulate through the food web, and may ultimately impact the health of humans who  
32 consume fish and shellfish.
- 33 • Information on the condition of fish communities, which can be affected by many different  
34 stressors.

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

38



### 3.3 WHAT ARE THE TRENDS IN 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 Earth's crust. The U.S. Geological Survey estimates that there are approximately 1,000,000 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.<sup>5</sup> 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.<sup>6</sup>

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 an estimated 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.<sup>7</sup>

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.

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—e.g., droughts that require

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<sup>5</sup> U.S. Geological Survey. 1999. Ground water (general interest publication). Reston, VA.  
<[http://capp.water.usgs.gov/GIP/gw\\_gip/](http://capp.water.usgs.gov/GIP/gw_gip/)>

<sup>6</sup> Ibid

<sup>7</sup> Alley, W.M, T.E. Reilly, and O.L. Franke. 1999. Sustainability of ground-water resources. Circular 1186. Denver, CO: U.S. Geological Survey.

1 humans to withdraw more water from the ground (e.g., for irrigation), while at the same time providing  
2 less precipitation for recharge. Additionally, some aquifers are more susceptible than others to changes in  
3 extent. For example, some deep aquifers may take thousands of years to recharge, particularly if they lie  
4 below highly impermeable confining layers.

5 Aquifer depletion—i.e., decreased extent—can adversely affect the humans and ecosystems that directly  
6 or indirectly depend on ground water. Less ground water available for human or ecological use could  
7 result in lower lake levels or—in extreme cases—cause perennial streams to become intermittent or  
8 totally dry, thus harming aquatic and riparian plants and animals that depend on regular surface flows.  
9 Areas with a high water table may have plant communities that tap ground water directly with their roots,  
10 so even a slight lowering of the aquifer could affect native species—which in turn could benefit invasive  
11 species.<sup>8</sup> In addition, lower water table levels may lead to land subsidence and sinkhole formation in areas  
12 of heavy withdrawal, which can damage buildings, roads, and other structures and can permanently  
13 reduce aquifer recharge capacity by compacting the aquifer medium (soil or rock). Finally, changes in the  
14 ground water flow regime can lead to consequences such as salt water intrusion, in which saline ground  
15 water migrates into aquifers previously occupied by fresh ground water.

16 Although aquifer depletion can have serious effects, the opposite, far less common problem—too much  
17 ground water—can also be detrimental. Too much ground water discharge to streams can cause erosion  
18 and can alter the balance of aquatic plant and animal species, as has been reported in association with  
19 some mining sites.<sup>9</sup>

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

32 Stressors that affect ground water condition ultimately affect the condition of water available for drinking,  
33 irrigation, or other human needs. In some cases, treatment may be needed to ensure that finished drinking  
34 water does not pose risks to human health. Because drinking water can come from many different types of  
35 water bodies, and because of the many complex issues associated with treatment and regulation of  
36 drinking water, this topic is addressed in greater detail in its own section of this report, Section 3.6. The  
37 condition of ground water also can affect ecological systems. For example, many fish species depend on

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<sup>8</sup> 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.

<sup>9</sup> U.S. DOI (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>>

1 cold, clear spring-fed waters for habitat or spawning grounds.<sup>10,11</sup> In some cases, aquifers themselves may  
2 constitute ecosystems. For example, caves and sinkholes are home to many types of aquatic fauna,  
3 including invertebrates and fish adapted to life underground.<sup>12</sup> Ground water can also affect the condition  
4 of other environmental media. For example, volatile ground water contaminants can potentially migrate  
5 into indoor air via soil vapor intrusion.

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

### 10 **3.3.2 ROE Indicators**

11 This report presents an indicator of ground water condition based on a nationwide survey of shallow wells  
12 in watersheds where agriculture is the predominant land use. The data come from the U.S. Geological  
13 Survey’s NAWQA study of major river basins with agricultural activities, representing a large portion of  
14 the nation’s land area. Agricultural land use is among the major sources of certain ground water  
15 contaminants such as nutrients and pesticides.

16 **Table 3.3.1. ROE Indicators of the Trends in Extent and Condition of Ground Water and their**  
17 **Effects on Human Health and the Environment**

<b>NATIONAL INDICATORS</b>	<b>LOCATION</b>
Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds	3.3.2 – p. 3-44

18

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<sup>10</sup> 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. 126 pp.

<sup>11</sup> 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.

<sup>12</sup> 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>>

## 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 one 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. (2006). Ground water samples were collected by the U.S. Geological Survey’s National Water Quality Assessment (NAWQA) program from 1992 to 2001. 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 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. Most wells were sampled once; a few were sampled multiple times as part of a detailed nutrient study, and the results were averaged. Related indicators report concentrations of nutrients and pesticides in streams that drain agricultural watersheds (see the N and P in Agricultural Streams indicator, p. 3-25, and the Pesticides in Agricultural Streams indicator, p. 3-32).

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 8 pesticide degradation products were collected from 1,412 of the wells in the NAWQA study. These 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., 2006). Three types of U.S. EPA human health-related standards and guidelines were used to evaluate pesticide data: Maximum

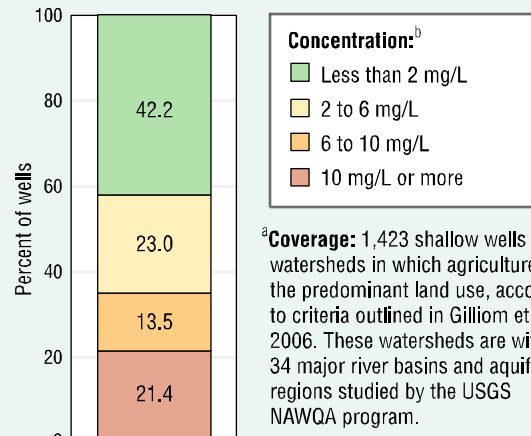
1 Contaminant Levels (MCLs) (as described above),  
 2 Cancer Risk Concentrations (CRCs), and Lifetime  
 3 Health Advisories (HA-Ls). In all three cases, the  
 4 standard and guideline levels are concentrations  
 5 pertaining to lifetime exposure through drinking water.  
 6 The CRC is a guideline for potential carcinogens  
 7 associated with a specified cancer risk of 1 in  
 8 1,000,000, based on drinking water exposure over a  
 9 70-year lifetime. The HA-L is an advisory guideline  
 10 for drinking water exposure over a 70-year lifetime,  
 11 considering non-carcinogenic adverse health effects.  
 12 Specific standards and guidelines used for this  
 13 indicator are listed in Gilliom et al. (2006), and  
 14 additional information on these types of benchmarks,  
 15 their derivation, and their underlying assumptions is  
 16 provided in Nowell and Resek (1994). For this  
 17 indicator, if a chemical had multiple benchmarks, the  
 18 MCL took precedence; if no MCL was available, the  
 19 lower of the CRC (at 1 in 1,000,000 cancer risk) and  
 20 HA-L values was selected. An exceedance was  
 21 identified if a yearly, time-weighted mean  
 22 concentration exceeded the relevant standard or  
 23 guideline (Gilliom et al., 2006).

24 **What the Data Show**

25 During the 1992-2001 period:

- 26 • Nitrate concentrations were above 2 mg/L  
 27 in 58 percent of wells sampled in areas  
 28 where agriculture is the primary land use  
 29 (Exhibit 3-14). By comparison,  
 30 background nitrate levels in relatively  
 31 undeveloped areas are generally expected  
 32 to be below 1 mg/L (Nolan and Hitt,  
 33 2002).
- 34 • Nitrate concentrations in about 21 percent  
 35 of the wells exceeded the federal drinking  
 36 water standard (10 mg/L).
- 37 • About 60 percent of wells had a least one  
 38 detectable pesticide compound, and 9.4  
 39 percent had detectable levels of five or  
 40 more pesticides (Exhibit 3-15). According  
 41 to NAWQA data, approximately 1 percent  
 42 of the wells in agricultural watersheds had  
 43 one or more pesticides at concentrations  
 44 exceeding human health standards or  
 45 guidelines (Gilliom et al., 2006).

**Exhibit 3-14. Nitrate in shallow ground water in agricultural watersheds of the contiguous U.S., 1992-2001<sup>a</sup>**

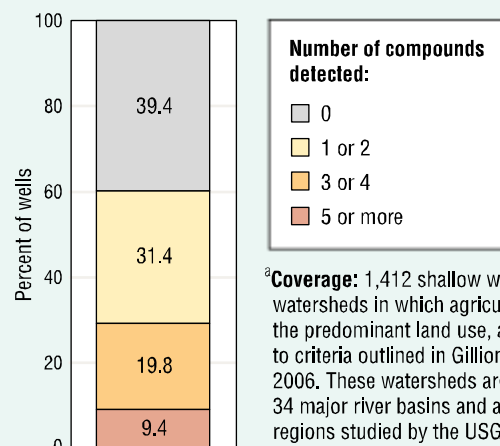


<sup>a</sup>**Coverage:** 1,423 shallow wells in watersheds in which agriculture is the predominant land use, according to criteria outlined in Gilliom et al., 2006. These watersheds are within 34 major river basins and aquifer regions studied by the USGS NAWQA program.

<sup>b</sup>EPA's drinking water standard for nitrate is a Maximum Contaminant Level (MCL) of 10 mg/L.

**Data source:** USGS, *National Water Quality Assessment (NAWQA) Program*

**Exhibit 3-15. Pesticides in shallow ground water in agricultural watersheds of the contiguous U.S., 1992-2001<sup>a, b</sup>**



<sup>a</sup>**Coverage:** 1,412 shallow wells in watersheds in which agriculture is the predominant land use, according to criteria outlined in Gilliom et al., 2006. These watersheds are within 34 major river basins and aquifer regions studied by the USGS NAWQA program.

<sup>b</sup>Samples were analyzed for 75 pesticides and 8 pesticide degradation products.

**Data source:** Gilliom et al., 2006 (*Appendix 6*)

1 **Indicator Limitations**

- 2 • These data only represent conditions in agricultural watersheds within 34 of the major river  
3 basins and aquifer regions sampled by the NAWQA program from 1992 to 2001. While they  
4 were chosen to be representative of agricultural watersheds across the United States, they are  
5 the result of a targeted sample design. The data also are highly aggregated and should only be  
6 interpreted as an indication of national patterns.
- 7 • This indicator does not provide information about trends over time, as the NAWQA program  
8 has completed only one full sampling cycle to date. Completion of the next round of  
9 sampling will allow trend analysis, using the data presented here as a baseline.
- 10 • Drinking water standards or guidelines do not exist for 43 percent (36 of 83) of the pesticides  
11 and pesticide degradation products analyzed. Current standards and guidelines also do not  
12 account for mixtures of pesticide chemicals and seasonal pulses of high concentrations.  
13 Possible pesticide effects on reproductive, nervous, and immune systems, as well as on  
14 chemically sensitive individuals, are not yet well understood.
- 15 • This indicator does not provide information on the extent to which pesticide concentrations  
16 exceed or fall below standards, nor the extent to which they exceed or fall below other  
17 reference points (e.g., Maximum Contaminant Level Goals [MCLGs] for drinking water).

18 **Data Sources**

19 Summary data for this indicator were provided by the U.S. Geological Survey's National Water Quality  
20 Assessment (NAWQA) program. Pesticide data have also been published in Gilliom et al. (2006), with  
21 raw sampling data available online in Appendix 6 of the same report  
22 (<http://ca.water.usgs.gov/pnsp/pubs/circ1291/appendix6/>). Summary data for nitrate have not yet been  
23 published; however, data from individual sample sites can be obtained from NAWQA's online data  
24 warehouse (USGS, 2006).

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- 4 <[http://www.epa.gov/safewater/contaminants/dw\\_contamfs/nitrates.html](http://www.epa.gov/safewater/contaminants/dw_contamfs/nitrates.html)>
- 5 USGS. 2006. USGS National Water Quality Assessment data warehouse. Accessed 2006.
- 6 <<http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:14620854136944137608>>
- 7 Vitousek, P., H. Mooney, L. Olander, and S. Allison. 2002. Nitrogen and nature. *Ambio* 31:97-101.

1 **3.3.3 Discussion**

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

4 The Nitrate and Pesticides in Ground Water indicator (p. 3-44) describes the extent to which the condition  
5 of shallow ground water may be influenced by human stressors—in this case, certain chemicals applied to  
6 land in agricultural areas. Collectively, the agricultural watersheds sampled across the nation had average  
7 nitrate concentrations that were substantially higher than the background levels one might expect in an  
8 undisturbed watershed. Nitrate concentrations exceeded MCLs for nitrate in one-fifth of the wells, though  
9 this does not necessarily reflect the condition of the water people drink if it is tested and treated. Nitrate  
10 concentrations were often high enough that they could impact ecological systems upon being introduced  
11 into surface waters.<sup>13,14</sup> Pesticide compounds were detected frequently (more than half of the shallow  
12 wells sampled). However, detected pesticide concentrations rarely exceeded human health-based  
13 reference points in the samples collected for this indicator.

14 ***Limitations, Gaps, and Challenges***

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

21 There are also several limitations, gaps, and challenges in addressing the issue of ground water condition.  
22 One notable limitation to the Nitrate and Pesticides in Ground Water indicator (p. 3-44) is that it does not  
23 provide information about trends over time. The indicator is also limited in its ability to represent the  
24 condition of entire aquifers. Because ground water condition is vertically heterogeneous, results from one  
25 depth do not necessarily represent other depths. This indicator characterizes the uppermost layer of  
26 shallow aquifers, which are used by many private wells. It does not provide information about the  
27 condition of deeper aquifers, which are more likely to be used for public water supplies.

28 The Nitrate and Pesticides in Ground Water indicator provides a representative national picture of shallow  
29 ground water condition in agricultural watersheds. At the present time, similar indicators do not exist for  
30 ground water in watersheds with non-agricultural land uses. Non-agricultural watersheds—particularly  
31 urban areas—reflect a different set of stressors, and to some extent a different set of chemicals (i.e.,  
32 VOCs and hydrocarbons like MTBE<sup>15</sup>). Because many ground water stressors in urban areas are localized

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<sup>13</sup> 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.

<sup>14</sup> 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.

<sup>15</sup> 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:



1 events such as plumes resulting from chemical spills or underground storage tank (UST) leaks, they may  
2 be harder to characterize on a national level—a potential challenge to gathering more information about  
3 ground water condition. Salt water intrusion is another issue that tends to occur locally, and for which  
4 national-scale data are not available.

5

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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](http://sd.water.usgs.gov/nawqa/pubs/wrir/wrir02_4084.pdf)>

1 **3.4 WHAT ARE THE TRENDS IN EXTENT AND CONDITION OF WETLANDS AND**  
2 **THEIR EFFECTS ON HUMAN HEALTH AND THE ENVIRONMENT?**

3 **3.4.1 Introduction**

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

8 In terms of extent, wetlands currently cover 5.5 percent of the surface area of the contiguous 48 states,  
9 with freshwater wetlands accounting for nearly 95 percent of the current wetland acreage and marine and  
10 estuarine wetlands accounting for the remaining 5 percent.<sup>16</sup> Condition is somewhat harder to measure, as  
11 it reflects a combination of physical, chemical, and biological attributes. To be in healthy condition,  
12 however, a wetland should generally demonstrate good water quality and support native plant and animal  
13 communities, without the presence of invasive non-indigenous species. A healthy wetland should not  
14 show signs of stress related to substantial degradation or cumulative effects of smaller degradations, and  
15 should be free of modifications that restrict water flow into, through, or out of the wetland, or that alter  
16 patterns of seasonality.

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

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

26 All wetlands share a few basic physical, chemical, and biological attributes. By definition, all wetlands  
27 are saturated or covered by water at least periodically, and wetland vegetation is adapted to these  
28 conditions. Thus, wetlands are like sponges, with a natural ability to store water. Wetlands also tend to  
29 have highly developed root systems that anchor trees and other vegetation in place. This web of roots not  
30 only holds the soil in place, but also filters pollutants out of the water as it flows through.

31 Because of their physical, chemical, and biological properties, wetlands serve many important  
32 environmental functions. They play an important role in improving natural water quality by filtering  
33 pollutants. This function is particularly important to human health because it may affect the condition of  
34 waters used as a source of drinking water—a topic described in greater detail in Section 3.6. Wetlands  
35 also act as a buffer to protect the shoreline from erosion and storm damage. Because of their sponge-like  
36 capacity to absorb water, wetlands slow the water’s momentum and erosive potential and reduce flood

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<sup>16</sup> 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/](http://wetlandsfws.er.usgs.gov/status_trends/)>

1 heights. During dry periods, the “sponge” releases water, which is critical in maintaining the base flow of  
2 many surface water systems.

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

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

14 The extent of wetlands can be affected by a variety of natural stressors, such as erosion, land subsidence,  
15 changes in precipitation patterns (e.g., droughts), sea level change, hurricanes, and other types of storms.  
16 However, the vast majority of wetland losses and gains over the last few centuries have occurred as a  
17 result of human activity.<sup>17</sup> For years, people have drained or filled wetlands for agriculture or urban and  
18 suburban development, causing habitat loss or fragmentation as well as a decline in many of the other  
19 important functions outlined above, such as improving water quality. Conversely, other human activities  
20 may increase the extent of wetlands—for example, creating shallow ponds or re-establishing formerly  
21 drained or modified wetlands on farmlands.

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

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

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<sup>17</sup> 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.  
<<http://wetlands.fws.gov/bha/SandT/SandTReport.html>>

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

### 8 **3.4.2 ROE Indicators**

9 An ROE indicator describes trends in wetland extent, as well as specific activities that have contributed to  
10 recent wetland losses and gains (Table 3.4.1). Data were collected as part of the U.S. Fish and Wildlife  
11 Service’s Wetlands Status and Trends survey, a probabilistic national survey of wetland acreage  
12 conducted approximately every 10 years for the past half-century. There is no ROE indicator for wetland  
13 condition.

14 **Table 3.4.1. ROE Indicators of the Trends in Extent and Condition of Wetlands and their Effects**  
15 **on Human Health and the Environment**

NATIONAL INDICATORS	LOCATION
Wetland Extent, Change, and Sources of Change	3.4.2 – p. 3-53

16

## 1 INDICATOR: Wetland Extent, Change, and Sources of Change

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

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

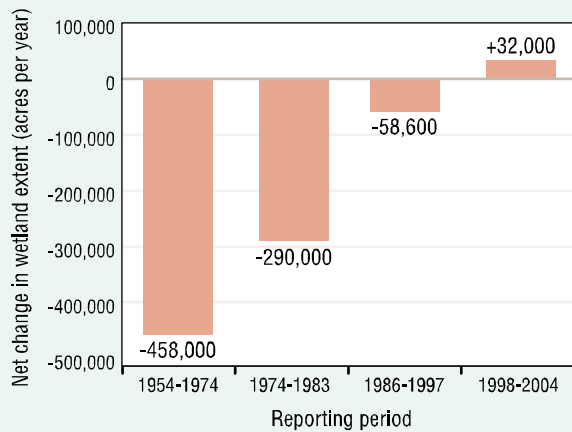
16 This indicator presents data from the U.S. Fish and Wildlife Service's Wetlands Status and Trends  
17 survey. Conducted approximately every 10 years, this survey provides an estimate of the extent of all  
18 wetlands in the contiguous U.S., regardless of land ownership. The Status and Trends survey uses a  
19 probabilistic design, based initially on stratification of the 48 contiguous states by state boundaries and 35  
20 physiographic subdivisions. Within these subdivisions are located 4,375 randomly selected, four square  
21 mile (2,560 acre) sample plots. These plots are examined with the use of aerial imagery. Although the  
22 imagery ranges in scale and type, most are 1:40,000 scale, color infrared from the National Aerial  
23 Photography Program. Field verification is conducted to address questions of image interpretation, land  
24 use coding, and attribution of wetland gains or losses; plot delineations are also completed. In the 1980s  
25 to 1990s analysis, 21 percent of the sample plots were field-verified; in the most recent analysis, 32  
26 percent were field-verified (Dahl, 2000, 2006). The Fish and Wildlife Service used the Cowardin et al.  
27 (1979) definition of wetlands, which is part of the draft national standard for wetland mapping,  
28 monitoring, and data reporting as determined by the Federal Geographic Data Committee.

29 This indicator shows trends in the total extent of wetlands, as well as the extent of several types of  
30 freshwater and intertidal wetlands. In this analysis, freshwater wetlands include forested, shrub, emergent,  
31 and non-vegetated wetlands (e.g., shallow ponds). Intertidal wetlands include marine areas (e.g., tidal flats  
32 and sandbars) and estuarine areas (vegetated or not) that are exposed and flooded by the tides. Data on  
33 wetland extent are described from several Status and Trends analyses: 1950s-1970s, 1970s-1980s, 1980s-  
34 1990s, and 1998-2004 (Frayer et al., 1983; Dahl and Johnson, 1991; Dahl, 2000, 2006). For the most  
35 recent period, the indicator also describes sources of wetland loss or gain, which the survey divided into  
36 five distinct categories along with an "other" category (Dahl, 2006).

### 37 **What the Data Show**

38 Total wetland acreage declined over the last 50 years, but the rate of loss appears to have slowed over  
39 time. From the 1950s to 1970s, an average of 458,000 acres was lost per year (Exhibit 3-16). By the  
40 1986-1997 period, the loss rate had declined to 58,600 acres per year; and in the most recent study period,  
41 1998-2004, wetland area *increased* at a rate of 32,000 acres per year (Exhibit 3-16).

**Exhibit 3-16.** Average annual change in wetland acreage in the contiguous U.S., 1954-2004



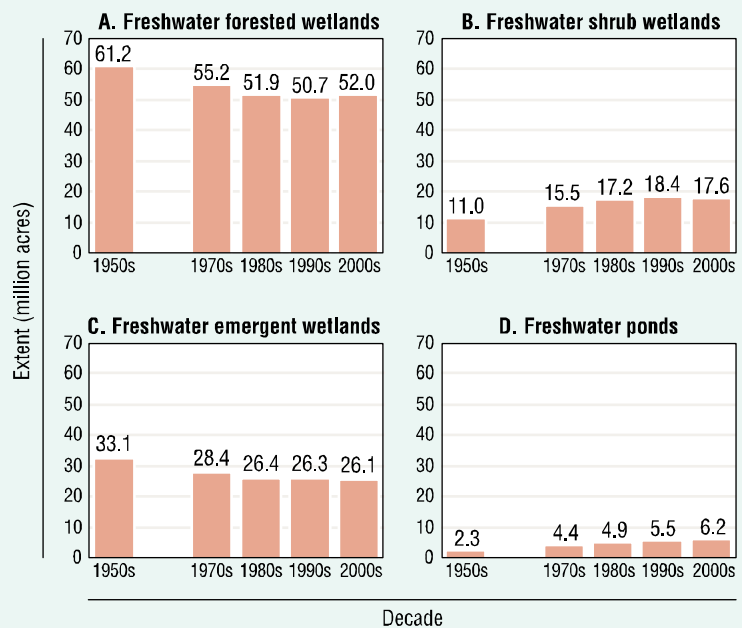
Data source: Dahl, 2006

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 since 1998 (Exhibit 3-17, 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 1998 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 3-17, 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 (panel D). These wetlands account for a large percentage of the recent gains illustrated in Exhibit 3-17 (Dahl, 2006).

22 Since the 1950s, intertidal wetland  
 23 acreage has decreased by about  
 24 700,000 acres, or 12 percent (Exhibit  
 25 3-18, panel A). This category  
 26 includes marine, estuarine vegetated,  
 27 and estuarine non-vegetated  
 28 wetlands. Both estuarine types lost  
 29 acreage overall, with estuarine  
 30 vegetated wetlands, the predominant  
 31 type, losing over 400,000 acres  
 32 (panel B). Long-term trends,  
 33 however, indicate that losses of  
 34 intertidal wetlands have slowed over  
 35 time, with estuarine non-vegetated  
 36 wetlands actually gaining acreage  
 37 from 1998 to 2004 (panel C).

38 Between 1998 and 2004, urban  
 39 development, rural development,  
 40 conversion to deepwater, and  
 41 silviculture all contributed to losses  
 42 in wetland acreage (Exhibit 3-19).  
 43 However, the net change in wetland  
 44 acreage during this period was  
 45 positive, due largely to wetland  
 46 creation and restoration on  
 47 agricultural lands (70,770 acres) and

**Exhibit 3-17.** Extent of selected freshwater wetlands in the contiguous U.S., 1950s-2000s<sup>a</sup>

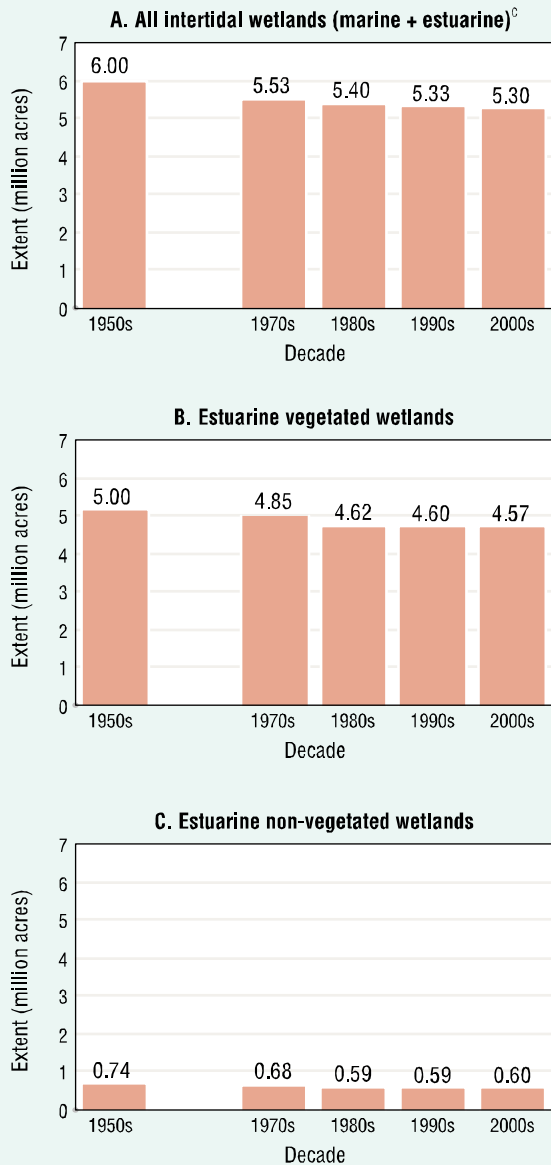


<sup>a</sup>Based on mid-decade surveys. No analysis was conducted for the 1960s.

Data source: Dahl, 2006

- 1 on lands classified as “other” (349,600 acres). This “other” category includes conservation lands, areas in
- 2 transition from one land use to another, and other lands that do not fall into the major land use categories
- 3 as defined in Dahl (2006).

**Exhibit 3-18.** Extent of marine and estuarine wetlands in the contiguous U.S., 1950s-2000s<sup>a,b</sup>



<sup>a</sup>Based on mid-decade surveys. No analysis was conducted for the 1960s.

<sup>b</sup>Surveys did not include Pacific coast estuarine wetlands.

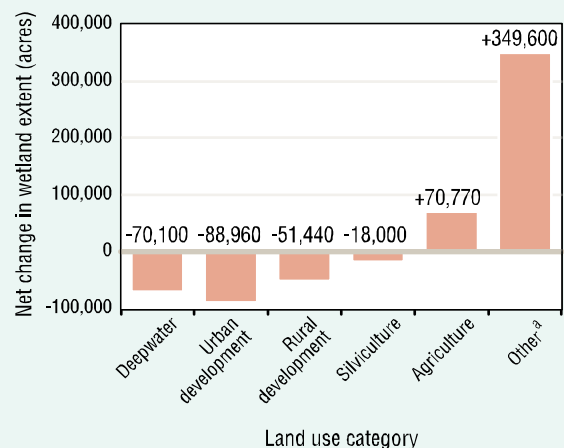
<sup>c</sup>Panel A is the sum of panel B, panel C, and marine wetland acreage.

**Data source:** 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.

**Exhibit 3-19.** Sources of wetland gain and loss in the contiguous U.S., 1998-2004



<sup>a</sup>“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

- 1           • Alaska and Hawaii are not included in the Status and Trends survey.  
2           • This survey does not include Pacific coast estuarine wetlands such as those in San Francisco  
3 Bay, Puget Sound, or Coos Bay, Oregon.

#### 4 **Data Sources**

5 Data for this indicator were obtained from Dahl (2006). Historical trends are based on data originally  
6 presented in earlier Fish and Wildlife Service reports (Dahl, 2000; Dahl and Johnson, 1991; Frayer et al.,  
7 1983).

#### 8 **References**

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14 <[http://wetlandfws.er.usgs.gov/status\\_trends/](http://wetlandfws.er.usgs.gov/status_trends/)>
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1 **3.4.3 Discussion**

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

4 Wetland extent in the contiguous 48 states is substantially lower than it was prior to widespread European  
5 settlement and it generally continued to decline over the last 50 years (Wetlands indicator, p. 3-53). The  
6 rate of loss of wetlands overall and for most types of wetlands has slowed over time, however, and since  
7 1998 the overall extent of wetlands has actually increased. Not all types of wetlands have experienced the  
8 same rate of losses or overall percent losses. For example, freshwater shrub wetlands actually increased  
9 over the last 50 years—providing evidence of wetland conversion, most likely from forested wetlands to  
10 shrub. The nation has also seen a steady increase in acreage of freshwater ponds, which account for a  
11 substantial portion of the recent gains in overall wetland acreage.

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

18 While this indicator does not directly quantify the condition of the nation’s wetlands, it suggests that the  
19 condition of many wetlands may be impacted. As discussed in Section 3.4.1, extent is only a partial  
20 surrogate for condition because wetland loss can increase the stress on those wetlands that remain, while  
21 decreasing their connectivity. Thus, the overall decline in extent over the last 50 years suggests the  
22 potential for substantial ecological impacts such as habitat loss and increased flood impacts. Changes in  
23 the extent of different *types* of wetlands also suggest changes in condition. Shallow ponds, which  
24 constitute a large fraction of the recent gains in wetland acreage, will not perform the same range and type  
25 of environmental functions as the vegetated wetlands that disappeared between the 1950s and the 1990s.  
26 Similarly, evidence of wetland conversion indicates that even if extent is no longer declining rapidly,  
27 changes in wetland structure and function are still occurring. In the past, studies have shown that wetlands  
28 that have been created to mitigate for wetland losses have not yet provided the same functions and values  
29 of the wetlands that were lost.<sup>18, 19</sup>

30 ***Limitations, Gaps, and Challenges***

31 By relying on aerial imagery and statistical surveying techniques, the Wetlands indicator (p. 3-53)  
32 provides a national estimate without an impractical number of samples. However, a limitation to this  
33 survey is that it may omit or undercount certain types of wetlands, including forested wetlands—which  
34 are difficult to photo-interpret—and ephemeral or well-drained agricultural wetlands, which are not  
35 necessarily obvious to the surveyor but are particularly threatened by development. This indicator also

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<sup>18</sup> National Research Council. 2001. Compensating for wetland losses under the Clean Water Act. Washington, DC: National Academy Press. <<http://www.nap.edu/books/0309074320/html/>>

<sup>19</sup> 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>>

1 does not include wetland parcels less than about 1 acre, which become more critical as larger wetlands are  
2 fragmented into smaller pieces.

3 Wetland condition poses a larger challenge for assessment. While the Wetlands indicator (p. 3-53)  
4 provides information that can be used to infer potential wetland condition, it does not explicitly measure  
5 condition—in part because condition is difficult to quantify. Condition is made up of many different  
6 attributes, and each wetland has its own unique baseline condition, with a unique hydrologic setting and  
7 combination of plant and animal species. Some studies have quantified regional changes in specific  
8 stressors; however, national indicators would have to bring together many regional datasets and cover  
9 many different aspects of condition in order to be truly comprehensive. The lack of such national-scale  
10 information is currently a gap in addressing the question of wetland condition. Potential human health  
11 effects associated with wetland extent and condition are also difficult to quantify, and there are no ROE  
12 indicators on this topic.

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

18

## 3.5 WHAT ARE THE TRENDS IN 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 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.<sup>20</sup> 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),<sup>21</sup> 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.<sup>22</sup> Lands adjacent to the coast are highly desirable places for people to live, and represent the most densely developed areas in the nation.<sup>23</sup>

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. 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

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<sup>20</sup> U.S. EPA. 2004. National coastal condition report II. EPA/620/R-03/002. Washington, DC. <http://www.epa.gov/owow/oceans/nccr/2005/index.html>

<sup>21</sup> U.S. EPA. 2004. National coastal condition report II. EPA/620/R-03/002. Washington, DC. <http://www.epa.gov/owow/oceans/nccr/2005/index.html>

<sup>22</sup> 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>

<sup>23</sup> 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.

1 eroding some areas while building up sediment in others, and rivers depositing sediments at their mouth.  
2 Human stressors can alter these patterns—for example, through the construction of seawalls or barriers or  
3 through the channeling of rivers, which can lead to subsidence in coastal areas that would otherwise be  
4 naturally replenished by sediments.

5 Changes in extent may in turn affect the condition of coastal waters. For example, beach erosion and  
6 coastal wetland loss can also affect contaminant and sediment levels, nutrient cycling, and the condition  
7 of spawning and feeding grounds for fish, shellfish, and other coastal species. As described in Section  
8 3.4.1, the loss of some wetlands can also affect the condition of the wetlands that remain.

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

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

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

## 28 **3.5.2 ROE Indicators**

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

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

1 imagery. The Harmful Algal Blooms indicator reflects water sampling guided by satellite imagery that  
2 can detect blooms.

3 **Table 3.5.1. ROE Indicators of the Trends in Extent and Condition of Coastal Waters and their**  
4 **Effects on Human Health and the Environment**

<b>NATIONAL INDICATORS</b>	<b>LOCATION</b>
Wetland Extent, Change, and Sources of Change	3.4.2 – p. 3-53
Trophic State of Coastal Waters (N/R)	3.5.2 – p. 3-62
Coastal Sediment Quality (N/R)	3.5.2 – p. 3-67
Coastal Benthic Communities (N/R)	3.5.2 – p. 3-71
Coastal Fish Tissue Contaminants (N/R)	3.8.2 – p. 3-103
<b>REGIONAL INDICATORS</b>	<b>LOCATION</b>
Submerged Aquatic Vegetation in the Chesapeake Bay	3.5.2 – p. 3-74
Hypoxia in the Gulf of Mexico and Long Island Sound	3.5.2 – p. 3-77
Harmful Algal Bloom Outbreaks Along the Western Florida Coastline	3.5.2 – p. 3-81

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

6

## INDICATOR: Trophic State of Coastal Waters

While 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 (DO), 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,” 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 algal abundance. 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 algal 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 one meter) also can be caused by storm-related events that cause erosion or mixing from the 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*, 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 period 1997-2000, within an index period from July to September. The indicator reflects average condition during this index period.

Reference conditions were established for each EPA Region for nutrients, water clarity, and chlorophyll-*a* because key factors like sediment load, mixing parameters, and ecosystem sensitivity naturally vary from one Region to the next. A single national reference range of 2-5 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 (pp. 19-20).

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 of the index received a score that would be considered environmentally unfavorable (high nitrogen, phosphorus, or chlorophyll-*a* levels or low DO 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 and for the entire nation.

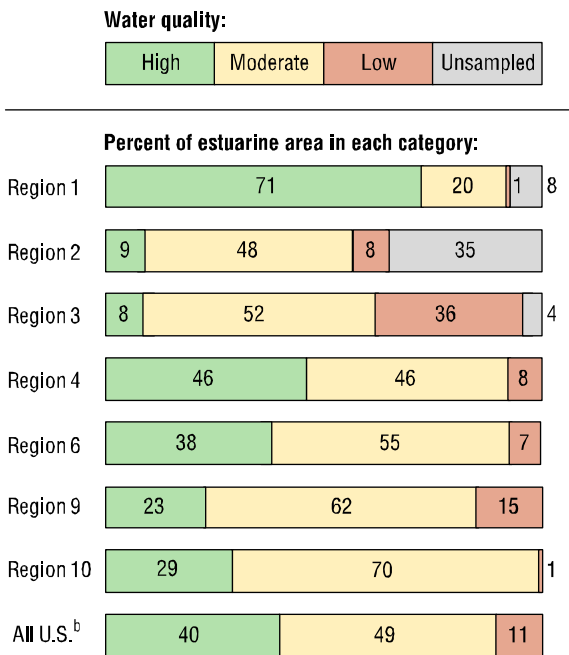
1 **What the Data Show**

2 According to the index, 40 percent of estuarine surface area nationwide exhibited high water quality over  
 3 the period 1997-2000, 11 percent had low water quality, and the remaining 49 percent was rated moderate  
 4 (Exhibit 3-20). Scores vary considerably among EPA Regions, ranging from high water quality in 71  
 5 percent of estuarine area in Region 1 to less than 10 percent in Regions 2 and 3. Only one EPA Region  
 6 had low water quality in more than 15 percent of its estuarine area (EPA Region 3, with 36 percent).  
 7 These percentages do not include the Great Lakes or the hypoxic zone in offshore Gulf Coast waters (see  
 8 the Hypoxia in Gulf of Mexico and Long Island Sound indicator, p. 3-77).

9 Nitrogen concentrations were low in 82 percent of estuarine area and high in 5 percent nationwide, and  
 10 were low in a majority of the estuarine area in all but one EPA Region (Exhibit 3-21). Regions 2 and 3  
 11 had the largest percentage of area with high concentrations (15 percent and 16 percent, respectively);  
 12 several other EPA Regions had no areas with high concentrations.

13

**Exhibit 3-20.** Coastal water quality index for the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a</sup>



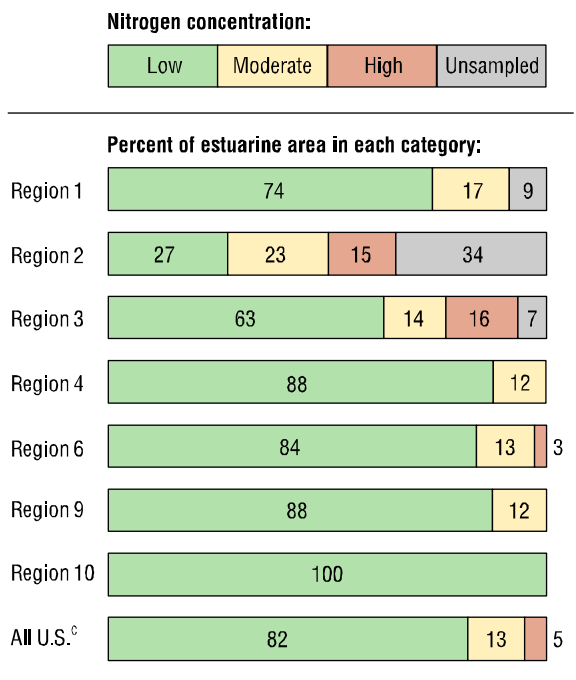
<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico. Does not include the hypoxic zone in offshore Gulf Coast waters.

<sup>b</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



**Exhibit 3-21.** Nitrogen concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a, b</sup>



<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

<sup>b</sup>This indicator measures dissolved inorganic nitrogen (DIN), which is the sum of nitrate, nitrite, and ammonia.

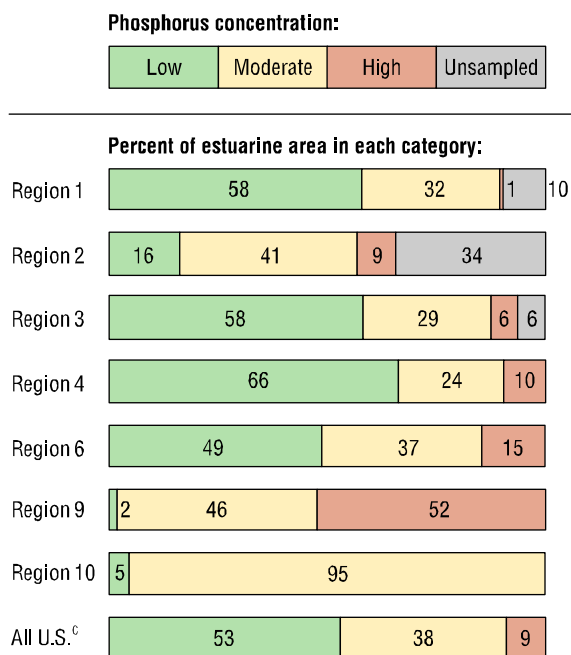
<sup>c</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



- 1 Phosphorus concentrations were low in 53 percent of estuarine area and high in 9 percent nationwide
- 2 (Exhibit 3-22). Region 9 had the largest proportion of area exceeding reference conditions (52 percent),
- 3 while Region 10 had the least (none).
- 4 Chlorophyll-*a* concentrations were low in 51 percent and high in 8 percent of estuarine area nationwide
- 5 (Exhibit 3-23). Region 3 had the largest percentage of area exceeding reference conditions (27 percent);
- 6 all other EPA Regions had 10 percent or less in this category.
- 7

**Exhibit 3-22.** Phosphorus concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a, b</sup>

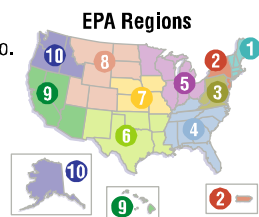


<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

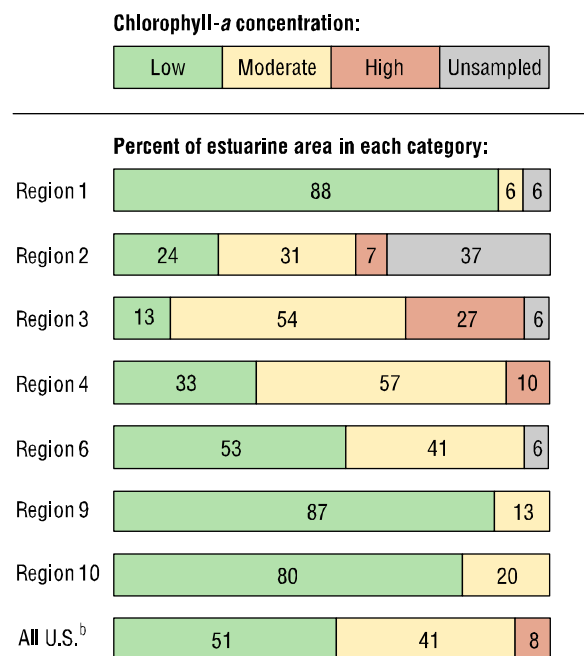
<sup>b</sup>This indicator measures dissolved inorganic phosphorus (DIP), which equals orthophosphate.

<sup>c</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



**Exhibit 3-23.** Chlorophyll-*a* concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a</sup>



<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

<sup>b</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



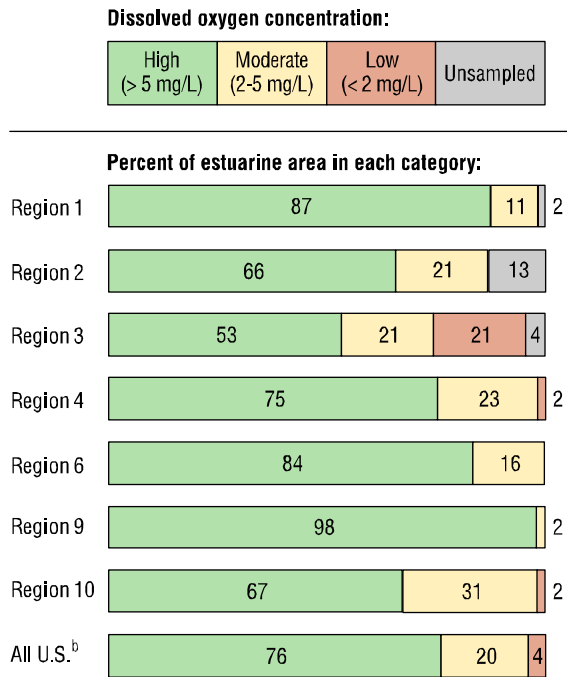


1 Bottom-water dissolved oxygen was above 5 mg/L in over three-fourths of the nation’s estuarine area and  
 2 below 2 mg/L in only 4 percent (Exhibit 3-24). While effects vary with temperature and salinity, as a  
 3 general rule, concentrations of DO above 5 mg/L are considered supportive of marine life, concentrations  
 4 below 5 mg/L are potentially harmful, and concentrations below 2 mg/L—a common threshold for  
 5 hypoxia—are associated with a wider range of harmful effects (e.g., some juvenile fish and crustaceans  
 6 that cannot leave the area may die). Region 3 had the greatest proportion of estuarine area with low DO  
 7 (21 percent), while four EPA Regions had no area below 2 mg/L.

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

11

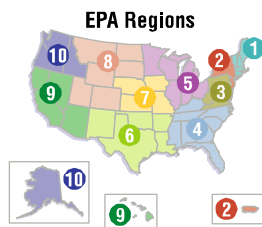
**Exhibit 3-24.** Dissolved oxygen levels in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a</sup>



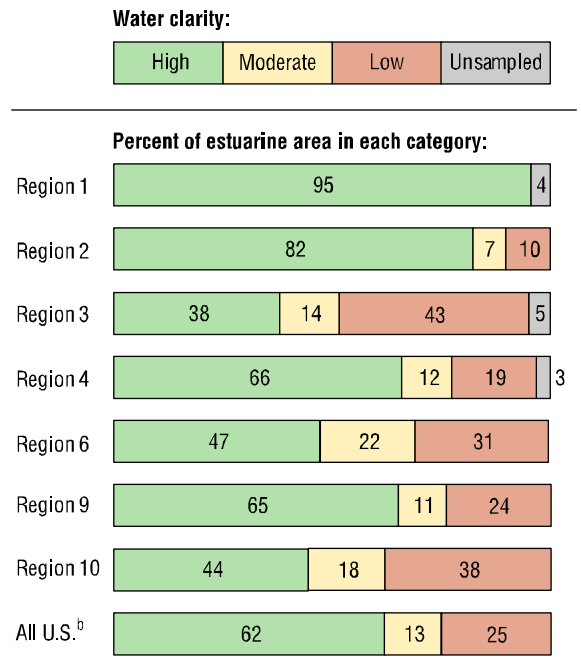
<sup>a</sup>**Coverage:** Bottom- or near bottom-water dissolved oxygen in estuarine waters of the contiguous 48 states and Puerto Rico. Does not include the hypoxic zone in offshore Gulf Coast waters.

<sup>b</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



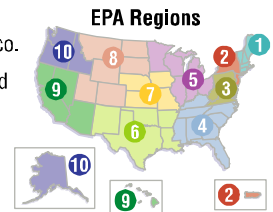
**Exhibit 3-25.** Water clarity in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a</sup>



<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

<sup>b</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



1 **Indicator Limitations**

- 2 • The indicator does not include data from the Great Lakes, which are monitored using a  
3 different index design. The coastal areas of Hawaii and a portion of Alaska have been  
4 sampled, but the data had not yet been assessed at the time this indicator was compiled. Data  
5 are also not available for the U.S. Virgin Islands and the Pacific territories.
- 6 • Trend data are not yet available for this indicator. Because of differences in methodology, the  
7 data presented here are not comparable with data that appeared in EPA’s first National  
8 Coastal Condition Report (NCCR I). The data presented here will serve as a baseline for  
9 future surveys.
- 10 • The National Coastal Assessment surveys measure dissolved oxygen conditions only in  
11 estuarine waters and do not include observations of dissolved oxygen concentrations in  
12 offshore coastal shelf waters, such as the hypoxic zone in Gulf of Mexico shelf waters.
- 13 • At each sample location, the components of this indicator may have a high level of temporal  
14 variability. This survey is intended to characterize the typical distribution of water quality  
15 conditions in coastal waters during an index period from July through September. It does not  
16 consistently identify the “worst-case” condition for sites experiencing occasional or  
17 infrequent hypoxia, nutrient enrichment, or decreased water clarity at other times of the year.

18 **Data Sources**

19 This indicator is based on an analysis published in EPA’s National Coastal Condition Report II (U.S.  
20 EPA, 2004). Summary data by EPA Region have not been published, but were provided by EPA’s  
21 National Coastal Assessment program. Underlying sampling data are housed in EPA’s National Coastal  
22 Assessment database (U.S. EPA, 2005) (<http://www.epa.gov/emap/nca/html/data/index.html>).

23 **References**

24 Diaz, R.J., and R. Rosenberg. 1995. Marine benthic hypoxia: a review of its ecological effects and the  
25 behavioral responses of benthic macrofauna. *Oceanogr. Mar. Biol. Ann. Rev.* 33:245-303.

26 U.S. EPA. 2005. EMAP national coastal database. Accessed 2005.  
27 <<http://www.epa.gov/emap/nca/html/data/index.html>>

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29 <<http://www.epa.gov/owow/oceans/nccr/2005/index.html>>

30 U.S. EPA. 2003. Mid-Atlantic integrated assessment, MAIA—estuaries 1997-98, summary report.  
31 EPA/620/R-02/003. Narragansett, RI.

32 U.S. EPA. 2000. Ambient aquatic life water quality criteria for dissolved oxygen (saltwater): Cape Cod to  
33 Cape Hatteras. EPA/822/R-00/12.

## 1 INDICATOR: Coastal Sediment Quality

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

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

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

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

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

37 Benthic community condition also can be a useful indication of sediment quality, particularly in terms of  
38 chronic or community effects that would not be captured in an acute exposure bioassay. The NCA  
39 evaluated estuarine sites for several aspects of benthic community condition, and these results are  
40 presented as a separate ROE indicator (Coastal Benthic Communities, p. 3-71).

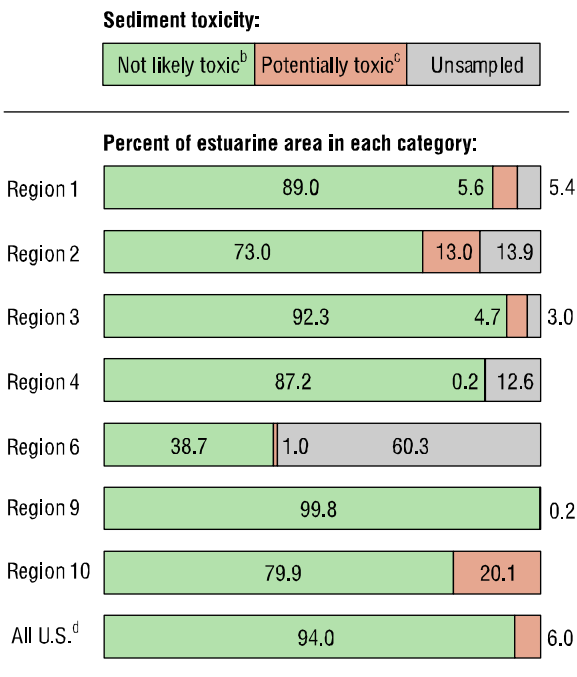
1 **What the Data Show**

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

7 Nationally, contaminants were present at “potentially toxic” levels in 7 percent of estuarine sediments for  
 8 which contamination data were available (Exhibit 3-27). There was considerable variability in sediment  
 9 contamination from one EPA Region to the next, with Region 4 showing the largest proportion of  
 10 estuarine area with sediments not likely to be toxic (99.9 percent), and Region 2 showing the largest  
 11 proportion with “potentially toxic” sediments (24.4 percent).

12

**Exhibit 3-26.** Sediment toxicity in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a</sup>



<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

<sup>b</sup>**Not likely toxic:** Mortality of test species = 20% or lower

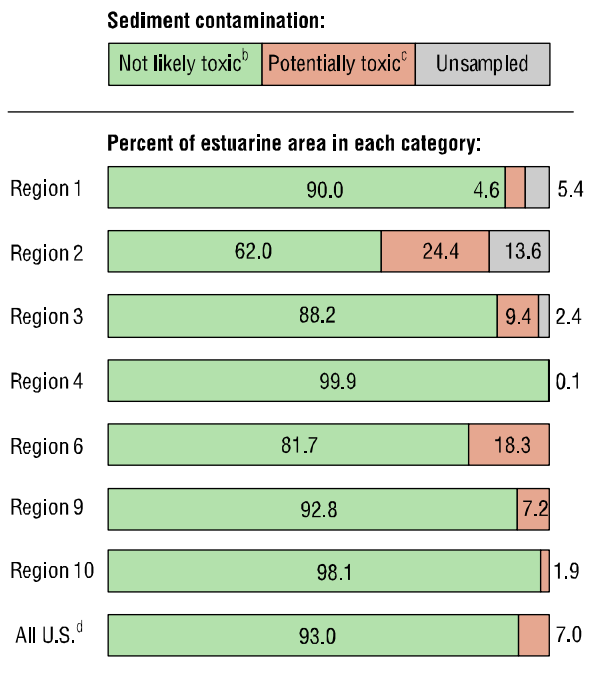
<sup>c</sup>**Potentially toxic:** Mortality of test species > 20%

<sup>d</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



**Exhibit 3-27.** Sediment contamination in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000<sup>a</sup>



<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico.

<sup>b</sup>**Not likely toxic:** No contaminants above “effects range median” (ERM)

<sup>c</sup>**Potentially toxic:** One or more contaminants above “effects range median” (ERM)

<sup>d</sup>U.S. figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



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

## 9 **Indicator Limitations**

- 10 • The coastal areas of Hawaii and a portion of Alaska have been sampled, but the data had not  
11 yet been assessed at the time this indicator was compiled. Data are also not available for the  
12 U.S. Virgin Islands and the Pacific territories.
- 13 • Trend data are not yet available for this indicator. Because of differences in methodology, the  
14 data presented here are not comparable with data that appeared in EPA’s first National  
15 Coastal Condition Report (NCCR I). The data presented here will serve as a baseline for  
16 future surveys.
- 17 • Sample collection is limited to an index period from July to September. It is not likely that  
18 contaminant levels vary from season to season, however.
- 19 • The *Ampelisca* bioassay is a single-organism screening tool, and the ERMs are general  
20 screening guidelines based largely on toxicity data from *Ampelisca*. Thus, these measures do  
21 not necessarily reflect the extent to which sediments may be toxic to the full range of biota  
22 (including microbes and plants) that inhabit a particular sampling location.
- 23 • The *Ampelisca* bioassay tests only for short-term, not long-term, exposure. Both screening  
24 tests characterize sediments in terms of their effects on benthic organism mortality. This  
25 indicator does not capture other effects of sediment contaminants on benthic organisms, such  
26 as disease, stress, and reproductive effects.
- 27 • This indicator cannot be compared quantitatively with indicators that use other types of  
28 contaminant guidelines. For example, the Pesticides in Agricultural Streams indicator (p. 3-  
29 32) uses thresholds intended to be protective of aquatic life with a margin of safety, instead of  
30 thresholds shown to cause biological effects (e.g., ERMs). The ERM approach also is not  
31 directly comparable with other sediment contaminant approaches, such as EPA’s equilibrium  
32 partitioning (EqP) benchmarks.

## 33 **Data Sources**

34 This indicator is based on an analysis published in EPA’s National Coastal Condition Report II (U.S.  
35 EPA, 2004). Summary data by EPA Region have not been published, but were provided by EPA’s  
36 National Coastal Assessment program. Underlying sampling data are housed in EPA’s National Coastal  
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## 1 INDICATOR: Coastal Benthic Communities

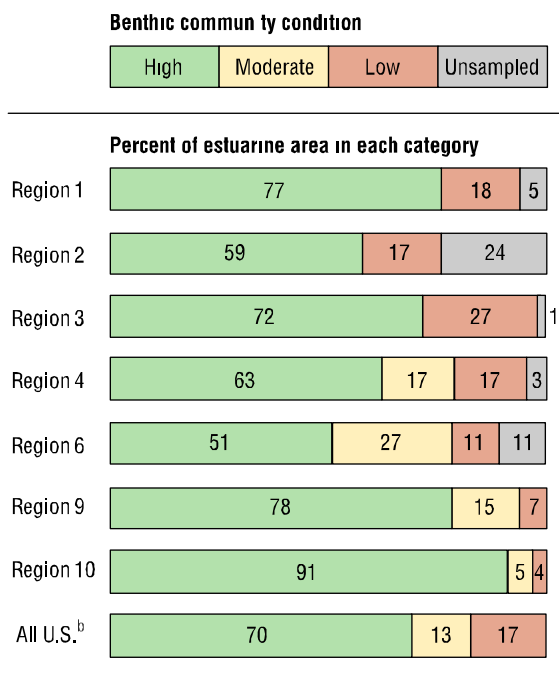
2 Benthic communities are largely composed of macroinvertebrates, such as annelids, mollusks, and  
 3 crustaceans. These organisms inhabit the bottom substrates of estuaries and play a vital role in  
 4 maintaining sediment and water quality. They also are an important food source for bottom-feeding fish,  
 5 invertebrates, and birds. Communities of benthic organisms are important indicators of environmental  
 6 stress because they are particularly sensitive to pollutant exposure (Holland et al., 1987). This sensitivity  
 7 arises from the close relationship between benthic organisms and sediments—which can accumulate  
 8 environmental contaminants over time—and the fact that these organisms are relatively immobile, which  
 9 means they receive prolonged exposure to any contaminants in their immediate habitat (Sanders et al.,  
 10 1980; Nixon et al., 1986).

11 This indicator is based on a multi-metric benthic communities index that reflects overall species diversity  
 12 in estuarine areas throughout the contiguous United States (adjusted for salinity, if necessary) and, for  
 13 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 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 (see U.S. EPA, 2004, p. 15). 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, 2004b). The survey was designed to provide a national picture of coastal benthic community condition by sampling sites in estuarine waters throughout the contiguous 48 states and Puerto Rico. Each site was sampled once during the period 1997-2000, within an index period from July to September. The indicator reflects average condition during this index period.

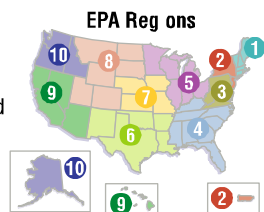
**Exhibit 3 28** Coastal benthic communities index for the contiguous U S and Puerto Rico, by EPA Region, 1997 2000<sup>a</sup>



<sup>a</sup>**Coverage** Estuarine waters of the contiguous 48 states and Puerto Rico

<sup>b</sup>U S figures reflect the total sampled area. Unsampled areas were not included in the calculation.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



### 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

1 low (Exhibit 3-28). Condition varied somewhat by EPA Region, with high index scores ranging from 51  
2 percent of the estuarine area in Region 6 to 91 percent in Region 10. Region 3 had the largest proportion  
3 of estuarine area rated low (27 percent), while Region 10 had the lowest (4 percent). In the figure, the  
4 portion of the estuarine area not represented by the sample is noted for each Region.

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

11 **Indicator Limitations**

- 12 • The indicator does not include data from the Great Lakes, which are monitored using a  
13 different index design. The coastal areas of Hawaii and a portion of Alaska have been  
14 sampled, but the data had not yet been assessed at the time this indicator was compiled.
- 15 • Trend data are not yet available for this indicator. Because of differences in methodology, the  
16 data presented here are not comparable with data that appeared in EPA’s first National  
17 Coastal Condition Report (NCCR I). The data presented here will serve as a baseline for  
18 future surveys.
- 19 • Benthic indices for the Northeast, West, and Puerto Rico do not yet include measures of  
20 pollution-tolerant or pollution-sensitive species. Although species diversity has the largest  
21 impact on index scores in the other regions, index values could change in the future as these  
22 components are added to the index values for these regions.
- 23 • Sample collection is limited to an index period from July to September. Further, because  
24 benthic communities can be strongly influenced by episodic events, trawling, or climate  
25 perturbations, this indicator may not reflect the full range of conditions that occur at each  
26 sampling location throughout these months.

27 **Data Sources**

28 This indicator is based on an analysis published in EPA’s National Coastal Condition Report II (U.S.  
29 EPA, 2004). Summary data by EPA Region have not been published, but were provided by EPA’s  
30 National Coastal Assessment program. Underlying sampling data are housed in EPA’s National Coastal  
31 Assessment database (U.S. EPA, 2005) (<http://www.epa.gov/emap/nca/html/data/index.html>).

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## INDICATOR: Submerged Aquatic Vegetation in the Chesapeake Bay

Submerged Aquatic Vegetation (SAV) is important to the Chesapeake Bay aquatic ecosystem. SAV supports the Bay's health 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.

The loss of SAV from shallow waters of the Chesapeake Bay, which was first noted in the early 1960s, is 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 current SAV acreage is less than half of that during the earlier period (Moore et al., 2004).

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

This indicator presents the distribution of SAV in the Chesapeake Bay and its tributaries from 1978 to 2005, 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

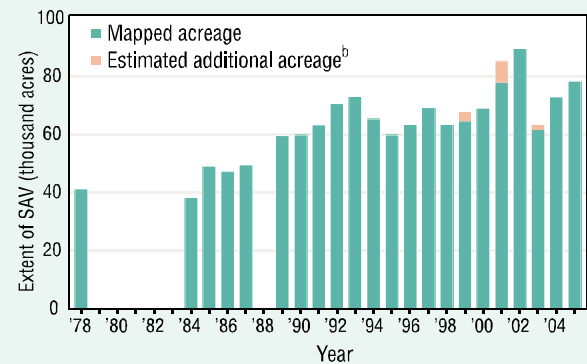
The extent of SAV in the Chesapeake Bay increased from 41,000 acres in 1978 to 78,000 acres in 2005 (Exhibit 3-29). The extent of SAV declined to a minimum of 38,000 acres in 1984 and the maximum extent of SAV during this period was 90,000 acres, in 2002. The notable decline in SAV distribution between 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 the Potomac River and Susquehanna region. While populations of SAV appeared to be present in these segments very early in the growing season, persistent

1 turbidity resulting from rain occurring throughout the spring and summer may have contributed to a very  
2 early decline, well before Hurricane Isabel affected the Chesapeake Bay (Orth et al., 2004). The extent of  
3 SAV gradually increased again through 2004 and 2005.

#### 4 **Indicator Limitations**

- 5 • There were no surveys in the years 1979-  
6 1983 or in 1988.
- 7 • The indicator includes some estimated  
8 data for years with incomplete  
9 photographic coverage. Spatial gaps in  
10 1999 occurred due to the inability to  
11 reliably photograph SAV following  
12 hurricane disturbance. Spatial gaps in  
13 2001 occurred due to flight restrictions  
14 near Washington D.C. after the September  
15 11<sup>th</sup> terrorist attacks. Other gaps occurred  
16 in 2003 due to adverse weather in the  
17 spring, summer, and fall (Hurricane  
18 Isabel). Acreage in the non-surveyed areas  
19 was estimated based on prior years'  
20 surveys.
- 21 • Photointerpretation methods changed over  
22 the course of this study. However, data  
23 have been adjusted to account for any  
24 methodological inconsistencies.
- 25 • Extent is just one of the variables that can  
26 be used to measure the condition of SAV  
27 communities. Information on vegetation  
28 health and density would also provide useful information.

**Exhibit 3-29.** Extent of submerged aquatic vegetation (SAV) in the Chesapeake Bay, 1978-2005<sup>a</sup>



<sup>a</sup>There were no Bay-wide surveys from 1979 to 1983, or in 1988.

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



**Data source:** Virginia Institute of Marine Science (VIMS)

#### 29 **Data Sources**

30 Data were obtained from the Chesapeake Bay Program, which has published a version of this indicator  
31 (Chesapeake Bay Program, 2006) along with a link to download the annual summary data presented in  
32 Exhibit 3-29 (<http://www.chesapeakebay.net/pubs/statustrends/88-data-2002.xls>). These acreage statistics  
33 are based on annual SAV distribution maps, which are available from the Virginia Institute of Marine  
34 Science (VIMS, 2006) (<http://www.vims.edu/bio/sav/savdata.html>).

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## 1 INDICATOR: Hypoxia in the Gulf of Mexico and Long Island Sound

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

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

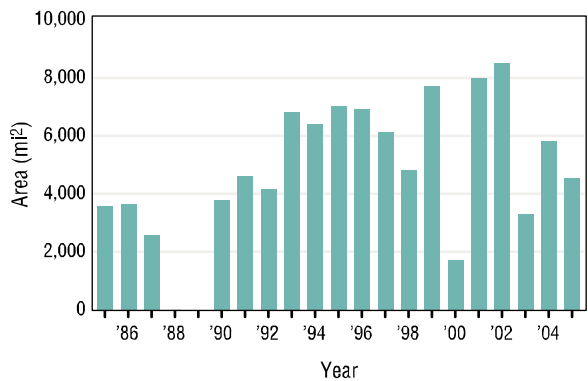
22 The Gulf of Mexico hypoxic zone on the Texas-Louisiana Shelf is the largest zone of coastal hypoxia in  
23 the Western Hemisphere (CAST, 1999). It exhibits seasonally low oxygen levels as a result of  
24 complicated interactions involving excess nutrients carried to the Gulf by the Mississippi and Atchafalaya  
25 Rivers; physical changes in the river basin, such as channeling, construction of dams and levees, and loss  
26 of natural wetlands and riparian vegetation; and the stratification in the waters of the northern Gulf caused  
27 by the interaction of fresh river water and the salt water of the Gulf (CENR, 2000; Rabalais and Turner,  
28 2001). Increased nitrogen and phosphorus inputs from human activities throughout the basin support an  
29 overabundance of algae, which die and fall to the sea floor, depleting oxygen in the water as they  
30 decompose. Fresh water from the rivers entering the Gulf of Mexico forms a layer of fresh water above  
31 the saltier Gulf waters and prevents re-oxygenation of oxygen-depleted water along the bottom.

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

37 Data for the two water bodies are presented separately because they are collected through two different  
38 sampling programs, each with its own aims and technical approach. The Gulf of Mexico survey is  
39 designed to measure the extent of bottom-water hypoxia in the summer, with samples collected during a  
40 cruise that generally occurs over a five-day period in mid-to-late July (LUMCON, 2006). Samples are  
41 collected day and night along several transects designed to capture the overall extent of the hypoxic zone.  
42 The number of locations varies from 60 to 90 per year, depending on the length of the sampling cruise,  
43 the size of the hypoxic zone, logistical constraints, and the density of station locations. Long Island Sound  
44 sampling is designed to determine both the maximum extent and the duration of hypoxia (Connecticut

- 1 DEP, 2006a). Sampling is performed every month from October to May and every two weeks from June
- 2 to September at a set of fixed locations throughout the Sound. All Long Island Sound samples are
- 3 collected during the day.

**Exhibit 3-30.** Extent of dissolved oxygen less than 2.0 mg/L in Gulf of Mexico bottom waters in mid-summer, 1985-2005<sup>a</sup>



<sup>a</sup>Only 15 square miles were affected in 1988. No data were collected in 1989.  
**Data source:** Louisiana Universities Marine Consortium (LUMCON)

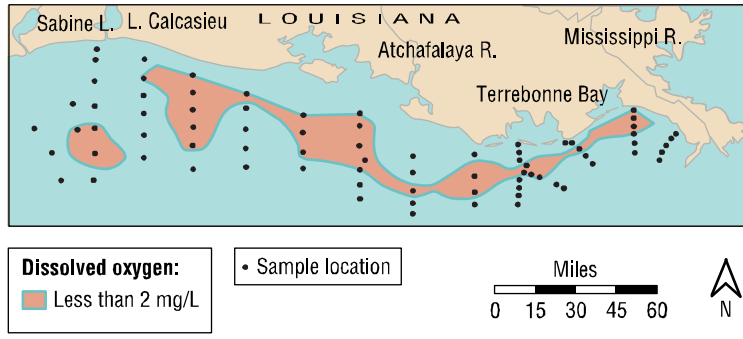
**What the Data Show**

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 40 square miles in 1988 (a drought year in the Mississippi Basin) to approximately 8,500 square miles in 2002 (Exhibit 3-30). The unusually low areal extent in 2000 also was associated with very low discharge from the Mississippi River (see the N and P Discharge from Large Rivers indicator, p. 3-28). In the latest year of sampling, 2005, the hypoxic zone measured over 4,500 square miles, slightly smaller than the state of Connecticut (Exhibit 3-31). Over the full period of record (1985–2005), the area with DO <2.0 mg/L has averaged approximately 4,900 square miles.

The maximum extent and duration of hypoxic events (<2 mg/L DO) in Long Island Sound also has varied considerably since 1987 (Exhibit 3-32). Since 1987, the largest area of DO less than 2 mg/L was 212

23 square miles, which occurred in 1994; the smallest area, 2 square miles, occurred in 1997 (panel A). The  
 24 shortest hypoxic event was 6 days in 1990 and the longest was 71 days, in 1989 (panel B). In 2005, the  
 25 latest year for which data are available, the maximum area and duration of DO <2 mg/L in Long Island  
 26 Sound were 95 square miles and 60 days, respectively, with the lowest DO levels occurring in the western  
 27 end of the Sound (Exhibits 3-32 and 3-33). Between 1987 and 2005, the average annual maximum was 71  
 28 square miles and 33 days.

**Exhibit 3-31.** Dissolved oxygen less than 2 mg/L in Gulf of Mexico bottom waters, July 24-29, 2005



**Data source:** Louisiana Universities Marine Consortium (LUMCON)

1 **Indicator Limitations**

2 Gulf of Mexico

- 3 • This indicator is based on a survey  
4 conducted over a five-day period when  
5 hypoxia is expected to be at its maximum  
6 extent. The indicator does not capture  
7 periods of hypoxia or anoxia (no oxygen  
8 at all) occurring at times other than the  
9 mid-summer surveys.
- 10 • Because the extent of hypoxia is measured  
11 through a single mid-summer sampling  
12 cruise, duration cannot be estimated.
- 13 • This indicator does not track vertical  
14 extent of hypoxia or anoxic volume.
- 15 • Surveys usually end offshore from the  
16 Louisiana-Texas State line; in years when  
17 hypoxia extends onto the upper Texas  
18 coast, the spatial extent of hypoxia is  
19 underestimated.

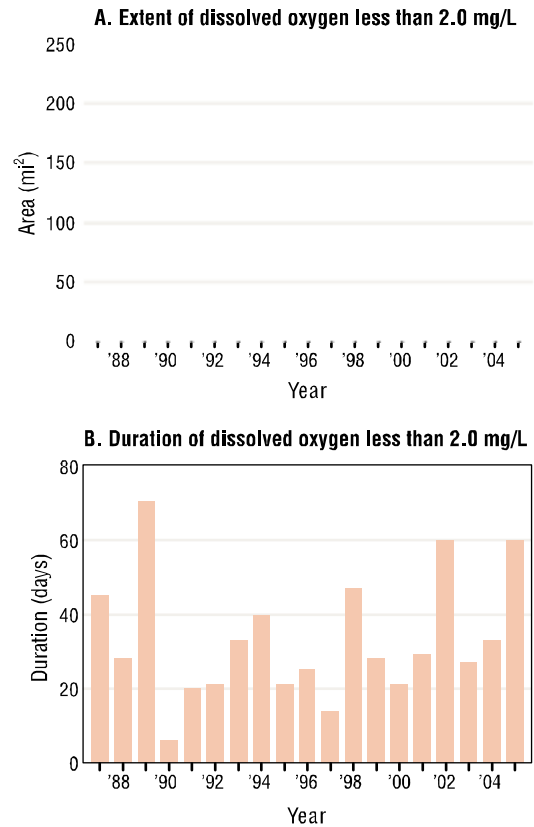
20 Long Island Sound

- 21 • Hypoxic or anoxic periods that may occur  
22 between the two-week surveys are not  
23 captured in the indicator.
- 24 • Samples are taken in the  
25 daytime, approximately  
26 one meter off the bottom.  
27 This indicator does not  
28 capture oxygen conditions  
29 at night, which may be  
30 lower because of the lack  
31 of photosynthesis, or  
32 conditions near the  
33 sediment-water interface.

34 **Data Sources**

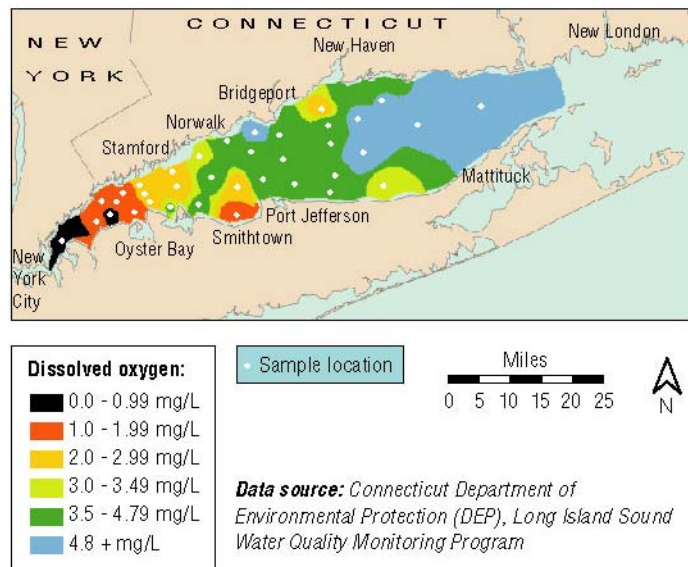
35 Gulf of Mexico data were provided by  
36 the Louisiana Universities Marine  
37 Consortium (LUMCON). Maps and  
38 summary data from the most recent  
39 Gulf of Mexico survey are published  
40 online (LUMCON, 2006).

**Exhibit 3-32.** Maximum extent and duration of dissolved oxygen less than 2.0 mg/L in Long Island Sound bottom waters, 1987-2005



*Data source: Connecticut Department of Environmental Protection (DEP), Long Island Sound Water Quality Monitoring Program*

**Exhibit 3-33.** Dissolved oxygen in Long Island Sound bottom waters, August 16-19, 2005



1 Long Island Sound data were provided by the Connecticut Department of Environmental Protection's  
2 Long Island Sound Water Quality Monitoring Program. Data on extent and duration of hypoxia have not  
3 been published, but concentration maps are available online (Connecticut DEP, 2006b)—including the  
4 2005 map shown in Exhibit 3-33.

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## INDICATOR: Harmful Algal Bloom Outbreaks Along the Western Florida Coastline

Harmful algal blooms (HABs) are “blooms” of large numbers of microscopic algae (phytoplankton) that can harm humans or the environment, especially when they occur in near-shore coastal waters and estuaries. HABs can be caused by a number of different species of phytoplankton. For example, in the Gulf of Mexico, approximately 50 species of toxic or potentially toxic marine microalgae have been identified (Fisher et al., 2003). HAB events along the Gulf coast are most commonly caused by the phytoplankton organism *Karenia brevis* (a dinoflagellate), also known as “red tide.” *K. brevis* can cause massive fish kills, marine mammal mortality, and in humans can cause neurotoxic shellfish poisoning (NSP) and respiratory irritation (NRC, 2000).

HABs can occur naturally, but some may be exacerbated by excess nutrients from terrestrial activities (NRC, 2000). In the Gulf of Mexico, red tide events occur almost every year, generally in late summer or early fall. The extent and duration of these blooms largely reflect the influence of winds, currents, and other factors such as ocean mixing parameters. Red tide events in the Gulf typically last three to six months and cover hundreds of square miles, although in extreme cases, blooms can last up to 18 months and cover thousands of square miles (Haverkamp et al., 2004). *K. brevis* blooms tend to be concentrated along the west coast of Florida and, to a lesser extent, along the Texas coast (HABSOS, 2004). These events can impact ecological systems, fishing and shellfishing, and recreational activities in the Gulf of Mexico. For example, severe red tide blooms in 1996 resulted in fish mortalities and beach and shellfish bed closures throughout the Gulf, and killed over 150 endangered manatees along the Florida coast (HABSOS, 2002).

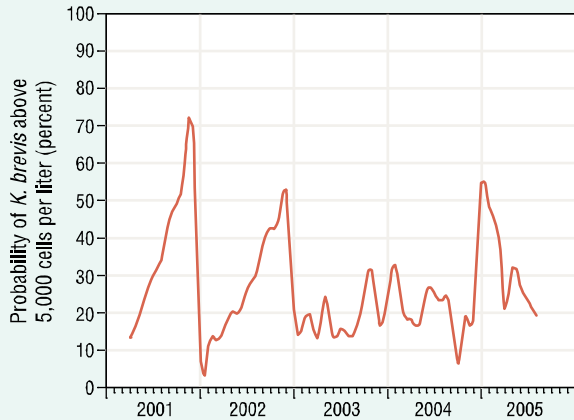
This indicator reports the occurrence of elevated *K. brevis* concentrations along Florida’s Gulf Coast, where the Florida Fish and Wildlife Research Institute (FWRI) oversees an extensive red tide monitoring network. FWRI and its partners (Mote Marine Laboratory, the University of South Florida, Collier County, the Red Tide Offshore Monitoring Program, and others) maintain a set of permanent monitoring sites from which they collect water samples at regular intervals for microscopic examination. When a bloom is detected, researchers conduct additional targeted sampling to characterize the event. These efforts are aided by NOAA satellite imagery, which is used to track the movement of blooms and to direct targeted sampling.

For this indicator, *K. brevis* concentrations from FWRI’s database were analyzed to determine the probability of a sample exceeding 5,000 *K. brevis* cells per liter in any given month (Christman and Young, 2006). At this concentration, the harvesting of shellfish in the area is prohibited (ISSC, 1999). For reference, background levels of *K. brevis* in the Gulf of Mexico are approximately 1,000 cells per liter year-round (Geesy and Tester, 1993). Although FWRI’s database extends back as far as the 1950s, a statistical review determined that prior to 2001, samples were not collected with sufficient regularity to provide meaningful information about trends over time (Christman and Young, 2006). Therefore, this indicator is restricted to the period 2001-2005. The analysis also was limited to a specific geographic area with a high sampling density (map in Exhibit 3-34).

### What the Data Show

Over the period of record (2001-2005), the probability of finding a *K. brevis* concentration above 5,000 cells per liter in a sample taken from the study area ranged from less than 5 percent to more than 70 percent, with both extremes occurring within the span of a few months in late 2001 and 2002 (Exhibit 3-34). The graphic also suggests a seasonal pattern, with *K. brevis* counts peaking in late fall or early

**Exhibit 3-34. *Karenia brevis* counts above 5,000 cells per liter along the western Florida coastline, 2001-2005**



Each small tick mark represents one month

Data source: TBD



winter; this pattern is particularly well-defined in 2001 and 2002. There is no discernable trend from year to year, however, and this period of record is currently too short to provide information about longer-term trends.

### Indicator Limitations

- These data are biased toward surface and inshore sampling. The data do not include blooms occurring well offshore.
- This indicator does not include HABs other than *K. brevis*.

### Data Sources

Probability values were provided by the authors of a statistical review of the Florida Fish and Wildlife Research Institute (FWRI) database (Christman and Young, 2006). This database can be accessed by contacting FWRI (<http://ocean.floridamarine.org/>).

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1 **3.5.3 Discussion**

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

4 *Extent*

5 Although the ROE indicators do not characterize the extent of coastal waters, the Wetlands indicator (p.  
6 3-53) shows that at least one type of coastal *system* has experienced changes in extent over the last half-  
7 century. The number of acres of marine and estuarine wetlands has decreased overall since the 1950s,  
8 although the rate of loss has slowed in recent years. While the indicator does not identify the exact  
9 stressors responsible for the decline in marine and estuarine wetlands, it does list several factors that have  
10 led to overall wetland loss, including development and conversion to deepwater. Section 3.4 provides  
11 further detail on how human activities can affect wetland extent, including human activities that  
12 exacerbate natural processes (e.g., storm damage). Ultimately, trends in wetland extent affect ecological  
13 systems, as described further below.

14 *Condition*

15 Together, these indicators cover much of the spectrum of “condition,” including four of the broad themes  
16 introduced in Section 3.5.1: nutrients, toxic chemical contaminants, biotoxins, and the condition of native  
17 populations and their habitat. As described in Section 3.5.1, excess nutrients can cause algal blooms that  
18 result in low dissolved oxygen and reduced water clarity, which in turn can harm plant and animal  
19 communities. For example, the Trophic State of Coastal Waters indicator (p. 3-62) shows elevated levels  
20 of nutrients and chlorophyll-*a* (a surrogate for algal abundance) in a small but substantial portion of the  
21 nation’s estuarine areas. These results are consistent with indicators that show evidence of eutrophication,  
22 such as decreased water clarity and hypoxia. The SAV in Chesapeake Bay indicator (p. 3-74) in turn  
23 offers an example of an ecological effect linked to eutrophication. Nutrient stressors cannot be attributed  
24 entirely to human activities; for example, the Gulf of Mexico hypoxic zone results in part from natural  
25 mixing parameters, and trends in the extent of hypoxic zones show large year-to-year variations related to  
26 factors like climate (Hypoxia in Gulf of Mexico and Long Island Sound indicator, p. 3-77). However, as  
27 the spatial distribution of hypoxia in Long Island Sound suggests, the nation’s coastal waters can  
28 experience eutrophic effects that are very closely related to human activities (e.g., the location of a large  
29 city). Further, as the SAV in Chesapeake Bay indicator (p. 3-74) shows, present conditions may be quite  
30 different from historical reference conditions.

31 Overall, levels of toxic chemical contaminants are low in most of the nation’s estuarine sediments, but as  
32 the Coastal Sediment Quality indicator (p. 3-67) shows, condition can vary greatly from one region to the  
33 next. In some EPA Regions, as much as 20 percent of estuarine area has sediments that either exceed  
34 contamination reference standards or fail a screening test for benthic toxicity. Other indicators discuss the  
35 extent to which toxic contaminants may be entering and affecting the food web. For example, benthic  
36 communities—which are most directly impacted by contaminants in sediment—generally show little  
37 evidence of disturbance (e.g., losses of pollution-sensitive species) (Coastal Benthic Communities  
38 indicator, p. 3-71). However, fish tissues had at least one contaminant above human health guidelines in  
39 22 percent of estuarine sampling sites (Coastal Fish Tissue indicator, p. 3-103), suggesting that  
40 bioaccumulation of certain toxic compounds is widespread and, in some instances, could pose risks to  
41 human health. This indicator suggests the importance of atmospheric deposition of mercury as a stressor  
42 to coastal water condition, as well as historical activities that released PCBs and DDT into upstream and  
43 coastal waters.

1 The HAB Outbreaks in Western Florida indicator (p. 3-81) describes the pervasive nature of red tide,  
2 which is one of many marine organisms that can produce dangerous biotoxins. As the data show, it is  
3 common for red tide events in the eastern Gulf of Mexico to persist for two or more months of the year at  
4 levels that trigger concerns about shellfish poisoning and associated human health effects (5,000 cells per  
5 liter). In extreme cases, these events also can be harmful to ecosystems. As this indicator shows, the  
6 condition of coastal waters with respect to HABs can vary greatly from year to year, depending on a  
7 number of factors.

8 In more general ecological terms (populations, communities, and habitat), trends in the condition of  
9 coastal waters vary. Benthic communities in the nation's estuaries are largely intact in terms of species  
10 diversity (Coastal Benthic Communities indicator, p. 3-71), which is critical because these organisms are  
11 a fundamental link in the coastal food web. Other populations, however, may be substantially lower than  
12 historical levels as a result of human stressors—for example, the Chesapeake Bay's SAV, which is  
13 vulnerable to changes in water clarity (SAV in Chesapeake Bay indicator, p. 3-74). SAV is ecologically  
14 important because it is not just a plant population; it also provides habitat and facilitates nutrient cycling,  
15 much like wetlands do. SAV has recently shown increases in extent, which may translate into increased  
16 habitat and breeding grounds for various species. However, coastal habitat still continues to be threatened  
17 by human stressors. As the Hypoxia in Gulf of Mexico and Long Island Sound indicator (p. 3-77) shows,  
18 large areas of some of the nation's coastal water bodies are unsuitable for fish and shellfish populations  
19 for at least a portion of the year.

## 20 ***Limitations, Gaps, and Challenges***

21 Although the seven indicators discussed here provide a good overview of many important aspects of  
22 coastal extent and condition, there are a few key limitations to their temporal and spatial coverage. For  
23 example, the four indicators derived from the National Coastal Condition Report do not provide  
24 information about trends over time, as there are insufficient data from previous surveys to compare with  
25 recent data to examine potential trends.<sup>24</sup> Another temporal limitation is that many surveys are conducted  
26 during an index period, not over a full year; thus, they may not capture phenomena that occur outside the  
27 sampling window.<sup>25</sup> Spatially, the National Indicators are limited because they do not include data from  
28 Alaska, Hawaii, and most U.S. territories. Alaska contains 75 percent of the bays, sounds, and estuarine  
29 surface area in the United States, while Hawaii, the Caribbean, and the Pacific territories represent a set of  
30 unique estuarine subsystems (i.e., coral reefs and tropical bays) that are not common in the contiguous 48  
31 states.

32 One challenge in assessing coastal waters is that some aspects of condition vary naturally from one area  
33 to another. For example, some rivers naturally carry a heavy load of sediments or nutrients into coastal  
34 waters, while benthic community structure may depend on climate, depth, and geology. To assess coastal  
35 waters with respect to natural background conditions, several of the ROE indicators use different  
36 reference conditions for different regions.

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<sup>24</sup> U.S. EPA. 2004. National coastal condition report II. EPA/620/R-03/002. Washington, DC.  
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<sup>25</sup> U.S. EPA. 2004. National coastal condition report II. EPA/620/R-03/002. Washington, DC.  
<<http://www.epa.gov/owow/oceans/nccr/2005/index.html>>

1 To assess the extent and condition of coastal waters more fully, it would help to have more information in  
2 several key areas, including:

- 3 • More information about the extent of coastal waters—e.g., an indicator on coastal subsidence.
- 4 • Nationally consistent data on coastal water pollutants beyond those associated with trophic  
5 state—for example, organics, toxics, metals, and pathogens.
- 6 • A National Indicator of invasive species, which are often transported from one area to another  
7 along shipping routes or via aquaculture. Little information exists on a national level, in part  
8 because of a lack of standard invasion metrics.
- 9 • Comprehensive information on the condition of the nation’s coral reefs—a unique and fragile  
10 habitat—and the status of coastal fish and shellfish communities.<sup>26</sup>

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<sup>26</sup> U.S. EPA. 2004. National coastal condition report II. EPA/620/R-03/002. Washington, DC.  
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## 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 1-2 liters of drinking water per day, including water used to make coffee, tea, and other beverages.<sup>27</sup> 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<sup>28</sup> (including private wells serving about 15 percent of U.S. households<sup>29</sup>). 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

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<sup>27</sup> U.S. EPA. 1997. Exposure factors handbook. Volume I—general factors. EPA/600/P-95/002Fa. Washington, DC. August.

<sup>28</sup> U.S. Geological Survey. 1999. Ground water (general interest publication). Reston, VA. [http://capp.water.usgs.gov/GIP/gw\\_gip/](http://capp.water.usgs.gov/GIP/gw_gip/)

<sup>29</sup> U.S. EPA. 2002. The clean water and drinking water infrastructure gap analysis. EPA/816/R-02/020. <http://www.epa.gov/safewater/gapreport.pdf>

- 1 containment wells or discharged into surface waters, as can mine waste (e.g., heavy metals) if  
2 not properly contained.
- 3 • **Natural sources.** As ground water travels through rock and soil, it can pick up naturally  
4 occurring contaminants such as arsenic, other heavy metals, or radionuclides. Some aquifers  
5 are naturally unsuitable for drinking because the local geology happens to include high levels  
6 of certain contaminants.
  - 7 • **Microbial pathogens.** Human wastes from sewage and septic systems can carry harmful  
8 microbes into drinking water sources, as can wastes from animal feedlots and wildlife. Major  
9 contaminants include *Giardia*, *Cryptosporidium*, and *E. coli* O157:H7. Coliform bacteria  
10 from human and animal wastes also may be found in drinking water if the water is not  
11 properly finished; these bacteria may indicate that other harmful pathogens are present as  
12 well.
  - 13 • **Treatment and distribution.** While treatment can remove many chemical and biological  
14 contaminants from the water, it may also result in the presence of certain disinfection  
15 byproducts that may themselves be harmful, such as trihalomethanes. Finished water can also  
16 become contaminated after it enters the distribution system, either from a breach in the  
17 system or from corrosion of plumbing materials, particularly those containing lead or copper.  
18 After water leaves the treatment plant, monitoring for lead in drinking water is done at the  
19 tap, and monitoring for microbial contaminants (as well as disinfection byproducts) occurs  
20 within the distribution system.

21 Chemical exposure through drinking water can lead to a variety of long- and short-term effects. Potential  
22 health effects of exposure to certain metals, solvents, and pesticides can include chronic conditions such  
23 as cancer, which can develop over long periods of time (up to 70 years). Higher doses over shorter  
24 periods of time can result in a variety of biological responses, including toxicity, mutagenicity, and  
25 teratogenicity (birth defects). Short-term results might include cosmetic effects (e.g., skin discoloration),  
26 unpleasant odors, or more severe problems such as nervous system or organ damage, and developmental  
27 or reproductive effects. The effects of some drinking water contaminants are not yet well understood. For  
28 example, certain disinfection byproducts have been associated with cancer, developmental, and  
29 reproductive risks, but the extent of this association is still uncertain.

30 Consuming water with pathogenic microbes can cause life-threatening diseases such as typhoid fever or  
31 cholera—rare in the U.S. today—as well as more common waterborne diseases caused by organisms such  
32 as *Giardia*, *Cryptosporidium*, *E. coli*, and *Campylobacter*. Health consequences of the more common  
33 illnesses can include symptoms such as gastrointestinal distress (stomach pain, vomiting, diarrhea),  
34 headache, fever, and kidney failure, as well as various infectious diseases such as hepatitis.

35 A number of factors determine whether the presence of contaminants in drinking water will lead to  
36 adverse health effects. These include the type of contaminant, its concentration in the water, individual  
37 susceptibility, the amount of contaminated water consumed, and the duration of exposure.

38 Disinfection of drinking water—the destruction of pathogens using chlorine or other chemicals—has  
39 dramatically reduced the incidence of waterborne diseases such as typhoid, cholera, and hepatitis, as well  
40 as gastrointestinal illness, in the United States. Other processes required depend on the physical,  
41 microbiological, and chemical characteristics and the types of contaminants present in the source water  
42 (e.g., filtration to remove turbidity and biological contaminants; treatment to remove organic chemicals  
43 and inorganic contaminants such as metals; and corrosion control to reduce the presence of corrosion  
44 byproducts such as lead at the point of use).



1 **3.6.2 ROE Indicators**

2 This section presents an indicator that tracks trends in the total population served by community water  
3 systems (CWS) for which states report no violations of health-based drinking water standards. Data for  
4 this indicator come from EPA’s Safe Drinking Water Information System, Federal Version. This system  
5 houses all data submitted by states, EPA Regions, and the Navajo Nation Indian Tribe on the community  
6 water systems they oversee.

7 **Table 3.6.1. ROE Indicators of the Trends in the Quality of Drinking Water and their Effects on**  
8 **Human Health**

<b>NATIONAL INDICATORS</b>	<b>LOCATION</b>
Population Served by Community Water Systems with No Reported Violations of Health-Based Standards (N/R)	3.6.2 – p. 3-90

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

10

## 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 281 million Americans in fiscal year (FY) 2005 (U.S. EPA, 2006)—more than 90 percent of the U.S. population (U.S. Census Bureau, 2005). 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.

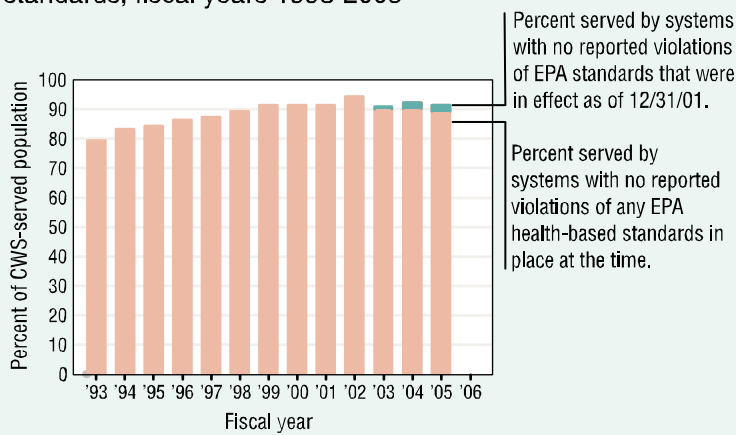
This indicator tracks the population served by CWS for which no violations were reported to EPA for the period from FY 1993 to FY 2005, the latest year for which data are available. Results are reported as a percentage of the overall population served by CWS, both nationally and by EPA Region. This indicator 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.

### 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 from 79 percent in 1993 to 94 percent in FY 2002 before declining to 89 percent in FY 2005 (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 2002 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 dark segment atop the last three columns). As EPA adds to or strengthens its requirements for water systems over time, compliance with standards comes to represent a higher level of public health protection.

When results are broken down by EPA Region, some variability over time is evident (Exhibit 3-36). Between FY 1993 and FY 2005, 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 2005, only one Region remained well below the national percentage, largely because of a small number of public water systems serving large populations.

**Exhibit 3-35.** U.S. population served by Community Water Systems with no reported violations of EPA health-based standards, fiscal years 1993-2005<sup>a,b</sup>

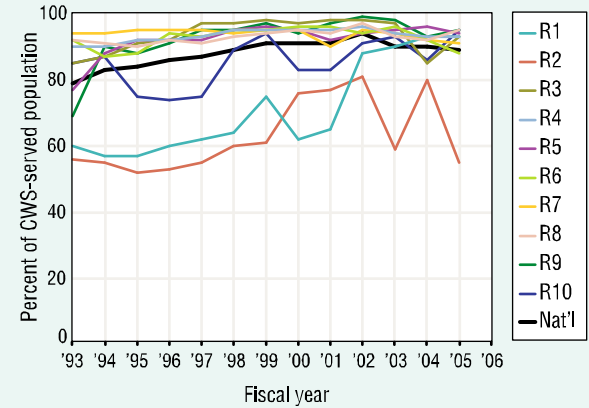


<sup>a</sup> **Coverage:** U.S. residents served by Community Water Systems (CWS) (approximately 95% of the total U.S. population).

<sup>b</sup> Based on reported violations of the standards in effect in any given year. 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 FY2003, the DBP rule applied to systems serving >10,000 people; as of January 2004, it applied to all CWS. Data are presented for the first full fiscal year that the rules were in effect.

**Data source:** U.S. EPA, *Safe Drinking Water Information System, Federal Version*

**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 1993-2005<sup>a,b</sup>



<sup>a</sup> **Coverage:** U.S. residents served by Community Water Systems (CWS) (approximately 95% of the total U.S. population).

<sup>b</sup> Based on reported violations of the standards in effect in any given year.



**Data source:** U.S. EPA, *Safe Drinking Water Information System, Federal Version*

**EPA Regions**

1

2 In FY 2005, reported violations involving surface water treatment rules in large CWS were responsible  
 3 for exceeding health-based standards for more than 14 million people (5 percent of the population served  
 4 by CWS nationally) (Exhibit 3-37). Reported violations of health-based coliform standards affected 11.6  
 5 million people (4.1 percent of the CWS-served population), and reported violations of the health-based  
 6 disinfection byproducts standards (Stage 1) affected nearly 6 million people (2.1 percent of the CWS-  
 7 served population). Overall, of the 11.5 percent of the population served by systems with reported  
 8 violations in FY 2005, 85 percent of these cases involved at least one of these three rules governing  
 9 treatment to prevent waterborne diseases—the most widespread and acute threat to health from drinking  
 10 water—or the contaminants created by such treatment.

11 **Indicator Limitations**

- 12 • Non-community water systems (typically relatively small systems) that serve only transient  
 13 populations such as restaurants or campgrounds, or serving those in a non-domestic setting  
 14 for only part of their day (e.g., a school, religious facility, or office building), are not included  
 15 in population served figures.

16

**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 2005<sup>a</sup>

	Population served	Percent of CWS-served population
<b>Any violation</b>	32,485,318	11.5
<b>Selected violations</b>		
Stage 1 Disinfection Byproducts Rule	5,967,270	2.1
Surface Water Treatment Rules	14,161,702	5.0
Total Coliform Rule	11,576,743	4.1
<b>Any of these selected rules<sup>b</sup></b>	27,676,881	9.8

<sup>a</sup> **Coverage:** U.S. residents served by Community Water Systems (CWS) (approximately 95% of the total U.S. population).

<sup>b</sup> Some CWS violated more than one of the selected rules.

**Data source:** U.S. EPA, *Safe Drinking Water Information System Federal Version*

- Domestic (home) use of drinking water supplied by private wells—which serve approximately 15 percent of the U.S. population (USGS, 2004)—is not included.
- Bottled water, which is regulated by standards set by the Food and Drug Administration, is not included.
- National statistics based on population served can be volatile, because a single very large system can sway the results by up to 2 to 3 percent; this effect becomes more pronounced when statistics are broken down at the regional level, and still more so for a single rule.
- Some factors may lead to overstating the extent of population receiving water that violates standards. For example, the entire population served by each system in violation is reported, even though only part of the total population served may actually receive water that is out of compliance. In addition, violations stated on an annual basis may suggest a longer duration of violation than may be the case, as some violations may be as brief as an hour or a day.

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- 43
- 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. 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 three-year period (U.S. EPA, 2004a). In late 2006, EPA expects to issue an updated estimate of data quality for the period 2002-2004.
  - 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.

1    **Data Sources**

2    Data for this indicator were obtained from EPA’s Safe Drinking Water Information System (U.S. EPA,  
3    2006) (<http://www.epa.gov/safewater/data/getdata.html>;  
4    <http://www.epa.gov/safewater/data/pivottables.html>). This database contains a record of violations  
5    reported to EPA by the states or other entities that oversee Community Water Systems, along with annual  
6    summary statistics.

7    **References**

8    U.S. Census Bureau. 2005. Annual population estimates 2000 to 2005. Released December 22, 2005.  
9    Washington, DC. <<http://www.census.gov/popest/states/tables/NST-EST2005-01.xls>> Available from  
10    <<http://www.census.gov/popest/states/NST-ann-est.html>>

11    U.S. EPA. 2006. Safe Drinking Water Information System, Federal Version. Accessed July 2006.  
12    <<http://www.epa.gov/safewater/data/getdata.html>>

13    U.S. EPA. 2004a. Safe Drinking Water Act 30<sup>th</sup> anniversary fact sheet: drinking water monitoring,  
14    compliance, and enforcement.  
15    <[http://www.epa.gov/safewater/sdwa/30th/factsheets/monitoring\\_compliance.html](http://www.epa.gov/safewater/sdwa/30th/factsheets/monitoring_compliance.html)>

16    U.S. EPA. 2004b. Safe Drinking Water Act 30<sup>th</sup> anniversary fact sheet: drinking water standards and  
17    health effects. <<http://www.epa.gov/safewater/sdwa/30th/factsheets/standard.html>>

18    U.S. EPA. 2004c. Safe Drinking Water Act 30<sup>th</sup> anniversary fact sheet: glossary.  
19    <<http://www.epa.gov/safewater/sdwa/30th/factsheets/glossary.html>>

20    USGS (U.S. Geological Survey). 2004. Estimated use of water in the United States in 2000. 2004  
21    revision. <<http://water.usgs.gov/pubs/circ/2004/circ1268/>>

1 **3.6.3 Discussion**

2 ***What This Indicator Says About Trends in the Quality of Drinking Water and***  
3 ***Their Effects on Human Health***

4 Most Americans served by CWS are served by facilities with no reported violations (Drinking Water  
5 indicator, p. 3-90). Since 1993, the percentage of Americans served by community water systems for  
6 which states reported no health-based violations has increased, although there has been some reversal  
7 nationally since the percentage peaked in 2002. While there have been noticeable differences among EPA  
8 Regions over the period of record, most Regions have been consistently above 90 percent since 1993.  
9 Only one Region has been consistently below the national average, though according to the data source,  
10 this result is due largely to one large metropolitan water system which is under a legal settlement to  
11 upgrade its treatment technology. As this result suggests, while the nation has thousands of community  
12 water systems, a substantial percentage of the population depends on the quality of a small number of  
13 large metropolitan water systems.

14 ***Limitations, Gaps, and Challenges***

15 As noted in the indicator description, a challenge in assessing national drinking water quality is that there  
16 are inherent limitations in using reporting data. Some violations may be unreported, particularly if  
17 monitoring is inadequate—leading to undercounting. Other violations may be overlooked because CWS  
18 may purchase water from other CWS and not test it for all contaminants themselves. Conversely, the data  
19 could also overstate the portion of the population receiving water in violation of standards, because a  
20 violation could be as short as an hour or a day and be limited to water received by only a small portion of  
21 a system’s customers.

22 Other challenges relate to the interpretation of the Drinking Water indicator (p. 3-90). For example, trends  
23 can be confounded by the fact that water quality standards and treatment requirements change over time.  
24 Thus, an apparent increase in violations over time may result from new or more stringent MCLs rather  
25 than simply a decline in the quality of drinking water, as these new requirements may also affect some  
26 systems’ compliance with existing standards.

27 As described in the indicator summary, the indicator does not address the quality of drinking water other  
28 than that obtained from CWSs. Information that would provide a more complete characterization of  
29 drinking water quality include National Indicators for:

- 30 • **Trends in drinking water quality from CWS that *did* have reported violations.** The  
31 Drinking Water indicator does not explain the nature of every reported violation; nor does it  
32 show how many contaminants may be above standards, the identity of the contaminants, the  
33 extent to which standards were exceeded, or the duration of the violations (some of which,  
34 especially in larger systems, were only a very few hours in length).
- 35 • **The quality of drinking water from other public water systems.** There is no ROE  
36 indicator for drinking water quality from transient and non-transient non-community water  
37 systems, which are required to monitor quality and report violations to state authorities, but  
38 are regulated only for certain contaminants.
- 39 • **The quality of drinking water from non-public water supplies.** Private wells, cisterns, and  
40 other non-public water supplies are not subject to federal regulation. Some private supplies  
41 are treated, and some people do test their private water for common contaminants. However,

1 no national infrastructure, and few if any systematic state efforts, currently exist to collect  
2 data on trends in the quality of these supplies. Bottled water is regulated by the Food and  
3 Drug Administration (FDA), which is required by law to apply standards that are no less  
4 stringent or protective of public health than EPA's, but there is no ROE indicator on the  
5 quality of bottled water.

6 In addition to these gaps, there are no ROE indicators to identify trends in health effects of interest, such  
7 as waterborne disease occurrence. Data are very limited for endemic waterborne illness as well as for  
8 acute waterborne disease outbreaks.

9

1 **3.7 WHAT ARE THE TRENDS IN THE CONDITION OF RECREATIONAL WATERS**  
2 **AND THEIR EFFECTS ON HUMAN HEALTH AND THE ENVIRONMENT?**

3 **3.7.1 Introduction**

4 The nation's rivers, lakes, and coastal waters are used for many different forms of recreation. Some  
5 recreational activities take place in or on the water, such as swimming, boating, whitewater rafting, and  
6 surfing. Other activities may not involve contact with the water yet may still require water—or be  
7 enhanced by proximity to water. Examples include a picnic at the beach, hiking, nature viewing (e.g., bird  
8 watching), and hunting (especially waterfowl). People also engage in fishing and shellfishing as  
9 recreational activities.

10 In the questions on fresh surface waters and coastal waters (Sections 3.2 and 3.5), condition is defined as  
11 a combination of physical, chemical, and biological attributes of a water body. For recreational waters,  
12 condition is more specific, focusing on those physical, chemical, and biological attributes that determine a  
13 water body's ability to support recreational activities. The particular attributes necessary to support  
14 recreation vary widely, depending on the nature of the activity in question. In a more general sense,  
15 however, the components of recreational condition fall into two main categories:

- 16 • Attributes that determine whether recreational activities can be enjoyed without unacceptable  
17 risk to human health—primarily pathogens and chemical contaminants that can affect the  
18 health of humans who are exposed during contact activities such as swimming.
- 19 • Attributes associated with ecological systems that support recreation—e.g., the status of fish  
20 and bird communities, as well as chemical and physical characteristics that may affect these  
21 populations and their habitat. These attributes also contribute to the aesthetic qualities  
22 important for recreational activities.

23 Many stressors affecting the condition of recreational waters fall into the broad category of contaminants.  
24 This category includes chemical contaminants, various pathogens (viruses, bacteria, and other parasites or  
25 protozoans) that can cause infectious disease, and pollutants such as trash or debris. These stressors can  
26 come from a variety of point sources and nonpoint sources, and can be discharged or washed directly into  
27 recreational waters or carried downstream to lakes or coastal areas. Among the major sources are storm  
28 water and sediment runoff, direct discharge (e.g., from industrial facilities and sewer systems),  
29 atmospheric deposition, and recreational activities themselves (e.g., outboard motor exhaust and  
30 overboard discharge of sanitary wastes). Some chemicals and pathogens occur naturally, but their  
31 abundance may be influenced by other human stressors such as land use and land cover (e.g., paved  
32 surfaces and forestry and irrigation practices, which can influence runoff patterns) or by natural stressors  
33 such as weather and climate. Land use and land cover can influence recreational condition in other ways  
34 as well.

35 In terms of human health, the stressors that pose the greatest potential risks are chemical and biological  
36 contaminants. People can be exposed to these contaminants if they swim in contaminated waters or near  
37 storm water or sewage outfall pipes—especially after a rainfall event. Boating also may pose risks of  
38 exposure, although to a lesser extent. For toxic chemical contaminants, the main routes of exposure are  
39 through dermal (skin) contact or accidental ingestion. For pathogens, the main route of exposure is by  
40 swallowing water, although some infections can be contracted simply by getting polluted water on the  
41 skin or in the eyes. In some cases, swimmers can develop illnesses or infections if an open wound is  
42 exposed to contaminated water.



1 Effects of exposure to chemical and biological contaminants range from minor illnesses to potentially  
2 fatal diseases. The most common illness is gastroenteritis, an inflammation of the stomach and the  
3 intestines that can cause symptoms such as vomiting, headaches, and diarrhea. Other minor illnesses  
4 include ear, eye, nose, and throat infections. While unpleasant, most swimming-related illnesses are  
5 indeed minor, with no long-term effects. However, in severely contaminated waters, swimmers can  
6 sometimes be exposed to serious and potentially fatal diseases such as meningitis, encephalitis, hepatitis,  
7 cholera, and typhoid fever.<sup>30</sup> Children, the elderly, and people with weakened immune systems are most  
8 likely to develop illnesses or infections after coming into contact with contaminated water.

9 From an ecological perspective, stressors to recreational waters can affect habitat, species composition,  
10 and important ecological processes. For example, changes in land cover (e.g., the removal of shade trees)  
11 may cause water temperature to rise above the viable range for certain fish species. Hydromodifications  
12 such as dams may create some recreational opportunities (e.g., boating), but they also may impede the  
13 migration of fish species such as salmon. Chemical and biological contaminants may harm plants and  
14 animals directly, or they may disrupt the balance of the food web. For example, acid deposition may lead  
15 to acidification in lakes, while excess nutrients can lead to eutrophic conditions such as low levels of  
16 dissolved oxygen, which in turn can harm fish and shellfish populations. Beyond their obvious effects on  
17 activities like fishing and nature viewing, stressors such as these also can be detrimental to recreational  
18 activities in a more aesthetic sense, as the presence of dead fish or visibly unhealthy plants may diminish  
19 one's enjoyment of recreation in or near the water.

20 Ultimately, ecological effects can also impact human health. For example, eutrophic conditions can  
21 encourage harmful algal blooms (HAB)—some of which can produce discomfort or illness when people  
22 are exposed through ingestion or skin or eye contact. One well-known type of HAB is “red tide,” which in  
23 humans can cause neurotoxic shellfish poisoning (NSP) and respiratory irritation.<sup>31</sup>

### 24 **3.7.2 ROE Indicators**

25 At this time, no National Indicators have been identified to quantify the condition of recreational waters.  
26 Individual states monitor certain recreational waters for a set of indicator bacteria and report monitoring  
27 results to EPA. However, the methodology and frequency of data collection vary among states, so the  
28 data are not necessarily comparable.

29 Challenges and information gaps for developing reliable National Indicators of recreational water  
30 condition are described in more detail in Section 3.7.3 below.

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<sup>30</sup> Pond, K. 2005. Water recreation and disease—plausibility of associations, sequelae and mortality. Published on behalf of World Health Organization. London, United Kingdom: IWA Publishers.  
<[http://www.who.int/water\\_sanitation\\_health/bathing/recreadis.pdf](http://www.who.int/water_sanitation_health/bathing/recreadis.pdf)>

<sup>31</sup> National Research Council. 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. Washington, DC: National Academy Press. 405 pp.

1 **3.7.3 Discussion**

2 ***Limitations, Gaps, and Challenges***

3 Several challenges exist in assessing the condition of the nation’s recreational waters. Foremost is the lack  
4 of a comprehensive national system for collecting data on pathogen levels at beaches, a key concern in  
5 assessing the suitability of recreational waters with respect to human health. In addition, data on the types  
6 and extent of health effects associated with swimming in contaminated water are limited. The number of  
7 occurrences is likely under-reported because individuals may not link common symptoms (e.g.,  
8 gastrointestinal ailments, sore throats) to exposure to contaminated recreational waters.

9 Another challenge to answering this question is the breadth of the subject. “Recreation” encompasses a  
10 wide range of activities, involving different types of water bodies and entailing varying concepts of  
11 condition. While the recreational condition of a whitewater stream with a native salmon population will  
12 be determined largely by flow levels and condition of fish habitat, for example, the recreational condition  
13 of a beach will be assessed more in terms of levels of pathogens and chemical contaminants.

14 Gaps in assessing the condition of the nation’s recreational waters include National Indicators of pathogen  
15 levels in recreational waters (rivers, lakes, and coastal beaches), the magnitude of specific stressors—  
16 particularly contaminant loadings (biological and chemical)—to recreational waters, harmful algal  
17 blooms (HABs) in recreational waters, and the condition of recreational fish and shellfish populations.

18

## 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 is commercial fish, purchased in supermarkets or fish stores. Fishing also is one of the most popular outdoor recreational activities in the country, with more than 34 million people per year fishing recreationally<sup>32</sup>—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. 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.<sup>33</sup> 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 smaller 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.<sup>34</sup> Mercury in water bodies can be methylated by certain bacteria in bottom sediments to form

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<sup>32</sup> 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.

<sup>33</sup> U.S. EPA. 2002. Estimated per capita fish consumption in the United States. EPA/821/C-02/003. Washington, DC. <[http://www.epa.gov/waterscience/fish/consumption\\_report.pdf](http://www.epa.gov/waterscience/fish/consumption_report.pdf)>

<sup>34</sup> U.S. and global sources of mercury are described in more detail in Section 2.2, which includes an indicator of domestic mercury emissions.

1 methylmercury, which is more toxic and bioavailable than other forms of mercury.<sup>35</sup> It also is  
2 biomagnified through aquatic food webs, so that it becomes particularly concentrated in  
3 larger and longer-lived predators such as bass, tuna, swordfish, and some sharks. Exposure to  
4 high levels of methylmercury can cause reproductive and other effects in wildlife;<sup>36</sup> in  
5 humans, exposure to elevated levels is primarily associated with developmental and  
6 neurological health effects.<sup>37</sup>

- 7 • **Polychlorinated biphenyls (PCBs) and the pesticide DDT.** Though PCBs and DDT are no  
8 longer manufactured or used in the U.S., they persist in historical deposits in watersheds and  
9 near-shore sediments, which can continue to contaminate fish and shellfish. These chemicals  
10 are also circulated globally as a result of use in other parts of the world. Levels of PCBs and  
11 DDT are a concern in some bottom-feeding fish and shellfish, as well as in some higher-level  
12 predators. These chemicals have been linked to adverse health effects such as cancer, nervous  
13 system damage, reproductive disorders, and disruption of the immune system in both humans  
14 and wildlife.

15 Other chemical contaminants that may be present in fish and shellfish include other pesticides, metals  
16 (such as arsenic), and dioxins and furans.<sup>38</sup>

17 Biological contamination also can affect the condition of fish and shellfish—particularly the latter. For  
18 example, shellfish contaminated with pathogens from human and animal fecal wastes can cause  
19 gastrointestinal illness and even death in individuals with compromised immune systems. Sources of fecal  
20 contamination in shellfish include urban runoff, wildlife, wastewater treatment systems and treatment  
21 plants, agricultural runoff, and boating and marinas.

22 Marine biotoxins produced by certain types of algae can contaminate fish and shellfish as well. These  
23 toxins not only can harm fish and fish communities—sometimes resulting in massive fish kills or losses  
24 to aquaculture operations—but they also can make their way through the food web to affect seabirds,  
25 marine mammals, and humans. Mollusks such as mussels, clams, oysters, whelks, and other shellfish can  
26 carry biotoxins that have common symptoms such as irritation of the eyes, nose, throat, and tingling of  
27 the lips and tongue. Consumption of contaminated seafood can cause a range of other health effects in  
28 humans, depending on the organism involved, including gastrointestinal illness, amnesia, memory loss,  
29 paralysis, and even death.<sup>39,40</sup>

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<sup>35</sup> U.S. EPA. 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>>

<sup>36</sup> U.S. EPA. 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>>

<sup>37</sup> National Research Council. 2000. Toxicological effects of methylmercury. Washington, DC: National Academies Press.

<sup>38</sup> U.S. EPA. In progress. National study of chemical residues in lake fish tissue. Washington, DC. <<http://www.epa.gov/waterscience/fishstudy>>

<sup>39</sup> 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 Press. pp. 141-175.

1 The growth of aquaculture, or fish farming, may affect the levels of certain contaminants in consumable  
2 fish and shellfish. Dense colonies can increase stress and disease transmission among fish, in some cases  
3 requiring the administration of antibiotics.<sup>41</sup> Studies have also found higher levels of certain contaminants  
4 in farmed fish than in their wild counterparts, possibly due to differences in diet. For example, several  
5 studies have found higher concentrations of PCBs, organochlorine pesticides, and polybrominated  
6 diphenyl ethers (PBDEs) in farmed salmon.<sup>42</sup>

7 Overfishing also can affect the condition of fish—not only the species being fished, but also the species  
8 that prey on them—by disrupting the food web. Because of depleted food sources, predators can become  
9 more susceptible to disease (such as infection of rockfish by mycobacterial lesions). These infections are  
10 often confined to internal organs and may not be apparent to anglers, although in some cases they are  
11 associated with external sores as well. Some types of mycobacteria can also infect humans who handle  
12 diseased fish if the infection comes into contact with an open wound. The slow-developing infections are  
13 usually not severe in humans, but in some cases they can cause major health problems, especially in  
14 people with compromised immune systems.

### 15 **3.8.2 ROE Indicators**

16 Two ROE indicators characterize levels of chemical contaminants in edible fish and shellfish species.  
17 One indicator reports levels and occurrence of contaminants in fish in estuarine areas; the other, in  
18 freshwater lakes and reservoirs. Both indicators are based on nationwide probabilistic surveys.

19 The coastal fish indicator is based on an index originally presented in EPA’s second National Coastal  
20 Condition Report (NCCR II). The underlying data were collected between 1997 and 2000 as part of  
21 EPA’s Environmental Monitoring and Assessment Program (EMAP). EMAP’s probabilistic coastal  
22 surveys are designed to be representative of 100 percent of estuarine acreage in the contiguous 48 states.  
23 This indicator presents results by EPA Region.

24 The other indicator describes contamination of fish in inland lakes. This indicator is derived from fish  
25 samples collected and analyzed for EPA’s National Study of Chemical Residues in Lake Fish Tissue, a  
26 probabilistic survey designed to estimate the national distribution of the mean levels of selected  
27 persistent, bioaccumulative, and toxic chemical residues in fish tissue from lakes and reservoirs.

28 Note that this question does not rely on information about fish and shellfish consumption advisories.  
29 While many states and tribes issue fish consumption advice and develop fish advisory programs, there is  
30 great variability in how monitoring is conducted, how decisions are made to place waters under advisory,  
31 and what specific advice is provided when contamination is found in fish. Further, trends in the number of

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<sup>40</sup> Van Dolah, F.M. 2000. Marine algal toxins: origins, health effects, and their increased occurrence. *Environ. Health Persp.* 108(Suppl 1):133-141.

<sup>41</sup> Barton, B.A., et al. 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.

<sup>42</sup> Easton, M.D.L., D. Lusznjak, 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.

1 advisories over time may reflect changes in the frequency and intensity of monitoring.<sup>43</sup> Thus, fish  
2 advisories cannot provide a consistent national metric for trends in the condition of consumable fish and  
3 shellfish.

4 **Table 3.8.1. ROE Indicators of the Trends in the Condition of Consumable Fish and Shellfish and**  
5 **their Effects on Human Health**

<b>NATIONAL INDICATORS</b>	<b>LOCATION</b>
Coastal Fish Tissue Contaminants (N/R)	3.8.2– p. 3-103
Contaminants in Lake Fish Tissue	3.8.2– p. 3-107

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

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<sup>43</sup> U.S. EPA. 2005. Fact sheet: national listing of fish advisories. EPA/823/F-05/004.  
<<http://epa.gov/waterscience/fish/advisories/fs2004.pdf>>

## 1 INDICATOR: Coastal Fish Tissue Contaminants

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

5 This indicator, derived from an indicator presented in EPA's second National Coastal Condition Report  
6 (NCCR II) (U.S. EPA, 2004), is based on National Coastal Assessment (NCA) fish tissue survey data  
7 from 653 estuarine sites throughout the United States. The survey was designed to provide a national  
8 picture of coastal fish tissue contaminants by sampling sites in estuarine waters throughout the contiguous  
9 48 states. Each site was sampled once during the period 1997-2000, within an index period from July to  
10 September. The indicator reflects average condition during this index period.

11 Fish and shellfish analyzed in the survey included Atlantic croaker, white perch, catfish, flounder, scup,  
12 blue crab, lobster, shrimp, whiffs, mullet, tomcod, spot, weakfish, halibut, sole, sculpins, sanddabs, bass,  
13 and sturgeon. At each site, five to ten whole-body fish samples were tested for 90 contaminants, 16 of  
14 which have EPA-established risk guidelines for recreational fishers. This indicator is based on data  
15 collected from 1997 to 2000.

16 To assess risks to human health, contaminant concentrations in fish tissue were compared with  
17 established EPA guidelines based on the consumption of four 8-ounce fish meals per month (U.S. EPA,  
18 2000, 2004). For most contaminants this is done using whole body concentrations, but for mercury, which  
19 concentrates in the edible fillet portion of the fish, a factor of 3.0 was used to correct whole-body  
20 concentrations in order to approximate fillet concentrations. The factor, 3.0, represents the median value  
21 (range 1.5-5.0) found in the available literature (Windom and Kendall, 1979; Mikac et al., 1985; Schmidt  
22 and Brumbaugh, 1990; Kannan et al., 1998; Canadian Council of Ministers of the Environment, 1999).

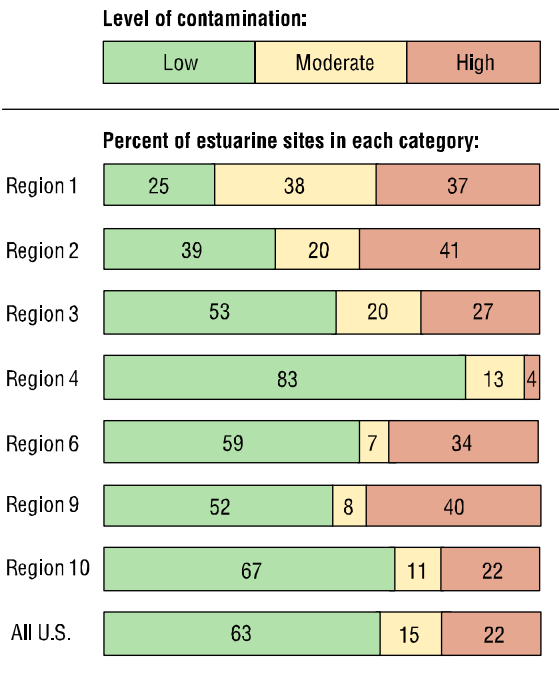
23 For this indicator, a site was given a high score if one or more contaminants were present at a  
24 concentration above the guideline ranges. A site was rated moderate if one or more contaminants were  
25 within the guideline ranges but none was in exceedance. Sites with all contaminants below their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

### 27 What the Data Show

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

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

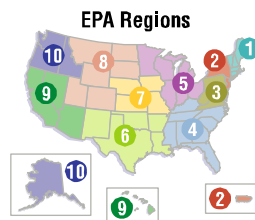
**Exhibit 3-38.** Coastal fish tissue contaminants in the contiguous U.S. by EPA Region, 1997-2000<sup>a, b</sup>



<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states.

<sup>b</sup>This indicator is based on a whole-body analysis of the fish.

**Data source:** U.S. EPA, 2004 (data modified to report by EPA Region)



1  
2  
3

**Exhibit 3-39.** Coastal fish tissue contaminant concentrations in the contiguous U.S., compared with health-based guidelines, 1997-2000<sup>a, b, c</sup>

Contaminant	Guideline range (ppm)	Percent of estuarine sites:		
		Below guideline range	Within guideline range	Exceeding guideline range
Arsenic (inorganic) <sup>d</sup>	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

<sup>a</sup>**Coverage:** Estuarine waters of the contiguous 48 states.

<sup>b</sup>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.

<sup>c</sup>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 Total PAHs, which is a cancer risk guideline.

<sup>d</sup>Inorganic arsenic estimated at 2% of total arsenic.

**Data source:** U.S. EPA, Environmental Monitoring and Assessment Program (EMAP) National Coastal Database



1 **Indicator Limitations**

- 2 • The indicator does not include data from Louisiana, Florida, Puerto Rico, Alaska, and  
3 Hawaii, which had not been assessed at the time this indicator was compiled. Some of these  
4 areas (e.g., portions of Alaska) have now been surveyed, and may be included in future  
5 indicators.
- 6 • Whole-body contaminant concentrations in fish overestimate the risk associated with  
7 consuming only the fillet portion of the fish, with the exception of mercury and cadmium,  
8 which are generally underestimated.
- 9 • This indicator focuses on contaminants from a human health risk perspective. No EPA  
10 guidance criteria exist to assess the ecological risk of whole-body contaminants in fish (U.S.  
11 EPA, 2004).
- 12 • Some fish samples used in the survey were non-market-size juveniles, which are known to  
13 have lower contaminant levels than larger, market-sized fish.
- 14 • Samples are collected during an index period from July to September, and the indicator is  
15 only representative of this time period. It is unlikely, however, that contaminant levels vary  
16 substantially from season to season.
- 17 • There are no trend data for this indicator. In NCCR II, fish tissue contaminants are  
18 characterized by whole-body concentrations and compared to EPA risk-based consumption  
19 guidelines. For EPA's first National Coastal Condition Report (NCCR I), fish contaminants  
20 were measured as fillet concentrations and compared to FDA criteria. The data presented here  
21 will serve as a baseline for future surveys, however.

22 **Data Sources**

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

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## 1 INDICATOR: Contaminants in Lake Fish Tissue

2 Lakes and reservoirs provide important sport fisheries and other recreational opportunities, and lake  
3 ecosystems provide critical habitat for aquatic species and support wildlife populations that depend on  
4 aquatic species for food. Lakes and reservoirs occur in a variety of landscapes and can receive  
5 contaminants from several sources, including direct discharges into the water, atmospheric deposition,  
6 and agricultural or urban runoff. A group of contaminants of particular concern are the persistent,  
7 bioaccumulative, and toxic (PBT) chemicals. These contaminants are highly toxic, long-lasting chemicals  
8 that can accumulate in fish, reaching levels that can affect the health of people and wildlife that eat them.

9 PBT contaminants can originate from a variety of sources, many of which are declining. The primary  
10 source of one of the most important PBTs, mercury, is atmospheric deposition. Among other important  
11 PBTs, most uses of DDT became illegal in the U.S. effective in 1973; production of PCBs in the U.S.  
12 ceased in 1977 (although they are still emitted as a byproduct of other manufacturing processes) and most  
13 uses phased out in 1979; chlordane was banned in 1988; and quantifiable emissions of dioxin-like  
14 compounds from all known sources have decreased in the U.S. by an estimated 89 percent between 1987  
15 and 2000 (U.S. EPA, 2006a).

16 This indicator is based on tissue samples of predator and bottom-dwelling fish species collected and  
17 analyzed for EPA's National Study of Chemical Residues in Lake Fish Tissue. The data generated from  
18 this probabilistic survey (Olsen et al., 1998; U.S. EPA, 1999; Stevens and Olsen, 2003, 2004) are  
19 designed to estimate the national distribution of the mean levels of PBT chemicals in fish tissue from  
20 lakes and reservoirs of the contiguous 48 states. Fish samples were collected from 500 lakes and  
21 reservoirs over a four-year period (2000-2003). Sampling locations were selected from the estimated  
22 147,000 target lakes and reservoirs in the contiguous 48 states based on an unequal probability survey  
23 design. The lakes and reservoirs were divided into six size categories, and varying probabilities were  
24 assigned to each category in order to achieve a similar number of lakes in each size category. The lakes  
25 and reservoirs ranged from 1 hectare (about 2.5 acres) to 365,000 hectares (about 900,000 acres), were at  
26 least 1 meter (3 feet) deep, and had permanent fish populations.

27 Because no predator or bottom-dwelling species occurs in all 500 lakes and reservoirs, the study focused  
28 on 12 target predator species and 6 target bottom-dwelling species in order to minimize the effect of  
29 sampling different species. These species were chosen because they are commonly consumed in the study  
30 area, have a wide geographic distribution, and potentially accumulate high concentrations of PBT  
31 chemicals. Sampling teams applied consistent materials and methods nationwide. From each lake or  
32 reservoir, teams collected composite samples of five adult fish of similar size for one predator species  
33 (e.g., bass or trout) and one bottom-dwelling species (e.g., carp or catfish) (U.S. EPA, 2000). Fillets were  
34 analyzed for predators, and whole bodies were analyzed for bottom-dwelling fish. Fillet data represent the  
35 edible part of the fish most relevant to human health, while whole body data are more relevant to wildlife  
36 consumption. A single laboratory prepared fish tissue samples for analysis in a strictly controlled  
37 environment, and tissue samples were sent to four analytical laboratories. The same laboratory analyzed  
38 tissue samples for each chemical group (e.g., PCBs or organochlorine pesticides), using the same standard  
39 analytical method, for the duration of the study. The indicator consists of statistical distributions of the  
40 concentrations of 15 PBT chemicals or chemical groups in predator and bottom-dwelling fish tissue,  
41 including mercury, arsenic (total inorganic), dioxins/furans, total PCBs, and 11 organochlorine pesticides.  
42 Fourteen of these chemicals or chemical groups also appear in the Coastal Fish Tissue indicator (p. 3-  
43 103).

1 **What the Data Show**

2 Mercury, polychlorinated biphenyls (PCBs), dioxins and furans, and DDT are widely distributed in lakes  
 3 and reservoirs in the contiguous 48 states (Exhibits 3-40, 3-41). Mercury and PCBs were detected in 100  
 4 percent of both predator and bottom-dweller composite samples. Dioxins and furans were detected in 81  
 5 percent of the predator composite samples and 99 percent of the bottom-dweller composite samples, and  
 6 DDT was detected in 78 percent of the predator composites and 98 percent of the bottom-dweller  
 7 composites. Some of the chemicals analyzed for this study were not detected in any of the fish tissue  
 8 samples.

9 Median concentrations in predator filets (i.e., half of the lakes and reservoirs had fish with higher values)  
 10 were as follows: mercury, 0.285 ppm; total PCBs, 2.161 ppb; dioxins and furans, 0.006 ppt [TEQ]; and  
 11 total DDT, 1.47 ppb (Exhibit 3-40). Median concentrations in whole, bottom-dwelling fish were lower for  
 12 mercury (0.069 ppm), but higher for total PCBs (13.88 ppb), dioxins and furans (0.406 ppt [TEQ]), and  
 13 total DDT (12.68 ppb) (Exhibit 3-41).

14

**Exhibit 3-40.** Lake fish tissue PBT contaminant concentration estimates for predators (filets) in the contiguous U.S., 2000-2003

Contaminant	Number of samples	Number of samples above MDL <sup>a</sup>	Percentiles for fillet tissue concentrations (ppm) <sup>b</sup>						
			5 <sup>th</sup>	10 <sup>th</sup>	25 <sup>th</sup>	50 <sup>th</sup> (median)	75 <sup>th</sup>	90 <sup>th</sup>	95 <sup>th</sup>
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 x 10 <sup>-9</sup>	46 x 10 <sup>-9</sup>	109 x 10 <sup>-9</sup>	318 x 10 <sup>-9</sup>
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	*	*	*	*	*	*	*

<sup>a</sup>MDL = method detection limit; MDLs are available online at <http://www.epa.gov/waterscience/fishstudy>.

<sup>b</sup>\* = less than MDL

**Data source:** U.S. EPA, National Study of Chemical Residues in Lake Fish Tissue

**Exhibit 3-41.** Lake fish tissue PBT contaminant concentration estimates for bottom-dwellers (whole fish) in the contiguous U.S., 2000-2003

Contaminant	Number of samples	Number of samples above MDL <sup>a</sup>	Percentiles for whole body tissue concentrations (ppm) <sup>b</sup>						
			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 x 10 <sup>-9</sup>	59 x 10 <sup>-9</sup>	165 x 10 <sup>-9</sup>	406 x 10 <sup>-9</sup>	1067 x 10 <sup>-9</sup>	1770 x 10 <sup>-9</sup>	2006 x 10 <sup>-9</sup>
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	*	*	*	*	*	*	*

<sup>a</sup>MDL = method detection limit; MDLs are available online at <http://www.epa.gov/waterscience/fishstudy>.

<sup>b</sup>\* = less than MDL

**Data source:** U.S. EPA, National Study of Chemical Residues in Lake Fish Tissue

1

2 **Indicator Limitations**

3

- Survey data are not available for Alaska, Hawaii, and Puerto Rico.

4

- The Great Lakes, the Great Salt Lake, and lakes without permanent fish populations are not included in the target population.

5

6

- 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.

7

8

9

- Due to the inaccessibility (e.g., landowner denial of access) of some target lakes, the results are representative of the sampled population of lakes (approximately 80,000) rather than the original target population of 147,000 lakes.

10

11

12

- 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.

13

14

15

16

1    **Data Sources**

2    The data for Exhibits 3-40 and 3-41 were provided by EPA’s National Lake Fish Tissue Study. A report  
3    on the findings of this study was still in progress at the time this Report on the Environment went to  
4    press; however, partial results (number of detections) have been published in U.S. EPA (2006b)  
5    (<http://www.epa.gov/waterscience/fishstudy/results.htm>), along with information about how to obtain  
6    more detailed results on CD.

7    **References**

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1 **3.8.3 Discussion**

2 ***What These Indicators Say About Trends in the Condition of Consumable***  
3 ***Fish and Shellfish and Their Effects on Human Health***

4 These indicators provide baseline information about consumable fish in inland lakes, reservoirs, and  
5 coastal areas. The data were collected from a variety of species, reflecting many parts of the food web.  
6 The results for fish in estuarine sites along the Atlantic, Gulf, and Pacific coasts of the contiguous 48  
7 states (Coastal Fish Tissue indicator, p. 3-103) varied substantially among the seven coastal EPA  
8 Regions. Fish from the coastal waters of the Southeast (EPA Region 4) generally had “low”  
9 contamination scores, while several other Regions had a substantial proportion with “high”  
10 contamination. In general, PCBs, mercury, and PAHs appeared to be the contaminants responsible for the  
11 most “high” contamination scores.

12 The results for lake fish (Lake Fish Tissue indicator, p. 3-107) suggest that several chemical contaminants  
13 are widely distributed in the nation’s lakes and reservoirs, including mercury, dioxins and furans, PCBs,  
14 and DDT. However, some of the other chemicals in this screening—including certain pesticides and  
15 PAHs—were detected rarely or not at all. There were some notable differences between predators and  
16 bottom-dwellers, which may be a result of how each type of fish was analyzed—fillets for predators and  
17 whole fish for bottom dwellers.

18 ***Limitations, Gaps, and Challenges***

19 As explained in Section 3.8.2, both of these indicators have important limitations. For example, like the  
20 other coastal indicators from NCCR II (presented in Section 3.5), the Coastal Fish Tissue indicator (p. 3-  
21 103) does not display trend data. It is also limited spatially, as adequate data for Alaska, Hawaii, the  
22 Caribbean, and the Pacific territories are not available. The lack of data from Alaska is especially notable  
23 because more than half of the nation’s commercial fish and shellfish catch comes from Alaskan waters.<sup>44</sup>

24 The Lake Fish Tissue indicator (p. 3-107) is also limited temporally and spatially, with no trend data and  
25 no coverage outside the contiguous 48 states. Further, unlike the coastal survey, the lake fish survey was  
26 not designed to produce results by region, and it also does not compare contaminant levels to any health-  
27 based guidelines. Thus, while both indicators present meaningful data, the results cannot easily be  
28 compared.

29 The Lake Fish Tissue and Coastal Fish Tissue indicators (pp. 3-107 and 3-103) do provide some  
30 information about contamination and safety of fish and shellfish. However, to fully assess the condition of  
31 the nation’s fish and shellfish, more data are needed—particularly on a national level, because many  
32 issues have been studied locally or regionally, but have not yet been studied in nationally representative  
33 surveys. In addition to the limitations of the indicators described above, information gaps for answering  
34 this question include nationally consistent indicators of pathogens in fish and shellfish, in both fresh water  
35 and coastal waters, and of the biological and chemical condition of fish and shellfish commercially  
36 farmed in the U.S. There are also no ROE indicators to describe the effects of fish and shellfish condition  
37 on human health. As noted in Chapter 1, it is often difficult to explicitly connect an observed effect to a

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<sup>44</sup> National Oceanic and Atmospheric Administration. 2005. Fisheries of the United States—2004.  
<[http://www.st.nmfs.gov/st1/fus/fus04/fus\\_2004.pdf](http://www.st.nmfs.gov/st1/fus/fus04/fus_2004.pdf)>

- 1 particular stressor (e.g., the condition of fish and shellfish that people consume), even though there may
- 2 be scientific evidence to suggest a possible association.