CHAPTER 3

WATER

WATER CHAPTER CONTENTS

3.1 INTRODUCTION

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

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

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

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

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

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

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

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

3.1.1 Overview of the Data

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

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

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

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

3.1.2 Organization of This Chapter

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

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

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

Question	Indicator Name	Section	Page
What are the trends in extent and condition of fresh surface waters and their effects on human health and the environment?	High and Low Stream Flows (N)	3.2.2	3-14
	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
What are the trends in extent and condition of ground water and their effects on human health and the environment?	Nitrate and Pesticides in Shallow Ground Water in Agricultural Areas (N)	3.3.2	3-44
What are the trends in extent and condition of wetlands and their effects on human health and the environment?	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-53
What are the trends in extent and condition of coastal waters and their effects on human health and the environment?	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-53
	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
What are the trends in the quality of drinking water and their effects on human health?	Population Served by Community Water Systems with No Reported Violations of Health-Based Standards (N/R)	3.6.2	3-90

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

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

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

3.2.1 Introduction

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

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

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

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

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

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

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

3.2.2 ROE Indicators

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

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

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

NATIONAL INDICATORS	LOCATION
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

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.

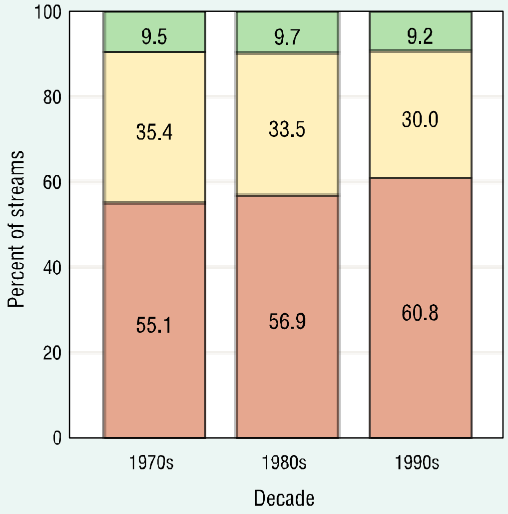
What the Data Show

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.

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

- Approximately two-thirds of streams had major changes in the volume of low flow, with about one-third of streams showing substantially larger low flows throughout the period of record (panel A) and another one-third showing substantially smaller low flows (panel B).
- In terms of high flow volume, more streams showed major decreases than major increases. In the 1970s and 1980s, only 12 percent of streams had substantially larger high-flow volumes than they had from 1930 to 1949, although this figure jumped to 31 percent in the 1990s (panel D). In contrast, throughout the 1970s, 1980s, and 1990s, nearly 40 percent of streams exhibited smaller high flows than they had during the reference period (panel E).
- Between the reference period and the 1970s-1990s period of record, about 30 percent of streams showed major changes in the timing of low flows (panel C), and 42 to 47 percent showed major changes in the timing of high flows (panel F). The number of streams in each of these categories increased somewhat between 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[a]



Degree of alteration:

🟩 Minimal[b]
🟨 Moderate[c]
🟥 Major[d]

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

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

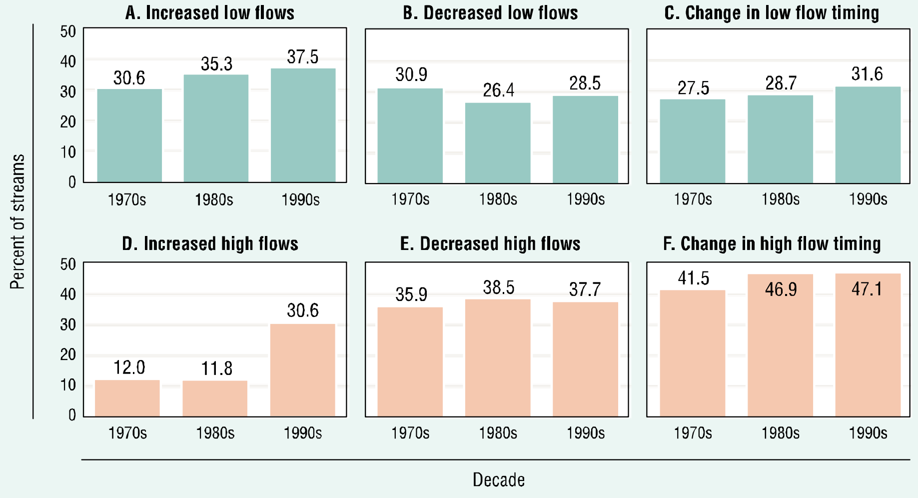
[c] **Moderate:** Between 25% and 75% increase or decrease in flow, or a 30- to 60-day change in timing of low or high flow.

[d] **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.*

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

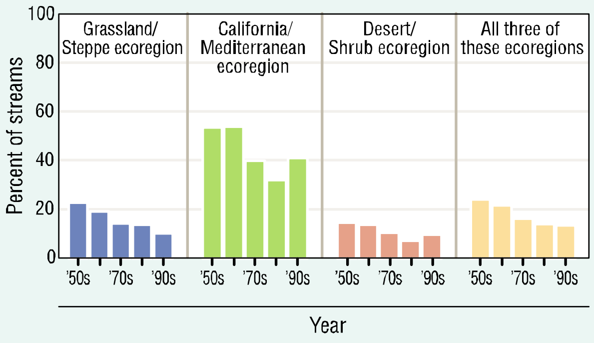


[a]**Coverage:** 867 stream gauging sites in the contiguous U.S. with continuous discharge measurements from 1930 to 1949 and from 1970 to 1999.

[b]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.*

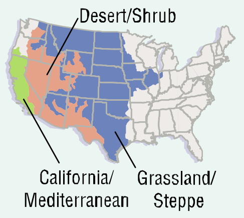
Exhibit 3-3. Percentage of grassland/shrubland streams in the contiguous U.S. experiencing periods of no flow, by ecoregion, 1950s-1990s[a, b]



[a]**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).

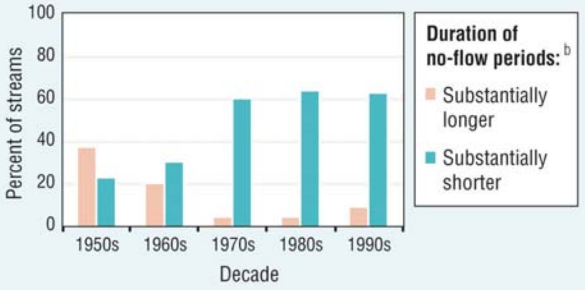
[b]Ecoregions based on Bailey, 1995.

Ecoregion divisions



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[a]



[a]**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).

[b]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.*

Indicator Limitations

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

Data Sources

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

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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 1st through 4th order in the Strahler Stream Order classification system (Strahler, 1952). The WSA is based on a probabilistic design, so the results from representative sample sites can be used to make a statistically valid statement about streambed stability in wadeable streams nationwide.

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

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

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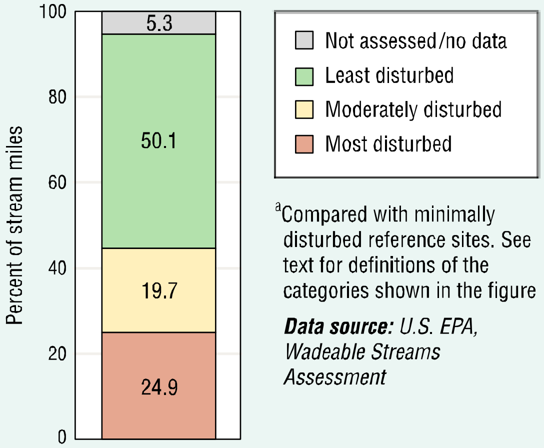
[2] For this analysis, the 48 contiguous states were divided into nine broad ecoregions. These “macro-level” ecoregions were defined by the WSA based on groupings of EPA Level III ecoregions (for a map of EPA Level III ecoregions, see http://www.epa.gov/wed/pages/ecoregions/level_iii.htm). A map of the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

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

Exhibit 3-5. Streambed stability in wadeable streams of the contiguous U.S., 2000-2004[a]



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

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

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.

Indicator Limitations

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

Data Sources

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

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U.S. EPA. 2004. Wadeable Streams Assessment: field operations manual. EPA/841/B-04/004. Washington, DC. <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 1st through 4th order in the Strahler Stream Order classification system (Strahler, 1952). The WSA is based on a probabilistic design, so the results from representative sample sites can be used to make a statistically valid statement about nitrogen and phosphorus concentrations in all of the nation's wadeable streams.

Crews sampled 1,392 randomized sites across the United States using standardized methods. Western sites were sampled between 2000 and 2004; eastern and central sites were 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.[3] In each ecoregion, a set of relatively undisturbed sites was sampled in order to determine the range of nutrient concentrations that would be considered "low." Next, observed nitrogen and phosphorus concentrations from all sites were compared to the distribution of concentrations among the ecoregion's reference sites. If the observed result was above the 95th percentile of the ecoregion's reference distribution, the concentration was labeled "high." This threshold was used because it offers a high degree of confidence that the observed condition is statistically different from the condition of the reference streams. Concentrations below the 75th percentile of the reference range were labeled "low," indicating a high probability that the site is similar to the relatively undisturbed reference sites. Concentrations falling between the 75th and 95th percentiles were labeled "moderate."

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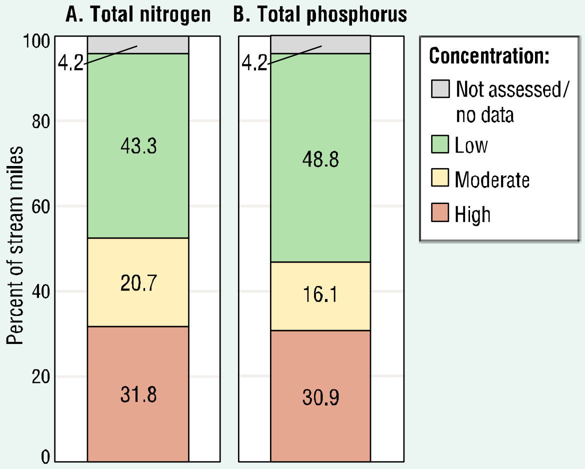
[3] For this analysis, the 48 contiguous states were divided into nine broad ecoregions. These "macro-level" ecoregions were defined by the WSA based on groupings of EPA Level III ecoregions (for a map of EPA Level III ecoregions, see http://www.epa.gov/wed/pages/ecoregions/level_iii.htm). A map of the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

What the Data Show

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

Exhibit 3-6. Nitrogen and phosphorus in wadeable streams of the contiguous U.S., 2000-2004[a]



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

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

Indicator Limitations

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

Data Sources

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

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

INDICATOR: Nitrogen and Phosphorus in Streams in Agricultural Watersheds

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

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

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

For nitrogen, the indicator reports the percentage of streams with average concentrations of nitrate and total nitrogen in one of five ranges: less than 1 milligram per liter (mg/L); 1-2 mg/L; 2-6 mg/L; 6-10 mg/L; and 10 mg/L or more. (This indicator measures nitrate (as N), i.e., the fraction of the material that is actually nitrogen.) The highest level (10 mg/L as N) represents the Maximum Contaminant Level (MCL) for nitrate allowed in finished drinking water in the United States (U.S. EPA, 2006). Because people are unlikely to drink untreated stream water, this concentration should be viewed as a point of reference, and not necessarily as a health risk to consumers. There is no human health guideline for total nitrogen and no comparable aquatic health guideline for either nitrate or total nitrogen because neither form represents a direct threat to organisms living in the stream.

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

What the Data Show

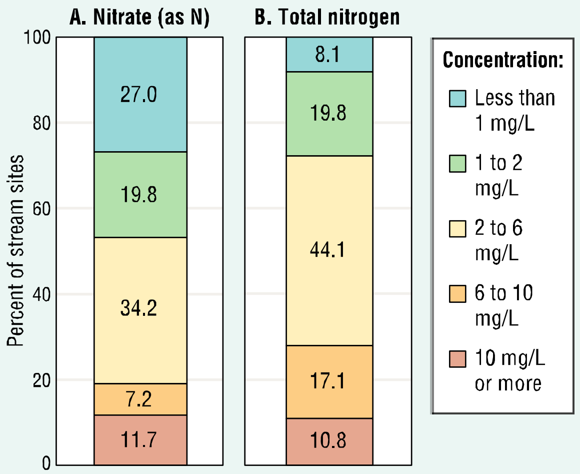
Average flow-weighted nitrate concentrations were above 2 mg/L in about half of the stream sites in these predominantly agricultural watersheds (Exhibit 3-7). About 12 percent of stream sites had nitrate concentrations above the federal drinking water MCL of 10 mg/L (the slightly smaller percentage of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

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

Indicator Limitations

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

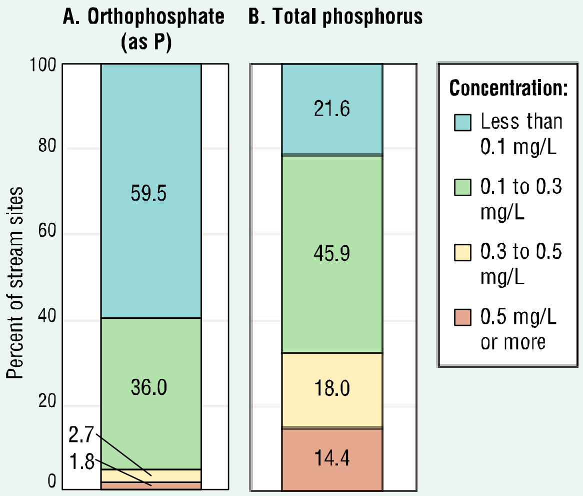
Exhibit 3-7. Nitrogen in streams in agricultural watersheds of the contiguous U.S., 1992-2001[a]



[a] **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[a]



[a] **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*

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

Data Sources

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

References

Mueller, D.K., and N.E. Spahr. 2005. Water-quality, streamflow, and ancillary data for nutrients in streams and rivers across the nation, 1992-2001: U.S. Geological Survey data series 152. <http://pubs.usgs.gov/ds/2005/152/>

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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_2 gas though the process of denitrification. Nitrogen cycling and retention is thus one of the most important functions of ecosystems (Vitousek et al., 2002). When loads of nitrogen from fertilizer, septic tanks, and atmospheric deposition exceed the capacity of terrestrial systems (including croplands), the excess may enter surface waters, where it may have "cascading" harmful effects as it moves downstream to coastal ecosystems (Galloway and Cowling, 2002). Other sources of excess nitrogen include direct discharges from storm water or treated wastewater. This indicator specifically focuses on nitrate, which is one of the most bioavailable forms of nitrogen in bodies of water.

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

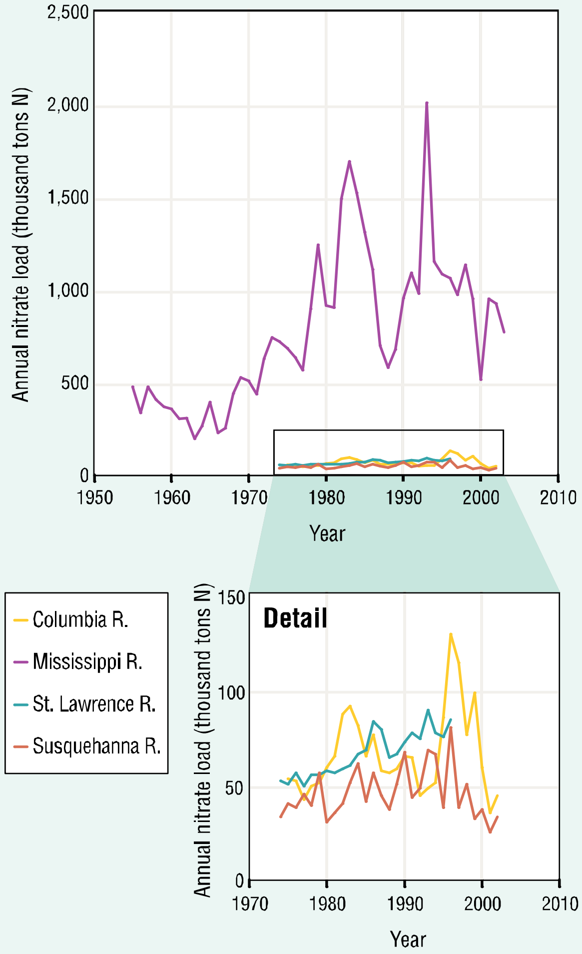
This indicator tracks trends in the discharge of nitrate and phosphorus from four of the largest rivers in the United States: the Mississippi, Columbia, St. Lawrence, and Susquehanna. While not inclusive of the entire nation, these four rivers account for approximately 55 percent of all freshwater flow 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

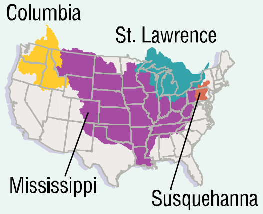
Exhibit 3-9. Nitrate discharge from four major U.S. rivers, 1955-2003[a]



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

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

Areas drained by these four rivers



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

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

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

Data Sources

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).

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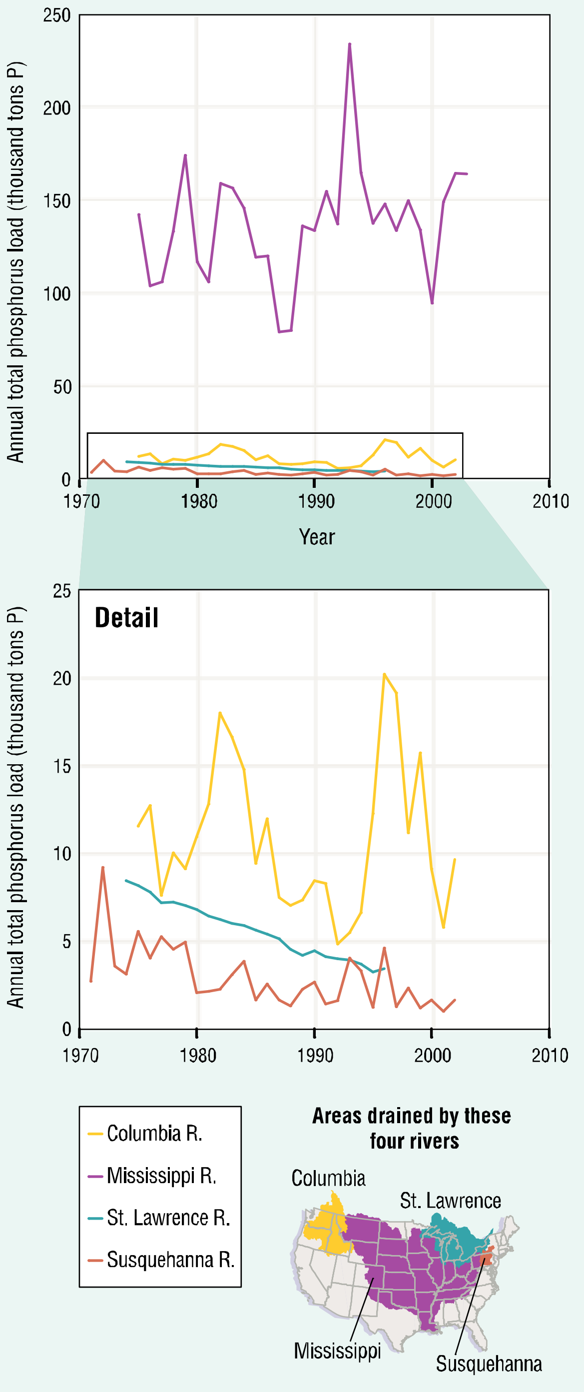
Exhibit 3-10. Total phosphorus discharge from four major U.S. rivers, 1971-2003



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

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

INDICATOR: Pesticides in Streams in Agricultural Watersheds

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

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

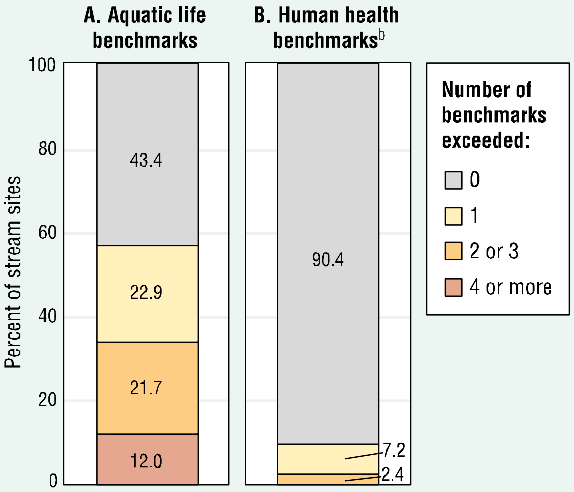
Three types of U.S. EPA standards and guidelines for drinking water were used as human health benchmarks for pesticide concentrations: Maximum Contaminant Levels (MCLs), Cancer Risk Concentrations (CRCs), and Lifetime Health Advisories (HA-Ls). All of these standards/guidelines are concentrations that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

Several types of water quality benchmarks were used for aquatic life. Where available, data were compared with EPA's acute and chronic ambient water-quality criteria for the protection of aquatic life (AWQC-ALs). The acute AWQC-AL is the highest concentration of a chemical to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. The chronic AWQC-AL is the highest concentration to which an aquatic community can be exposed *indefinitely* without resulting in an unacceptable effect. An exceedance was identified if a single sample exceeded the acute AWQC-AL or if a 4-day moving average exceeded the chronic AWQC-AL (per EPA's definition of the chronic AWQC-AL). Results were also compared with aquatic life benchmarks derived from toxicity values presented in registration and risk-assessment documents developed by EPA's Office of Pesticide Programs (OPP). These benchmarks included acute and chronic values for fish and invertebrates, acute values for vascular and nonvascular plants, and a value for aquatic community effects. An exceedance was identified if a single sample exceeded any acute benchmark or if the relevant moving average exceeded a chronic benchmark. More information about the derivation and application of aquatic life guidelines for this indicator can be found in Gilliom et al. (2006).

What the Data Show

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

Exhibit 3-11. Pesticides in streams in agricultural watersheds of the contiguous U.S., 1992-2001[a]



[a] **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.

[b] No streams exceeded 4 or more human health benchmarks.

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

Indicator Limitations

- These data represent streams draining agricultural watersheds in 36 of the study units (major river basins) sampled by the NAWQA program in the contiguous United States. While they were chosen to be representative of agricultural watersheds across the nation, they are the result of a targeted sampling design, and may not be an accurate reflection of the distribution of concentrations in all streams in the nation’s agricultural watersheds.

- This indicator does not provide information about trends over time, as the NAWQA program has completed only one full sampling cycle to date. Completion of the next round of sampling will allow trend analysis, using the data presented here as a baseline.

- Drinking water treatment can significantly reduce concentrations of many pesticides, so the levels reported in this indicator are not necessarily representative of the exposures to people when these waters are used as public drinking water supplies.

- Aquatic life benchmarks do not currently exist for 21 of the 83 pesticides and pesticide degradation products analyzed, while drinking water standards or guidelines (MCLs, CRCs, and HAs) do not exist for 36 of 83. Current standards and guidelines do not account for mixtures of pesticide chemicals and seasonal pulses of high concentrations. Possible pesticide effects on reproductive, nervous, and immune systems, as well as on chemically sensitive individuals, are not yet well understood.

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

Data Sources

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

References

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

U.S. EPA. 2006. List of drinking water contaminants and MCLs. <http://www.epa.gov/safewater/mcl.html>

USGS (U.S. Geological Survey). 2000. Pesticides in stream sediment and aquatic biota. <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 1st through 4th order in the Strahler Stream Order classification system (Strahler, 1952). Between 2000 and 2004, crews sampled 1,392 sites throughout the contiguous 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.[4] Each metric was scaled against the 5th-95th percentiles for the streams in each region to create an overall IBI, whose value ranges from 0 to 100 (Stoddard et al., 2005).

Once the overall IBI was established, a set of relatively undisturbed sites was selected in order to determine the range of IBI scores that would be expected among "least disturbed" sites. A separate reference distribution was developed for each ecoregion. Next, the IBI score for every sampled site was compared to the distribution of IBI scores among the ecoregion's reference sites. If a site's IBI score was below the 5th percentile of the regional reference distribution, the site was classified as "most disturbed." This threshold was used because it offers a high degree of confidence that the observed condition is statistically different from the "least disturbed" reference condition. Streams with an IBI score above the 25th percentile of the reference range were labeled "least disturbed," indicating a high probability that the

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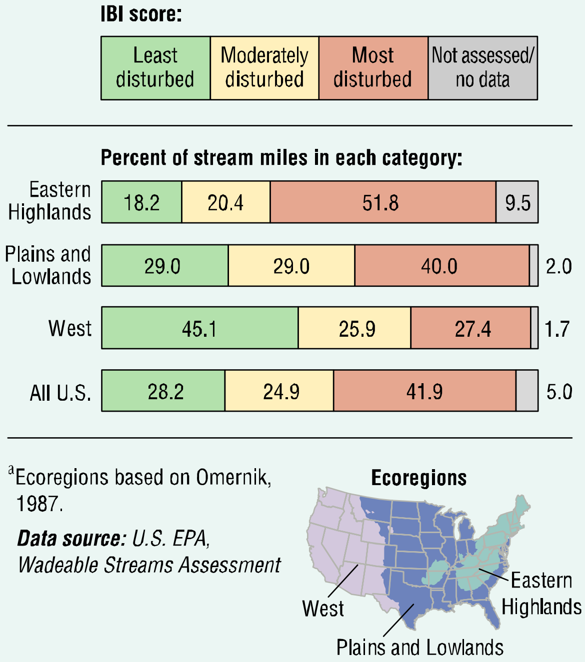
[4] For this analysis, the 48 contiguous states were divided into nine broad ecoregions. These "macro-level" ecoregions were defined by the WSA based on groupings of EPA Level III ecoregions (for a map of EPA Level III ecoregions, see http://www.epa.gov/wed/pages/ecoregions/level_iii.htm). A map of the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

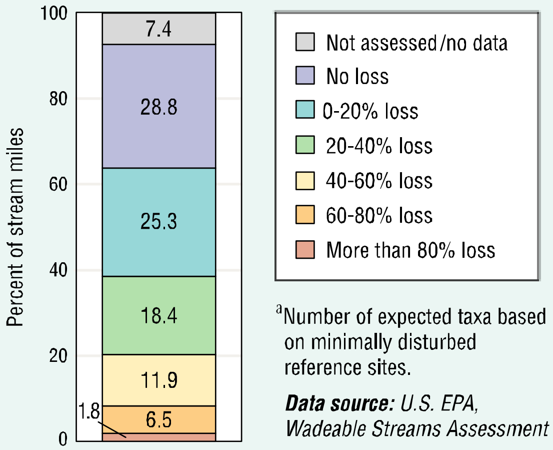
Exhibit 3-12. Index of Biological Integrity (IBI) for benthic macroinvertebrates in wadeable streams of the contiguous U.S., by ecoregion, 2000-2004[a]



[a] Ecoregions based on Omernik, 1987.

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

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[a]



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

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

site is similar to the relatively undisturbed reference sites. Streams falling between the 5th and 25th 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.

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).

Because there are no agreed-upon thresholds for the O/E model, the results are presented in 20 percent increments of taxa losses for the contiguous 48 states

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

Indicator Limitations

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

Data Sources

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

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

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3.2.3 Discussion

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

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

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

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

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

Limitations, Gaps, and Challenges

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

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

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

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

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

3.3 WHAT ARE THE TRENDS IN 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.[5] 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.[6]

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.[7]

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

[6] Ibid

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

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

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

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

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

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

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[8] 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.

[9] 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>

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

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

3.3.2 ROE Indicators

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

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

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

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[10] 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.

[11] 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.

[12] 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

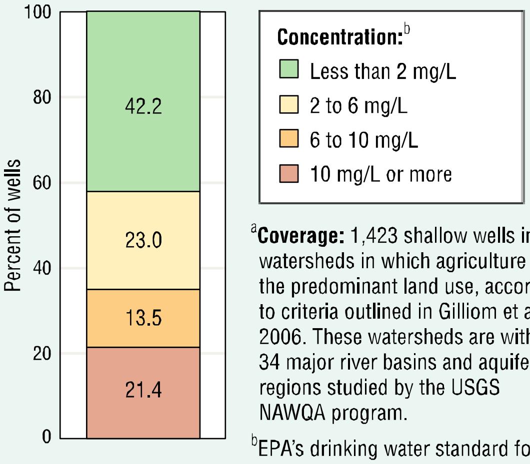
Contaminant Levels (MCLs) (as described above), Cancer Risk Concentrations (CRCs), and Lifetime Health Advisories (HA-Ls). In all three cases, the standard and guideline levels are concentrations pertaining to lifetime exposure through drinking water. The CRC is a guideline for potential carcinogens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

What the Data Show

During the 1992-2001 period:

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

Exhibit 3-14. Nitrate in shallow ground water in agricultural watersheds of the contiguous U.S., 1992-2001[a]

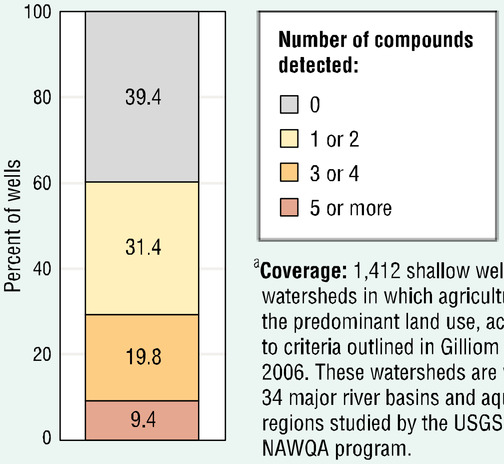


[a] **Coverage:** 1,423 shallow wells in watersheds in which agriculture is the predominant land use, according to criteria outlined in Gilliom et al., 2006. These watersheds are within 34 major river basins and aquifer regions studied by the USGS NAWQA program.

[b] 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[a, b]



[a] **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.

[b] Samples were analyzed for 75 pesticides and 8 pesticide degradation products.

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

Indicator Limitations

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

Data Sources

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

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Gilliom, R.J., J.E. Barbash, C.G. Crawford, P.A. Hamilton, J.D. Martin, N. Nakagaki, L.H. Nowell, J.C. Scott, P.E. Stackelberg, G.P. Thelin, and D.M. Wolock. 2006. Pesticides in the Nation's Streams and Ground Water, 1992–2001: U.S. Geological Survey circular 1291. <http://pubs.usgs.gov/circ/2005/1291/>

Nolan, B.T., and K.J. Hitt. 2002. Nutrients in shallow ground waters beneath relatively undeveloped areas in the conterminous United States: U.S. Geological Survey water resources investigation report 02-4289. 17 pp. <http://water.usgs.gov/nawqa/nutrients/pubs/wri02-4289/wri02-4289.pdf>

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

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

3.3.3 Discussion

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

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

Limitations, Gaps, and Challenges

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

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

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

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[13] 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.

[14] 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.

[15] 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:

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

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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>

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

3.4.1 Introduction

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

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

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

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

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

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

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[16] 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/>

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

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

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

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

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

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

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[17] 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>

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

3.4.2 ROE Indicators

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

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

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

INDICATOR: Wetland Extent, Change, and Sources of Change

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

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

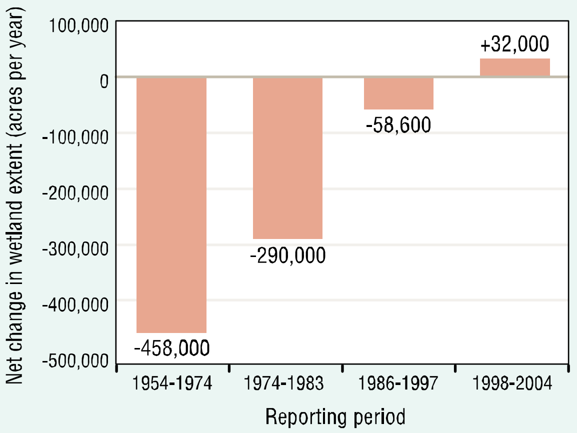
This indicator presents data from the U.S. Fish and Wildlife Service's Wetlands Status and Trends survey. Conducted approximately every 10 years, this survey provides an estimate of the extent of all wetlands in the contiguous U.S., regardless of land ownership. The Status and Trends survey uses a probabilistic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

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

What the Data Show

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

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



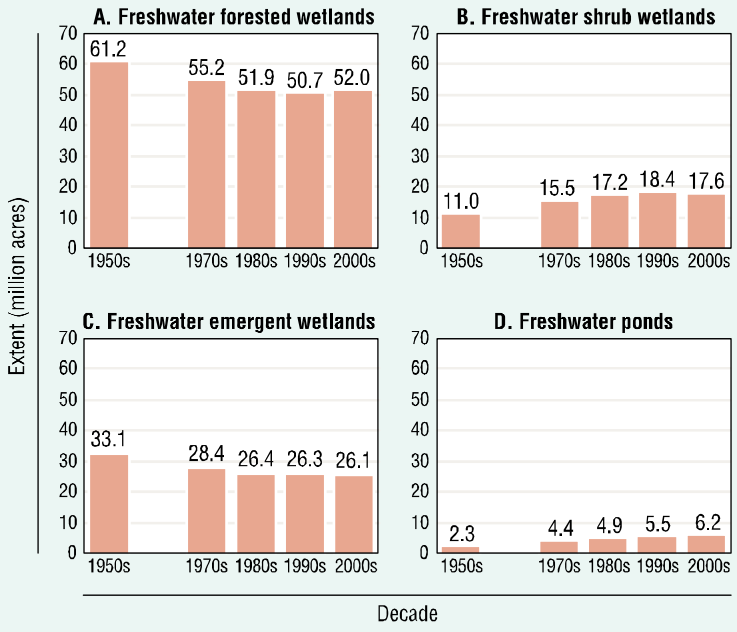
Data source: *Dahl, 2006*

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).

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

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

Exhibit 3-17. Extent of selected freshwater wetlands in the contiguous U.S., 1950s-2000s[a]

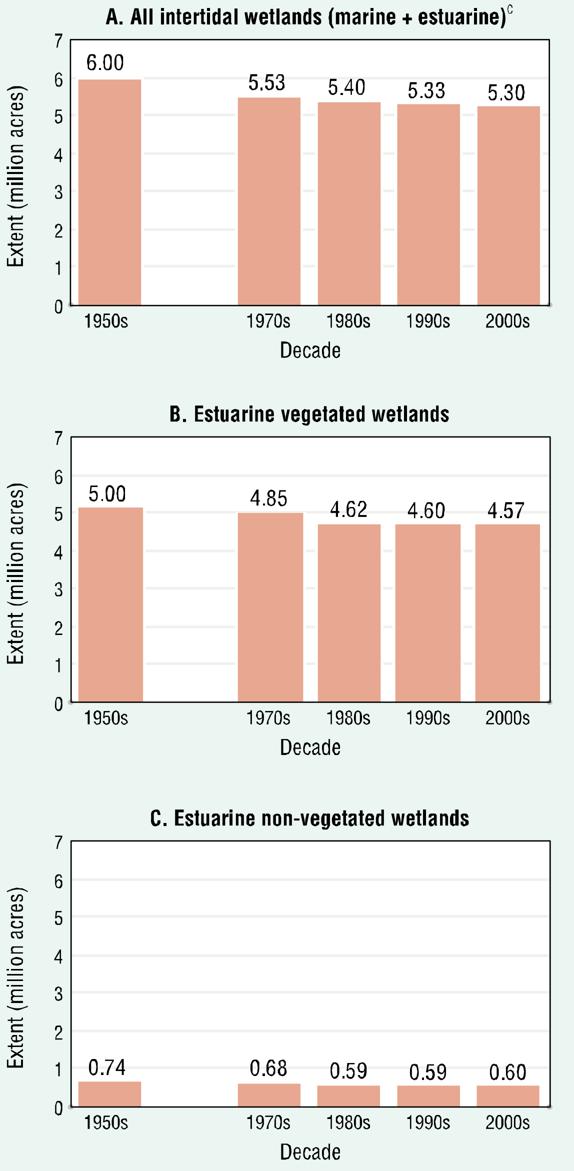


[a] Based on mid-decade surveys. No analysis was conducted for the 1960s.

Data source: *Dahl, 2006*

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

Exhibit 3-18. Extent of marine and estuarine wetlands in the contiguous U.S., 1950s-2000s[a,b]



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

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

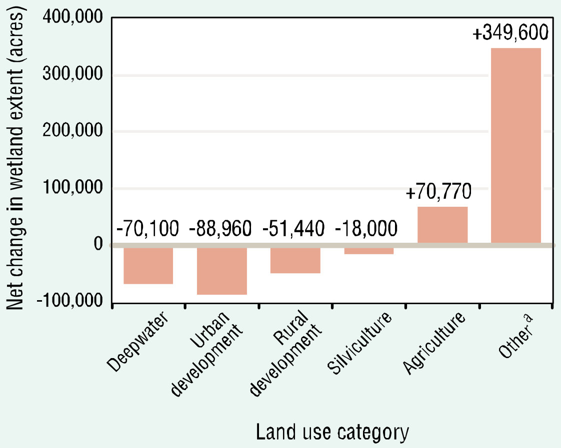
[c] Panel A is the sum of panel B, panel C, and marine wetland acreage.

Data source: *Dahl, 2006*

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



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

Data source: *Dahl, 2006*

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

Data Sources

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

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3.4.3 Discussion

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

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

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

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

Limitations, Gaps, and Challenges

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

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[18] 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/>

[19] 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>

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

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

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

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

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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[20] 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>

[21] 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>

[22] 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>

[23] 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.

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

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

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

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

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

3.5.2 ROE Indicators

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

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

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

NATIONAL INDICATORS	LOCATION
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
REGIONAL INDICATORS	**LOCATION**
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

N/R = National Indicator displayed at EPA Regional scale

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).

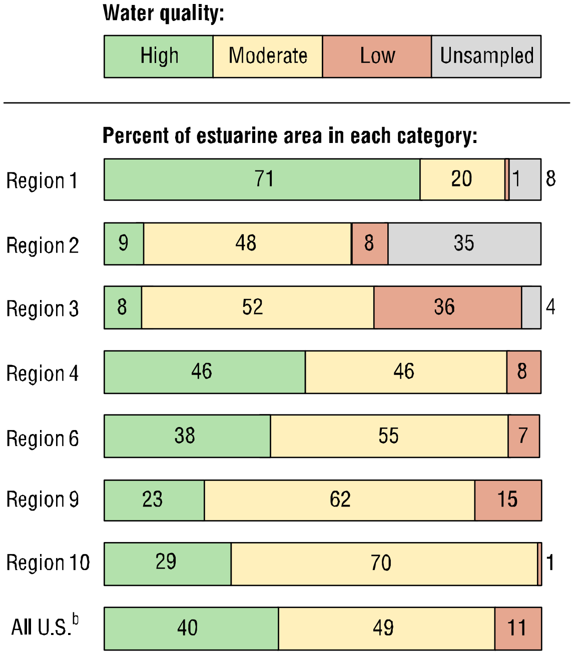
The overall water quality index is a compilation of the five components. For each site, the index is rated high if none of the five components of the index received a score that would be considered environmentally unfavorable (high nitrogen, phosphorus, or chlorophyll-*a* levels or low DO or water clarity), 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.

What the Data Show

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

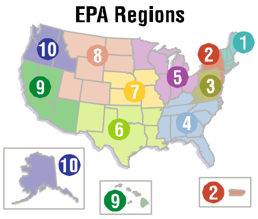
Nitrogen concentrations were low in 82 percent of estuarine area and high in 5 percent nationwide, and were low in a majority of the estuarine area in all but one EPA Region (Exhibit 3-21). Regions 2 and 3 had the largest percentage of area with high concentrations (15 percent and 16 percent, respectively);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

Exhibit 3-20. Coastal water quality index for the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a]



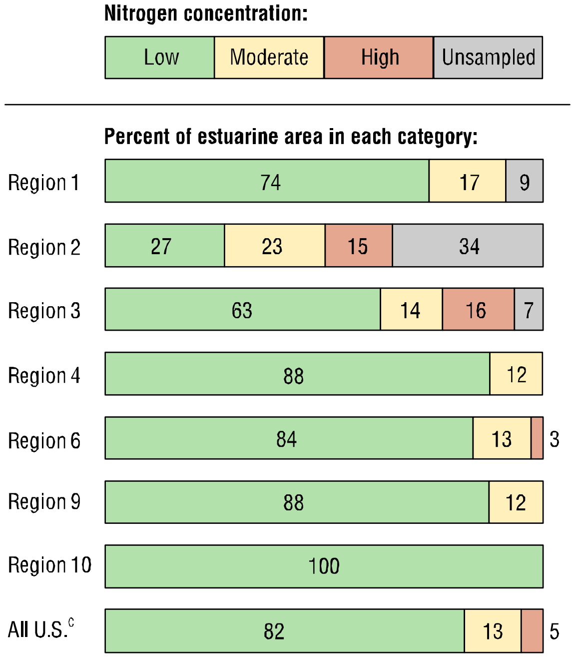
[a]**Coverage:** Estuarine waters of the contiguous 48 states and Puerto Rico. Does not include the hypoxic zone in offshore Gulf Coast waters.

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



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

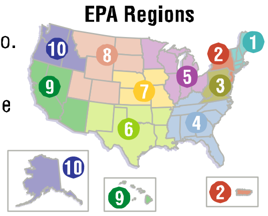
Exhibit 3-21. Nitrogen concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a, b]



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

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

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

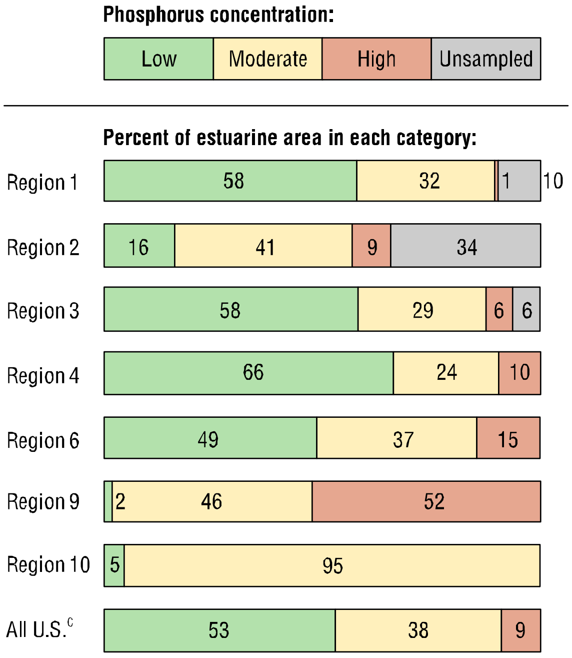


Data source: *U.S. EPA, 2004 (data modified to report by EPA Region)*

Phosphorus concentrations were low in 53 percent of estuarine area and high in 9 percent nationwide (Exhibit 3-22). Region 9 had the largest proportion of area exceeding reference conditions (52 percent), while Region 10 had the least (none).

Chlorophyll-*a* concentrations were low in 51 percent and high in 8 percent of estuarine area nationwide (Exhibit 3-23). Region 3 had the largest percentage of area exceeding reference conditions (27 percent); all other EPA Regions had 10 percent or less in this category.

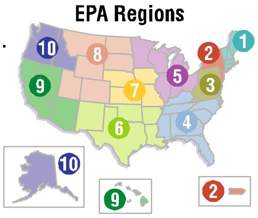
Exhibit 3-22. Phosphorus concentrations in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a, b]



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

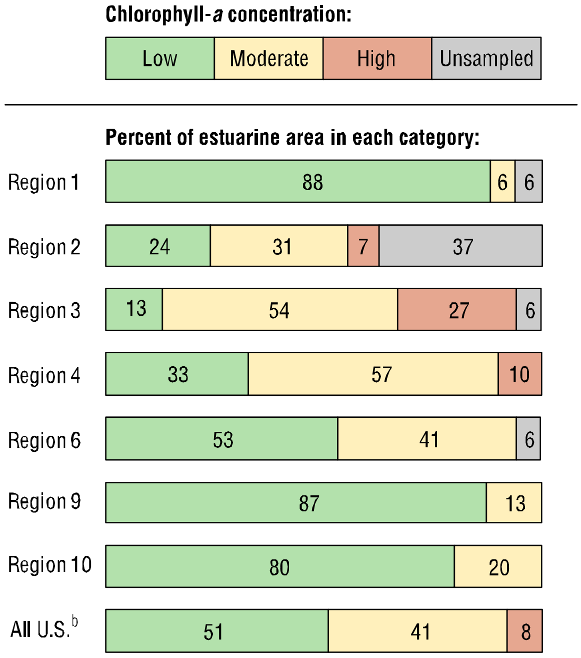
[b] This indicator measures dissolved inorganic phosphorus (DIP), which equals orthophosphate.

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



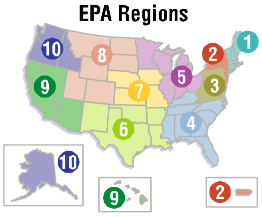
Data source: *U.S. EPA, 2004 (data modified to report by EPA Region)*

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



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

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

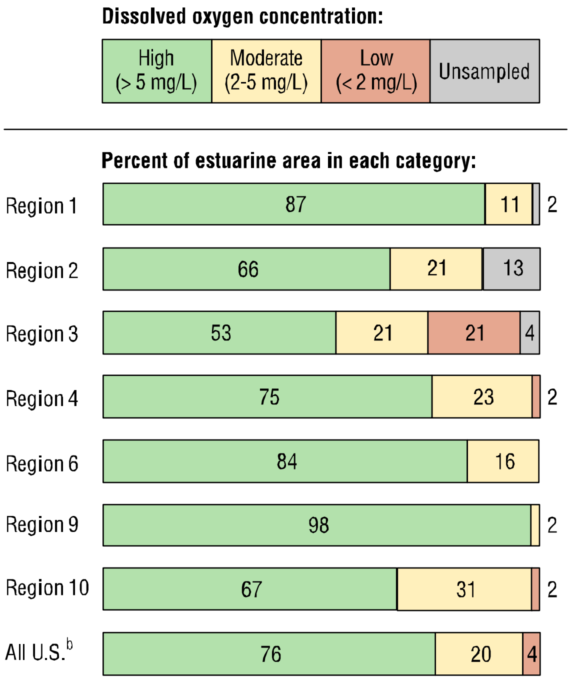


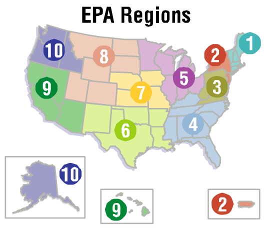
Data source: *U.S. EPA, 2004 (data modified to report by EPA Region)*

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

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

Exhibit 3-24. Dissolved oxygen levels in coastal waters of the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a]



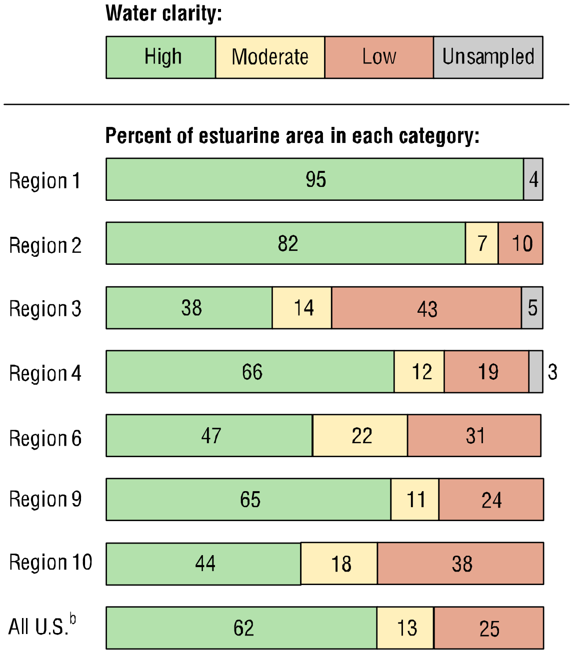


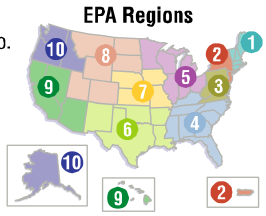
[a] **Coverage:** Bottom- or near bottom-water dissolved oxygen in estuarine waters of the contiguous 48 states and Puerto Rico. Does not include the hypoxic zone in offshore Gulf Coast waters.

[b] 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[a]





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

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

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

Indicator Limitations

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

Data Sources

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

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INDICATOR: Coastal Sediment Quality

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

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

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

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

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

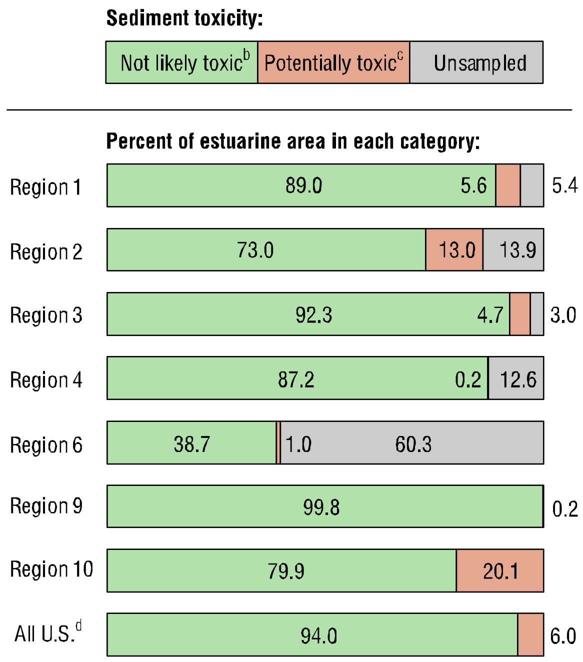
Benthic community condition also can be a useful indication of sediment quality, particularly in terms of chronic or community effects that would not be captured in an acute exposure bioassay. The NCA evaluated estuarine sites for several aspects of benthic community condition, and these results are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

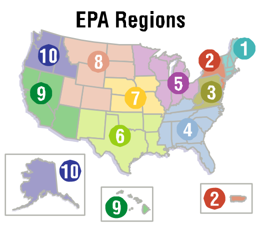
What the Data Show

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

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

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





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

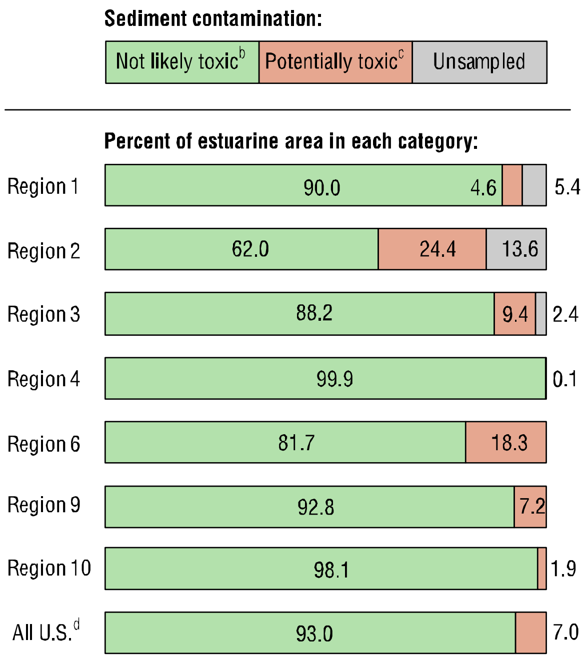
[b] **Not likely toxic:** Mortality of test species = 20% or lower

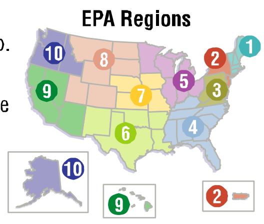
[c] **Potentially toxic:** Mortality of test species > 20%

[d] 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[a]





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

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

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

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

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

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

Indicator Limitations

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

Data Sources

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

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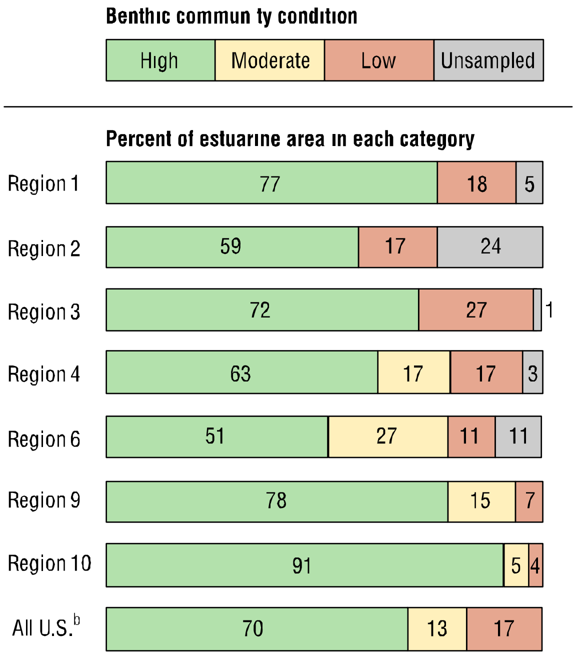
INDICATOR: Coastal Benthic Communities

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

This indicator is based on a multi-metric benthic communities index that reflects overall species diversity in estuarine areas throughout the contiguous United States (adjusted for salinity, if necessary) and, for some regions, the presence of pollution-tolerant and pollution-sensitive species (e.g., Weisberg et al., 1997; Engle and Summers, 1999; U.S. EPA, 2004). The benthic community condition at each sample site is given a high score if the index exceeds a particular threshold (e.g., has high diversity or populations of many pollution-sensitive species), a low score if it falls below the threshold conditions, and a moderate score if it falls within the threshold range. The exact structure of the index and the threshold values vary from one 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.

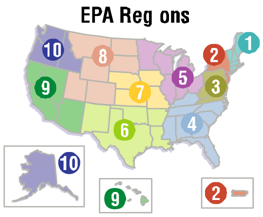
Exhibit 3-28. Coastal benthic communities index for the contiguous U.S. and Puerto Rico, by EPA Region, 1997-2000[a]



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

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

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

What the Data Show

Nationally, 70 percent of the sampled estuarine area had a high benthic communities index score, with 13 percent in the moderate range and 17 percent scoring low (Exhibit 3-28). Condition varied somewhat by EPA Region, with high index scores ranging from 51 percent of the estuarine area in Region 6 to 91 percent in Region 10. Region 3 had the largest proportion of estuarine area rated low (27 percent), while Region 10 had the lowest (4 percent). In the figure, the portion of the estuarine area not represented by the sample is noted for each Region.

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

Indicator Limitations

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

Data Sources

This indicator is based on an analysis published in EPA's National Coastal Condition Report II (U.S. EPA, 2004). Summary data by EPA Region have not been published, but were provided by EPA's National Coastal Assessment program. Underlying sampling data are housed in EPA's National Coastal 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.

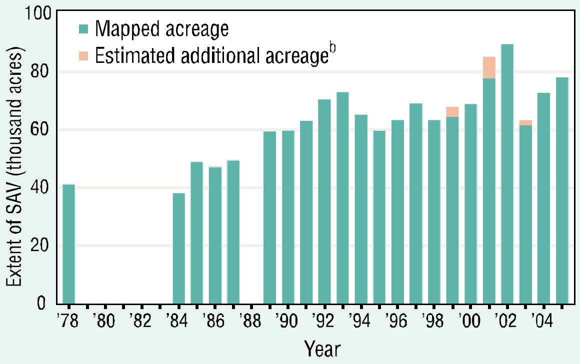
What the Data Show

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

Indicator Limitations

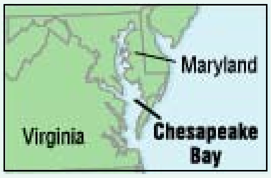
- There were no surveys in the years 1979-1983 or in 1988.
- The indicator includes some estimated data for years with incomplete photographic coverage. Spatial gaps in 1999 occurred due to the inability to reliably photograph SAV following hurricane disturbance. Spatial gaps in 2001 occurred due to flight restrictions near Washington D.C. after the September 11th terrorist attacks. Other gaps occurred in 2003 due to adverse weather in the spring, summer, and fall (Hurricane Isabel). Acreage in the non-surveyed areas was estimated based on prior years' surveys.
- Photointerpretation methods changed over the course of this study. However, data have been adjusted to account for any methodological inconsistencies.
- Extent is just one of the variables that can be used to measure the condition of SAV communities. Information on vegetation health and density would also provide useful information.

Exhibit 3-29. Extent of submerged aquatic vegetation (SAV) in the Chesapeake Bay, 1978-2005[a]



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

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



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

Data Sources

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

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VIMS. 2006. SAV distribution data archive. Virginia Institute of Marine Science. Accessed 2006. <http://www.vims.edu/bio/sav/savdata.html>

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

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

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

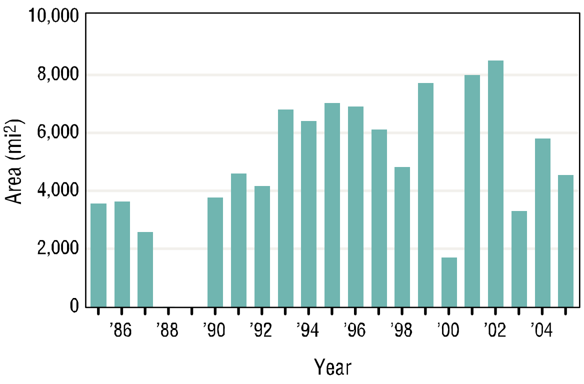
The Gulf of Mexico hypoxic zone on the Texas-Louisiana Shelf is the largest zone of coastal hypoxia in the Western Hemisphere (CAST, 1999). It exhibits seasonally low oxygen levels as a result of complicated interactions involving excess nutrients carried to the Gulf by the Mississippi and Atchafalaya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

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

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

DEP, 2006a). Sampling is performed every month from October to May and every two weeks from June to September at a set of fixed locations throughout the Sound. All Long Island Sound samples are 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[a]



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

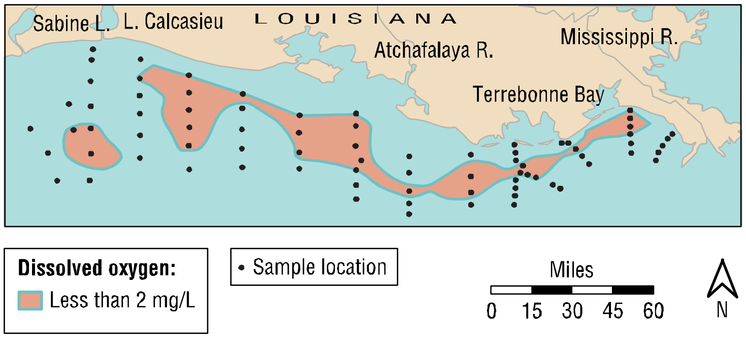
Data source: *Louisiana Universities Marine Consortium (LUMCON)*

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

Indicator Limitations

Gulf of Mexico

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

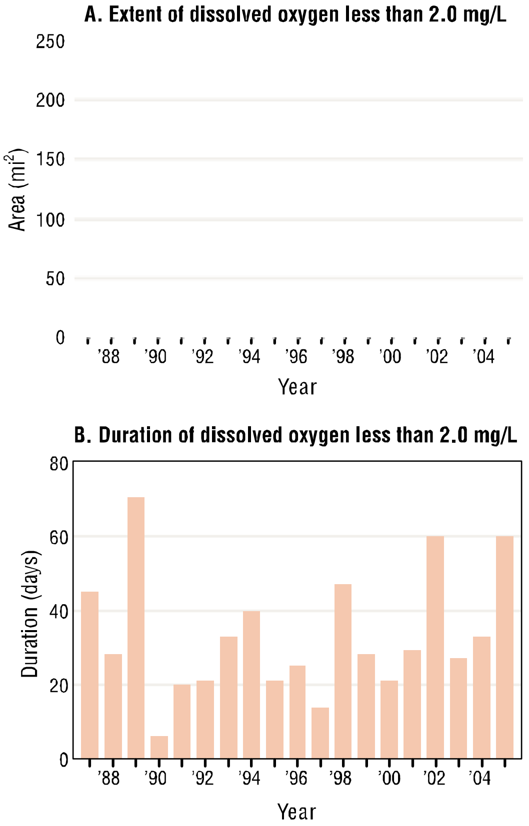
Long Island Sound

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

Data Sources

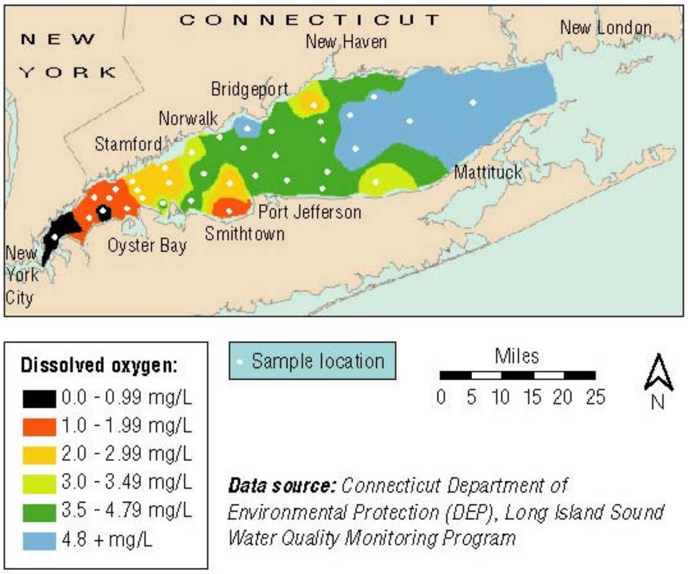
Gulf of Mexico data were provided by the Louisiana Universities Marine Consortium (LUMCON). Maps and summary data from the most recent Gulf of Mexico survey are published online (LUMCON, 2006).

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



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

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

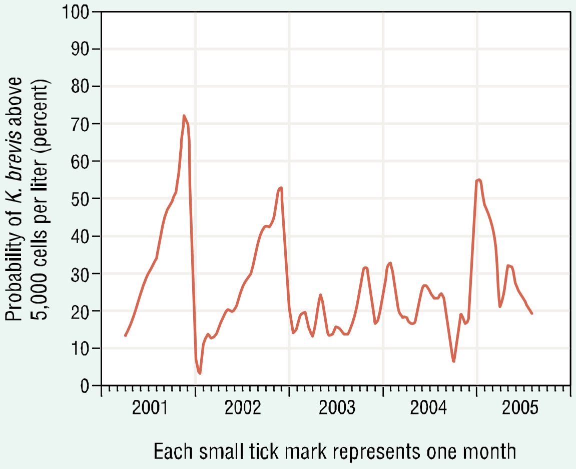
This indicator reports the occurrence of elevated *K. brevis* concentrations along Florida’s Gulf Coast, where the Florida Fish and Wildlife Research Institute (FWRI) oversees an extensive red tide monitoring network. FWRI and its partners (Mote Marine Laboratory, the University of South Florida, Collier 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 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.

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



Data source: *TBD*

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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3.5.3 Discussion

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

Extent

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

Condition

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

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

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

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

Limitations, Gaps, and Challenges

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

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

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[24] 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>

[25] 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>

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

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

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

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.[27] 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[28] (including private wells serving about 15 percent of U.S. households[29]). 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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[27] U.S. EPA. 1997. Exposure factors handbook. Volume I—general factors. EPA/600/P-95/002Fa. Washington, DC. August.

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

[29] 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>

containment wells or discharged into surface waters, as can mine waste (e.g., heavy metals) if not properly contained.

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

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

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

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

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

3.6.2 ROE Indicators

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

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

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

N/R = National Indicator displayed at EPA Regional scale

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

Community Water Systems (CWS), public water systems that supply water to the same population year-round, served over 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.

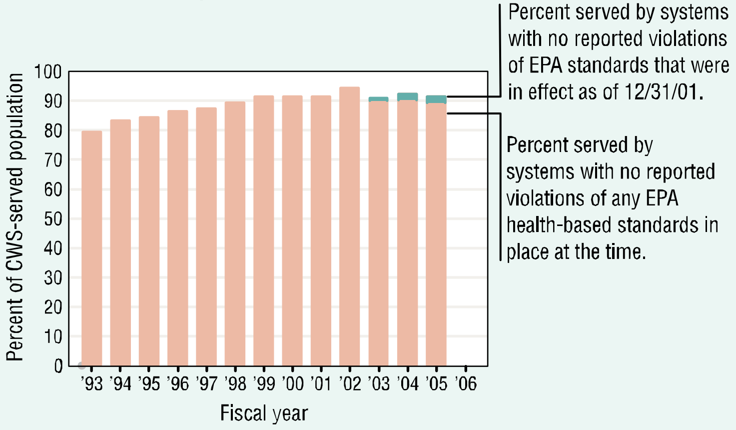
This indicator tracks the population served by CWS for which no violations were reported to EPA for the period from FY 1993 to FY 2005, the latest year for which data are available. Results are reported as a percentage of the overall population served by CWS, both nationally and by EPA Region. This indicator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

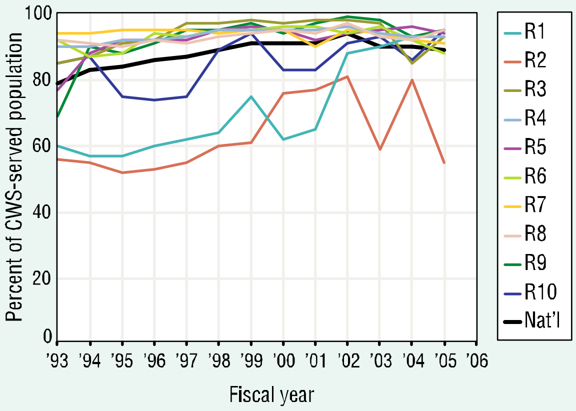


[a] **Coverage:** U.S. residents served by Community Water Systems (CWS) (approximately 95% of the total U.S. population).

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

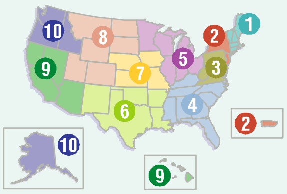
Exhibit 3-36. U.S. population served by Community Water Systems with no reported violations of EPA health-based standards, by EPA Region, fiscal years 1993-2005[a,b]



[a] **Coverage:** U.S. residents served by Community Water Systems (CWS) (approximately 95% of the total U.S. population).

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

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



EPA Regions

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

Indicator Limitations

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

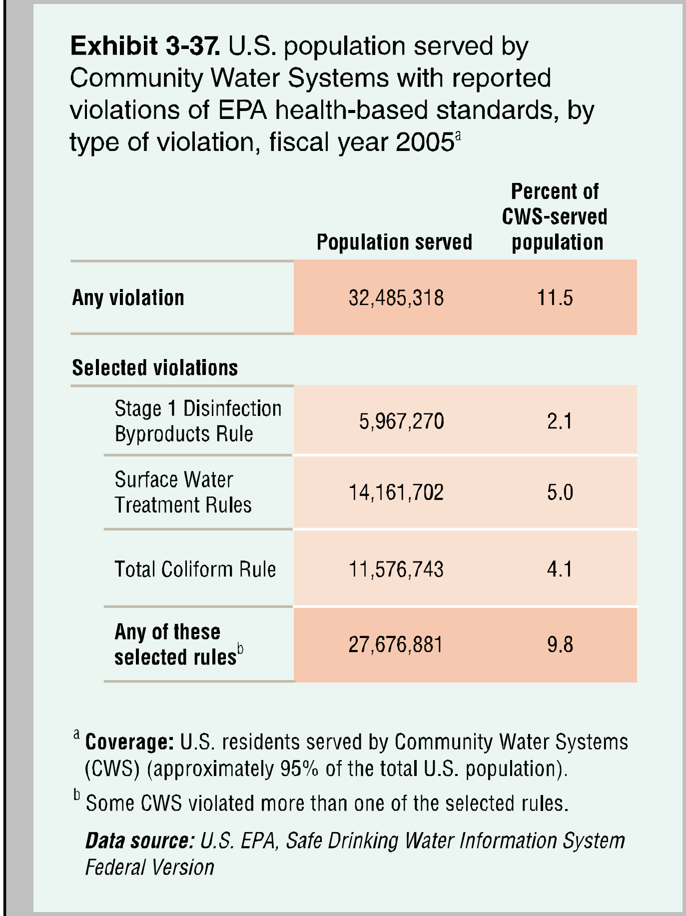


Exhibit 3-37. U.S. population served by Community Water Systems with reported violations of EPA health-based standards, by type of violation, fiscal year 2005[a]

	Population served	Percent of CWS-served population
Any violation	32,485,318	11.5
Selected violations		
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
Any of these selected rules[b]	27,676,881	9.8

[a] **Coverage:** U.S. residents served by Community Water Systems (CWS) (approximately 95% of the total U.S. population).

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

Data source: *U.S. EPA, 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.

- 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.

Data Sources

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

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U.S. EPA. 2004a. Safe Drinking Water Act 30th anniversary fact sheet: drinking water monitoring, compliance, and enforcement. <http://www.epa.gov/safewater/sdwa/30th/factsheets/monitoring_compliance.html>

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

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

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

3.6.3 Discussion

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

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

Limitations, Gaps, and Challenges

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

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

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

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

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

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

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

3.7.1 Introduction

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

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

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

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

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

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

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

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

3.7.2 ROE Indicators

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

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

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

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

3.7.3 Discussion

Limitations, Gaps, and Challenges

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

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

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

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[32]—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.[33] 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.[34] Mercury in water bodies can be methylated by certain bacteria in bottom sediments to form

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[32] 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.

[33] 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>

[34] U.S. and global sources of mercury are described in more detail in Section 2.2, which includes an indicator of domestic mercury emissions.

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

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

Other chemical contaminants that may be present in fish and shellfish include other pesticides, metals (such as arsenic), and dioxins and furans.[38]

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

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

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[35] 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>

[36] 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>

[37] National Research Council. 2000. Toxicological effects of methylmercury. Washington, DC: National Academies Press.

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

[39] 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.

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

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

3.8.2 ROE Indicators

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

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

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

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

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

[41] 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.

[42] Easton, M.D.L., D. Luszniak, and E. Von der Geest. 2002. Preliminary examination of contaminant loadings in farmed salmon, wild salmon and commercial salmon feed. Chemosphere 46(7):1053-1074.

advisories over time may reflect changes in the frequency and intensity of monitoring.[43] Thus, fish advisories cannot provide a consistent national metric for trends in the condition of consumable fish and shellfish.

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

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

N/R = National Indicator displayed at EPA Regional scale

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

INDICATOR: Coastal Fish Tissue Contaminants

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

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

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

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

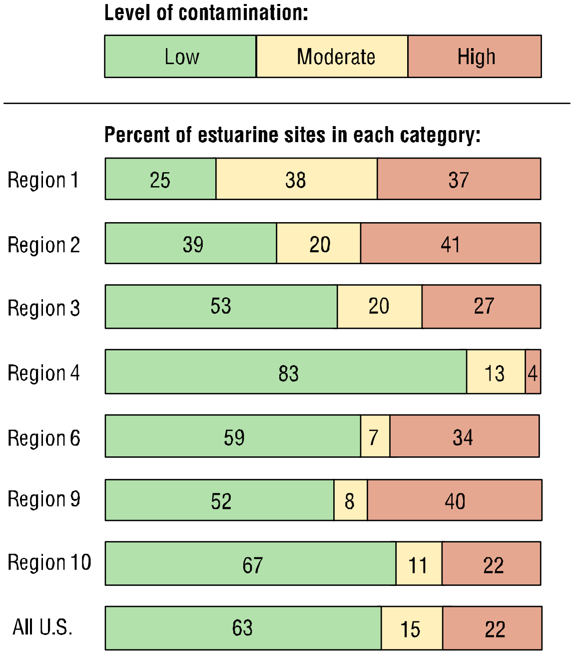
For this indicator, a site was given a high score if one or more contaminants were present at a concentration above the guideline ranges. A site was rated moderate if one or more contaminants were within the guideline ranges but none was in exceedance. Sites with all contaminants below their guideline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

What the Data Show

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

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



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

[b] 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)*

EPA Regions

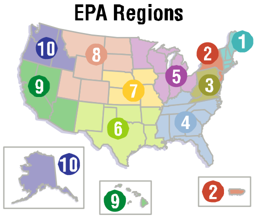


Exhibit 3-39. Coastal fish tissue contaminant concentrations in the contiguous U.S., compared with health-based guidelines, 1997-2000[a,b,c]

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

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

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

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

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

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

Indicator Limitations

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

Data Sources

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

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INDICATOR: Contaminants in Lake Fish Tissue

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

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

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

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

What the Data Show

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

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

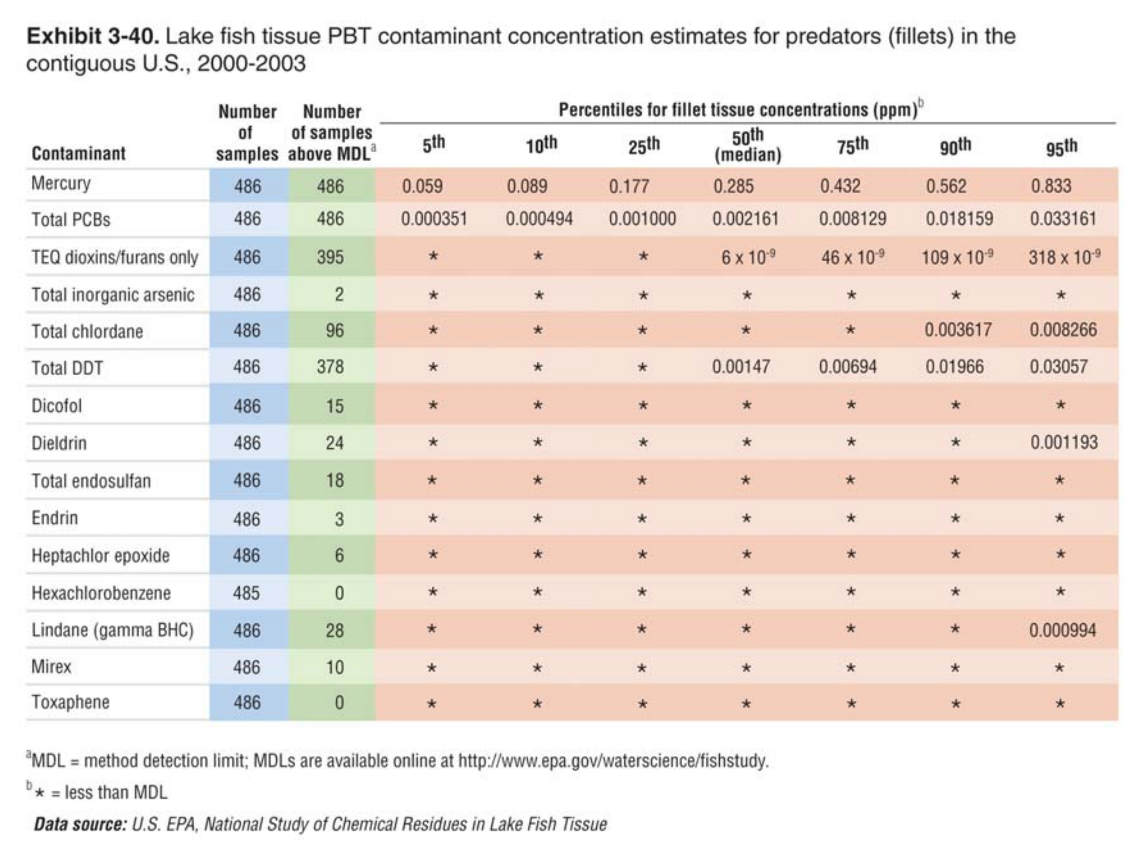

Exhibit 3-40. Lake fish tissue PBT contaminant concentration estimates for predators (fillets) in the contiguous U.S., 2000-2003

Contaminant	Number of samples	Number of samples above MDL[a]	Percentiles for fillet tissue concentrations (ppm)[b]						
			5th	10th	25th	50th (median)	75th	90th	95th
Mercury	486	486	0.059	0.089	0.177	0.285	0.432	0.562	0.833
Total PCBs	486	486	0.000351	0.000494	0.001000	0.002161	0.008129	0.018159	0.033161
TEQ dioxins/furans only	486	395	★	★	★	6×10^{-9}	46×10^{-9}	109×10^{-9}	318×10^{-9}
Total inorganic arsenic	486	2	★	★	★	★	★	★	★
Total chlordane	486	96	★	★	★	★	★	0.003617	0.008266
Total DDT	486	378	★	★	★	0.00147	0.00694	0.01966	0.03057
Dicofol	486	15	★	★	★	★	★	★	★
Dieldrin	486	24	★	★	★	★	★	★	0.001193
Total endosulfan	486	18	★	★	★	★	★	★	★
Endrin	486	3	★	★	★	★	★	★	★
Heptachlor epoxide	486	6	★	★	★	★	★	★	★
Hexachlorobenzene	485	0	★	★	★	★	★	★	★
Lindane (gamma BHC)	486	28	★	★	★	★	★	★	0.000994
Mirex	486	10	★	★	★	★	★	★	★
Toxaphene	486	0	★	★	★	★	★	★	★

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

[b] ★ = less than MDL

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

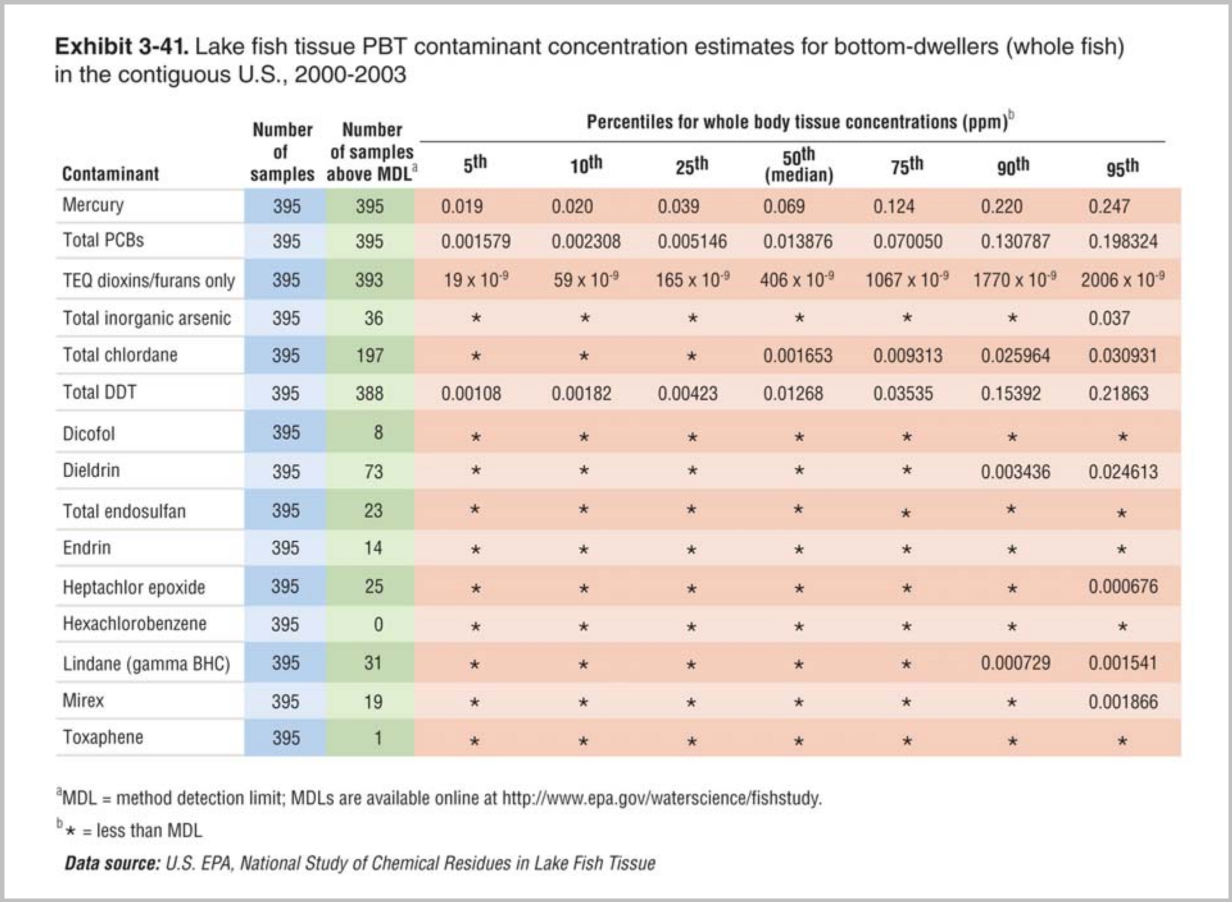

Exhibit 3-41. Lake fish tissue PBT contaminant concentration estimates for bottom-dwellers (whole fish) in the contiguous U.S., 2000-2003

Contaminant	Number of samples	Number of samples above MDL[a]	Percentiles for whole body tissue concentrations (ppm)[b] 5th	10th	25th	50th (median)	75th	90th	95th
Mercury	395	395	0.019	0.020	0.039	0.069	0.124	0.220	0.247
Total PCBs	395	395	0.001579	0.002308	0.005146	0.013876	0.070050	0.130787	0.198324
TEQ dioxins/furans only	395	393	19×10^{-9}	59×10^{-9}	165×10^{-9}	406×10^{-9}	1067×10^{-9}	1770×10^{-9}	2006×10^{-9}
Total inorganic arsenic	395	36	★	★	★	★	★	★	0.037
Total chlordane	395	197	★	★	★	0.001653	0.009313	0.025964	0.030931
Total DDT	395	388	0.00108	0.00182	0.00423	0.01268	0.03535	0.15392	0.21863
Dicofol	395	8	★	★	★	★	★	★	★
Dieldrin	395	73	★	★	★	★	★	0.003436	0.024613
Total endosulfan	395	23	★	★	★	★	★	★	★
Endrin	395	14	★	★	★	★	★	★	★
Heptachlor epoxide	395	25	★	★	★	★	★	★	0.000676
Hexachlorobenzene	395	0	★	★	★	★	★	★	★
Lindane (gamma BHC)	395	31	★	★	★	★	★	0.000729	0.001541
Mirex	395	19	★	★	★	★	★	★	0.001866
Toxaphene	395	1	★	★	★	★	★	★	★

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

[b] ★ = less than MDL

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

Indicator Limitations

- Survey data are not available for Alaska, Hawaii, and Puerto Rico.
- The Great Lakes, the Great Salt Lake, and lakes without permanent fish populations are not included in the target population.
- Because the distribution of sampling sites was based on the frequency of occurrence of lakes and reservoirs, contaminants in lakes and reservoirs in arid states (e.g., Arizona, New Mexico, and Nevada) are not well-represented.
- Due to the inaccessibility (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.
- Trend data are not yet available, as this is the first time that a national lake fish tissue survey has been conducted using a probabilistic sampling design. These data will serve as a baseline for future surveys.

Data Sources

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

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3.8.3 Discussion

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

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

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

Limitations, Gaps, and Challenges

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

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

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

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

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