Water Quality in the Nation's Streams and Aquifers—
Overview of Selected Findings, 1991–2001

U.S. Department of the Interior
U.S. Geological Survey

Circular 1265

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By Pixie A. Hamilton, Timothy L. Miller, and Donna N. Myers

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U.S. Department of the Interior
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Contents

This report accompanies the publication of the last 15 of 51 river basin and aquifer assessments by the USGS National Water-Quality Assessment (NAWQA) Program during 1991–2001. It highlights selected water-quality findings of regional and national interest through examples from river basins and aquifer systems across the Nation. Forthcoming reports in the USGS series "*The Quality of Our Nation's Waters*" will present comprehensive national syntheses of information collected in the 51 study units on pesticides in water, sediment, and fish; volatile organic compounds in major aquifers used for domestic and public supply; nutrients and trace elements in streams and ground water; and aquatic ecology. This report, summaries of the 51 water-quality assessments, and a 1999 national synthesis of information on nutrients and pesticides, are available free of charge as USGS Circulars and on the World Wide Web at *water.usgs.gov/nawqa/nawqa_sumr.html*.

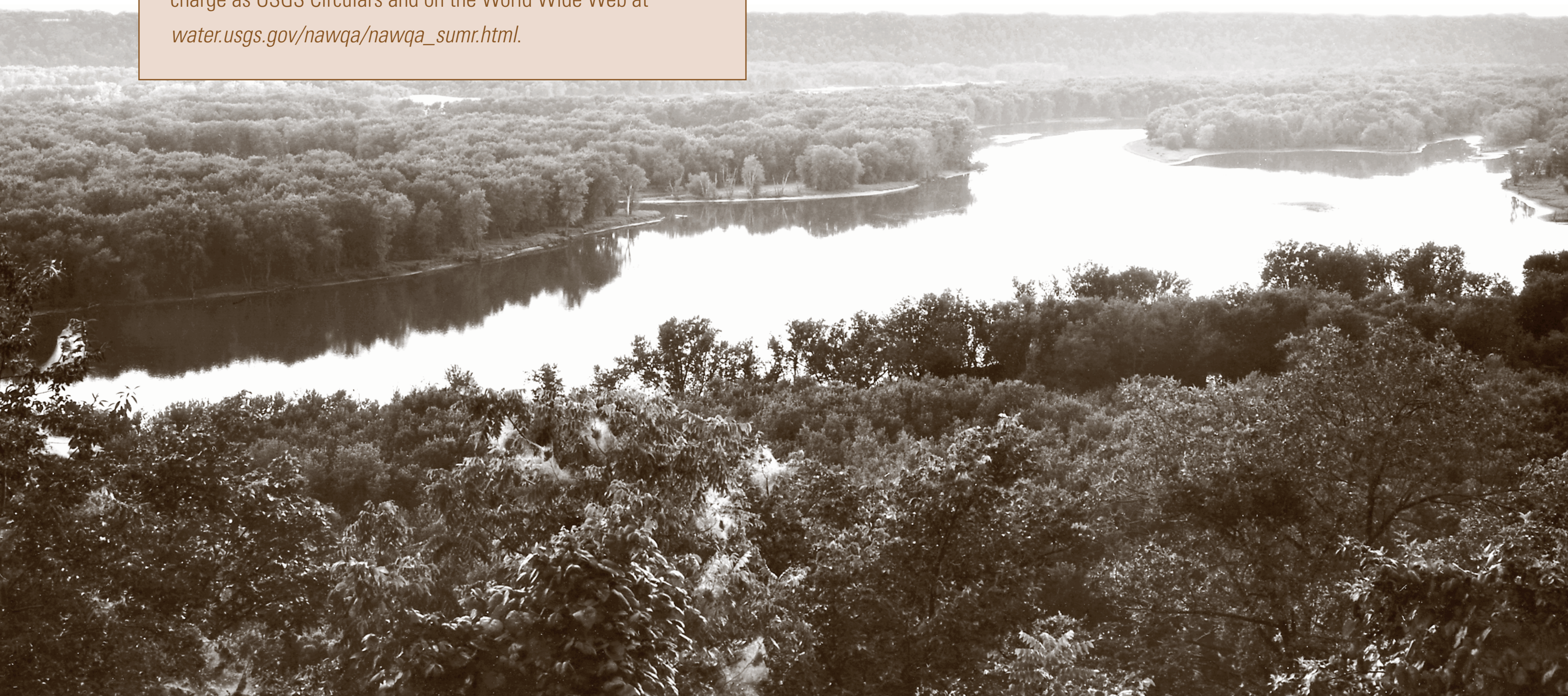

Photo by Phillip J. Redman, USGS

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The U.S. Geological Survey (USGS) serves the Nation by providing reliable and timely scientific information that helps enhance and protect our quality of life, and facilitates effective management of water, biological, energy, and mineral resources.

Photo by Phillip J. Redman, USGS

Information to Manage, Protect, and Restore Water Quality

> "The USGS provides local, State, and Federal agencies with top quality data and accurate reporting that both the farming community and the environmental community can trust. NAWQA's ability to look at water quality over the long term helps to evaluate the effectiveness of water-management decisions, conservation activities, and certain farming practices that are used to reduce sediment and runoff of agricultural nutrients and chemicals from fields."
>
> *Jeff Loser,*
> *National Leader for Clean Water Programs,*
> *USDA Natural Resources Conservation Service*

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) assesses the quality of streams, ground water, and aquatic ecosystems in major river basins and aquifer systems across the Nation (known as "study units"; see map on p. 19). These assessments characterize the ambient water resource—the source for more than 60 percent of the Nation's drinking water and water for irrigation and industry.

During its first decade (1991–2001), NAWQA completed assessments in 51 study units, which provided baseline data and information on the occurrence of pesticides, nutrients, volatile organic compounds (VOCs), trace elements, and radon in water, and on the condition of aquatic habitats and fish, insect, and algal communities. Conditions are compared to selected benchmarks, such as for drinking-water quality and the protection of aquatic organisms (see p. 18). Each assessment follows a nationally consistent study design and methodology, thereby providing information about local water-quality conditions as well as providing insight on where and when water quality varies regionally and nationally. This document contains findings of regional and national interest along with examples from the study units illustrating these findings.

During its second decade (2002–2012), NAWQA plans to reassess 42 of the 51 study units. These assessments will fill critical gaps in the characterization of water-quality conditions; determine trends at many of the monitoring sites; and build upon earlier assessments that link water-quality conditions and trends to natural and human factors (see p. 18 for more details about the NAWQA Program).

The first round of NAWQA assessments indicates that while many of our Nation's waters are suitable for most uses, contaminants from nonpoint and point sources continue to affect our streams and ground water in parts of every study unit. Findings from the 51 study units show that

- contamination of streams and ground water is widespread in agricultural and urban areas, and is characterized by complex mixtures of nutrients, trace elements, pesticides, VOCs, and their chemical breakdown products, and
- water quality and aquatic-ecosystem health are controlled by a combination of factors, including chemical use, land use, land-management practices, and natural features, such as geology, hydrology, soils, and climate.

Photo by Phillip J. Redman, USGS

Local, State, Tribal, and national stakeholders use NAWQA information to design and implement strategies for managing, protecting, and monitoring water resources in many different hydrologic and land-use settings across the Nation, such as to:

- support development of regulations, standards, and guidelines that reflect actual contaminant occurrence, including contaminant mixtures, breakdown products, seasonal patterns, and variability among different settings;
- identify key sources of nonpoint pollution in agricultural and urban areas;
- prioritize geographic areas and basins in which water resources and aquatic ecosystems are most vulnerable to contamination and where improved treatment or management can have the greatest benefits;
- improve strategies and protocols for monitoring, sampling, and analysis of all hydrologic components, including the atmosphere, surface water, ground water, and biological communities;
- contribute to State assessments of beneficial uses and impaired waters (Total Maximum Daily Loads or TMDLs), strategies for source-water protection and management, pesticide and nutrient management plans, and fish-consumption advisories; and,
- sustain the health of aquatic ecosystems through improved stream protection and restoration management.

"Data from the NAWQA Program supplied critical information for Ohio EPA's Total Maximum Daily Load (TMDL) effort in the Stillwater River Basin, and will continue to provide valuable data for future TMDLs in other sub-basins of the Great Miami River. Additionally, the NAWQA study has helped further our understanding of linkages between nutrients, land use, and impairment of aquatic life."

Robert Miltner,
Aquatic Ecologist,
Ohio Environmental Protection Agency

"Properly balancing competing water-resource demands while conserving our significant fish and wildlife resources for future generations is one of the most critical environmental management issues facing the Service today. The NAWQA Program provides an objective scientific foundation to assist resource agencies charged with making difficult management decisions. It synthesizes surface-water, ground-water, and biological data in an accessible and understandable way for a wide variety of readers."

Larry E. Goldman,
Field Supervisor,
U.S. Fish and Wildlife Service

"The New England Coastal Basins NAWQA study has been very valuable to the U.S. Environmental Protection Agency's New England regional water programs. The study has provided contaminated sediment data, which will be incorporated into our National and regional sediment inventories; has highlighted the importance of arsenic in drinking water wells in New England; and has established relationships between land use and environmental quality of rivers and streams, including flow, nutrient status, and biological communities. The data from, and the monitoring approaches of, the study will help the USEPA in its monitoring and regulatory roles."

Matthew Liebman,
Environmental Biologist,
U.S. Environmental Protection Agency-
New England

"The NAWQA Program has filled a tremendous void in the pesticide data that the State of Alabama must acquire in the development of the USEPA-mandated State Pesticide Management Plan… The NAWQA data are used to make important determinations and the plan can target the areas of greatest importance."

Tony Cofer,
Program Director—
Pesticide Division,
Alabama Department of Agriculture and Industries

Photo by Dennis K. Demcheck, USGS

Water Quality and Its Connection to Land Use — *Agricultural and Urban Sources of Nonpoint Pollution*

NAWQA studies indicate that contaminants are widespread, albeit often at low concentrations, in river basins and aquifer systems across a wide range of landscapes and land uses. In the mostly agricultural Lower Tennessee River Basin, for example, 52 different pesticides were detected in streams and rivers, and VOCs were detected in about 67 percent of sampled springs and wells that tap underlying carbonate aquifers. Nationally, at least one pesticide was found in about 94 percent of water samples and in 90 percent of fish samples from streams, and in about 55 percent of shallow wells sampled in agricultural and urban areas.

The type and concentrations of contaminants that are found in urban and agricultural water resources are closely related to the chemicals that are used (such as fertilizers and pesticides) or that are released with waste products (such as sewage or manure). For example, phosphorus and many insecticides, such as diazinon, carbaryl, chlorpyrifos, and malathion, were detected more frequently and usually at higher concentrations in urban streams than in agricultural streams (see **Thornton Creek near Seattle, Washington** example). Nationally, at least one pesticide guideline established to protect aquatic life was exceeded in nearly all (about 93 percent) of the urban streams sampled.

Nitrogen and many herbicides—most commonly atrazine and its breakdown product deethylatrazine (DEA), metolachlor, alachlor, and cyanazine—generally were detected more frequently and usually at higher concentrations in streams and shallow ground water in agricultural areas than in urban areas. Occurrence is linked to use; these herbicides rank in the top five used for agriculture. Concentrations of nitrate exceeded the U.S. Environmental Protection Agency (USEPA) drinking-water standard of 10 milligrams per liter in samples collected from about 20 percent of shallow wells in agricultural areas (versus about 3 percent in urban areas).

VOCs were detected frequently in shallow ground water beneath urban areas (in about 90 percent of monitoring wells sampled) and less frequently in shallow ground water beneath agricultural areas (in 20 percent of monitoring wells). Some of the most common VOCs in urban areas, such as in the Delaware River Basin, were the solvents trichloroethene (TCE), tetrachloroethene (PCE), 1,1,1-trichloroethane (TCA), and trichloromethane (also known as chloroform), which is also a disinfection by-product of water treatment; and the gasoline-related compounds benzene, toluene, xylene, and methyl *tert*-butyl ether (MTBE).

New pesticides, VOCs, and other synthetic chemicals are introduced into the environment every year as products are approved for agricultural or urban use. USGS has expanded its laboratory methods to analyze for these “emerging” contaminants, testing new methods in areas where their use is the greatest (see **southern Louisiana** example).

Implications

Reducing chemical use and improving disposal practices can help reduce contaminant concentrations in both urban and agricultural settings. More information about chemical use—data that are virtually unavailable in urban areas—is critical to linking contaminants to their sources, thus helping individuals, businesses, and industry as well as local, State, and Federal governments to improve water quality.

Insecticides are frequently detected in the urban stream **Thornton Creek near Seattle, Washington**

Insecticides in Thornton Creek, which drains urban areas in King County outside of Seattle, were typical of those detected in urban streams across the Nation. Diazinon, carbaryl, chlorpyrifos, and malathion were frequently detected; diazinon concentrations exceeded the guideline established to protect aquatic life in 20 percent of the samples from Thornton Creek. These pesticide detections are strongly related to pesticide use. For example, diazinon is the number one insecticide sold to King County residents. (King County provided data on pesticide sales in 10 large home and garden stores.) Moreover, in a USGS study done with Washington State Department of Ecology and King County, 23 of 98 pesticides were detected in King County urban streams—homeowner use was identified as the probable source of diazinon and the herbicide 2,4-D. Almost half of the pesticides detected, however, had no known or identified retail sales, indicating other possible sources such as applications in commercial areas, along road rights-of-way, and in parks and recreational areas (USGS Circular 1216).

Photo by Sandra Embrey, USGS

Fipronil is widely detected in **southern Louisiana** streams

Fipronil was licensed for use in 1996 as a replacement for carbofuran to control organisms such as fleas, termites, water weevils, and fire ants. Its use became widespread in Louisiana in 1999, particularly on rice fields in the Mermentau River Basin. Fipronil was detected in about 72 percent of water samples from agricultural streams in the Mermentau River Basin. Concentrations of fipronil reached a maximum of 6.41 micrograms per liter and exceeded Total Maximum Daily Load (TMDL) numeric freshwater targets at 17 sites (U.S. Environmental Protection Agency, 2002). Fipronil and some of its breakdown products, particularly fipronil sulfone and fipronil sulfide, are of concern because of their possible effects on crawfish and other aquatic life (USGS Circular 1232).

> "The Acadian-Pontchartrain Drainages NAWQA program has contributed valuable information to the U.S. EPA's Office of Pesticide Programs' (OPP) understanding of the occurrence of pesticides in ground and surface water in one of the Nation's major rice and sugarcane production areas. As a reliable source of comprehensive information, results from the USGS study unit have been used in pesticide exposure and risk assessments. The OPP has found the data useful in understanding the relationship between land use (e.g., agriculture) and the frequency and levels of pesticide detections in water."
>
> *Sid Abel, Environmental Fate and Effects Division,*
> *Office of Pesticide Programs,*
> *U.S. Environmental Protection Agency*

Photo by Phillip J. Redman, USGS

Effects of Natural Features and Land-Management Practices

Implications

A better understanding of natural features controlling the occurrence and movement of contaminants allows water-resource managers to identify streams and aquifers most vulnerable to contamination. Because vulnerability to contamination can differ from place to place, a national strategy for managing nonpoint source pollution should consider local and regional differences in natural features.

The effects of natural features, such as geology, climate, hydrology, and soils, on the transport of chemicals from land to water often result in different contaminant concentrations among basins that have similar land-use settings and chemical use. For example, ground water is vulnerable to nitrate contamination in well-drained areas with permeable soils that are underlain by sand and gravel, such as in the Platte River Valley in Colorado and Nebraska, or in karst (fractured carbonate rocks) in parts of Florida and the Susquehanna and Potomac River Basins in Pennsylvania, Maryland, and Virginia.

In contrast, streams are most vulnerable to contamination in basins with poorly drained clay soils, steep slopes, or where sparse vegetation does not slow runoff. Streams also are vulnerable in agricultural areas where tile drains and ditches quickly transport runoff from fields to streams, such as in the Eastern Iowa Basins and the White River Basin in Indiana. Stream hydrology and basin characteristics also affect contaminant movement. Small streams respond quickly to rainfall or irrigation and, therefore, contaminants usually peak at higher concentrations, and these peaks rise and fall more quickly than in larger rivers. In large rivers, peak concentrations of contaminants generally are lower than in small streams because of dilution; however, concentrations remain moderate in large rivers for longer periods (see **Mississippi River** example).

A comparison of findings in the NAWQA study units shows that water-quality conditions are similar over large regions that have similar natural features and land-management practices. For example, throughout much of the Upper Midwest, ground water underlying intensive agriculture generally has low concentrations of agricultural chemicals where the water is protected by low-permeability soils and glacial till. As demonstrated in the White River Basin, local hotspots of contamination occur where ancient glacial streams deposited sand and gravel, which enable rapid infiltration and downward movement of water and chemicals. In parts of the Southeast, streams and ground water contain low concentrations of nitrate, in part because the high organic content of the soils and aquifers favors the conversion of nitrate into nitrogen gas (denitrification). In contrast, concentrations of nitrate are relatively high in streams and shallow ground water in the Central Valley of California and parts of the Northwest, Great Plains, and Mid-Atlantic regions where permeable, well-drained soils having a lower organic content favor rapid transport of water and chemicals and limited denitrification.

Geology, soils, and climate can affect concentrations of constituents that occur naturally in water, such as dissolved solids, nutrients, radon, and trace elements (see **Yellowstone River Basin** example). For example, phosphatic limestone deposits are a major source of phosphorus in the Duck and Elk Rivers draining the Lower Tennessee River Basin; concentrations of phosphorus in these rivers were in the upper 10 percent of the concentrations in 473 streams and rivers sampled nationwide even though phosphorus from point and nonpoint sources in these basins is relatively low. Radon, a radioactive gas that forms in rocks and soils through the decay of uranium, is often present in ground water, in large part depending on rock characteristics. For example, the median concentration of radon in wells tapping the Edwards-Trinity aquifers beneath parts of central Texas was relatively low at 170 picocuries per liter (pCi/L), whereas the median concentration in wells tapping the crystalline-rock aquifers underlying New York and New England was 2,200 pCi/L (which exceeds the USEPA proposed drinking-water standard of 300 pCi/L). Arsenic, a mineral present in certain rocks and soils, also is naturally elevated in ground water in parts of the Nation, and generally highest in the West and parts of the Midwest and Northeast (Welch and others, 2000).

Contamination extends deep in the ground-water system underlying the **Island of Oahu, Hawaii**

The deep volcanic-rock aquifer in central Oahu and Honolulu supplies more than 90 percent of the island's public-water supply and is a designated Sole Source Drinking-Water Aquifer. The aquifer is highly permeable and unconfined except near the coast, and is vulnerable to contamination despite the deep water table (100-1,000 feet deep). Solvents were detected in the drinking-water aquifer throughout central Oahu, with highest concentrations beneath urban areas and military installations. Fumigants, herbicides, and elevated nutrients were prevalent in ground water beneath central Oahu agricultural lands. Concentrations of only a few contaminants, however, exceeded Federal and State drinking-water standards. To the southeast in urban Honolulu, few contaminants were detected in drinking-water wells due to a century of urban planning and watershed protection that has directed intensive chemical use and storage away from upland recharge areas of Honolulu (USGS Circular 1239).

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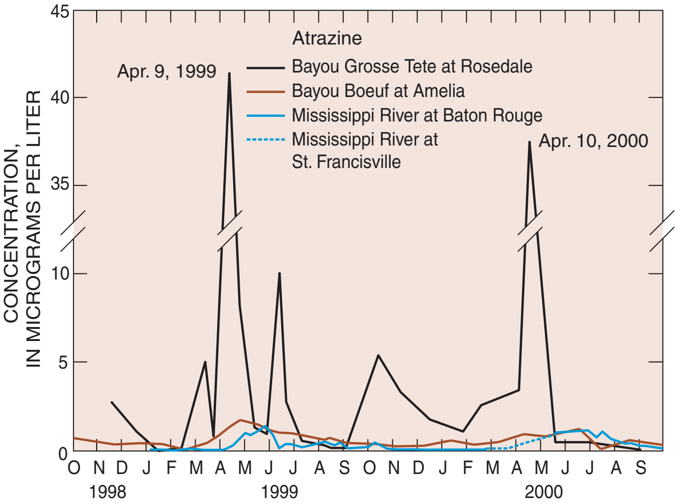
Mississippi River hydrology affects atrazine concentrations in Louisiana's streams and rivers

Atrazine concentrations in streams and rivers in the Acadian-Pontchartrain Drainages in Louisiana are affected by hydrology. In the Mississippi River at Baton Rouge, which receives runoff (referred to as the "spring flush") from agricultural areas throughout the Midwest, atrazine concentrations peaked during May and June 1999 and 2000. Atrazine concentrations peaked earlier (in April 1999 and 2000) and were much higher in Bayou Grosse Tete at Rosedale, a relatively small and hydrologically isolated system dominated by local inputs from urban and agricultural lands in the Terrebonne Basin. Peak atrazine concentrations in Bayou Boeuf at Amelia are of longer duration than in the other two systems because the bayou receives water from Mississippi River by way of the Atchafalaya River and water draining nearby sugarcane fields, and because of tide-induced backwater effects (USGS Circular 1232).



Atrazine concentrations were as much as 10 times higher and increased more rapidly in the relatively small Bayou Grosse Tete than in the larger Mississippi River and in Bayou Boeuf that receive water from multiple sources.

Naturally occurring contaminants are elevated in **Yellowstone River Basin** streams

Geology and climate affect concentrations of dissolved solids, nutrients, and trace elements in streams in the Yellowstone River Basin. Naturally occurring phosphorus in igneous and marine sedimentary rocks results in high concentrations of phosphorus in water at some sites in the Yellowstone River; average concentrations of total phosphorus (adjusted for flow) ranged up to 2.1 milligrams per liter, which is more than 20 times the USEPA goal for minimizing nuisance plant growth. In the Yellowstone River at Corwin Springs, Montana (see photo), near the relatively pristine headwaters, the average concentration of ammonia (also adjusted for flow) was 0.04 milligrams per liter as nitrogen, which was about twice that in streams sampled by NAWQA in other undeveloped areas across the Nation. Elevated ammonia at Corwin Springs most likely results from organic-rich sedimentary rocks in contact with high-temperature geothermal waters that flow into the river. Arsenic, also present in geothermal waters, was elevated in the Yellowstone River at Corwin Springs; concentrations in 78 percent of samples exceeded the USEPA drinking-water standard of 10 micrograms per liter (USGS Circular 1234).

Photo by Gregory K. Boughton, USGS

Complex Contaminant Patterns — *Mixtures, Breakdown Products, and Seasonality*

NAWQA studies show that although the concentrations of many contaminants in streams and ground water often do not exceed USEPA drinking-water standards, the risk to human and aquatic health is unclear for several reasons. In almost all 51 study units, contaminant exposure varies with the seasons, with long periods of low or non-detectable concentrations punctuated by brief periods of much higher concentrations. Seasonal patterns in concentrations of pesticides and nutrients are related primarily to the timing and amount of chemical use, the frequency and magnitude of runoff from rainstorms or snowmelt, and land-management practices such as soil tillage, irrigation, and the use of tile drains. Concentrations in agricultural streams are generally highest during runoff following chemical applications (see **Lake Erie-Lake St. Clair Drainages** example). Water temperature can have a significant effect on seasonal VOC concentrations, as shown in Deer Creek in the Pittsburgh area, where VOCs were detected in samples collected in February, November, and December, but not in samples collected in July, August, and September. VOCs are more likely to be stable and detectable in cold water because warm temperatures can cause VOCs to volatilize.

Individual compounds seldom occur alone—streams and ground water in basins with significant agriculture or urban development almost always contain mixtures of VOCs, nutrients, pesticides, and their chemical breakdown products (Squillace and others, 2002). In Oahu, for example, combinations of VOCs and pesticides were detected in 53 percent of sampled public-supply wells, and some individual samples contained as many as 10 herbicide compounds. Nationally, about 15 percent of samples collected from urban streams contained at least 10 VOCs. Similarly, about 23 percent of urban stream samples contained 10 or more pesticides. Possible cumulative effects on human and aquatic health from low concentrations of multiple compounds are unknown.

Breakdown products frequently are as common in the environment as parent compounds (see **Eastern Iowa Basin** example). Ground-water samples collected on the Delmarva Peninsula, for example, contained breakdown products of the pesticides alachlor and metolachlor at median concentrations generally higher than 0.1 micrograms per liter, whereas median concentrations of their parent compounds were about 10 times lower. Atrazine, the most heavily used herbicide in the Nation, and its breakdown product deethylatrazine (DEA), were found together in about 75 percent of stream samples and about 40 percent of ground-water samples collected in agricultural areas across the Nation. DDT was detected in whole fish collected from about 30 percent of agricultural stream sites, whereas its stable breakdown products DDE and DDD were detected in fish at up to 90 percent (for DDE) of agricultural sites. Standards or guidelines to protect human health or aquatic life have not been established for breakdown products, yet they can be as toxic, or even more toxic, than parent compounds.

Implications

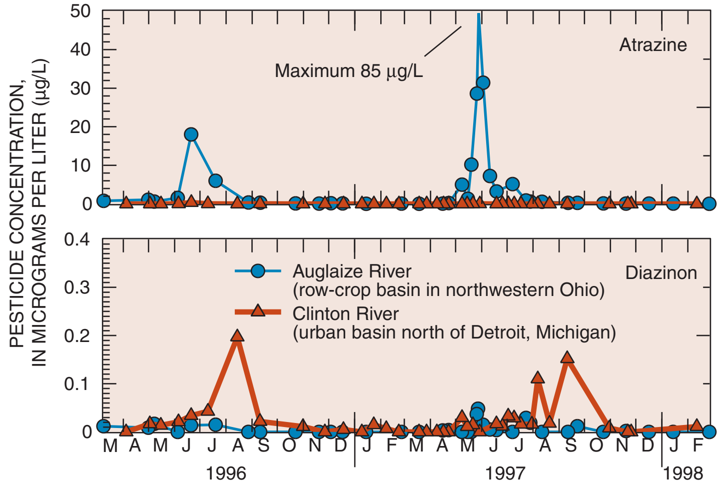
Effective water-resource management and watershed protection may require monitoring programs that analyze samples for breakdown products and multiple compounds, and that evaluate patterns related to seasons and storms when peak contaminant concentrations could possibly affect drinking-water supplies and critical life stages of aquatic organisms.

"The California State Water Resources Control Board has worked closely with the U.S. Geological Survey to develop a comprehensive monitoring and assessment program for California's groundwater basins. The approach, methods, and results from NAWQA studies have been fully integrated into California's plans to evaluate ground-water quality on a statewide basis."

Arthur G. Baggett, Jr.,
Chair, State Water Resources
Control Board

Seasonal patterns of contamination are related to chemical use, land use, and precipitation in the **Lake Erie-Lake St. Clair Drainages**

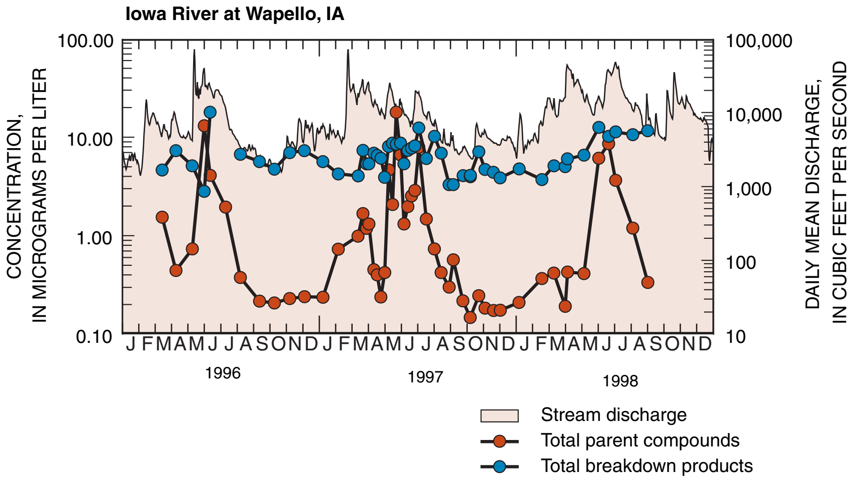
Concentrations of the pesticides prometon and diazinon typically increased in streams draining urban areas in the Lake Erie-Lake St. Clair Drainages (Ohio, Michigan, Indiana, Pennsylvania, and New York) following summertime applications. Herbicides such as atrazine, metolachlor, cyanazine, and acetochlor were elevated in streams draining row-crop agriculture in the Lake Erie-Lake St. Clair Drainages for 4 to 6 weeks after rainfall and runoff in the spring and early summer (USGS Circular 1203). Elevated concentrations of herbicides and nutrients during spring runoff following agricultural applications were typical of streams that drain much of the farmland in the Midwest. Different seasonal patterns, however, were noted in other agricultural areas. For example, concentrations of diazinon in streams in the San Joaquin-Tulare Basins were highest during winter because of high rainfall and use of sprays on dormant orchards (USGS Circular 1159).



Elevated concentrations of herbicides during spring runoff following agricultural applications were typical of streams that drain much of the farmland in the Midwest.

Most pesticide compounds in **Eastern Iowa Basin** streams are breakdown products

Breakdown products were some of the most frequently detected pesticide compounds in streams in the Eastern Iowa Basin in Iowa. On average, nearly 85 percent of the total amount of pesticides in stream samples was composed of 10 breakdown products of the agricultural herbicides acetochlor, alachlor, atrazine, cyanazine, and metolachlor. Concentrations of breakdown products acetochlor ESA, alachlor ESA, and metolachlor ESA commonly were more than 10 times higher than the concentrations of their parent compounds. Thus, breakdown products make up the largest amount of pesticides that are transported from the basin to the Mississippi River, accounting for more than 80 percent of the yearly pesticide load in the Iowa River at Wapello. Pumping from public-supply wells near Cedar Rapids, Iowa, induces infiltration from the Cedar River, which has allowed pesticides and their breakdown products to enter ground water. City officials are pursuing additional research on breakdown products and parent compounds in ground water used for city water supplies (USGS Circular 1210).



Breakdown products were some of the most frequently detected pesticide compounds in streams in the Eastern Iowa Basin.

Interactions Among Water, Air, and Aquatic Ecosystems

Implications

Ground-water contributions to streams and rivers can be substantial. For this reason, ground-water flow and quality should be considered in making decisions for stream protection, such as in establishing Total Maximum Daily Loads (TMDLs). Surface-water recharge to ground water also is important, particularly where public-supply wells are located near streams, and should be considered in source-water management and well-head protection programs.

Interactions among surface water, ground water, land, and the atmosphere govern the occurrence and movement of water and contaminants, and thus affect the health of aquatic ecosystems. NAWQA studies therefore include assessments of multiple components of the hydrologic system, including streams, rivers, and ground water within the study units; the atmosphere; and biological communities (primarily fish, aquatic invertebrates, and algae) and stream habitat.

Interactions between surface water and ground water

Ground-water discharge can influence the quality of streams and ultimately the receiving water. For example, ground water supplies about half of the water and nitrogen to streams in the Chesapeake Bay watershed and is therefore an important source of nitrogen to the Chesapeake Bay (Phillips and Lindsey, 2003). Streams, in turn, can influence the quality of ground water. Contaminants generally are more prevalent and detected at higher concentrations in streams than in ground water. This is largely determined by chemical properties of contaminants and flow conditions—ground water typically is not vulnerable to contamination by compounds that attach to soils or that are unstable in water, and relatively long residence times along ground-water flow paths allow many chemicals to degrade, disperse, or be diluted before reaching a well.

Interactions between surface water and ground water are affected by natural features such as soils, geology, and hydrology, and by human activities such as ground-water pumping. Exchanges of water and contaminants can be rapid in areas underlain by carbonate rocks (see **Edwards aquifer near San Antonio, Texas** example) or by permeable and well-drained soils and sediment, such as sand and gravel (see **North Carolina** example). Pumping ground water can accelerate exchanges between streams and ground water (see **Great Miami River Basin** example). In some areas, concentrations of contaminants can decrease during these exchanges, such as when chemicals are sorbed onto soil particles or are transformed by chemical or biological processes (see **southern New Jersey** example).

Exchanges are substantial in the **Edwards aquifer near San Antonio, Texas**

Ground-water and surface-water exchanges are substantial in carbonate aquifers near San Antonio, Texas. Major streams lose water to the Edwards aquifer as they flow across the highly permeable, faulted and fractured carbonate rocks of the aquifer outcrop. Although streams that recharge the aquifer originate in and flow through mostly undeveloped rangeland, some of them also flow through urbanized northern San Antonio. Urban contami-

Ground-water and surface-water exchanges are substantial in carbonate aquifers near San Antonio, Texas.

nants, such as chloroform and commonly used herbicides (including atrazine, and its breakdown product DEA, simazine, and prometon) are transported to wells in the recharge zone of the Edwards aquifer, the principal source of water supply for the greater San Antonio region (USGS Circular 1212).

Phosphorus in ground-water discharge affects streams in **North Carolina**

Ground-water and surface-water interactions in sand and gravel aquifers of the Albemarle-Pamlico Drainage Basin in North Carolina help to explain elevated concentrations of phosphorus in selected streams. Deep ground water underlying parts of the Atlantic Coastal Plain contains naturally high concentrations of phosphorus (a median concentration of 0.25 milligrams per liter), which likely originates from phosphate minerals in the aquifer sands. Upward discharge of the ground water results in elevated phosphorus in streams, particularly in the Tar River and Neuse River Basins, as shown by similarities in phosphorus concentrations in discharging ground water and in streams. Documenting this natural source of phosphorus has increased the accuracy of TMDLs for some North Carolina streams (USGS Circular 1157).

Pumping induces contamination in the **Great Miami River Basin**

Pesticides such as bentazon, atrazine, metolachlor, and prometon were detected frequently in public-supply wells near streams in the Great Miami River Basin in Ohio and Indiana. At least one pesticide was detected in about 60 percent of samples from public-supply wells (about 80 feet deep) versus about 15 percent of samples from shallow domestic wells (about 60 feet deep). The most likely source of the pesticides was pumping-induced infiltration of stream water, which can reach the high-capacity public-supply wells near streams within weeks or even days. These wells may be vulnerable to contaminants discharged to the river upstream of the well fields (USGS Circular 1229).

Nitrate is reduced naturally in **southern New Jersey**

NAWQA scientists studied denitrification (conversion of nitrate to nitrogen gas) in southern New Jersey using a three-dimensional model of ground-water flow that simulated the movement of nitrate through the shallow aquifer system to streams and public-supply wells. Modeled concentrations of nitrate generally matched measured concentrations in public-supply wells, indicating that nitrate remains relatively stable as it moves through the aquifer. Measured nitrate concentrations in three streams during base-flow (when most streamflow is derived from ground water) were about 60 percent of the modeled concentrations over a 9-year period. The apparent loss of nitrate in streams indicates that about 40 percent of the nitrate was removed by processes, such as denitrification and biological uptake, as ground water moves upward through the organic-rich sediment (USGS Circular 1201).

> "The combined surface- and ground-water quality and ecological assessments of the Flint River Basin by the Lower Tennessee River Basin NAWQA Program have heightened our awareness of how vulnerable our water resources are due to karst features of the watershed. These technical, interdisciplinary assessments of watershed conditions have helped focus our watershed restoration efforts within the Flint River Basin."
>
> *Susan Weber,*
> *Flint River Conservation*
> *Association*

Photo by J.R. Gilhousen, USGS

Ground-water and surface-water interactions in sand and gravel aquifers of the Albemarle-Pamlico Drainage Basin in North Carolina help to explain elevated concentrations of phosphorus in selected streams.

Photos by Douglas Harned, USGS

Interactions Among Water, Air, and Aquatic Ecosystems

Atmospheric contributions

The atmosphere can be a major source of contaminants. For example, as much as 25 percent of the nitrogen entering the Chesapeake Bay comes from the atmosphere (Fisher and Oppenheimer, 1991). Nearly every pesticide that has been investigated has been detected in air, rain, snow, or fog throughout the Nation at different times of the year (Majewski, 1995). Atmospheric deposition also is a major source of mercury to most ecosystems; mercury enters the atmosphere from natural and human-related sources, mostly coal combustion, waste incineration, industrial uses, and mining (Krabbenhoft and others, 1999). NAWQA findings indicate that concentrations of methylmercury (the most toxic form of mercury) are strongly related to the amount of wetlands in a watershed, and are increased by the presence of sulfur, carbon, organic matter, and dissolved oxygen (see **New England** example).

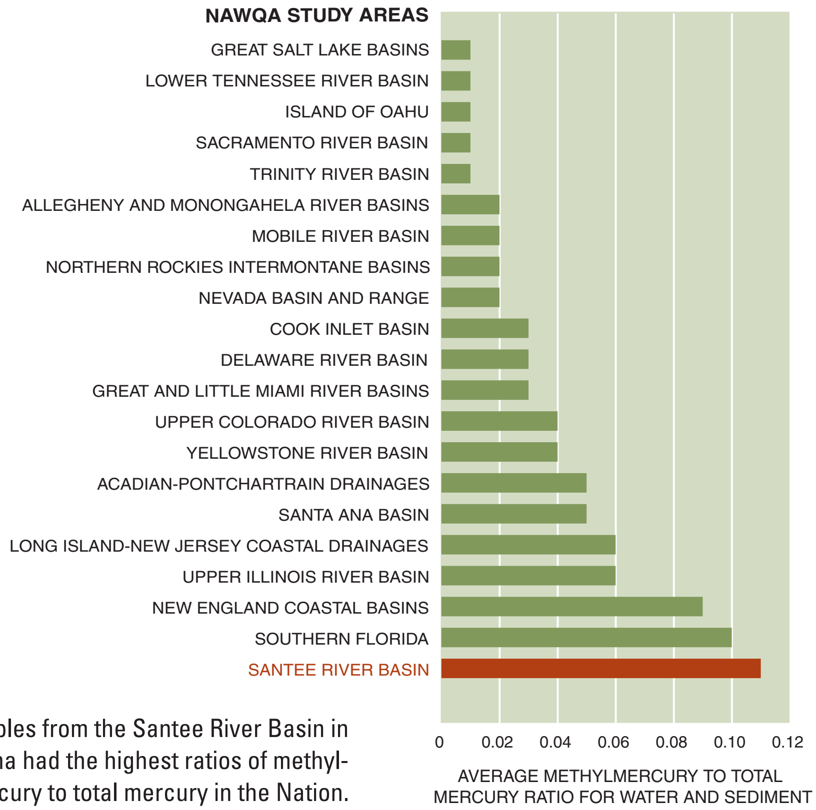
The interconnection of water and the atmosphere can lead to unintended consequences. For example, methyl *tert*-butyl ether (MTBE)—a chemical that allows gasoline to burn cleaner—was not regarded as a water contaminant when its use as an oxygenate in gasoline was increased in the 1990s to help improve air quality in many cities. MTBE's high solubility in water, persistence, and widespread usage has led to its occurrence at low concentrations in ground water and community water supplies, especially in those areas where it is used in reformulated gasoline (Grady, 2003; Moran and others, 2003). The USEPA has issued a drinking-water advisory on MTBE (U.S. Environmental Protection Agency, 1997), and 17 States, including California and New York, have passed legislation to ban or limit its use in gasoline (Tancred Lidderdale, Energy Information Administration, written communication, 2004). Such legislation is pending in other states, such as Maine and New Hampshire, where MTBE is commonly detected in ground water.

Mercury contamination in **New England** is typical of national patterns

NAWQA findings on mercury in the New England Coastal Basins were typical of patterns documented at many geographic scales. Specifically, concentrations of total mercury in sediment were highest in urban watersheds in the Boston metropolitan area, where there are many urban sources, including historical point-source discharges, nonpoint sources, and atmospheric deposition. Concentrations were lowest in sediment in adjacent, more forested watersheds in Maine and New Hampshire. In contrast, concentrations of total mercury in fish (more than 95 percent of which is methylmercury, the most toxic form) were higher in the forested watersheds near the Boston metropolitan area than in fish in the more urban watersheds. Elevated con-

Implications

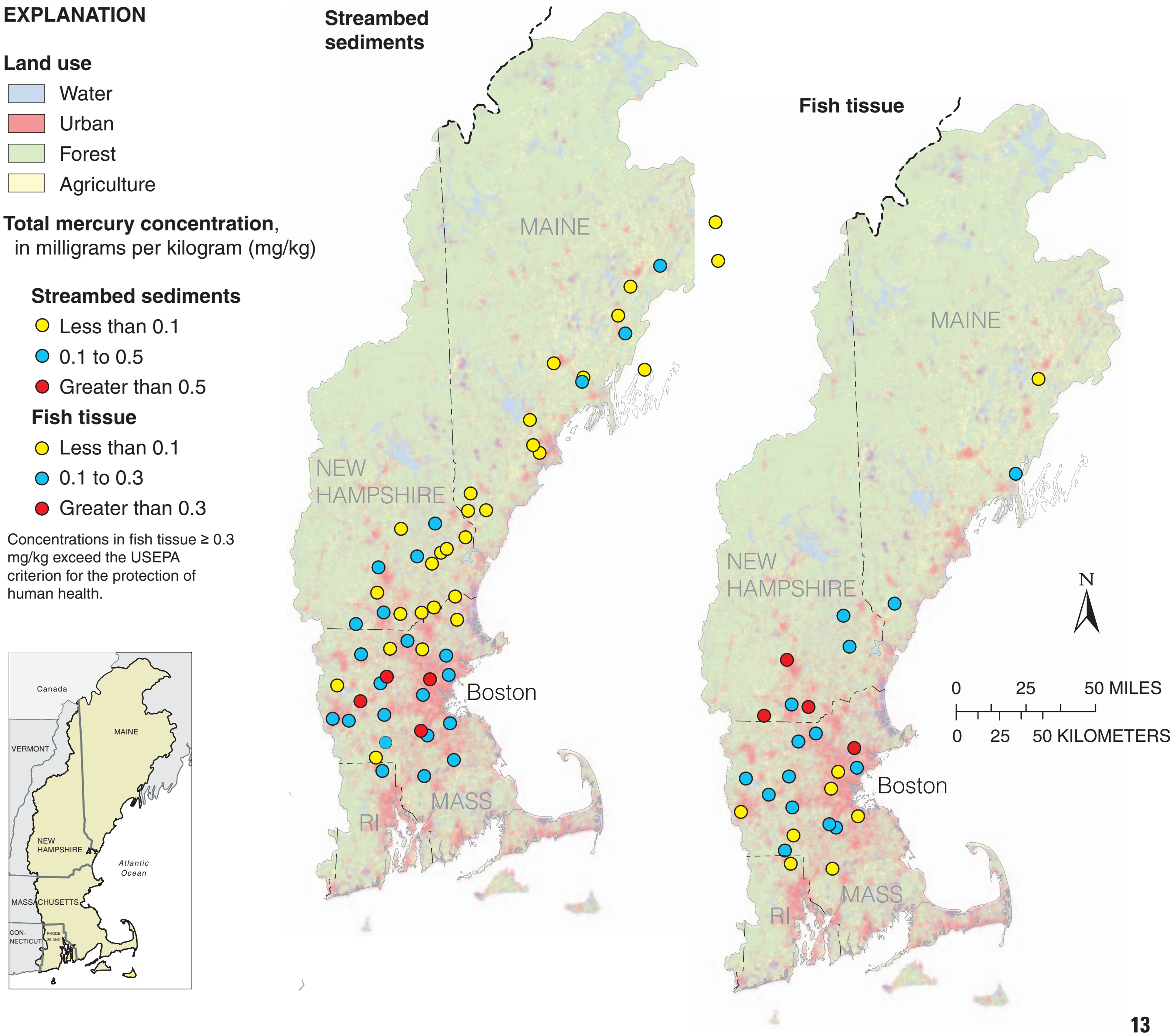
Water quality cannot be fully protected without consideration of atmospheric deposition of contaminants. Water quality can be impaired by emissions from both local and distant sources; therefore, water-management strategies require coordination at the State, regional, and national levels.



Samples from the Santee River Basin in South Carolina had the highest ratios of methylmercury to total mercury in the Nation.

centrations in fish in the forested watersheds result largely from natural factors, such as the presence of wetlands that enhance the process of converting total mercury to methylmercury. Nationwide, study units that had the highest ratios of methylmercury to total mercury were along the East Coast (Krabbenhoft and others, 1999), with the highest ratios in samples from the Santee River Basin in South Carolina. The Santee River Basin sites represent primarily blackwater streams, which typically have large amounts of dissolved organic carbon and low concentrations of dissolved oxygen.

Nationwide, concentrations of methylmercury in fish tissue exceeded the USEPA human health criterion of 0.3 milligrams per kilogram (U.S. Environmental Protection Agency, 2001) in about 40 percent of sampled game fish, two-thirds of which were bass. Concentrations of methylmercury were highest in fish collected from southeastern streams, such as those in South Carolina, Georgia, and Florida, and in streams locally contaminated by mining (Brumbaugh and others, 2001).



Concentrations in fish tissue ≥ 0.3 mg/kg exceed the USEPA criterion for the protection of human health.

Condition of biological communities and stream habitat

Potentially toxic compounds, such as DDT, chlordane, dieldrin, polychlorinated biphenyls (PCBs), and mercury, were commonly detected in fish in sampled urban streams, often at higher concentrations than in the sediment. Nationally, one or more organochlorine compounds (including organochlorine pesticides and PCBs) were detected in about 95 percent of whole-fish samples collected at urban sites. Concentrations of organochlorine compounds in fish tissue exceeded guidelines to protect wildlife at nearly 75 percent of urban sites.

Activities associated with agriculture, urban areas, and (or) forests can affect stream-habitat conditions and fish, aquatic invertebrate, and algal communities. Degraded water and sediment, and physical alterations to streams that result in changes to streamflow, temperature, and channel morphology, commonly result in degraded stream habitat, reduced biological diversity, and an increase in the number of species tolerant of disturbance, such as worms, midges, and omnivorous fish communities. The most profound effects can be seen in urbanizing areas (see **Birmingham, Alabama** example).

NAWQA stream-ecology studies in the metropolitan areas of Anchorage, Birmingham, Boston, Chicago, Dayton-Cincinnati, Los Angeles, Philadelphia-Trenton, and Salt Lake City show that changes in aquatic communities are noticeable at low levels of urbanization within a basin (Couch and Hamilton, 2002). For example, in Anchorage, changes in aquatic communities are evident when watersheds reach about 5 percent impervious area, which in Anchorage correlates with a population density as low as 125 to 250 people per square mile. Findings also indicate that physical characteristics are altered with increasing urbanization, which can greatly affect aquatic communities. Specifically, increased residential and commercial development and road density often are associated with less tree canopy for shading, increased water temperatures, and more impervious surfaces, storm drains, and other artificial controls, all of which can increase the amount and rate of runoff during storms. As a result, increases in the magnitude and volume of peak streamflows can destroy fish-spawning beds, remove woody debris, transport large amounts of sediment, and remove natural substrates. These physical alterations are not typically tolerated by sensitive aquatic communities. Water temperatures often are increased in urban streams as a result of runoff flowing over impervious areas, such as parking lots and buildings. Many aquatic organisms can survive only within a narrow temperature range.

Aquatic communities do not respond uniformly to changes in water quality and habitat conditions; rather, responses can differ among species and among streams. For example, aquatic invertebrate and fish communities in streams draining the Mobile River Basin were degraded with increasing urbanization in a constant or linear fashion; degradation continued in watersheds with about 75 percent urban land and about 4,000 people per square mile and did not level off or reach a “threshold” point. In contrast, changes in aquatic invertebrate and fish communities in streams draining the New England Coastal Basins continued in watersheds associated with about 20 percent urban land and less than 3,000 people per square mile, at which point the changes began to level off. Thresholds can be useful for understanding where water-quality management actions are likely to have the most benefit. Thresholds are not applicable to all streams, however, and an understanding of individual stream ecosystems is necessary before making decisions on the most appropriate and beneficial actions for individual systems.

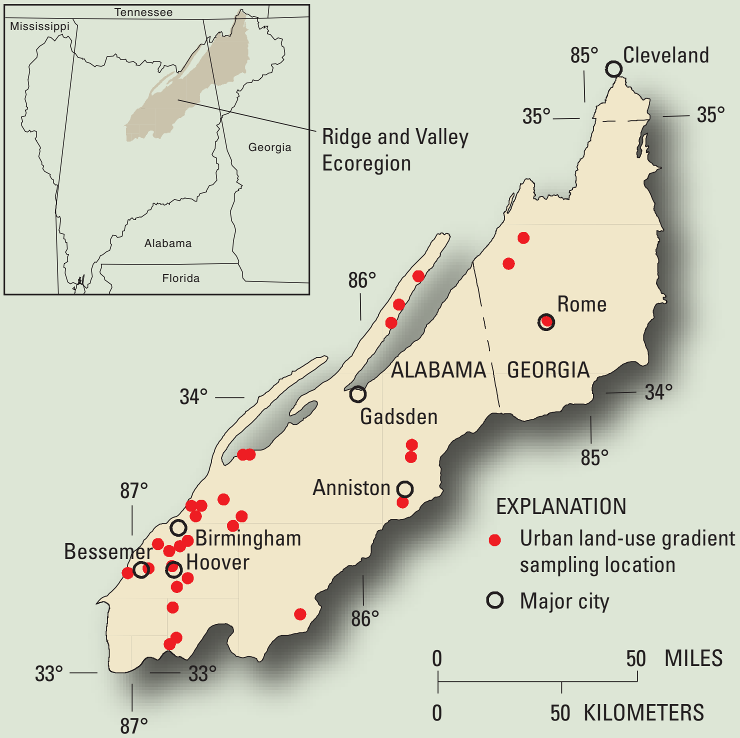
Implications

Information on the effects of urbanization on aquatic life can help planners and decision makers to design and prioritize cost-effective strategies for stream protection and restoration (such as managing chemical use, controlling storm runoff, or restoring riparian habitat). Information on links between water quality and aquatic communities can improve biological monitoring and methods for assessing results of water-management strategies.

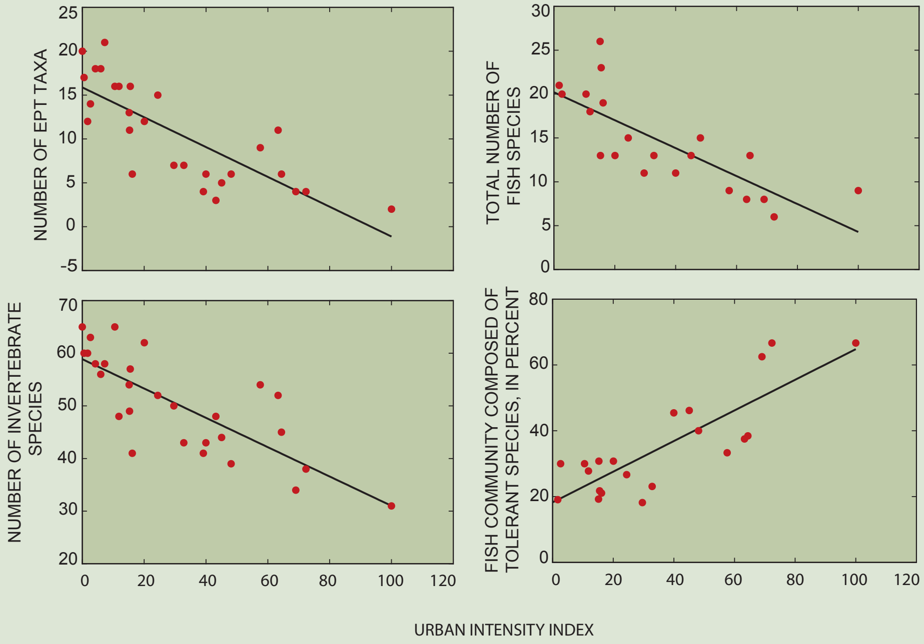
Studies on the relation of biological communities to physical and chemical characteristics of streams that vary in degree of urbanization were conducted in the metropolitan areas of Anchorage (USGS Circular 1240), Birmingham (USGS Circular 1231), Boston (USGS Circular 1226), Chicago (USGS Circular 1230), Dayton-Cincinnati (USGS Circular 1229), Los Angeles (USGS Circular 1238), Philadelphia-Trenton (USGS Circular 1227), and Salt Lake City (USGS Circular 1236).

Aquatic communities are affected by urban development near **Birmingham, Alabama**

NAWQA assessed physical, chemical, and biological characteristics in 30 similar-sized streams that vary in degree of urbanization in the Ridge and Valley ecoregions within the Mobile River Basin. The study showed that aquatic invertebrate and fish communities change as watersheds become increasingly urbanized. For example, the number of invertebrate species intolerant to pollution, such as mayflies, caddis flies, and stoneflies (referred to as "EPT taxa") decreased with increasing urban intensity. Specifically, the number of EPT taxa ranged from 21 species per stream site in a relatively undeveloped watershed (draining less than 1 percent urban land) to 2 species per site in the highly urbanized watersheds, such as Valley Creek at Birmingham (draining about 73 percent urban land). Overall, the number of aquatic invertebrate species decreased by about half, from about 60 species in the least urbanized watersheds to about 30 species in the most urbanized watersheds. Similarly, the number of different fish species decreased from about 20 to 5 species. The decreases were mostly in pollution-intolerant fish species, such as black bass. More tolerant species, including green sunfish, blue gill, yellow bullhead, and creek cub, dominated the most urbanized streams (up to about 70 percent of the fish community). Declines in the types and abundance of aquatic invertebrate and fish communities were observed in watersheds with less than 5 percent urban land and a population density less than 200 people per square mile (USGS Circular 1231).



"Urban intensity" ranges along a gradient from 0 to 100 and is based on 24 measures, including amounts of urban land (residential, commercial, industrial, and transportation) within a watershed, and socioeconomic factors related to housing, income, and population characteristics. An urban intensity index of 60 in the Mobile River Basin, for example, is associated with watersheds with about 40 percent urban land and a population density of about 1,870 people per square mile.



Changes in Water Quality Over Time

Water quality varies from season to season and from year to year and, therefore, long-term trends are sometimes difficult to distinguish from short-term fluctuations. It is too early to tell whether some types of chemical contamination are increasing or decreasing because historical data are either insufficient or too inconsistent to measure trends. Some trends and patterns, however, are evident from data collected over the last decade of NAWQA studies in 51 major river basins and aquifer systems.

NAWQA studies document the long-term presence of some contaminants, which in large part depends on their chemical properties. Not many, for example, would have anticipated the long-term persistence in some ground water of the fumigants 1,2-dibromomethane (EDB) and 1,2-dibromo-3-chloropropane (DBCP), nor the persistence in streams of certain organochlorine compounds, such as PCBs and the insecticides DDT, dieldrin, and chlordane. Nationally, for example, one or more organochlorine compounds were detected in sediment at about 60 and 80 percent of agricultural and urban stream sites, and concentrations exceeded sediment-quality guidelines at nearly 20 and 50 percent of those sites, respectively.

Studies also show that changes in water quality over time frequently are controlled by changes in chemical use and land-management practices. For example, concentrations of modern, short-lived pesticides such as acetochlor change as chemical use changes. Concentrations of acetochlor increased and those of alachlor decreased in many streams in the Upper Illinois River Basin and other parts of the Upper Midwest, where acetochlor partly replaced alachlor for weed control in corn and soybeans beginning in 1994. The changes in chemical use were reflected in stream quality, generally within 1 to 2 years. Contaminant concentrations also change with land-management practices. For example, conversion from rill (or "furrow") irrigation to sprinkler or drip irrigation in many parts of the Yakima River Basin since the early 1990s has reduced runoff from farm fields, resulting in decreases in suspended sediment, total phosphorus, dissolved nitrate, and organochlorine compounds in streams (see **Yakima River Basin** example).

Ground-water quality also responds to changes in chemical use and land-management practices, but usually more slowly than surface water. Ground-water age-dating techniques developed by USGS within the last decade indicate that improvements in ground-water quality can lag behind land-management changes by decades because of the slow rate of ground-water flow (see **Delmarva Peninsula** example). Long-term monitoring is needed to track the progress of improvements in ground-water quality.

Analyses of sediment cores (vertical tubes of mud) from reservoir and lake bottoms provide a quick snapshot of long-term water-quality changes (Van Metre and others, 2000). Runoff carries soil, debris, and attached contaminants to lakes and reservoirs, where they settle to the bottom; changes in water quality are thereby recorded in the successive layers of sediment. Studies show common patterns in sediment quality, such as decreases in lead and increases in polycyclic aromatic hydrocarbons (PAHs), over several decades in 42 reservoirs and lakes sampled in 20 metropolitan areas from 1996 to 2001 (see **Town Lake in Austin, Texas** example).

Nitrate concentrations are increasing in ground water on the **Delmarva Peninsula**

Concentrations of nitrate in ground water used for domestic supply (median well depth 45 feet) on the Delmarva Peninsula (Delaware, Maryland, and Virginia) increased by an average 2 milligrams per liter between 1988 and 2001. The median concentration in 2001 exceeded the USEPA drinking-water standard of 10 milligrams per liter. Increases in nitrate concentration most likely reflect an increased use of nitrogen fertilizers over the last 50 years. In contrast, the median concentration of nitrate in shallow ground water underlying agricultural areas (median well depth 25 feet) did not change significantly over the same period, remaining below the drinking-water standard. Lower nitrate concentrations in the shallow ground water may reflect positive

Implications

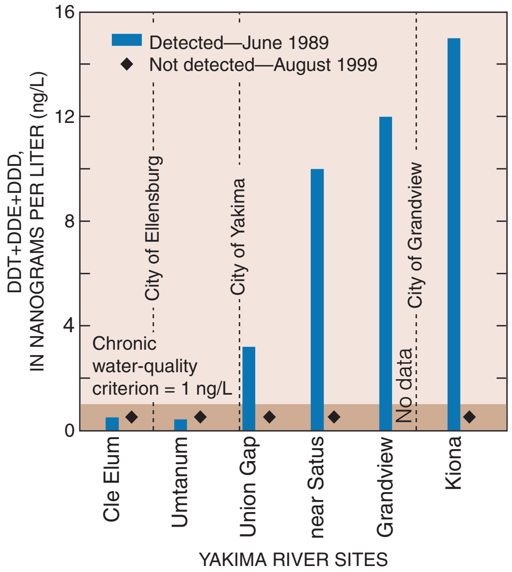
NAWQA findings confirm that long-term, systematic, and consistent monitoring is essential for distinguishing trends from short-term fluctuations, anticipating unintended consequences, and choosing cost-effective management strategies.

Photo by David F. Usher, USGS

effects of nutrient management practices on shallow ground-water quality, implemented in many agricultural areas on the Delmarva Peninsula over the last 10 years. These improvements may not be apparent in the deeper parts of the aquifer because of the slow movement of ground water. Continued monitoring will show if trends continue and improvement occurs (USGS Circular 1228).

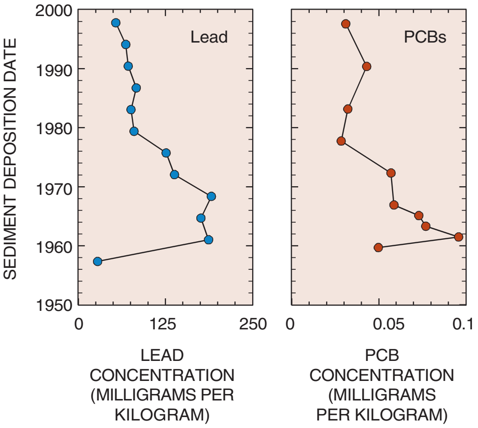
DDT is declining in the **Yakima River Basin**, central Washington

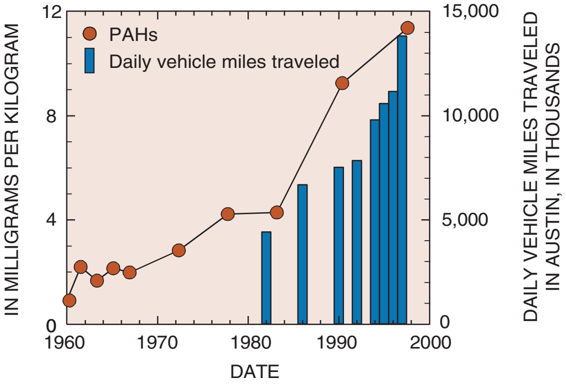
Previous NAWQA assessments (1988-1991) showed widespread detections of DDT and its breakdown products DDE and DDD (total DDT) in agricultural soils, stream water, suspended sediment, and fish in the Yakima River Basin in central Washington. Elevated concentrations of total DDT in bottom fish in the lower Yakima River were among the highest in the Nation. On the basis of these findings, the Washington Department of Health recommended that people eat no more than one meal per week of bottom fish from the lower Yakima River. Concentrations of total DDT in fish such as largescale suckers, smallmouth bass, and carp from the lower Yakima River decreased by about half from the late 1980s to 1998, but still exceeded guidelines for the protection of fish-eating wildlife. Decreases also were noted in stream water—total DDT was detected frequently in unfiltered water samples from the Yakima River in 1989, but was not detected in the Yakima River samples one decade later (1999). Reduced concentrations of total DDT in the Yakima River Basin were attributed primarily to the implementation of best-management practices (BMPs) that limit runoff of sediment and sorbed DDT, including drip and sprinkler irrigation systems, cover crops and ground cover, sediment retention basins, and the use of PAM (polyacrylamide, which causes soil particles to adhere to one another) (USGS Circular 1237).



Changes are positive and negative in **Town Lake in Austin, Texas**

Analysis of sediment layers from Town Lake in Austin, Texas, showed changes in selected contaminants that are typical of changes in lakes and reservoirs of rapidly urbanizing watersheds across the Nation. Lead concentrations in the lake sediments peaked in the late 1960s and then declined by about 70 percent, a direct response to the elimination of lead in gasoline. Concentrations of DDT generally followed its historical use in the United States, which peaked from the late 1950s to the mid-1960s and then declined substantially after its ban in 1972. Concentrations of PCBs, which were used primarily as insulation fluids in transformers and appliances, peaked during the early 1960s and then declined by about 70 percent by 1998 (restrictions on PCBs were imposed in 1971). In contrast to trends in these regulated or banned contaminants, concentrations of total PAHs in Town Lake substantially increased. PAHs result from the burning of hydrocarbons and are present in road asphalt and roofing materials. The increase in PAHs generally corresponded to increases in automobile use in the greater Austin area—both increased by about 2.5 times from 1982 to 1996. The relation between PAH concentrations and motor vehicle traffic is evidence of the effect of non-industrial sources, such as vehicle emissions, road and tire wear, and engine oil leaks associated with growth on the city fringes. This land-use pattern is typical of many urban areas across the Nation (Van Metre and Mahler, 1999).





The NAWQA Program

"Alaska's social and economic fabric is inextricably bound to the health of our salmon habitat and water quality. The NAWQA Program has played a critical role in helping policy makers, businesses and citizens better understand the complexities of our watersheds, and as a result, we now have better tools to manage our salmon and water resources for future generations."

Bob Shavelson,
Executive Director,
Cook Inlet Keeper, Alaska

"NAWQA data on benthic invertebrates is a major contribution to the State of Hawaii because the data have never been collected in Hawaiian streams and never before in conjunction with such a wealth of water-quality parameters. The information could provide the basis for an important new component in water-quality monitoring in Hawaii, which would be especially useful for volunteer monitors and educational groups."

Dr. Carl Evenson,
University of Hawaii
at Manoa

Water-quality assessments by a single program cannot possibly address all the Nation's water-resources needs and issues. Therefore, it is necessary to define the context within which NAWQA information is most useful.

Source-water characterization—NAWQA studies characterize the quality of the available, untreated resource (source water), such as water upstream from treatment plants and water from public-supply and domestic wells. In the second round of assessments, NAWQA will continue to conduct source-water assessments for critical surface- and ground-water supplies and collaborate with other agencies and organizations that regulate, manage, and supply drinking water.

Strategic monitoring and assessment—Water quality is assessed in representative river basins and aquifers across the Nation. Geographic areas represent a wide range of hydrologic environments and priority ecological resources; a variety of contaminant sources, including agricultural, urban, and natural sources; and a high percentage of people (about 60 percent) served by municipal water supply and irrigated agriculture water use. During the second round of assessments, NAWQA will continue to evaluate key processes that affect water quality, including land use, natural characteristics of the land, and hydrologic transport. Such information allows improved prediction of water quality in unsampled but comparable areas—a critical step for cost-effective management of water resources.

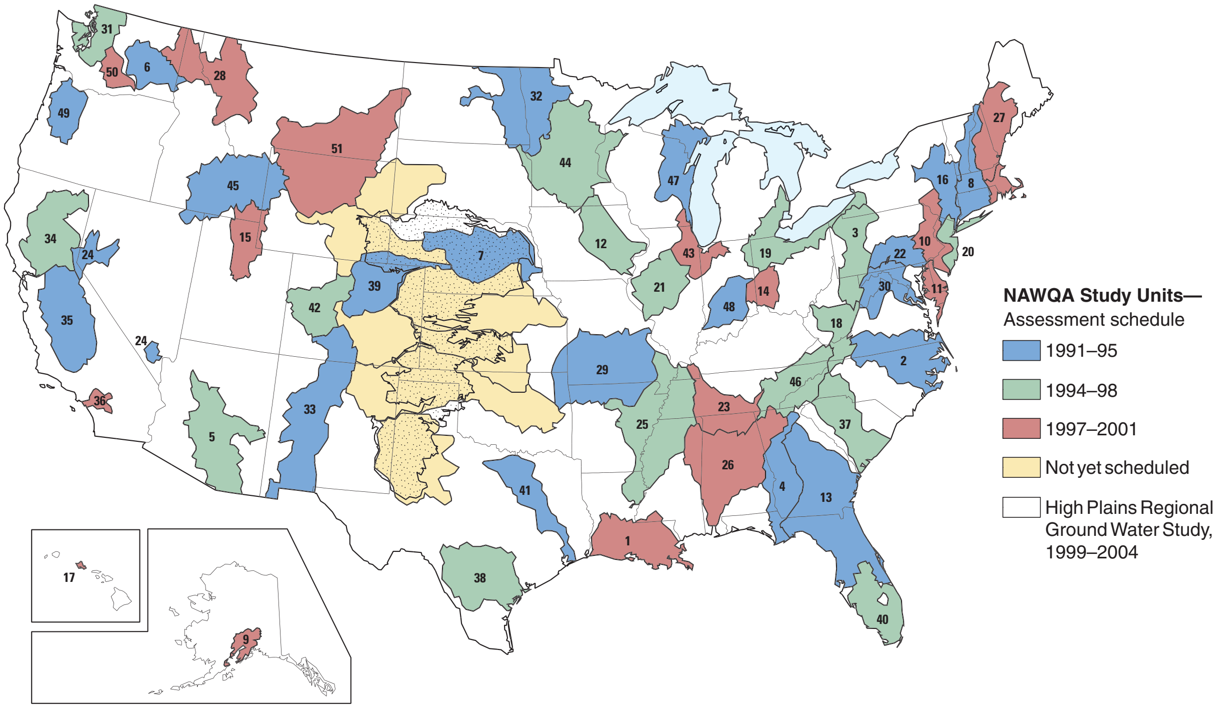
Total resource assessment—Assessments are not limited to a specific site or water-resource problem, but rather focus on the condition of the total resource. The information provides a scientific basis for prioritizing decisions involving competing water demands for drinking, irrigation, aquatic ecosystem health, and recreation.

Comparisons to benchmarks—Concentrations in water are compared to available USEPA drinking-water standards and guidelines, and to USEPA chronic water-quality criteria, Canadian water-quality guidelines, or Great Lakes water-quality objectives for protection of aquatic life (in order of priority, as available). Concentrations in sediment are compared to Canadian sediment-quality guidelines for protection of aquatic life, and concentrations in whole fish are compared to New York fish flesh criteria for protection of fish-eating wildlife (Nowell, 2004).

Detection versus risk—Compounds are measured at very low concentrations, often 10 to 100 times lower than Federal or State standards and health advisories. Detection of compounds by NAWQA studies, therefore, does not necessarily translate to risks to human health or aquatic life; however, the findings are useful for identifying emerging issues and tracking contaminant concentrations over time.

Trends—Baseline conditions were assessed in the first round of NAWQA studies (1991-2001). A major evaluation of trends is planned in the second decade when study units are reassessed and an increasing number of stream and ground-water sampling sites will have had over 10 years of consistent monitoring.

National priorities—The occurrence and distribution of nutrients, pesticides, VOCs, and trace elements, as well as the condition of aquatic habitat and ecological communities, are described on a nationwide basis. In addition, national and regional water-quality topics are addressed. Five topics initiated in 2002 include (1) effects of urbanization on stream ecosystems; (2) ecological effects of nutrient enrichment; (3) transport of contaminants to public-supply wells; (4) sources, transport, and fate of agricultural chemicals; and (5) mercury in stream ecosystems. Certain topics may be emphasized and new topics added as the NAWQA Program continues throughout the second decade (Gilliom and others, 2001).



NAWQA assessed 51 hydrologic basins (referred to as "study units") from 1991 through 2001. NAWQA plans to reassess 42 of the 51 study units in the second round of assessments, from 2002 through 2012 (see Gilliom and others, 2001, for map).

NAWQA Circulars

Available on the World Wide Web at
water.usgs.gov/nawqa/nawqa_sumr.html

River Basin Assessments

1. Acadian-Pontchartrain Drainages (Circular 1232)
2. Albemarle-Pamlico Drainage Basin (Circular 1157)
3. Allegheny and Monongahela River Basins (Circular 1202)
4. Apalachicola-Chattahoochee-Flint River Basin (Circular 1164)
5. Central Arizona Basins (Circular 1213)
6. Central Columbia Plateau (Circular 1144)
7. Central Nebraska Basins (Circular 1163)
8. Connecticut, Housatonic and Thames River Basins (Circular 1155)
9. Cook Inlet Basin (Circular 1240)
10. Delaware River Basin (Circular 1227)
11. Delmarva Peninsula (Circular 1228)
12. Eastern Iowa Basins (Circular 1210)
13. Georgia-Florida Coastal Plain (Circular 1151)
14. Great and Little Miami River Basins (Circular 1229)
15. Great Salt Lake Basins (Circular 1236)
16. Hudson River Basin (Circular 1165)
17. Island of Oahu (Circular 1239)
18. Kanawha - New River Basins (Circular 1204)
19. Lake Erie - Lake Saint Clair Drainages (Circular 1203)
20. Long Island - New Jersey Coastal Drainages (Circular 1201)
21. Lower Illinois River Basin (Circular 1209)
22. Lower Susquehanna River Basin (Circular 1168)
23. Lower Tennessee River Basin (Circular 1233)
23. Las Vegas Valley Area and the Carson and Truckee River Basins (Circular 1170)
25. Mississippi Embayment (Circular 1208)
26. Mobile River Basin (Circular 1231)
27. New England Coastal Basins (Circular 1226)
28. Northern Rockies Intermontane Basins (Circular 1235)
29. Ozark Plateaus (Circular 1158)
30. Potomac River Basin (Circular 1166)
31. Puget Sound Basin (Circular 1216)
32. Red River of the North Basin (Circular 1169)
33. Rio Grande Valley (Circular 1162)
34. Sacramento River Basin (Circular 1215)
35. San Joaquin-Tulare Basins (Circular 1159)
36. Santa Ana Basin (Circular 1238)
37. Santee River Basin and Coastal Drainages (Circular 1206)
38. South-Central Texas (Circular 1212)
39. South Platte River Basin (Circular 1167)
40. Southern Florida (Circular 1207)
41. Trinity River Basin (Circular 1171)
42. Upper Colorado River Basin (Circular 1214)
43. Upper Illinois River Basin (Circular 1230)
44. Upper Mississippi River Basin (Circular 1211)
45. Upper Snake River Basin (Circular 1160)
46. Upper Tennessee River Basin (Circular 1205)
47. Western Lake Michigan Drainages (Circular 1156)
48. White River Basin (Circular 1150)
49. Willamette Basin (Circular 1161)
50. Yakima River Basin (Circular 1237)
51. Yellowstone River Basin (Circular 1234)

For Additional Information

NAWQA reports and data are readily available

The USGS promotes public access to scientific information and strives to communicate and disseminate credible, timely, and relevant information about water resources. USGS Circulars referenced in this document, along with hundreds of other publications that describe individual study-unit and national-scale assessments, are available on the NAWQA Web site at *water.usgs.gov/nawqa*. The Web site also includes maps and water-quality data. The large NAWQA database on national water-quality conditions at *water.usgs.gov/nawqa/data* can be used for a wide range of analyses at national, regional, State, and local scales.

References Cited and Suggested Readings

Brumbaugh, W.G., Krabbenhoft, D.P., Helsel, D.R., Wiener, J.G., and Echols, K.R., 2001, A National Pilot Study of Mercury Contamination of Aquatic Ecosystems along Multiple Gradients—Bioaccumulation in Fish: U.S. Geological Survey Biological Science Report 2001–0009, 25 p.

Couch, C.A. and Hamilton, P.A., 2002, Effects of Urbanization on Stream Ecosystems: U.S. Geological Survey Fact Sheet 042-02, 2 p.

Fisher, D.C. and Oppenheimer, M., 1991, Atmospheric Nitrogen Deposition and the Chesapeake Bay Estuary: AMBIO, v. 20, no. 3-4, p. 102-108.

Gilliom, R.J., Hamilton, P.A., and Miller, T.L., 2001, The National Water-Quality Assessment Program—Entering a New Decade of Investigations: U.S. Geological Survey Fact Sheet 071-01, 6 p.

Grady, S.J., 2003, A National Survey of Methyl *tert*-Butyl Ether and Other Volatile Organic Compounds in Drinking-Water Sources—Results of the Random Survey: U.S. Geological Survey Water-Resources Investigations Report 02-4079, 85 p.

Krabbenhoft, D.P., Wiener, J.G., Brumbaugh, W.G., Olson, M.L., DeWild, J.F., and Sabin, T.J., 1999, A National Pilot Study of Mercury Contamination of Aquatic Ecosystems along Multiple Gradients, in Morganwalp, D.W., and Buxton, H.T., eds., 1999, U.S. Geological Survey Toxics Substances Hydrology Program — Proceedings of the Technical Meeting, Charleston, S.C., March 8-12, 1999—Volume 2—Contamination of Hydrologic Systems and Related Ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 147-160.

Lidderdale, Tancred, 2003, Motor Gasoline Outlook and State MTBE Bans: Energy Information Administration, accessed April 8, 2004 at *http://www.eia.doe.gov/emeu/steo/pub/special/mtbeban.html*

Majewski, M.S., 1995, Pesticides in the Atmosphere: Current Understanding of Distribution and Major Influences: U.S. Geological Survey Fact Sheet 152-95, 4 p.

Moran, M.J., Zogorski, J.S., and Squillace, P.J., 2003, Occurrence and Implications of Methyl *tert*-Butyl Ether and Gasoline Hydrocarbons in Ground Water and Source Water in the United States and in Drinking Water in 12 Northeast and Mid-Atlantic States, 1993-2002: U.S. Geological Survey Water-Resources Investigations Report 03-4200, 26 p.

Nolan, B.T., Hitt, K.J., and Ruddy, B.C., 2000, Probability of Nitrate Contamination of Recently Recharged Ground Waters in the Conterminous United States: Environmental Science and Technology, v. 36, no. 10, p. 2138-2145.

Nowell, Lisa H., 2004, Sources of Information on Standards and Guidelines for Pesticides in Water, Bed Sediment, and Fish, U.S. Geological Survey information available on the Web, accessed April 12, 2004 at URL *http://ca.water.usgs.gov/pnsp/source*

Phillips, S.W. and Lindsey, B.D., 2003, The Influence of Ground Water on Nitrogen Delivery to the Chesapeake Bay: U.S. Geological Survey Fact Sheet 091-03, 6 p.

Squillace, P.J., Scott, J.C., Moran, M.J., Nolan, B.T., and Kolpin, D.W., 2002, VOCs, Pesticides, Nitrate, and Their Mixtures in Groundwater Used for Drinking Water in the United States: Environmental Science and Technology, v. 36, no. 9, 1923-1930.

U.S. Environmental Protection Agency (USEPA), 1997, Drinking Water Advisory—Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-Butyl Ether (MtBE): EPA-822-F-97-009, Office of Water, USEPA, accessed April 8, 2004 at URL *http://www.epa.gov/waterscience/drinking/mtbefact.pdf*

U.S. Environmental Protection Agency, 2001, Water-Quality Criterion for the Protection of Human Health—Mercury: EPA 823-R-0-001, Office of Water, USEPA, accessed April 2, 2004 at URL *http://www.epa.gov/waterscience/criteria/methylmercury/document.html*

U.S. Environmental Protection Agency, 2002, Total Maximum Daily Load for the Pesticide Fipronil in the Mermentau River Basin, accessed April 7, 2004 at URL *http://www.epa.gov/earth1r6/6wq/ecopro/latmdl/fipronil_merm(f).pdf*

Van Metre, P.C., and Mahler, B.J., 1999, Town Lake Bottom Sediments: A Chronicle of Water-Quality Changes in Austin, Texas, 1960-98: U.S. Geological Survey Fact Sheet 183-99, 6 p.

Van Metre, P.C., Mahler, B.J., and Furlong, E.T., 2000, Urban Sprawl Leaves its PAH Signature: Environmental Science and Technology, v. 34, no. 19, 4064-4070.

Welch, A.H., Watkins, S.A., Helsel, D.R., and Focazio, M.J., 2000, Arsenic in Ground-Water Resources of the United States: U.S. Geological Survey Fact Sheet 063-00, 4 p.

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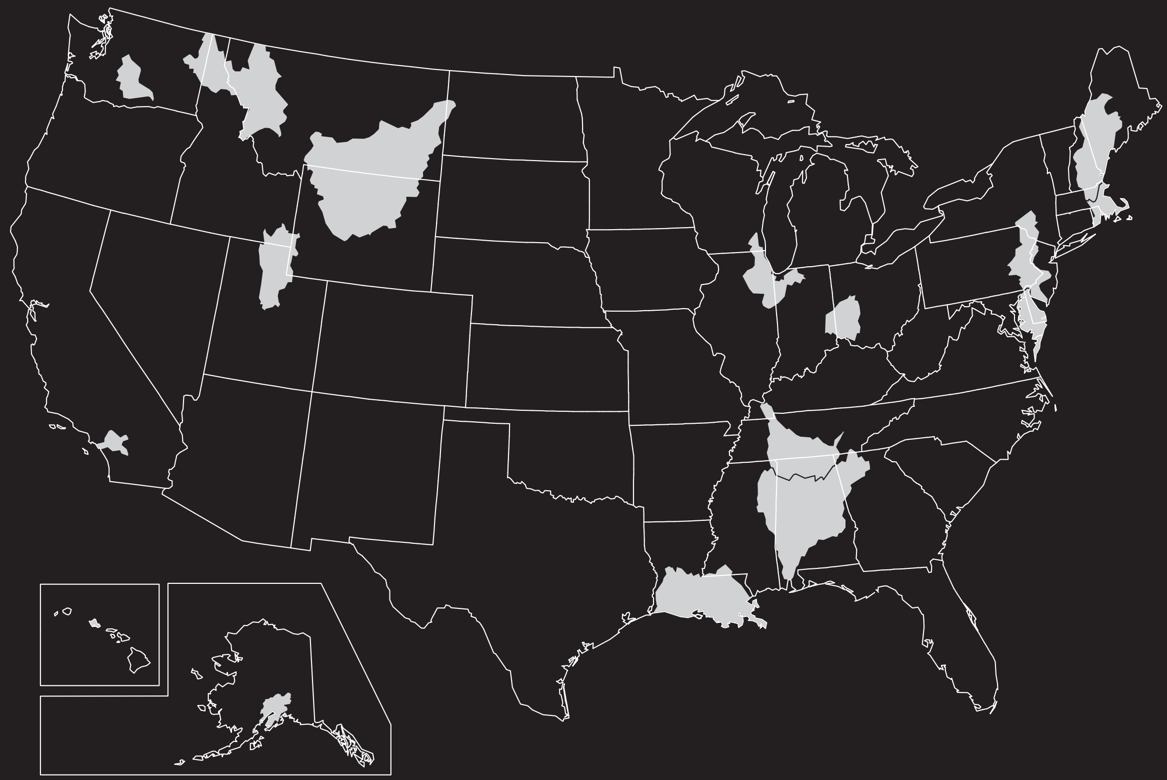

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