Water Quality in the Lower Tennessee River Basin

Tennessee, Alabama, Kentucky, Mississippi, and Georgia, 1999–2001

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

Circular 1233

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National Assessments

The Quality of Our Nation's Waters—Nutrients and Pesticides (Circular 1225)

Front cover: Brier Fork Creek near Three Forks, Alabama
Back cover: Left, spring below Wheeler Dam near Florence, Alabama; middle, Northern studfish–*Fundulus catenatus*; right, electroshock sampling in Fortyeight Creek near Topsy, Tennessee.

Water Quality in the Lower Tennessee River Basin, Tennessee, Alabama, Kentucky, Mississippi, and Georgia, 1999–2001

By Michael D. Woodside, Anne B. Hoos, James A. Kingsbury, Jeffrey R. Powell, Rodney R. Knight, Jerry W. Garrett, Reavis L. Mitchell III, and John A. Robinson

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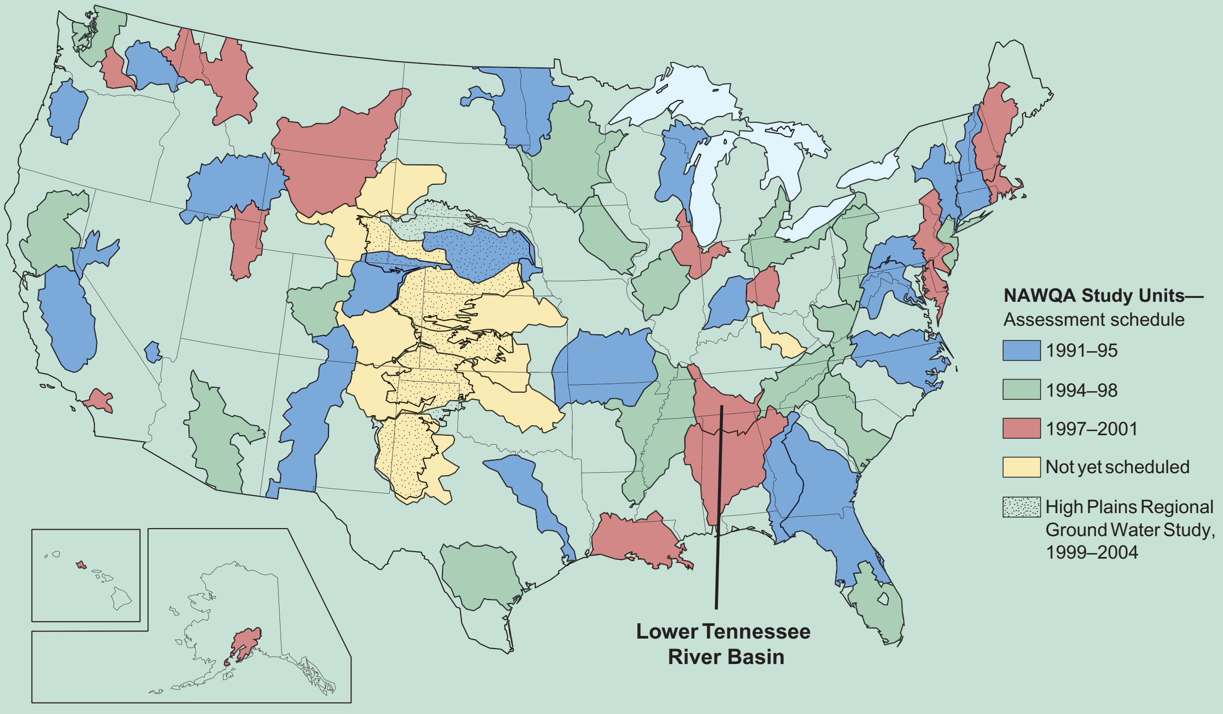
Contents

National Water-Quality Assessment Program

The quality of the Nation's water resources is of great interest because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Recognizing the need for long-term, nationwide assessments of water resources, the U.S. Congress has appropriated funds since 1991 for the USGS to conduct the **National Water-Quality Assessment (NAWQA) Program**. Scientists in the NAWQA Program work with partners in government, research, and public interest groups to assess the spatial extent of water-quality conditions, how water quality changes with time, and how human activities and natural factors affect water quality. This information is useful for guiding water-management and protection strategies, research, and monitoring in different hydrologic and land-use settings across the Nation.



The Lower Tennessee River Basin is one of 51 water-quality assessments initiated since 1991. Together, the 51 major river basins and aquifer systems, referred to as "Study Units," include water resources used by more than 60 percent of the population in watersheds that cover about half of the land areas of the conterminous United States. Timing of the assessments varies because of the Program's rotational design, in which one-third of all Study Units are intensively investigated for 3 to 4 years, with trends assessed every 10 years. As indicated on the map, the Lower Tennessee River Basin is part of the third set of intensive investigations, which began in 1997.

What kind of water-quality information does the NAWQA Program provide?

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

- Total resource assessment—NAWQA assessments are long-term and interdisciplinary, and include information on water chemistry, hydrology, land use, stream habitat, and aquatic life. Assessments are not limited to a specific geographic area or water-resource problem at a specific time. Therefore, the findings describe the general health of the total water resource, as well as emerging water issues, thereby helping managers and decision makers to set priorities.
- Source-water characterization—Assessments focus on the quality of the available, untreated resource and thereby complement (rather than duplicate) Federal, State, and local programs that monitor drinking water. Findings are compared to drinking-water standards and health advisories as a way to characterize the resource.
- Compounds studied—Assessments focus on chemical compounds that have well-established methods of investigation. It is not financially or technically feasible to assess all the contaminants in our Nation's waters. In general, the NAWQA Program investigates those pesticides, nutrients, volatile organic compounds, and metals that have been or are currently used commonly in agricultural and urban areas across the Nation. A complete list of compounds studied is on the NAWQA Web site at *water.usgs.gov/nawqa*.
- 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, therefore, does not necessarily translate to risks to human health or aquatic life. These analyses, however, are useful for identifying and evaluating emerging issues, as well as for tracking contaminant levels over time.
- Multiple scales—Assessments are guided by a nationally consistent study design and uniform methods of sampling and analysis. Findings thereby pertain not only to water quality of a particular stream or aquifer, but also contribute to the larger picture of how and why water quality varies regionally and nationally. This consistent, multi-scale approach helps to determine if a water-quality issue is isolated or pervasive. It also allows direct comparisons of how human activities and natural processes affect water quality in the Nation's diverse environmental settings.

Introduction to this Report

"The NAWQA Program has contributed significantly to Alabama's assessment of water resources in the Lower Tennessee River Basin."

Lynn Sisk,
Alabama Department of Environmental Management

"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 the 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

This report contains the major findings of a 1999–2001 assessment of water quality in the Lower Tennessee River Basin. It is one of a series of reports by the National Water-Quality Assessment (NAWQA) Program that present major findings in 51 major river basins and aquifer systems across the Nation.

In these reports, water quality is discussed in terms of local, State, and regional issues. Conditions in a particular basin or aquifer system are compared to conditions found elsewhere and to selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms.

This report is intended for individuals working with water-resource issues in Federal, State, or local agencies, universities, public interest groups, or in the private sector. The information will be useful in addressing a number of current issues, such as the effects of agricultural and urban land use on water quality, human health, drinking water, source-water protection, hypoxia and excessive growth of algae and plants, pesticide registration, and monitoring and sampling strategies. This report is also for individuals who wish to know more about the quality of streams and ground water in areas where they live, and how that water quality compares to the quality of water in other areas across the Nation.

The water-quality conditions in the Lower Tennessee River Basin summarized in this report are discussed in detail in other reports that can be accessed from the Lower Tennessee River Basin Web site (*tn.water.usgs.gov/lten/lten.html*). Detailed technical information, data and analyses, collection and analytical methodology, models, graphs, and maps that support the findings presented in this report in addition to reports in this series from other basins can be accessed from the national NAWQA Web site (*water.usgs.gov/nawqa*).

From the collection of the Huntsville-Madison County Public Library, Huntsville, Alabama.

Residents of Huntsville, Alabama, have relied on ground water discharging from Big Spring as a source of drinking water and for recreation since the early 1800's.

Summary of Findings

Stream and River Highlights

The Lower Tennessee River Basin is one of the Nation's most biologically diverse river systems, with nearly 200 species of fish, 75 freshwater mussels, 50 aquatic snails, and 20 crayfish. More than 50 aquatic species are listed as either threatened or endangered, and numerous others are of special concern or in need of management. Caves, springs, sinkholes, and other karst landforms provide unique aquatic habitats that can be adversely affected by changes in land use.

Surface water sampled in the Lower Tennessee River Basin generally meets Federal and State guidelines for drinking-water quality and protection of aquatic life. However, agricultural activities have affected water quality, as indicated by elevated concentrations of bacteria, nutrients, and pesticides in some streams and rivers.

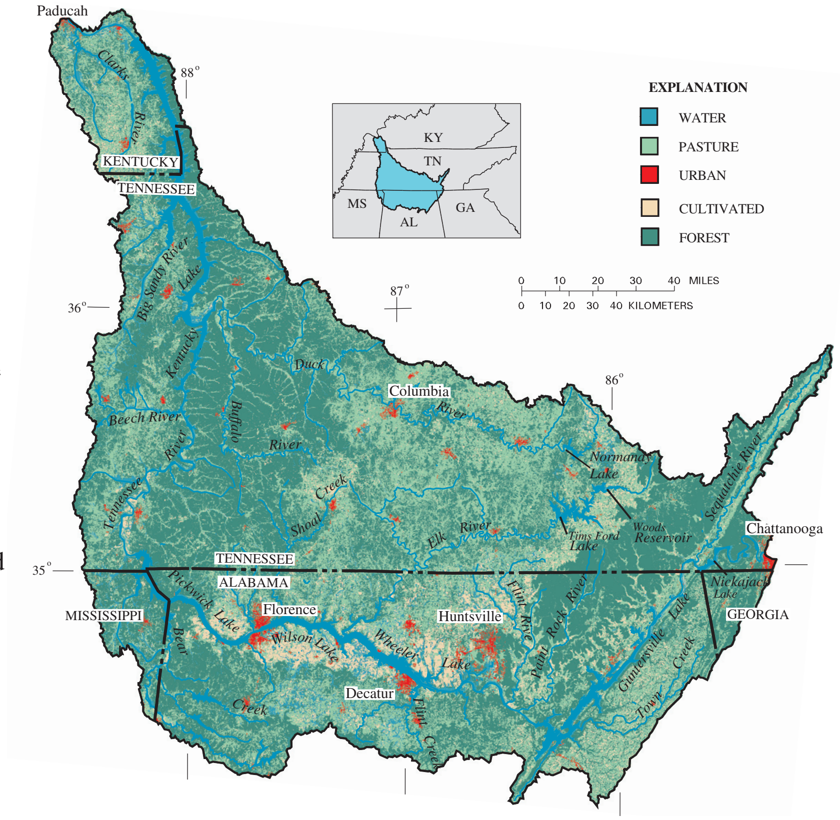
- Sediment from cultivated fields and eroded streambanks decreases water clarity and blankets the streambed, degrading spawning habitats for many fish, such as the saffron darter and laurel dace (p. 7).

- In the Eastern and Western Highland Rim, the number of native species was lower for streams draining agricultural land compared with streams draining forested land (p. 9).

- During storms, runoff from pasture land and other nonpoint sources commonly contain fecal-associated pathogens, such as *Escherichia coli (E. coli)*. *E. coli* concentrations in the Duck, Elk, and Flint Rivers frequently exceeded the United States Environmental Protection Agency (USEPA) recreational criterion during and up to 6 days following a storm event (p. 10).

- Nonpoint sources—primarily livestock wastes and agricultural fertilizers—contribute the largest proportion (about 85 percent) of total nitrogen to streams and rivers (p. 12).

- Concentrations of phosphorus in Cane Creek and the Duck and Elk Rivers rank in the upper 10 percent of 473 streams and rivers monitored nationwide by the NAWQA Program, yet amounts of phosphorus from point and nonpoint sources in these basins are relatively low. Natural deposits of phosphatic limestone are a major source of phosphorus in some streams and rivers in the Lower Tennessee River Basin (p. 13).



About 1.5 million people reside in the Lower Tennessee River Basin, which encompasses about 19,500 square miles, mostly in middle Tennessee and northern Alabama, and small areas of Kentucky, Georgia, and Mississippi. Surface water is the primary source of drinking water for the cities located along the main stem of the Tennessee River and its major tributaries. Large springs and ground water are the main sources of drinking water in rural areas.

- Fifty-two pesticides, including 38 herbicides, 11 insecticides, and 3 fungicides, were detected in streams and rivers. Aquatic-life guidelines were exceeded in less than 6 percent of the samples. Pesticides that exceeded aquatic-life guidelines include atrazine, cyanazine, and malathion (p. 16).

- Residues of DDT and PCBs frequently were detected in whole fish and fish fillets; however, less than 3 percent of the sites had concentrations that exceeded human health action levels or wildlife guidelines (p. 21).

Major Influences on Streams and Rivers

- Ground-water contributions to streamflow from springs
- Sediment, bacteria, nutrients, and pesticides in runoff from agricultural areas
- Naturally occurring phosphatic limestones

Ground-Water Highlights

Ground water in the Lower Tennessee River Basin generally meets Federal and State guidelines for drinking-water quality. However, elevated concentrations of fecal indicator bacteria and the presence of pesticides and volatile organic compounds in wells that supply drinking water indicate that the Mississippian and Ordovician carbonate aquifers are vulnerable to contamination. The karst hydrology of these aquifers, with numerous sinkholes and other karst landforms, likely increases the probability of ground-water contamination.

- The presence of *E. coli* in about 29 percent of the drinking-water wells and 80 percent of the springs sampled indicates that the Mississippian and Ordovician carbonate aquifers are vulnerable to fecal contamination. Concentrations of *E. coli* ranged from less than 1 to 440 colonies per 100 milliliters (col/100 mL) in wells that supply drinking water and from less than 1 to 32,000 col/100 mL in springs (p. 11).

- Although a considerable amount of fertilizer is applied to cropland in the Eastern Highland Rim, concentrations of nitrate were less than 2 milligrams per liter (mg/L) in about 50 percent of the shallow monitoring wells installed near agricultural fields. The relatively low concentrations are in part due to fine-grained soils that impede the downward movement of water and enhance the biochemical transformation of nitrate to nitrogen gas (p. 13).

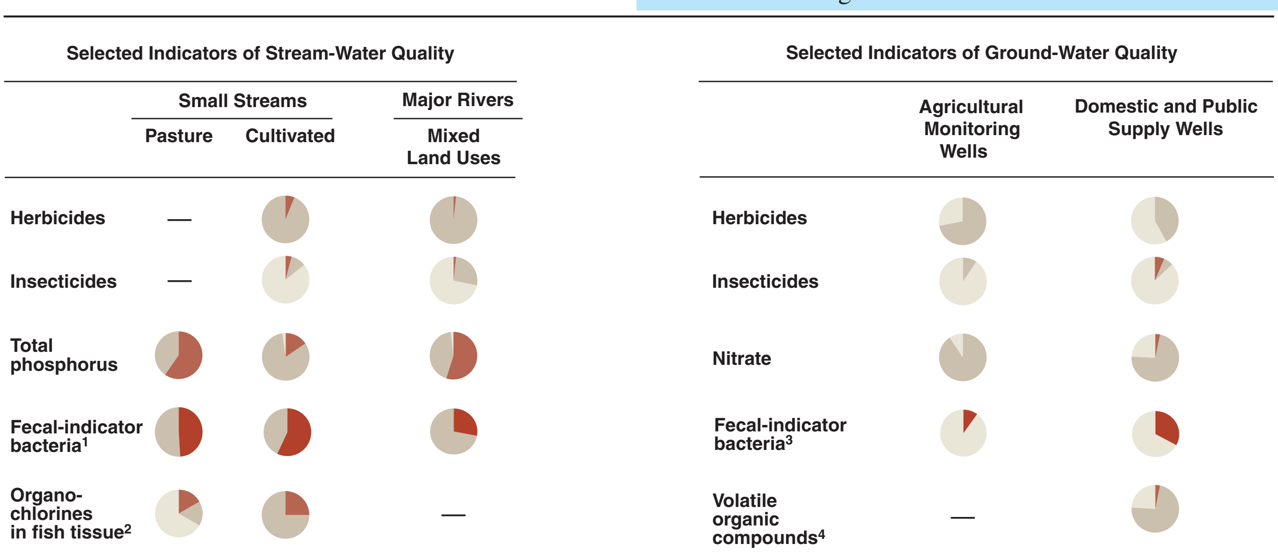
- Nitrate concentrations were less than the USEPA drinking-water standard of 10 mg/L in 71 of the 73 wells sampled in the Mississippian and Ordovician carbonate aquifers (p. 14).

- Thirty-five pesticides, including 28 herbicides, 6 insecticides, and 1 fungicide, were detected in wells and springs sampled in the Mississippian and Ordovician carbonate aquifers. None of the detected pesticides exceeded USEPA drinking-water standards (p. 17).

- Volatile organic compounds were detected at low concentrations, generally less than 0.2 microgram per liter (µg/L), in 67 percent of the wells and springs in the Mississippian and Ordovician carbonate aquifers. Concentrations of tetrachloroethylene (PCE) and trichloroethylene (TCE) exceeded drinking-water standards in 2 of 63 wells sampled (p. 20).

Major Influences on Ground Water

- Karst landforms, such as caves and sinkholes
- Thickness of the regolith (fine-grained soils and weathered rock) that overlies the aquifer
- Fecal contamination from animal agriculture and failing septic systems
- Pesticides and organic compounds associated with urban and agricultural land uses



Proportion of samples with detected concentrations **greater than or equal to** health-related national guidelines for drinking water, protection of aquatic life, or water-contact recreation; or above the desired goal for preventing nuisance plant growth

Proportion of samples with detected concentrations **less than** health-related national guidelines for drinking water, protection of aquatic life, or water-contact recreation; or below the desired goal for preventing nuisance plant growth

Proportion of samples with **no detections**

— Not assessed

[1] Bacteria samples from streams and rivers are compared to the recreational criterion of 298 colonies per 100 milliliters (U.S. Environmental Protection Agency, 1986a).
[2] DDT and PCBs.
[3] Bacteria samples from wells are compared to the drinking-water criterion of 1 colony per 100 milliliters (U.S. Environmental Protection Agency, 2002a).
[4] Solvents, refrigerants, fumigants, and gasoline compounds.

Introduction to the Lower Tennessee River Basin

The Lower Tennessee River Basin Study Unit extends from Walden Gorge near Chattanooga, Tennessee, to the confluence of the Ohio River near Paducah, Kentucky. The basin encompasses about 19,500 square miles, mostly in Middle Tennessee and northern Alabama, and small areas in Kentucky, Georgia, and Mississippi (fig. 1).

Once known for treacherous stretches along the main stem, eloquently named by early navigators as the Suck and the Boiling Pot, the Tennessee River is now highly regulated with few free-flowing stream reaches. Reservoirs constructed primarily by the Tennessee Valley Authority for power generation, flood control, and navigation are located along the Lower Tennessee River and major tributaries. These reservoirs also are used extensively for drinking water and recreational activities, such as fishing, swimming, and boating.

The Lower Tennessee River Basin is divided into nine areas (fig. 1), which generally correspond to physiographic provinces and to level IV ecoregions (Griffith and others, 1997), to provide a framework to assess the effects of natural and cultural features on water quality. Natural features that can affect water quality include geology, soils, climate, and surface- and ground-water hydrology. Wastewater discharge, water use, and land use are a few of the cultural activities that affect water quality.

Urban and Agricultural Land Uses Are Prevalent in the Eastern Highland Rim and Inner and Outer Nashville Basins

Land use in the Lower Tennessee River Basin reflects the geology and physiography of the area and distribution of the population. Forested land covers about 51 percent of the basin. Areas with the highest percentages of forested land include the Plateau Escarpment and Valleys, Transition, and the Western Highland Rim. Pasture land covers about 34 percent of the basin and is prevalent in the Inner and Outer Nashville Basins. Chicken production is

Reservoirs along the Tennessee River prevent flooding and generate power and also are important to the regional economy. An estimated 50 million tons of goods are transported annually on the river in more than 34,000 barges.

Pasture land covers much of the Outer and Inner Nashville Basins. Karst features, such as sinkholes, caves, and disappearing streams, are common and increase the vulnerability of surface and ground water to contamination.

Cotton, corn, and soybeans are the primary crops grown throughout the fertile, rolling terraces and flood plains of the Eastern Highland Rim.

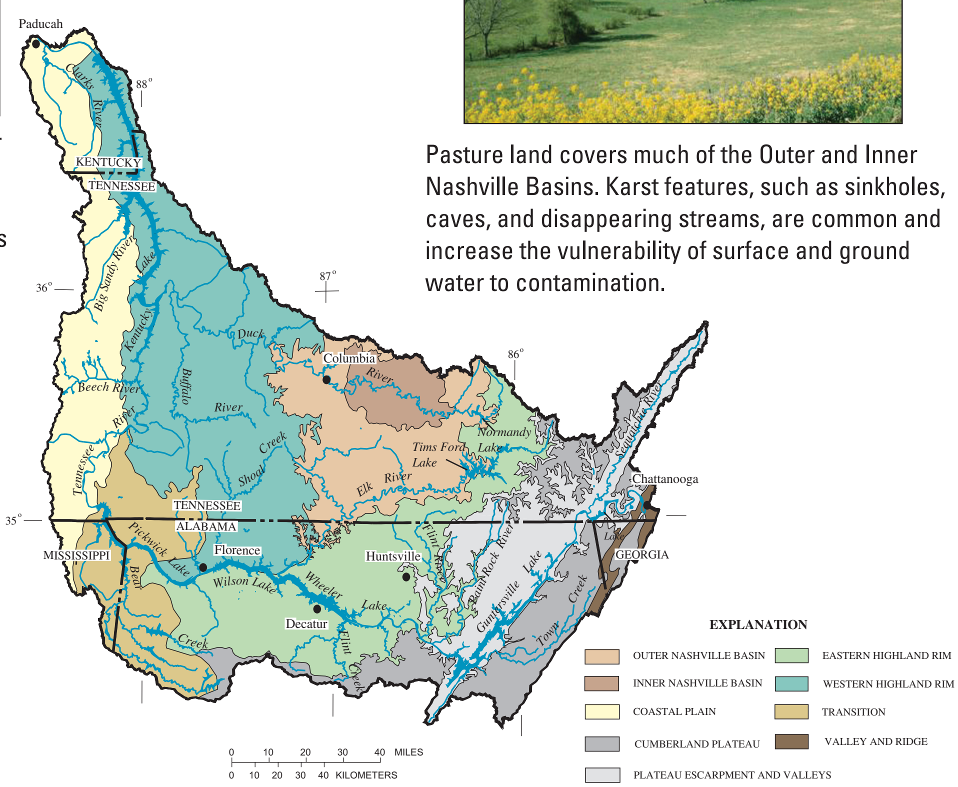


Figure 1. Water quality in the Lower Tennessee River Basin is affected by the combination of land uses and natural setting.

concentrated in the Cumberland Plateau, whereas cattle production is largest in the Inner and Outer Nashville Basins. Cultivated land covers about 6 percent of the basin and is concentrated primarily in the Eastern Highland Rim. Cotton, corn, and soybeans are the primary row crops.

About 1.6 million people (U.S. Census Bureau, 2003) live in the Lower Tennessee River Basin, with about 50 percent of the population living in the Eastern Highland Rim and the Inner and Outer Nashville Basins. The largest cities (Chattanooga, Tennessee; Huntsville, Alabama; and Decatur, Alabama) are along the main stem of the Tennessee River.

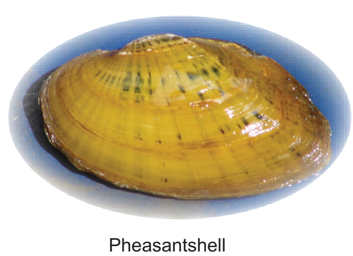
Diverse Assemblages of Fish, Mussels, and Snails Live in the Basin

The Lower Tennessee River Basin is recognized nationally for its diverse aquatic fauna and is home to nearly 200 species of fish, 75 freshwater mussels, 50 aquatic snails, 20 crayfish, and the continent's largest salamander, the hellbender (*Cryptobranchus alleganiensis*). The U.S. Fish and Wildlife Service has listed 51 aquatic species (fish and mussels) in the Lower Tennessee River Basin as either threatened or endangered and numerous others as special concern or in need of management (Tennessee Valley Authority, 2003).

Most of the aquatic diversity is concentrated in the free-flowing streams—most notably, the Duck River. The Duck River spans over 260 miles across a variety of landscapes from the cedar glades of the Eastern Highland Rim, through karst topography of the Central Basin, to the dissected forested hills of the Western Highland Rim.

Currently home to 146 species of fish, 52 species of mussels, and more than 25 species of snails, the Duck River is considered one of the most diverse rivers in North America, containing more species of fish than all of Europe. The Nature Conservancy recognized the upper Duck River as a hot spot for freshwater species at risk, with 33 imperiled and vulnerable fish and mussel species (Masters and others, 1998).


Redline darter


Pheasantshell

Anglers enjoy catching small- and large-mouth bass, rock bass, and many other sport fish in the streams, rivers, and reservoirs throughout the Lower Tennessee River Basin. In addition to sport fishing, the basin also is recognized nationally for its diverse aquatic fauna.

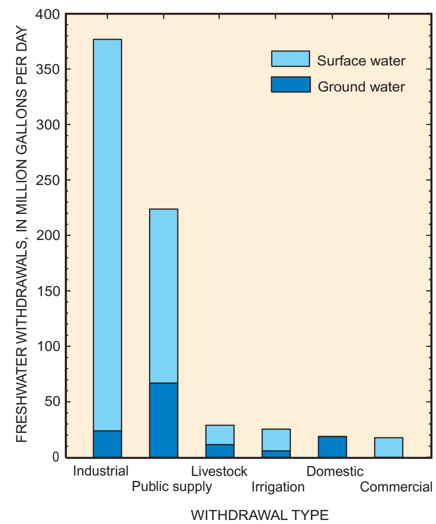


Figure 2. In 1996, surface water accounted for about 73 percent of withdrawals for public supply in the Lower Tennessee River Basin.

Water Availability Is an Issue in Some Areas of the Basin

Although surface water is the primary source of drinking water for most of the cities along the major tributaries and the main stem of the Lower Tennessee River, ground water is relied on as a source of drinking water in rural areas and some cities (fig. 2). Large springs prevalent in the Eastern and Western Highland Rim and the Inner and Outer Nashville Basin also are a source of drinking water in rural areas.

Although the Lower Tennessee River Basin generally is noted for its abundant water resources, water availability is an issue in some areas of the basin. Balancing increased demands for water for waste assimilation and for agricultural, commercial, industrial, and public-supply uses with the need to maintain instream flows for aquatic fauna has become a major issue within the Duck River Basin, upstream from Columbia, Tennessee.

Surface- and Ground-Water Resources Are Vulnerable to Contamination in Karst Areas

Throughout most of the Inner and Outer Nashville Basins and the Eastern and Western Highland Rims (fig. 1), ground water moves through regolith, a mixture of soil and weathered rock, from 10 to more than 100 feet thick, and subsequently into underlying carbonate aquifers. These carbonate aquifers are important sources of drinking water; however, karst landforms, such as caves, sinkholes, and springs, increase the susceptibility of ground water to contamination. In karst areas, contaminants on the land surface can be transported rapidly into nearby streams and ground water.

Annual Streamflows Were Above and Below Average Conditions during the Sampling Period

Water quality in streams, rivers, and shallow ground water often varies in response to hydrologic conditions; thus, information on streamflows is critical for assessing water-quality conditions. Because annual streamflows were above and below average conditions during the 3-year sampling period in the Lower Tennessee River Basin, water-quality data collected during the study reflect a range of hydrologic conditions (fig. 3).

In water year 1999 (October 1, 1998, to September 30, 1999), streamflows at most sites were similar to average streamflows (fig. 3). Despite a few large storms in April 2000, water year 2000 was dry, and streamflows at many sites were about 40 percent less than average streamflows. Numerous storms throughout water year 2001 resulted in above-average streamflows.

Surface-Water-Quality Assessment Focused on the Effects of Land Use

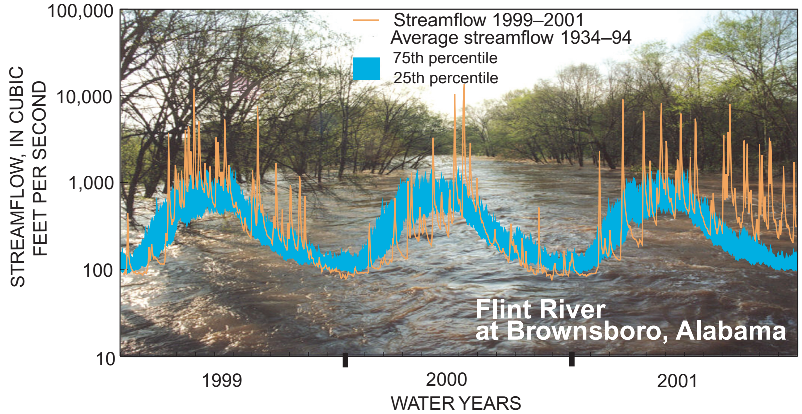


Figure 3. The 3-year sampling period included both wet and dry years; thus, water-quality data collected during the study reflect a range of hydrologic conditions.

Surface-water-quality assessments focused on describing water-quality conditions in four streams draining predominately pasture and cultivated land and in two rivers draining a mixture of land uses and natural settings. Biological assessments also were conducted at streams in the Eastern Highland Rim and Western Highland Rim to assess the effects of agricultural land use on aquatic communities. See pages 22–23 for additional information on study design and sampling locations.

Ground-Water-Quality Assessment Focused on Carbonate Aquifers

Ground-water-quality assessments focused on carbonate aquifers underlying the Eastern Highland Rim and the Inner and Outer Nashville Basins. Karst landforms and agricultural activities in these areas increase the susceptibility of ground water to contamination.

Carbonate aquifers in the Eastern Highland Rim and the Inner and Outer Nashville Basins are important sources of drinking water for public supply systems and for domestic uses in rural settings. Estimated ground-water withdrawals from the Mississippian aquifer, underlying the Eastern Highland Rim, were about 40 million gallons per day (Mgal/d) in 1995. Within the Eastern Highland Rim, the City of Huntsville, Alabama, is the largest ground-water user, withdrawing about 14 Mgal/d from shallow (less than 125 feet) wells. The Ordovician aquifer, underlying the Inner and Outer Nashville Basins, is used primarily for domestic supply in rural areas, with estimated ground-water withdrawals of about 2.4 Mgal/d in 1995 (Kingsbury and others, 1999). See pages 22–23 for additional information on study design and sampling locations.

Additional Information

For a detailed description of the natural and human factors affecting water quality in the lower Tennessee River Basin, refer to Kingsbury and others (1999).

The report is available at http://water.usgs.gov/pubs/wri/wri994080

Major Findings

Ecology

Karst Landforms Provide a Unique Habitat for Diverse Populations of Fish, Mussels, and Snails

The Lower Tennessee River Basin is recognized nationally for its diverse aquatic fauna. In spite of recent losses (extinction) of fishes, such as the harelip sucker (*Lagochila lacera*) and whiteline topminnow (*Fundulus albolineatus*), and mussels, such as the sugarspoon (*Epioblasma arcaeformis*) and acornshell (*Epioblasma haysiana*), the Lower Tennessee River still ranks as one of North America's most biologically diverse river systems. The Lower Tennessee River Basin contains about 200 fish, 75 freshwater mussels, 50 snails, and 20 crayfish species with the highest diversity (or number) of species concentrated in karst areas. Caves, springs, sinkholes, and other karst landforms provide unique habitats that deliver a sustained, clean source of water to streams and rivers. Unfortunately, water resources associated with these landforms are vulnerable to changes in land use.

Whether spawning in a clear spring run or attaching eggs to vegetation found only in headwater wetlands, many fish species in the Lower Tennessee River Basin are dependent on springs, caves, and ground-water seepage for survival. Freshwater mussels depend on springs and other karst landforms to provide a clean, sustained source of water.

Fish Distributions Vary Across the Eastern Highland Rim Because of Variations in Base Flow

Although the Eastern Highland Rim is considered a relatively homogeneous area in terms of its karst geology and physiography, hydrological and ecological variation exists. One of the most important factors influencing fish distributions in the Eastern Highland Rim is base flow (Powell, 2003). Base flow largely consists of ground-water contributions, which are highly variable in karst settings. For example, base flows in the Barrens (fig. 4) are highly influenced by sinkholes and springs, which are scattered across the landscape and serve as collection points for surface runoff and conduits for runoff to streams. Relatively shallow, low-gradient streams of the Barrens tend to have lower base flows than streams in the Dissected Tablelands, but not as low as those in the Moulton Valley. Common fishes include the flame chub (*Hemitremia flammea*), blacknose dace (*Rhinich-*

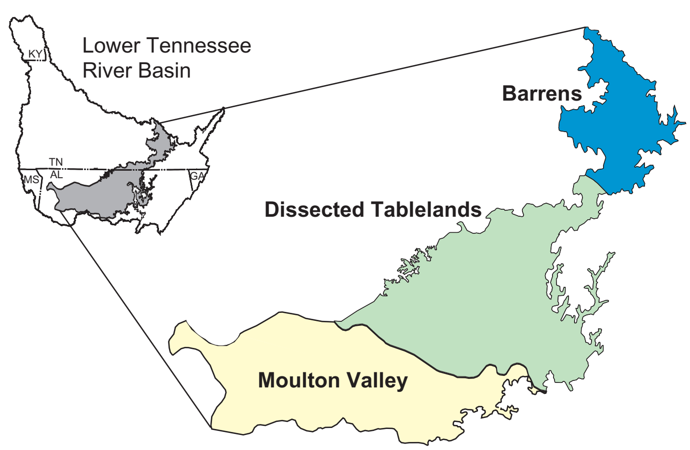


Figure 4. Three distinct areas were identified in the Eastern Highland Rim ecoregion based on differences in streamflow and fish distributions.

thys atratulus), and banded sculpin (*Cottus carolinae*), all of which prefer cool, spring-fed conditions.

The Moulton Valley is composed of deep, low-gradient streams that slowly meander across the landscape. Although ground water is an important component of streamflow, many of the headwater reaches of Moulton Valley streams tend to go dry periodically because of the sandstone-capped hills. These sandstones have low porosity, which decreases ground-water storage and base flow. Base flows in the Moulton Valley are lower than in either of the other two areas. Fish commonly found in these streams include the western mosquitofish (*Gambusia affinis*), spotfin shiner (*Cyprinella spiloptera*), and several sunfish species (*Lepomis* sp.). These fish are capable of quickly retreating to larger streams or rivers during periods of low base flow or surviving in isolated pools that remain in partially dry stream channels.

The most biologically and topographically diverse area in the Eastern Highland Rim is the Dissected Tablelands. Because of numerous springs in the Dissected Tablelands, base flows are considerably higher than in comparably sized streams in the Barrens or Moulton Valley. It is not uncommon for streams in the Dissected Tablelands to support 30 to 40 native species of fish, such as the largescale stoneroller (*Campostoma oligolepis*), scarletfin shiner (*Lythrurus fasciolaris*), longear sunfish (*Lepomis megalotis*), and black darter (*Etheostoma duryi*).

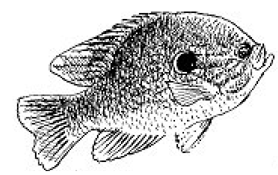
Fish Communities Are Affected by Sediment Deposition

State agencies in the Lower Tennessee River Basin list sediment in agricultural runoff as the most significant of all river pollutants (Tennessee Department of Environment and Conservation, 2002; Alabama Department of Environmental Management, 2002). Agriculture also is listed as the leading source of stream impairment nationally (U.S. Environmental Protection Agency, 2002b).

As the percentages of cropland increase in watersheds in the Dissected Tablelands, the percentage of the streambed covered with sediment increases, causing a decline in the percentage of insect-eating and crevice-spawning fishes (fig. 5). Increased sediment decreases water clarity and eliminates suitable spawning habitat for insect-eating and crevice-spawning fishes. Insect-eating fish require clear water to locate their prey. As sediment blankets the stream bottom, it destroys the habitat needed by aquatic insects to construct nests and forage.

Crevice spawners, such as the laurel dace, are fishes that deposit or physically attach eggs to rocks or in the cracks and crevices between them. As these areas fill with sediment, the egg survival rate is reduced.

Sediment from cultivated fields, construction sites, and eroded streambanks adversely affects fish spawning and feeding by filling in crevices between and under rocks.



Drawing by Bob Savannah, U. S. Fish and Wildlife Service

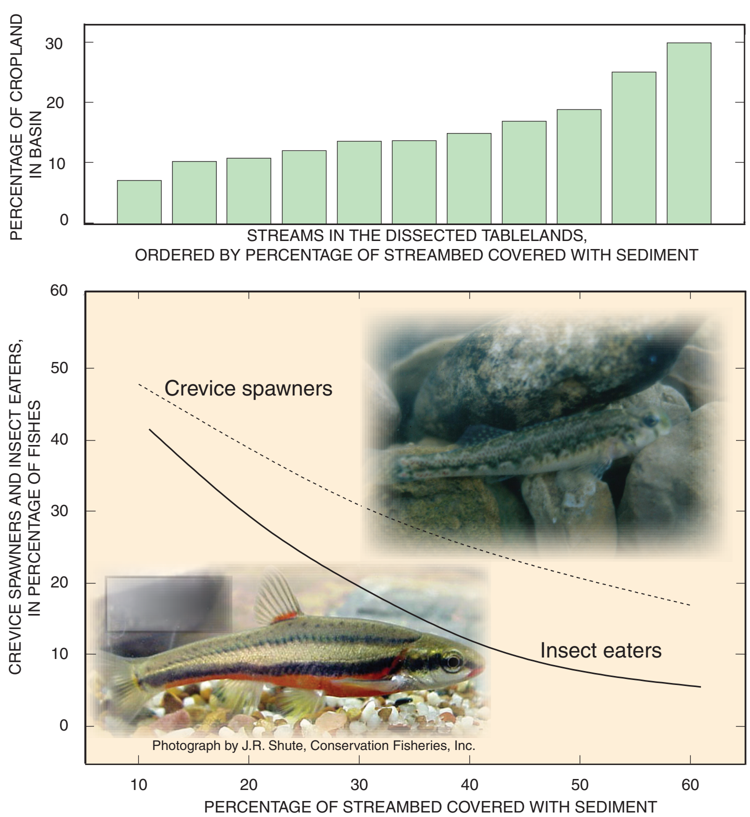
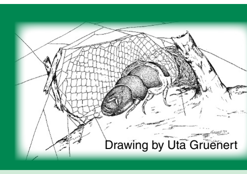


Figure 5. Fishes such as the laurel dace (*Phoxinus saylori*), which feeds on insects, and the saffron darter (*Etheostoma flavum*), which requires clean substrate to spawn (crevice spawners), were negatively affected by increases in sedimentation associated with agricultural land use in the Dissected Tablelands.

AGRICULTURAL LAND USE AFFECTS AQUATIC INSECTS

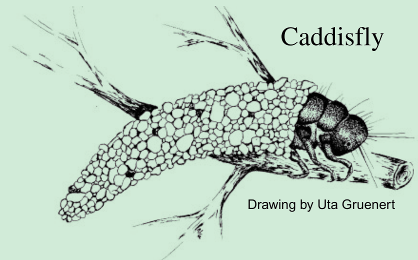


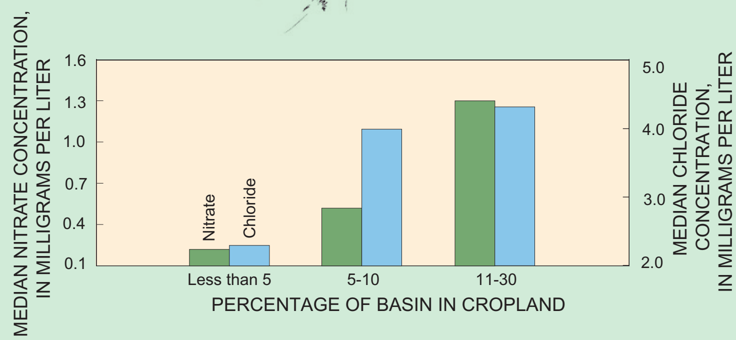
Pollution-tolerant insects

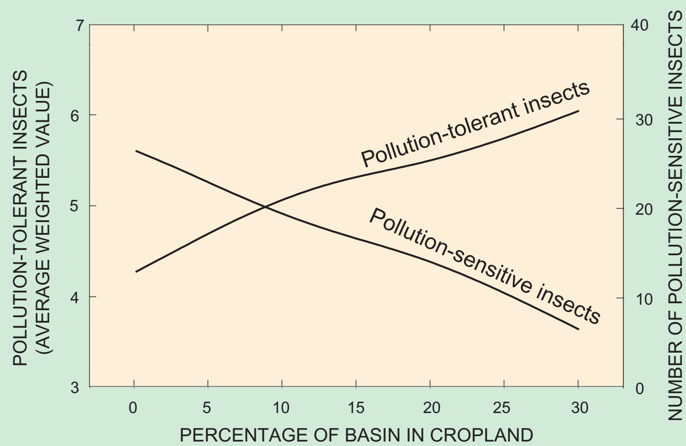
Black flies (*Simulid* sp.) and midges (*chironomids*) are considered some of the most tolerant of aquatic insects. They tend to thrive by out-competing other insects that are less tolerant of pollution.

Pollution-sensitive insects

Mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), and caddisflies (*Trichoptera*) are collectively referred to as EPT taxa. Most of these organisms are considered to be pollution-sensitive insects.







Pollution-tolerant and pollution-sensitive are examples of biological measures or metrics that group aquatic insects according to their feeding habits, means of locomotion, tolerance levels, or habitat preferences. Metrics are used in environmental assessments to express how biological communities respond to changing environmental conditions, such as nutrient levels or water temperature. For example, pollution-sensitive insects, such as caddisflies, decline in abundance when their food-trapping nets become choked with algae and silt that result from excessive nutrients or sediment.

In streams draining the Eastern Highland Rim and Western Highland Rim, nitrate and chloride concentrations increase with increasing amounts of cropland and correlate with a decrease in the number of pollution-sensitive insects and an increase in pollution-tolerant insects. The number of pollution-sensitive insects decreased from 28 to 6, and the average weighted value for pollution-tolerant insects, based on criteria developed for southeastern streams (Cuffney, 2003), increased from 4.1 to 6.1, when the percentage of cropland increased from 0.8 percent to 30 percent.

Although nitrogen and chloride occur naturally in the environment and are essential to all plant growth, the application of agricultural fertilizers to cropland increases the concentrations of these constituents in streams and rivers above natural, or background, levels. On average, 85 percent of the total nitrogen transported by streams and rivers in the Lower Tennessee River Basin originates from nonpoint sources, such as agricultural fertilizers and livestock waste (see page 12 for additional information on nutrients).

Stream Health Is Affected by Land Use

Fish and aquatic insects are used as indicators of stream health because they integrate water-quality and habitat conditions over time. Unlike water-quality analyses, which provide only a snapshot in time of stream conditions, fish and aquatic insect community data provide a long-term, living indication of stream health. Biotic health scores were used to compare the health of fish and aquatic insect communities among the streams in the Eastern Highland Rim and the Western Highland Rim. These scores combine a number of community metrics, such as the abundance of pollution-tolerant and pollution-sensitive insects and the abundance of crevice-spawning and insect-eating fishes, into individual stream health scores (fig. 6). Fish scores were based on 12 metrics designed to assess three broad community segments—the number of native species, the types of feeding groups represented, and the physical condition of the fish. Aquatic insect scores were based on six metrics designed to assess these same broad segments of the community.

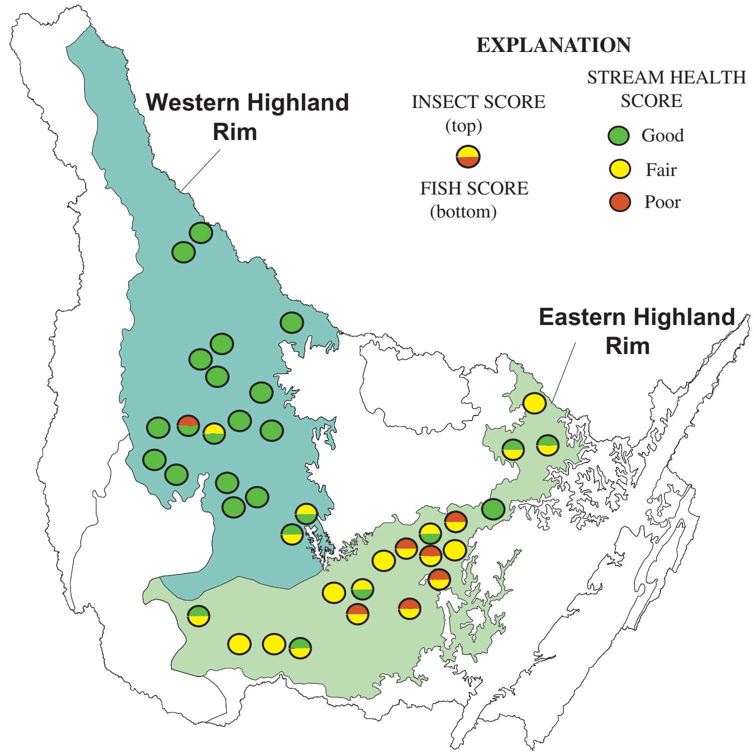
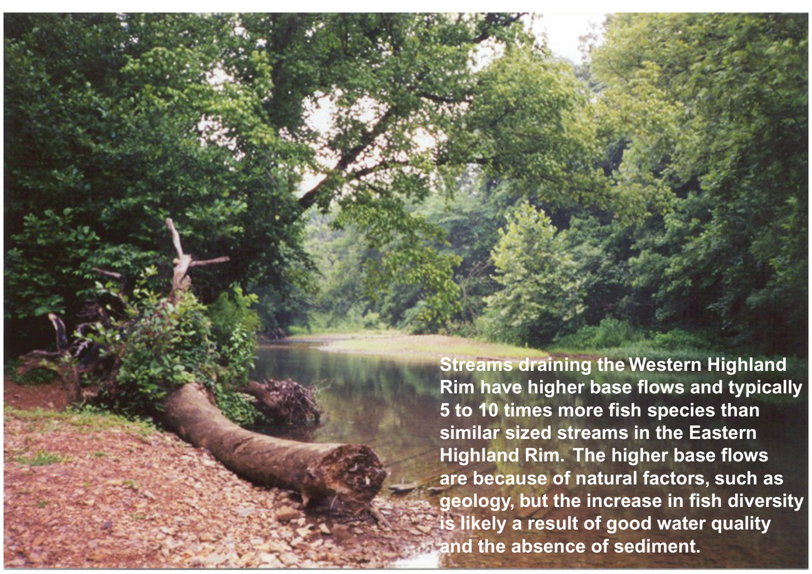


Figure 6. Fish and aquatic insect health scores varied in relation to land use. Health scores were highest in the forested basins of the Western Highland Rim and lowest in the agricultural basins of the Eastern Highland Rim.

Fish health scores, particularly those associated with numbers of native species and feeding group composition, were lower for streams draining agricultural land than for streams draining forested land. Streams draining forested basins in the Western Highland Rim typically had 5 to 10 times more fish species than streams draining agricultural basins in the Eastern Highland Rim. The insect-eater abundance and numbers of native species were lower in the predominantly agricultural basins and higher in the forested basins.

Aquatic insect health scores also were lower for streams draining agricultural land than for streams draining forested land. Numbers of pollution- sensitive insects



Streams draining the Western Highland Rim have higher base flows and typically 5 to 10 times more fish species than similar sized streams in the Eastern Highland Rim. The higher base flows are because of natural factors, such as geology, but the increase in fish diversity is likely a result of good water quality and the absence of sediment.

Additional Information

For more information on the natural setting and fishes of the Eastern Highland Rim, refer to Powell (2003).

The report is available at http://water.usgs.gov/pubs/wri/wri024268

Bacteria

Fecal Contamination of Surface- and Ground-Water Resources

Water-quality assessments conducted by State agencies indicate that 102 streams throughout the Lower Tennessee River Basin are impaired for recreational uses because of elevated levels of pathogens. Although *Escherichia coli* (*E. coli*) bacteria are not typically pathogenic (disease-causing), the presence of *E. coli* indicates fecal contamination from warm-blooded animals and has been associated with waterborne pathogens.

Swimming, canoeing, and other water-contact activities in fecal-contaminated streams and rivers can result in infections of the eyes, ears, nose, and throat. In addition, ingestion of fecal-contaminated water can cause mild to acute gastroenteritis, with symptoms that include vomiting, diarrhea, stomachache, nausea, and fever. These symptoms often appear several days following water-contact activities; thus, people rarely associate these symptoms with exposure to fecal-contaminated water. Fecal-contaminated water may pose an even greater risk to infants, young children, and people with severely compromised immune systems.

Recreational Criterion is Infrequently Exceeded During Base Flows

E. coli concentrations in streams and rivers during base flows generally were less than the USEPA recreational criterion of 298 col/100 mL (U.S. Environmental Protection Agency, 1986a), except at Hester Creek (fig. 7). About 53 percent of the base-flow samples from Hester Creek exceeded the USEPA recreational criterion. The most likely sources of fecal contamination in Hester Creek during base flows are failing septic systems and livestock that have direct access to the stream.

Recreational Criterion Is Frequently Exceeded During Stormflows

Numerous people enjoy water-contact activities, such as canoeing and kayaking, along the Elk, Duck, and Flint Rivers. Participating in water-contact activities in these rivers during and following a storm may increase the risk of developing infections caused by waterborne pathogens.

During stormflows, runoff from pasture and forested lands and other nonpoint sources that contain fecal- associated pathogens washes into streams and rivers. *E. coli* concentrations in the Duck, Elk, and Flint Rivers during and up to 6 days following a storm event ranged from 46 to 100,000 col/100 mL and frequently exceeded the USEPA recreational criterion (fig. 7).

During stormflows, *E. coli* bacteria in rivers and streams frequently exceed the USEPA recreational criterion, increasing the risks of developing waterborne infections.

Turbidity Is an Indicator of Fecal Contamination in Rivers

During stormflows, sediment often is washed into streams and rivers, increasing the turbidity of the water. Increased turbidity in the Duck, Elk, and Flint Rivers is correlated with increased concentrations of *E. coli*. Turbidity measurements above 20 nephelometric units generally correspond to *E. coli* concentrations that exceed the USEPA recreational criterion (fig. 8).

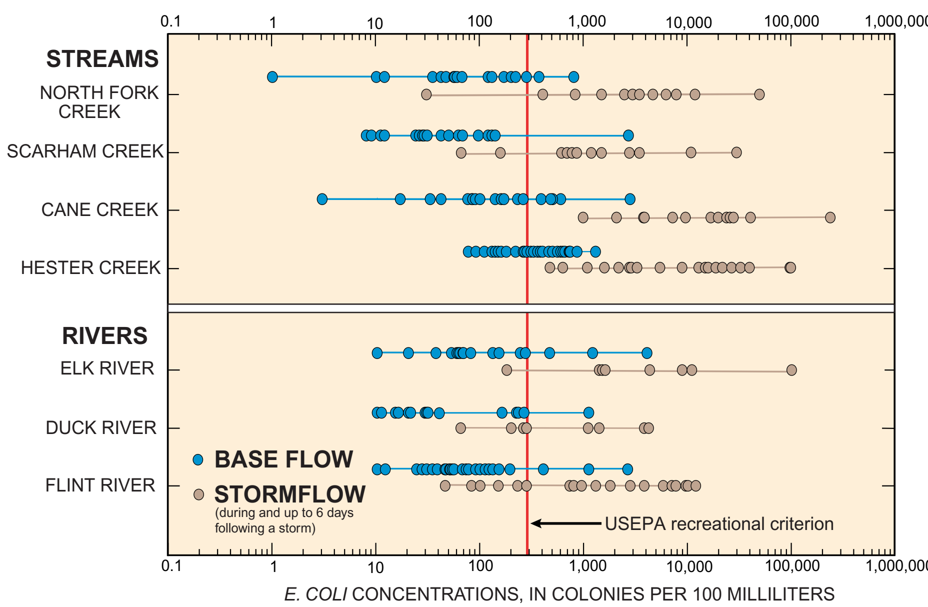


Figure 7. Concentrations of *E. coli* bacteria detected in streams and rivers in the Lower Tennessee River Basin exceeded recreational criterion rarely during base flows but frequently during stormflows.

Understanding the relation between the turbidity of the Duck, Elk, and Flint Rivers and *E. coli* concentrations enables canoers, kayakers, and other water-sport enthusiasts to make informed decisions about exposure to fecal-contaminated waters during and following storms.

Carbonate Aquifers Are Vulnerable to Fecal Contamination

Sinkholes, caves, and other karst landscape features increase the vulnerability of the Mississippian and Ordovician carbonate aquifers to fecal contamination. During heavy rainfalls, surface runoff containing pathogens can be transported quickly into carbonate aquifers. Curriero and others (2001) reported a strong association between waterborne disease outbreaks in the Nation during 1948–94 and extreme rainfall events.

The detection of *E. coli* in drinking water is a human health concern. *E. coli* bacteria were detected in at least 29 percent of the wells sampled in the Mississippian and Ordovician carbonate aquifers, in concentrations ranging from less than 1 to 440 col/100 mL (fig. 9).

E. coli Frequently Are Detected at Elevated Levels in Springs

Springs are often considered sources of safe drinking water. The frequency of detection and variability of *E. coli* concentrations in springs from the Mississippian and Ordovician carbonate aquifers, however, indicates a potential human health concern.

E. coli bacteria were detected in 8 of the 10 springs sampled in the Ordovician carbonate aquifer, with concentrations ranging from less than 1 to 32,000 col/100 mL (fig. 9). Johnson (2002) reported similar findings in springs from carbonate aquifers in the Upper Tennessee River Basin.

The quality of water from springs can be extremely variable over time, depending on land-use activities and rainfall conditions. Two springs in the Mississippian carbonate aquifer were sampled at least bimonthly for 2 years and had *E. coli* concentrations that ranged from less than 1 to 1,600 col/100 mL.

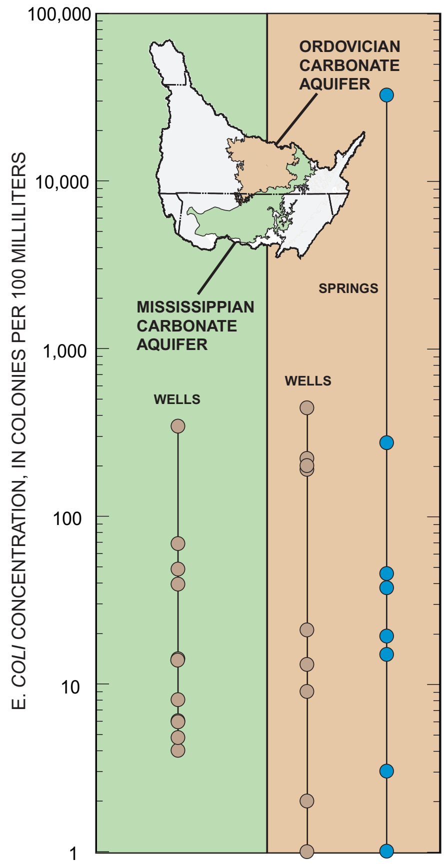


Figure 9. The presence of *E. coli* bacteria in about 29 percent of the wells and 80 percent of the springs indicates that Mississippian and Ordovician carbonate aquifers are vulnerable to fecal contamination.

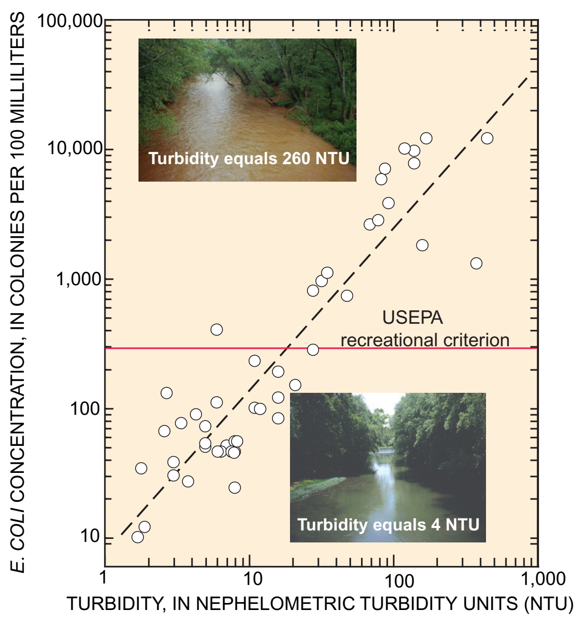


Figure 8. The correlation between *E. coli* and turbidity can be used by canoers and kayakers to estimate the level of fecal contamination in the Flint River before entering the water.

Additional Information

For additional information on fecal-indicator bacteria in the Flint River Basin, refer to Hoos and others (2002).

The report is available at http://water.usgs.gov/pubs/wri/wri014185

Nutrients

Why are Nutrients a Concern in Streams and Ground Water?

Nitrogen and phosphorus are naturally occurring nutrients that are present in streams and ground water, but human activities add significant quantities through nonpoint and point sources. Nonpoint sources include agricultural fertilizer, livestock manure, failing septic systems, and atmospheric deposition of fossil-fuel combustion by-products. Point sources include municipal and industrial wastewater. Excessive amounts of nutrients in streams and lakes can accelerate growth of aquatic plants and may degrade the aquatic ecosystem and restrict recreational use. According to water-quality assessments conducted by State agencies in 2002, 93 streams in the Lower Tennessee River Basin are impaired because of nutrient enrichment. In rural areas where untreated water from wells is the primary source of drinking water, nitrate in ground water is a concern because elevated concentrations are hazardous to human health.

Nonpoint Sources Are Major Contributors of Nitrogen to Streams and Rivers

Nonpoint sources—primarily livestock waste and agricultural fertilizers—contribute the largest proportion (about 85 percent) of total nitrogen to streams and rivers in the Lower Tennessee River Basin compared to about 10 percent from natural sources (Alexander and others, 2000) and about 5 percent from point sources. Statistical analyses indicated a strong relation between amounts of agricultural fertilizer applied and livestock waste in a watershed and the amount of total nitrogen that is transported annually in streams and rivers (fig. 10). Relatively small amounts of total nitrogen were transported (less than 2 tons per square mile per year [(tons/mi^2)/yr] in the Buffalo River, which drains mostly forested land. The largest amounts of total nitrogen [greater than 4 (tons/mi^2)/yr] were transported in Town Creek, which drains predominantly pasture land that contains a large number of confined-animal operations.

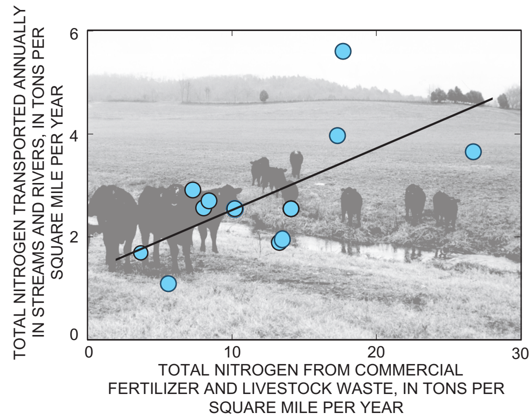
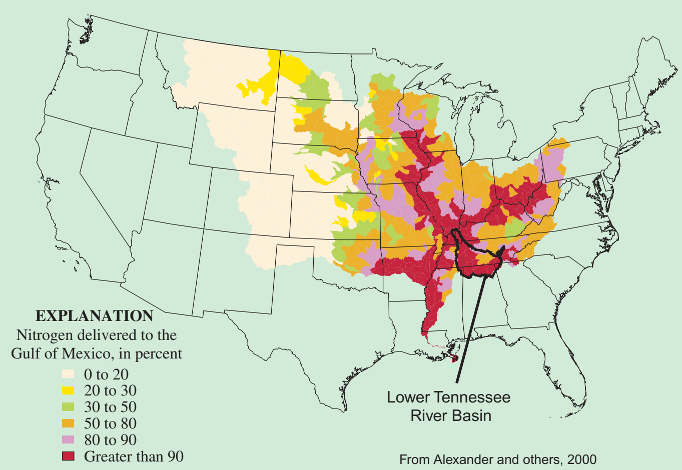


Figure 10. The amount of agricultural fertilizer applied and livestock waste produced in a basin relates strongly to the amount of total nitrogen transported annually in streams and rivers in the basin (statistical correlation coefficient of 0.65).

NITROGEN IN THE TENNESSEE RIVER CONTRIBUTES TO HYPOXIA IN THE GULF OF MEXICO

Point and nonpoint sources of nitrogen in the Lower Tennessee River Basin not only cause impairment of streams and rivers within the basin but also pose an environmental threat to the Gulf of Mexico downstream, which is experiencing widespread hypoxia and degradation of aquatic resources (Rabalais, 1996). Annual nitrogen loads from the Tennessee River Basin comprise less than 5 percent of the annual nitrogen load of the entire Mississippi River Basin; however, about 90 percent of the nitrogen transported in the lower Tennessee River is delivered to the Gulf of Mexico. Nitrogen is readily assimilated by natural processes in small streams but is slowly assimilated in large rivers, such as the Tennessee River. Because agricultural and wastewater sources of nitrogen are concentrated along the main stem of the lower Tennessee River, nitrogen from these sources is readily transported from the Tennessee River Basin to the Gulf of Mexico. In fact, the watersheds in the Lower Tennessee River Basin deliver more than 1.5 (tons/mi^2)/yr of nitrogen to the Gulf of Mexico, compared to less than 0.9 (ton/mi^2)/yr contributed by most watersheds in the Mississippi River Basin (Alexander and others, 2000).



Point Sources of Nitrogen Can Affect Streams and Rivers When Streamflows Are Low

Point sources, such as municipal and industrial discharges, generally contribute a small percentage (about 5 percent) of the total nitrogen transported annually in streams and rivers in the Lower Tennessee River Basin. Point sources, however, can account for a significant percentage of the total nitrogen in streams and rivers during base-flow conditions in the summer and early fall when inputs from nonpoint sources are reduced. For example, point sources account for 50 to 90 percent of the total nitrogen in the Duck River during base-flow conditions in the summer (Hoos and others, 2000). During periods of low streamflow, which generally coincide with optimal conditions for algal growth (long periods of sunlight and warm temperatures), point sources of nitrogen can impair stream health by promoting the growth of nuisance algae.

Nitrate Concentrations in Shallow Ground Water Are Lower than Expected

Although a considerable amount of fertilizer (about 45 (tons/mi^2)/yr) is applied to cropland in the Eastern Highland Rim, nitrate concentrations are generally low in shallow agricultural monitoring wells (generally less than 60 feet deep). About 50 percent of the agricultural monitoring wells had concentrations less than 2 mg/L (fig. 11)—a commonly used threshold indicating input of anthropogenic nitrogen to ground water (Mueller and others, 1995). Agricultural monitoring wells with elevated nitrate concentrations also had elevated total pesticide concentrations.

Denitrification and the uptake of nitrogen by plants are two natural processes that moderate nitrate concentrations in ground water. In the Mississippian carbonate aquifer, low concentrations of nitrate (less than 2 mg/L) are associated with low concentrations of dissolved oxygen, suggesting the removal of nitrate by denitrification (the biochemical conversion of nitrate to nitrogen gas). The predominantly fine-grained soils and weathered rock that overlie bedrock

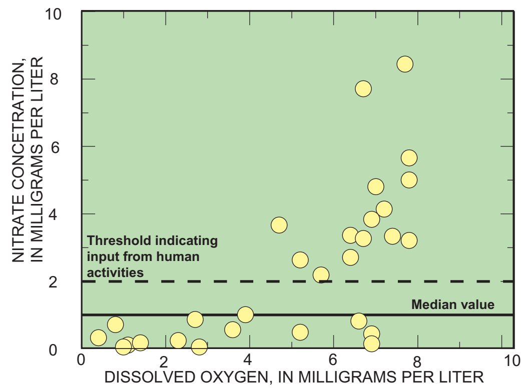
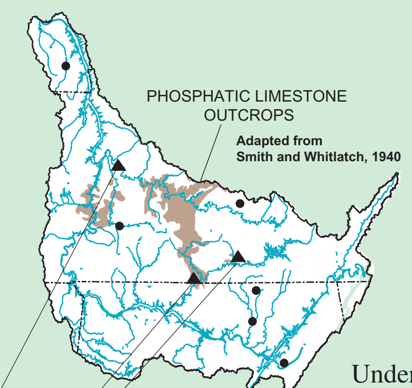
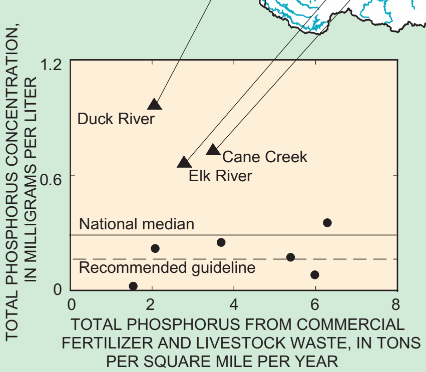
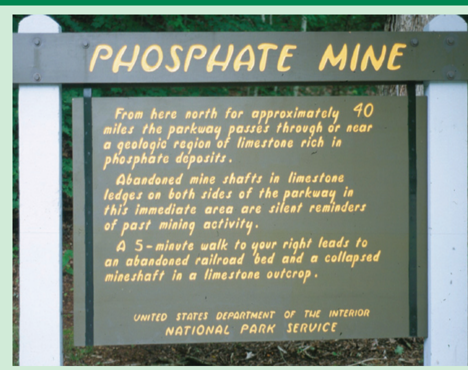


Figure 11. Nitrate concentrations in shallow agricultural monitoring wells are strongly correlated to dissolved-oxygen levels, indicating that denitrification may reduce the amount of nitrate transported into the Mississippian carbonate aquifer.

NATURAL DEPOSITS OF PHOSPHATIC LIMESTONE ARE A MAJOR SOURCE OF PHOSPHORUS IN SOME STREAMS







Understanding naturally occurring sources and levels of phosphorus in streams and rivers is critical in setting attainable numeric criteria for protection of stream ecology and in managing the sources of phosphorus contributed by human activities. Instream concentrations of phosphorus in basins containing outcrops of phosphatic limestone, such as Cane Creek and the Duck and Elk Rivers, are naturally elevated and exceed the USEPA-recommended guideline (U.S. Environmental Protection Agency, 1986b) of 0.1 mg/L by almost eightfold. Among 473 streams and rivers monitored nationwide in the NAWQA Program, Cane Creek and the Duck and Elk Rivers rank in the upper 10 percent for phosphorus concentrations, even though amounts of phosphorus from point and nonpoint sources in these basins are relatively low (Hoos and others, 2000).

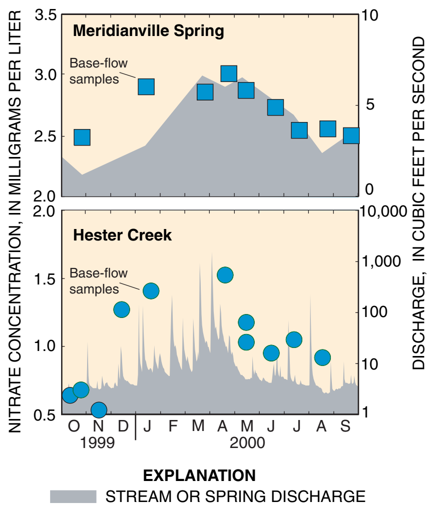


Figure 12. Nitrate concentrations in ground water and in base-flow samples from Hester Creek have similar seasonal variations. Decreases in the summer probably relate to uptake of soil nitrogen by plants, resulting in less transport of nitrate to the Mississippian carbonate aquifer and, subsequently, into streams.

in the Mississippian carbonate aquifer facilitate denitrification by slowing the downward movement of recharge water, leading to decreases in dissolved oxygen and nitrate concentrations. Nitrate concentrations were elevated (greater than 2 mg/L) where dissolved-oxygen concentrations were high (fig. 11). These samples likely represent parts of the aquifer where dissolved oxygen is replenished by ground-water recharge and denitrification does not appreciably affect nitrate concentrations.

The maximum concentration of nitrate in the monitoring wells was 8 mg/L, which is less than the USEPA drinking-water standard for nitrate (10 mg/L). Although most drinking-water-supply wells in the Mississippian carbonate aquifer are completed in bedrock and do not withdraw water from shallow depths, shallow ground water moves downward through conduits in the bedrock and can affect the quality of drinking water in the aquifer.

Nitrate Concentrations Decrease in Ground Water and Base Flow During Summer and Fall

Nitrate concentrations in ground water decrease during summer and fall months (fig. 12); thus, the transport of nitrate to streams decreases at a time when streams are at greatest risk of eutrophication. The seasonal variation of nitrate in the Mississippian carbonate aquifer is illustrated by concentration data from Meridianville Spring. Lower nitrate concentrations in ground water during the summer likely are caused by decreased transport of nitrate from the land surface to the aquifer, resulting from increased uptake of soil nitrogen by plants. Nitrate concentrations during base flow in nearby Hester Creek follow a similar pattern of decreasing in the late summer and fall during periods of base flow when ground water is the primary source of nitrate to the stream.

Nitrate Concentrations in Drinking Water Generally Were Below Level of Concern

Ground water in the Lower Tennessee River Basin generally is safe to drink with respect to nitrate. Nitrate concentrations in the Mississippian and Ordovician carbonate aquifers were less than the USEPA drinking-water standard of 10 mg/L in 71 of the 73 wells sampled. Point sources may have contributed to the elevated nitrate concentrations, which exceeded the USEPA drinking-water standard for nitrate, in the other two wells. In addition, nitrate concentrations in about 70 percent of the springs and wells in the Mississippian and Ordovician carbonate aquifers were less than the 2–mg/L threshold, indicating background levels.

The median nitrate concentration for wells in the Ordovician carbonate aquifer was lower (less than 0.2 mg/L) than the median concentration for springs in the same aquifer (1.2 mg/L) (fig. 13). Nitrate can be removed by denitrification in aquifers with low dissolved-oxygen concentrations, and the median dissolved-oxygen concentration for wells in the Ordovician carbonate aquifer was less than 1 mg/L, compared to 8 mg/L for the springs.

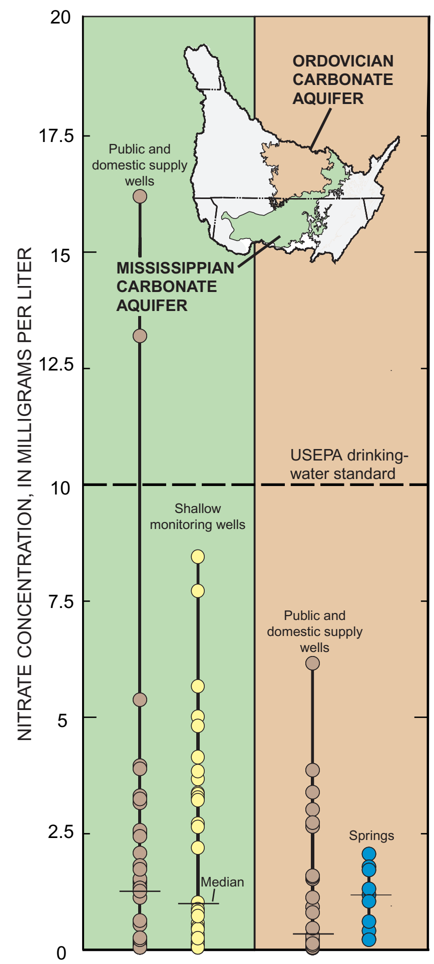
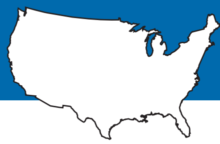


Figure 13. Nitrate concentrations in almost all wells and springs sampled in the Lower Tennessee River Basin were below the USEPA drinking-water standard.

Additional Information

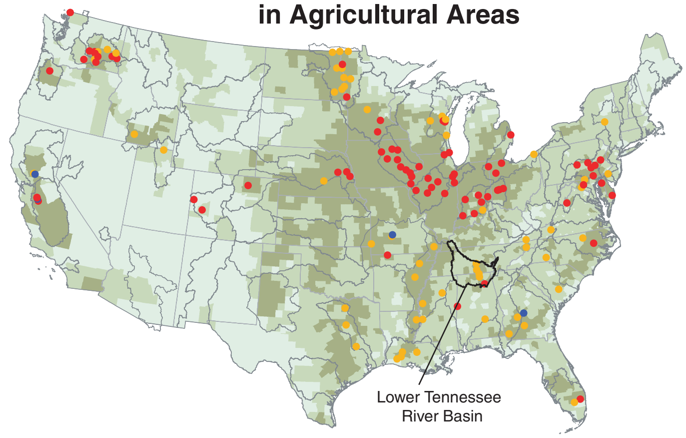
For additional information on nutrients in the Lower Tennessee River Basin, refer to Hoos and others (2000), Woodside and Hoos (2001), Kingsbury and Shelton (2002), and Kingsbury (2003). These reports are available at http://water.usgs.gov/pubs/wri/wri994139, http://water.usgs.gov/pubs/FS/fs02501, http://water.usgs.gov/pubs/wri/wri024083, and http://water.usgs.gov/pubs/wri/wri034181



NITRATE CONCENTRATIONS IN STREAMS AND GROUND WATER GENERALLY ARE SIMILAR TO THE NATIONAL MEDIAN

Mean annual nitrate concentrations in Hester, North Fork, and Cane Creeks, which drain agricultural land, are below the national median for 79 agricultural streams sampled nationwide as part of the NAWQA Program. Mean annual nitrate concentration in Scarham Creek, which drains an area with a high density of poultry-feeding operations, is slightly higher than the national median. Mean annual nitrate concentrations in the Flint, Elk, and Duck Rivers, which drain basins with mixed land uses, are similar to concentrations in agricultural streams in the Lower Tennessee River Basin and are similar to or above the national median for rivers with mixed land use.

Total Nitrogen in Streams in Agricultural Areas

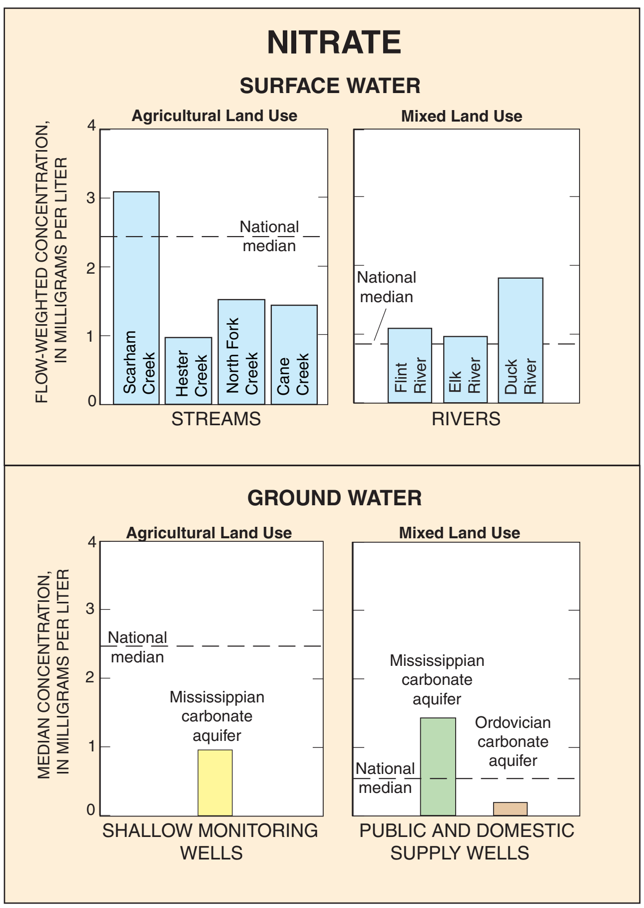


EXPLANATION

MEAN ANNUAL CONCENTRATION OF TOTAL NITROGEN—IN MILLIGRAMS PER LITER
- Highest (greater than 3)
- Meduim (0.6 to 3)
- Lowest (less than 0.6)

Median: 2.4 mg/L

AVERAGE ANNUAL TOTAL NITROGEN INPUT—IN POUNDS PER ACRE, BY COUNTY. INPUTS ARE FROM FERTILIZER, MANURE, AND ATMOSPHERE.
- Greater than 25 pounds per acre
- 6 to 25 pounds per acre
- Less than 6 pound per acre



The median nitrate concentration in shallow agricultural monitoring wells in the Mississippian carbonate aquifer is below the national median in about 1,440 agricultural monitoring wells sampled nationwide as part of the NAWQA Program, whereas the median concentration for public and domestic supply wells in the Mississippian carbonate aquifer is above the national median. The low concentrations of nitrate in public and domestic supply wells in the Ordovician carbonate aquifer (median value 0.2 mg/L) may be related to the instability of nitrate in this aquifer. Dissolved-oxygen concentrations in wells in this aquifer were low (median below 1 mg/L), resulting in conditions favorable for denitrification.

In streams, rivers, and lakes, elevated concentrations of nutrients can stimulate nuisance growth of algae. As the algae decay, dissolved oxygen is depleted, thereby affecting fish and other aquatic life.

Pesticides

Pesticides in Surface- and Ground-Water Resources

About 3.7 million pounds of pesticides were applied to cropland in the Lower Tennessee River Basin in 1992 (Kingsbury and others, 1999). Six pesticides (atrazine, monosodium methanearsonate (MSMA), 2,4-D, metolachlor, methyl parathion, and fluometuron) accounted for about 42 percent of the total amount of pesticides applied in the basin. Almost half of the agricultural pesticides used in the basin are applied to crops, such as cotton, corn, and soybeans, in the Eastern Highland Rim, which is underlain by the Mississippian carbonate aquifer.

Although pesticide concentrations in surface- and ground-water resources in the Lower Tennessee River Basin infrequently exceeded standards and guidelines to protect human health and aquatic life, mixtures of pesticides were frequently detected. The effects of long-term exposure to mixtures of pesticides at low concentrations are poorly understood; thus, it is important to understand the fate of pesticides in the environment.

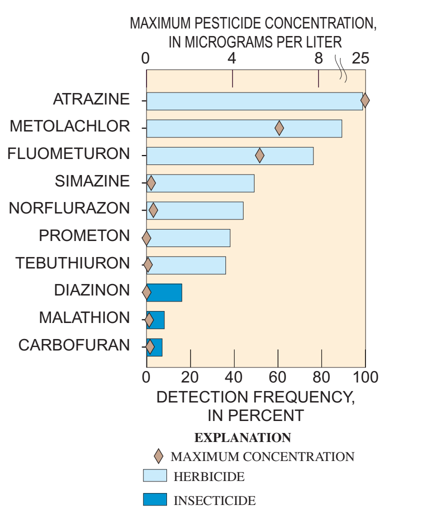


Figure 14. Herbicides were detected at higher concentrations and more frequently than insecticides in streams and rivers in the Lower Tennessee River Basin.

Pesticides Were Commonly Detected in Streams and Rivers

Fifty-two pesticides, including 38 herbicides, 11 insecticides, and 3 fungicides, were detected in streams and rivers in the Lower Tennessee River Basin. The herbicides atrazine (applied to corn) and metolachlor (applied to soybeans) were detected in more than 89 percent of the samples (fig. 14). Other herbicides frequently detected include fluometuron and norflurazon, which are applied to cotton, and prometon and tebuthiuron, commonly applied to control vegetation along highway and railroad rights-of-way. Insecticides applied in agricultural and urban areas, such as diazinon, malathion, and carbofuran, were detected in less than 16 percent of the samples.

Although pesticides were frequently detected, aquatic-life guidelines were exceeded in less than 6 percent of the 134 samples. Pesticides that exceeded aquatic-life guidelines include atrazine, cyanazine, and malathion; however, no aquatic-life guidelines have been established for 31 of the 52 pesticides detected.

Pesticides Detected Vary with Streamflow and Season

The mixtures of pesticides detected in streams and rivers varied with streamflow conditions and season. The largest numbers of pesticides (as many as 25 pesticides in one sample) and the highest pesticide concentrations in Hester Creek and the Flint River were detected during the growing season following a storm (fig. 15).

In Hester Creek and the Flint River, two or more pesticides were detected in every sample collected during base-flow conditions when there was no surface runoff, indicating transport of some pesticides through the ground-water system. The number of pesticides detected in

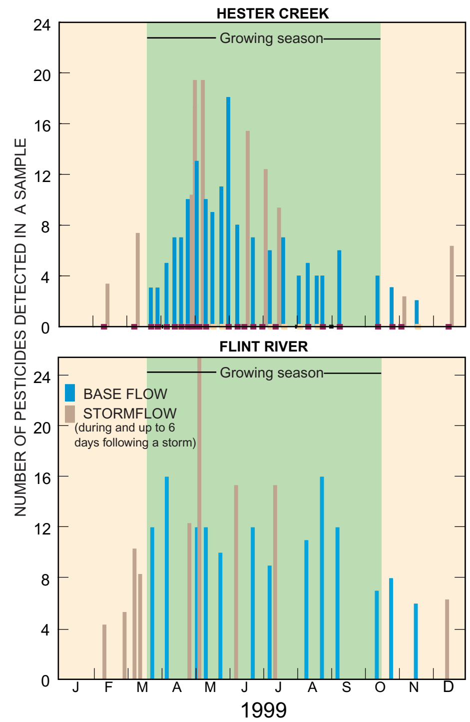


Figure 15. Although a large number of pesticides were detected in surface water during the early part of the growing season, a small number of pesticides were present throughout the year.

base-flow samples from Hester Creek decreased from eight or more early in the growing season to fewer than four during the fall and winter (fig. 15). In contrast, base-flow samples from the Flint River generally contained eight or more pesticides throughout the year with little seasonal variability. The differences in the numbers of pesticides in base-flow samples between Hester Creek and the Flint River likely are the result of differences in average residence times of ground water in these basins. The decrease in the number of pesticides in base-flow samples from Hester Creek in the fall and winter suggests that ground-water flow paths are relatively short. The high number of pesticides detected in base-flow samples from the Flint River throughout the year suggests longer ground-water flow paths and indicates that pesticides applied during the growing season persist in the aquifer throughout the year.

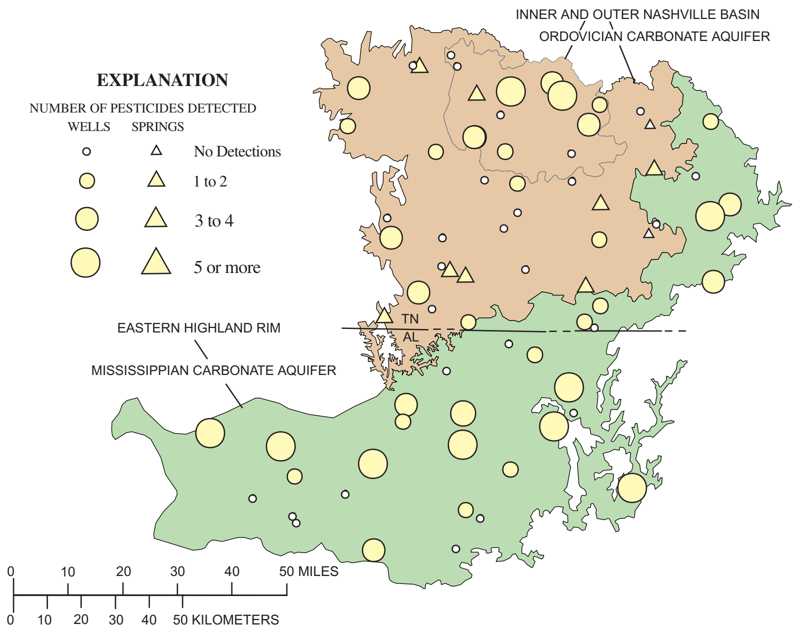


Figure 16. Pesticide mixtures were more prevalent in wells in the Eastern Highland Rim, which is about 16 percent cropland, than in wells in the Inner and Outer Nashville Basin, which is about 4 percent cropland.

Pesticides Were Detected at Low Concentrations in Carbonate Aquifers

Although one or more pesticides were detected in about 60 percent of the wells and springs sampled in the Mississippian and Ordovician carbonate aquifers, 95 percent of the pesticide concentrations were less than 0.5 µg/L, well below drinking-water standards. Little is known, however, about the potential health effects of exposure to low levels of multiple pesticides. Thirty-five pesticides, including 28 herbicides, 6 insecticides, and 1 fungicide, were detected in wells and springs sampled in the Mississippian and Ordovician carbonate aquifers. The most frequently detected pesticides were atrazine and deethylatrazine, a degradation product of atrazine. Five or more pesticides were detected in 19 percent of the wells in the Mississippian carbonate aquifer and in 10 percent of the wells in the Ordovician carbonate aquifer (fig. 16).

None of the pesticides detected in the carbonate aquifers exceeded drinking-water standards; however, a human health benchmark was exceeded for dieldrin, a potentially carcinogenic insecticide. Dieldrin was detected in 19 percent of the wells in the Mississippian carbonate aquifer, and concentrations exceeded 0.02 µg/L, the risk-specific dose for a cancer-risk level of 1 in 100,000 (U.S. Environmental Protection Agency, 2002a), in about 13 percent of the wells.

Prior to being banned in 1984, dieldrin was used as an insecticide on cotton and as a termiticide in homes. The lack of detections of dieldrin in shallow agricultural monitoring wells in the Mississippian carbonate aquifer is an indication that dieldrin residues associated with termite treatments are a likely source of this insecticide rather than residues associated with cotton cultivation.

Carbonate Aquifers Are Vulnerable to Nonpoint-Source Contamination

Pesticides detected in the carbonate aquifers reflect differences in land use in the Eastern Highland Rim and in the Inner and Outer Nashville Basins. General-use pesticides that are applied along road and powerline rights-of-way and in urban areas to control woody vegetation and weeds (tebuthiuron and prometon) were detected at similar frequencies in wells in both carbonate aquifers (fig. 17). Agricultural pesticides were detected more frequently in the Mississippian carbonate aquifer than in the Ordovician carbonate aquifer. In the Ordovician carbonate aquifer, atrazine was the only agricultural pesticide detected in more than 9 percent of the samples (three detections, fig. 17). In contrast, eight pesticides were detected in 9 percent or more of samples from the Mississippian carbonate aquifer. Several of these pesticides, such as the herbicide fluometuron (fig. 17), are used on cotton and were detected in less than 3 percent of the samples from the Ordovician carbonate aquifer. Only a small amount of cotton (about 4,000 acres) is cultivated in the Inner and Outer Nashville Basin (Kingsbury and others, 1999).

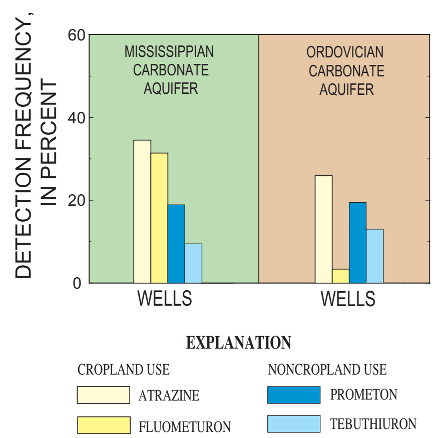


Figure 17. Pesticides that are used predominantly on cropland were detected more frequently in samples from wells in the Mississippian carbonate aquifer, whereas noncropland pesticides were detected at similar frequencies in both aquifers.

Shallow monitoring wells installed near agricultural fields and deeper wells that supply drinking water throughout the Eastern Highland Rim were sampled to describe the quality of water in the Mississippian carbonate aquifer.

The detection of similar pesticides in shallow and deep wells in the Mississippian carbonate aquifer indicates that the aquifer is vulnerable to nonpoint-source contamination (fig. 18). Shallow agricultural monitoring wells (generally less than 60 feet deep) were installed near agricultural fields throughout the Eastern Highland Rim to characterize the quality of water in the Mississippian carbonate aquifer that is most likely to be affected by agricultural land uses (primarily the production of cotton, corn, and soybeans). Although detection frequencies were somewhat higher in the shallow agricultural monitoring wells than in the deep wells used for drinking-water supply in the Mississippian carbonate aquifer, the same pesticides were detected frequently and at comparable concentrations in both well networks (fig. 18). Detection of the same pesticides in both types of wells is probably the result of the karst hydrology of the Mississippian aquifer, which increases the transport of nonpoint-source contaminants away from agricultural areas.

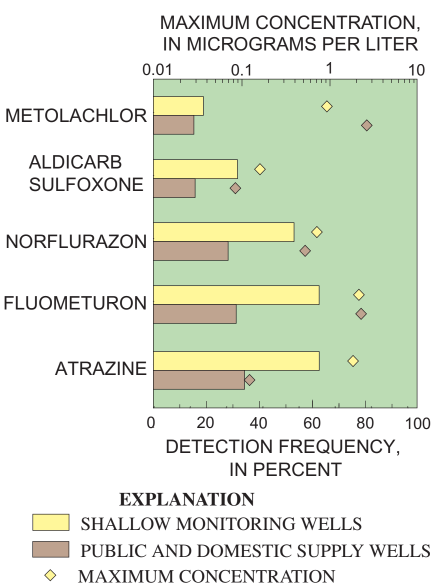


Figure 18. Pesticides detected in shallow monitoring wells also were detected in public- and domestic-supply wells in the Mississippian carbonate aquifer.

Pesticide Degradates Were Detected in Surface and Ground Water

Knowledge of the occurrence of pesticide degradates in the hydrologic system is important in understanding the fate of pesticides in the environment. Pesticides typically are designed to degrade in a few days or weeks after application. Some pesticides, such as aldicarb, degrade into compounds that are about as toxic as the original pesticide. For most pesticide degradates, the long-term effects on human health and aquatic life generally are not well understood.

Degradates of atrazine, fluometuron (fig. 19), norflurazon, and aldicarb were detected frequently in surface water and ground water in the Eastern Highland Rim. In surface water, degradate concentrations varied seasonally. Concentrations were highest in the spring, similar to the seasonal variation in concentration of the parent pesticides. Detection of degradates generally coincided with detection of the parent pesticide, except for aldicarb. Aldicarb degradates were detected frequently in surface and ground water at concentrations less than 0.5 µg/L; however, aldicarb was detected in only one ground-water sample (fig. 19).

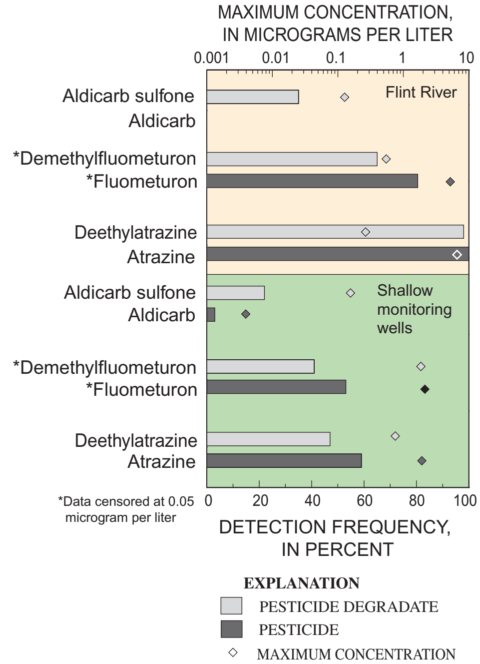


Figure 19. Pesticides and their degradates were detected in surface water and in shallow ground water.

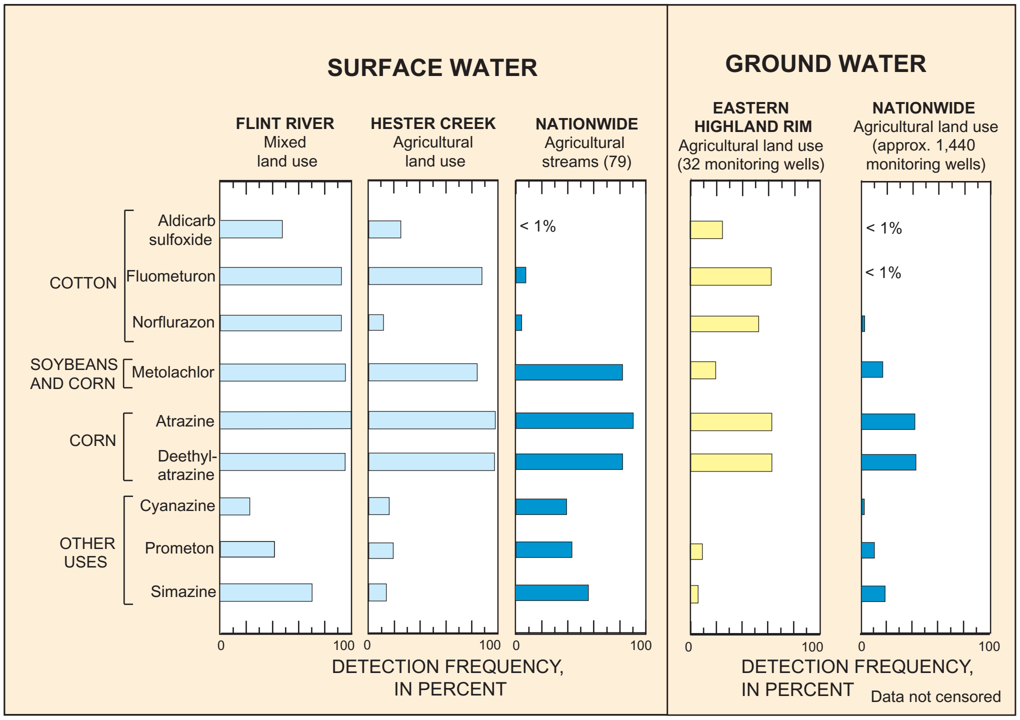
Additional Information

For additional information on pesticides in surface- and ground-water resources in the Lower Tennessee River Basin, refer to Hoos and others (2002), Kingsbury and Shelton (2002), and Kingsbury (2003).

These reports are available at http://water.usgs.gov/pubs/wri/wri014185, http://water.usgs.gov/pubs/wri/wri024083, and http://water.usgs.gov/pubs/wri/wri034181

PESTICIDE DETECTIONS IN THE LOWER TENNESSEE RIVER BASIN WERE HIGHER THAN NATIONAL RESULTS

Pesticides applied to corn, cotton, and soybeans were frequently detected in Hester Creek, the Flint River, and in shallow monitoring wells in the Mississippian carbonate aquifer.



Pesticides frequently detected in surface and ground water in the Lower Tennessee River Basin generally are similar to those frequently detected throughout the Nation. Atrazine is among the pesticides with the highest estimated use in the Lower Tennessee River Basin and across the Nation and was detected in more than 90 percent of the samples collected from agricultural streams both in the Lower Tennessee River Basin and nationwide. Sixty-two percent of the agricultural monitoring wells in the Lower Tennessee River Basin contained atrazine, compared to 40 percent of the agricultural monitoring wells across the Nation.

Herbicides applied to cotton, fluometuron and norflurazon, were detected more frequently in Hester Creek, the Flint River, and in ground water in the Eastern Highland Rim than nationwide. This probably is because cotton cultivation is limited to small geographic areas throughout the Nation. However, fluometuron was detected in the Flint River at higher frequencies compared to a subset of 34 basins across the Nation with cotton cultivation and fluometuron use. The instream detection frequency of fluometuron for the Flint River, relative to the amount applied in the basin and normalized by drainage area, was second to the highest among the subset of 34 basins across the Nation.

The occurrence of pesticides in surface water and ground water is related not only to the amounts applied but also to physical and chemical properties controlling pesticide mobility in the environment. In the Lower Tennessee River Basin, several pesticides, such as atrazine and fluometuron, were detected both in ground-water and base-flow samples, indicating pesticide movement into and through the ground-water system. Other pesticides, such as cyanazine, were detected in storm samples from streams but typically were not detected in ground-water or base-flow samples. Estimates of the half-life of cyanazine are only about 10 percent as long as the half-life of atrazine, suggesting that cyanazine breaks down more rapidly than atrazine; thus, the transport of cyanazine to ground water is negligible.

Although thousands of pounds of pesticides are applied to cropland annually, sorption of pesticides to soils and degradation by microbes, sunlight, and chemical reactions reduce the amount of pesticides that can be washed into streams and rivers. The amounts of atrazine, metolachlor, fluometuron, and norflurazon transported from cropland to the Flint River and Hester Creek ranged from 3 to 5 percent of the estimated amount applied (Hoos and others, 2002). These herbicides are applied to the soil before crops emerge, thus increasing the likelihood of transport in surface runoff.

Volatile Organic Compounds

VOCs Were Detected at Low Concentrations in Carbonate Aquifers

Volatile organic compounds (VOCs) are a water-quality concern because of their widespread use, toxicity, and documented presence at low concentrations in ground water across the Nation (Squillace and others, 1999). Paints, solvents, fuels, refrigerants, fumigants, and fuel additives contain VOCs. Many VOCs, such as the dry-cleaning solvent PCE, are known or suspected carcinogens.

VOCs were detected in about 67 percent of the wells and springs sampled in the Mississippian and Ordovician carbonate aquifers in the Lower Tennessee River Basin. Although VOCs were detected frequently, 70 percent of the detections were less than 0.2 µg/L, which is at least 20 times less than drinking-water standards for most VOCs. Eleven of the 29 VOCs detected in the carbonate aquifers have drinking-water standards. Concentrations of VOCs equaled or exceeded drinking-water standards in only two wells. PCE and TCE, both of which have a drinking-water standard of 5 µg/L (U.S. Environmental Protection Agency, 2002b), were detected at 7.5 and 5 µg/L, respectively. Although 29 VOCs were detected, 13 VOCs were detected only once, and most were in one well in the Ordovician carbonate aquifer, where natural deposits of crude oil and natural gas may be a source of VOCs in ground water.

Numerous roadside springs throughout the Lower Tennessee River Basin are commonly used for drinking water even though springs are susceptible to nearby sources of contamination.

Carbonate Aquifers Are Vulnerable to Contamination

VOCs detected in carbonate aquifers in the Lower Tennessee River Basin were similar to those detected in major aquifers across the Nation; however, detection frequencies were higher in the Mississippian carbonate aquifer (fig. 20). The karst hydrology of this aquifer, with numerous sinkholes and other karst landforms, likely increases the probability of ground-water contamination. Springs are particularly susceptible to nearby sources of contamination on the surface. VOCs were detected more frequently in springs than in wells in the Ordovician carbonate aquifer.

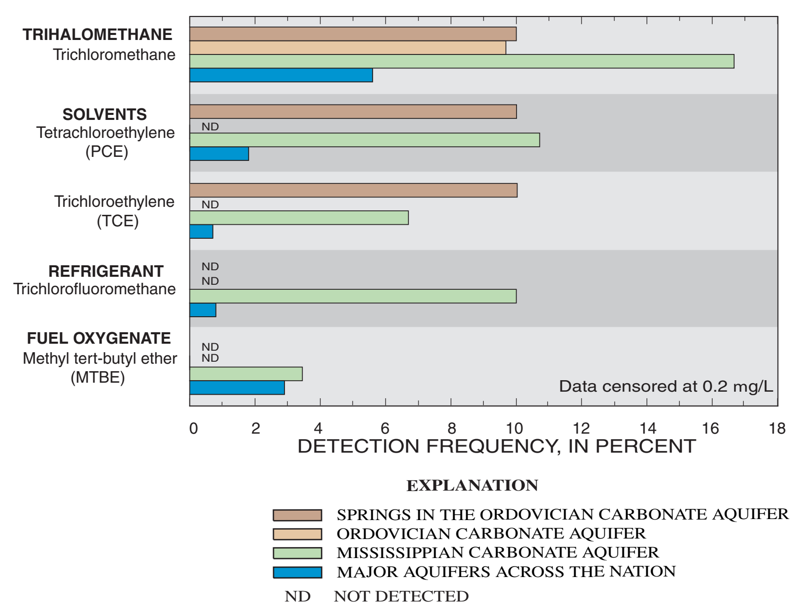


Figure 20. Volatile organic compounds were detected more frequently in the Mississippian carbonate aquifer than in the Ordovician carbonate aquifer and across the Nation.

Detection of VOCs Is Related to Population Density

VOCs are prevalent nationwide in shallow aquifers near urban areas (Squillace and others, 1999). This also is true in the Lower Tennessee River Basin. VOCs were detected in 80 percent of the wells sampled in the Mississippian carbonate aquifer and in 55 percent of the wells and 70 percent of the springs sampled in the Ordovician carbonate aquifer. The Eastern Highland Rim, which overlies the Mississippian carbonate aquifer, had about 170 people per square mile in 1995, compared to about 70 people per square mile in the Inner and Outer Nashville Basins, which overlie the Ordovician carbonate aquifer.

Fish Tissue

DDT and PCBs Persist in Fish Tissue

Although uses of DDT and PCBs were discontinued more than 20 years ago, residues of these compounds continue to be detected in fish tissue throughout the Lower Tennessee River Basin. DDT and PCBs are stored in fatty tissue and are slow to degrade, resulting in bioaccumulation of these compounds in fish.

DDT was used as an insecticide in urban and agricultural areas, with peak usage in the United States occurring in the early 1960s. The use of DDT was discontinued in the United States in 1973, except during public health emergencies. Prior to 1973, DDT was applied in the basin primarily to cotton fields to control insects, and to wetlands, marshes, and reservoirs to prevent the occurrence of mosquitoes and the spread of malaria.

DDT and PCBs were detected frequently in whole fish and fish fillets in samples collected by State and Federal agencies from 1980 to 1998; however, less than 3 percent of the sites had concentrations that exceeded human health action levels or wildlife guidelines (Knight and Powell, 2001). Specifically, DDT and its degradation products DDD and DDE were detected either singly or in combination at 136 of 144 sites in the basin. The human health action level for total DDT in fish fillets was exceeded at four sites (fig. 21). Total DDT concentrations in whole fish also exceeded the guideline for the protection of fish-eating wildlife at four sites.

Courtesy of the Tennessee Valley Authority Historic Collection, 1938

In addition to agricultural uses, DDT also was applied to wetlands, marshes, and reservoirs in the Lower Tennessee River Basin to control mosquito populations and prevent the spread of malaria.

PCBs were developed more than 120 years ago for use as lubricants, heat-transfer agents, and flame retardants in electrical components. In 1979, the use of PCBs was restricted primarily to totally enclosed systems. PCBs were detected in whole fish and fish fillets at 78 percent of the sites sampled from 1985 to 1998 in the basin. The U.S. Food and Drug Administration (2003) temporary tolerance level of 2,000 µg/kg for concentrations of PCBs in fish fillets was exceeded at six sites along the main stem of the Tennessee River. At two sites, PCBs in whole fish exceeded the 110–µg/kg guideline to protect fish-eating wildlife (Newell and others, 1987).

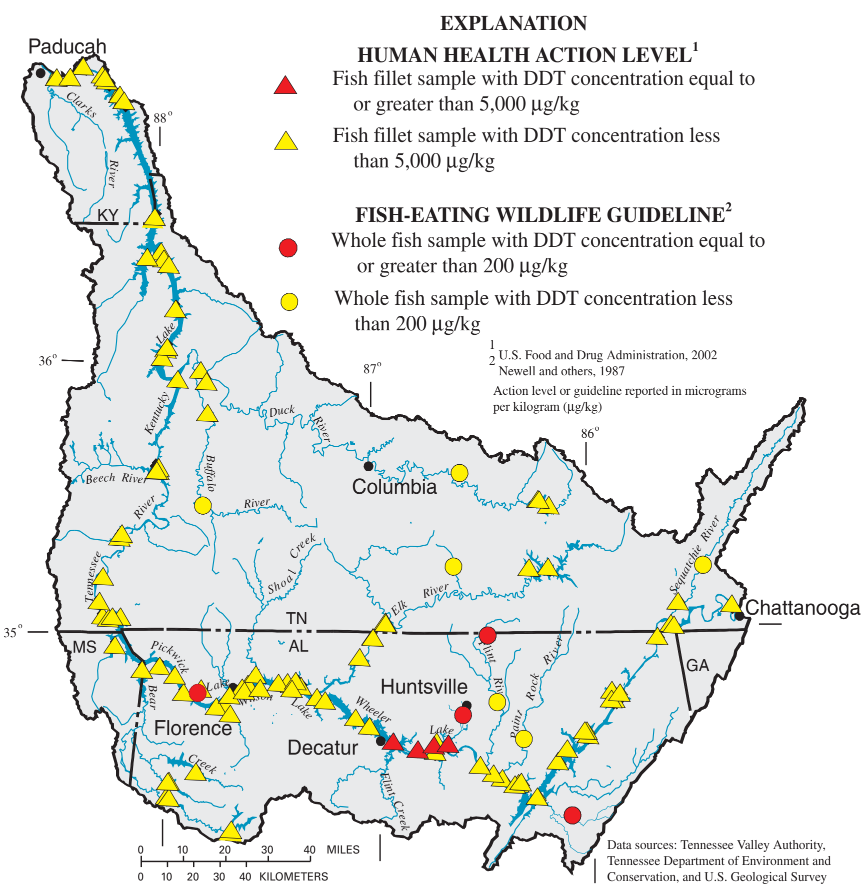


Figure 21. Although the use of DDT was banned in 1973, residues of DDT are detected frequently in fish tissue at sites throughout the Lower Tennessee River Basin.

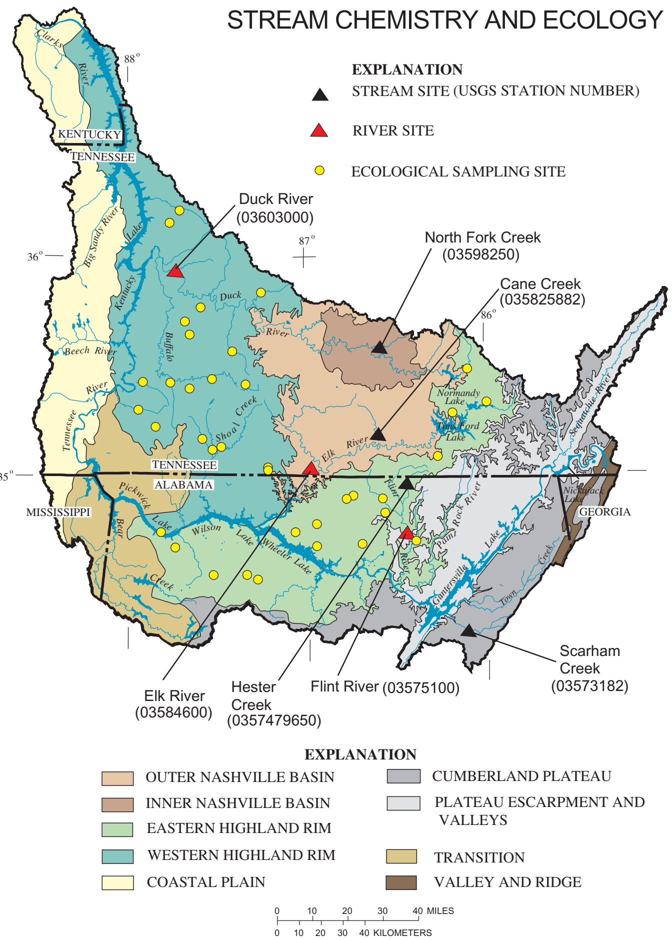
Additional Information

For a detailed description of the occurrence and distribution of pesticides and trace elements in fish tissue in the Lower Tennessee River Basin, refer to Knight and Powell (2001).

The report is available at http://water.usgs.gov/pubs/wri/wri014184

Study Unit Design

The Lower Tennessee River Basin Study Unit design blends an assessment of local water-quality issues within a nationally consistent design structure that incorporates a multi-scale, interdisciplinary approach consisting of stream chemistry, stream ecology, and ground-water chemistry (Gilliom and others, 1995). Surface-water, ecological, and ground-water studies focused primarily on the Inner and Outer Nashville Basins and the Eastern and Western Highland Rims. Karst landforms, such as caves, sinkholes, and springs, in these areas increase the vulnerability of surface- and ground-water resources to contamination.



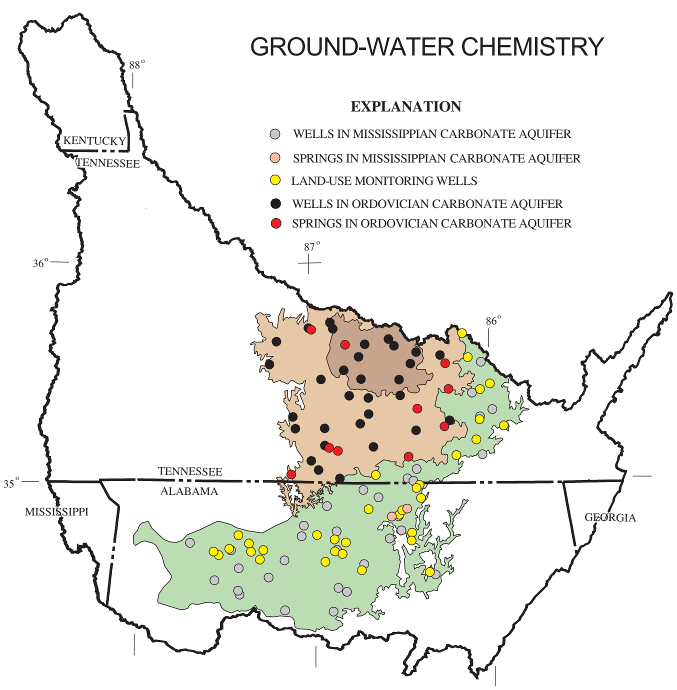
Stream Chemistry and Ecology

Stream-chemistry assessments focused on how water quality varies in rivers and streams in relation to land use and natural setting—a combination of geology, soils, and physiography. The quality of water in the Duck, Elk, and Flint Rivers reflects a complex mixture of land uses and natural settings. The quality of water in the four selected streams (North Fork Creek, Cane Creek, Hester Creek, and Scarham Creek) represents the effects of mostly agricultural land uses, both pastureland and cropland, within distinct, relatively homogeneous natural settings.

Ecological assessments focused primarily on describing how fish, invertebrate, and algal communities and instream habitat vary in relation to land use throughout the Eastern and Western Highland Rim.

Ground-Water Chemistry

Ground-water assessments focused on carbonate aquifers underlying the Eastern Highland Rim and the Inner and Outer Nashville Basin. These aquifers are important sources of drinking water for public water systems and domestic uses in rural areas. These aquifers also are vulnerable to contamination because of the karst landforms. Domestic wells and springs were sampled to characterize the water quality of the carbonate aquifers. Shallow monitoring wells, installed in or near cotton, corn, or soybean fields, were sampled to characterize the effects of agriculture on recently recharged ground water in the Eastern Highland Rim.



Additional Information

Additional information on water-quality conditions in the Lower Tennessee River Basin is available at http://tn.water.usgs.gov/lten/tenn.html

Water-quality data and collection and analytical methods can be accessed at http://water.usgs.gov/nawqa

Study component	What data were collected and why	Types of sites sampled	Number of sites sampled	Sampling frequency and period
Stream Chemistry				
Bottom sediment	Trace metals, organochlorine pesticides, PCBs, and semivolatile organic compounds were measured in bottom sediment collected from depositional zones to assess the presence of potentially toxic compounds.	Rivers and streams draining a mixture of land uses with drainage areas ranging from 29.3 to 2,557 square miles	14	Once, 1998.
Rivers	Major ions, nutrients, organic carbon, bacteria, and suspended sediment were measured to describe seasonal variations of concentrations and loads in rivers draining a mixture of land uses and subunits.	Duck River (2,557 square miles), Elk River (1,805 square miles)	2	Monthly and storm events, 1999–2000.
Streams	Major ions, nutrients, organic carbon, bacteria, and suspended sediment were measured to describe seasonal variations of concentrations and loads in streams draining pasture and cultivated land in three subunits (fig. 1).	Cane Creek, Outer Nashville Basin (78.8 square miles); North Fork Creek, Inner Nashville Basin (74.1 square miles); Scarham Creek, Cumberland Plateau (54.4 square miles)	3	Monthly and storm events, 1999–2001.
Pesticides— in rivers and streams	Pesticides, major ions, nutrients, organic carbon, bacteria, and suspended sediment were measured to determine short-term temporal variations in concentrations and loads.	Flint River (374 square miles), Hester Creek (29.3 square miles); Both basins located in the Eastern Highland Rim	2	Biweekly, Mar.–Nov. 2000; monthly and storm events, 1999–2001.
Stream Ecology				
Fish tissue	Organochlorine pesticides, PCBs, and trace elements in fish tissue were measured to assess the presence of potentially toxic compounds.	Rivers and streams draining a mixture of land uses with drainage areas ranging from 29.3 to 447 square miles	10	Aug.–Sept. 1998.
Streams	Aquatic communities (fish, macroinvertebrates, and algae) and stream habitat were measured to describe aquatic communities in four subunits (fig. 1) in the basin.	Cane Creek, Outer Nashville Basin; North Fork Creek, Inner Nashville Basin; Scarham Creek, Cumberland Plateau; Hester Creek, Eastern Highland Rim	4	Annually, 1999–2001.
Land use—agricultural	Aquatic communities (fish, macroinvertebrates, and algae), stream habitat, nutrients, bacteria, and streamflow were measured to assess the effects of agricultural land use on aquatic communities.	Streams in the Eastern Highland Rim, Streams in the Western Highland Rim	20, 17	Once, 1999; 2000–2001.
Ground-Water Chemistry				
Carbonate aquifer survey	Major ions, nutrients, dissolved organic carbon, trace metals, pesticides, volatile organic compounds, bacteria, and radon were measured to describe the quality of water in the Mississippian aquifer.	Domestic and public-supply wells, ranging in depth from 38 to 157 feet, distributed throughout the Eastern Highland Rim	32 wells	Once, June–July 1999.
Springs—temporal variability	Discharge, major ions, dissolved organic carbon, pesticides, and bacteria were measured to describe the temporal variability in ground-water quality in the Mississippian aquifer.	Springs located in the Eastern Highland Rim — Meridianville Spring and McGeehee Spring	2 springs	Bimonthly, Apr. 1999 – Feb. 2000; monthly, Mar. 2000–2001.
Land use—agricultural	Major ions, nutrients, dissolved organic carbon, pesticides, and bacteria were measured to assess the effects of agriculture on the quality of shallow ground water in the Mississippian aquifer.	Monitoring wells, ranging in depth from 14 to 79 feet, installed at randomly selected sites in agricultural areas in the Eastern Highland Rim	28 wells, 4 wells	Once, May–June 2000; April 2001.
Carbonate aquifer survey	Major ions, nutrients, dissolved organic carbon, trace metals, pesticides, volatile organic compounds, bacteria, and radon were measured to describe the quality of water in the Ordovician aquifer.	Domestic and public-supply wells, ranging in depth from 22 to 300 feet, and springs distributed throughout the Inner and Outer Nashville Basins	31 wells, 10 springs	Once, Sept.–Oct. 2000.

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Glossary

Aquatic-life criteria - Water-quality guidelines for protection of aquatic life. Often refers to U.S. Environmental Protection Agency water-quality criteria for protection of aquatic organisms.

Aquifer - A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.

Base flow - Sustained, low flow in a stream; ground-water discharge is the source of base flow in most places.

Bioaccumulation - The net accumulation of a substance by an organism as a result of uptake from all environmental sources, including gills, epithelial tissues, and dietary sources.

Carbonate rocks - Rocks (such as limestone or dolostone) that are composed primarily of minerals (such as calcite and dolomite) containing the carbonate ion (CO_3^{2-}).

Community - In ecology, the species that interact in a common area.

Cubic foot per second (ft^3/s, or cfs) - Rate of water discharge representing a volume of 1 cubic foot passing a given point during 1 second, equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.02832 cubic meter per second.

Degradation products - Compounds resulting from transformation of an organic substance through chemical, photochemical, and/or biochemical reactions.

DDT - Dichloro-diphenyl-trichloroethane. An organochlorine insecticide no longer registered for use in the United States.

Drinking-water standard or guideline - A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

Ecoregion - An area of similar climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

Escherichia coli (E. coli) - Bacteria present in the intestine and feces of warm-blooded animals. *E. coli* are a member species of the fecal coliform group of indicator bacteria.

Eutrophication - The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Flow-weighted mean - A concentration calculated by first multiplying each sample concentration by its associated streamflow value, then dividing the sum of these products by the sum of the streamflows. The resultant mean value accounts for the effects of variable streamflow on concentrations.

Hypoxia - Low dissolved oxygen concentrations, usually less than 2 parts per million, in lakes, estuaries, and coastal waters. In many cases, hypoxic waters do not have enough oxygen to support fish and other aquatic animals. Hypoxia can be caused by an excess of nutrients.

Karst - A type of topography that results from dissolution and collapse of carbonate rocks such as limestone and dolomite, and characterized by closed depressions or sinkholes, caves, and underground drainage.

Load - General term that refers to a material or constituent in solution, in suspension, or in transport; usually expressed in terms of mass or volume.

Main stem - The principal course of a river or a stream.

Maximum contaminant level (MCL) - Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

Micrograms per liter (µg/L) - A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion in most streamwater and ground water. One thousand micrograms per liter equals 1 milligram per liter.

Milligrams per liter (mg/L) - A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million in most streamwater and ground water. One thousand micrograms per liter equals 1 milligram per liter.

Monitoring well - A well designed for measuring water levels and testing ground-water quality.

Nitrate - An ion consisting of nitrogen and oxygen (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

Nonpoint-source water pollution - Water contamination that originates from a broad area (such as leaching of agricultural chemicals from crop land) and enters the water resource diffusely over a large area.

Nutrient - Element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Phosphorus - A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Point source - A source at a discrete location such as a discharge pipe, drainage ditch, tunnel, well, concentrated livestock operation, or floating craft.

Polychlorinated biphenyls (PCBs) - A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

Turbidity - Reduced clarity of surface water because of suspended particles, usually sediment.

Volatile organic compounds (VOCs) - Organic chemicals that have a high vapor pressure relative to their water solubility. VOCs include components of gasoline, fuel oils, and lubricants, as well as organic solvents, fumigants, some inert ingredients in pesticides, and some byproducts of chlorine disinfection.

Water-quality standards - State-adopted and U.S. Environmental Protection Agency-approved ambient standards for water bodies. Standards include the use of the water body and the water-quality criteria that must be met to protect the designated use or uses.

Water year - The continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with the surface-water supply. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1980, is referred to as water year 1980.

Appendix—Water Quality Data from the Lower Tennessee River Basin in a National Context

Concentrations and detection frequencies of the most commonly detected constituents, constituents that exceed a drinking-water standard or aquatic-life guideline, or constituents that are of regulatory or scientific importance are presented below. Plots of other pesticides, nutrients, VOCs, and trace elements assessed in the Lower Tennessee River Basin are available at our Web site at:

http://water.usgs.gov/nawqa/graphs

These summaries of chemical concentrations and detection frequencies from the Lower Tennessee River Basin are compared to findings from 51 NAWQA Study Units investigated from 1991 to 2001 and to water-quality benchmarks for human health, aquatic life, fish-eating wildlife, or prevention of nuisance plant growth. These graphical summaries provide a comparison of chemical concentrations and detection frequencies between (1) surface- and ground-water resources, (2) agricultural, urban, and mixed land uses, and (3) shallow ground water and aquifers commonly used as a source of drinking water.

CHEMICALS IN WATER

Concentrations and detection frequencies, Lower Tennessee River Basin, 1999–2001

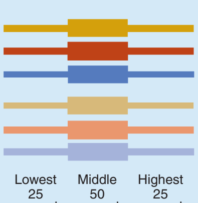
◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

- - Not measured or sample size less than two

12 Study-unit sample size. For ground water, the number of samples is equal to the number of wells sampled

National ranges of detected concentrations, by land use, in 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected



Streams in agricultural areas
Streams in urban areas
Streams and rivers draining mixed land uses
Shallow ground water in agricultural areas
Shallow ground water in urban areas
Major aquifers

Lowest 25 percent | Middle 50 percent | Highest 25 percent

National water-quality benchmarks

National benchmarks include standards and guidelines related to drinking-water quality, criteria for protecting the health of aquatic life, and the desired goal for preventing nuisance plant growth due to phosphorus. Sources include the U.S. Environmental Protection Agency and the Canadian Council of Ministers of the Environment

| Drinking-water quality (applies to ground water and surface water)
| Protection of aquatic life (applies to surface water only)
| Prevention of nuisance plant growth in streams
* No benchmark for drinking-water quality
** No benchmark for protection of aquatic life

For example, the graph for metolachlor shows that detections and concentrations in the Lower Tennessee River Basin generally are (1) higher than national findings in major aquifers and shallow aquifers in agricultural areas; (2) within the USEPA drinking-water standard; and (3) detected in a higher percentage of samples in surface water than in ground water.

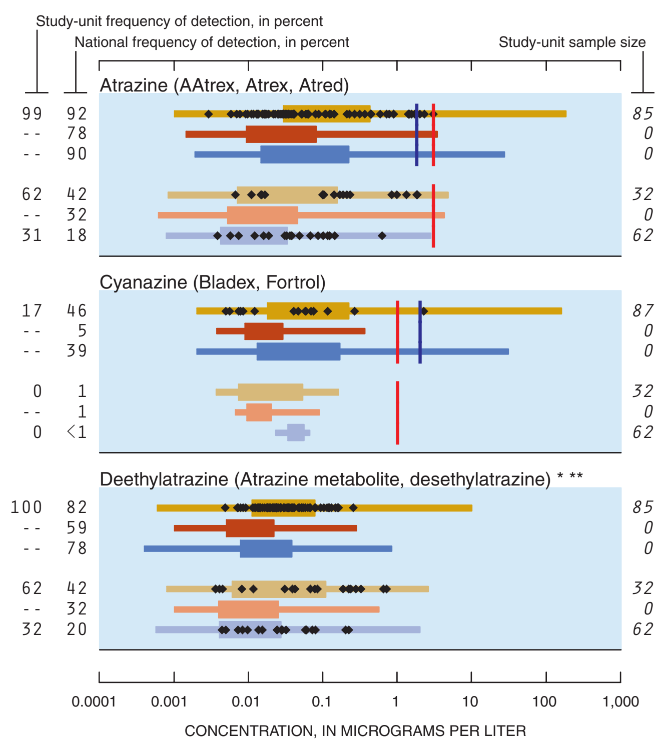
NOTE to users:

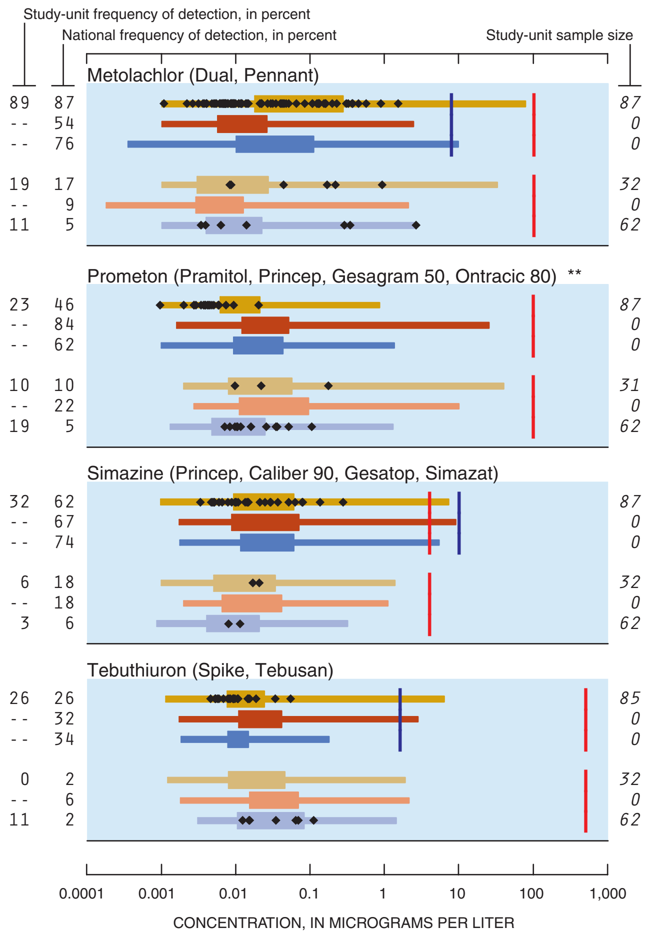
- The analytical detection limit varies among the monitored chemicals, thus frequencies of detections are not comparable among chemicals.
- It is important to consider the frequency of detection along with concentration. For example, dissolved ammonia plus organic nitrogen was detected more frequently in mixed land use streams in the Lower Tennessee River Basin than in mixed land use streams nationwide (91 percent compared to 76 percent), but generally was detected at lower concentrations.

Quality-control data for these analytes indicate relatively frequent low-level contamination of samples during sample processing for analysis. Results for these analytes cannot, therefore, be presented using the generalized methods that were applied to other analytes in this appendix. Analysis of results for analytes potentially affected by contamination requires special statistical treatment beyond the scope of this report. For more information about these analytes and how to interpret data on their occurrence and concentrations, please contact the appropriate NAWQA Study Unit.

Trace elements in groundwater: aluminum, barium, boron, cadmium, chromium, cobalt, copper, lithium, nickel, strontium, zinc
SVOCs in bed sediment: phenol, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, di-*n*-butylphthalate, diethylphthalate
Insecticides in water: *p,p'*-DDE

Pesticides in water—Herbicides





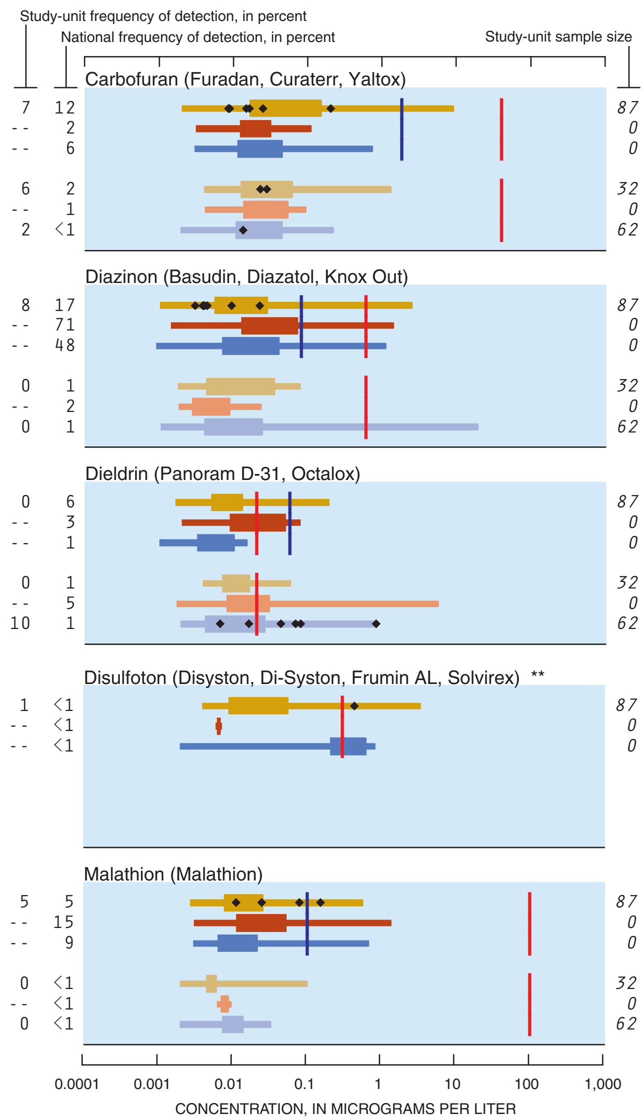
Other herbicides detected

Acetochlor (Harness Plus, Surpass) * **
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
Metribuzin (Lexone, Sencor)
Pendimethalin (Pre-M, Prowl, Weedgrass Control, Stomp, Herbadox) * **
Trifluralin (Treflan, Gowan, Tri-4, Trific, Trilin)

Herbicides not detected

Chloramben, methyl ester (Amiben methyl ester) * **
Benfluralin (Balan, Benefin, Bonalan, Benefex) * **
Butylate (Sutan +, Genate Plus, Butilate) **
DCPA (Dacthal, chlorthal-dimethyl) **
2,6-Diethylaniline (Metabolite of Alachlor) * **
EPTC (Eptam, Farmarox, Alirox) * **
Ethalfluralin (Sonalan, Curbit) * **
Molinate (Ordram) * **
Napropamide (Devrinol) * **
Pebulate (Tillam, PEBC) * **
Pronamide (Kerb, Propyzamid) **
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job) * **
Terbacil (Sinbar) **
Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *

Pesticides in water—Insecticides



Other insecticides detected

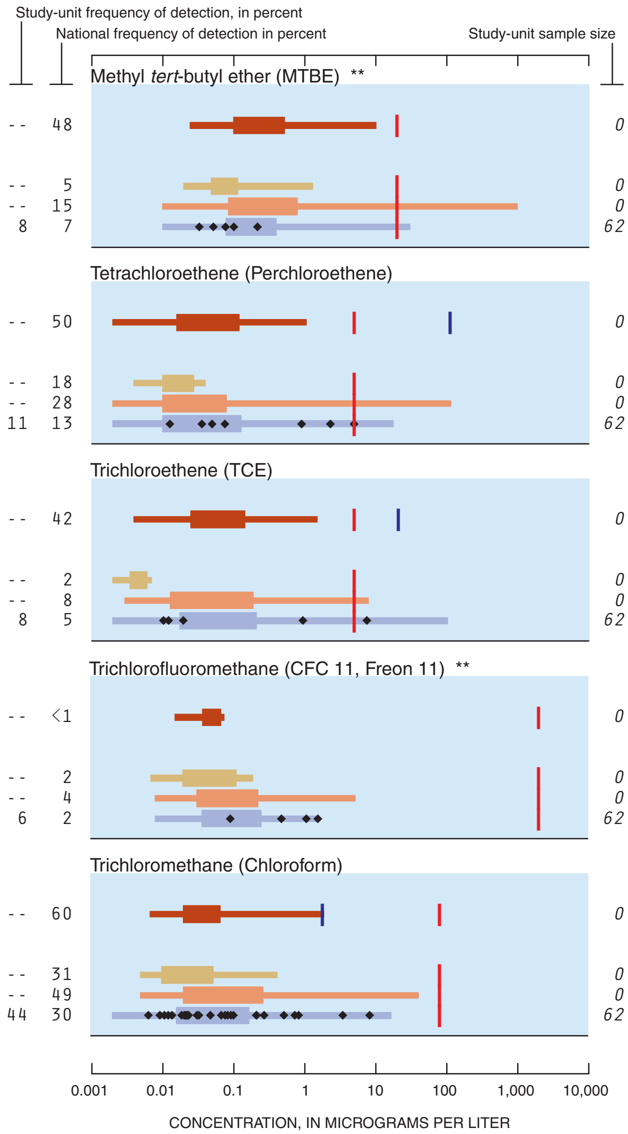
Carbaryl (Carbamine, Denapon, Sevin)
Chlorpyrifos (Brodan, Dursban, Lorsban)

Insecticides not detected

Azinphos-methyl (Guthion, Gusathion M) *
Ethoprop (Mocap, Ethoprophos) * **
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
gamma-HCH (Lindane, gamma-BHC, Gammexane)
Methyl parathion (Penncap-M, Folidol-M, Metacide, Bladan M) **
Parathion (Roethyl-P, Alkron, Panthion) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propargite (Comite, Omite, Ornamite) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in water

These graphs represent data from 32 Study Units, sampled from 1994 to 2001



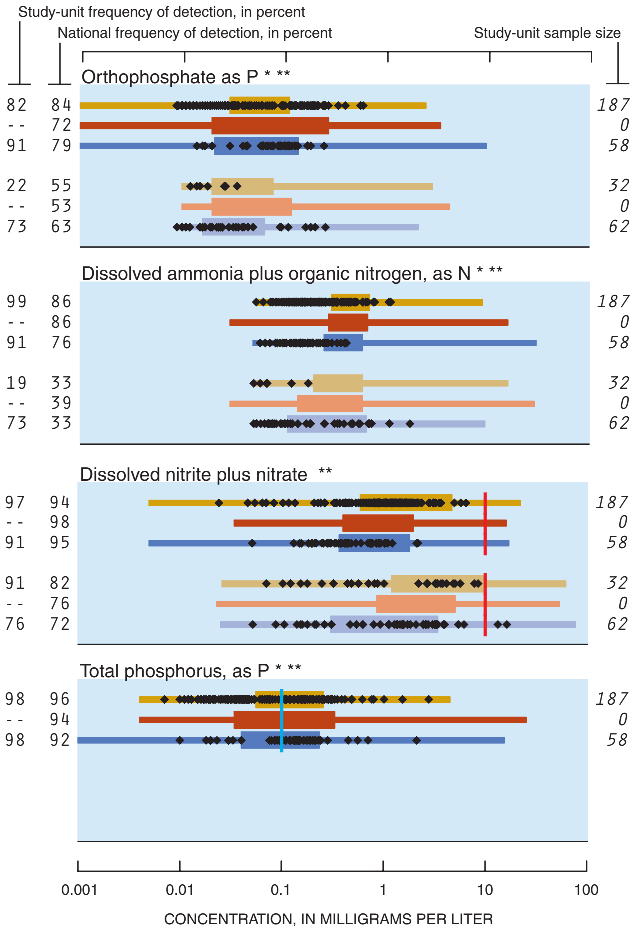
Other VOCs detected

Benzene
Bromodichloromethane (Dichlorobromomethane) **
Carbon disulfide (Carbon Disulfide) * **
Chloromethane (Methyl chloride) **
Dibromochloromethane (Chlorodibromomethane) **
1,1-Dichloroethane (Ethylidene dichloride) * **
1,1-Dichloroethene (Vinylidene chloride) **
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene) **
Dichloromethane (Methylene chloride)
1,2-Dimethylbenzene (*o*-Xylene) **
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene) **
Ethenylbenzene (Styrene) **
Ethylbenzene (Phenylethane)
Isopropylbenzene (Cumene) * **
Methylbenzene (Toluene)
Tetrachloromethane (Carbon tetrachloride)
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113) * **
1,1,1-Trichloroethane (Methylchloroform) **
1,2,4-Trimethylbenzene (Pseudocumene) * **

VOCs not detected

Acetone (Acetone) * **
Bromobenzene (Phenyl bromide) * **
Bromochloromethane (Methylene chlorobromide) **
Bromoethene (Vinyl Bromide) * **
Bromomethane (Methyl bromide) **
2-Butanone (Methyl ethyl ketone (MEK)) **
n-Butylbenzene (1-Phenylbutane) * **
sec-Butylbenzene ((1-Methylpropyl)benzene) * **
tert-Butylbenzene ((1,1-Dimethylethyl)benzene) * **
3-Chloro-1-propene (3-Chloropropene) * **
1-Chloro-2-methylbenzene (*o*-Chlorotoluene) **
1-Chloro-4-methylbenzene (*p*-Chlorotoluene) **
Chlorobenzene (Monochlorobenzene)
Chloroethane (Ethyl chloride) * **
Chloroethene (Vinyl Chloride) **
1,2-Dibromo-3-chloropropane (DBCP, Nemagon) **
1,2-Dibromoethane (Ethylene dibromide, EDB) **
Dibromomethane (Methylene dibromide) * **
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) * **
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)
Dichlorodifluoromethane (CFC 12, Freon 12) **
1,2-Dichloroethane (Ethylene dichloride)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene) **
1,2-Dichloropropane (Propylene dichloride) **
2,2-Dichloropropane * **
1,3-Dichloropropane (Trimethylene dichloride) * **
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene) **
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene) **
1,1-Dichloropropene * **
Diethyl ether (Ethyl ether) * **
Diisopropyl ether (Diisopropylether (DIPE)) * **
Ethyl methacrylate (Ethyl methacrylate) * **
Ethyl *tert*-butyl ether (Ethyl-t-butyl ether (ETBE)) * **
2-Ethyltoluene (*o*-Ethyltoluene) * **
1,1,2,3,4,4-Hexachloro-1,3-butadiene (Hexachlorobutadiene)
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane) **
2-Hexanone (Methyl butyl ketone (MBK)) * **
Iodomethane (Methyl idodide) * **
p-Isopropyltoluene (*p*-Cymene, 1-Isopropyl-4-methylbenzene) * **
Methyl acrylonitrile (Methacrylonitrile) * **
Methyl methacrylate (Methyl-2-methacrylate) * **
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) * **
Methyl-2-propenoate (Methyl Acrylate) * **
Naphthalene
2-Propenenitrile (Acrylonitrile) **
n-Propylbenzene (Isocumene) * **
1,1,2,2-Tetrachloroethane **
1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA) **
Tetrahydrofuran (Diethylene oxide) * **
1,2,3,4-Tetramethylbenzene (Prehnitene) * **
1,2,3,5-Tetramethylbenzene (Isodurene) * **
Tribromomethane (Bromoform) **
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene (1,2,3-TCB) *
1,1,2-Trichloroethane (Vinyl trichloride) **
1,2,3-Trichloropropane (Allyl trichloride) **
1,2,3-Trimethylbenzene (Hemimellitene) * **
1,3,5-Trimethylbenzene (Mesitylene) * **
tert-Amyl methyl ether (TAME) * **

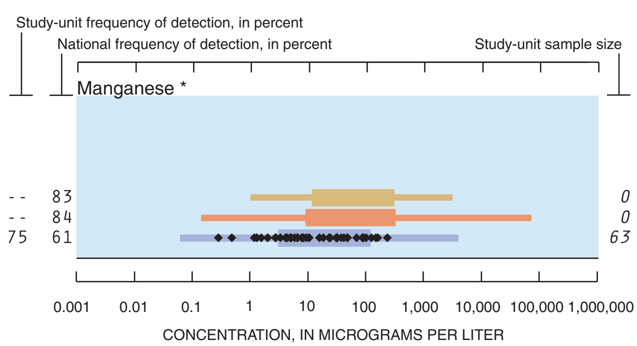
Nutrients in water

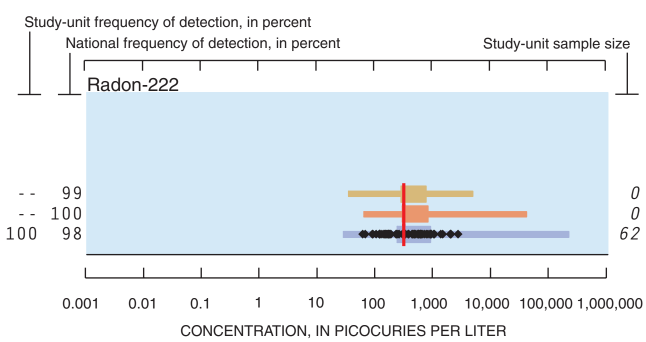


Other nutrient detected

Ammonia **

Trace elements in ground water





Other trace elements detected

Antimony
Arsenic
Beryllium
Lead
Molybdenum
Selenium
Uranium

Trace element not detected

Silver

CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Lower Tennessee River Basin 1999–2001—Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

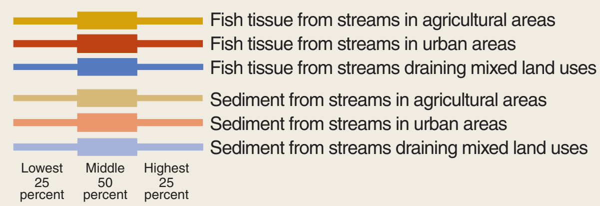
◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

-- Not measured or sample size less than two

12 Study-unit sample size

National ranges of concentrations detected, by land use, in 51 NAWQA Study Units, 1991–2001—Ranges include only samples in which a chemical was detected



National benchmarks for fish tissue and bed sediment

National benchmarks include standards and guidelines related to criteria for protection of the health of fish-eating wildlife and aquatic organisms. Sources include the U.S. Environmental Protection Agency, other Federal and State agencies, and the Canadian Council of Ministers of the Environment.

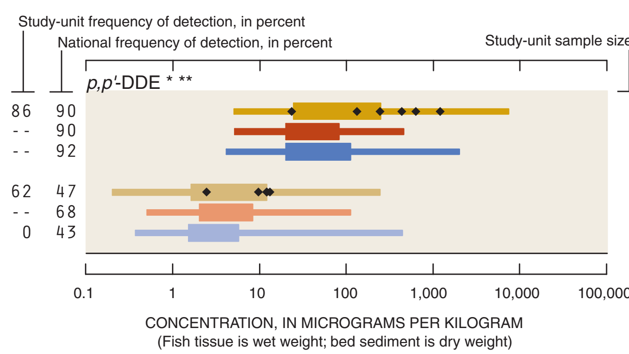
| Protection of fish-eating wildlife (applies to fish tissue)

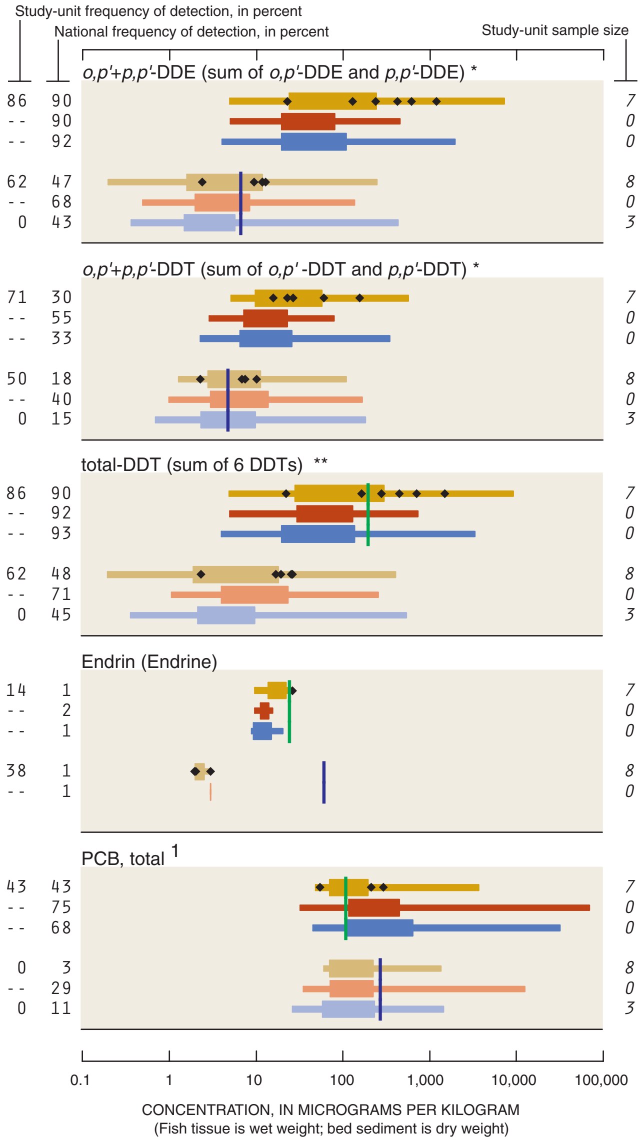
| Protection of aquatic life (applies to bed sediment)

* No benchmark for protection of fish-eating wildlife

** No benchmark for protection of aquatic life

Organochlorines in fish tissue (whole body) and bed sediment





[1] The national detection frequencies for total PCB in sediment are biased low because about 30 percent of the samples nationally had elevated detection limits compared to this Study Unit. See http://water.usgs.gov/nawqa/ for additional information.

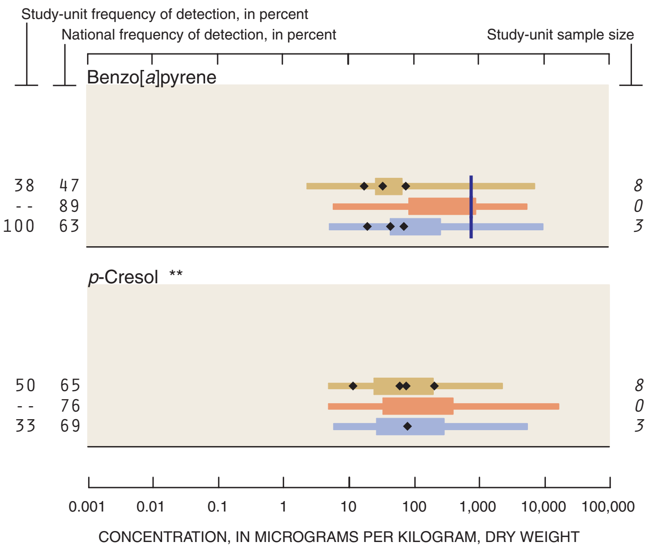
Other organochlorines detected

total-Chlordane (sum of 5 chlordanes)
o,p'+*p,p'*-DDD (sum of *o,p'*-DDD and *p,p'*-DDD) *
Dieldrin (Panoram D-31, Octalox) *
Dieldrin+aldrin (sum of dieldrin and aldrin) **
Heptachlor epoxide (Heptachlor metabolite) *
Heptachlor+heptachlor epoxide **
o,p'-Methoxychlor * **

Organochlorines not detected

Chloroneb (chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Total HCH (sum of alpha, beta, gamma, and delta-HCH) **
Hexachlorobenzene (HCB) **
Isodrin (Isodrine, Compound 711) * **
p,p'-Methoxychlor (Marlate, methoxychlore) * **
Mirex (Dechlorane) **
Pentachloroanisole (PCA, pentachlorophenol metabolite) * **
cis-Permethrin (Ambush, Astro, Pounce) * **
trans-Permethrin (Ambush, Astro, Pounce) * **
Toxaphene (Camphechlor, Hercules 3956) * **

Semivolatile organic compounds (SVOCs) in bed sediment



Other SVOCs detected

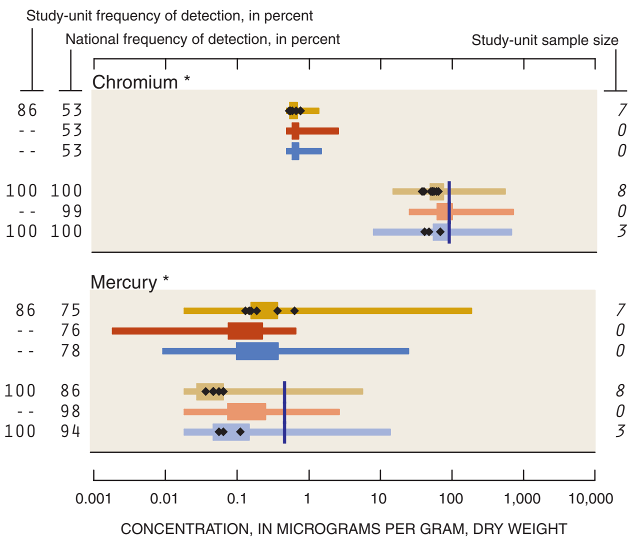
Acenaphthylene
Acridine **
Anthracene
Anthraquinone **
Benz[*a*]anthracene
Benzo[*b*]fluoranthene **
Benzo[*g,h,i*]perylene **
Benzo[*k*]fluoranthene **
9*H*-Carbazole **
Chrysene
Dibenz[*a,h*]anthracene
Dibenzothiophene **
1,2-Dimethylnaphthalene **
1,6-Dimethylnaphthalene **
2,6-Dimethylnaphthalene **
Fluoranthene
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*c,d*]pyrene **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Naphthalene
Phenanthrene
Pyrene
2,3,6-Trimethylnaphthalene **

SVOCs not detected

Acenaphthene
C8-Alkylphenol **
Azobenzene **
Benzo[*c*]cinnoline **
2,2-Biquinoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis (2-Chloroethoxy)methane **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
Di-*n*-octylphthalate **
1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB) **
3,5-Dimethylphenol **

Dimethylphthalate **
2,4-Dinitrotoluene **
Isophorone **
Isoquinoline **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
Phenanthridine **
Quinoline **
1,2,4-Trichlorobenzene **

Trace elements in fish tissue (livers) and bed sediment



Other trace elements detected

Arsenic *
Cadmium *
Copper *
Lead *
Nickel * **
Selenium *
Zinc *

Coordination with agencies and organizations in the Lower Tennessee River Basin was integral to the success of this water-quality assessment. We thank those who served as members of our liaison committee.

Federal Agencies
Tennessee Valley Authority
Natural Resources Conservation Service
U.S. Fish and Wildlife Service

State Agencies
Alabama Department of Environmental Management
Alabama Department of Conservation and Natural Resources
Geological Survey of Alabama
Tennessee Department of Environment and Conservation
Tennessee Wildlife Resources Agency
Tennessee Department of Agriculture

Local Agencies
Huntsville Utilities
Madison County Water Department
Sand-Mountain-Lake Guntersville Conservancy District

Universities
University of Alabama
Auburn University

Other public and private organizations
The Nature Conservancy
Duck River Development Agency
Flint River Conservation Association

We thank the following individuals, agencies, and organizations for contributing to this study.

- Susan Weber (Flint River Conservation Association) for providing watershed information and coordinating stream access with landowners.
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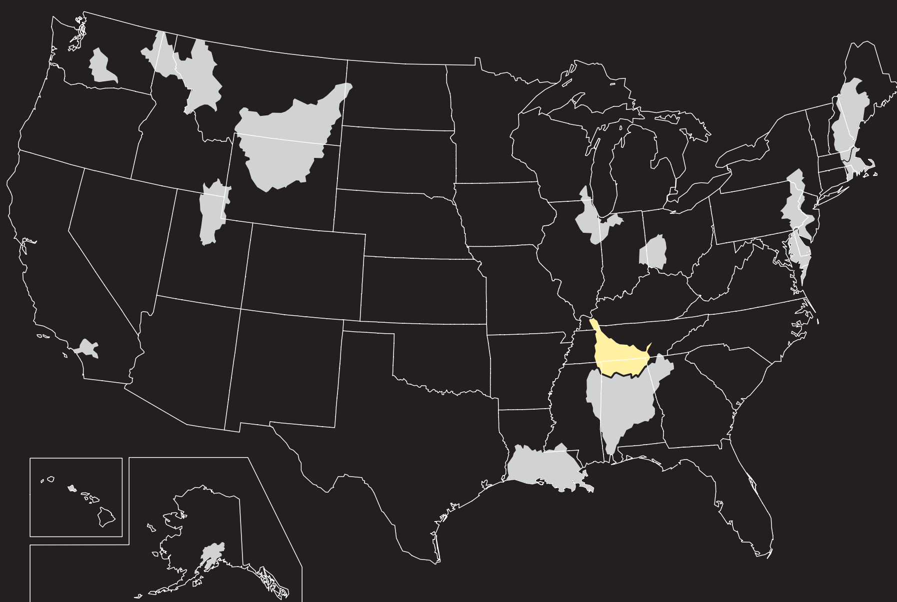
NAWQA

National Water-Quality Assessment (NAWQA) Program
Lower Tennessee River Basin



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