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Water Quality in the Upper Tennessee River Basin

Tennessee, North Carolina, Virginia, and Georgia, 1994–98

U.S. Department of the Interior
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Circular 1205

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Back cover: Tobacco in Cocke County, Tennessee *(photograph by G.C. Johnson, U.S. Geological Survey)*; center, Whitewater rafting (*photograph courtesy of National Park Service, Obed Wild and Scenic River*); right, French Broad River Valley, North Carolina *(photograph by P.S. Hampson, U.S. Geological Survey)*.

Water Quality in the Upper Tennessee River Basin, Tennessee, North Carolina, Virginia, and Georgia 1994–98

By Paul S. Hampson, M.W. Treece, Jr., Gregory C. Johnson, Steven A. Ahlstedt,
and Joseph F. Connell

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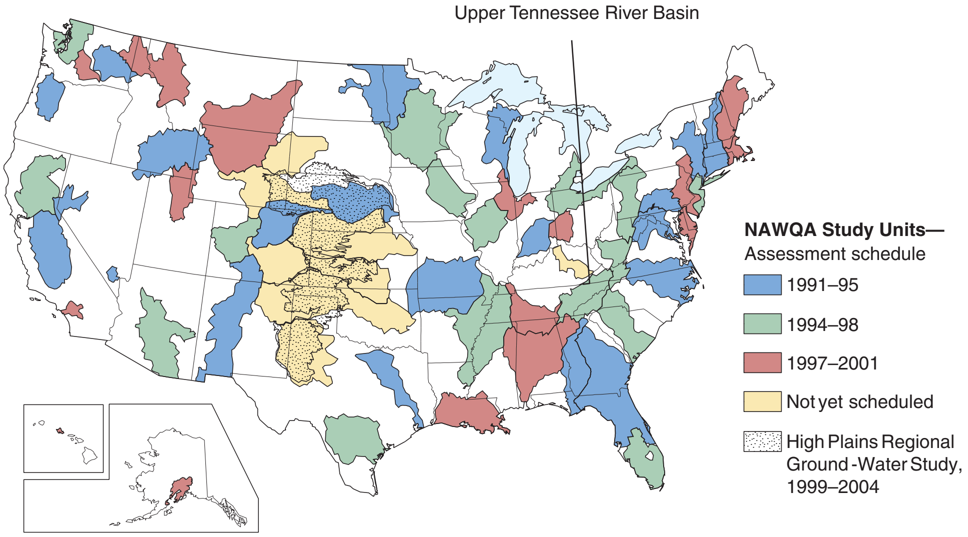
CONTENTS

THIS REPORT summarizes major findings about water quality in the Upper Tennessee River Basin that emerged from an assessment conducted between 1994 and 1998 by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Water quality is discussed in terms of local and regional issues and compared to conditions found in all 36 NAWQA study areas, called Study Units, assessed to date. Findings are also explained in the context of selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms. The NAWQA Program was not intended to assess the quality of the Nation's drinking water, such as by monitoring water from household taps. Rather, the assessments focus on the quality of the resource itself, thereby complementing many ongoing Federal, State, and local drinking-water monitoring programs. The comparisons made in this report to drinking-water standards and guidelines are only in the context of the available untreated resource, Finally, this report includes information about the status of aquatic communities and the condition of in-stream habitats as elements of a complete water-quality assessment.

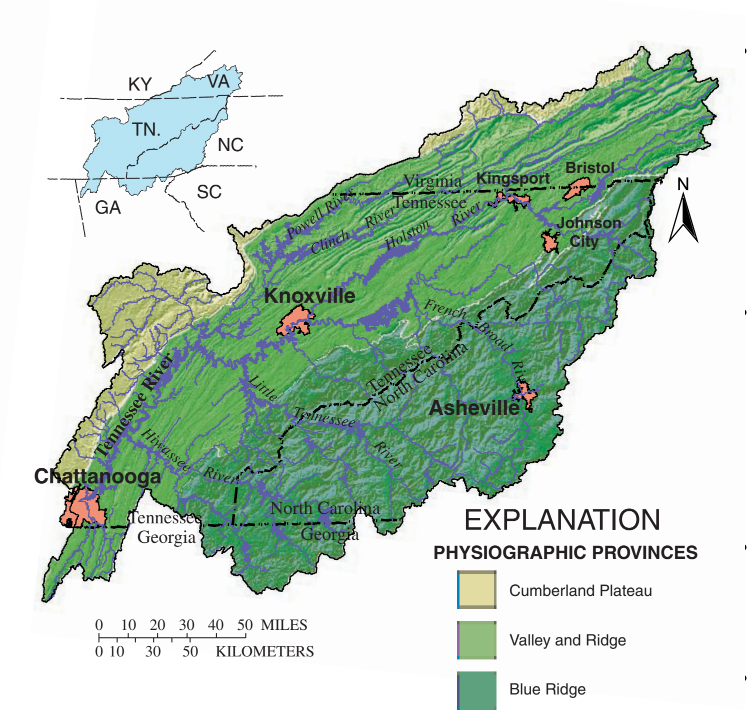
Many topics covered in this report reflect the concerns of officials of State and Federal agencies, water-resource managers, and members of stakeholder groups who provided advice and input during the Upper Tennessee River Basin assessment. Basin residents who wish to know more about water quality in the areas where they live will find this report informative as well.



THE NAWQA PROGRAM seeks to improve scientific and public understanding of water quality in the Nation's major river basins and ground-water systems. Better understanding facilitates effective resource managment, accurate identification of water-quality priorities, and successful development of strategies that protect and restore water quality. Guided by a nationally consistent study design and shaped by ongoing communication with local, State, and Federal agencies, NAWQA assessments support the investigation of local issues and trends while providing a firm foundation for understanding water quality at regional and national scales. The ability to integrate local and national scales of data collection and analysis is a unique feature of the USGS NAWQA Program.

The Upper Tennessee River Basin Study Unit is one of 51 water-quality assessments initiated since 1991, when the U.S. Congress appropriated funds for the USGS to begin the NAWQA Program. As indicated on the map, 36 assessments have been completed, and 15 more assessments will conclude in 2001. Collectively, these assessments cover about one-half of the land area of the United States and include water resources that are available to more than 60 percent of the U.S. population.

SUMMARY OF MAJOR FINDINGS



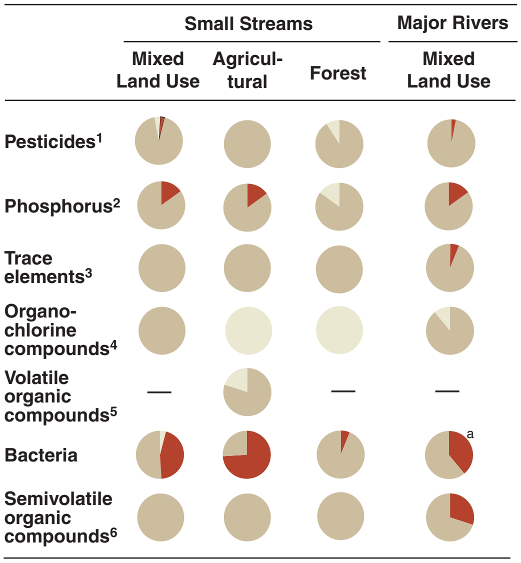
The Upper Tennessee River Basin encompasses about 21,390 square miles and includes parts of four States: Tennessee, North Carolina, Virginia, and Georgia. Three major physiographic provinces are represented in the basin: the Cumberland Plateau, Valley and Ridge, and Blue Ridge Provinces. Most of the 2.4 million people residing in the basin live in the four metropolitan areas of Knoxville and Chattanooga, Tennessee; Asheville, North Carolina; and the Tri-Cities area of Tennessee and Virginia.

Surface-Water Highlights

The Upper Tennessee River Basin is characterized by an abundance of surface water that usually meets existing guidelines for drinking-water supply, recreation, and the protection of aquatic life. Bacteria levels, however, frequently exceed State standards for contact recreation both in agricultural and urban areas. In addition, mixtures of pesticides were detected at 67 of the 74 stream sites sampled. No pesticide concentrations exceeded drinking-water standards, but standards have not been determined for 11 of the 31 compounds detected.

- Bacteria levels frequently exceeded State standards in agricultural streams and streams in urban areas. Runoff from pasture land and direct livestock access to streams contribute to elevated bacterial counts in agricultural streams. Aging wastewater infrastructures are the most likely cause of elevated bacteria counts in urban streams.
- Inputs from urban and agricultural land uses have increased nutrient levels in streams. Yields of total nitrogen in streams are correlated to agricultural inputs, such as animal waste and fertilizer applications, whereas yields of total phosphorus are correlated with wastewater discharges. Tributary reservoirs serve as effective sinks for both nitrogen and phosphorus species in the basin.
- Herbicides and herbicide degradates were detected in 98 percent of the 428 total stream-water samples collected but at levels within drinking-water standards and aquatic-life guidelines. Insecticides used on agricultural fields, gardens, and lawns were detected infrequently (less than 12 percent of samples) and were at levels within drinking-water standards. Concentrations exceeding aquatic-life guidelines were observed, however, for carbaryl, diazinon, and lindane.
- Contamination from previous industrial and mining activities persists in parts of the basin resulting in fish-consumption advisories for PCB's (polychlorinated biphenyls), dioxin, and mercury in certain reservoirs and stream reaches. SVOC (semivolatile organic compounds) sediment concentrations exceeding aquatic-life guidelines were detected in some stream reaches draining coal mining areas.
- The Upper Tennessee River Basin is widely known for its aquatic diversity of fish and mussel species. While mussel populations are recovering in some parts of the basin, overall diversity is slowly declining.
- Releases and spills resulting in fish and mussel kills have occurred in many parts of the basin and pose a threat to isolated and endangered populations of aquatic species.

Selected Indicators of Stream-Water Quality



🟥 Percentage of samples with concentrations **equal to or greater than** a health-related national guideline for drinking water, aquatic life, or water-contact recreation; or below a national goal for preventing excess algal growth

🟫 Percentage of samples with concentrations **less than** a health-related national guideline for drinking water, aquatic life, or water-contact recreation; or below a national goal for preventing excess algal growth

⬜ Percentage of samples with **no detection** ([a] Percentage is 1 or less and may not be clearly visible

— Not assessed

[1] Insecticides, herbicides, and pesticide metabolites, sampled in water.
[2] Total phosphorus, sampled in water.
[3] Arsenic, mercury, and metals, sampled in sediment.
[4] Organochlorine compounds including DDT and PCBs, sampled in sediment.
[5] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in sediment.
[6] Miscellaneous industrial chemicals and combustion by-products, sampled in sediment.

Trends in Stream-Water Quality

Because of water-treatment improvements, nitrogen and phosphorus levels for most of the streams in the Upper Tennessee River Basin remained unchanged or decreased from 1970 to 1993. Nitrogen concentrations, however, increased significantly for many streams in the Blue Ridge physiographic province because of nonurban residential development and aquaculture.

Trends in other water-quality constituents are difficult to assess because of changes in data-collection methods over time and an overall lack of data. Persistent organochlorine compounds such as DDE, a breakdown product of DDT, which was discontinued in 1973, and chlordane, which was discontinued in 1988, are still detected in fish tissues and bottom sediments in various parts of the basin.

Major Influences on Surface Waters

- Runoff from agricultural and urban areas
- Effluent from wastewater-treatment facilities
- Persistent sediment contamination
- Episodic spills and toxic releases

Ground-Water Highlights

Although ground-water use accounts for a little more than 3 percent of the total water use in the basin, over one-third of the population relies upon ground-water sources for drinking water. In the Upper Tennessee River Basin, ground-water studies focused on the carbonate rock formations of the Valley and Ridge physiographic province, which compose the most prolific aquifers in the basin and are the most susceptible to contamination. These aquifers typically provide water that meets all Federal and State drinking-water standards with the exceptions of nitrate and bacteria. Nitrate concentrations in domestic wells and springs used as drinking-water sources were within drinking-water standards and guidelines. Levels of nitrate exceeding drinking-water standards were detected only in shallow agricultural monitoring wells. Numerous pesticides and volatile organic compounds were detected in wells and springs, but none exceeded drinking-water standards.

- Bacteria levels exceeding finished drinking-water standards were detected in 11 of 30 wells used for untreated domestic drinking-water supply and in all 35 springs sampled. Bacteria levels in two springs exceeded State standards for recreation. Seventeen of the springs sampled are used for untreated drinking-water supplies.

- Nitrate was present in all domestic wells and springs but usually in concentrations well within the Federal drinking-water standard. Five of 30 monitoring wells that were installed adjacent to burley tobacco fields contained nitrate concentrations exceeding the drinking-water standard.

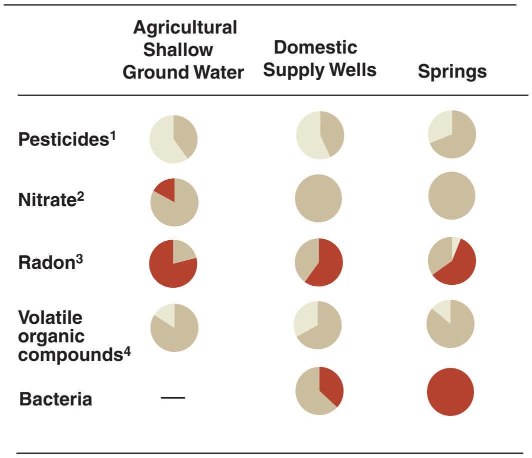
- Pesticides were detected in 40 percent of the agricultural wells, 43 percent of domestic water-supply wells, and 69 percent of the springs in relatively low concentrations. No pesticide concentrations exceeded drinking-water standards; however, 5 of the 18 compounds detected currently do not have standards. The most frequently detected pesticides were atrazine and metalaxyl (tobacco-specific) in the agricultural wells and atrazine, tebuthiuron, and prometon in domestic wells and springs.

- Volatile organic compounds were detected in 86 percent of the springs and 67 percent of the domestic wells sampled. Trichloromethane was the most frequently detected compound of the 28 volatile organic compounds that were detected; but carbon disulfide, propanone, and methylbenzene generally were detected in the highest concentrations. None of the volatile organic compounds exceeded drinking-water standards or guidelines, but only 12 of the 28 currently have standards.

Major Influences on Ground Water

- Agricultural and urban land uses
- Permeability of soils and aquifer materials
- Bedrock fracture patterns and karst features

Selected Indicators of Ground-Water Quality



🟥 Percentage of samples with concentrations **equal to or greater than a** health-related national guideline for drinking water

🟫 Percentage of samples with concentrations **less than** a health-related national guideline for drinking water

⬜ Percentage of samples with **no detection**

— Not assessed

[1] Insecticides, herbicides, and pesticide metabolites, sampled in water.

[2] Nitrate (as nitrogen), sampled in water.

[3] Radon, sampled in water.

[4] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in water.

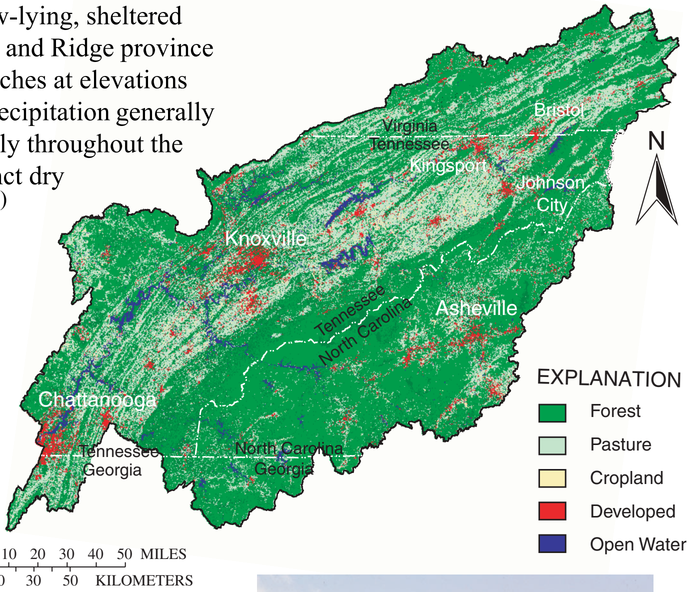
INTRODUCTION TO THE UPPER TENNESSEE RIVER BASIN

The Upper Tennessee River Basin Study Unit encompasses about 21,390 square miles and includes the entire drainage area of the Tennessee River and its tributaries upstream from the USGS gaging station at Chattanooga, Tennessee. The study area includes parts of four States: Tennessee (11,500 square miles), North Carolina (5,480 square miles), Virginia (3,130 square miles), and Georgia (1,280 square miles). In 1990, the total population of the study area was about 2.4 million, of which about 1.6 million resided in the four metropolitan statistical areas of Chattanooga and Knoxville, Tennessee; Asheville, North Carolina; and the Tri-Cities area of Kingsport and Johnson City, Tennessee, and Bristol, Tennessee and Virginia.

Parts of three physiographic provinces–the Cumberland Plateau, Valley and Ridge, and Blue Ridge Provinces–compose the Upper Tennessee River Basin. Altitudes range from 621 feet above sea level at Chattanooga to 6,684 feet at Mount Mitchell, which is just northeast of Asheville, North Carolina, and is the highest point in the Eastern United States. The Study Unit contains some of the most rugged terrain in the Eastern United States, including the Great Smoky Mountains range. The crest of the Smoky Mountains exceeds 5,000 feet for 34 miles along the Tennessee-North Carolina State line, has 16 peaks that exceed 6,000 feet, and is the most massive mountain range east of the Mississippi River.

The region generally has a temperate climate; temperatures and annual precipitation totals largely are dependent on land-surface elevations. Average annual temperatures in the area generally decrease by about 3 degrees Fahrenheit for every 1,000-foot increase in elevation. Average annual precipitation ranges from about 40 inches in some low-lying, sheltered areas in the Valley and Ridge province to more than 90 inches at elevations over 6,000 feet. Precipitation generally is distributed evenly throughout the year with no distinct dry and wet seasons.(1)

Forests cover more than 67 percent of the Study Unit (fig. 1) and five National Forests–Jefferson, Pisgah, Cherokee, Nantahala, and Chattahooche National Forests–wholly or partially lie within the basin. Agricultural land, predominantly pasture, is the second most common land use and accounts for more than 26 percent of the study area. Row crops account for only about 2.6 percent of the study area. Most of the agricultural land is located in the stream valleys and gently rolling parts of the Valley and Ridge physiographic province. The crests of steep ridges and more rugged areas of the basin remain forested. Less than 4.5 percent of the basin is developed. Row crops and developed areas, however, generally affect water-quality conditions much more than their small percentages would indicate.



Forest is the predominant land use in the Upper Tennessee River Basin.

Pasture is the predominant agricultural land use in the Upper Tennessee Basin.

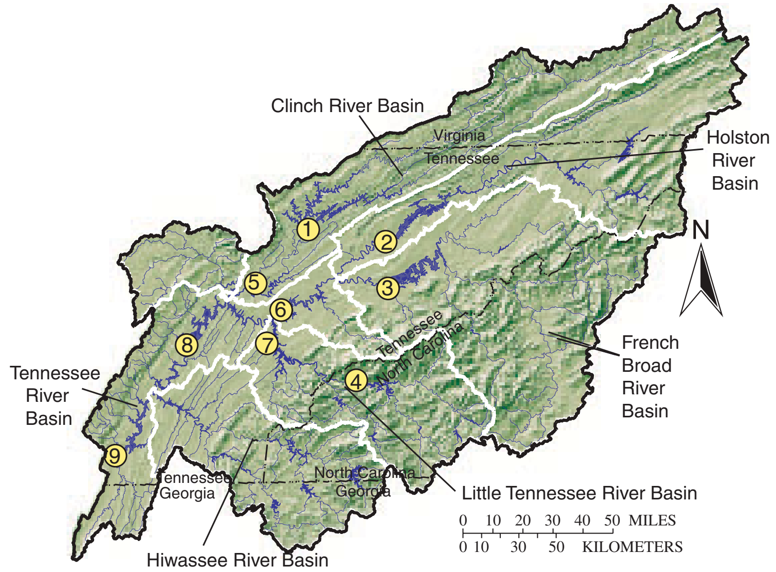
Row crops account for only 2.6 percent of the Upper Tennessee River Basin.

Urban and industrial land uses have greater water-quality effects than their land-use percentages might indicate.

Figure 1. Water-quality conditions in the Upper Tennessee River Basin are influenced by land uses.

Surface-Water Features

The most prominent surface-water features of the Upper Tennessee River Basin are the tributary and main-stem reservoirs constructed and maintained by the Tennessee Valley Authority (TVA) and sometimes referred to as the “Great Lakes of the South.” Four main-stem reservoirs are primarily flow-through systems that provide power generation and maintain navigational depths but provide little flood storage. These four reservoirs have a combined capacity of about 3.1 million acre-feet. Seventeen tributary reservoirs provide flood storage and power generation. These tributary reservoirs have a combined storage capacity of some 10 million acre-feet. An additional 17 privately owned and operated reservoirs also are located in the study area and have a combined storage capacity of about 0.6 million acre-feet. (2)



Reservoir number	Reservoir name	Reservoir type	Surface area, in acres	Total capacity, in acre-feet
1	Norris	Tributary storage	34,200	969,000
2	Cherokee	Tributary storage	30,300	580,300
3	Douglas	Tributary storage	30,400	631,200
4	Fontana	Tributary storage	10,640	476,900
5	Melton Hill	Flow-through	5,960	16,100
6	Fort Loudon	Flow through	14,600	120,000
7	Tellico	Flow through	15,860	63,800
8	Watts Bar	Flow through	39,000	191,000
9	Chickamauga	Flow through	35,000	175,000

Figure 2. Two types of major reservoirs are on five major tributaries of the Upper Tennessee River.

Five major tributaries (fig. 2) account for about 86 percent of the annual mean discharge of 35,450 cubic feet per second at the Tennessee River at Chattanooga and over 87 percent of the total area of the upper Tennessee River Basin. The Clinch (4,413 square miles), Holston (3,776 square miles), French Broad (5,124 square miles), Little Tennessee (2,627 square miles), and Hiwassee (2,700 square miles) Rivers each exhibit distinctive climatic and runoff characteristics. Average annual precipitation in these river basins ranges from about 45 inches in the Holston River Basin to almost 60 inches in the Little Tennessee River Basin, which receives the highest rainfall in the continental United States outside of the Puget Sound area of Washington State.(3) Average annual runoff totals have similar variations and range from about 18 inches in the Holston River Basin to more than 34 inches in the Little Tennessee River Basin.(4)


Large reservoirs are the most prominent surface water features of the Upper Tennessee Basin.

Water Use

In 1995, withdrawals of surface and ground water in the Upper Tennessee River Basin totaled about 4.8 billion gallons per day. Surface-water withdrawals for once-through cooling at thermoelectric plants accounted for about 3.5 billion gallons per day, or 73 percent of this total. Other uses (fig. 3) were commercial and industrial, 702 million gallons per day; public and domestic supply, 394 million gallons per day; agricultural, 203.3 million gallons per day: and mining, 10.4 million gallons per day, all of which were predominantly surface-water withdrawals.(5) A total of 897 facilities were permitted to discharge wastewater in 1995 to area streams.

Total ground-water withdrawals in the basin for 1995 were about 138 million gallons per day and accounted for about 10.5 percent of the total non-thermoelectric water use in the basin. About 77 percent of the ground-water withdrawals were for public and domestic supply for over one-third of the basin’s population.

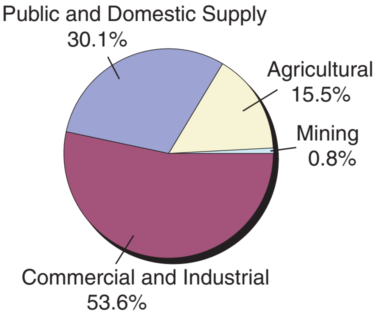


Figure 3. Nonthermoelectric water use in the Upper Tennessee River Basin, 1995. (Thermoelectric water use accounted for 73 percent of the total water use.)

Hydrologic Conditions

Understanding hydrologic variations over time is necessary for assessing water-quality conditions as well as for providing a context with which to evaluate trends. Overall, rainfall during the data-collection period was about 10 percent greater than the long-term mean values. Most of the excess rainfall occurred in the northern part of the basin, as the Knoxville and Tri-Cities weather stations both recorded about 4 inches per year more than their long-term averages of 46.7 and 41.3 inches, respectively. During this same period, rainfall at Chattanooga averaged only about 1 inch per year more than the long-term average of 53.3 inches.(6)

Although precipitation usually is distributed relatively evenly throughout the year in the Upper Tennessee River Basin with no pronounced dry or wet seasons, two relatively dry periods occurred in the late summer and fall of 1997 and 1998. These periods are reflected in the rainfall departures in figure 4 and streamflow discharges in figure 5.

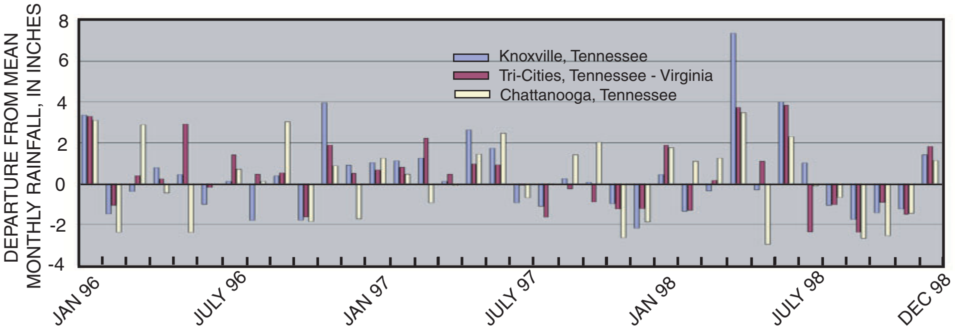


Figure 4. Departures from mean monthly rainfall at three stations in the Upper Tennessee River Basin reflect hydrologic conditions during the 1996-98 study period. (Data from National Weather Service, Morristown, Tenn.)

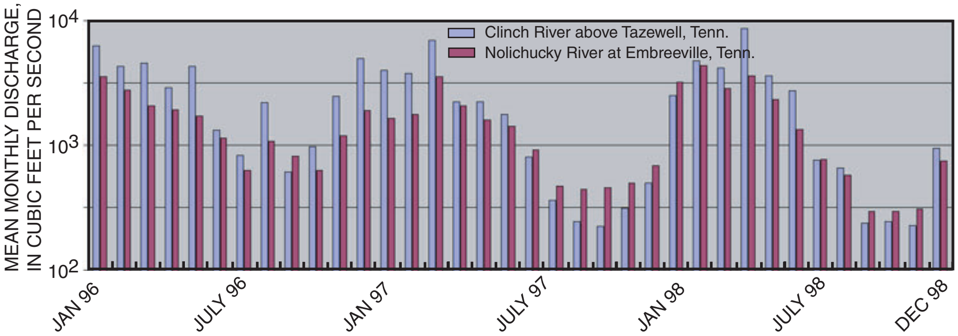


Figure 5. Mean monthly discharge for the Clinch and Nolichucky Rivers reflect the abnormally dry summers of 1997 and 1998.

Ground-Water Resources

Ground water in the Upper Tennessee River Basin occurs almost exclusively in unconfined water-table conditions with no regional flow systems. Ground-water flow systems usually are less than 10 square miles in areal extent and are largely controlled by the bedrock geology (fig. 6) and thickness of overlying regolith.

The Cumberland Plateau is characterized by hard, relatively impermeable sandstone of Pennsylvanian age generally overlain by thin soils. Well yields generally range from 5 to 50 gallons per minute from fractures, faults, and bedding-plane openings. Over much of the province, however, reliable ground-water supplies are not obtainable. Similarly, the Blue Ridge physiographic province is characterized by fractured crystalline igneous and metamorphic rock of low porosity and little storage capacity. Well yields depend upon interception of water-bearing fracture systems and usually range from 10 to 25 gallons of water per minute where available.

The Valley and Ridge physiographic province is underlain by folded and extensively faulted limestone, dolomite, shale, and sandstones that occur in long subparallel belts trending southwest to northeast. The principal water-bearing units are the carbonate-based dolomites and limestones, which provide water for many cities and industries. Yields generally range from 5 to 200 gallons per minute, but wells penetrating extensive solution features may yield as much as 2,000 gallons per minute.(7) Solution features, such as caves and sinkholes with their inherent permeability, make the Valley and Ridge carbonate aquifers the most susceptible in the basin to contamination.

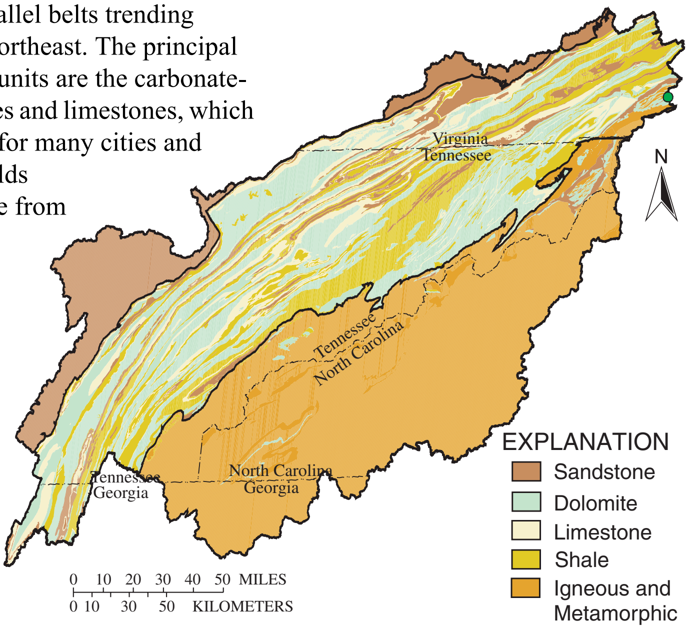


Figure 6. Ground-water availability is a function of surface geology in the Upper Tennessee River Basin.

Biological Diversity

The Upper Tennessee River Basin is noted nationally for its diversity of freshwater fishes and mussels. The basin provides habitat for 174 species of fish, including 25 species that are non-native.

Of the 149 fish species native to the Upper Tennessee River, 29 are found only in the Tennessee and adjacent Cumberland River Basins, and 15 are found only in the Upper Tennessee River. Fifteen fish species in the basin are federally listed as endangered or threatened and 50 species are listed under management categories used by the four States.

Most of the fish diversity in the basin is concentrated in the Valley and Ridge physiographic province, which includes 141 of the 149 native Upper Tennessee species, most notably in the Upper Clinch and lower Holston River Basins (fig. 7). The Clinch River alone is home to 126 Upper Tennessee River native species, 12 of which are federally protected and 41 of which are State listed. Four previously recorded fish species are no longer found in the Clinch River, the largest number of eliminated fish species for any Upper Tennessee drainage.

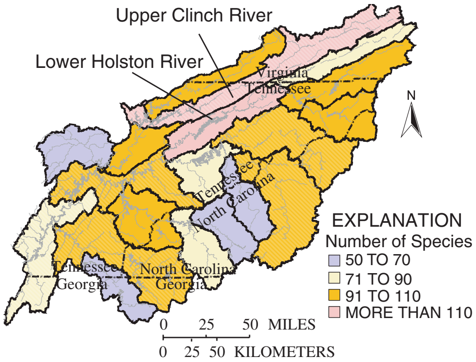


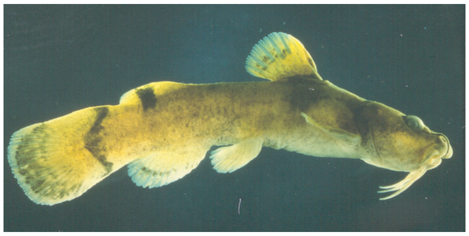
Figure 7. Fish diversity is highest in the Lower Holston and Upper Clinch River systems.

The Upper Tennessee River also includes one of the most diverse freshwater mussel fauna in the world with 85 different species having historically been recorded. Twenty-five of these species are no longer found in the basin, mostly because of habitat destruction associated with reservoir impoundment, and 11 are now believed to be extinct. Of the 60 freshwater mussel species now found in the Upper Tennessee River Basin, 30 species are under Federal protection and 52 species are listed by the States.

The Upper Tennessee River Basin includes one of the world's most diverse freshwater mussel faunas. (Photograph courtesy of Richard Neves, Virginia Polytechnic and State University.)

As with fishes, most of the freshwater mussel diversity is associated with the Valley and Ridge physiographic province, especially the Clinch River system (fig. 8). The Clinch River is now home to about 52 species of a previously recorded total of 79. Of the current total, 28 are federally listed and 38 are listed by the States.

Home to more than 300 globally rare species, the Upper Clinch River system, which includes the Powell River, has attracted attention from a number of environmental organizations including the designation as one of the “Last Great Places” by the Nature Conservancy. The Clinch River system also is considered to be one of the more biologically threatened river systems in the country (fig. 9). Of the 178 freshwater fish and mussel species presently inhabiting the Clinch River Basin, more than one-fourth are considered to be at-risk.(8)



The yellowfin madtom is one of the threatened fish species in the Upper Tennessee River Basin. (Photograph courtesy of the Tennessee Valley Authority.)

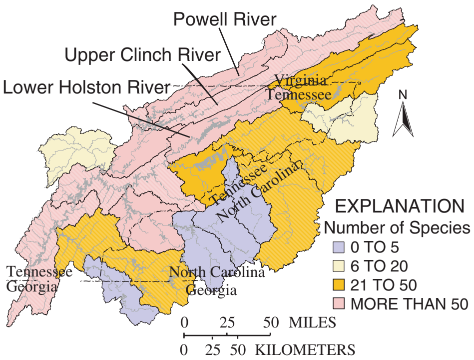


Figure 8. Freshwater mussel diversity is highest in the Valley and Ridge physiographic province.

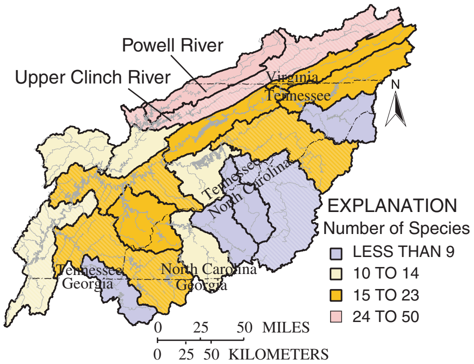


Figure 9. The Upper Clinch and Powell Rivers have the highest numbers of freshwater fish and mussel species considered to be at risk.(8)

Study Unit Design Focuses on Land Use.

Chemical and biological samples were collected from selected rivers and streams draining different land-use areas to assess overall quality as well as the effects of specific land uses. The study focused on agricultural land use and unregulated streams in the Valley and Ridge physiographic province. At Basic Fixed Sites, water samples were collected monthly and during storms to assess runoff conditions. Synoptic sites were sampled only once during periods of average flow.

Springs, domestic wells, and specifically installed agricultural monitoring wells were sampled to assess overall ground-water quality in the basin. Ground-water studies focused on the dolomite and limestone areas of the Valley and Ridge province, which provide the best aquifers and are the most susceptible areas in the basin to ground-water contamination. (See Study Unit Design, page 23, for details.)

Bacteria in the Upper Tennessee River Basin

Fecal indicator bacteria are the most frequent and widespread water-quality standard exceedances involving potential adverse effects to human health in the Upper Tennessee River Basin. The indicator bacteria themselves usually are harmless and easy to detect, but they are indicators of the presence of fecal material and have been shown to be associated with some waterborne disease-causing organisms. The presence of indicator bacteria, however, cannot be considered direct proof of any threat to human health, and research is underway to find better indicators.

Bacterial Counts Frequently Exceed Standards

The State of Tennessee's current water-quality standards are based on a total fecal coliform level of 200 colonies per 100 milliliters of water, as a mean value.$^{(9)}$ This value is commonly exceeded in agricultural and urban streams in the Upper Tennessee River Basin (fig. 10). In agricultural areas, livestock waste is the most likely bacterial source both from allowing livestock direct access to streams and runoff from animal-waste areas. Bacterial counts generally increase during higher streamflows associated with runoff events in the agricultural areas (fig. 11).

Deteriorated and leaky sewage systems, faulty sewage treatment plants, urban runoff, and combined sewer overflow systems are among the sources of bacterial contamination in many urban streams. For example, all of the urban streams draining the central Knoxville, Tennessee, area regularly exceed bacterial standards$^{(10)}$ because of widespread leakage from very old and deteriorating sewer systems in the older parts of the city. Replacement in 1998 of an obsolete combined sewer overflow system for one city neighborhood, however, has improved conditions for that neighborhood and adjacent parts of Fort Loudon Reservoir. These conditions highlight the continuing need for infrastructure improvements, especially in older urban areas.

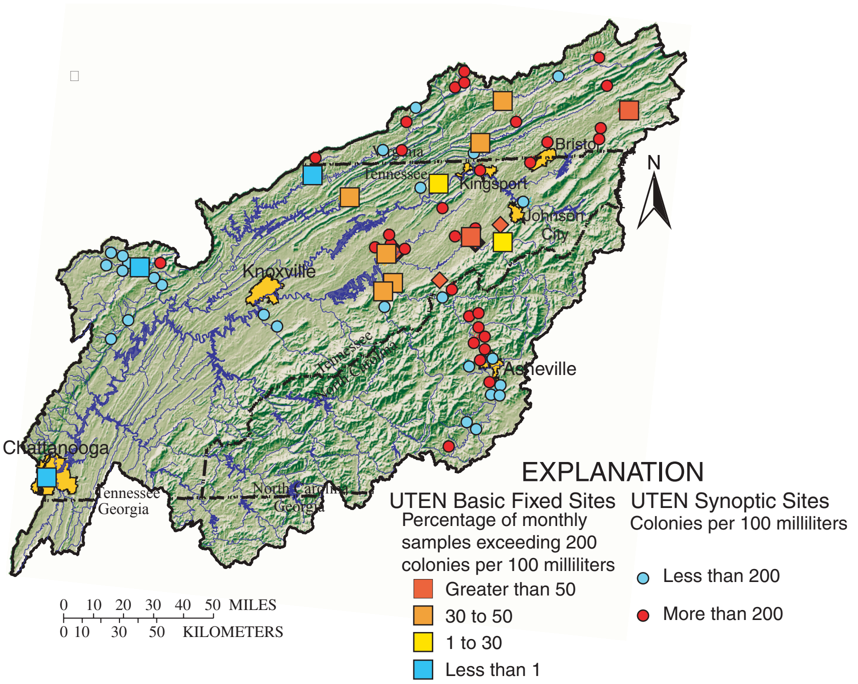


Figure 10. Fecal coliform bacteria frequently exceed standards in Upper Tennessee River (UTEN) streams.

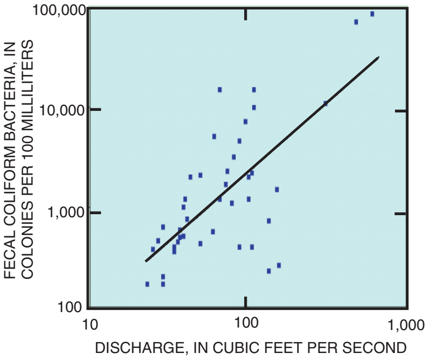


Figure 11. Fecal coliform counts vary with streamflow at Big Limestone Creek in Tennessee.

Livestock are a major contributor to fecal coliform levels in area streams.

In Upper Tennessee River Basin urban areas, deteriorated sewerage systems and combined sewer overflows produce elevated fecal coliform levels.

Bacteria Frequently Are Detected in Domestic Wells and Springs

A common misconception is that untreated ground water from wells and springs generally is safe for consumption because percolation through the soil removes most contaminants. While the soil can act as a natural filter, this does not guarantee the absence of contaminants. In fact, about half of the waterborne-disease outbreaks in the United States since 1900 have involved contaminated ground water.(11)

Ground-water systems such as the carbonate systems of the Upper Tennessee River Basin are particularly susceptible to contamination from surface sources. Ground-water flow paths in these systems usually are shallow, principally involving the upper 10 to 20 feet of highly fractured and heavily weathered rock. In addition, the common presence of bedrock outcrops, areas of thin overburden, and karst features such as sinkholes provide direct avenues for aquifer contamination (fig. 12). Other potential sources for bacterial contamination include faulty or poorly placed septic systems and poor well construction or sanitation practices.

For finished drinking water, the detection of as few as 4 coliform bacteria colonies per 100 milliliters (col/100 mL) or the detection of 1 col/100 mL of fecal coliform bacteria, or *E. coli,* warrants concern for human health.(12) Of 30 domestic wells used as sources for untreated drinking water, 11 (37 percent) exceeded the total coliform drinking-water standard and 9 (30 percent) the *E. coli* drinking-water standard (fig. 13). The highest *E. coli* value detected was 1,600 col/100 mL.

Total coliform values for 35 springs sampled in the Upper Tennessee River Basin ranged from 10 to 1,900 col/100 mL and *E. coli* ranged from 0 to 660 col/100 mL. All of the springs tested exceeded drinking-water standards for total coliform bacteria, and 95 percent of the springs exceeded the *E. coli* standard. Two springs exceeded the *E. coli* body-contact standard of 126 col/100 mL. Sixteen of the 35 springs are used as domestic water supplies and others are used for filling water containers by the roadside with what usually is believed to be “clean mountain spring water.”

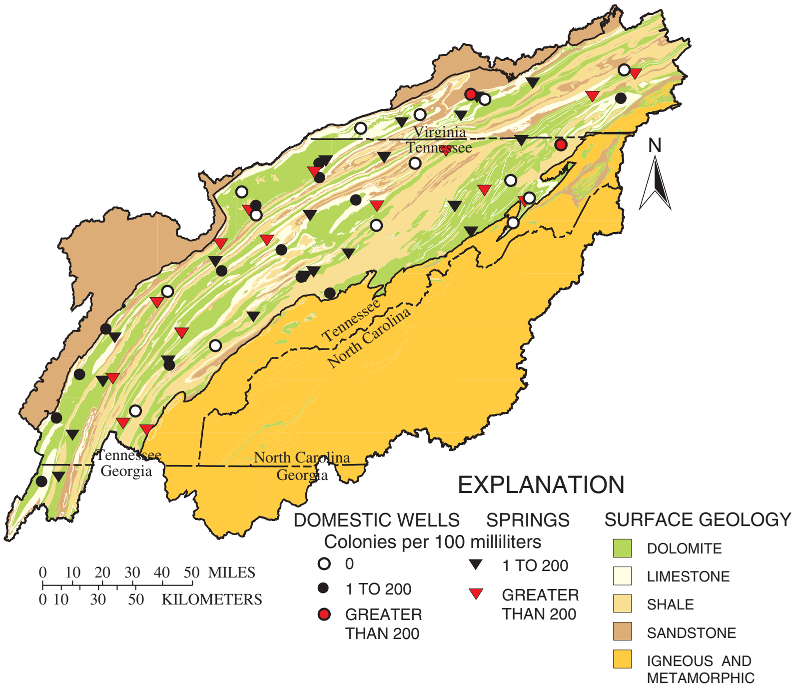


Figure 13. Coliform bacteria are often detected in Upper Tennessee River Basin ground water.

Most of the rural population in the Upper Tennessee River Basin depend on shallow domestic wells for water supply.

Although much of the public perceives them as clean sources of drinking water, springs are very susceptible to contamination.

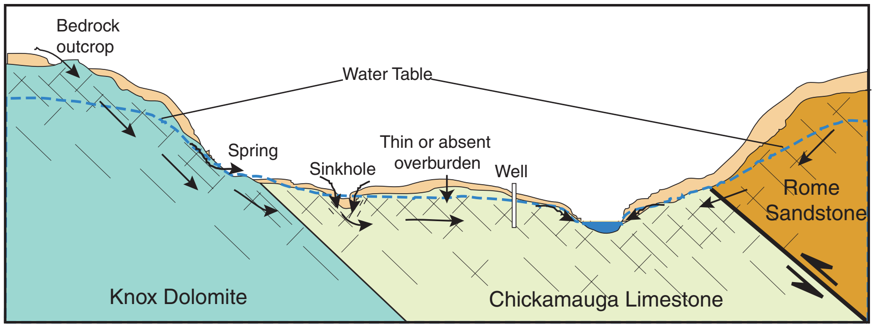


Figure 12. Upper Tennessee ground-water flow systems can be affected by a number of potential contamination sources such as sinkholes, outcrops of bedrock, and areas with thin overburden. (Not to scale)

Nutrients in the Upper Tennessee River Basin

Nutrients are nitrogen and phosphorus compounds that are essential for plant growth. When found at elevated concentrations, however, nutrients can degrade water quality. The enrichment of a water body with nutrients, called eutrophication, can result in dense, rapidly multiplying growths, or blooms, of algal species and other nuisance aquatic plants. These can clog water intake pipes and filters and interfere with recreational activities, such as fishing, swimming, and boating. Subsequent decay of algal blooms can overload water bodies with oxidizable debris and result in foul odors, bad taste, and reduced dissolved oxygen levels, which are harmful to other aquatic life.(13)

Nutrients in the Upper Tennessee River Basin originate from point and nonpoint sources. Point sources are typically piped discharges from wastewater-treatment facilities and large urban and industrial stormwater systems. Nonpoint sources include stormwater runoff from urban and agricultural areas. In the Upper Tennessee River Basin, applications of synthetic fertilizers and manure are major sources.

Nutrient Loadings and Yields Vary among Upper Tennessee River Subbasins

Nutrient loadings in the Upper Tennessee River subbasins are primarily influenced by land use and streamflow conditions. Loads were estimated by using a constituent transport model and multiple regression to relate streamflow to the concentration of a water-quality constituent to derive loads.(14) Twenty-three stations with adequate streamflow and chemical records were used for nitrogen calculations and 20 for total phosphorus.

The highest yields in the study area for both nutrient species were detected in the French Broad River Basin, particularly the upstream portion that includes Asheville, North Carolina (figs. 14 and 15). The French Broad River, as a whole, accounted for about 40 percent of the 138,000 pounds per day (lb/d) average annual total nitrogen load(15) and about 25 percent of the 13,500 lb/d average annual total phosphorus load,(16) leaving the basin at Chattanooga, Tennessee. The Holston River Basin added another 22 percent of the total nitrogen load but only 8 percent of the total phosphorus load.

A combination of agricultural and urban runoff is probably responsible for conditions in the French Broad River. In addition, the French Broad River and its tributaries have a history of water-quality problems associated with industrial point-source discharges. These basins also had the highest yields and loadings in the Upper Tennessee River Basin for total ammonia and organic forms of nitrogen.

Nutrient loadings and yields generally were lowest in those basins with relatively low percentages of agricultural land use and at sites directly downstream from tributary reservoirs. The fate of nutrients in the reservoirs depends on the physical characteristics of the reservoir (volume, surface area, depth, and hydraulic retention time) and its trophic state.(17) The tributary reservoirs in the Upper Tennessee River Basin commonly function as sinks for nutrient species by providing a favorable environment for nitrogen transformation and by efficiently trapping both dissolved and sediment-bound phosphorus. Outflow loads of total phosphorus below Norris Lake on the Clinch River, for example, were 37 percent of the inflow load from the Clinch and Powell River Basins. Load estimates for the Holston River upstream and downstream from

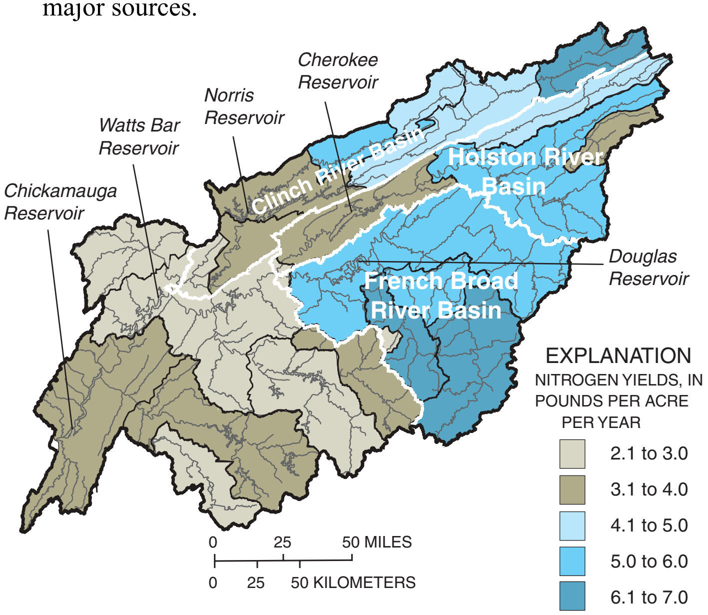


Figure 14. Mean annual total nitrogen yields between 1973 and 1993 were highest in the upper French Broad and upper Clinch River Basins.

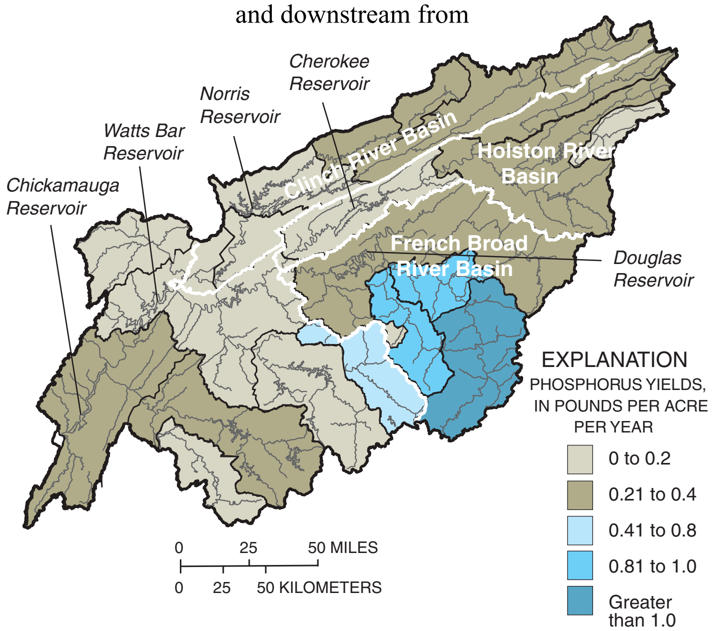


Figure 15. Mean annual total phosphorus yields between 1973 and 1993 were highest in the upper French Broad River Basin.

Cherokee Reservoir similarly indicate that the reservoir traps about 46 percent of the incoming load of total phosphorus. In contrast, less trapping occurs in the main-stem reservoirs, which are predominantly flow-through systems with limited storage capacity and relatively short residence times. Outflow phosphorus loads downstream from Chickamauga and Watts Bar Reservoirs significantly exceeded the inflow loads from upstream drainages. The increased loads can be attributed to low rates of trapping as well as additional input from ungaged areas adjacent to the reservoirs.(16)

Nutrient Concentrations and Yields Vary with Land Use

The relation between total nitrogen concentrations and land-use percentages was investigated for 87 sites in the Upper Tennessee River Basin and was found to be statistically significant. Stations in forested watersheds had the lowest concentrations of total nitrogen, whereas stations in agricultural areas had the highest. Concentrations of nitrogen in urban and mixed land-use areas were significantly greater than forested watersheds but were somewhat less than nitrogen concentrations in agricultural watersheds. Total nitrogen concentrations tended to increase with increased development whether agricultural or urban (fig.16).(15)

Nitrogen sources also were investigated by using regression analysis between annual basin yields and total annual inputs from fertilizer, animal waste, wastewater discharges, and atmospheric deposition. For total nitrogen, basin yields significantly and positively correlated with agricultural inputs but only weakly correlated with wastewater discharges and atmospheric inputs. This tends to identify agricultural land use as the major contributor to annual instream nitrogen yields.(18)

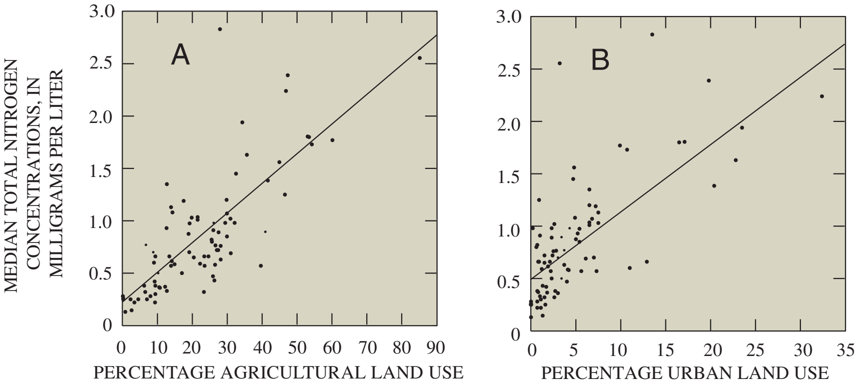


Figure 16. Median total nitrogen concentrations can be related to (A) agricultural, and (B) urban land uses.

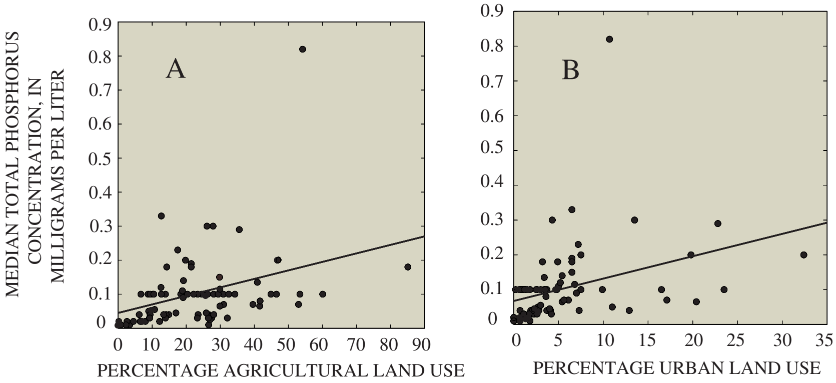


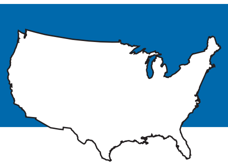
Figure 17. Median total phosphorus concentrations can be related to (A) agricultural and (B) urban land uses.

The relation between total phosphorus concentrations and land-use percentages also were investigated for 83 sites in the Upper Tennessee River Basin. Although the relation was not quite as clear as with nitrogen, statistically significant increases in total phosphorus concentrations also accompanied increased development whether urban or agricultural (fig. 17). As with total nitrogen, the lowest phosphorus concentrations were detected at sites in predominantly forested watersheds, whereas sites in urban and agricultural areas had the highest phosphorus concentrations.(16)

Phosphorus sources also were investigated by using calculated basin yields and total annual inputs from fertilizer, animal waste, wastewater discharges, and the atmosphere. Phosphorus yields were found to strongly correlate with wastewater discharges but not with the agriculturally related input categories. This suggests that wastewater discharges may account for most of the total phosphorus load in basin streams (J.F. Connell, U.S. Geological Survey, written comun., October 20, 2000). Agriculturally applied phosphorus may be assimilated quickly by area soils thereby reaching area streams slowly if at all.

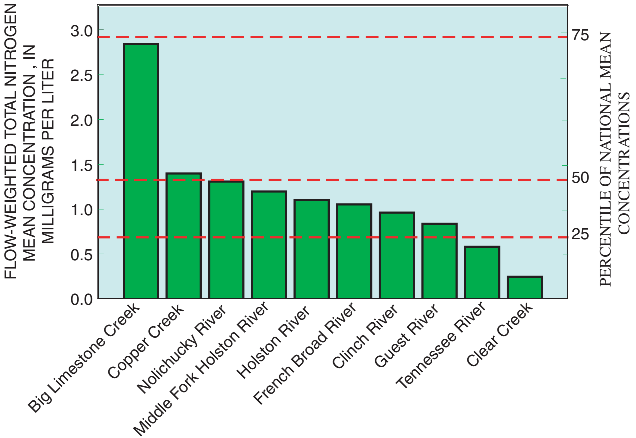
Agricultural land uses appear to account for most of the total nitrogen loads to area streams.

Wastewater discharges appear to account for most of the total phosphorus in Upper Tennessee River Basin streams.

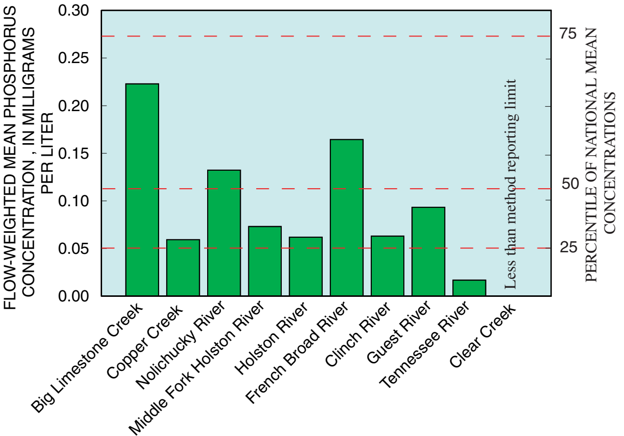


Nutrient Concentrations in Upper Tennessee River Basin Surface Waters Generally Are Lower Than National Median Concentrations

Although nutrient concentrations and loadings are a concern in parts of the Upper Tennessee River Basin, concentrations generally are low for most area subbasins when compared with national averages. Mean total nitrogen concentrations exceeded or equaled the national median values only for three agricultural sites: Big Limestone Creek (83 percent agricultural), Copper Creek (51 percent agricultural), and the Nolichucky River (39 percent agricultural). Similar results were obtained for total phosphorus at Big Limestone Creek and the Nolichucky River, but the French Broad River flowing into Tennessee from North Carolina also exceeded the national median value. Although relatively low, mean total phosphorus concentrations at most sites exceeded the U.S. Environmental Protection Agency (USEPA) goal of 0.05 mg/L total phosphorus for surface water entering reservoirs.



Total nitrogen exceeded the national median value only at the two intensively sampled agricultural sites.



Total phosphorus exceeded the national mean in two heavily agricultural drainages and also in the French Broad River below the Asheville, N.C., urban area.

Nitrogen Species Changed by Wastewater Treatment

Prior to the widespread implementation of wastewater treatment, nitrogen loadings for most Upper Tennessee River Basin streams primarily consisted of reduced species such as ammonia and various organic forms. These nitrogen species generally are undesirable in surface water because of associated color changes and decreases in dissolved oxygen levels. In addition, under certain conditions, ammonia nitrogen can be highly toxic to aquatic life. Wastewater-treatment facilities convert these undesirable forms to the oxidized species, nitrite and nitrate.

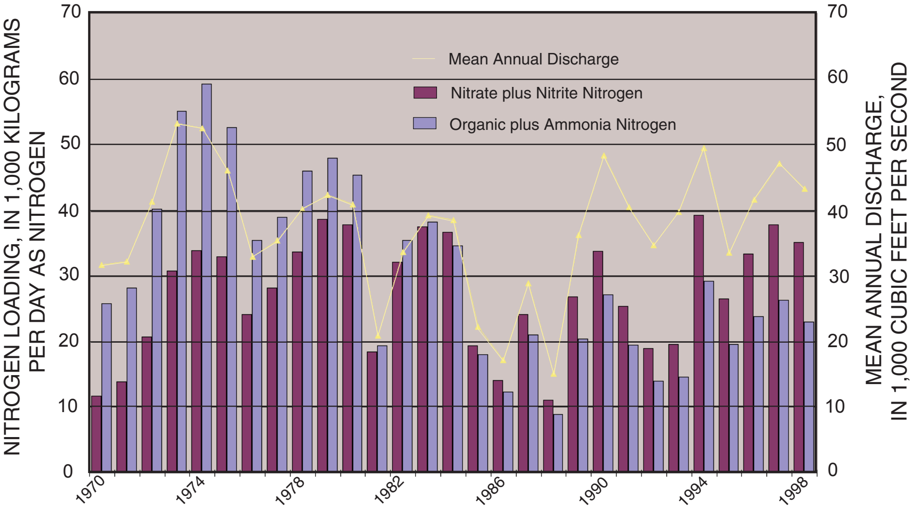


Figure 18. The predominant nitrogen species changed at the Tennessee River at Chattanooga, Tennessee, between 1970 and 1998.

At the Tennessee River at Chattanooga, Tennessee, as with most major streams in the Upper Tennessee River Basin, the ratio of reduced to oxidized nitrogen species began to change in the late 1970s (fig. 18), corresponding to the implementation of wastewater-treatment facilities. By about 1983, the oxidized nitrogen species, nitrate and nitrite, became the predominant forms of nitrogen discharged from the basin, a trend which has continued to the present.

Loading Trends Increase in Parts of the Upper Tennessee Basin

Trend analyses for 56 stations using the seasonal Kendall statistical analysis test indicated significant increases in total nitrogen at seven sites in the Upper Tennessee River Basin and significant decreases at eight sites (fig. 19). Sites showing decreases were all on relatively major streams (average drainage area, 2,600 square miles) or below major impoundments. Of the seven sites showing increases, six are in the Blue Ridge physiographic province and six drain basins with forests accounting for more than 75 percent of the total land use. The exception is Beaver Creek, which drains the Bristol, Tennessee and Virginia, urban area in the Valley and Ridge Province. The average area of basins showing nitrogen increases was only 276 square miles.(15)

Of the seven sites showing increases, five are in the Blue Ridge in North Carolina–two sites on the French Broad River and one each on the Little Tennessee River and tributaries to the Hiwassee and Pigeon Rivers. Much of this area is undergoing nonurban residential development in the form of vacation homes. Nitrogen loads are probably increased by the sewage and fertilizer use associated with this development.

Similar trend analyses for 42 sites to detect changes in total phosphorus concentrations yielded only one site with significant increases (fig. 20). West Chickamauga Creek, which drains a major industrial and urban setting, showed high concentrations for the entire period of record. Most (33) sites showed no trend, and eight sites showed significant decreases. These sites are dominated for the most part by pasture and forest; however, three sites are downstream from major wastewater discharges.(16) For sites in these more urbanized basins, improvements in wastewater-treatment processes are clearly responsible for the downward phosphorus trends.

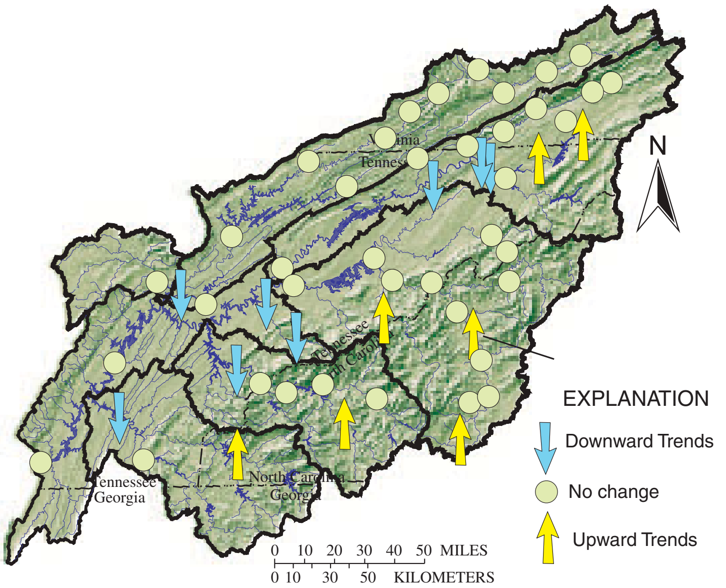


Figure 19. Total nitrogen increased in parts of the Upper Tennessee River Basin between 1970 and 1993.

Nonurban residential development in the Blue Ridge Mountains is most likely the largest contributor to increasing total nitrogen concentrations.

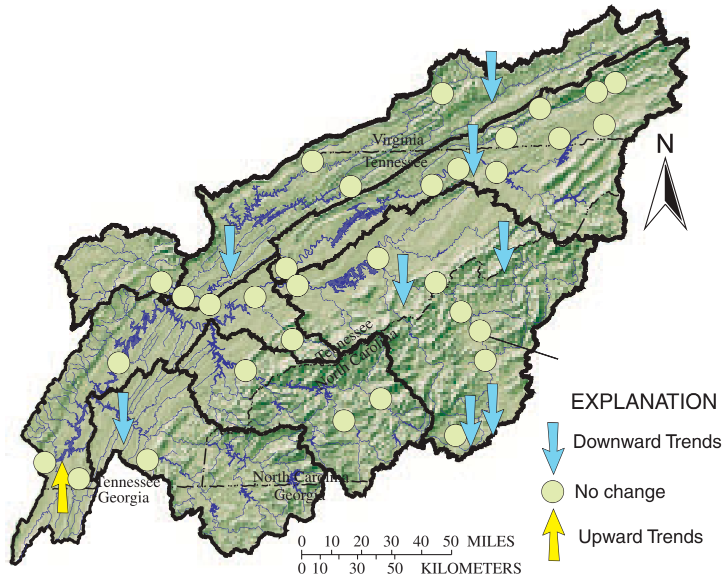


Figure 20. Total phosphorus decreased or remained unchanged in the Upper Tennessee River Basin between 1970 and 1993.

Nutrient Concentrations Generally Are Low in Upper Tennessee River Basin Ground Water

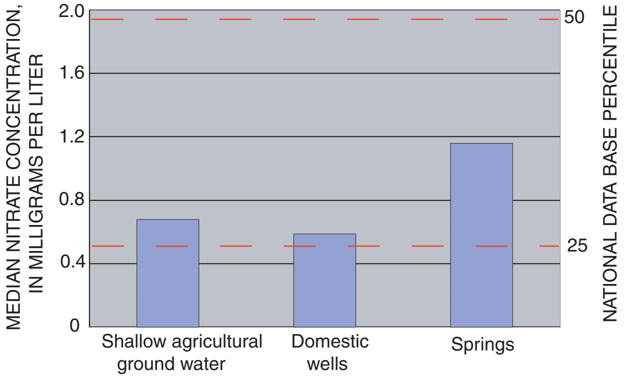
All of the nutrients measured in the Upper Tennessee River Basin ground water were relatively low, as is usually typical of ground water. Most nutrient species are retained by soil particles or organic matter, taken up by plants, or utilized by soil bacteria and never enter the ground-water flow system. Exceptions are the nitrate and ammonia forms of nitrogen; however, only nitrate has a drinking-water standard, which is 10 mg/L. Drinking water containing nitrate concentrations higher than the standard can cause methemoglobinemia, a life-threatening illness in infants.

Nitrate was present in all wells and springs sampled in the Upper Tennessee River Basin but usually at concentrations of 3 mg/L or less. This included all of the 30 domestic wells used for drinking-water supply that were sampled and the 35 springs sampled across the basin. The median nitrate concentration for domestic wells was 0.59 mg/L, slightly more than the 25th percentile value nationally; the median nitrate concentration for springs was 1.16 mg/L, which was significantly lower than the national 50th percentile. The higher concentrations detected in springs most likely reflect the predominance of relatively short ground-water flow paths associated with localized recharge and runoff. No nitrate concentrations in excess of the 10-mg/L standard were detected in any domestic wells or springs.

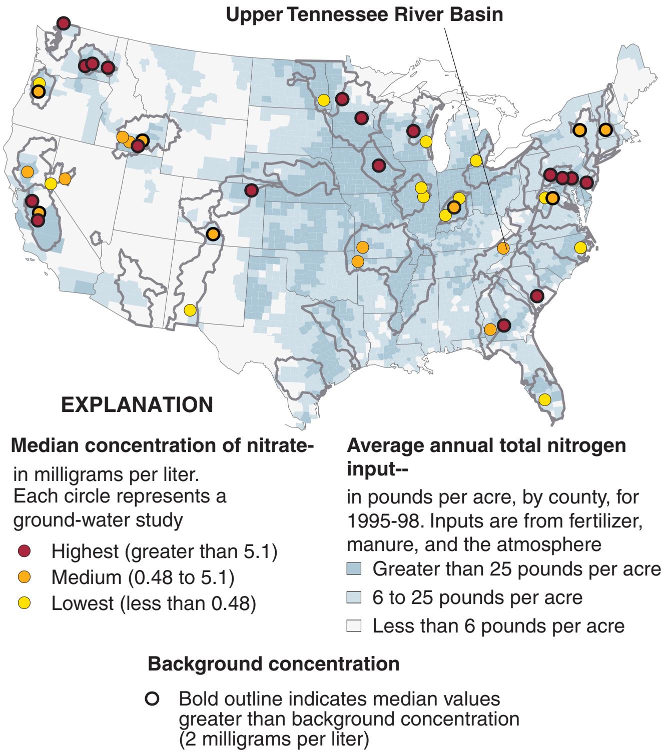
Nitrate concentrations in excess of the 10 mg/L standard were detected in 5 of the 30 wells installed during the study period to monitor shallow ground-water quality under and adjacent to tobacco fields. Tobacco is the main cash crop in the Upper Tennessee River Basin and is usually grown in small but intensively fertilized and cultivated plots. In general, fertilizer applications for tobacco cultivation are much greater than for any other row-type crop raised in the Upper Tennessee River Basin.

The median nitrate concentration in the shallow agricultural monitoring wells, however, was 0.68 mg/L–only slightly more than the median concentration for domestic wells and the national 25th percentile. Among the concentrations found nationally for agricultural and urban land uses, this value falls in the lower end of the medium range as shown in the accompanying figure.

The results indicate that nitrate contamination of extensive areas of ground water in the Upper Tennessee River Basin is very unlikely. High nitrate concentrations relative to the 10 mg/L drinking-water standard were detected only in shallow ground water directly under heavily fertilized tobacco plots. Tobacco fields typically cover only about 2 acres and are widely scattered across the study area. The potential for nitrate contamination of drinking-water sources is, therefore, very low outside of the immediate vicinity of tobacco fields.



Median ground-water nitrate concentrations in the Upper Tennessee River Basin were significantly lower than the national median



Median nitrate concentrations in shallow ground water beneath agricultural land use in the Upper Tennessee River Basin were in the medium range on a national basis.

Pesticides in the Upper Tennessee River Basin

Pesticides are widely used in the Upper Tennessee River Basin to control insects, fungi, weeds, and other undesirable organisms. These compounds vary in their toxicity, persistence in the environment, and transport characteristics. Use of some of the more persistent organochlorine compounds, such as DDT, chlordane, dieldrin, and aldrin has been discontinued in the United States, but their residues are still detected in the environment. Although pesticides usually are applied to specific areas and directed at specific organisms, these compounds often become widely distributed and pose hazards to nontarget organisms. Of 18 sites sampled for organochlorine residues in bottom material and biota in the Upper Tennessee River Basin, chlordane was detected at three sites and dieldrin and DDT-related residues at two sites.

Pesticides were Frequently Detected in Surface Water

Pesticide use in the Upper Tennessee River Basin is primarily for agricultural purposes. Herbicides, including atrazine and its degradation product, deethylatrazine, had some of the highest application rates and were also among the most frequently detected pesticides in the basin. Herbicides were detected in 98 percent of the 428 surface-water samples collected; atrazine was found in 91 percent and deethylatrazine in 86 percent. Metolachlor and simazine were detected in 62 and 40 percent, respectively. Tebuthiuron and prometon, which are used most commonly in noncrop areas, were also among the most frequently detected herbicides (in 58 and 31 percent of the samples collected, respectively). The most frequently detected insecticides were diazinon (12 percent), carbaryl (10 percent), and chlorpyrifos (10 percent), all of which are used on a variety of crops to control pests.

Detection frequencies for 27 pesticides detected at 3 intensively sampled agricultural sites in the Upper Tennessee River Basin (fig. 21) generally illustrate the results obtained at all 13 Basic Fixed Sites from which surface-water samples were collected. Overall, a total of 32 pesticides were detected. Chlorothalonil, alpha-BHC, and terbacil each were detected once and ethoprop was detected twice.

Some differences among the three sites are notable and probably reflect different agricultural practices and hydrologic conditions. For example, at the Nolichucky River site, compounds generally not found at other sites such as cyanazine, alachlor, DCPA, metribuzin, bromacil, and diazinon, were detected. Molinate, trifluralin, and p,p'-DDE were detected only at the Copper Creek site, which also had a significantly higher frequency of detection for tebuthiuron. Pesticide detection frequencies at Big Limestone Creek and the Nolichucky River were, as expected, similar for several compounds including metolachlor, simazine, prometon, and napropamide. Big Limestone Creek is a tributary to the Nolichucky River, and both drain the same general agriculturally dominated area. The Big Limestone Creek drainage basin, however, contains more dairy operations than other parts of the Nolichucky drainage basin, which may account for some of the differences between the two sites.

Pesticides are widely used in the Upper Tennessee Basin for control of insects, fungi, weeds, and other undesirable organisms.

Table 1. Major pesticides used in the Upper Tennessee River Basin, listed in order of estimated total pounds of active ingredient applied annually (1991-94) (18)

Insecticides		*Herbicides*		*Fungicides*	
Oil	256,000	Atrazine	116,000	Methyl bromide	423,000
Acephate	80,700	2-4-D	55,600	1-3-D	342,000
Chlorpyrifos	71,500	Metolachlor	46,300	Captan	108,000
Carbaryl	27,200	Alachlor	40,900	Ziram	69,500
Fenamiphos	17,200	Pebulate	31,400	Sulfur	58,700
Carbofuran	17,000	Pendimethalin	25,200	Chloropicrin	45,100
Formetanate	16,300	Butylate	24,800	Mancozeb	40,400
Azinphos-methyl	14,400	Simazine	23,800	Metalaxyl	28,100
Phosmet	9,420	Glyphosate	16,100	Manab	21,500

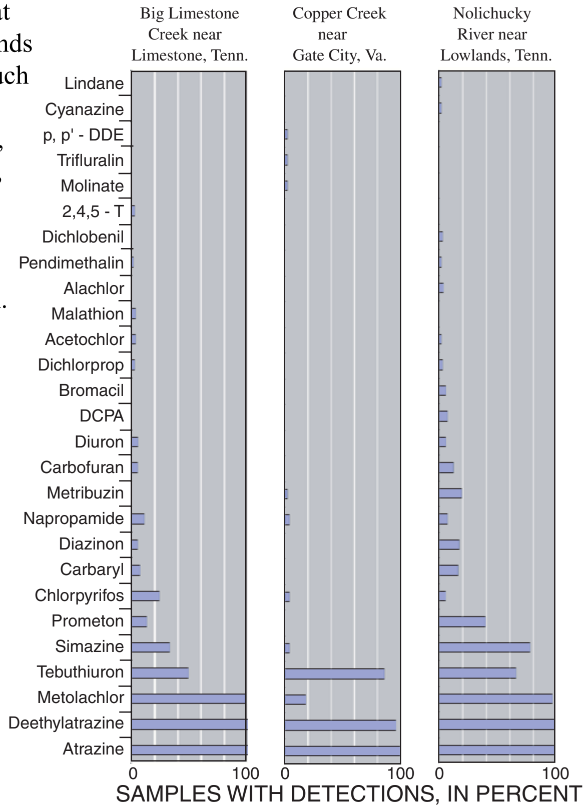


Figure 21. Pesticide detections at three agriculturally dominated sites followed similar patterns.

Mixtures of Pesticides Are Common

Pesticides were seldom detected alone in surface-water samples and usually occurred as mixtures of several compounds. Generally, the effects of pesticide mixtures on biota or humans are not included in water-quality criteria, which are most commonly based on single-species, single-chemical toxicity tests conducted under laboratory conditions. As a result, potential adverse effects on biota may be underestimated.

Of the 163 samples collected at the three intensive sites, only 2 samples at Copper Creek contained only one detectable pesticide compound, and only 5 total samples contained only two compounds (fig. 22). Among the intensively sampled sites, samples from the Nolichucky River at Lowlands, Tennessee, generally contained more detectable pesticide compounds than samples from the other sites, but usually at lower concentrations. This reflects the larger drainage area of the Nolichucky River (1,687 square miles) as compared to the drainage areas of the other intensive sites (79 and 106 square miles for Big Limestone and Copper Creeks, respectively). Similarly, more pesticides also were detected in samples from Big Limestone Creek, which has a larger percentage of agricultural land use and a greater variety of crops than the Copper Creek Basin in Virginia.

Peak Pesticide Concentrations Are Seasonal

Pesticide concentrations were found to be seasonal and closely related to land use. The highest concentrations occurred in the more heavily agricultural basins in late spring and early summer, coinciding with crop applications. Results of weekly sampling results at the three intensively sampled agricultural sites illustrate the seasonality and short-lived nature of the peak concentrations in streams draining agricultural areas (fig. 23). Peak concentrations coincided with the first substantial runoff event following agricultural applications in May 1996, after which concentrations declined relatively rapidly to near-background levels. Less frequent sampling would have made it less likely to have noted the existence of the peaks. Because these streams are “flashy” in that peak discharges come and go very quickly, it is possible that even higher concentrations can occur for short periods of time. Seasonality also was evident at sites not characterized or directly influenced by intense agricultural activities. Atrazine and metolachlor concentrations at Clear Creek at Lilly Bridge, a predominantly forested watershed and part of the Obed National Wild and Scenic River watershed, also showed a distinct seasonality but with much lower concentrations (fig. 24). The seasonal pattern at this site is more gradual, suggesting atmospheric input more than runoff from agricultural activity.

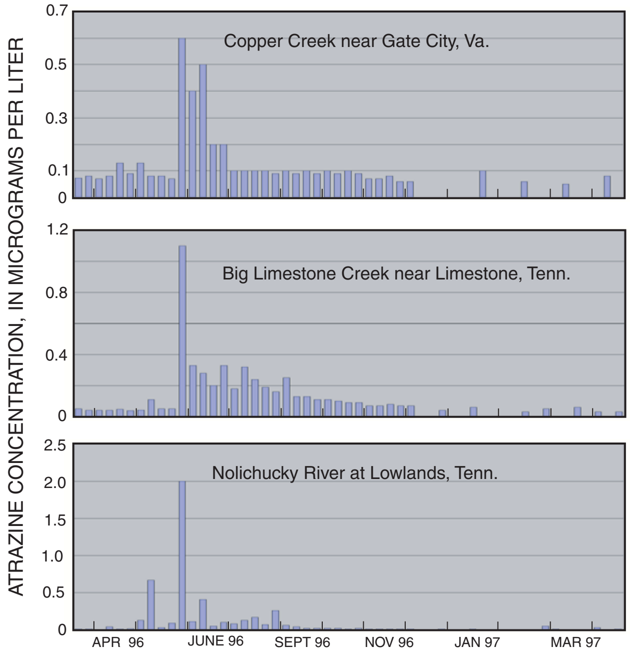


Figure 23. Atrazine concentrations were seasonal in the Upper Tennessee River Basin intensively sampled sites, March 1996 - April 1997.

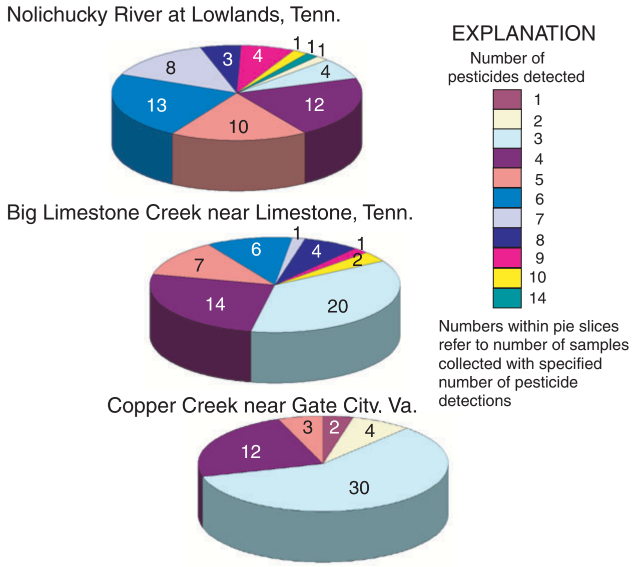


Figure 22. Pesticides usually were detected as mixtures of different compounds.

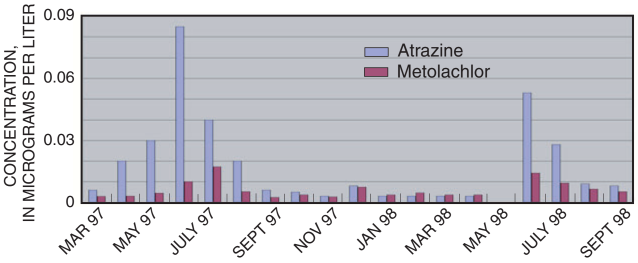


Figure 24. Atrazine and metolachlor concentrations were seasonal in monthly samples at Clear Creek at Lilly Bridge, March 1997 - September 1998.

Pesticide Concentrations Usually Meet Guidelines

Although most of the water samples collected contained detectable concentrations of one or more pesticides, no concentrations exceeded any drinking-water standards or guidelines. Only 20 of the 31 pesticides detected, however, have established guidelines. Of the 15 compounds that have aquatic-life guidelines, four were detected at concentrations higher than the guidelines. Carbaryl concentrations in excess of the 0.20-µg/L (micrograms per liter) aquatic-life criterion(19) were found in four samples—two each from the Guest River near Millers Yard, Virginia, and the Nolichucky River at Lowlands, Tennessee (fig. 25). Lindane, an organochlorine used primarily for the protection of tobacco transplants, was above the 0.01-µg/L criterion in three samples from three different sites, two of which were in the same subbasin - Little Limestone Creek and the Nolichucky River at Lowlands, Tennessee.

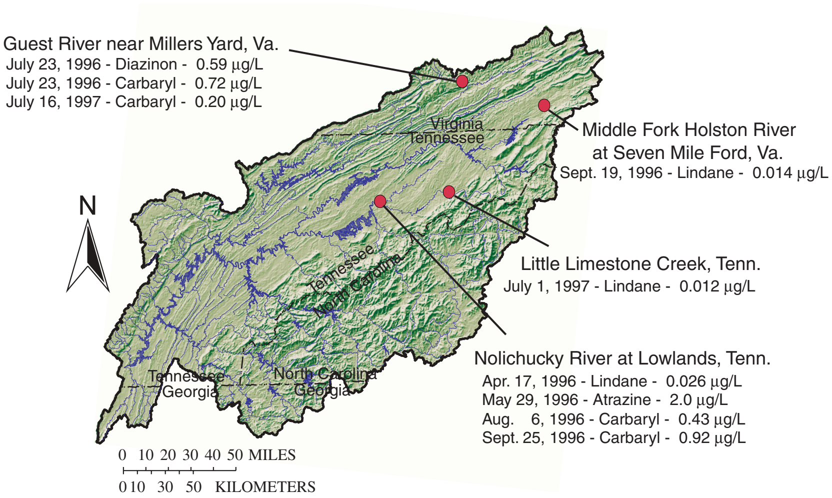
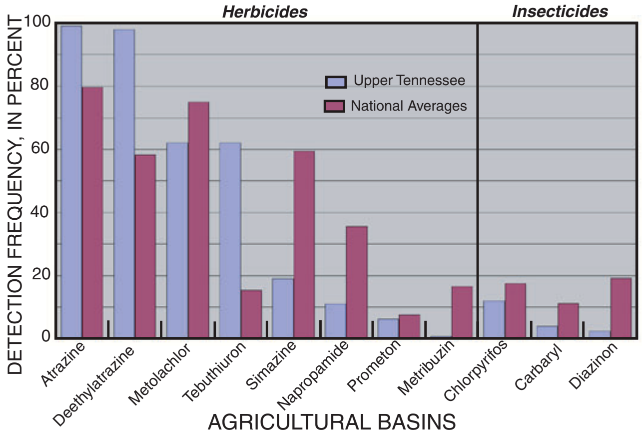


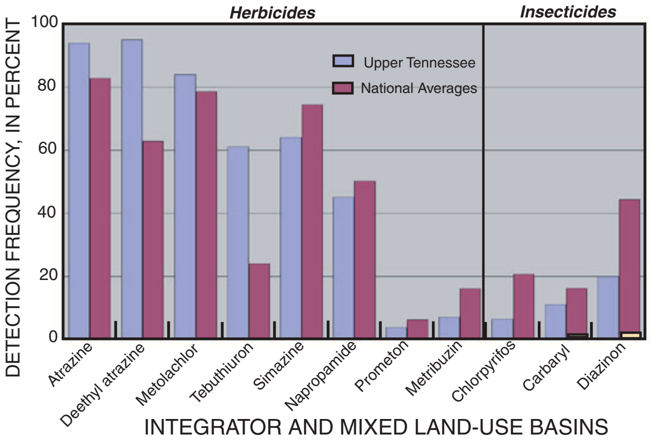
Figure 25. Pesticide concentrations, in micrograms per liter (µg/L), infrequently exceeded aquatic-life criteria in the Upper Tennessee River Basin, 1996-98.

An atrazine concentration higher than the 0.18-µg/L criterion(20) also was detected in one sample taken at the Nolichucky River at Lowlands, Tennessee, in May 1996. This was the only criterion exceedance noted for any herbicide even though herbicides were detected much more frequently than the other pesticide types. One sample collected at the Guest River near Millers Yard, Virginia, contained a diazinon concentration that was not only greater than the aquatic-life guideline of 0.08 µg/L but approached the USEPA lifetime health advisory level of 0.60 µg/L for drinking water.

Some Pesticides Were Detected More Frequently in the Upper Tennessee River Basin Than Nationally

Three herbicides consistently were detected more frequently in the Upper Tennessee River Basin than in other basins across the Nation. Atrazine and deethylatrazine were detected in 99 and 98 percent, respectively, of samples from agricultural basins in the Upper Tennessee River Basin and in 94 and 95 percent, respectively, of samples from mixed land-use basins - significantly more frequently than the national averages of about 80 and 60 percent, respectively. Tebuthiuron also was detected in about 60 percent of the Upper Tennessee River Basin samples as opposed to an overall average of about 20 percent nationally. Detection frequencies for most of the other herbicides probably reflect different herbicide-use patterns in the Upper Tennessee River Basin resulting from particular crop patterns. The three most commonly detected insecticides in the Upper Tennessee River Basin - diazinon, carbaryl, and chlorpyrifos - were detected less frequently than the national averages in all land-use categories.





Pesticides Were Detected at Low Levels in Ground Water

Pesticides were detected in Upper Tennessee River Basin ground-water samples more often than not, but generally at concentrations less than 0.01 µg/L. Pesticide concentrations in ground water did not exceed any drinking-water standards or guidelines. Usually, however, pesticides occur in mixtures for which criteria are not available. In addition, 5 of the 11 pesticides detected have no established guidelines or criteria.

Pesticides were detected in springs significantly more often and in more pesticide detections per sample than in other ground-water sources sampled (fig. 26). This probably reflects the greater vulnerability of springs to surface contamination either from the immediate area or karst features in the carbonate bedrocks. More frequent detections also may reflect the larger drainage areas from which springs capture ground water as opposed to wells. Of the 35 springs sampled, 24 (69 percent) contained detectable pesticide concentrations, and 12 (34 percent) contained detectable quantities of three or more different compounds. Detection frequencies in agricultural and domestic wells, by contrast, were significantly lower and similar to one another; 12 of 30 (40 percent) agricultural wells and 13 of 30 (43 percent) domestic wells contained detectable pesticide concentrations. Of these detections, only three (10 percent) samples from agricultural wells had detections of three or more pesticides. Eight (27 percent) domestic wells, however, had detections of three or more compounds.

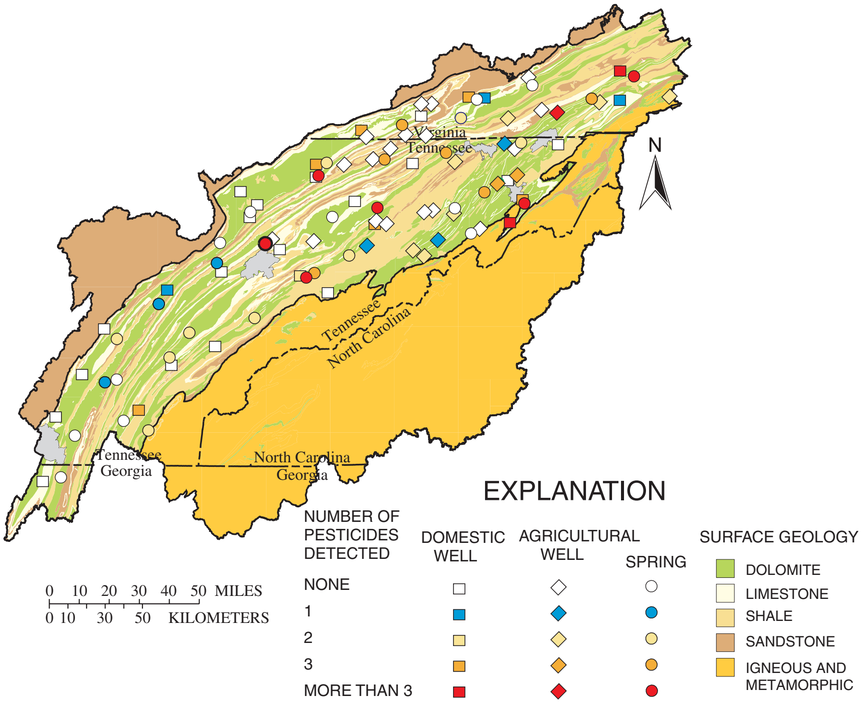


Figure 26. Pesticides were detected at low concentrations in Upper Tennessee River Basin ground water.

Atrazine and its degradation product, deethylatrazine, were the pesticides most commonly detected in all ground-water samples but were detected twice as frequently in springs as in other ground-water sources (fig. 27). Tebuthiuron, the third most frequently detected pesticide, also was detected more than twice as frequently in springs as in domestic wells. The different pesticide mixtures typical of the agricultural wells sampled reflect the focus on tobacco in this phase of the study. In general, a different suite of pesticides are used for tobacco than for most other crops. For example, atrazine and other broadleaf herbicides are toxic to tobacco.

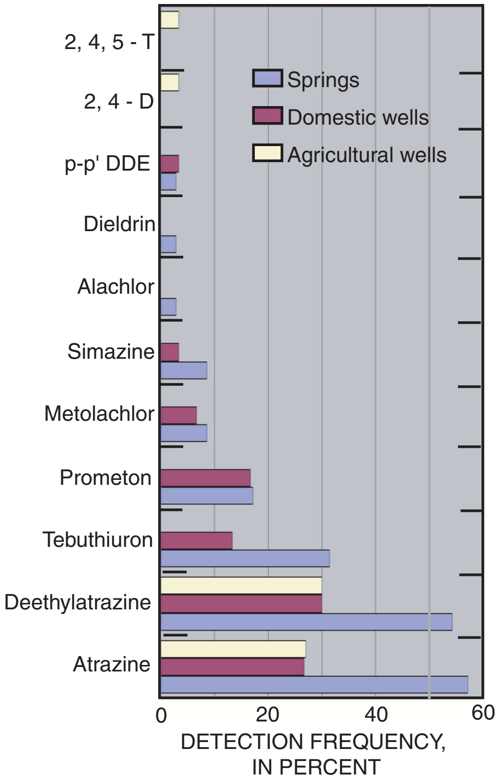


Figure 27. Pesticides were detected more frequently in springs than in wells in the Upper Tennessee River Basin.

Pesticides were detected more frequently in Upper Tennessee River Basin springs than in other sources of ground water.

Volatile Organic Compounds Were Frequently Detected in Ground Water

Ground-water samples were collected from 30 domestic wells and 35 springs tapping carbonate strata in the Upper Tennessee River Basin. Volatile organic compounds (VOCs) were detected in most of the ground-water samples (fig. 28) but generally at very low concentrations–often in orders of magnitude below the established reporting limit. Twenty-eight different VOCs were detected during sampling, 12 of which have drinking-water standards. No measured concentrations, however, exceeded these standards.

VOCs were detected more frequently in springs (86 percent) than in domestic wells (67 percent) and generally at slightly higher concentrations. Of the 20 samples with one or more concentrations greater than 0.1 µg/L, 14 were taken from springs and only 6 from wells. Similarly, of the 28 compounds detected, 22 were detected in spring samples and only 18 were detected in domestic wells.

The most frequently detected VOCs were trichloromethane (51 percent), chloromethane (28 percent), styrene (23 percent), tetrachloroethane (18 percent), carbon disulfide (11 percent), and trichloroethene (9 percent). The remaining 22 compounds were detected in three or fewer samples (less than 5 percent).

Other than the greater detection frequencies for spring samples, no areal or other occurrence patterns could be found. As is the case nationally, the source for many of the most common VOCs detected in ground water, such as trichloromethane, is unclear. The greater occurrence of detections in springs as well as the widespread but random pattern of occurrence suggests the possibility of atmospheric origins, but no definite source can be identified at present.

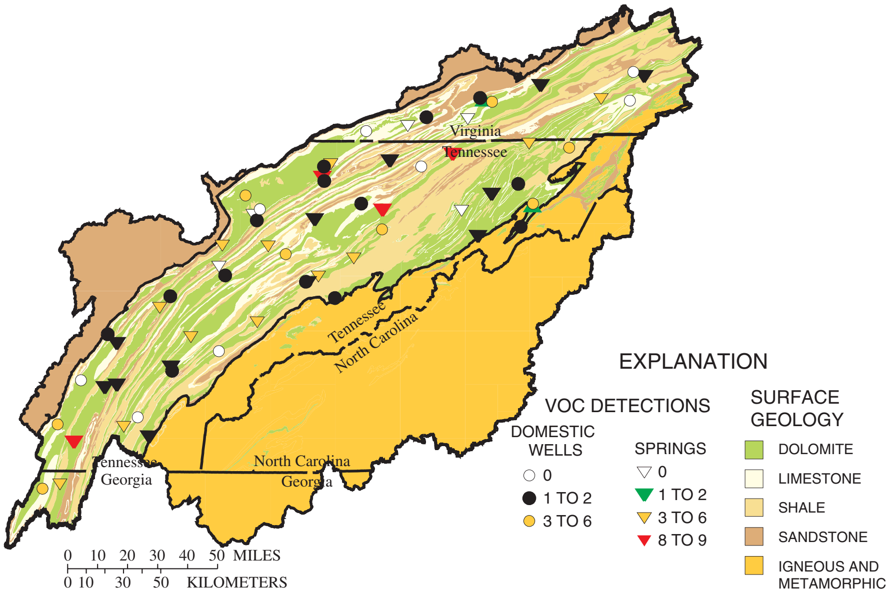
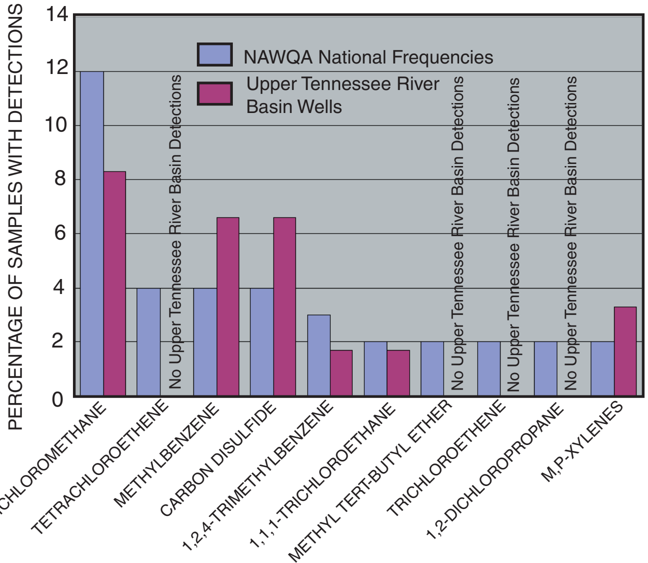


Figure 28. Volatile organic compounds (VOCs) are often detected in Upper Tennessee River Basin ground water.

Upper Tennessee River Basin and National VOC Detection Frequencies Are Similar

Detection frequencies in Upper Tennessee River Basin wells for the 10 most commonly detected VOCs nationally were similar to national detection frequencies found for ambient ground water in all land-use settings. All compounds were assessed at a common detection level of 0.1 µg/L. Trichloromethane was the most commonly detected compound nationally as well as in the Upper Tennessee River Basin but typically was detected at concentrations far below drinking-water standards. The results are consistent with the mixed urban and rural land uses surrounding most Upper Tennessee River Basin ground-water sites.

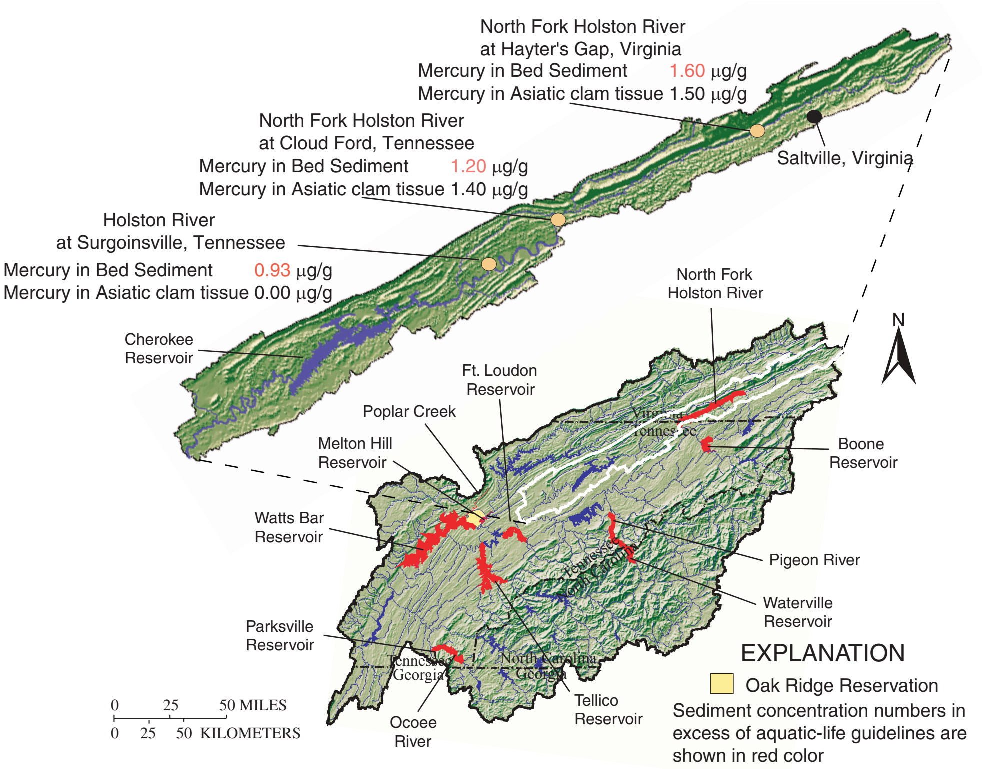


Upper Tennessee River Basin detection frequencies were similar to national results for the 10 most commonly detected VOCs nationally. (Assessment level of 0.1 microgram per liter)

Water-Quality Influences of Industry and Mining

Industrial and mining activities prior to the passage of the Clean Water Act in 1972 have left a legacy of contaminated sediment that continues to affect water quality in parts of the Upper Tennessee River Basin. The most widespread contaminants are PCBs (polychlorinated biphenyls) and mercury, mostly from industrial activities dating from 1950 to1972. Sources for some of the other contaminants, however, such as those affecting the Pigeon and Ocoee Rivers date back as far as 1908 and 1843, respectively.

Mercury in the North Fork Holston River is a result of the operation of a chlor-alkali plant on the banks of the river from 1950 through 1971. An estimated 75 pounds of mercury per day were discharged either directly to the river or into unlined holding ponds along the riverbank.(21) Although soils at the site have been remediated, the site continues to discharge mercury.(22) Bed-sediment and tissue samples taken from the Holston River system (fig. 29) were the only samples taken during the study that were above the Canadian guideline for aquatic-life protection (0.486 micrograms per gram total mercury). Although tissue samples in the main-stem Holston River site at Surgoinsville were free of mercury, the bed-sediment results suggest that mercury may be migrating farther downstream than previously thought and may eventually reach Cherokee Reservoir.



Location	Contaminant	Source	Comment
N. Fk. Holston River	Mercury	Industrial point source	Fish consumption advisory
Boone Resevoir	PCBs, Chlordane	Not identified	Fish consumption advisory
Pigeon River	Dioxin	Industrial point source	Fish consumption advisory
Waterville Reservoir	Dioxin	Industrial point source	Fish consumption advisory
Melton Hill Reservoir	PCBs, Chlordane	Industrial point source	Fish consumption advisory
E. Fk. Poplar Creek	PCBs, Mercury	Industrial point source	Fish consumption advisory
Watts Bar Reservoir	PCBs, Mercury	Industrial point source	Fish consumption advisory
Ft. Loudon Reservoir	PCBs	Industrial point source	Fish consumption advisory
Tellico Reservoir	PCBs	Not identified	Fish consumption advisory
Parksville Reservoir	Metals	Abandoned mining area	None
Ocoee River	Metals	Abandoned mining area	None

Figure 29. Mercury, in micrograms per gram, and organic contaminants persist in bed sediments and biological tissues in parts of the Upper Tennessee River Basin.

Mercury is also a major contaminant in the drainages downstream from the Department of Energy's 35,585-acre Oak Ridge Reservation (ORR), such as East Fork Poplar Creek, the White Oak Creek watershed, and the lower Clinch River - Watts Bar Reservoir. The ORR, established in 1942 as part of the Manhattan Project to develop the atomic bomb, encompasses three major facilities — X–10, originally for weapons research but now Oak Ridge National Laboratory (ORNL); Y–12, for the fabrication of nuclear weapons components; and K–25, for uranium enrichment by gaseous diffusion. As a result of these operations, about 527 sites covering approximately 15 percent of the total ORR area have been identified as contaminated with metals, including mercury, radionuclides, a variety of VOCs, and nitrates.(23)

Most of the contamination has remained confined within the ORR, which was added in its entirety to USEPA's National Priorities List in 1989. A number of contaminants, most notably mercury, PCBs, and cesium-137, however, have migrated to downstream areas. The State of Tennessee has posted a fish-consumption advisory for ORR drainages as wells as Watts Bar Reservoir as a result of bioaccumulation of mercury and PCBs in some fish species.

A 1983 inventory estimated that about 2 million pounds (1,088 metric tons) of mercury was 'lost' from operations related to thermonuclear bomb development on the ORR.(24) Most of this mercury is believed to have volatilized into the atmosphere, but much remains within ORR facilities and in Watts Bar Reservoir sediments. Analyses of sediment cores indicate that the highest discharges of mercury and cesium-137 occurred during the 1950s, and that about 76 metric tons of mercury has accumulated in Watts Bar sediments. About 91 percent of the 335 curies of cesium-137 released from the ORR have also been retained by the lake sediments. The concentrations detected are not believed to pose an imminent human health risk, especially if the deep sediments are not disturbed.(25)

Mining of the massive sulfide deposits in the Copper Basin along the Ocoee River began in 1843. Copper was the primary metal extracted, but iron, sulfur, zinc, and small amounts of gold and silver also were produced. Before 1900, Copper Basin was the largest metal-mining district in the Southeast. The last mine was closed in 1987.(26)

High concentrations of sulfur dioxide produced by smelting operations devastated the surrounding environment, resulting in a “moonscape” of about 25 square miles. Erosion of the area resulted in high sediment and associated metal loads to area streams. Although thousands of acres have been revegetated and the landscape is being slowly transformed back to forest, relatively high metal concentrations remain in the upper reaches of Parksville Reservoir and the Ocoee River.

Discharge of essentially untreated paper-mill effluent to the Pigeon River began in early 1908 and continued until plant improvements were instituted in the 1990s. Dioxins were first detected in fish samples from the river in 1988 (dioxin detection methods were not available until 1985) and became an immediate priority with respect to human health effects.(27) Dioxins have not been detected in recent samples, including bed-sediment and tissue samples taken during the Upper Tennessee NAWQA study. The State of Tennessee, however, continues a precautionary fish-consumption advisory for the Tennessee portion of the river.

Even though discussions regarding the Pigeon River continue between the States of Tennessee and North Carolina, all parties agree that conditions have improved significantly. Once nearly devoid of aquatic life, benthic invertebrate and fish populations in the Tennessee portion of the Pigeon River are showing signs of recovery. Waterville Lake, however, still retains tons of contaminated sediments deposited since the dam became operational in 1930, and these sediments remain a potential source of dioxin and other contaminants.

Polycyclic aromatic hydrocarbons (PAHs) commonly are detected as pollutants in soils and sediments, occur naturally in crude oil and coal, and also can result from the incomplete combustion of fossil fuels and forest fires.(28) In the upper Clinch River Basin, PAH concentrations reflect the presence of coal fines from upstream mining activities.

Twenty-nine PAHs were found in upper Clinch River bed-sediment samples and, with only a few exceptions, were not detected in the 12 samples taken from other parts of the Upper Tennessee Basin. Although PAHs are known to be toxic to fish, mussels, and aquatic insects, sediment-quality guidelines for the protection of aquatic life have been established for only 12 of the compounds detected. Of these, only two compounds – naphthalene and phenanthrene – exceeded their respective Canadian probable-effect levels of 391 µg/kg (micrograms per kilogram) and 515 µg/kg (fig. 30). The probable-effect levels define concentrations above which adverse effects are expected. A third compound, benzo(a)anthracene, occurred in concentrations very near its guideline of 385 µg/kg, and a number of compounds lacking guidelines were found at concentrations of 1,000 µg/kg or greater.

The highest concentrations generally follow the results for naphthalene and phenanthrene and occurred in the major river sites nearest, on a relative basis, to upstream mining activities. For example, concentrations at the Powell River and Pendleton Island sites exceeded those found at the Clinch River near Tazewell, which is farther removed from active mining in terms of river miles. Higher gradients and water velocities in the tributaries to the major streams prevent the accumulation of fine-grained sediment and coal fines. The main river channels, however, contain large pools and backwater areas where fine-grained material and associated constituents are deposited.

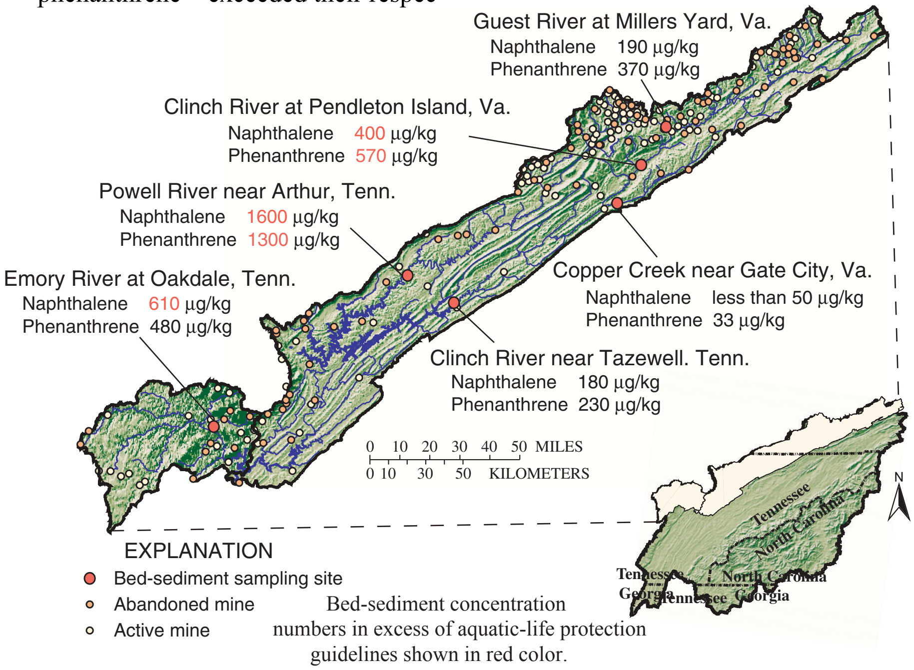


Figure 30. Relatively high polycyclic aromatic hydrocarbon (PAH) concentrations, in micrograms per kilogram, are common in bed sediments in the upper Clinch River Basin.

Freshwater Mussels in the Clinch and Powell Rivers

Freshwater mussel species diversity has been slowly declining in the Clinch and Powell Rivers of Tennessee and Virginia over the past 100 years. The numbers of mussel species found in these rivers are shown in figure 31 for selected periods of time and illustrate the long-term trend in loss of species diversity. The numbers do not precisely show numbers of species lost but reflect difficulties in finding specimens as species decline and, in some cases, difficulty with basin access. For example, prior to 1915, the upper parts of the river basins were inaccessible and remained unsurveyed.

Although some forms were lost, survey results from 1963 to 1971 indicate that the fauna survived TVA impoundment largely intact. Mussel declines became apparent, however, in the mid-1970's, and by that time many previously common mussel species had become rare, extirpated, or extinct.

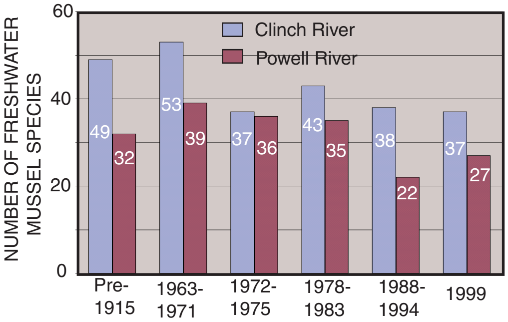


Figure 31. Freshwater mussel species diversity in the Clinch and Powell Rivers, Tennessee and Virginia, 1899-1999.

The greatest declines in mussel abundance occurred during the record drought from 1983 to 1988 (fig. 32). Since that time, the Clinch River in Tennessee has shown remarkable recovery, both in mussel densities and species numbers. The Virginia parts of the Clinch and the Powell Rivers, however, have recovered to a only a little more than half the densities recorded in 1979, mostly reflecting recovery of the three most abundant species. Most of the rare and more sensitive species continue to decline in the Powell River and in the Virginia part of the Clinch River.(29)

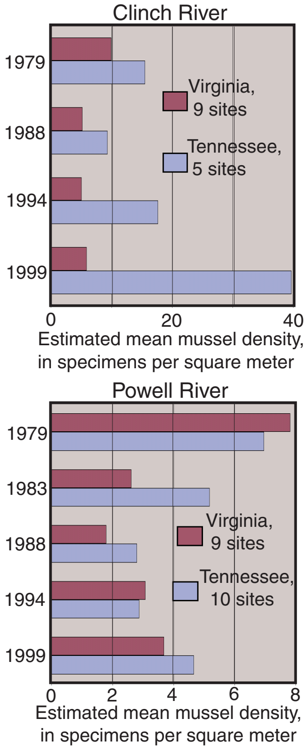


Figure 32. Estimated mean densities of freshwater mussel specimens in the Clinch and Powell Rivers, Tennessee and Virginia, 1979-99. (29)

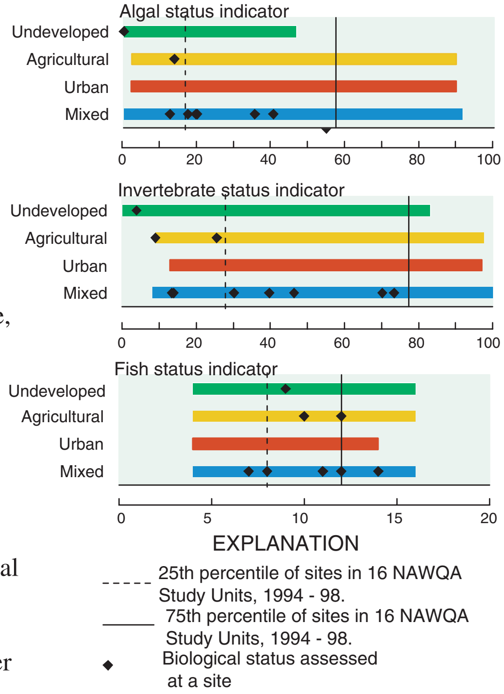
Upper Tennessee River Biological Communities in a National Context

Three biological indicators, which typically respond to changes in stream degradation, illustrate the relation of Upper Tennessee River Basin sites to the overall range of NAWQA sites nationwide. For all indicators, higher values suggest a more degraded stream site.

Algal status focuses on the changes in the percentage of certain algae in response to increasing siltation. Within the Upper Tennessee River Basin, the only sites in the highest 25 percent nationally are Big Limestone Creek, which drains predominantly agricultural land use, and the Pigeon River, which has been heavily affected by industrial wastes.

Invertebrate status is the average of 11 invertebrate (primarily insects, worms, crayfish, clams) metrics that summarize changes in richness, tolerance, trophic conditions, and dominance commonly associated with water-quality degradation. Among the Upper Tennessee River Basin sites, the two that rank highest on the index are the Pigeon and French Broad Rivers. The Pigeon River is recovering from decades of receiving industrial wastes. The French Broad River is principally affected by urban development in the Asheville, North Carolina, area and agriculture in the lower part of the basin.

Fish status is the sum of scores of four fish metrics (percentage of tolerant, omnivorous, non-native individuals, and percentage of individuals with external anomalies) that tend to increase in association with water-quality degradation. The Holston River at Surgoinsville, Tennessee, which ranked highest on this index, is characterized by relatively high concentrations of mercury and copper in bed sediments, probably derived from upstream industrial activities.

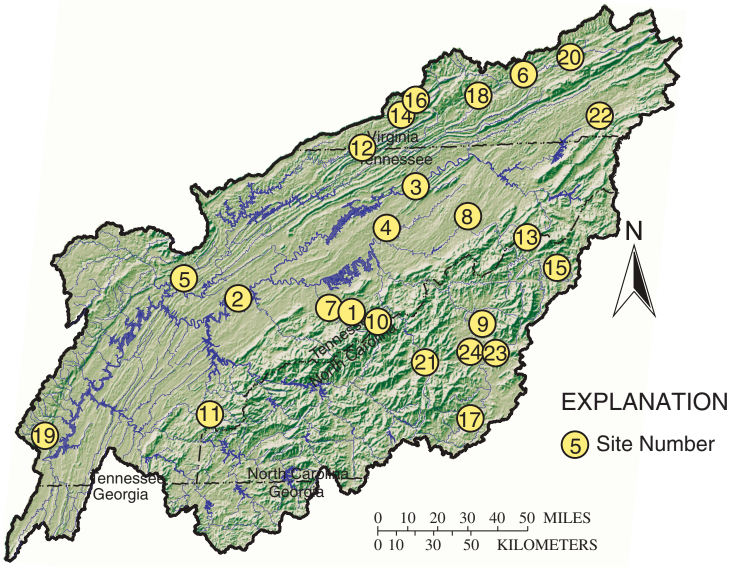


Toxic Spills and Releases

The NAWQA Program, like most water-quality assessments, is designed to gather information on general water-quality conditions and analyze problems that tend to be chronic as opposed to episodic. Even though the NAWQA Program provides for sampling during storm events in order to achieve a more complete “picture” of water-quality conditions, detection of every instance of water contamnation is clearly beyond the program’s defined scope. In general, this is true of every other ongoing State or Federal water-quality assessment.

In late May 1996, however, a toxic release was recorded at the Big Limestone Creek site (fig. 33, number 8) that resulted in a fishkill over several miles in the lower end of the stream. The apparent cause was excessive ammonia concentrations that were traced to agricultural activities upstream. If not for the sampling activity being conducted at the site, the kill most likely would have gone unreported. Given the relatively remote nature of many biologically diverse stream reaches in the Upper Tennessee River Basin, it is possible that many similar episodes go unreported as well.

The number of relatively rare and threatened aquatic species in the Upper Tennessee River Basin make accidental spills and releases a particular concern in parts of the basin. Habitat modifications resulting from human activities, such as impoundments and pollution, have restricted the greatest numbers and variety of aquatic fauna to only a few tributaries.(32) In addition, impoundments have effectively separated once contiguous biological communities into smaller, more vulnerable subunits.



Number and Date of incident		Site name	Spill source	Contaminant
1	Apr 95	West Prong, Bird Creek , Tenn.	Industrial	Concrete
2	May 95	Second Creek, Tenn.	Urban	Raw sewage
3	Sept. 95	Crockett Creek, Tenn.	Urban	Unknown
4	Sept. 95	Flat Creek, Tenn.	Industrial	Sulfuric acid, zinc
5a	Aug. 95	E. Fork Poplar Creek	Industrial	Styrene
5b	July 97	E. Fork Poplar Creek	Industrial	Sodium bisulfite
6a	Nov 95	Clinch River, Va.	Mining	Coal fines
6b	Feb. 96	Clinch River, Va.	Mining	Coal fines
6c	Mar. 96	Clinch River, Va.	Mining	Coal fines
7a	May 96	W. Prong, Little Pigeon River, Tenn.	Urban	Sodium hypochlorite
7b	July 96	W. Prong, Little Pigeon River, Tenn.	Urban	Sodium hypochlorite
8	May 96	Big Limestone Creek, Tenn.	Agriculture	Ammonia
9	June 96	Reems Creek, N.C.	Urban	Raw sewage
10	July 96	Webb Creek, Tenn.	Industrial	Asphalt sealant
11	July 96	Citico Creek, Tenn.	Agricultural	Concrete
12	Oct. 96	Powell River, Va.	Mining	Coal fines
13	Mar. 97	North Indian Creek, Tenn.	Urban	Chlorine
14	July 97	North Fork Powell River, Va.	Mining	Coal fines
15	July 97	North Toe River, N.C.	Urban	Chlorine
16	Aug. 97	Straight Creek, Va.	Mining	Acid mine drainage
17	Aug. 97	French Broad River, N.C.	Unknown	Unknown
18	Sept. 97	Stone Creek, Va.	Mining	Oil
19	Feb. 98	Rogers Branch, Tenn.	Urban	Pesticide
20	Aug. 98	Clinch River, Va.	Industrial	Octocure 554
21	Nov 98	Richland Creek, N.C.	Other	Oxygen demand
22	June 99	M. Fork Holston River, Va.	Unknown	Pesticide
23	Sept. 99	Swannanoa River, N.C.	Urban	Chlorine
24	Nov. 99	Smith Mill Creek, N.C.	Urban	Unknown

Figure 33. Contaminant releases have resulted in fish and mussel kills in the Upper Tennessee River Basin, 1995-99.(30, 31)

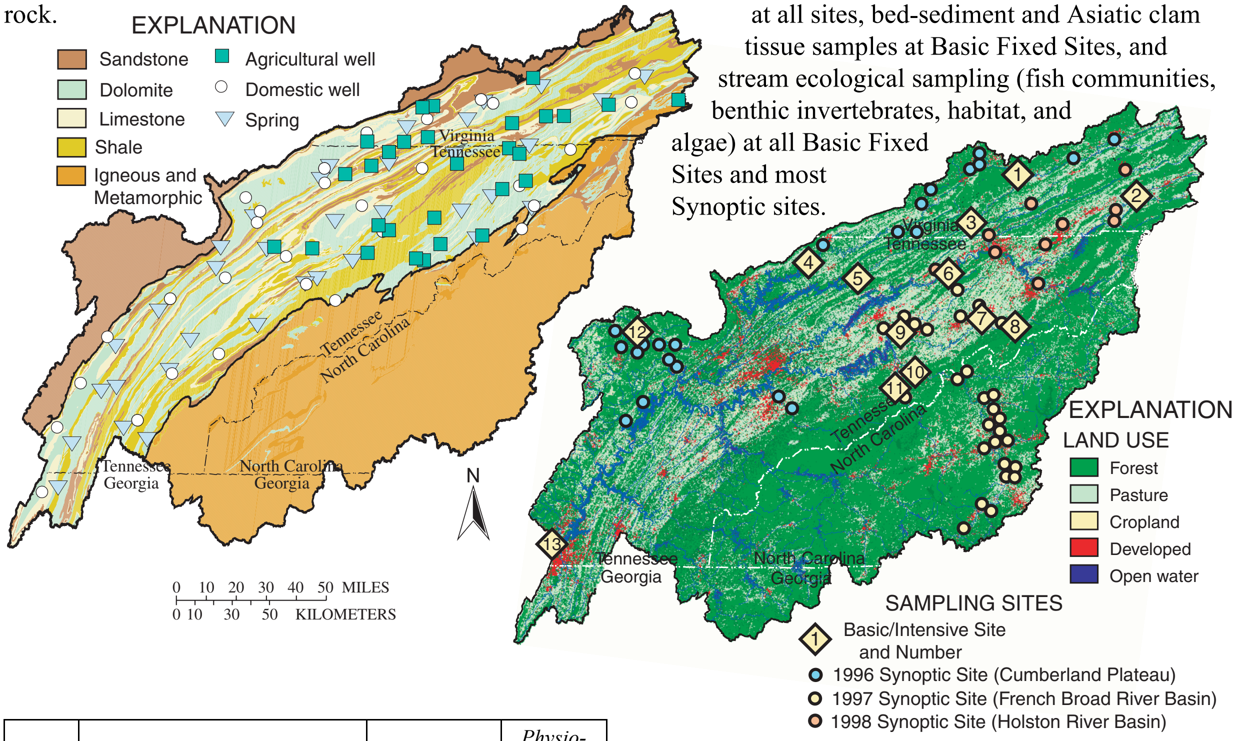
The upper Clinch and Powell watersheds are home to the most diverse fish and mussel fauna in the Upper Tennessee River Basin. These two subbasins are effectively separated from biological interaction, however, by Norris Lake and are very vulnerable to coal-fine spills from numerous active and abandoned mining sites in their headwaters. At least five coal-fine spills occurred during the 1995–99 study period (G. Heffinger, U.S Fish and Wildlife Service, written commun., April 17, 2000).

Mussel species generally are of the greatest concern because of their lack of mobility and the longer times typically required for populations to recover. For example, data collected in 1971 following a very large 1967 fly-ash spill in the Clinch River found that fish and aquatic insects were reestablished relatively quickly. Mussels, however, have yet to recolonize the 9- to 10-mile reach directly downstream from the spill site.(33)

STUDY UNIT DESIGN

Study designs for both ground-water and surface-water components focused principally on the Valley and Ridge province. The Valley and Ridge is home to the majority of the Study Unit population and is the most highly developed in terms of agriculture and urban land uses. Ground-water studies focused on the carbonate-based dolomites and limestones of the Valley and Ridge. These geologic units form the most prolific aquifers in the Upper Tennessee River Basin and also are the most susceptible to contamination because of their associated karst and solution features. Ground-water resources are very limited in the Blue Ridge and Cumberland Plateau provinces because of the relatively impermeable nature of the bedrock and the low water-storage capacity of the thin soils that overlie the bedrock.

Surface-water studies focused on the unregulated portions of the Upper Tennessee River Basin principally in the Valley and Ridge province, which contains the most intense agricultural activity in the basin. Thirteen basic fixed stream-sampling sites were operated during the study to monitor water-quality conditions with time in various parts of the basin. Data-collection sites were selected to cover the major subbasins of the Upper Tennessee River and to encompass the major land uses. An additional 61 sites were sampled during the study as part of three synoptic networks designed to better describe areal water-quality variations of the subbasins. In keeping with the NAWQA multiple lines of evidence approach to describe water-quality conditions,(34) data-collection activities included water-column chemistry at all sites, bed-sediment and Asiatic clam tissue samples at Basic Fixed Sites, and stream ecological sampling (fish communities, benthic invertebrates, habitat, and algae) at all Basic Fixed Sites and most Synoptic sites.



Site number	*Site name*	*Site type*	*Physiographic province**
1	Guest River near Millers Yard, Virginia	Indicator, Mining	CP
2	Middle Fork Holston River at Seven-Mile Ford, Virginia	Indicator, Mixed	VR
3	Copper Creek near Gate City, Virginia	Indicator, Agriculture	VR
4	Powell River near Arthur, Tennessee	Integrator	CP-VR
5	Clinch River at Tazewell, Tennessee	Integrator	VR-CP
6	Holston River at Surgoinsville, Tennessee	Integrator	VR
7	Big Limestone Creek near Limestone, Tennessee	Indicator, Agriculture	VR
8	Nolichucky River at Embreeville, Tennessee	Indicator, Mining	BR
9	Nolichucky River at Lowlands, Tennessee	Indicator, Mixed	BR-VR
10	French Broad River near Newport, Tennessee	Indicator, Agriculture	BR
11	Pigeon River at Newport, Tennessee	Integrator	BR-VR
12	Clear Creek at Lilly Bridge, Tennessee	Integrator	CP
13	Tennessee River at Chattanooga, Tennessee	Integrator	CP-VR-BR

* CP - Cumberland Plateau, BR - Blue Ridge, VR - Valley and Ridge

SUMMARY OF DATA COLLECTION IN THE UPPER TENNESSEE RIVER BASIN, 1994–98

Study component	What data were collected and why	Types of sites sampled	Number of sites	Sampling frequency and period
Stream Chemistry				
Bottom-sediment survey	Sediment in depositional zones was sampled for pesticides, other synthetic organic compounds, and trace elements to determine the presence of potentially toxic compounds. Water-quality samples also were taken at each site, including major ions, nutrients, organic carbon, pesticides, bacteria, and suspended sediment.	Selected rivers and streams.	15	Once (1995, 1996, 1998)
Water-chemistry sites	Water-chemistry data, including major ions, nutrients, organic carbon, pesticides, bacteria, and suspended sediment, were used to describe concentrations and loads.	Sampling occurred near selected continuous streamflow sites.	13	Variable (1996–98)
Storm sampling program	Water-chemistry data, including major ions, nutrients, organic carbon, pesticides, bacteria, and suspended sediment, were used to describe concentrations and loads.	Samples were taken at water-chemistry sites during high-flow conditions.	variable	Variable (1996–98)
Nutrient/pesticide synoptic studies	Water-chemistry data, including major ions, nutrients, organic carbon, pesticides, bacteria, and suspended sediment, were used to describe concentrations of selected constituents.	Surface-water sampling sites in the Cumberland Plateau, French Broad River Basin, and the Valley and Ridge were selected to describe conditions across the Study Unit.	64	Variable (1996) (1997) (1998)
Intensive pesticide sampling	Pesticides, major ions, organic carbon, suspended sediment, bacteria, and nutrients were analyzed to determine seasonal variations in concentrations and loads.	Water-chemistry sites located in intensive agricultural basins or mixed land-use basins.	3	Biweekly (March–Nov.,1996)
Stream Ecology				
Contaminants in Asiatic clams	Asiatic clams were sampled for pesticides, other synthetic organic compounds, and trace elements to determine the presence of potentially toxic compounds.	Selected rivers and streams.	15	Once (1995, 1996, 1998)
Aquatic biology	Biological communities and stream habitat were assessed and fish, macroinvertebrates, and algae were quantitatively sampled.	Biological communities and habitat at basic fixed water-chemistry sites, and biological communities at synoptic sites.	13 fixed sites, 63 synoptic sites	Once (1995–98)
Spring synoptic study	Macroinvertebrates were qualitatively sampled.	Spring sites.	35	Once (Aug.–Nov.,1997)
Ground-Water Chemistry				
Agricultural land-use survey	Water-chemistry data, including major ions, nutrients, organic carbon, pesticides, and radon, were analyzed to determine the effects of burley tobacco production on shallow ground-water quality.	Shallow 2-inch monitoring wells were installed adjacent to tobacco fields in the Valley and Ridge in northeastern Tennessee and southwestern Virginia.	30	Once (June and July, 1997)
Study Unit spring survey	Water-chemistry data, including major ions, nutrients, organic carbon, pesticides, bacteria, and radon were analyzed to determine the quality of ground water.	Randomly selected springs in the Valley and Ridge.	35 springs	Once (Aug.–Nov.,1997)
Study Unit well survey	Water-chemistry data, including major ions, nutrients, organic carbon, pesticides, bacteria, and radon, were analyzed to determine the quality of ground water.	Randomly selected wells in the Valley and Ridge.	30 wells	Once (Sept. 98–Nov. 99)

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.

Basic Fixed Sites—Sites on streams at which streamflow is measured and samples are collected for temperature, salinity, suspended sediment, major ions and metals, nutrients, and organic carbon to assess the broad-scale spatial and temporal character and transport of inorganic constituents of stream water in relation to hydrologic conditions and environmental settings.

Bed sediment—The material that temporarily is stationary in the bottom of a stream or other watercourse.

Bed sediment and tissue studies—Assessment of concentrations and distributions of trace elements and hydrophobic organic contaminants in streambed sediment and tissues of aquatic organisms to identify potential sources and to assess spatial distribution.

Benthic invertebrates—Insects, mollusks, crustaceans, worms, and other organisms without a backbone that live in, on, or near the bottom of lakes, streams, or oceans.

Constituent—A chemical or biological substance in water, sediment, or biota that can be measured by an analytical method.

Contamination—Degradation of water quality compared to original or natural conditions and due to human activity.

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.

Detection limit—The minimum concentration of a substance that can be identified, measured, and reported within 99 percent confidence that the analyte concentration is greater than zero; determined from analysis of a sample in a given matrix containing the analyte.

Discharge—Rate of fluid flow passing a given point at a given moment in time, expressed as volume per unit of time.

Drainage area—The drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide.

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.

Indicator sites—Stream sampling sites located at outlets of drainage basins with relatively homogeneous land use and physiographic conditions; most indicator-site basins have drainage areas ranging from 20 to 200 square miles.

Integrator or Mixed-use site—Stream sampling site located at an outlet of a drainage basin that contains multiple environmental settings. Most integrator sites are on major streams with relatively large drainage areas.

Intensive Fixed Sites—Basic Fixed Sites with increased sampling frequency during selected seasonal periods and analysis of dissolved pesticides for 1 year. Most NAWQA Study Units have one to two integrator Intensive Fixed Sites and one to four indicator Intensive Fixed Sites.

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.

Metamorphic rock—Rock that has formed in the solid state in response to pronounced changes of temperature, pressure, and chemical environment.

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 stream water and ground water. One thousand micrograms per liter equals 1 mg/L.

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 stream water and ground water.

Nonpoint source—A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution.

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

Synoptic sites—Sites sampled during a short-term investigation of specific water-quality conditions during selected seasonal or hydrologic conditions to provide improved spatial resolution for critical water-quality conditions.

Tributary— A river or stream flowing into a larger river, stream, or lake.

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 by-products 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 table—The point below the land surface where ground water is first encountered and below which the earth is saturated. Depth to the water table varies widely across the country.

Yield—The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

REFERENCES

1 Murless, Dick, and Stallings, Constance, 1973, Hiker's guide to the Smokies: San Francisco, Calif., Sierra Club Books, 375 p.

2 Tennessee Valley Authority, 1987, Tennessee Valley Authority handbook—Dams and reservoirs, Knoxville, Tenn., 265 p.

3 Brewer, Alberta, and Brewer, Carson, 1975, Valley so wild: Knoxville, Tenn., East Tennessee Historical Society, 382 p.

4 Hampson, P.S., 1995, National Water-Quality Assessment Program - the Upper Tennessee River Basin: U.S. Geological Survey Fact Sheet FS–150–95, 2 p.

5 U.S. Geological Survey, 1999, Downloading 1995 water-use data: accessed on October 20, 2000, at http://water.usgs.gov/watuse/spread95.html

6 National Weather Service, 2000, East Tennessee climatological data, Monthly climate data for Chattanooga, Knoxville, and Tri-Cities: accessed on October 20, 2000, at http://www.srh.noaa.gov/ftproot/

7 Zurawski, Ann, 1978, Summary appraisals of the Nation's ground-water resources—Tennessee Region: U.S. Geological Survey Professional Paper 813–L, 35 p.

8 Master, L.L., Flack, S.R., and Stein, B.A., eds., 1998, Rivers of life—critical watersheds for protecting freshwater biodiversity: Arlington, Va., The Nature Conservancy, 71 p.

9 State of Tennessee, 1999, Rules of the Tennessee Department of Environment and Conservation, Chapter 1200–4–3, General Water Quality Criteria, 25 p.

10 State of Tennessee, 1998, Final 1998 303(d) list for the State of Tennessee: accessed on October 20, 2000, at http://www.state.tn.us/environment/water.htm

11 Yates, M.V., and Yates, S.R., 1993, Pathogens, *in* Alley, W.M., ed., Regional ground-water quality: New York, Van Nostrand Reinhold, p. 383–404.

12 U.S. Environmental Protection Agency, 1986, Ambient water-quality criteria for bacteria—1986: U.S. Environmental Protection Agency 44015–84–002, 18 p.

13 U.S. Geological Survey, 1999, The quality of our Nation's waters —Nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

14 Helsel, D.R., 1993, Hydrology of stream quality—Statistical analysis of water-quality data, *in* National Water Summary 1990–91—Hydrologic events and stream-water quality: U.S. Geological Survey Water-Supply Paper 2400, p. 93–100.

15 Treece, M.W., Jr., and Johnson, G.C., 1997, Nitrogen in streams of the Upper Tennessee River Basin, 1970–93, U.S. Geological Survey Open-File Report 97–117, 4 p.

16 Johnson, G.C., and Treece, M.W., Jr.,1998, Phosphorus in streams of the Upper Tennessee River Basin, 1970–93, U.S. Geological Survey Open-File Report 98–532, 6 p.

17 Tennessee Valley Authority, 1991, Reservoir vital signs monitoring—1990, physical and chemical characteristics of water and sediment: Tennessee Valley Authority TVA/WR/WQ–91/10, 142 p.

18 Thelin, G.P., 1999, County-level pesticide use estimates (1991–1993, 1995) in the conterminous United States (metadata): U.S. Geological Survey, accessed on October 20, 2000, at ftp://ftpdcascr.wr.usgs.gov/nsp/thelin/ncfap.html

19 U.S. Environmental Protection Agency, 1999, National recommended water quality criteria—Correction: EPA 822–Z—99–001, 26 p. accessed on October 20, 2000, at (http://www.epa.gov/ost/pc/revcom.pdf)

20 Environment Canada, 1999, Canadian sediment quality guidelines: accessed on October 20, 2000, at (www.ec.gc.ca/ceqg-rcqe/sediment.htm)

21 Milligan, J.D., and Ruane, R.J., 1978,Analysis of mercury data collected from the North Fork of the Holston River: Tennessee Valley Authority, Division of Environmental Planning, TVA/EP–78112, 32 p.

22 Seivard, L.D., Stilwell, D.A., Rice, Stephen O., and Seeley, K.R., 1993, Geographic distribution of mercury in asiatic clams, *Corbicula fluminea*, from the North Fork Holston River, Virginia: U.S. Fish and Wildlife Service, Environmental Contaminants Division, 16 p.

23 State of Tennessee, 1999, Tennessee Department of Environment and Conservation, DOE Oversight Division: Status report to the public, 72 p.

24 U.S. Department of Energy, 2000, Y-12 Mercury Task Force files—A guide to record series of the Department of Energy and its contractors: accessed on October 20, 2000, at http://www.tis.eh.doe.gov/ohre/new/findingaids/epidemiologic/oakridge1/intro.html

25 Olsen, C.R., Larsen,I.L., Lowry, P.D., Moriones, C.R., Ford, C.J.,Deerstone, K.C.,Turner, R.R., Kimmel, B.L., and Brandt, C.C., 1992, Transport and accumulation of cesium-137 and mercury in the Clinch River and Watts Bar Reservoir system: Oak Ridge National Laboratory, Environmental Sciences Division Publication 3471.

26 U.S. Geological Survey, 1996, The Ocoee River story: accessed on October 20, 2000, at http://pubs.usgs.gov/gip/ocoee2

27 Bartlett, R.A., 1995, Troubled waters—Champion International and the Pigeon River controversy: Knoxville, Tennessee, University of Tennessee Press, 348 p.

28 Swartz, R.C., 1999, Consensus sediment quality guidelines for polycyclic aromatic hydrocarbon mixtures: Environmental Toxiology and Chemistry, v. 18, no. 4, p. 780–787.

29 Ahlstedt, S.A. and Tuberville, J.D., 1997, Quantitative reassessment of the freshwater mussel fauna in the Clinch and Powell Rivers, Tennessee and Virginia, *in* Cummings, K.S., Buchanan, A.C., Mayer, C.A., and Naimo, T.J., eds., Conservation and management of freshwater mussels II, Proceedings of a Upper Mississippi River Conservation Committee symposium, October 16–18, 1995, St.Louis, Mo., p. 71–77.

30 State of Tennessee, 2000, Fish kill report database: Tennessee Wildlife Resources Agency.

31 State of North Carolina, 2000, North Carolina Division of Water Quality 2000 Fish kill event update: accessed on October 20, 2000, at http://www.esb.enr.state.nc.us/Fishkill/fishkill00.htm

32 Parmalee, P.W. and Bogan, A.E., 1998, The freshwater mussels of Tennessee: Knoxville, Tenn., University of Tennessee Press, 328 p.

33 The Nature Conservancy, 1993, Clinch River Valley Bioreserve, Strategic Plan: The Nature Conservancy, Abingdon, Va., 135 p.

34 Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program: Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

APPENDIX—WATER-QUALITY DATA FROM THE UPPER TENNESSEE RIVER BASIN IN A NATIONAL CONTEXT

For a complete view of Upper Tennessee River Basin data and for additional information about specific benchmarks used, visit our Web site at http://water.usgs.gov/nawqa/. Also visit the NAWQA Data Warehouse for access to NAWQA data sets at http://water.usgs.gov/nawqa/data.

This appendix is a summary of chemical concentrations and biological indicators assessed in the Upper Tennessee River Basin. Selected results for this Basin are graphically compared to results from as many as 36 NAWQA Study Units investigated from 1991 to 1998 and to national water-quality benchmarks for human health, aquatic life, or fish-eating wildlife. The chemical and biological indicators shown were selected on the basis of frequent detection, detection at concentrations above a national benchmark, or regulatory or scientific importance. The graphs illustrate how conditions associated with each land use sampled in the Upper Tennessee River Basin compare to results from across the Nation, and how conditions compare among the several land uses. Graphs for chemicals show only detected concentrations and, thus, care must be taken to evaluate detection frequencies in addition to concentrations when comparing study-unit and national results. For example, tebuthiuron concentrations in Upper Tennessee River Basin major aquifers were similar to the national distribution, but the detection frequency was much higher (31 percent compared to 3 percent).

CHEMICALS IN WATER

Concentrations and detection frequencies, Upper Tennessee River Basin, 1995–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals

◆ 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 36 NAWQA Study Units, 1991–98—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 a goal for preventing stream eutrophication 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)

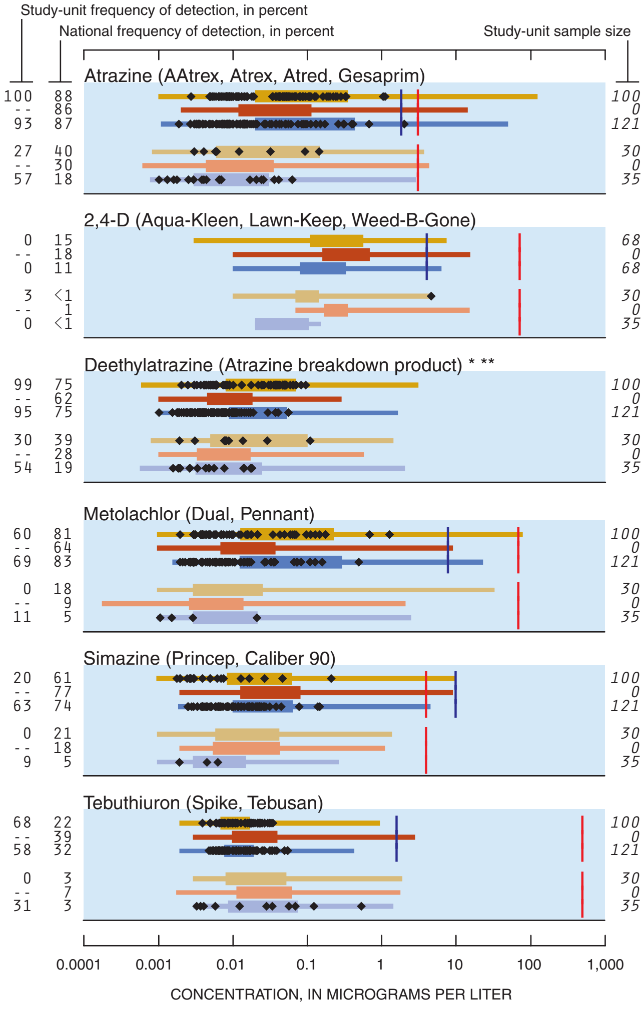
| Protection of aquatic life (applies to surface water only)

| Prevention of eutrophication in streams not flowing directly into lakes or impoundments

* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

Pesticides in water—Herbicides

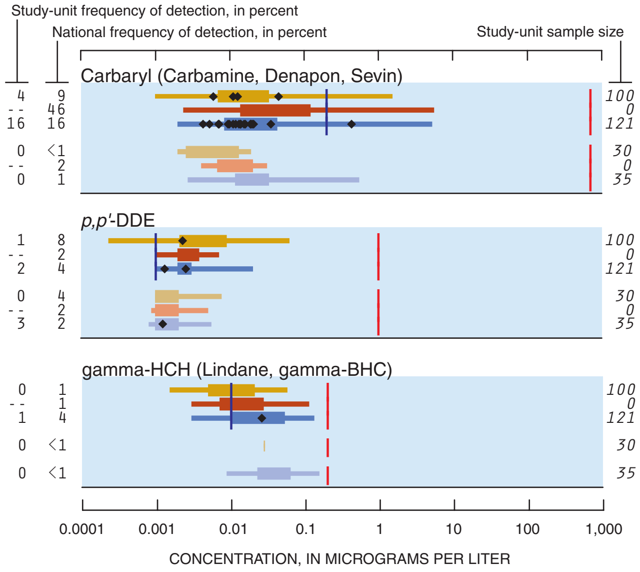


Other herbicides detected
Acetochlor (Harness Plus, Surpass) * **
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Bromacil (Hyvar X, Urox B, Bromax)
Cyanazine (Bladex, Fortrol)
DCPA (Dacthal, chlorthal-dimethyl) * **
Dichlorprop (2,4-DP, Seritox 50, Lentemul) * **
Diuron (Crisuron, Karmex, Diurex) **
Metribuzin (Lexone, Sencor)
Molinate (Ordram) * **
Napropamide (Devrinol) * **
Pendimethalin (Pre-M, Prowl, Stomp) * **
Prometon (Pramitol, Princep) **
2,4,5-T **
2,4,5-TP (Silvex, Fenoprop) **
Trifluralin (Treflan, Gowan, Tri-4, Trific)

Herbicides not detected
Acifluorfen (Blazer, Tackle 2S) **
Benfluralin (Balan, Benefin, Bonalan) * **
Bentazon (Basagran, Bentazone) **
Bromoxynil (Buctril, Brominal) *
Butylate (Sutan +, Genate Plus, Butilate) **
Chloramben (Amiben, Amilon-WP, Vegiben) **
Clopyralid (Stinger, Lontrel, Transline) * **
2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone) * **
Dacthal mono-acid (Dacthal breakdown product) * **

Dicamba (Banvel, Dianat, Scotts Proturf)
2,6-Diethylaniline (Alachlor breakdown product) * **
Dinoseb (Dinosebe)
EPTC (Eptam, Farmarox, Alirox) * **
Ethalfluralin (Sonalan, Curbit) * **
Fenuron (Fenulon, Fenidim) * **
Fluometuron (Flo-Met, Cotoran) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPA (Rhomene, Rhonox, Chiptox)
MCPB (Thistrol) * **
Neburon (Neburea, Neburyl, Noruben) * **
Norflurazon (Evital, Predict, Solicam, Zorial) * **
Oryzalin (Surflan, Dirimal) * **
Pebulate (Tillam, PEBC) * **
Picloram (Grazon, Tordon)
Pronamide (Kerb, Propyzamid) **
Propachlor (Ramrod, Satecid) **
Propanil (Stam, Stampede, Wham) * **
Propham (Tuberite) **
Terbacil (Sinbar) **
Thiobencarb (Bolero, Saturn, Benthiocarb) * **
Triallate (Far-Go, Avadex BW, Tri-allate) *
Triclopyr (Garlon, Grandstand, Redeem, Remedy) * **

Pesticides in water—Insecticides

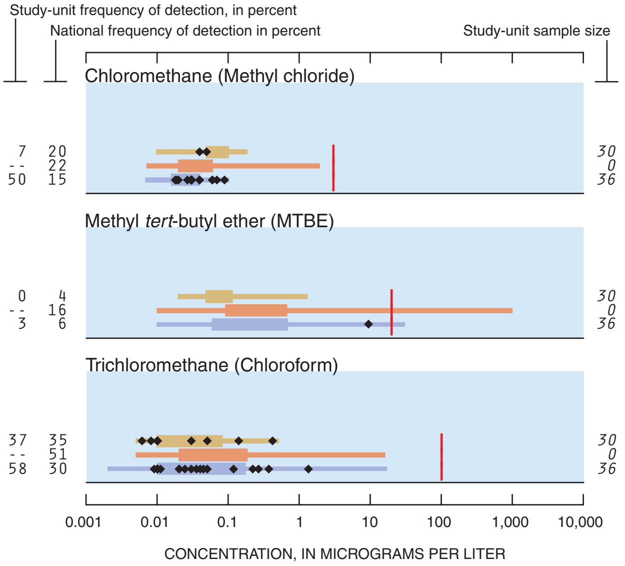


Other insecticides detected
Carbofuran (Furadan, Curaterr, Yaltox)
Chlorpyrifos (Brodan, Dursban, Lorsban)
Diazinon (Basudin, Diazatol, Neocidol, Knox Out)
Malathion (Malathion)

Insecticides not detected
Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfone (Standak, aldoxycarb)
Aldicarb sulfoxide (Aldicarb breakdown product)
Azinphos-methyl (Guthion, Gusathion M) *
Dieldrin (Panoram D-31, Octalox, Compound 497)
Disulfoton (Disyston, Di-Syston) **
Ethoprop (Mocap, Ethoprophos) * **
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
3-Hydroxycarbofuran (Carbofuran breakdown product) * **
Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
Methomyl (Lanox, Lannate, Acinate) **
Methyl parathion (Penncap-M, Folidol-M) **
Oxamyl (Vydate L, Pratt) **
Parathion (Roethyl-P, Alkron, Panthion, Phoskil) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propargite (Comite, Omite, Ornamite) * **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in ground water

These graphs represent data from 16 Study Units, sampled from 1996 to 1998

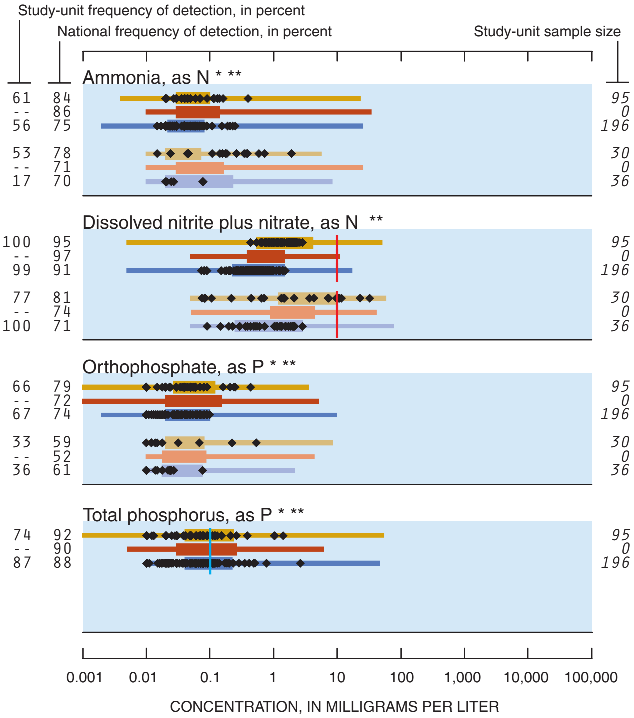


Other VOCs detected
tert-Amylmethylether (*tert*-amyl methyl ether (TAME)) *
Benzene
Bromodichloromethane (Dichlorobromomethane)
2-Butanone (Methyl ethyl ketone (MEK)) *
n-Butylbenzene (1-Phenylbutane) *
Carbon disulfide *
Chlorobenzene (Monochlorobenzene)
Chloroethane (Ethyl chloride) *
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene)
Dichlorodifluoromethane (CFC 12, Freon 12)
1,1-Dichloroethane (Ethylidene dichloride) *
1,1-Dichloroethene (Vinylidene chloride)
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
Diethyl ether (Ethyl ether) *
Diisopropyl ether (Diisopropylether (DIPE)) *
1,2-Dimethylbenzene (*o*-Xylene)
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene)
Ethenylbenzene (Styrene)
1-Ethyl-2-methylbenzene (2-Ethyltoluene) *
Ethylbenzene (Phenylethane)
Iodomethane (Methyl iodide) *
Isopropylbenzene (Cumene) *
p-Isopropyltoluene (*p*-Cymene) *
Methylbenzene (Toluene)
2-Propanone (Acetone) *
n-Propylbenzene (Isocumene) *
Tetrachloroethene (Perchloroethene)
1,2,3,4-Tetramethylbenzene (Prehnitene) *
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) *
1,1,1-Trichloroethane (Methylchloroform)
Trichloroethene (TCE)
1,2,3-Trimethylbenzene (Hemimellitene) *
1,2,4-Trimethylbenzene (Pseudocumene) *
1,3,5-Trimethylbenzene (Mesitylene) *

VOCs not detected
Bromobenzene (Phenyl bromide) *
Bromochloromethane (Methylene chlorobromide)
Bromoethene (Vinyl bromide) *
Bromomethane (Methyl bromide)
sec-Butylbenzene *
tert-Butylbenzene *
3-Chloro-1-propene (3-Chloropropene) *
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
Chlorodibromomethane (Dibromochloromethane)
Chloroethene (Vinyl chloride)
1,2-Dibromo-3-chloropropane (DBCP, Nemagon)
1,2-Dibromoethane (Ethylene dibromide, EDB)

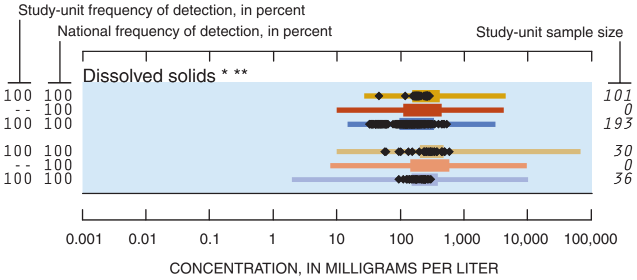
Dibromomethane (Methylene dibromide) *
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) *
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,2-Dichloroethane (Ethylene dichloride)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
Dichloromethane (Methylene chloride)
1,2-Dichloropropane (Propylene dichloride)
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 *
1-4-Epoxy butane (Tetrahydrofuran, Diethylene oxide) *
Ethyl methacrylate *
Ethyl *tert*-butyl ether (Ethyl-*t*-butyl ether (ETBE)) *
Hexachlorobutadiene
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane)
2-Hexanone (Methyl butyl ketone (MBK)) *
Methyl acrylonitrile *
Methyl-2-methacrylate (Methyl methacrylate) *
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) *
Methyl-2-propenoate (Methyl acrylate) *
Naphthalene
2-Propenenitrile (Acrylonitrile)
1,1,2,2-Tetrachloroethane *
1,1,1,2-Tetrachloroethane
Tetrachloromethane (Carbon tetrachloride)
1,2,3,5-Tetramethylbenzene (Isodurene) *
Tribromomethane (Bromoform)
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene *
1,1,2-Trichloroethane (Vinyl trichloride)
Trichlorofluoromethane (CFC 11, Freon 11)
1,2,3-Trichloropropane (Allyl trichloride)

Nutrients in water

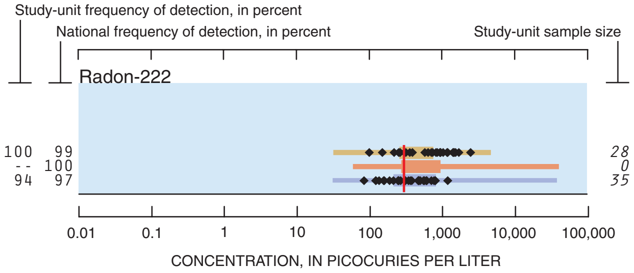


Other nutrients detected
Dissolved ammonia plus organic nitrogen as N * **

Dissolved solids in water



Trace elements in ground water



CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Upper Tennessee River Basin, 1995–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals. 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 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected

▬ Fish tissue from streams in agricultural areas
▬ Fish tissue from streams in urban areas
▬ Fish tissue from streams draining mixed land uses

▬ Sediment from streams in agricultural areas
▬ Sediment from streams in urban areas
▬ Sediment from streams draining mixed land uses

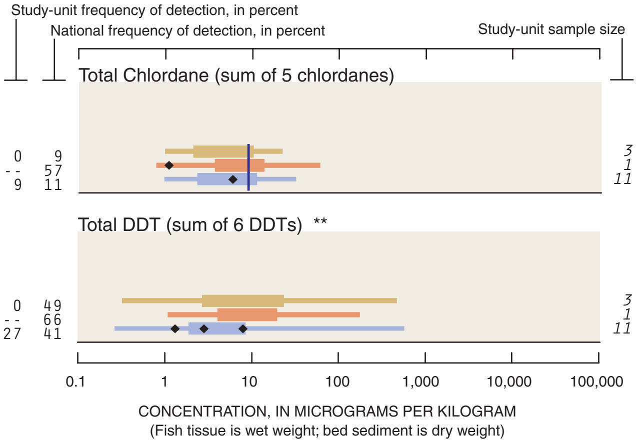
Lowest 25 percent | Middle 50 percent | Highest 25 percent

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

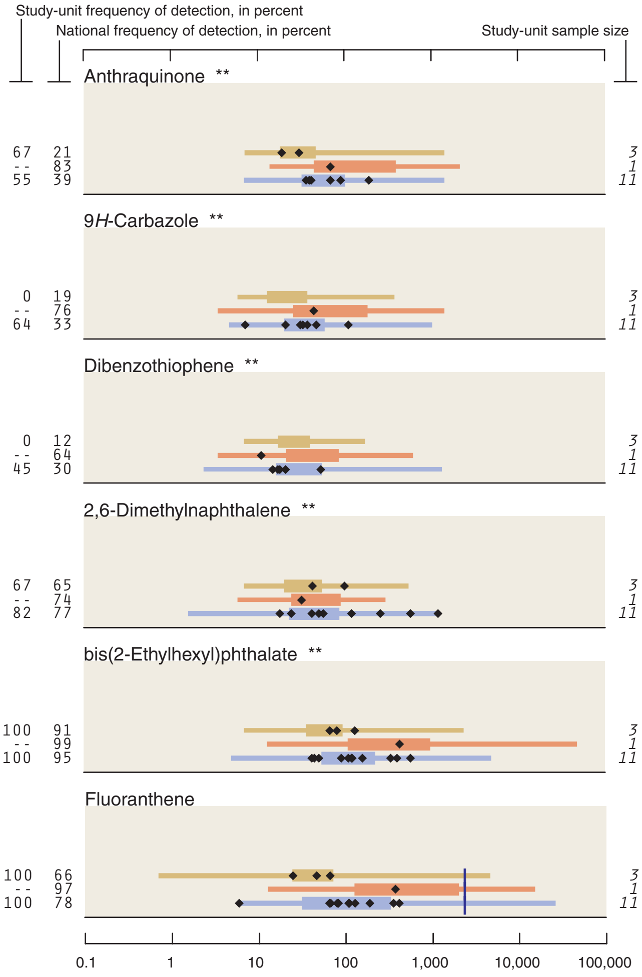


CONCENTRATION, IN MICROGRAMS PER KILOGRAM
(Fish tissue is wet weight; bed sediment is dry weight)

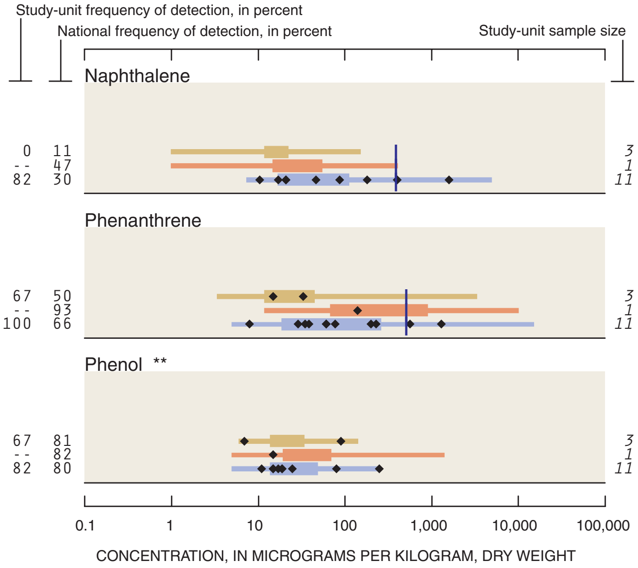
Other organochlorines detected
o,p'+*p,p'*-DDD (sum of *o,p'*-DDD and *p,p'*-DDD) *
p,p'-DDE * **
o,p'+*p,p'*-DDE (sum of *o,p'*-DDE and *p,p'*-DDE) *
o,p'+*p,p'*-DDT (sum of *o,p'*-DDT and *p,p'*-DDT) *

Organochlorines not detected
Chloroneb (Chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
Endrin (Endrine)
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Heptachlor epoxide (Heptachlor breakdown product) *
Heptachlor+heptachlor epoxide (sum of heptachlor and heptachlor epoxide) **
Hexachlorobenzene (HCB) **
Isodrin (Isodrine, Compound 711) * **
p,p'-Methoxychlor (Marlate, methoxychlore) * **
o,p'-Methoxychlor * **
Mirex (Dechlorane) **
Total PCB
Pentachloroanisole (PCA) * **
cis-Permethrin (Ambush, Astro, Pounce) * **
trans-Permethrin (Ambush, Astro, Pounce) * **
Toxaphene (Camphechlor, Hercules 3956) * **

Semivolatile organic compounds (SVOCs) in bed sediment



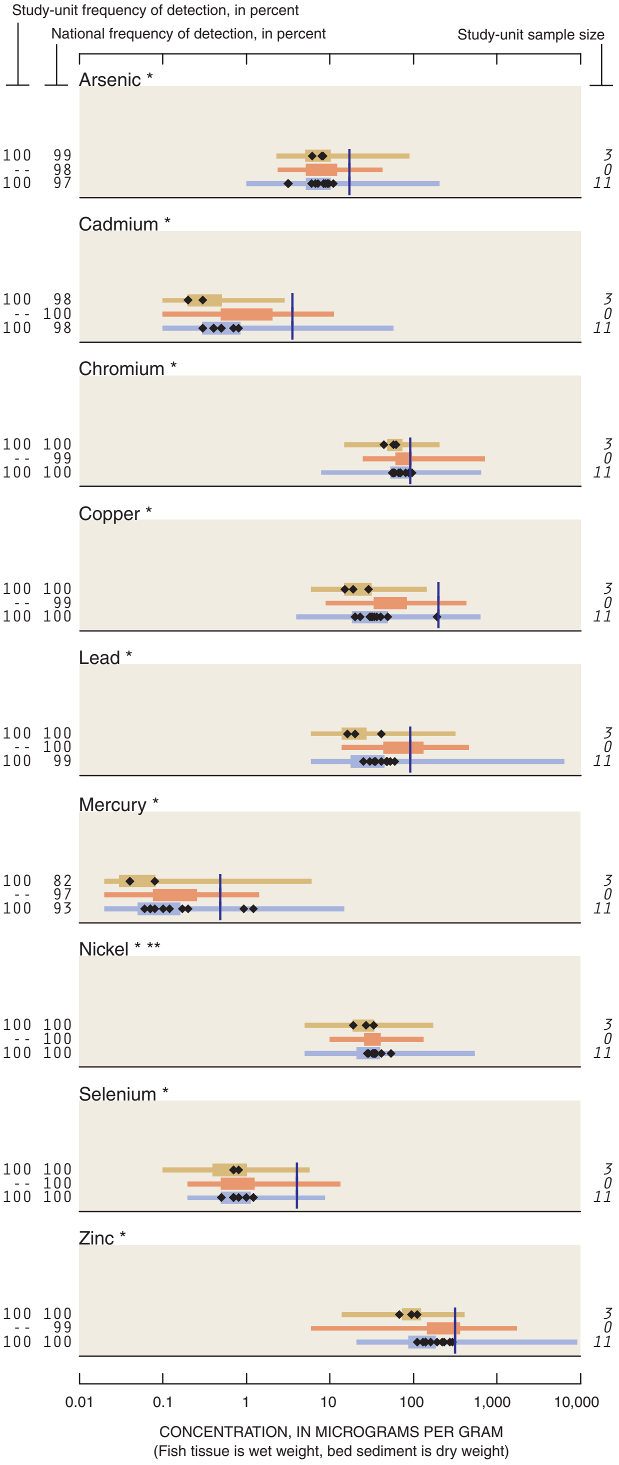
CONCENTRATION, IN MICROGRAMS PER KILOGRAM, DRY WEIGHT



Other SVOCs detected
Acenaphthene
Acenaphthylene
Acridine **
C8-Alkylphenol **
Anthracene
Benz[*a*]anthracene
Benzo[*a*]pyrene
Benzo[*b*]fluoranthene **
Benzo[*ghi*]perylene **
Benzo[*k*]fluoranthene **
2,2-Biquinoline **
Butylbenzylphthalate **
Chrysene
p-Cresol **
Di-*n*-butylphthalate **
Di-*n*-octylphthalate **
Dibenz[*a,h*]anthracene
Diethylphthalate **
1,2-Dimethylnaphthalene **
1,6-Dimethylnaphthalene **
Dimethylphthalate **
2-Ethylnaphthalene **
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*cd*]pyrene **
Isophorone **
Isoquinoline **
1-Methyl-9*H*-fluorene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
1-Methylpyrene **
Phenanthridine **
Pyrene
Quinoline **
2,3,6-Trimethylnaphthalene **

SVOCs not detected
Azobenzene **
Benzo[*c*]cinnoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis(2-Chloroethoxy)methane **
bis(2-Chloroethyl)ether **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
1,2-Dichlorobenzene (*o*-Dichlorobenzene) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene) **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **
N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
1,2,4-Trichlorobenzene **

Trace elements in fish tissue (livers) and bed sediment



BIOLOGICAL INDICATORS

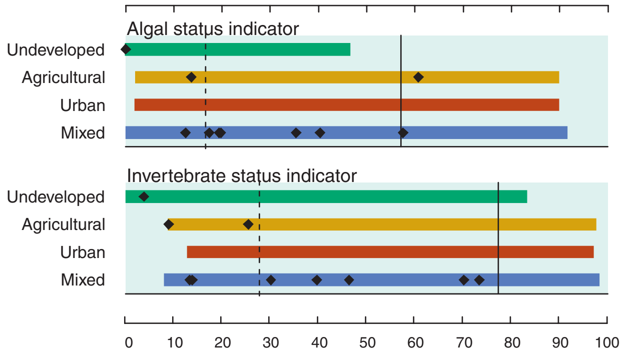
Higher national scores suggest habitat disturbance, water-quality degradation, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), and fish provide a record of water-quality and stream conditions that water-chemistry indicators may not reveal. **Algal status** focuses on the changes in the percentage of certain algae in response to increasing siltation, and it often correlates with higher nutrient concentrations in some regions. **Invertebrate status** averages 11 metrics that summarize changes in richness, tolerance, trophic conditions, and dominance associated with water-quality degradation. **Fish status** sums the scores of four fish metrics (percent tolerant, omnivorous, non-native individuals, and percent individuals with external anomalies) that increase in association with water-quality degradation

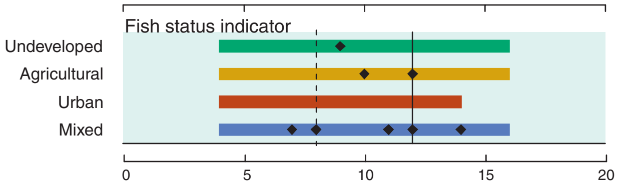
Biological indicator value, Upper Tennessee River Basin, by land use, 1995–98

◆ Biological status assessed at a site

National ranges of biological indicators, in 16 NAWQA Study Units, 1994–98

🟩 Streams in undeveloped areas
🟨 Streams in agricultural areas
🟥 Streams in urban areas
🟦 Streams in mixed-land-use areas
—— 75th percentile
– – – 25th percentile





A COORDINATED EFFORT

Coordination with agencies and organizations in the Upper 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
U.S. Fish and Wildlife Service
National Park Service
U.S. Department of Energy,
  Oak Ridge National Laboratory
U.S. Environmental Protection Agency
U.S. Forest Service
U.S. Department of Agriculture,
  Natural Resources Conservation Service

State Agencies

Tennessee Wildlife Resources Agency
Tennessee Department of Environment and Conservation
Tennessee Department of Agriculture
North Carolina Department of Environment and Natural Resources
North Carolina Wildlife Resources Commission
Virginia Department of Environmental Quality
Virginia Department of Game and Inland Fisheries
Virginia Department of Mines, Minerals, and Energy

Local Agencies

Knox County, Tennessee
City of Johnson City, Tennessee

Universities

University of Tennessee
Virginia Polytechnic and State University
Tennessee Technological University

Other public and private organizations

Southern Appalachian Man and the Biosphere Program
Nature Conservancy

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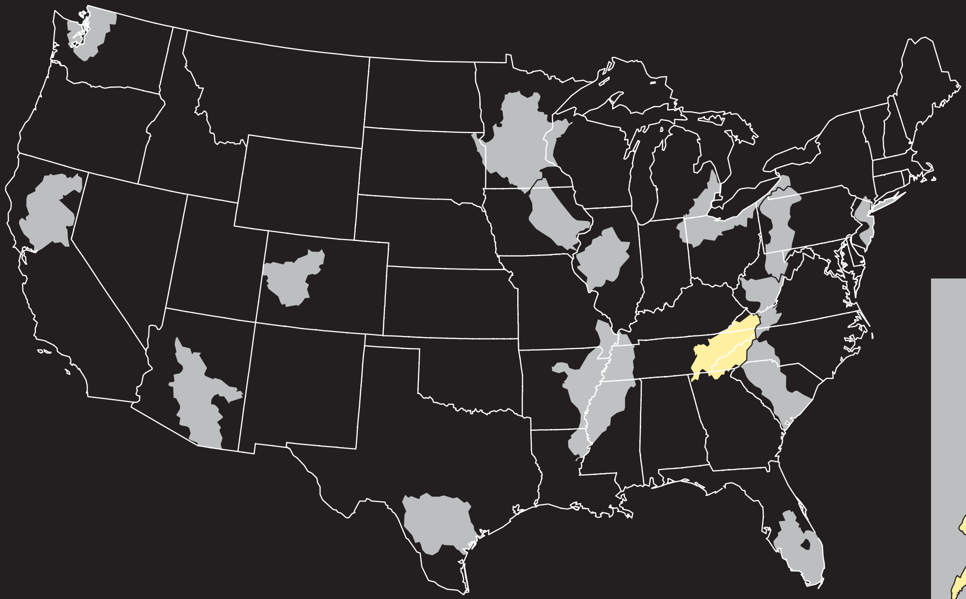
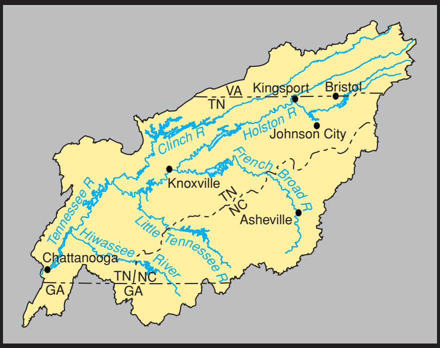
NAWQA

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





Hampson and others—Water Quality in the Upper Tennessee River Basin
U.S. Geological Survey Circular 1205

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