USGS
science for a changing world

Water Quality in the Upper Tennessee River Basin

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

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

Circular 1205

POINTS OF CONTACT AND ADDITIONAL INFORMATION

The companion Web site for NAWQA summary reports:

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

Upper Tennessee River Basin contact and Web site:

District Chief
U.S. Geological Survey
Water Resources Division
640 Grassmere Park Drive, Suite 100
Nashville, TN 37211
e-mail: dc_tn@usgs.gov
http://tn.water.usgs.gov/

National NAWQA Program:

Chief, NAWQA Program
U.S. Geological Survey
Water Resources Division
12201 Sunrise Valley Drive, M.S. 413
Reston, VA 20192
http://water.usgs.gov/nawqa/

Other NAWQA summary reports

River Basin Assessments

Albemarle-Pamlico Drainage Basin (Circular 1157)
Allegheny and Monongahela River Basins (Circular 1202)
Apalachicola-Chattahoochee-Flint River Basin (Circular 1164)
Central Arizona Basins (Circular 1213)
Central Columbia Plateau (Circular 1144)
Central Nebraska Basins (Circular 1163)
Connecticut, Housatonic and Thames River Basins (Circular 1155)
Eastern Iowa Basins (Circular 1210)
Georgia-Florida Coastal Plain (Circular 1151)
Hudson River Basin (Circular 1165)
Kanawha-New River Basins (Circular 1204)
Lake Erie-Lake Saint Clair Drainages (Circular 1203)
Las Vegas Valley Area and the Carson and Truckee River Basins (Circular 1170)
Lower Illinois River Basin (Circular 1209)
Long Island-New Jersey Coastal Drainages (Circular 1201)
Lower Susquehanna River Basin (Circular 1168)
Mississippi Embayment (Circular 1208)
Ozark Plateaus (Circular 1158)
Potomac River Basin (Circular 1166)
Puget Sound Basin (Circular 1216)
Red River of the North Basin (Circular 1169)
Rio Grande Valley (Circular 1162)
Sacramento River Basin (Circular 1215)
San Joaquin-Tulare Basins (Circular 1159)
Santee River Basin and Coastal Drainages (Circular 1206)
South-Central Texas (Circular 1212)
South Platte River Basin (Circular 1167)
Southern Florida (Circular 1207)
Trinity River Basin (Circular 1171)
Upper Colorado River Basin (Circular 1214)
Upper Mississippi River Basin (Circular 1211)
Upper Snake River Basin (Circular 1160)
Western Lake Michigan Drainages (Circular 1156)
White River Basin (Circular 1150)
Willamette Basin (Circular 1161)

National Assessments

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

Front cover: Clear Creek, Tennessee *(courtesy of National Park Service, Obed Wild and Scenic River)*.
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

U.S. GEOLOGICAL SURVEY CIRCULAR 1205

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, SECRETARY

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

2000

Free on application to the
U.S. Geological Survey
Information Services
Box 25286 Federal Center
Denver, CO 80225

Or call: 1-888-ASK-USGS

Library of Congress Cataloging-in-Publications Data

Water quality in the Upper Tennessee River Basin, Tennessee, North Carolina, Virginia, and Georgia, 1995–98 / by Paul S. Hampson…]et al.].
p. cm. -- (U.S. Geological Survey Circular ; 1205)
Includes bibliographical references.
ISBN 0-607-95546-5 (alk. paper)
1. Water quality--Tennessee River Watershed. I. Hampson, Paul S. II. Geological Survey (U.S.) III. Series.

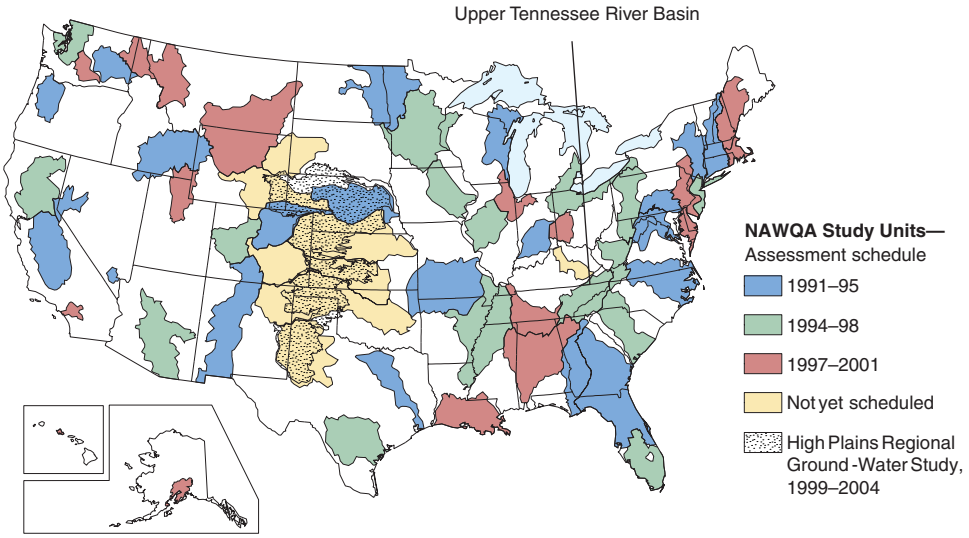
TD223.5 .W388 2000
363.739'42'09768--dc21

00-049460

CONTENTS

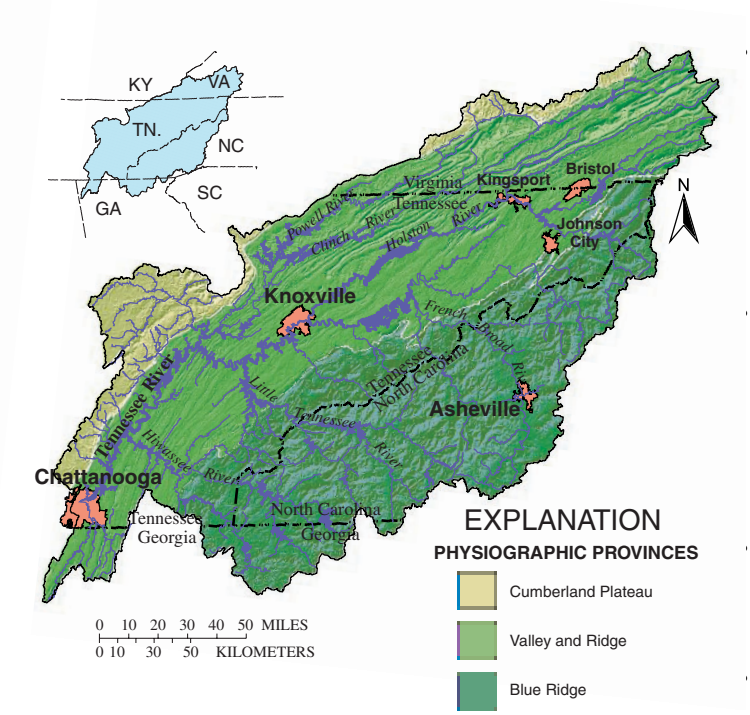
THIS REPORT summarizes major findings about water quality in the Upper Tennessee River Basin that emerged from an assessment conducted between 1994 and 1998 by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Water quality is discussed in terms of local and regional 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.



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.

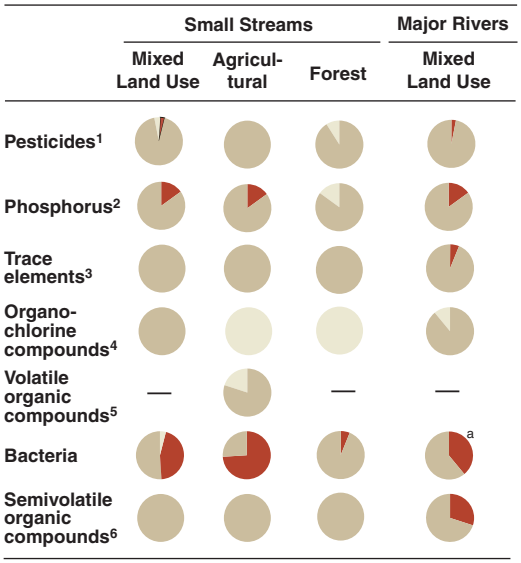
Herbicides and herbicide degradates were detected in 98 percent of the 428 total stream-water samples collected but at levels within drinking-water standards and aquatic-life guidelines. Insecticides used on agricultural fields, gardens, and lawns were detected infrequently (less than 12 percent of samples) 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

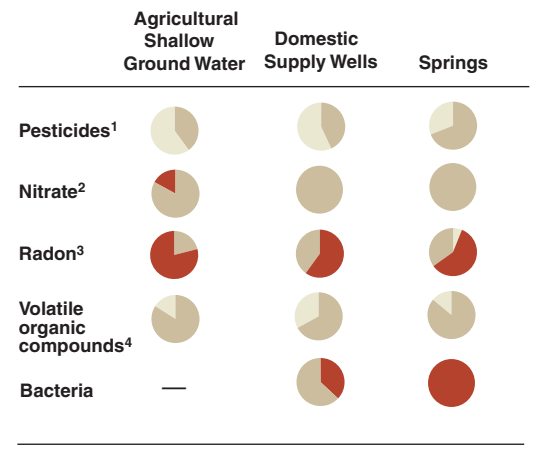
Although ground-water use accounts for a little more than 3 percent of the total water use in the basin, over one-third of the population relies upon ground-water sources for drinking water. In the Upper Tennessee River Basin, ground-water studies focused on the carbonate rock formations of the Valley 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



[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.

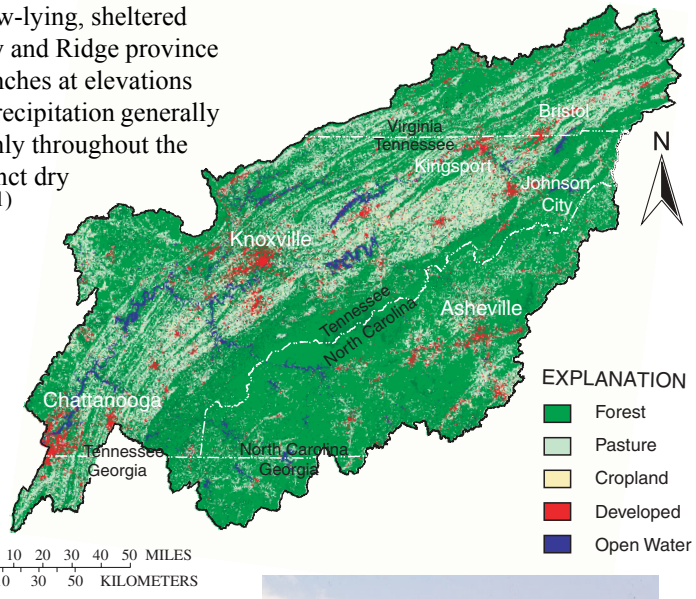
The region generally has a temperate climate; temperatures and annual precipitation totals largely are dependent on land-surface elevations. Average annual temperatures in the area generally decrease by about 3 degrees Fahrenheit for every 1,000-foot increase in elevation. Average annual precipitation 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]

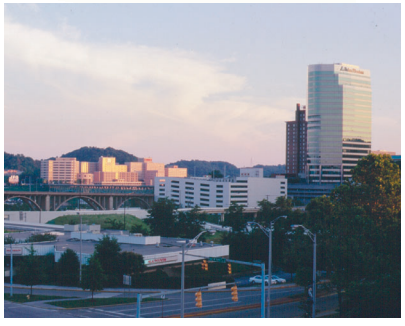
Forests cover more than 67 percent of the Study Unit (fig. 1) and five National Forests–Jefferson, Pisgah, Cherokee, Nantahala, and Chattahooche National Forests–wholly or partially lie within the basin. Agricultural land, predominantly pasture, is the second most common land use and accounts for more 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.

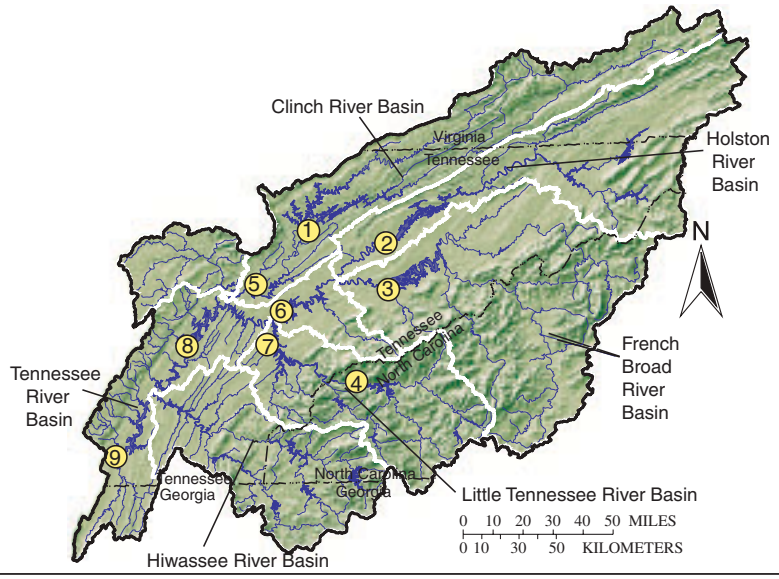
Figure 1. Water-quality conditions in the Upper Tennessee River Basin are influenced by land uses.

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]

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.



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.

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 nonthermoelectric 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.

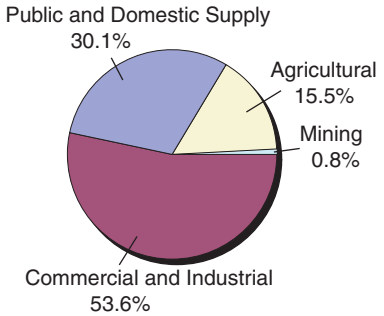


Figure 3. Nonthermoelectric water use in the Upper Tennessee River Basin, 1995. (Thermoelectric water use accounted for 73 percent of the total water use.)

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.

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.

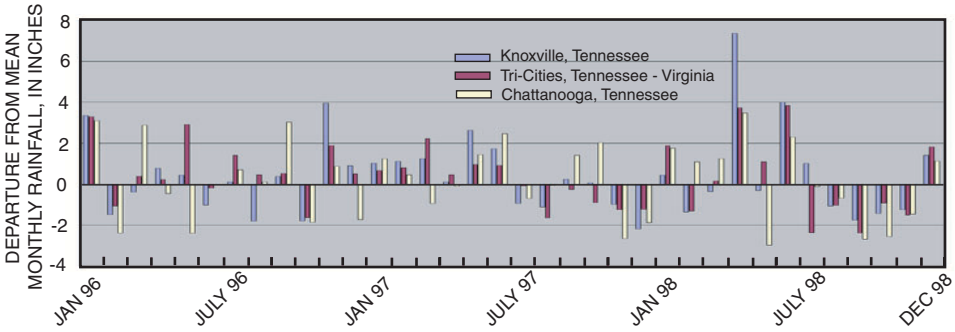


Figure 4. Departures from mean monthly rainfall at three stations in the Upper Tennessee River Basin reflect hydrologic conditions during the 1996-98 study period. (Data from National Weather Service, Morristown, Tenn.)

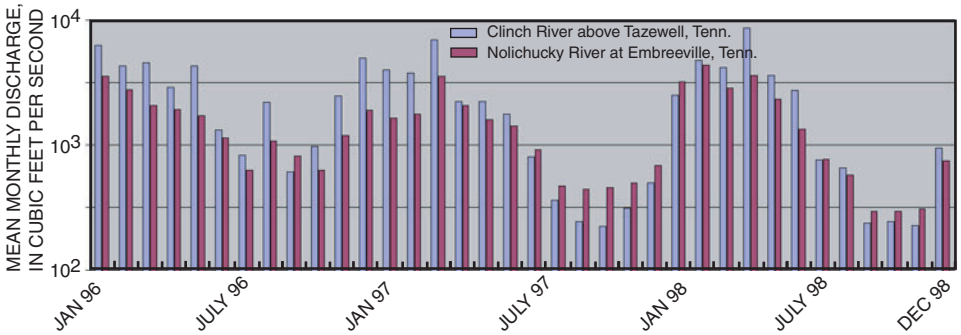


Figure 5. Mean monthly discharge for the Clinch and Nolichucky Rivers reflect the abnormally dry summers of 1997 and 1998.

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.

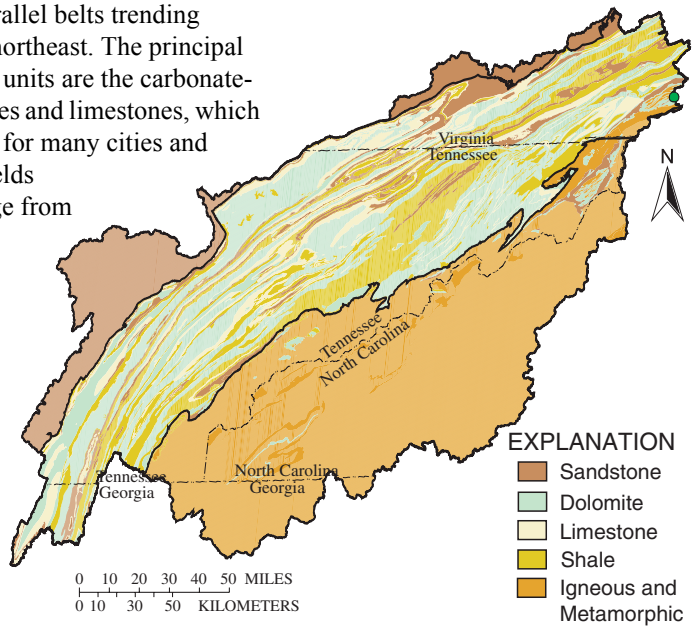


Figure 6. Ground-water availability is a function of surface geology in the Upper Tennessee River Basin.

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.

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.)

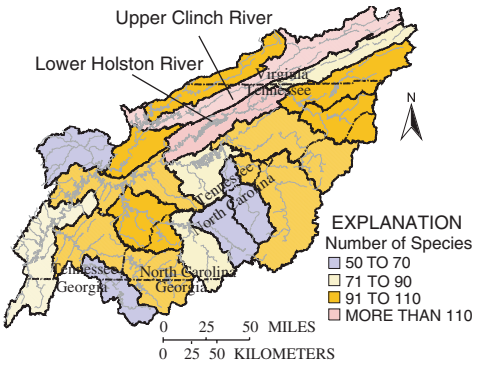
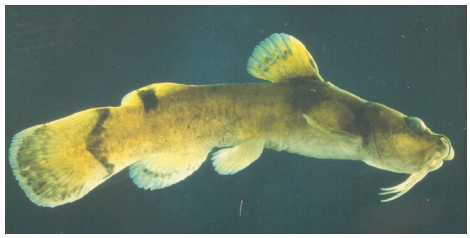


Figure 7. Fish diversity is highest in the Lower Holston and Upper Clinch River systems.

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.)

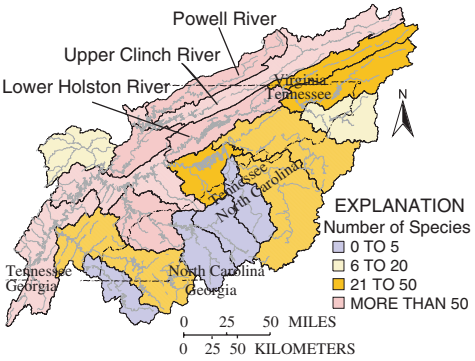


Figure 8. Freshwater mussel diversity is highest in the Valley and Ridge physiographic province.

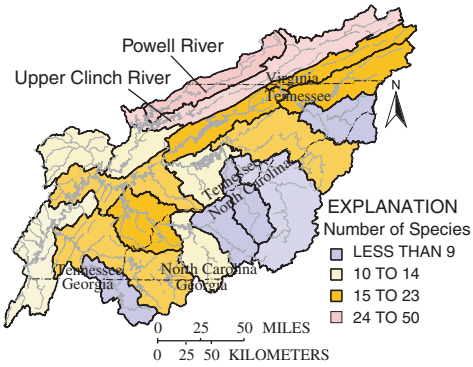


Figure 9. The Upper Clinch and Powell Rivers have the highest numbers of freshwater fish and mussel species considered to be at risk.[8]

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.)