Environmental Setting and Water-Quality Issues in the Lower Tennessee River Basin

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch per year (in/yr)	2.54	centimeter per year
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.004047	square kilometer
square mile (mi^2)	2.590	square kilometer
pound (lb)	0.4536	kilogram
ton	0.9072	metric ton
pound per square mile (lb/mi^2)	1.1748	kilogram per square kilometer
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
foot per mile (ft/mi)	0.1894	meter per kilometer

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32) / 1.8

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

Environmental Setting and Water-Quality Issues in the Lower Tennessee River Basin

By James A. Kingsbury, Anne B. Hoos, *and* Michael D. Woodside

Abstract

The goals of the National Water-Quality Assessment Program are to describe current water-quality conditions for a large part of the Nation's water resources, identify water-quality changes over time, and identify the primary natural and human factors that affect water quality. The lower Tennessee River Basin is one of 59 river basins selected for study. The water-quality assessment of the lower Tennessee River Basin study unit began in 1997. The lower Tennessee River Basin study unit encompasses an area of about 19,500 square miles and extends from Chattanooga, Tennessee, to Paducah, Kentucky. The study unit had a population of about 1.5 million people in 1995.

The study unit was subdivided into subunits with relatively homogeneous geology and physiography. Subdivision of the study unit creates a framework to assess the effects of natural and cultural settings on water quality. Nine subunits were delineated in the study unit; their boundaries generally coincide with level III and level IV ecoregion boundaries. The nine subunits are the Coastal Plain, Transition, Western Highland Rim, Outer Nashville Basin, Inner Nashville Basin, Eastern Highland Rim, Plateau Escarpment and Valleys, Cumberland Plateau, and Valley and Ridge.

The lower Tennessee River Basin consists of predominantly forest (51 percent) and agricultural land (40 percent). Activities related to agricultural land use, therefore, are the primary cultural factors likely to have a widespread effect on surface- and ground-water quality in the study unit. Inputs of total nitrogen and phosphorus from agricultural activities in 1992 were about 161,000 and 37,900 tons, respectively. About 3.7 million pounds (active ingredient) of pesticides was applied to crops in the lower Tennessee River Basin in 1992.

State water-quality agencies identified nutrient enrichment and pathogens as water-quality issues affecting both surface and ground water in the lower Tennessee River Basin. Water-quality data collected by State and Federal agencies between 1980 and 1996 were summarized to characterize surface- and ground-water quality of the subunits with respect to these issues. Median concentrations of nitrogen species generally were less than 1 milligram per liter in surface and ground water in all subunits, and were highest throughout the subunits that had the largest percentages of agricultural land use. Median phosphorus concentrations also were less than 1 milligram per liter in all subunits. Phosphatic limestones present in two subunits had a larger effect on phosphorus concentrations in surface and ground water than did the amount of agricultural land use in these subunits. Median counts of fecal coliform were higher in surface water than in ground water in all subunits. The highest median counts in surface water were in the Valley and Ridge (7,500 colonies per 100 milliliters) and the Outer Nashville Basin subunits (5,000 colonies per 100 milliliters). Highest median counts in ground water were in the Inner and Outer Nashville Basin subunit. Natural setting likely has an important effect with respect to fecal contamination of surface and ground water in the lower Tennessee River Basin.

INTRODUCTION

The U.S. Geological Survey (USGS) began full scale implementation of the National Water-Quality Assessment (NAWQA) Program in 1991. The goals of the NAWQA Program are (1) to describe current water-quality conditions for a large number of the Nation's freshwater streams and aquifers; (2) to describe how water quality is changing over time; and (3) to improve understanding of the primary natural and human factors that affect water quality. To achieve these goals, water-quality investigations of 59 river basins and aquifer systems have been conducted or are currently ongoing (fig. 1). About 70 percent of the Nation's freshwater use is within these basins. The basins, referred to as study units, were selected to represent the diverse geography, water resources, and land and water use of the Nation. The lower Tennessee River Basin is one of the 59 river basins selected for a water-quality assessment.

The lower Tennessee River Basin NAWQA study unit extends from Chattanooga, Tennessee, to near Paducah, Kentucky (fig. 1), and encompasses about 19,500 square miles (mi^2). Most of the study unit is in Middle Tennessee and northern Alabama, with smaller parts in southwestern Kentucky, northeastern Mississippi, and northwestern Georgia (fig. 1). Parts of the Coastal Plain, Interior Lowland Plateaus, and Appalachian Plateaus Physiographic Provinces are in the study unit (fig. 1). The main stem of the Tennessee River is highly regulated with few free-flowing stream reaches. Six large reservoirs are located on the main stem (fig. 1), and many additional reservoirs are located on tributaries to the main stem.

Project activities for the water-quality assessment of the lower Tennessee River Basin began in 1997. Initial activities for the study included characterizing the environmental setting of the study unit, subdividing the study unit into subunits with relatively homogeneous geology and physiography, and inventorying and analyzing historical water-quality data. The historical data analysis helped to identify water-quality issues in the study unit and to determine the spatial distribution of existing water-quality data.

Purpose and Scope

The purpose of this report is to describe the environmental setting and water-quality issues of the lower Tennessee River Basin. The environmental setting includes the natural and cultural factors that affect water quality. Natural factors in the lower Tennessee River Basin include geology, physiography, soils, climate, and surface- and ground-water hydrology. Geology and physiography are the primary natural factors that were used to subdivide the study unit into nine subunits within which the effects of anthropogenic (cultural) factors on water quality can be evaluated. Cultural factors described in this report include wastewater discharge, water use, and land use. Land use can be used as a surrogate for the distribution of nonpoint-source inputs that affect water quality. This report also presents data for the distribution of major crops, livestock, and agricultural-chemical use for 1992. Historical water-quality data for two constituents (nutrients and bacteria) that are water-quality issues in the study unit are summarized.

Acknowledgments

The authors thank the following individuals for their thoughtful input and suggestions in the delineation of the subunits in the lower Tennessee River Basin—Danny Moore, Geological Survey of Alabama, for providing a technical review of the subunit boundaries; Glendon Smalley, formerly of the U.S. Forest Service, for providing guidance on the delineation of the Highland Rim subunits; John Jenkins, Natural Resources Conservation Service, Tennessee, for providing insight on the surficial deposits and soils; Jim Omernik, U.S. Environmental Protection Agency, and Glenn Griffith, Natural Resources Conservation Service, for their contribution to the conceptualization of the subunits through their work on delineating level IV ecoregions in Tennessee, and Glenn Griffith for providing a digital version of the level IV ecoregion boundaries; as well as Bob Kidd, Pat Hollyday, and Bill Wolfe of the U.S. Geological Survey for providing insight on the hydrogeologic and geomorphologic aspects of the subunits. We also thank Enid Bittner, Alabama Department of Environmental Management, Sydney DeJarnette, Geological Survey of Alabama, and Ken Nafe and Tim Thompson, Tennessee Department of Agriculture who provided water-quality data from ground-water studies.

ENVIRONMENTAL SETTING

Environmental setting described in this report includes aspects of both natural and cultural settings of

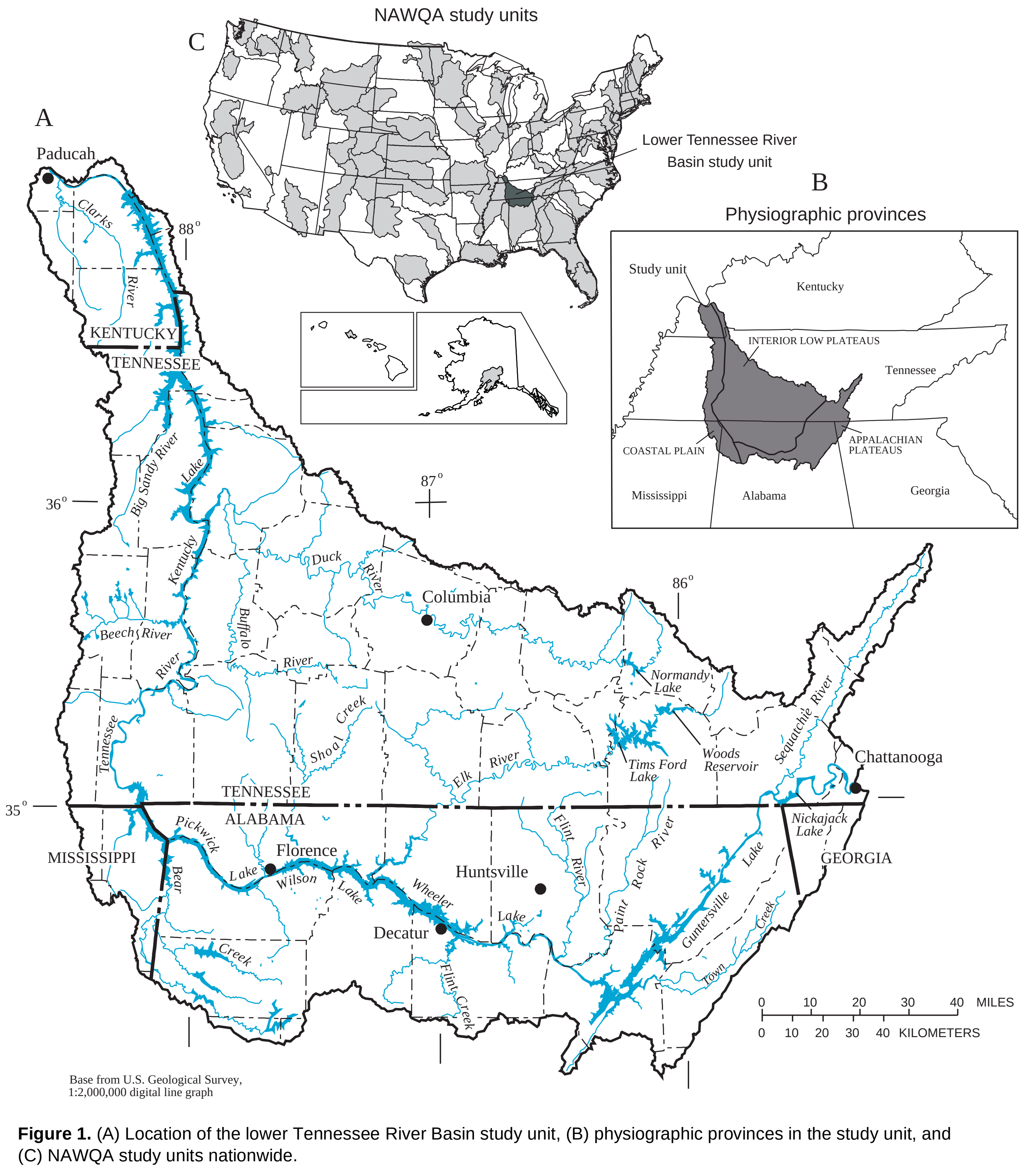


Figure 1. (A) Location of the lower Tennessee River Basin study unit, (B) physiographic provinces in the study unit, and (C) NAWQA study units nationwide.

the lower Tennessee River Basin and their effects on water quality. Natural setting affects the distribution of physical properties, such as temperature, dissolved oxygen, and pH, and the occurrence and distribution of major and some trace inorganic constituents of surface and ground water. Cultural setting influences the quality of water that results from natural processes. Modification of the hydrologic system and other activities, such as dam construction, cultivation of land, and mining, increase the mobility of naturally occurring water-quality constituents and affect water quality. Human activities also introduce naturally occurring compounds where they are not normally present, or in amounts greater than would be present naturally (fertilizer use), and introduce compounds that do not occur naturally anywhere in the environment (synthetic organic compounds such as pesticides). In order to assess the effect of human-related activities on water quality, an estimate of the natural variability in water quality is needed.

Geology and physiography were the primary natural factors used to subdivide the lower Tennessee River Basin into nine subunits that represent areas of relative lithologic, and physical or geomorphic homogeneity (fig. 2). Subdivision of the study unit based on these natural factors provides a framework in which natural variability in water quality can be quantified and the effects of cultural factors on water quality can be assessed. This framework is similar to the ecoregion framework used by State and Federal agencies for

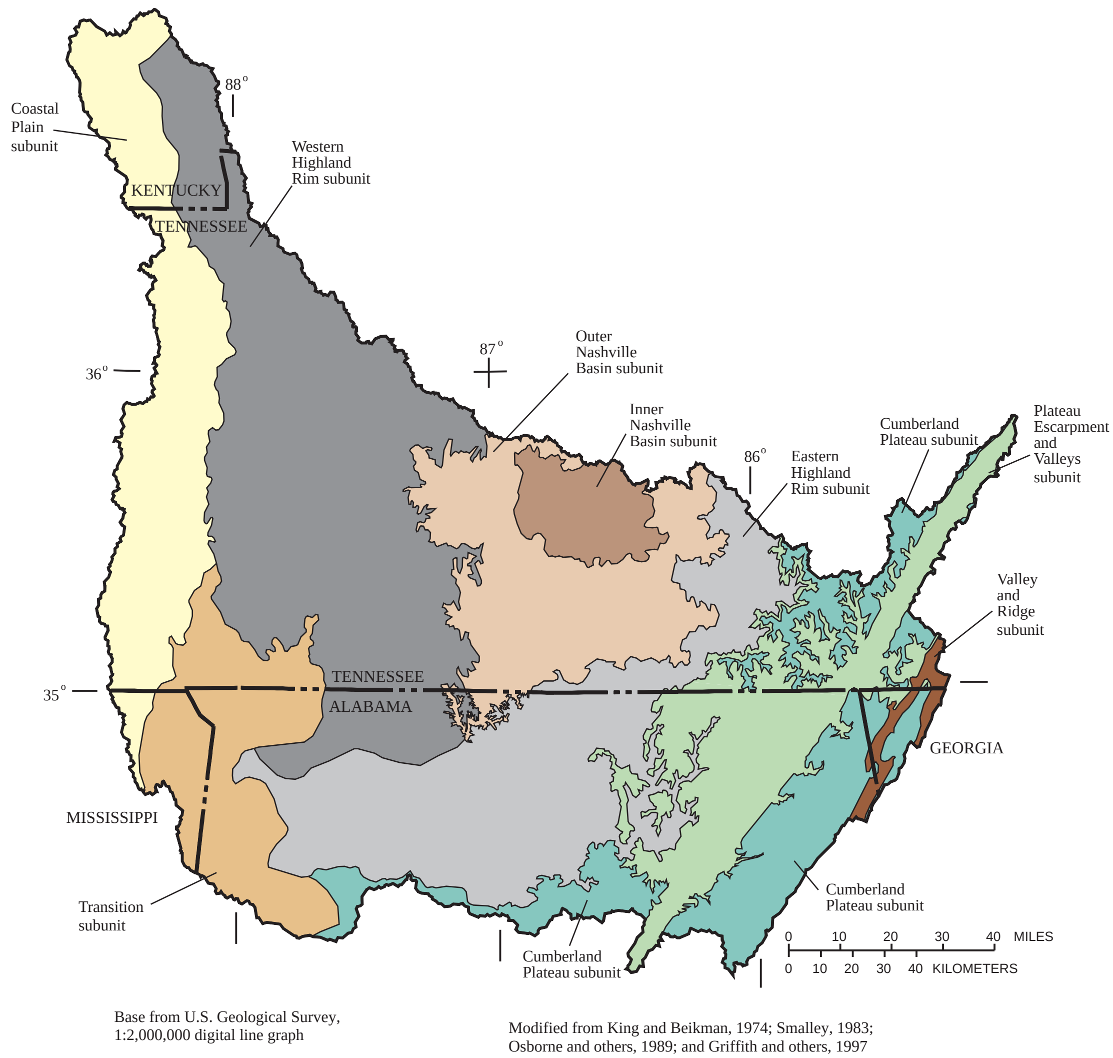


Figure 2. Location of subunits of the lower Tennessee River Basin.

evaluating and managing environmental and water resources (Bailey and others, 1994). Level III ecoregion boundaries were used to define the boundaries for the subunits and level IV ecoregion boundaries were used in Tennessee (Griffith and others, 1997). Geologic contacts were used instead of level IV ecoregion boundaries to define subunit boundaries in northern Alabama, Georgia, and Mississippi, because level IV ecoregion boundary delineations were unavailable in these areas. However, this substitution for the boundaries does not affect regional consistency of the delineation, because the boundaries for the level IV ecoregions in the lower Tennessee River Basin generally correspond to the boundaries of geologic units.

Subunits delineated in the lower Tennessee River Basin are the Coastal Plain, Transition, Western Highland Rim, Outer Nashville Basin, Inner Nashville Basin, Eastern Highland Rim, Plateau Escarpment and Valleys, Cumberland Plateau, and Valley and Ridge (fig. 2). The natural and cultural settings within these subunits is described in the following sections.

Natural Setting

Geology and soils are the primary factors of the natural setting that affect the chemical composition of ground and surface water. The effect of the water-rock interaction on water quality or the amount of solids that dissolve from the rock is dependent on rock type and length of time water is in contact with rock. Soil properties, climate, and ground- and surface-water hydrology affect the movement of water in a watershed, and therefore affect the water-rock interaction.

Geology and Soils

Carbonate rocks underlie much of the lower Tennessee River Basin, but unconsolidated sediments and siliciclastic rocks crop out in the extreme western part and in the eastern parts and extreme southern parts of the study unit, respectively (fig. 3). Ordovician-age carbonates generally crop out near the center of the study unit (fig. 3), and are predominantly limestone with some thin shaly beds and bentonite layers. Phosphatic limestones are present in three Ordovician-age formations: the Hermitage Formation, the Bigby Limestone, and the Leipers Formation. Phosphate has been mined commercially in the Bigby Limestone and the Leipers Formation in the Nashville Basin (Miller, 1974). Ordovician phosphatic limestones and residuum in the study unit generally crop out in a north-south trending band in Maury and Giles Counties, Tennessee, and Limestone County, Alabama (fig. 4).

Most of the Ordovician-age rocks crop out in an area that is a topographic basin (fig. 3), but was originally a structural dome (Nashville Dome). Uplift and fracturing of this area during the late Paleozoic Era accelerated erosion of the younger, more resistant rocks overlying the Ordovician carbonates, and resulted in subsequent erosion of the Ordovician carbonates creating a topographic basin (fig. 3). The Ordovician carbonates are undeformed and relatively flat-lying to gently dipping; however, stresses related to doming formed joints in most of the area. A thin outcrop of Ordovician carbonate is present in the Sequatchie Valley, an eroded anticlinal valley (fig. 3), and minor outcrops are present in the extreme eastern part of the study unit. The Sequatchie Valley represents the western extent of deformation and folding associated with the Appalachian Mountains. The Ordovician carbonates are characterized by karst landforms, such as sinkholes, caves, and disappearing streams. These rocks are the predominant geologic units in the Outer and Inner Nashville Basin.

Devonian- and Silurian-age rocks crop out in a limited area in the western part of the study unit (fig. 3) and are predominantly carbonates. Phosphatic limestones and phosphatic residuum also are present in areas underlain by Devonian- and Silurian-age rocks (fig. 4); however, these deposits are generally scattered and isolated (Smith and Whitlatch, 1940). These rocks are relatively flat-lying to gently dipping away from the Nashville Dome. The Chattanooga Shale is the uppermost unit of the Devonian-age rocks (fig. 3). These rocks crop out primarily in the Western Highland Rim, with minor outcrops also in the Transition and Coastal Plain.

Mississippian-age carbonate rocks are the most areally extensive geologic unit in the study unit (fig. 3). The Mississippian-age carbonates are predominantly limestone, but some shaly beds and chert interbeds and nodules also are present. The amount of insoluble material (clay and chert) in the Mississippian-age carbonates is greater than that in the Ordovician-age carbonates, resulting in the development of a thicker regolith or residuum above bedrock than is present above the Ordovician-age carbonates. The Mississippian-age carbonates are relatively flat-lying to gently dipping away from the Nashville Dome, except in the areas near the Sequatchie Valley where folding has occurred. Parts of the study unit underlain

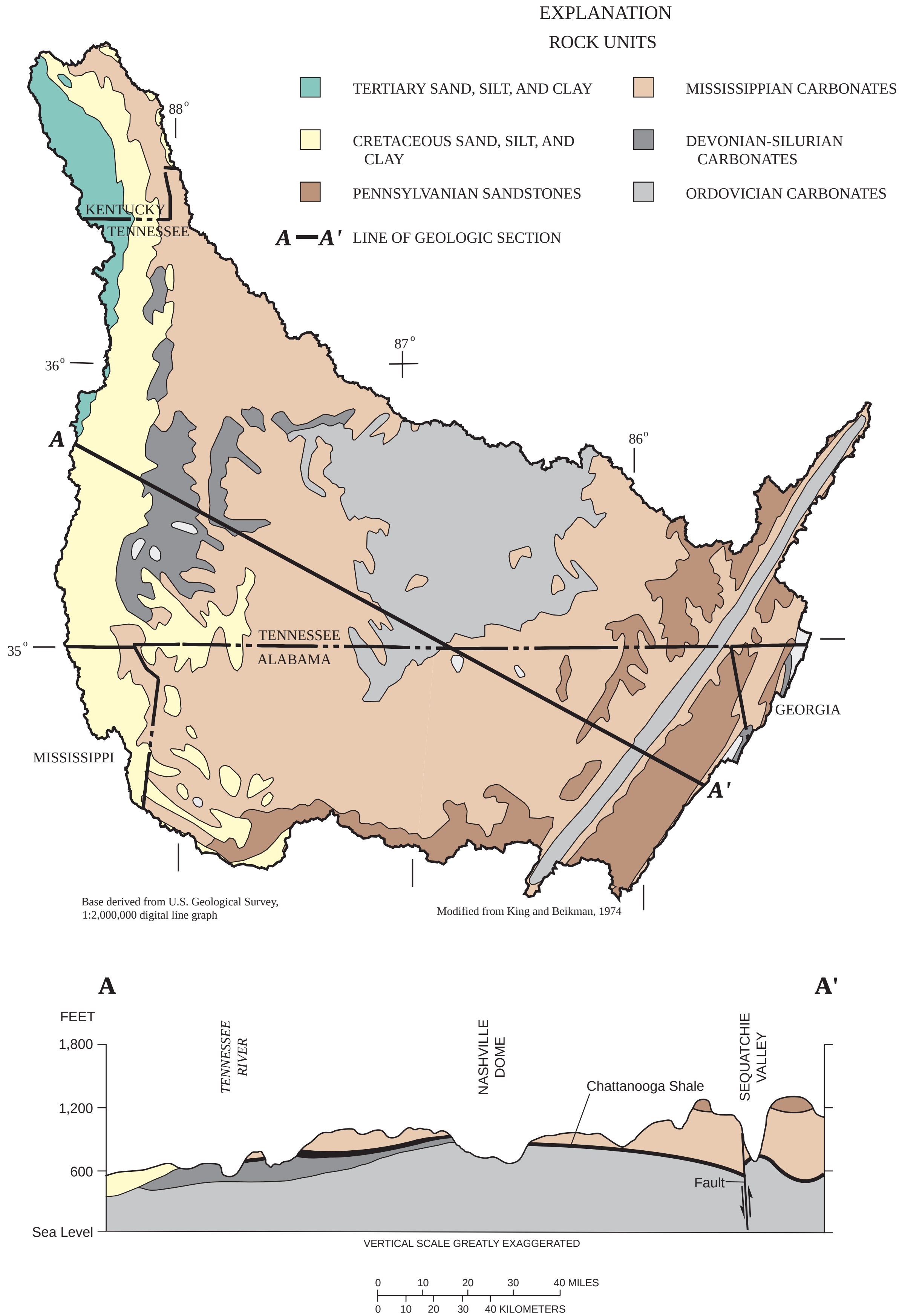


Figure 3. Generalized geology of the lower Tennessee River Basin.

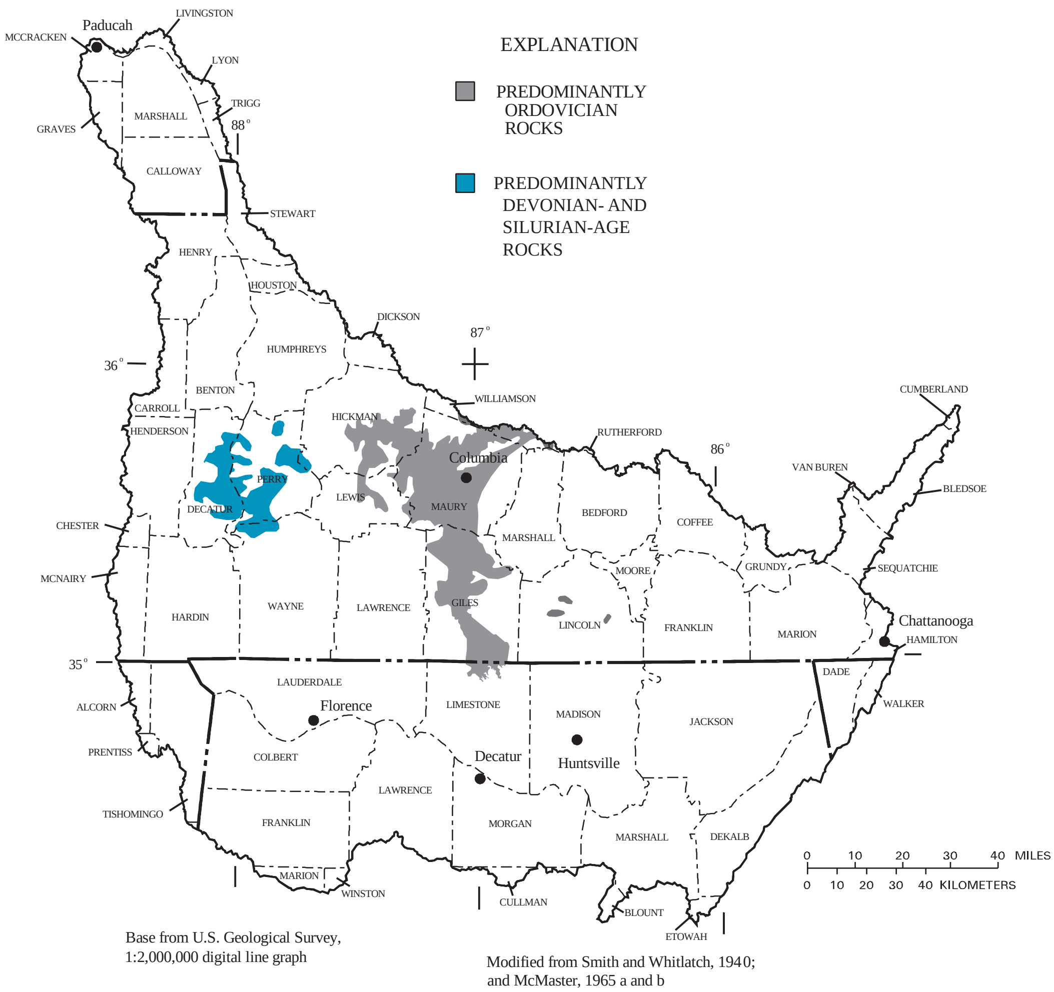


Figure 4. Location of phosphatic limestones in the lower Tennessee River Basin.

by Mississippian-age carbonates are characterized by karst landforms. The Eastern and Western Highland Rim are underlain by these rocks, and these rocks outcrop in the valleys of the Plateau Escarpment and Valleys and Transition.

Pennsylvanian-age rocks located in the eastern and southern part of the study unit (fig. 3) generally are siliciclastic with some coal beds present. These rocks are characterized by repeating sequences of sandstone, shale, and coal. The rocks dip gently [20 to 50 feet per mile (ft/mi)] to the east (Brahana and others, 1986a). Generally, the Pennsylvanian-age rocks are undeformed, but fractures are present in many parts of these geologic units. These rocks are the predominant lithology in the Cumberland Plateau and also cap the hills in the Plateau Escarpment and Valleys.

Unconsolidated sand, silt, and clay of predominantly Late Cretaceous to Tertiary age are located at the western edge of the study unit (fig. 3). These sediments dip to the west at a rate of about 35 ft/mi (Brahana and others, 1986b) and thicken in the direction of dip. Quaternary alluvial deposits and loess are present locally. These sediments are primarily in the Coastal Plain and the Transition.

Soils develop from physical and chemical weathering of the underlying rocks or sediments: sandy, well-drained soils tend to develop in areas where sand or sandstone are the predominant lithology and clayey, poorly drained soils develop in areas where clays, shale, or shaly limestone are present. Other factors that affect the development of soils are topographic relief, climate, and plant growth.

Soil type has implications for ground- and surface-water quality. Well-drained, coarse textured soils have a higher relative infiltration rate and transmit precipitation or recharge to aquifers more readily than poorly drained soils. A higher infiltration rate increases the probability of contamination of groundwater aquifers from surface sources. A slower infiltration rate increases the potential for precipitation to become surface runoff, and increases the probability of surface contaminant transport to surface-water bodies.

About 60 percent of the area of the lower Tennessee River Basin is covered with soils with moderate infiltration rates. These soils overlie primarily the Ordovician- and Mississippian-age carbonate rocks and generally are in the Outer Nashville Basin, Western Highland Rim, and Transition subunits (fig. 5). Soils with slow infiltration rates cover about 38 percent of the study unit. These soils primarily overlie the sandstone and unconsolidated sand, but also overlie carbonate rock in the Inner Nashville Basin, Plateau Escarpment and Valleys, and Cumberland Plateau. The Eastern Highland Rim and Coastal Plain have a mixture of soils with moderate to slow infiltration rates, and in some places very slow infiltration rates, which cover about 2 percent of the area. Soils with high infiltration rates are present in less

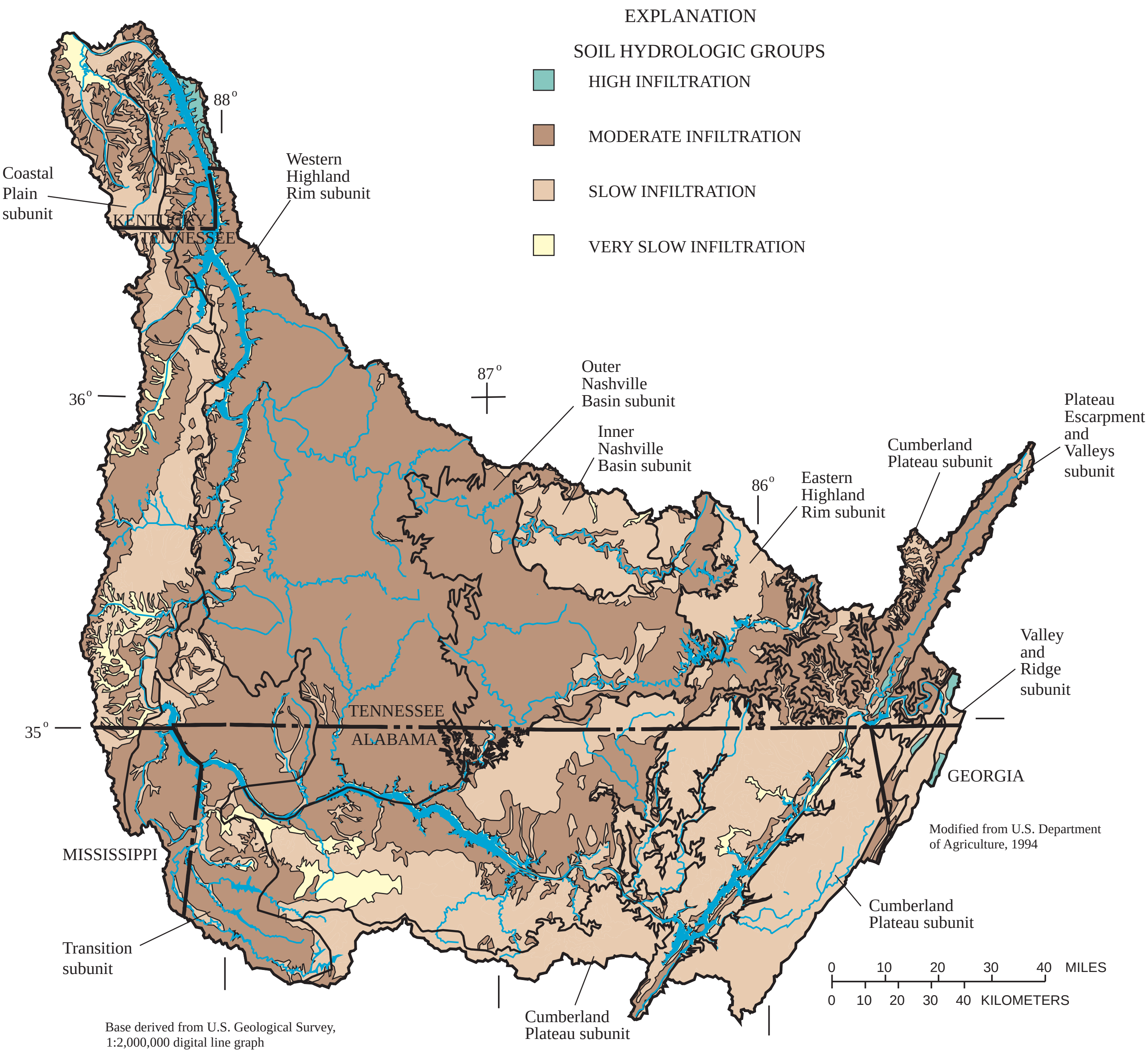


Figure 5. Soil hydrologic groups in the lower Tennessee River Basin.

than 1 percent of the area and are located at the northern and eastern parts of the area in the Valley and Ridge and the Western Highland Rim. The remainder of the study unit is open water bodies.

Other properties of soil that have implications for water quality are the organic content of the soil, which affects the transport of pesticides and other organic compounds. Soil slope and erosion potential affects the movement of both soil and water-quality constituents associated with soil. The chemical composition of soil also affects water quality through processes such as cation exchange between water and soil.

Physiography and Ecoregions

The lower Tennessee River Basin includes parts of the Coastal Plain, Interior Low Plateaus, and Appalachian Plateaus Physiographic Provinces. The Coastal Plain Physiographic Province is located along the western edge of the study unit (fig. 1). It is an area of relatively low topographic relief with land-surface altitudes of about 650 ft above sea level.

The Interior Low Plateaus Physiographic Province covers most of the study unit (fig. 1) and is subdivided into the Nashville Basin and Highland Rim Physiographic Sections (fig. 2). The Nashville Basin, locally also called the Central Basin, has low to moderate relief with some small hills and knobs. Local relief of more than 100 ft is common (Fenneman, 1938). Land-surface altitudes generally are about 700 ft above sea level. The Highland Rim surrounds the Nashville Basin and is underlain predominantly by Mississippian carbonate rocks. The boundary between these two physiographic sections is an escarpment with about 300 ft of relief. Southwest and west of the Nashville Basin the Highland Rim generally has more relief and is more dissected than to the south and east. Land-surface altitudes range from 500 ft near the Tennessee River to 900 ft elsewhere. East of the Nashville Basin, the Highland Rim is a relatively even plateau dissected by a few entrenched meandering streams. Land-surface altitudes reach 1,300 ft, but generally are about 1,000 ft above sea level. Total relief in the Highland Rim is about 650 ft. Karst features such as caves, sinkholes, and springs are present in the Nashville Basin and the Highland Rim.

The Interior Low Plateaus are bounded to the south and east by the Cumberland Plateau Section of the Appalachian Plateaus Physiographic Province (figs. 1 and 2). A steep escarpment separates the Cumberland Plateau from the Highland Rim with the average altitude of the plateau about 1,000 ft above the Highland Rim. The Sequatchie Valley (fig. 3) lies about 500 ft lower than the adjacent upland parts of the Cumberland Plateau (Fenneman, 1938). East of the Sequatchie Valley is a plateau locally known as Walden Ridge or Sand Mountain, with an average land-surface altitude of about 1,300 ft and relief generally between 100 and 200 ft. In contrast, west of the Sequatchie Valley, the Cumberland Plateau is more dissected with land-surface altitudes ranging from about 1,000 to 1,600 ft with local relief as much as 300 ft.

Ecoregions represent areas in which factors (soils, vegetation, climate, geology, and physiography) affecting terrestrial and aquatic ecological systems are relatively uniform (Griffith and others, 1997). Ecoregion boundaries provide a framework for evaluating and managing environmental resources. Ninety-eight level III ecoregions have been defined across the nation (Bailey and others, 1994). The lower Tennessee River Basin includes parts of six level III ecoregions (fig. 6), which generally correspond to the physiographic provinces with some additional subdivision. Most of the study unit is in the Interior Plateau ecoregion, which corresponds to the Interior Low Plateaus Physiographic Province. The Southwestern Appalachians ecoregion corresponds to the Appalachian Plateaus Physiographic Province, and the Southeastern Plains is roughly coincident with the Coastal Plain Physiographic Province (fig. 6). The remaining level III ecoregions (Interior River Lowlands, Mississippi Valley Loess Plains, and Ridge and Valley) cover relatively small areas and are subdivisions within the physiographic provinces (fig. 6).

Subdivisions of level III ecoregions (level IV) decrease the heterogeneity within the larger-scale ecoregions. Level IV ecoregions are being defined on a state by state basis. This level of definition was not available for Alabama; however, level IV ecoregions had been delineated for Tennessee (Griffith and others, 1997) and were used for the subdivision of the study unit in that State.

Climate

Temperature is an important variable that influences the rate of most physical and chemical reactions. The quantity and quality of precipitation affect the quality of water in watersheds. The lower Tennessee River Basin has a temperate and warm, humid climate. Average temperature across the study unit ranges from

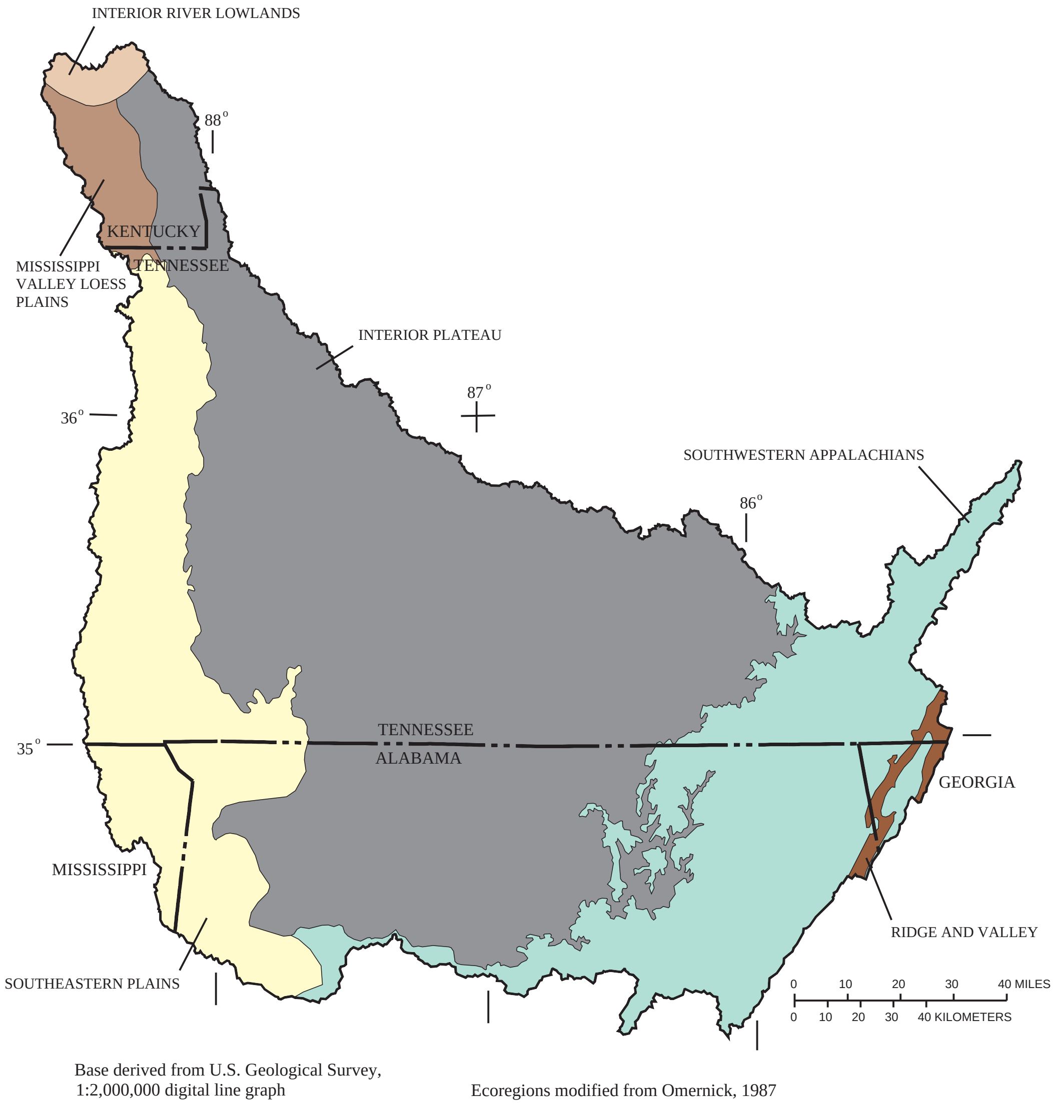


Figure 6. Level III ecoregions in the lower Tennessee River Basin.

56 to 61 °F with an average annual temperature of about 59 °F (U.S. Department of Commerce, 1995). The warmest months are July and August and the coolest month is January. The difference between the average monthly high and low temperature for the year is about 40 °F.

Average annual precipitation in the lower Tennessee River Basin is about 56 inches (in.) (U.S. Department of Commerce, 1995). The average amount of precipitation for individual sites in the study unit ranges from about 50 in. in the western part of the study unit to about 60 in. in the eastern part of the study unit (fig. 7). The increase in precipitation from west to east generally corresponds to the increase in elevation from west to east. Average rainfall amounts are highest during November through May, with March generally being the wettest month (fig. 8). Average rainfall amounts are lowest June through October (fig. 8). The month in which rainfall is lowest varies from site to site. August through October usually is the driest part of the year (fig. 8).

Surface Water

The main stem of the Tennessee River is highly regulated with few free-flowing stream reaches. Six large reservoirs are located on the main stem (fig. 1), and many additional reservoirs are located on tributaries to the main stem. Most of these reservoirs were constructed from the 1930’s to the 1970’s for power generation, navigation, flood control, and for water supply. The largest tributaries to the Tennessee River

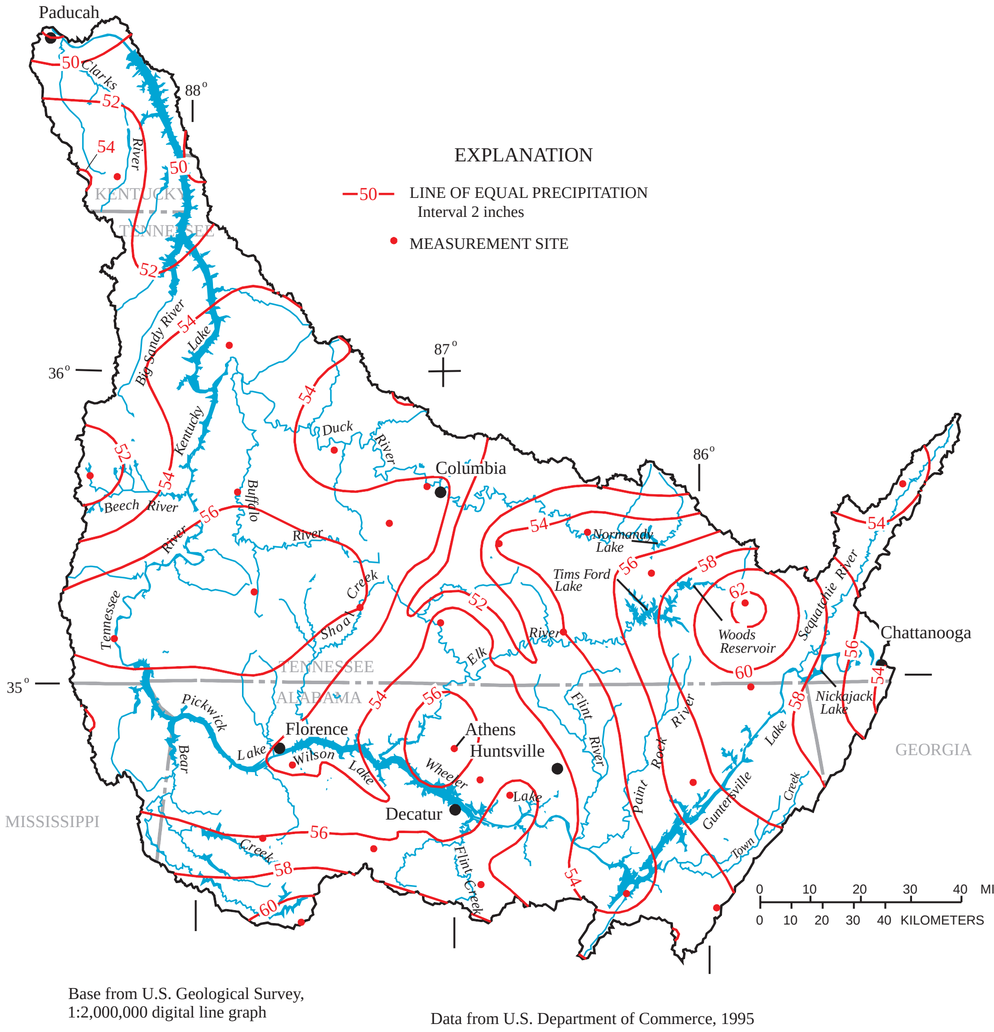


Figure 7. Distribution of average annual precipitation in the lower Tennessee River Basin, 1961-90.

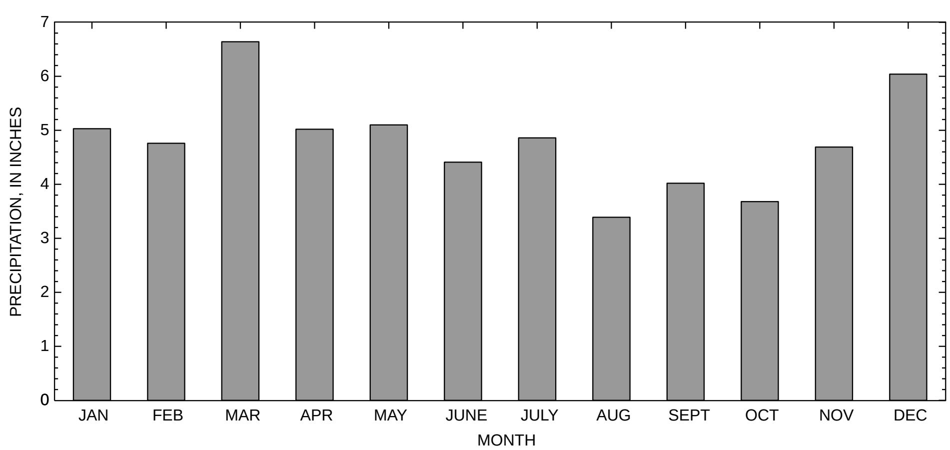


Figure 8. Average monthly precipitation at Athens, Alabama, in the lower Tennessee River Basin, 1961-90. (Data from U.S. Department of Commerce, 1995.)

are the Duck and Elk Rivers, which drain areas of 2,700 and 2,250 mi^2, respectively. Mean-annual discharge for the Tennessee River is about 35,900 cubic feet per second (ft^3/s) at Chattanooga, Tennessee, and is about 65,600 ft^3/s at the mouth of the Tennessee River at Paducah, Kentucky. The Duck and Elk Rivers combined contribute about 7,700 ft^3/s, or only about 26 percent of the 29,700 ft^3/s of flow that is gained in the study unit; most of the streamflow is contributed from river basins smaller than 1,000 mi^2.

Long-term streamflow data at selected sites illustrate the range of mean-annual discharges for large rivers in the lower Tennessee River Basin (fig. 9). The time series of mean-annual discharge was similar at all of the sites shown in figure 9. During the selected period (1930-95), the lowest mean-annual discharge on the Tennessee River occurred during 1988 (fig. 9) at Chattanooga and Savannah (23,000 ft^3/s at Savannah). The largest mean-annual discharge during the selected period at Savannah was about 87,000 ft^3/s in 1973. The 1970's were the "wettest" years at these sites with

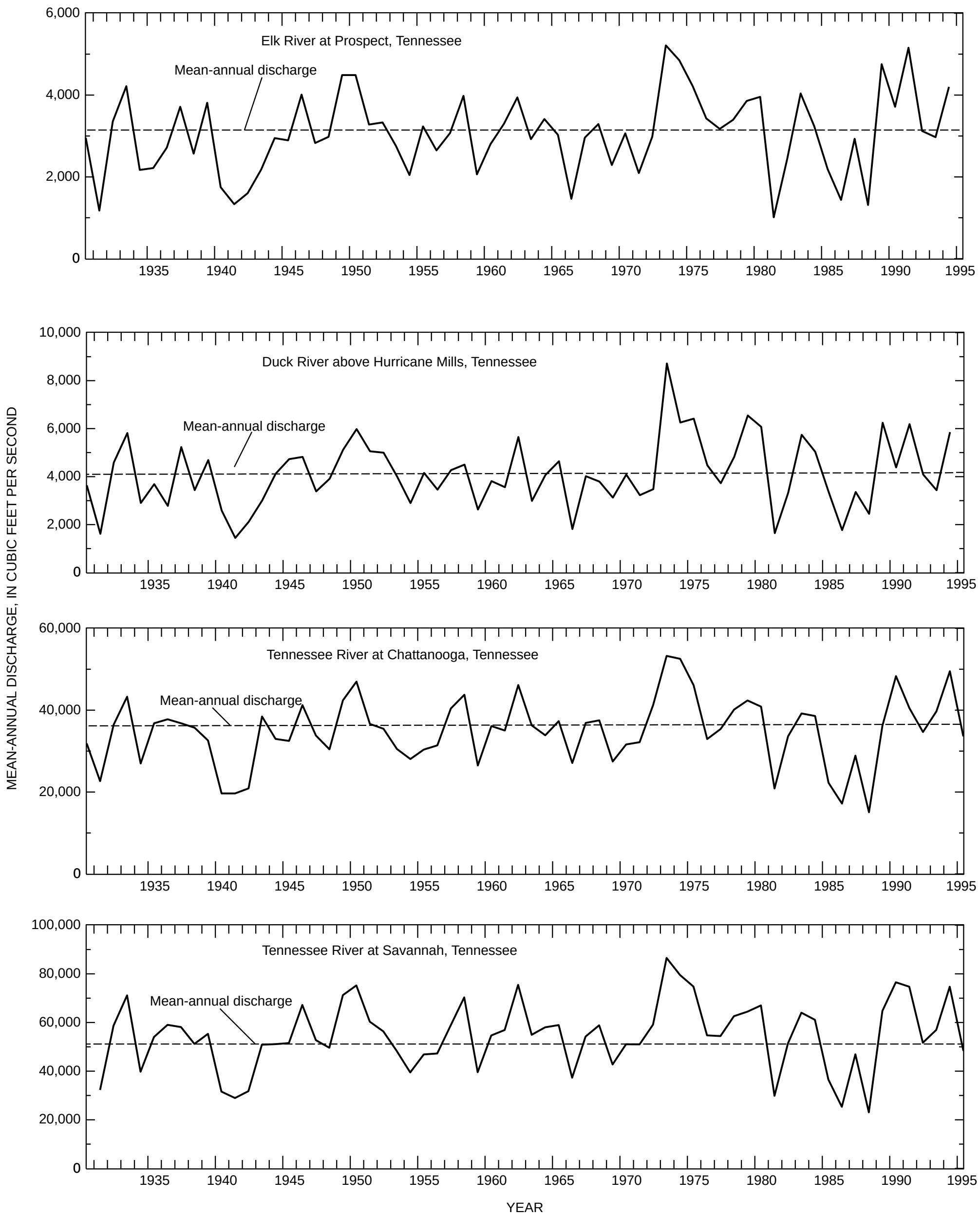


Figure 9. Long-term mean-annual streamflow for selected streams in the lower Tennessee River Basin.

6 of the 10 years having streamflow above the long-term mean-annual discharge. The 1980’s were the “driest” 10-year period, with 3 years of streamflow well below the long-term mean-annual discharge (fig. 9).

The regulation of flow on the Tennessee River and the upper parts of the Elk and Duck Rivers and other tributaries moderates extremes that normally occur in streamflow. Streamflow data for the 1992 water year (October 1 through September 30), a year with near average streamflow (fig. 10), show the combined effects of basin size and reservoirs. Streamflow in the Duck River above Hurricane Mills (2,557 mi^2) is minimally affected by Normandy Lake, which is located about 220 mi upstream; storm peaks generally are followed by smooth recessions in discharge (fig. 10). Streamflow in the Tennessee River at Savannah (33,140 mi^2) is affected by several reservoirs upstream, primarily Pickwick Lake. Storm peaks on the hydrograph generally are broader and the corresponding recessions are somewhat slower than for the same storms affecting the Duck River (fig. 10). The hydrograph for Savannah also shows peaks and recessions resulting from upstream reservoir operations. Streamflow response to changes in releases from reservoirs generally are more rapid than response to storm events.

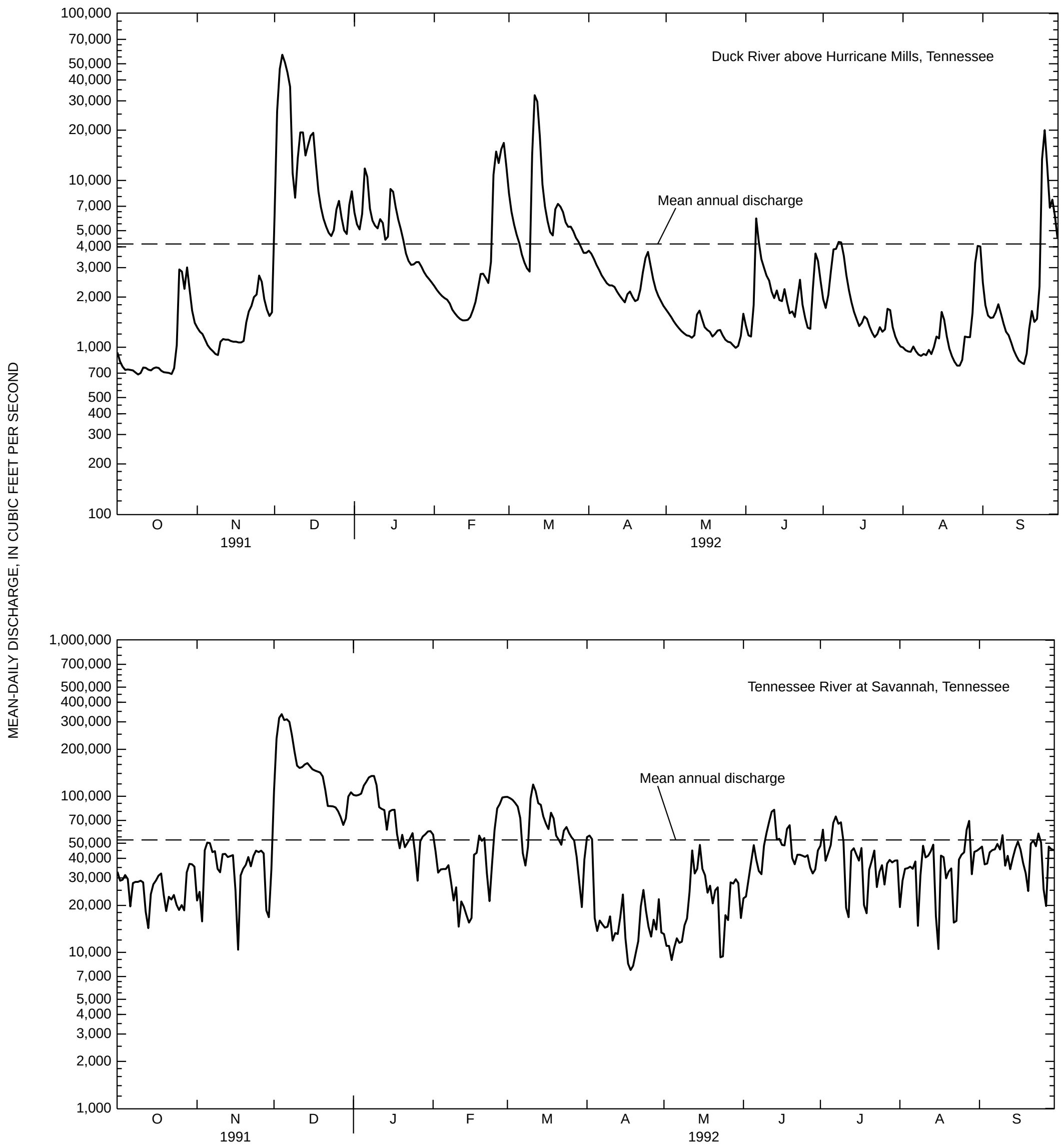


Figure 10. Mean-daily discharge for the Tennessee River at Savannah, Tennessee, and the Duck River above Hurricane Mills, Tennessee, water year 1992.

Reservoir operations also affect longer periods of streamflow in addition to short-term releases. Streamflow was generally lower than average during July through October in the Duck River as a result of less precipitation and runoff. However, streamflow at Savannah was near the mean-annual discharge between July and October (fig. 10). Near average streamflow during these months was maintained by releases from Pickwick Lake to generate power during the summer months.

Ground Water

Principal aquifers in the lower Tennessee River Basin are the Cretaceous sand, Pennsylvanian sandstone, Mississippian carbonate, and Ordovician carbonate aquifers (fig. 11). The areal extent of these aquifers in the study unit generally corresponds to the principal geologic units. Ground-water flow in the principal aquifers in the study unit generally is along relatively short flow paths through solution openings, bedding planes, joints, fractures in bedrock, and unconsolidated sediments. The amount of flow to a deeper, regional ground-water-flow system from the principal aquifers is relatively small.

Sediments of predominantly Cretaceous age, and minor Quaternary-age alluvium and Tertiary-age sediments, which consist of unconsolidated sand, silt, clay, and minor gravel constitute the Cretaceous sand aquifer (fig. 11), which is confined in most places. Recharge to the aquifer is from precipitation on sandy units in the outcrop areas. Ground water flows through the primary porosity of this aquifer. East of the Tennessee River, ground water in the Cretaceous sand aquifer moves along short flow paths and discharges within the Tennessee River Basin (Brahana and others, 1986b). Ground water west of the Tennessee River also discharges to streams in the study unit, but a component of ground water flows to the west, along regional flow paths, in the direction of the regional dip of the sediments. Ground-water gradients and velocities generally are lower in the Cretaceous sand aquifer than in other hydrogeologic settings in the study unit.

Sandstones and conglomerates are the primary water-bearing units that constitute the Pennsylvanian sandstone aquifer (fig. 11). These rocks generally have low permeability, and ground water flows primarily through fractures in these rocks (fig. 12). The number, size, and density of fractures decreases with depth, limiting the regional component of ground-water flow. Flow paths typically are short and ground water discharges to streams and springs. Recharge to the aquifers occurs where precipitation falls on outcrops of these units and where streambeds intersect these units (Brahana and others, 1986a). A shale confining unit between the Pennsylvanian sandstone aquifer and the underlying Mississippian carbonate aquifer retards the movement of ground water between these aquifers (fig. 12).

The Mississippian carbonate aquifer is the most areally extensive and productive aquifer in the lower Tennessee River Basin (fig. 11). Ground water in this aquifer flows in solution openings along bedding planes, joints, and fractures. These openings and the zone of dynamic ground-water circulation generally are at depths less than 300 ft below land surface (fig. 12). Recharge to the Mississippian carbonate aquifer is from precipitation percolating through the overlying regolith to the bedrock aquifer. The regolith can store large amounts of water that is slowly transmitted downward into the bedrock aquifer. Locally, the regolith may contain abundant gravel and is a productive aquifer. Generally, flow paths are short and ground-water gradients are relatively steep; ground water moves rapidly and discharges to streams and springs. The Mississippian carbonate aquifer is underlain by the Devonian-age Chattanooga Shale (fig. 3), a regional confining unit that effectively limits the movement of ground water between the Mississippian carbonate and the underlying Ordovician carbonate aquifers.

Ground water in the Ordovician carbonate aquifer (fig. 11) flows primarily in solution openings along bedding planes, joints, and fractures. These solution openings are most common and shallow ground-water flow occurs primarily within about 300 ft of land surface. Shaly beds and bentonite layers present in the Ordovician rocks retard the downward movement of ground water, but locally, joints in or erosion of these layers allows deeper circulation of ground water (fig. 12). The limestones that make up these aquifers are predominantly calcite, and contain little insoluble, soil-forming material and little or no regolith (generally less than 20 ft) overlies the aquifer. Flow paths are short and ground water moves rapidly and discharges to streams and springs.

Surface- and Ground-Water Interactions

Ground-water discharge to streams is a significant component of streamflow and affects the water quality of streams in the lower Tennessee River Basin.

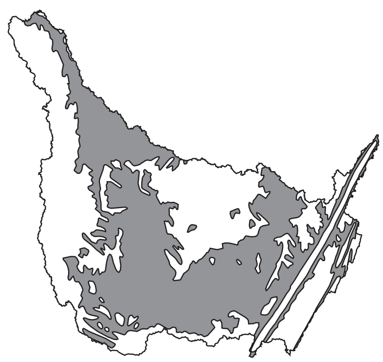
Areal extent	Aquifer	Lithology and hydrogeology
	Cretaceous sand aquifer	Unconsolidated sand, silt, clay, and gravel. Ground-water flow occurs in intergranular pore spaces. Flow paths are short to very long. Wells in these aquifers produce enough water for domestic use and locally small public supplies. Wells can yield up to 100 gallons per minute.
	Pennsylvanian sandstone aquifer	Sandstone, conglomerate, siltstone, shale, and coal. Aquifers consist primarily of sandstone and conglomerate. Permeability of these formations is low and ground-water flow generally occurs along fractures. Artesian conditions often occur. Flow paths generally are short, small springs are common. Well yields typically are low but yield enough for domestic use.
	Mississippian carbonate aquifer	Limestone and chert. Aquifers occur primarily in massive bedded limestone formations. Locally, productive aquifers are present in chert gravels present in regolith overlying bedrock. Most ground-water flow occurs in solution channels formed in joints and bedding planes. Flow paths generally are short, moderately large springs are common. Aquifers used for domestic and public supply. Well yields range from low to very high (more than 3,000 gallons per minute).
	Ordovician carbonate aquifer	Predominantly limestone, minor dolomite. Most ground-water flow occurs in solution channels formed in joints and bedding planes. Ground-water flow paths typically are short and springs are common. Well yields generally are between 2 to 20 gallons per minute but can be as high as 300 gallons per minute.

Figure 11. Principal aquifers in the lower Tennessee River Basin. (Geology modified from King and Beikman, 1974.)

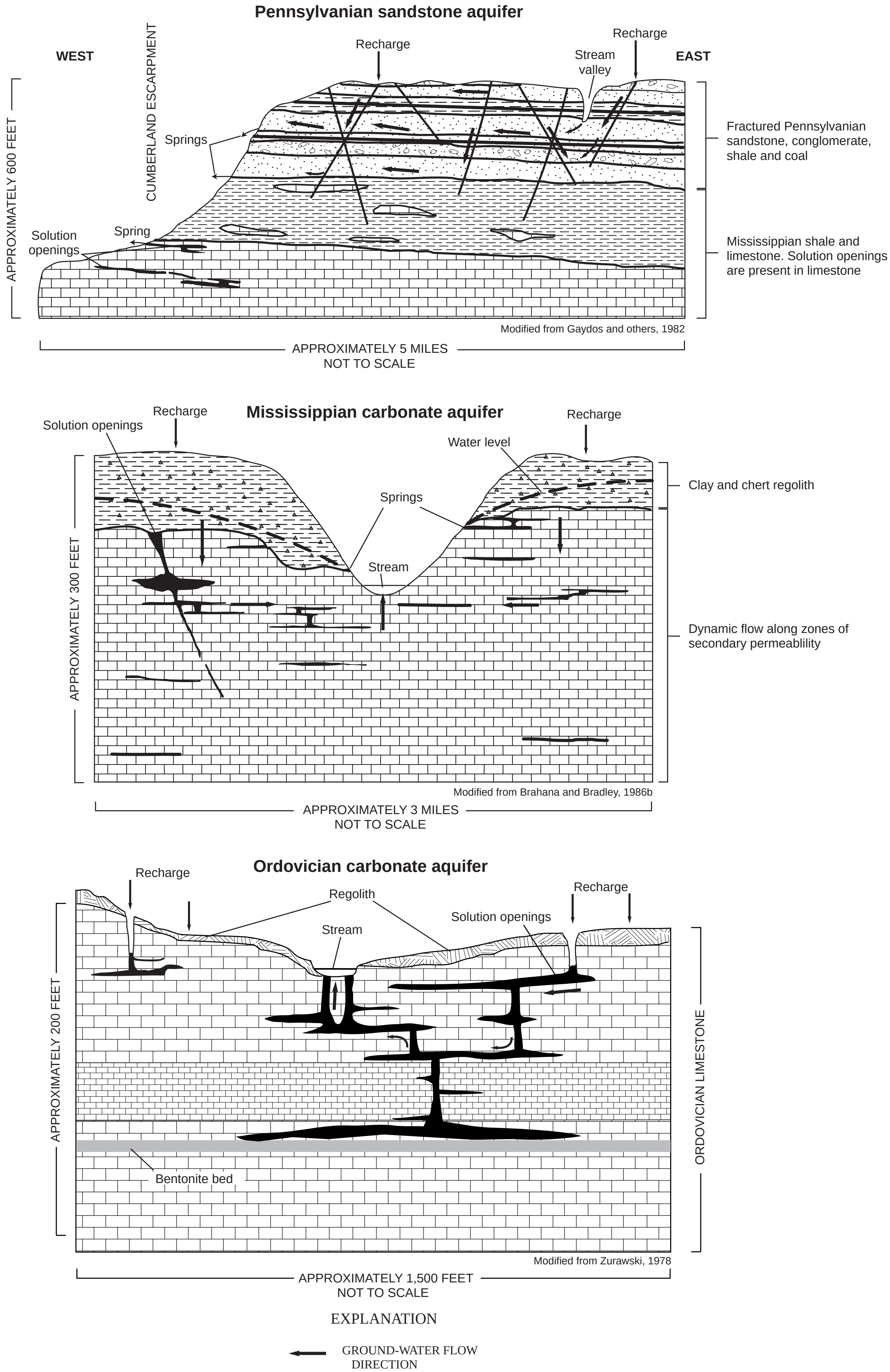


Figure 12. Conceptual models of ground-water occurrence in bedrock aquifers in the lower Tennessee River Basin.

Water-quality properties that often are affected by ground-water discharge to streams include pH, temperature, dissolved oxygen, and concentrations of dissolved inorganic constituents. During dry periods of the year, ground-water discharge to springs and streams provides much or all of the flow in streams.

Hydrograph-separation and baseflow estimation methods were applied to streamflow data for selected streams in the lower Tennessee River Basin to estimate the contribution of ground water to streamflow. To cover a broad range of hydrologic conditions, surface-water discharge records of 10 or more years were selected for analysis; a few shorter periods of record also were used (table 1). The computer program RORA (Rutledge, 1998), which automates the Rorabaugh (1964) and Daniel (1976) method, estimates ground-water recharge using the recession-curve-displacement method. The computer program PART estimates baseflow using streamflow partitioning (Rutledge, 1998). Generally, the estimated ground-water discharge (PART) is less than the estimated recharge (RORA); this difference is attributed to riparian evapotranspiration if ground-water withdrawals are negligible (Rutledge, 1998). For the purposes of this report, the results of both programs are termed baseflow estimates and results from RORA represent an upper limit of the baseflow estimate. Both programs require the assumptions that the aquifers contributing baseflow are isotropic and uniform and that the streams and aquifers are not significantly affected by withdrawals, discharges, or impoundments. All of these assumptions are not met, particularly the first, in the selected stream basins and throughout much of the lower Tennessee River Basin; therefore, the results of this analysis are considered estimates.

Estimates of baseflow calculated by both programs (table 1) are considerably higher than estimates of net annual recharge for average flow years reported for the same streams (Hoos, 1990) calculated by the manual Rorabaugh-Daniel hydrograph-separation method. However, estimates of baseflow calculated by PART fall within the range reported for streams with watersheds underlain by the Pennsylvanian, Mississippian, and Ordovician aquifers using the manual baseflow estimation technique (Zurawski, 1978). Although estimates differ between the methods and studies (Zurawski, 1978; Hoos, 1990), the ranking of each principal aquifer setting based on estimates of baseflow is similar for all methods. Baseflow (ground-water discharge) is highest for basins underlain by the Mississippian aquifers and lowest in basins underlain by the Cretaceous sand aquifer (table 1). Baseflow in basins underlain by the Cretaceous sand aquifer is low, in part, because of loss of ground water to a regional flow system. Baseflow in basins underlain by the Ordovician carbonate aquifer and Pennsylvanian sandstone aquifer is about the same. Estimates for basins underlain by both Mississippian carbonate and Pennsylvanian sandstone aquifers were slightly higher than basins underlain by Pennsylvanian sandstone aquifer only (table 1).

Mean-annual runoff (inches of water discharged per unit area) in the study unit ranges from about 30 in/yr [about 2 $(ft^3/s)/mi^2$] in the area near Guntersville Lake to about 18 in. [about 1 $(ft^3/s)/mi^2$] in the northwestern part of the study unit (fig. 13). Runoff is affected by climate (temperature and precipitation), topography (slope), and soils. The decrease in runoff from east to west generally corresponds to a decrease in the amount of precipitation across the study unit (fig. 7). In the eastern part of the study unit, about 45 percent of rainfall becomes runoff and in the western part about 35 percent does. The movement of ground water along a regional flow path in the Coastal Plain may contribute to the decrease in runoff across the study unit.

Cultural Setting

Cultural setting includes human activities that affect natural surface- and ground-water quality. Human activities affect water quality through input of physical and chemical constituents to a water body or to land surface in a watershed, modifications to the hydrologic system, such as reservoirs and impoundments, and surface- and ground-water use. Inputs of constituents from human activities to a watershed can be characterized as one of two types, point or nonpoint sources. Nonpoint sources to surface and ground water may be a mix of cultural and natural sources and include runoff and infiltration of constituents from urban and agricultural areas and atmospheric deposition of constituents. Whereas the distribution and magnitude of point sources are generally well documented, the distribution and magnitude of nonpoint sources are more difficult to quantify. Land-use data are often used as a surrogate for the distribution of nonpoint sources in water-quality studies.

Reservoirs, water use, land-use data, and inputs of selected constituents in the lower Tennessee River

Table 1. Streamflow and baseflow estimates for selected streams in the lower Tennessee River Basin

[ID, identification number; mi^2, square miles; ft^3/s, cubic feet per second; in/yr, inches per year; C, Cretaceous sand aquifer; P, Pennsylvanian sandstone aquifer; M, Mississippian carbonate aquifer; O, Ordovician carbonate aquifer]

Station name	Principal aquifer	Station ID	Drainage area, mi^2	Period of record	Recession index	Mean streamflow		Baseflow, range of estimates[a]		Ground-water discharge,[b] in/yr
						ft^3/s	in/yr	in/yr	Percentage of streamflow	
Clarks River at Almo, Ky.	C	03610200	134	1983-95	30	180	18.2	3.7-4.8	20-26	--
Crow Creek at Bass, Ala.	P	03572110	131	1976-95	21	281	29.2	13.4-19.2	46-66	--
Town Creek near Geraldine, Ala.	P	03572900	141	1992-94	33	336	32.4	13.3-17.8	41-55	--
Flint Creek near Falkville, Ala.	M & P	03576500	84	1993-96	22	142	23.1	11.0-14.7	48-64	--
Sequatchie River near Whitwell, Tenn.	M & P	03571000	402	1921-93	35	752	25.4	15.1-18.4	59-72	8.7
Paint Rock River near Woodville, Ala.	M & P	03574500	320	1936-96	28	689	29.2	12.1-15.2	41-52	
Shoal Creek at Iron City, Tenn.	M	03588500	348	1926-94	63	653	25.5	14.9-16.8	58-66	9.2
Buffalo River near Flatwoods, Tenn.	M	03604000	447	1921-97	54	768	23.3	14.2-16.2	61-70	8.7
Buffalo River below Lobelville, Tenn.	M	03604400	702	1928-93	55	202	23.3	14.9-17.0	64-73	7.3
Indian Creek near Madison, Ala.	M	03575830	49	1976-96	34	70	19.3	10.9-12.8	56-66	--
Flint River near Chase, Ala.	M	03575000	342	1931-80	48	558	22.2	11.5-13.2	52-59	--
Big Nance Creek at Courtland, Ala.	M	03586500	166	1989-97	26	350	28.7	10.9-13.9	38-48	--
Piney River at Vernon, Tenn.	M	03602500	193	1926-93	55	315	22.2	14.8-17.2	67-77	5.0
West Flint Creek near Oakville, Ala.	M	03577000	88	1993-96	20	168	26.1	12.0-15.9	46-61	--
Elk River at Prospect, Tenn.	M & O	03584600	1,805	1920-93	40	3,090	23.3	11.5-14.5	49-62	4.1
Duck River above Hurricane Mills, Tenn.	M & O	03603000	2,557	1926-93	48	4,106	21.8	11.1-13.5	51-62	6.2
Carters Creek at Butler Road at Carters Creek, Tenn.	O	03600088	20	1987-97	30.1	34	22.6	11.6-15.7	51-69	--
Garrison Fork above L&N Railroad at Wartrace, Tenn.	O	03597210	86	1990-97	21.5	169	26.9	10.8-15.3	40-57	--
E. Fork Mulberry Creek below Jack Daniels Distillery at Lynchburg, Tenn.	O	03580995	23	1988-93	45.5	48	28.1	14.2-18.0	51-64	--
Wartrace Creek below County Road at Wartrace, Tenn.	O	03597590	36	1990-97	16.7	72	27.3	7.4-11.3	27-41	--

[a]The lower value of the ranges was estimated using streamflow partitioning (PART computer program, Rutledge, 1998); the higher value of the ranges was estimated by using recession-curve displacement (RORA computer program, Rutledge, 1998).

[b]From Hoos, 1990, table 2, average net annual recharge.

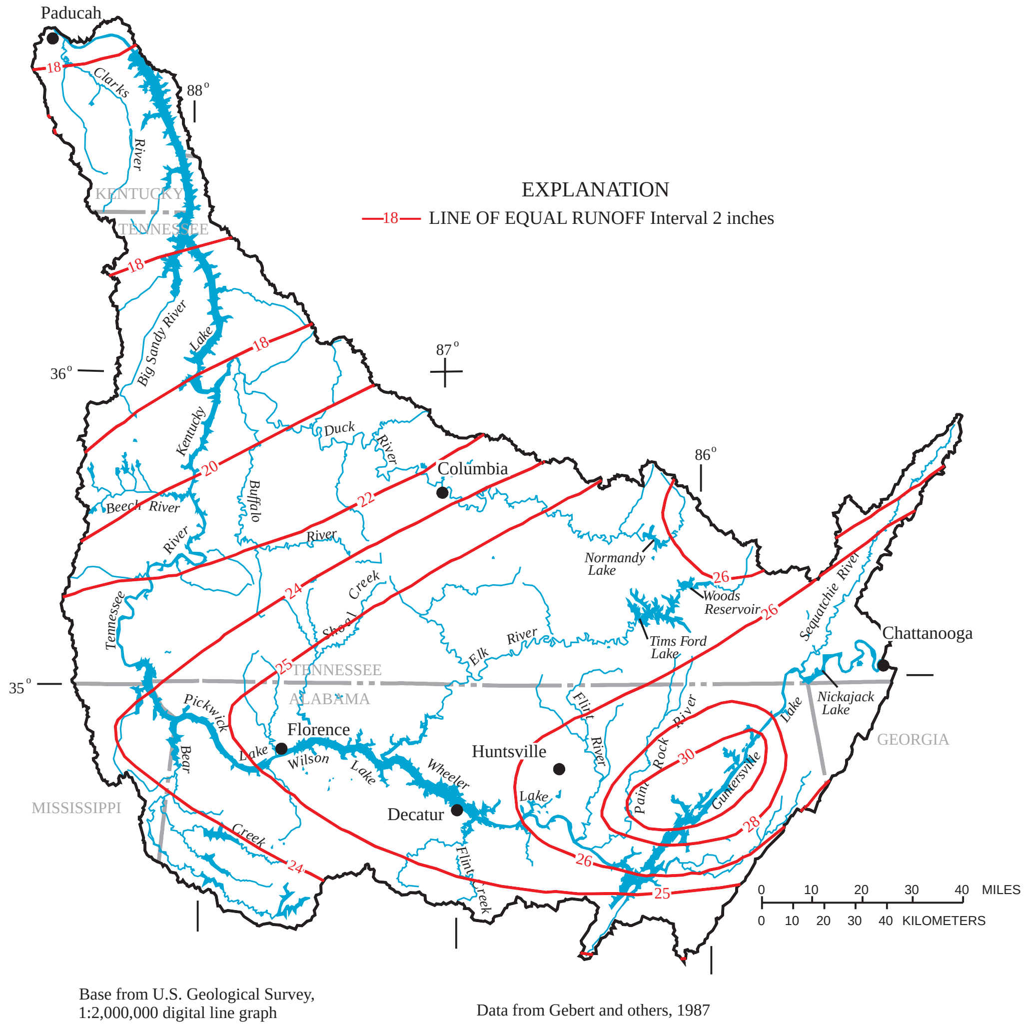


Figure 13. Major drainages and mean-annual surface-water runoff, 1951-80, in the lower Tennessee River Basin.

Basin are described and quantified in the following sections. Inputs of nitrogen, phosphorus, and pesticides were estimated because occurrence and distribution of these constituents are largely influenced by human activities.

Reservoirs

Reservoirs on the main stem of the Tennessee River and its tributaries are used for power generation, navigation, flood control, water supply, and recreation. Wilson Lake (fig. 1), completed in 1924, was the first reservoir constructed on the main stem in the study unit. Four additional reservoirs were completed on the main stem by 1944. Nickajack Lake, completed in 1967, was last reservoir constructed on the main stem in the lower Tennessee River Basin. The Barkley-Kentucky Canal, which is used for navigation and power generation at Kentucky Lake, allows interbasin transfer of water between the lower Tennessee River Basin and the Cumberland River Basin. Interbasin transfer of water also occurs between the Mobile and lower Tennessee River Basins via the Tennessee-Tombigbee Waterway near Pickwick Lake.

Reservoirs affect water quality by acting as sinks for sediment, nutrients, metals, and hydrophobic organic compounds. Reservoirs also affect stream water temperature, dissolved oxygen concentrations, and concentrations of other water-quality constituents. Hydraulic residence time in reservoirs is an important factor in the effect of reservoirs on water quality. The average hydraulic residence time for main stem reservoirs ranges from about 4 to 35 days;

whereas the average residence time of five tributary reservoirs maintained by the Tennessee Valley Authority ranges from about 10 to 500 days (E.A. Thornton, Tennessee Valley Authority, written commun., 1998). These tributary reservoirs are more likely to function as sinks for sediment and nutrients associated with sediment or for aquatic-plant uptake of nutrients because of longer residence times. The storage volume of the six reservoirs on the main stem of the Tennessee River is about 6.7 million acre-ft and the tributaries to the Tennessee River have a total storage volume of about 800,000 acre-ft (E.A. Thornton, Tennessee Valley Authority, written commun., 1998).

Water Use

Total average water use in the lower Tennessee River Basin was about 5,380 million gallons per day (Mgal/d) in 1995 (U.S. Geological Survey, 1997). Thermoelectric use accounted for about 4,700 Mgal/d, and most of this water was returned to streams and reservoirs in the basin. The second largest water-use category was industrial water use, about 380 Mgal/d with about 350 Mgal/d of the total amount withdrawn from surface-water sources (fig. 14). Most of the thermoelectric and much of the industrial surface-water use

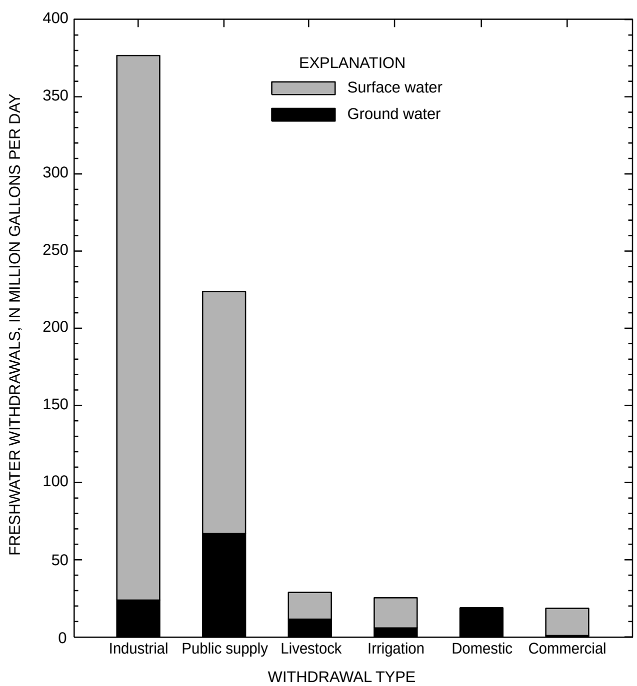


Figure 14. Estimated water use by withdrawal type in the lower Tennessee River Basin, 1995. (U.S. Geological Survey, 1997.)

occurs along the main stem of the Tennessee River. Public supply was the third largest water-use category, about 220 Mgal/d; most of this, about 160 Mgal/d, was withdrawn from surface-water sources. Water used for livestock amounted to about 30 Mgal/d and commercial water use was about 20 Mgal/d; most of the water for these uses was withdrawn from surface-water sources. Domestic, self-supplied water use was about 20 Mgal/d and was exclusively from ground-water sources.

The location and size of public-water supply surface-water withdrawals in the study unit are shown in figure 15a; withdrawal amounts grouped by subunit and water body are shown in figure 15b. The main stem of the Tennessee River supports the largest amount of public water supply (fig. 15b), including the largest surface-water public supply in the study unit, the City of Decatur, Alabama, which withdrew about 28 Mgal/d in 1995. The City of Huntsville, Alabama, withdrew about 22 Mgal/d in 1995 from the Tennessee River. The Duck and Elk Rivers and their tributaries supplied about 50 Mgal/d for public supply. Withdrawals from these streams are shown as mixed Eastern Highland Rim/Nashville Basin in figure 15b, because the drainage areas contributing to the streams at the withdrawal point include parts of both of these subunits. Withdrawals from the other tributaries in the study unit are associated with a single subunit, and accounted for about 46 Mgal/d combined.

The location and size of public-water supply ground-water withdrawals in the study unit are shown in figure 16a; withdrawal amounts of both public-supply and self-supplied domestic use by subunit are shown in figure 16b. Domestic and public supply ground-water use were highest in the Eastern Highland Rim subunit (fig. 16b), where about 40 Mgal/d was withdrawn from the Mississippian aquifers in 1995 (35 Mgal/d for public supply, 5 Mgal/d domestic use). The City of Huntsville, Alabama, located in this subunit, is the largest ground-water public supply in the study unit (fig. 16a); ground water makes up 40 percent of the water used to supply the city’s needs. About 14 Mgal/d was withdrawn from relatively shallow wells (maximum depth 125 ft) and a large spring. About 14 Mgal/d of ground water was withdrawn in both the Western Highland Rim and the Coastal Plain subunits (fig. 16b); domestic water use accounted for about 30 percent of the water used in the Western Highland Rim, but only about 15 percent of the water used in the Coastal Plain. Total ground-water use in each of the remaining subunits was about 5 Mgal/d or less in 1995. Ground-water withdrawals

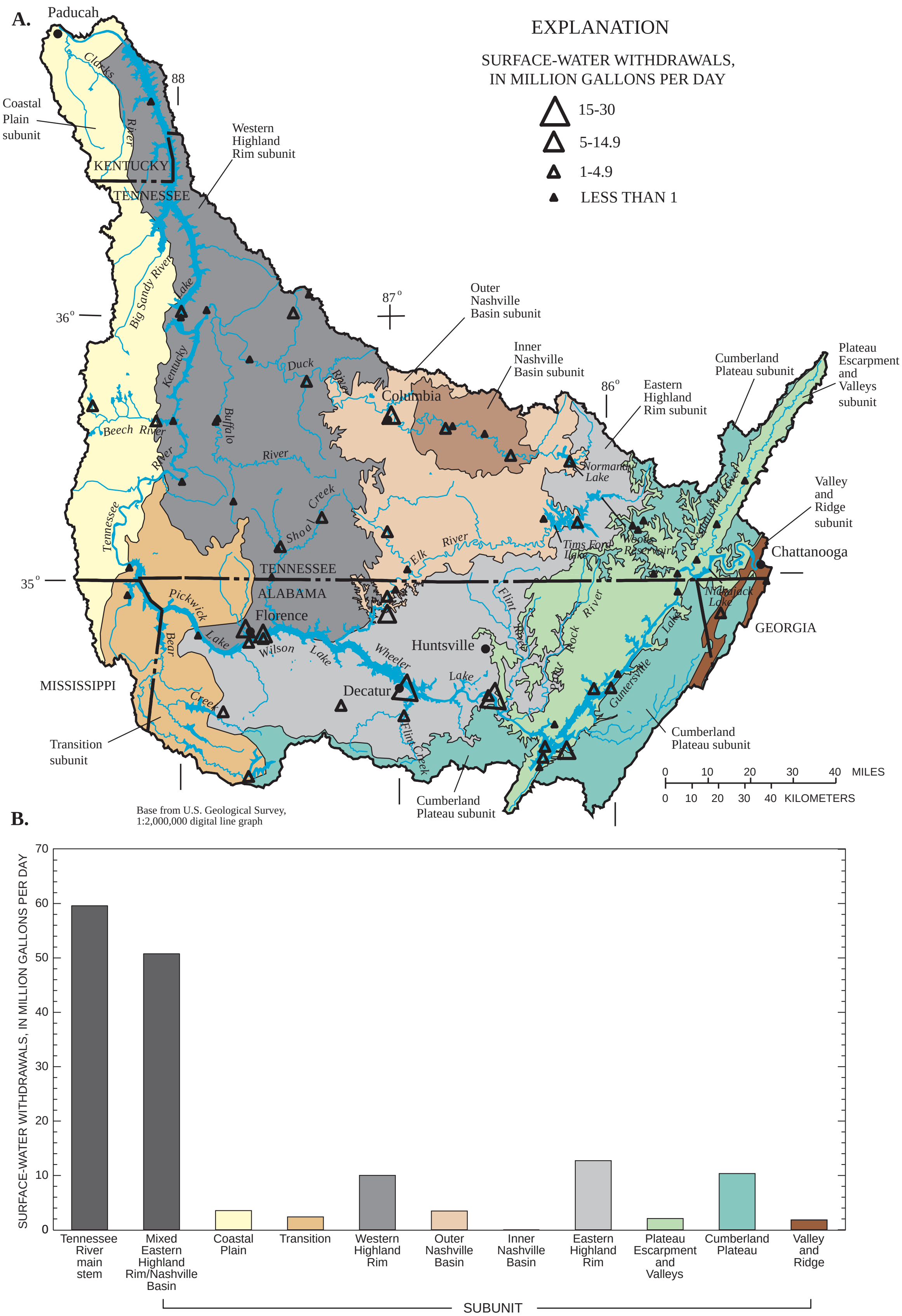


Figure 15. (A) Location and size of public-supply surface-water withdrawals and (B) summary of withdrawals by subunit and water body in the lower Tennessee River Basin, 1995.

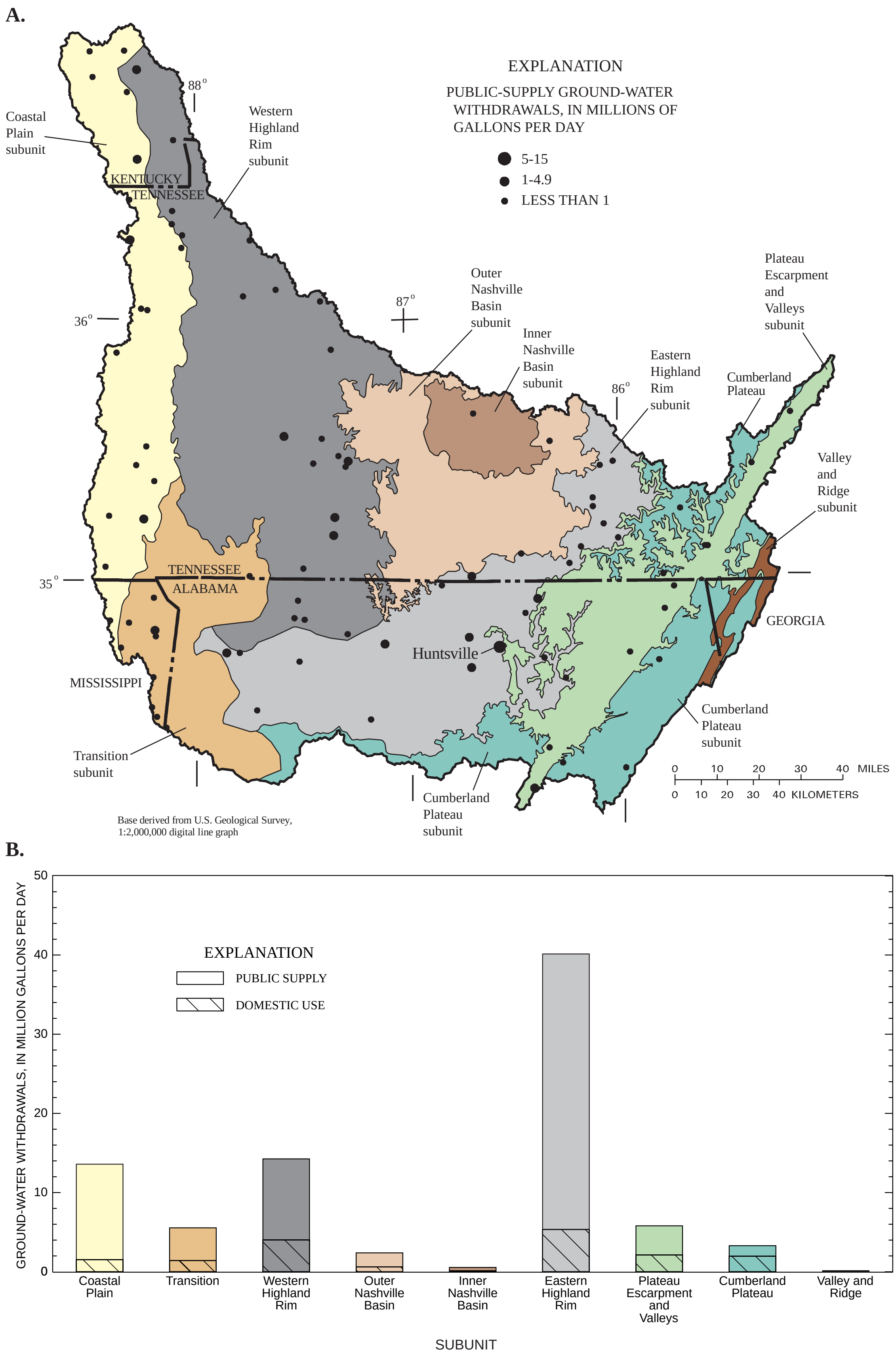


Figure 16. (A) Location and size of public-supply ground-water withdrawals and (B) distribution of public-supply and domestic withdrawals by subunit in the lower Tennessee River Basin, 1995.

may induce recharge or reverse hydraulic gradients, which could have implications for water quality.

Wastewater Discharge

Wastewater and stormwater discharges are the primary point-source discharges to streams and rivers in the lower Tennessee River Basin. Wastewater discharge to streams in the lower Tennessee River Basin were estimated using effluent monitoring data reported to State agencies by permitted wastewater dischargers (J. Hughes, Tennessee Department of Environment and Conservation, written commun., 1998; M. Rief and T. Cleveland, Alabama Department of Environmental Management, written commun., 1998; V. Prather, Kentucky Department of Environmental Protection, written commun., 1998; G. Odom, Mississippi Department of Environmental Quality, written commun., 1998). Mean-daily flow data for 1992 or 1995 were available for 264 permitted dischargers (fig. 17), including all of the dischargers that were classified as major dischargers. In general, a municipal facility discharging more than 1 Mgal/d, or

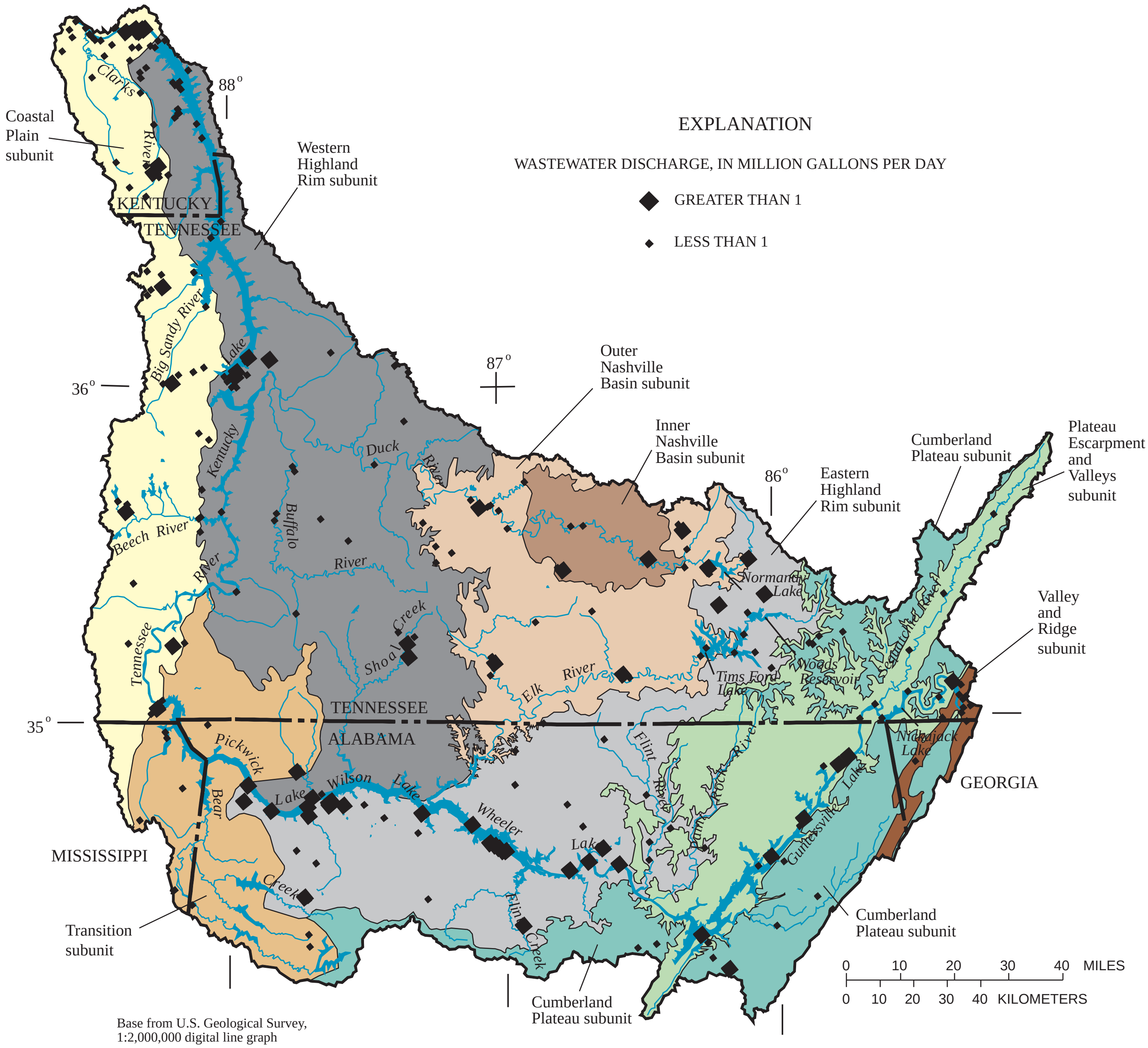


Figure 17. Location of wastewater dischargers, and relative size of discharge, in the lower Tennessee River Basin, 1995.

an industrial facility with specific process wastewater of concern, is considered to be a major discharger; others are classified as minor dischargers. Many additional wastewater dischargers are permitted, but because flow data were not available in digital format, they were not included in this estimate. These discharges represent a small percentage of the total wastewater discharged to streams in the lower Tennessee River Basin (S. Fishel, Tennessee Department of Environment and Conservation, written commun., 1998).

Facilities discharging 1 Mgal/d or more contributed about 90 percent of the 13,396 Mgal/d of wastewater effluent from the 264 dischargers. Most of the discharges (about 13,300 Mgal/d) were to the main stem of the Tennessee River (fig. 17). About 66 Mgal/d of wastewater was discharged to streams in the Elk River Basin and about 17 Mgal/d was discharged to streams in the Duck River Basin. Of the total amount of wastewater discharged, industrial and power generation (federal) facilities accounted for about 99 percent of the total effluent from permitted facilities in the study unit. Much of this water (about 88 percent) was used for cooling at power generation facilities and at manufacturing plants, and the predominant effects on water quality are on water temperature and dissolved oxygen concentrations. Municipal wastewater discharges totaled about 135 Mgal/d, with 21 Mgal/d of that (about 15 percent) discharged to the Elk and Duck River Basins.

Nutrient loads were estimated for the 264 dischargers with flow data in digital format. Generally, concentration data for total nitrogen and phosphorus in effluent were not reported, so average concentration values were used for the various types of treatment facilities (S. Fishel, Tennessee Department of Environment and Conservation, oral commun., 1998; National Oceanic and Atmospheric Administration, 1993). The estimated total nitrogen wastewater load discharged to streams throughout the lower Tennessee River Basin was about 13,430 tons in 1995. About 68 percent of the total nitrogen load was from facilities discharging a mean of 1 Mgal/d or more. Slightly more than half of the total nitrogen load was discharged directly into Wheeler Reservoir on the main stem. About 4 percent of the total nitrogen load was discharged into streams in the Elk and Duck River Basins combined. Although municipal facilities contributed about 1 percent of the flow from wastewater discharges, they contributed about 23 percent of the total nitrogen load in wastewater.

The estimated total phosphorus load from wastewater discharged within the study unit was about 770 tons in 1995. About 40 percent of the phosphorus load was discharged directly into Wheeler Reservoir on the main stem. About 14 percent of the total phosphorus load was discharged into the Elk and Duck River basins. Municipal wastewater effluent contributed about 93 percent of the total phosphorus load in wastewater.

Population, Land Use, and Land Cover

About 1.5 million people (1995) reside in the study unit. Huntsville, Alabama (160,000), Chattanooga, Tennessee (152,000), and Decatur, Alabama (52,000), are the largest urban areas (U.S. Department of Commerce, 1997). Much of the population in the study unit is located in counties along the Tennessee River in northern Alabama (fig. 18), with much of this area lying within the Eastern Highland Rim. About 38 percent of the population is located in the Eastern Highland Rim (table 2), about 14 percent in the Coastal Plain, 14 percent in the Western Highland Rim, and 13 percent is located in the Inner and Outer Nashville Basin combined (table 2). The remaining 20 percent of the total population is distributed across the Plateau Escarpment and Valleys, Cumberland Plateau, Transition, and Valley and Ridge. Between 1980 and 1995 the population in the study unit grew by about 15 percent. The largest increases in population (up to 20 percent) between 1980 and 1995 occurred in the Inner and Outer Nashville Basin and the Eastern Highland Rim.

Land use in the lower Tennessee River Basin largely reflects the geology and physiography of the study unit and the distribution of people (fig. 19). About 51 percent of the study unit is forested land (table 2) based on 1992 land-use data. The amount of forested land by subunit in the lower Tennessee River Basin ranges from about 27 percent in the Eastern Highland Rim to 68 percent in the Plateau Escarpment and Valleys. Forested land is the predominant land cover in six of the nine subunits (table 2), with the largest forested areas located in the Western Highland Rim, Plateau Escarpment and Valleys, and Transition subunits, where topographic relief is the highest. Agricultural land (pasture and cultivated land) accounts for about 40 percent of the land use in the study unit (table 2); agriculture by subunit ranges from 25 percent of the Plateau Escarpment and Valleys to 63 percent of the Inner Nashville Basin (table 2).

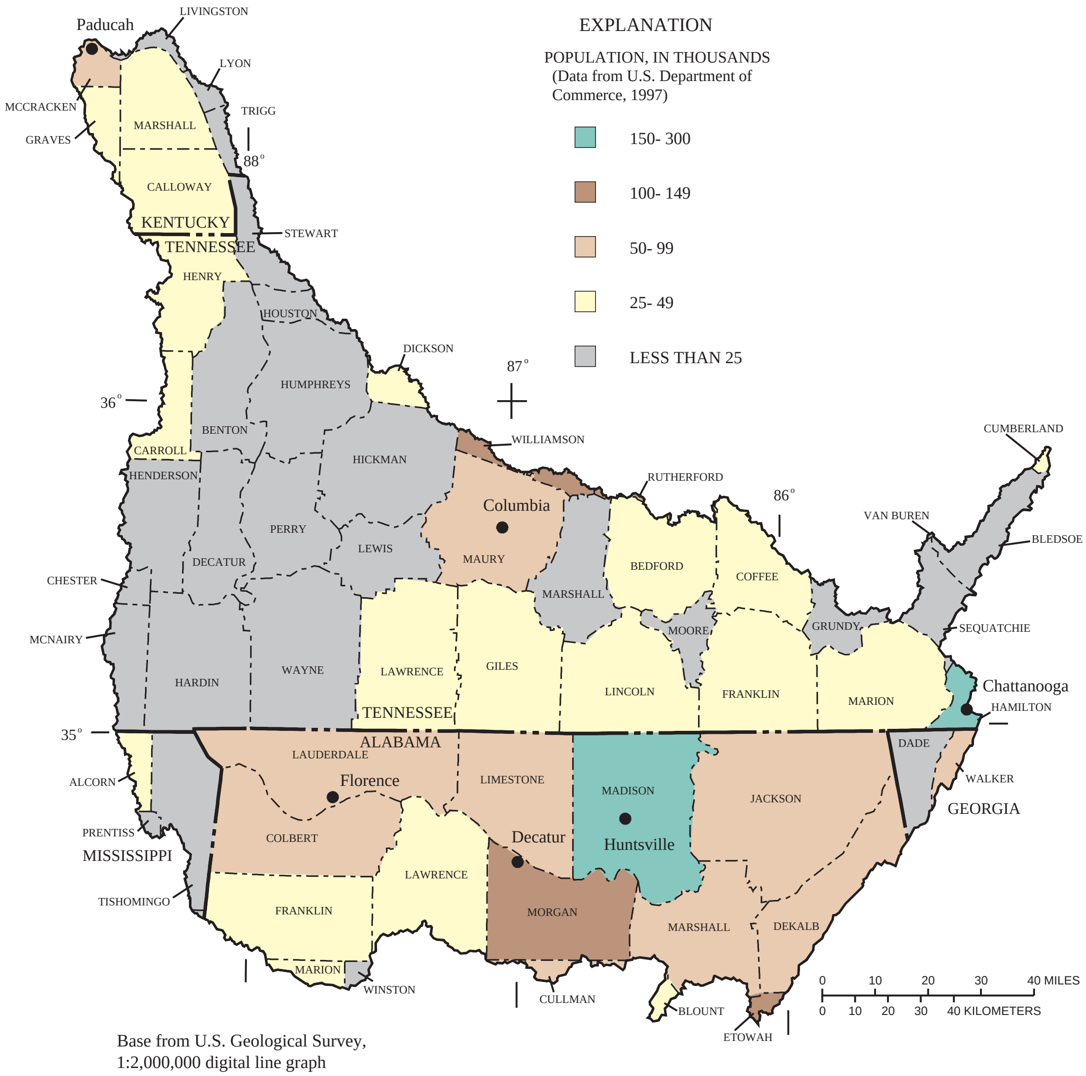


Figure 18. Population in the lower Tennessee River Basin, by county, 1995.

Pasture land accounts for about 72 to 97 percent of all agricultural land throughout the lower Tennessee River basin, and is the predominant land use in the Inner and Outer Nashville Basin and in the Eastern Highland Rim (table 2). Cultivated land generally is located in the Eastern Highland Rim, Cumberland Plateau, Inner Nashville Basin, and Coastal Plain (table 2 and fig. 19) where relief is lowest. The Eastern Highland Rim contains the largest percentage of cultivated land (16 percent) in the study unit (table 2); less than 6 percent of the land in other subunits is cultivated. Urban areas in the lower Tennessee River Basin represent 1 percent or less of the land use in most subunits (table 2) and about 1 percent of the study unit overall. Exceptions are the Valley and Ridge with about 11 percent urban land (the outlying area of Chattanooga, Tennessee), and the Eastern Highland Rim with about 3 percent urban land. The remaining 8 percent of the study unit includes open water and other land uses (mined land and wetlands).

The cultural activities related to land use most likely to have a widespread effect on water quality in the lower Tennessee River Basin are animal and rowcrop agriculture. County-level data for crop production and livestock population from the 1992 Census of Agriculture (U.S. Department of Commerce, 1994) were converted to estimates by subunit through a land-use weighting algorithm. This weighting algorithm apportions the county level data to each subunit based on the portion of cultivated land or pasture land, by county, encompassed within each subunit.This procedure required the assumption that different crop types and livestock were evenly distributed across their respective land use in each county.

Table 2. Summary of land use and population by subunit in the lower Tennessee River Basin, 1992

[Data from Tennessee Valley Authority (Frank Sagona, Tennessee Valley Authority, written commun., 1998). Land cover data were derived spectrally from satellite imagery (from the period 1989-92), and ground truthed using infrared aerial photography. Boundaries for certain land-use classifications (urban and wetland areas) were digitized from topographic maps. Population data from U.S. Department of Commerce, 1997; <, less than]

Subunit	Area, in square miles	Percent of study unit area	Population, in thousands, 1995	Percentage of subunit in major land use category					
				Forest	Culti-vated	Pasture	Urban	Open water	Other
Coastal Plain	2,395	12	220	44	5	41	1	1	8
Transition	1,709	7	36	65	2	24	<1	3	6
Western Highland Rim	5,154	27	207	64	3	25	1	5	2
Outer Nashville Basin	2,093	11	102	41	3	53	1	1	1
Inner Nashville Basin	569	3	93	34	6	57	1	1	1
Eastern Highland Rim	3,423	18	584	27	16	41	3	3	10
Plateau Escarpment and Valleys	1,892	11	123	68	3	22	<1	6	1
Cumberland Plateau	2,173	10	119	57	6	36	<1	1	<1
Valley and Ridge	160	1	33	51	1	34	11	2	1
Lower Tennessee River Basin	19,568	100	1,517	51	6	34	1	3	5

Corn, soybeans, cotton, and wheat were the predominant crops grown in the lower Tennessee River Basin in 1992 (table 3). Corn acreage was the largest of the crop areas in 1992 and accounted for about 34 percent of the total harvested acreage of these crops (U.S. Department of Commerce, 1994). Soybean acreage accounted for about 32 percent, cotton about 23 percent, and wheat about 11 percent of the total harvested acreage of all four crops in 1992.

Harvested acreage for each crop type was normalized by the area of each subunit to illustrate the relative intensity of the agricultural activity by subunit in 1992 (fig. 20). The Eastern Highland Rim and the Coastal Plain ranked highest with respect to the number of cultivated acres per square mile. Cotton was grown primarily in the Eastern Highland Rim and was the largest crop both in total acreage in a subunit (table 3) and acreage per square mile (fig. 20). Corn and soybeans were grown in all of the subunits. The Coastal Plain, Eastern Highland Rim, and Inner Nashville Basin ranked highest in farming intensity for corn and soybeans and also supported the greatest amount of harvested acreage of wheat per square mile.

County-level 1992 livestock population data were used to estimate the number of livestock by subunit (table 3). These data also were normalized by the area of each subunit to illustrate the relative intensity of livestock production by subunit (fig. 21). About 42 million chickens, 0.9 million cattle, and 0.3 million hogs were raised in the study unit in 1992 (table 3). The Cumberland Plateau ranked highest with respect to the number of head per square mile (fig. 21). Chicken production was the largest livestock activity in the Cumberland Plateau, which supported about 8,000 chickens per square mile. The Valley and Ridge, Eastern Highland Rim, Inner Nashville Basin, and Plateau Escarpment and Valleys supported more than 2,000 chickens per square mile. The Inner and Outer Nashville Basin ranked first and second in cattle production and supported more than twice as many cows per square mile as did the remaining subunits. The Coastal Plain ranked first in hog production, with about twice as many hogs per square mile as the second highest-ranking subunit.

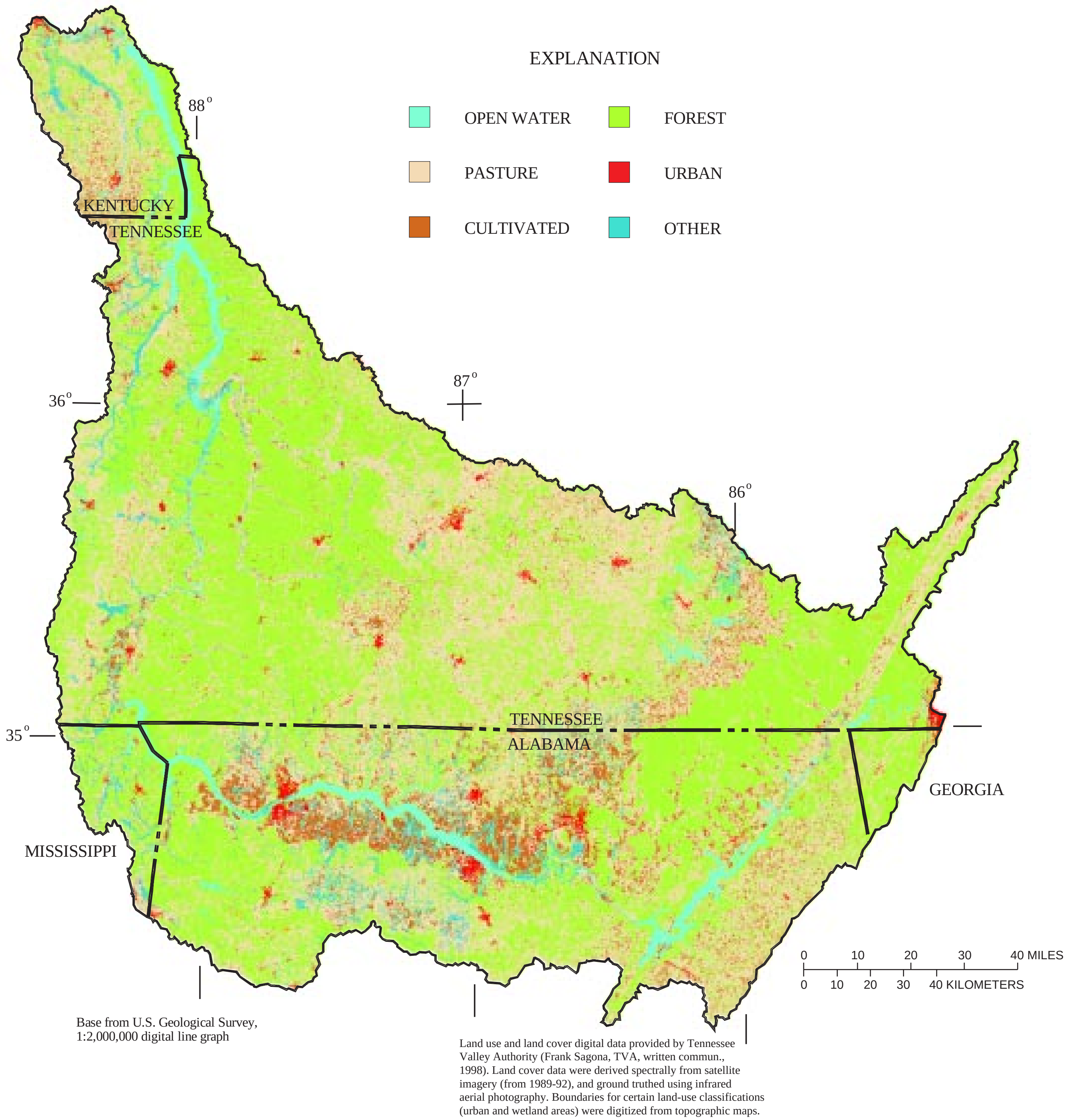


Figure 19. Land use in the lower Tennessee River Basin.

Table 3. Estimated crop production and livestock population by subunit in the lower Tennessee River Basin, 1992

[Crops in acres harvested; livestock in number of animals. Estimates based on 1992 Census of Agriculture (U.S. Department of Commerce, 1994)]

Subunit	Corn	Soybeans	Cotton	Wheat	Chickens	Cattle	Hogs
Coastal Plain	93,900	80,000	4,900	29,500	1,210,000	78,400	89,100
Transition	11,400	24,600	14,500	4,400	2,750,000	46,500	12,100
Western Highland Rim	61,300	30,600	26,800	13,600	811,000	175,000	69,900
Outer Nashville Basin	19,600	18,200	4,000	8,000	1,840,000	219,000	36,600
Inner Nashville Basin	12,300	9,700	10	6,500	1,740,000	63,200	9,700
Eastern Highland Rim	73,400	96,600	164,000	34,200	10,900,000	193,000	48,300
Plateau Escarpment and Valleys	19,200	22,400	540	3,400	4,990,000	55,000	17,700
Cumberland Plateau	27,700	22,600	4,500	2,900	17,300,000	99,000	40,400
Valley and Ridge	980	670	20	260	865,000	7,000	2,400
Lower Tennessee River Basin	319,780	305,370	219,270	102,760	42,406,000	936,100	326,200

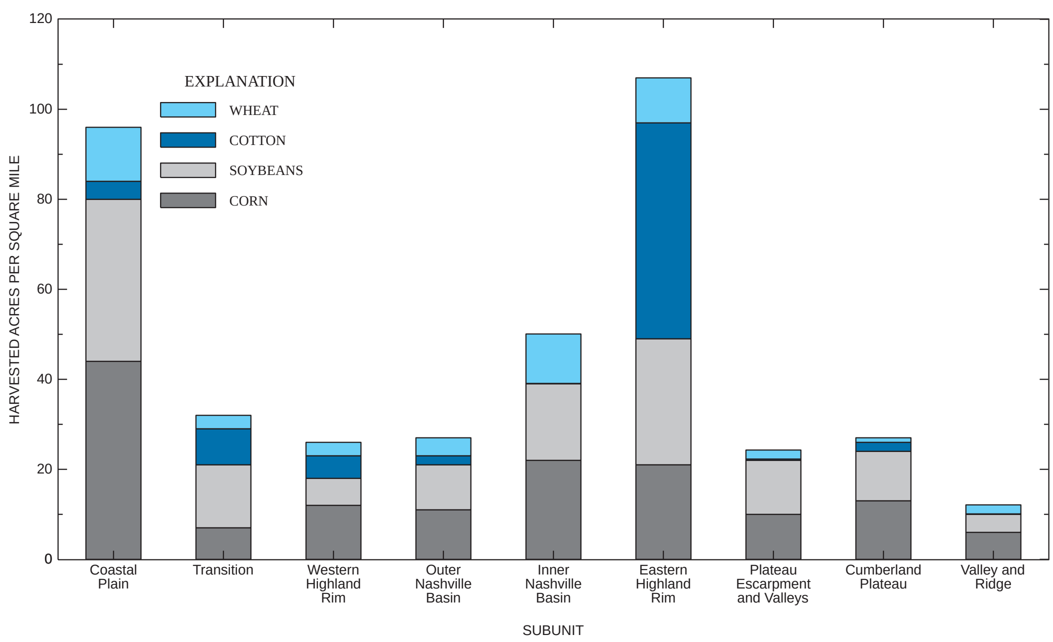


Figure 20. Distribution of predominant crops by subunit in the lower Tennessee River Basin, 1992. (Estimates based on 1992 Census of Agriculture, U.S. Department of Commerce, 1994.)

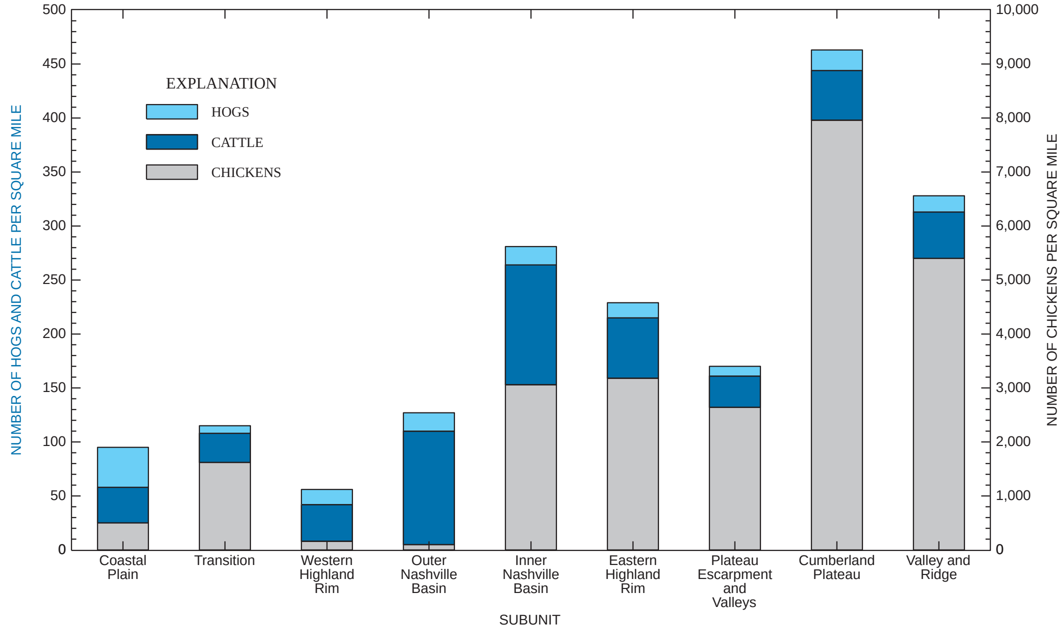


Figure 21. Distribution of predominant livestock by subunit in the lower Tennessee River Basin, 1992. (Estimates based on 1992 Census of Agriculture, U.S. Department of Commerce, 1994.)

Nonpoint-Source Nutrient Inputs

Nonpoint sources of the nutrients nitrogen and phosphorus include urban runoff, fertilizer application, failing septic tanks, livestock waste, nitrogen fixation, sediment and rock dissolution, and atmospheric deposition. Nutrient inputs to the study unit from atmospheric deposition, fertilizer application, livestock waste, and nitrogen fixation (from soybean crops) were estimated by subunit for 1992. The contribution of nutrients from failing septic tanks, urban runoff, and dissolution of rocks could not be estimated from available data.

Estimates of total nitrogen inputs from precipitation were derived from deposition rates for total nitrogen from five stations in the National Atmospheric Deposition Program/National Trends Network, a national network of precipitation chemistry monitoring stations operated in cooperation between State agricultural experiment stations, the U.S. Geological Survey, U.S. Department of Agriculture, and other governmental and private entities. Nitrogen deposition rates for subunits were estimated by calculating a weighted average deposition rate in 1992 from the five stations, based on their distance from the centroid of each subunit, and were multiplied by the subunit area to compute a total nitrogen input. Because phosphorus concentrations in precipitation generally are below the reporting level of the analytical method, atmospheric deposition is not expected to be a significant source of phosphorus (M.A. Nilles, U.S. Geological Survey, written commun., 1999); however, atmospheric deposition may contribute significant amounts of phosphorus in some regions (Harned, 1995).

Nitrogen and phosphorus inputs related to agricultural activities include fertilizer application, livestock waste, and nitrogen fixation. Estimates of inputs from fertilizer application were based on county sales data for 1991 and agricultural census data for 1987. The sources for these data and the methods of calculating county estimates are described in detail in Battaglin and Goolsby (1995). Estimates of inputs from livestock waste are based on the 1992 Census of Agriculture and estimates of nutrient content of livestock waste (U.S. Department of Commerce, 1994). Nitrogen fixation estimates were based on 1992 harvested acreage of soybeans, multiplied by a rate for nitrogen fixation (Craig and Kuenzler, 1983; U.S. Department of Commerce, 1994). County-level estimates of nutrient inputs from agricultural activities were converted to subunit-level estimates by weighting the area of cultivated and pasture land in a county and in each subunit.

Estimated nitrogen inputs to the study unit from nonpoint sources were about 195,000 tons (table 4). The nitrogen input to the study unit from agricultural activities (fertilizer, livestock waste, and nitrogen fixation) was about 161,000 tons in 1992. Atmospheric deposition of nitrogen totalled about 34,100 tons in 1992 (table 4) and contributed about 18 percent of the nitrogen input. Most of that input was contributed by livestock waste and fertilizer application; nitrogen fixation by soybeans accounted for about 8 percent of the nitrogen input. Although much of the nitrogen input from agricultural activities is taken up by crops and removed by harvest, some of this input may affect water quality, where inputs greatly exceed crop uptake.

The magnitude of nonpoint-source inputs varies across the lower Tennessee River Basin. The distribution of nitrogen input by subunit is shown, on a per unit area basis, in figure 22. The Eastern Highland Rim had the largest nitrogen input in the study unit (table 4) and also had the highest nitrogen input per unit area (fig. 22). Unit-area nitrogen inputs from livestock waste were the largest nonpoint source of nitrogen in the Cumberland Plateau, the Inner and Outer Nashville Basin, and the Valley and Ridge, and accounted for at least a quarter of the nitrogen input for all subunits. Unit-area nitrogen inputs from fertilizer application were the largest nonpoint source of nitrogen in the Eastern Highland Rim and Coastal Plain. Unit-area nitrogen inputs from atmospheric deposition were about the same for all subunits. In the Transition, Western Highland Rim, and Plateau Escarpment and Valleys, however, atmospheric deposition accounted for about 25 percent of the nitrogen

Table 4. Estimated total nitrogen and phosphorus inputs from nonpoint sources by subunit in the lower Tennessee River Basin, 1992

[Values in tons per year. Inputs for livestock are based on 1992 Census of Agriculture (U.S. Department of Commerce, 1994)]

Subunit	Area, in square miles	Nitrogen					Phosphorus		
		Atmospheric deposition	Fertilizer	Livestock waste	Nitrogen fixation	Total nitrogen input	Fertilizer	Livestock waste	Total phosphorus input
Coastal Plain	2,395	3,800	12,000	6,200	4,200	26,200	2,800	2,200	5,000
Transition	1,709	2,900	3,900	4,000	1,300	12,100	600	1,200	1,800
Western Highland Rim	5,154	8,900	12,000	10,000	1,600	32,500	2,700	3,300	6,000
Outer Nashville Basin	2,093	3,800	4,900	12,000	1,000	21,700	1,200	3,600	4,800
Inner Nashville Basin	569	1,000	2,900	4,200	500	8,600	700	1,200	1,900
Eastern Highland Rim	3,423	6,200	25,000	16,000	5,100	52,300	4,700	4,900	9,600
Plateau Escarpment and Valleys	1,892	3,900	3,200	5,700	1,200	14,000	600	1,800	2,400
Cumberland Plateau	2,173	3,300	5,900	16,000	1,300	26,500	1,000	5,000	6,000
Valley and Ridge	160	300	400	900	40	1,640	100	300	400
Lower Tennessee River Basin (total)	19,568	34,100	70,200	75,000	16,240	195,540	14,400	23,500	37,900

input from nonpoint sources (fig. 22) because inputs from other sources are relatively low. Nitrogen fixation contributed the smallest amount of nitrogen in all subunits, but accounted for as much as about 16 percent of the nitrogen input in the Coastal Plain.

Inputs of phosphorus from livestock waste also were larger on a per unit area basis than inputs from fertilizer application for each subunit except the Eastern Highland Rim and Coastal Plain, where phosphorus input from fertilizer application was about the same or slightly more than from animal waste (fig. 22). About 23,500 tons of phosphorus were contributed by livestock waste and 14,500 tons of phosphorus by fertilizer application to the study unit in 1992 (table 4).

Pesticide Use

Pesticide use has increased tenfold since 1975, with 75 percent of the pesticide use related to agricultural production (Ware, 1989). Pesticides have become an important crop management tool for controlling insects, weeds, fungi, and bacteria, and their use has significantly increased crop production. Despite the increases in agricultural productivity and the associated economic benefits, a general concern exists about dispersing large quantities of these substances, which are designed to be toxic, into the environment.

The fate of pesticides in the environment is influenced by the method of application, physical and chemical properties of each pesticide, and many environmental factors. Pesticides are designed to degrade

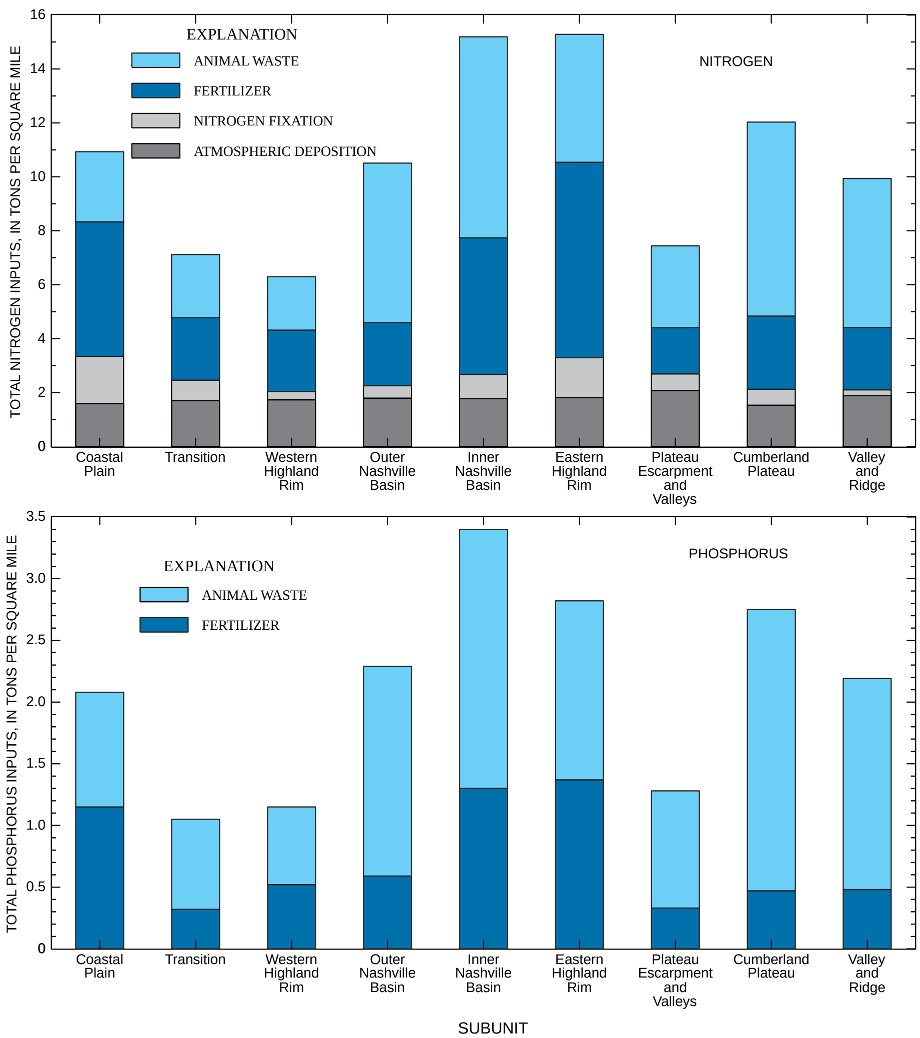


Figure 22. Estimated unit area total nitrogen and phosphorus inputs from nonpoint sources by subunit in the lower Tennessee River Basin, 1992. (U.S. Department of Commerce, 1994.)

in a few days or weeks after application under ideal conditions. Movement of pesticides into ground-water or surface-water systems may reduce the rate at which pesticides degrade. Degradation products of pesticides can behave quite differently than parent compounds and may be more persistent or mobile in the environment.

Use of pesticides (herbicides, insecticides, and other pesticides) was estimated for each subunit to identify the primary compounds used, and the areal distribution of use in the lower Tennessee River Basin. For the purpose of this report, organic compounds used in crop production such as growth inhibitors and defoliants, are referred to as other pesticides. Estimates of pesticide use are based on reported harvested acreage of crops (U.S. Department of Commerce, 1994) and statewide application rates for a given compound (Gianessi and Anderson, 1995). These estimates, therefore, do not account for municipal and private use of pesticides or where local farming practices differ from general practices in the State.

About 3.7 million pounds of pesticides (active ingredient) was used in the lower Tennessee River Basin in 1992. Herbicides accounted for about two-thirds of total pesticide use (table 5). Eleven herbicides were used in amounts exceeding 100,000 pounds (table 5). Atrazine, a herbicide used primarily for corn production, was used in the largest amounts; followed by monosodium methanearsonate (MSMA), used primarily on cotton; 2,4-D used on corn and pasture land; and metalochlor used on corn and soybeans. Insecticide use in 1992 totalled about 0.9 million pounds (table 5) and accounted for about a quarter of the total pesticide use. Methyl parathion was used in the largest amounts, and was primarily applied to cotton. Thiodicarb, 1,3 dichloropropene, and aldicarb followed methyl parathion in amount used in 1992 and also were used primarily on cotton. Compounds termed other pesticides in table 5 include plant growth regulators (mancozeb and ethephon), defoliants (tribufos), fumigants (methyl bromide), and fungicides (sulfur). Methyl bromide was used in the largest amounts, primarily as a soil fumigant for tomato and tobacco cultivation. Tribufos and ethephon were used primarily on cotton and followed methyl bromide in 1992 estimated use (table 5).

Almost half of the total pesticides used in 1992 were applied to cropland in the Eastern Highland Rim, which had the largest unit-area pesticide use of all subunits, about 540 lb/mi^2 (table 5). Insecticide use in the Eastern Highland Rim represented 69 percent of the total insecticide use for the study unit and herbicide use there represented about 40 percent of the total. The majority of the insecticide used in the study unit was for cotton, which was primarily grown in the Eastern Highland Rim. Estimates of unit-area pesticide use for the Coastal Plain and Inner Nashville Basin were ranked second and third among the subunits; these ranks generally correlate with the relative percentage of cultivated land in each subunit (table 2).

WATER-QUALITY ISSUES

Increases in population, water use, and urban and agricultural land development affect the quality of surface- and ground-water resources in parts of the lower Tennessee River Basin. State water-quality agencies have identified 109 stream segments and 3 lakes in the study unit that are water-quality impaired with respect to their designated use (Alabama Department of Environmental Management, 1996; Georgia Department of Natural Resources, 1996; Kentucky Natural Resources and Environmental Protection Cabinet, 1996; Mississippi Department of Environmental Quality, 1996; Tennessee Department of Environment and Conservation, 1996). The primary nonpoint sources affecting surface-water quality cited by these agencies were agricultural and urban runoff. In order of frequency of citation, the predominant causes of impairment resulting from nonpoint sources were siltation, organic enrichment and dissolved-oxygen depletion, nutrient enrichment, and pathogens. The primary point sources affecting surface-water quality cited by these agencies were industrial and municipal discharges. In order of frequency of citation, causes for impairment from point sources were pathogens, organic enrichment and dissolved-oxygen depletion, ammonia, and siltation.

These State agencies also have documented contamination of ground water from both nonpoint and point sources. Ground-water studies conducted in the study unit have documented shallow ground-water contamination by pesticides, nutrients, and bacteria from nonpoint sources (Alabama Department of Environmental Management, 1996; Tennessee Department of Environment and Conservation, 1996). Carbonate rock aquifers are common in the study unit and have a high potential to be affected by nonpoint sources. Point sources affecting ground-water quality included underground storage tanks, landfills, and contamination from industrial sites. Volatile organic compounds were the constituents most often associated with point-source contamination of ground-water aquifers.

The changes in water quality as a result of contamination from these sources can affect both human health and the health of aquatic ecosystems. Excessive nitrate concentrations (greater than 10 mg/L as N) in untreated, domestic drinking water can pose a health risk to infants by causing methemoglobinemia, or blue baby syndrome. Nutrient enrichment in surface-water bodies may produce algal blooms that cause taste and odor problems in drinking water. Excessive growth of algae and aquatic macrophytes also can deplete dissolved oxygen in streams and reservoirs, adversely affecting fish and other aquatic life. Degradation of water quality and destruction of instream and riparian habitat threatens freshwater mussels and fish in streams in the study unit. For example, the Muscle Shoals area, near Florence, Alabama, once had one of the most diverse assemblages of mussels in the world. Many species have become extinct and several of the remaining species are now endangered or threatened. Pesticides and other organics can be toxic to aquatic invertebrates and fish or may accumulate in fish tissue and sediment. Six fish consumption advisories have been issued for streams and reservoirs in the study unit. These advisories include DDT in fish in Indian Creek, polychlorinated biphenols (PCB's) in fish in Woods Reservoir and Nickajack Lake, and chlordane in fish in Nickajack Lake (Alabama Department of Environmental Management, 1996; Tennessee Department of Environment and Conservation, 1996).

Selected Water-Quality Data

Data for nutrients and bacteria in surface and ground water collected between 1980 and 1996 and available in digital format were summarized by subunit to characterize the water quality of the subunits for constituents that represent major water-quality issues in the study unit. Nutrients and bacteria were selected because these constituents were cited as affecting both surface- and ground-water quality. The U.S. Environmental Protection Agency's STOrage and RETrieval (STORET) data base and the U.S. Geological Survey water-quality data base WATer STOrage and REtrieval system (WATSTORE) were the primary sources for both surface- and ground-water-quality data. Additional data from local ground-water studies conducted by State agencies were included in the data set. Data retrieved from STORET and WATSTORE were screened to select ambient data. Median values were used in this data summary for sites with multiple samples. Data likely to be affected by point sources were excluded from the data set. Only surface-water-quality sites with drainage areas contained within a single subunit were included in this data summary. Ground-water-quality data were limited to sites that represented the shallow ground-water flow system. In most of the subunits, wells with depths less than 300 ft were selected, but in the Coastal Plain and Transition, wells less than 200 ft deep were selected.

Data from STORET and WATSTORE were combined to improve the spatial distribution of sites in each subunit. Combining the data bases resulted in a total of about 520 surface-water sites with water-quality data for at least one of the nutrients (nitrogen and phosphorus) and about 360 surface-water sites with data for fecal coliform occurrence. The distribution of surface-water sites was similar for STORET and WATSTORE, though the total number of sites was considerably higher in STORET (fig. 23). Most subunits had 40 or more surface-water sites with data for nutrients and 30 or more sites with data for fecal coliform. The Eastern Highland Rim had the most surface-water-quality sites. The Inner Nashville Basin and the Valley and Ridge, the smallest subunits, had the fewest number of sites with data for both nutrients and bacteria.

Ground-water data from the two data bases were unevenly distributed across the study unit (fig. 23). Combining data from STORET and WATSTORE and the local ground-water studies yielded about 1,240 wells and springs with data for at least one nutrient. Much of the available ground-water data for nutrients were collected in the Eastern Highland Rim as part of a study by the Alabama Department of Environmental Management, in which about 400 shallow wells located in agricultural areas in four counties in northern Alabama were sampled twice for nitrate and four pesticides (E. Bittner, Alabama Department of Environmental Management, written commun., 1997). About 490 ground-water sites had data for fecal coliform.

Nutrients in Surface and Ground Water

Nutrient enrichment was cited as the cause of impairment for 37 of the 109 impaired stream segments and was identified as an important issue for ground-water quality in the lower Tennessee River Basin (Alabama Department of Environmental Management, 1996; Georgia Department of Natural

Table 5. Estimated use of selected pesticides by subunit in the lower Tennessee River Basin, 1992

[Values in pounds of active ingredient applied rounded to the nearest hundred pound. Estimated use calculated using application rates from Gianessi and Anderson, 1995, and crop acreages from 1992 Agricultural Census, U.S. Department of Commerce, 1994]

	Coastal Plain	Transition	Western Highland Rim	Outer Nashville Basin	Inner Nashville Basin	Eastern Highland Rim	Plateau and Escarpment Valleys	Cumberland Plateau	Valley and Ridge	Total use
Herbicides										
2,4-D	22,500	26,000	39,500	26,800	9,900	85,900	20,800	43,100	3,100	277,700
Acifluorfen	3,000	3,300	1,600	1,000	600	8,100	1,900	2,100	<100	21,700
Alachlor	37,300	6,900	22,000	9,800	6,600	36,800	8,100	8,500	300	136,400
Atrazine	125,300	13,600	84,100	33,500	24,000	101,300	24,200	31,700	1,300	439,000
Bentazon	4,500	2,300	2,100	1,500	800	7,800	1,800	1,800	100	22,600
Butylate	50,900	3,500	23,600	7,100	5,100	23,600	6,100	8,600	300	128,700
Cyanazine	17,400	6,300	18,300	18,300	3,300	58,100	1,400	1,600	100	124,700
DSMA	500	3,900	7,300	900	<100	48,100	100	1,300	<100	62,200
Fluometuron	3,600	10,400	17,400	2,700	<100	105,600	400	2,900	<100	142,900
Glyphosate	32,700	4,900	14,400	7,500	4,300	27,900	4,800	5,100	300	101,800
Metolachlor	75,700	7,200	34,900	14,700	9,600	37,100	7,600	6,700	300	193,700
MSMA	3,000	18,600	37,300	4,600	<100	242,400	800	6,700	<100	313,400
Norflurazon	300	4,800	9,900	1,100	<100	65,800	200	1,800	<100	84,000
Paraquat	8,000	1,900	4,900	2,100	1,200	11,400	1,200	1,100	<100	31,800
Pendimethalin	11,400	10,700	12,100	3,900	1,500	66,200	5,000	6,800	100	117,700
Simazine	20,000	700	14,200	6,100	4,500	12,000	1,900	900	100	60,300
Trifluralin	15,900	11,400	14,300	4,100	1,500	78,100	7,200	9,500	200	142,300
Total herbicide use	432,000	136,400	357,900	145,700	72,900	1,016,200	93,500	140,200	6,200	2,400,900
Insecticides										
1,3 Dichloropropene	<100	3,500	9,000	4,400	<100	64,700	200	1,700	<100	83,400
Acephate	5,800	4,200	7,800	2,800	1,000	37,800	800	1,800	<100	61,900
Aldicarb	1,700	4,700	9,600	1,400	<100	58,700	200	1,600	<100	78,100
Carbaryl	2,500	1,400	1,500	800	500	3,300	2,200	1,500	100	13,900
Carbofuran	5,900	1,600	4,500	1,600	1,000	10,200	3,500	6,300	200	34,800
Chlorpyrifos	10,100	1,300	9,700	4,600	3,100	13,100	1,200	800	100	43,900
Dicrotophos	1,100	1,800	3,300	600	<100	18,700	100	500	<100	26,100
Disulfoton	700	2,200	4,900	700	<100	30,500	200	900	<100	40,000
Ethyl parathion	<100	300	400	0	<100	2,300	900	1,900	100	5,800
Malathion	1,200	3,800	7,500	1,100	300	48,400	200	1,400	<100	63,900

Table 5. Estimated use of selected pesticides by subunit in the lower Tennessee River Basin, 1992—Continued

	Coastal Plain	Transition	Western Highland Rim	Outer Nashville Basin	Inner Nashville Basin	Eastern Highland Rim	Plateau and Escarpment Valleys	Cumberland Plateau	Valley and Ridge	Total use
Insecticides—Continued										
Methyl parathion	1,700	17,000	20,100	2,300	100	134,300	1,300	5,400	100	182,200
PCNB	1,000	4,500	7,800	1,000	<100	49,300	200	1,400	<100	65,200
Profenofos	600	5,700	7,200	800	<100	47,900	100	1,300	<100	63,800
Thiodicarb	700	5,900	11,700	1,400	<100	77,300	300	2,200	<100	99,500
Total insecticide use	33,000	57,900	105,000	23,500	6,000	596,500	11,400	28,700	600	862,500
Other Pesticides										
Chloropicrin	1,400	<100	1,200	1,100	500	900	3,600	700	<100	9,500
Ethephon	1,300	5,100	9,700	1,600	200	60,600	200	1,700	<100	80,300
Mancozeb	4,200	800	2,600	1,700	1,000	5,400	5,300	10,800	700	32,600
Methyl Bromide	13,500	3,000	12,300	11,000	5,100	14,200	24,000	33,000	1,400	117,500
Sodium chlorate	300	5,200	8,300	900	<100	55,700	200	1,600	<100	72,200
Sulfur	1,300	1,800	1,200	1,300	100	26,200	3,600	5,900	300	41,600
Tribufos	1,100	7,100	11,600	1,400	<100	75,000	200	2,100	<100	98,500
Total other pesticide use	23,100	23,000	46,900	19,000	6,900	238,000	37,100	55,800	2,400	452,200
Total pesticide use	488,100	217,300	509,800	188,200	85,800	1,850,700	142,000	224,700	9,200	3,715,600
Total pesticide use per square mile	204	127	99	90	151	541	75	103	58	

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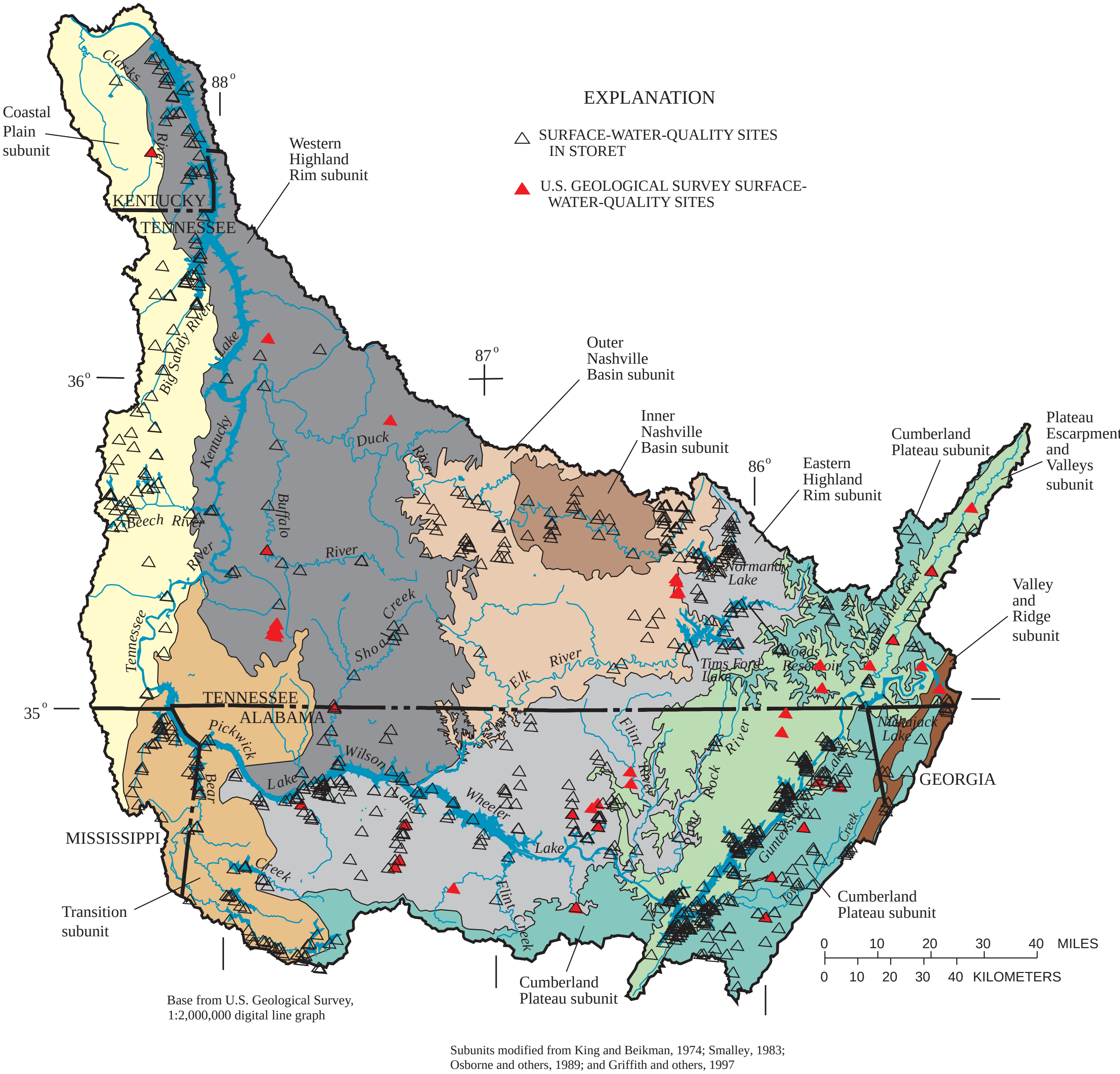

Figure 23. Location of (A) surface-water-quality sites and (B) ground-water-quality sites that have data for nutrients in STORET or WATSTORE, 1980-96.

B.

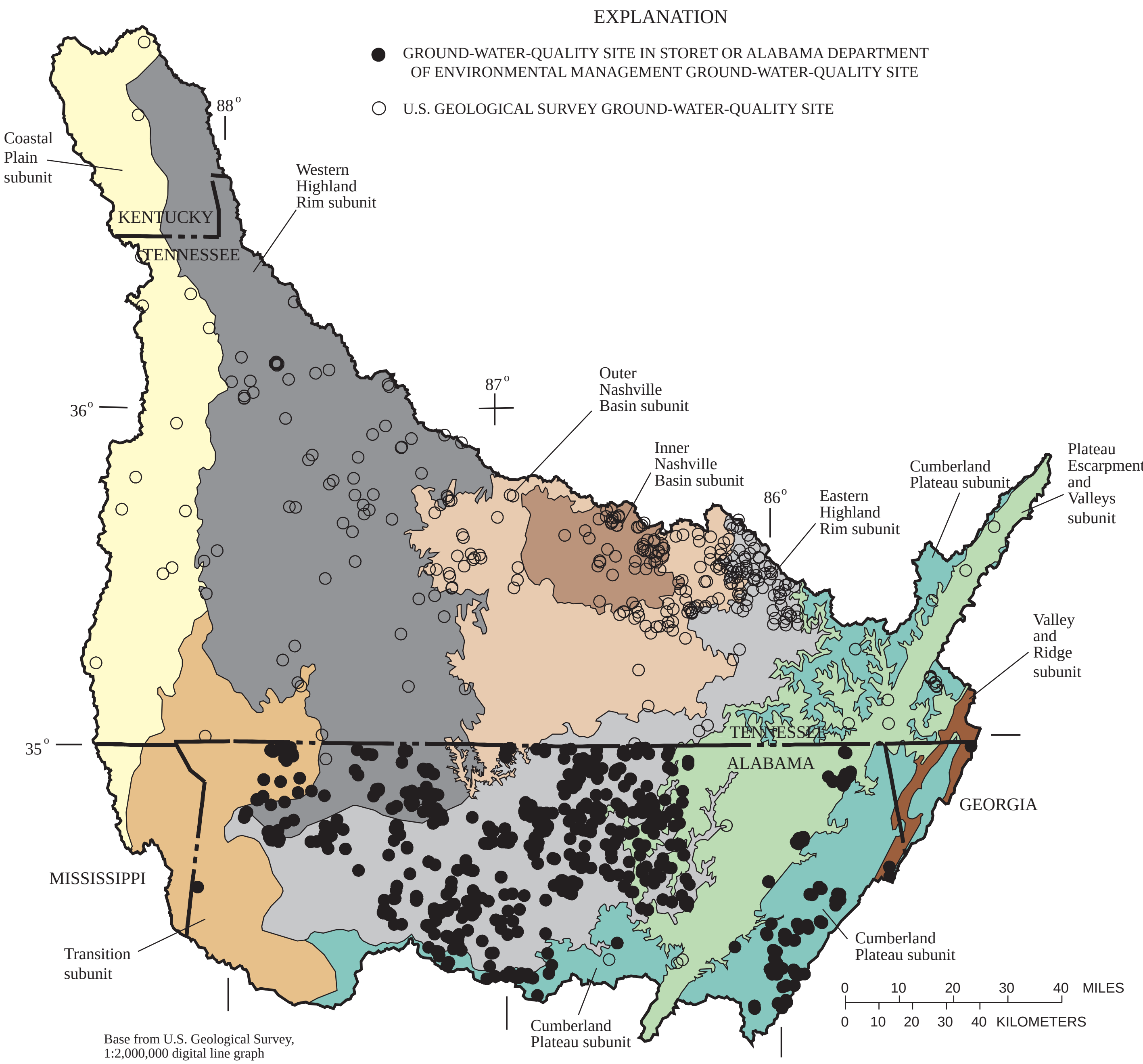

Figure 23. Location of (A) surface-water-quality sites and (B) ground-water-quality sites that have data for nutrients in STORET or WATSTORE, 1980-96—Continued.

Resources, 1996; Kentucky Natural Resources and Environmental Protection Cabinet, 1996; Mississippi Department of Environmental Quality, 1996; Tennessee Department of Environment and Conservation, 1996). Nutrients were the most commonly analyzed water-quality constituents in surface and ground water in the lower Tennessee River Basin during 1980-96. Nitrogen can be found in surface and ground water in several oxidation states. In its reduced valence states, nitrogen is found primarily as ammonia, ammonium, and organic compounds; in its oxidized valence state, nitrogen is found primarily as nitrate and nitrite. Phosphorus also can occur in several oxidation states, but in natural waters the fully oxidized species (phosphate) is most common, but phosphorus also can be found in organic compounds. Phosphorus in its oxidized state has a low solubility and is often associated with sediment or other particulate material.

Given the various forms that nitrogen and phosphorus can be found in natural waters and the fact that data were collected for different objectives, available nutrient data were stored under a mix of different parameter codes. To obtain adequate spatial coverage across the study unit, data stored with different nutrient parameter codes were combined. For example, data for nitrate and nitrite were commonly reported as nitrite-plus-nitrate, nitrite, or nitrate in both dissolved (filtered) or total concentrations (unfiltered). Generally, nitrite concentrations are small compared to those of nitrate in oxic waters (including shallow ground water), and the concentrations of nitrite and nitrate associated with sediment and particulate material also are small. Therefore, nitrite-plus-nitrate and nitrate, filtered and unfiltered, were combined as an estimate of nitrate-nitrogen, when data for only one of these constituents were available. Ammonia and organic nitrogen were summed as an alternate to total Kjeldahl nitrogen (total ammonia and organic nitrogen) where total Kjeldahl nitrogen was not reported. If more than one minimum reporting level was present in the data, the highest minimum reporting level was applied to all of the data.

Nitrate-nitrogen was the most commonly reported nutrient species in both surface- and ground-water samples between 1980 and 1996. Median concentrations of nitrate in surface water in each subunit were less than 1 mg/L (fig. 24). Median concentrations (0.6 to 0.8 mg/L) were higher in the Outer and Inner Nashville Basins, Eastern Highland Rim, and Cumberland Plateau, than in the remaining subunits (less than 0.3 mg/L). Median concentrations of nitrate in ground water in most subunits were less than 1 mg/L, but were greater than 1 mg/L in samples collected in the Eastern Highland Rim and the Cumberland Plateau (fig. 24). The ninetieth percentile concentration in the Cumberland Plateau exceeded the recommended drinking water maximum contaminant level of 10 mg/L (U.S. Environmental Protection Agency, 1995). Median nitrate concentrations were higher in ground water than surface water in most subunits (fig. 24). In both the Outer and Inner Nashville Basins, however, median concentrations were higher in surface water. In all subunits, concentrations at the ninetieth percentile were higher in ground water than in surface water.

Median concentrations of total Kjeldahl nitrogen were generally less than 0.5 mg/L in each subunit (fig. 24), except those in the Inner Nashville Basin, Valley and Ridge, and Cumberland Plateau which exceeded 1 mg/L. Ground-water data for total Kjeldahl nitrogen were not available in many of the subunits, and data were insufficient in the remaining subunits to make a meaningful comparison. Concentrations for total Kjeldahl nitrogen in ground water, where available, were less than 1 mg/L.

Nutrient concentrations in surface and ground water were compared to the density of agricultural land use in each subunit. The rank of median concentrations by subunit for nitrate and total Kjeldahl nitrogen (fig. 24) in surface water roughly correlates with the percentage of agricultural land use in each subunit (table 2) and estimates of total nitrogen input from nonpoint sources (fig. 22). Concentrations of nitrogen in surface-water samples are highest in the Outer and Inner Nashville Basins, Eastern Highland Rim, and the Cumberland Plateau. Agricultural land use was also greatest for these subunits. However, the Coastal Plain, which had total nitrogen inputs comparable to the Outer Nashville Basin (fig. 22), has small nitrogen concentrations relative to the other subunits (fig. 24). The lower than expected nitrogen concentrations in samples collected from streams in the Coastal Plain may be a result of the type of nitrogen input and hydrogeology of the subunit. The nitrogen input from livestock waste is much lower in the Coastal Plain than in the other four subunits with comparable total nitrogen input (fig. 22). No relation could be identified between nitrogen concentrations in ground water and land use in a subunit. Agricultural land use was highest in the Inner Nashville Basin, but nitrate concentrations in ground water were lowest in this subunit.

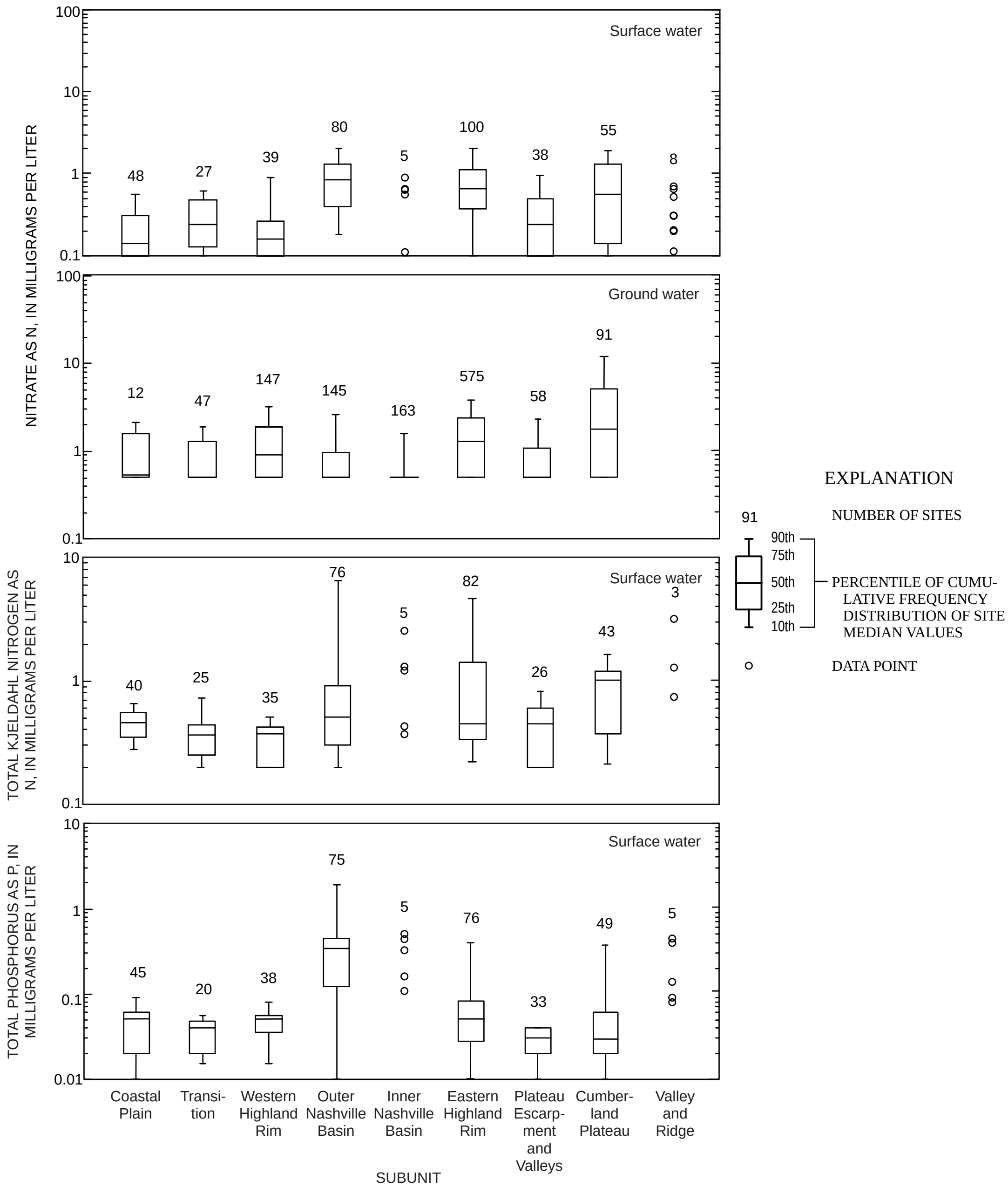

Figure 24. Concentrations of selected nutrients in surface and ground water by subunit in the lower Tennessee River Basin, 1980-96.

Natural setting is likely as important to concentrations of total phosphorus as the distribution of inputs of phosphorus in the lower Tennessee River Basin. Total-phosphorus data were available for about 350 surface-water sites and fewer than 70 ground-water sites in the nine subunits. Median concentrations of total phosphorus for surface-water sites were highest (about 0.3 mg/L) in the Inner and Outer Nashville Basins; median total phosphorus concentrations were about 0.1 mg/L or less in the remaining subunits (fig. 24). Phosphatic limestones present in the Inner and Outer Nashville Basin likely contribute to the elevated phosphorus concentrations there. This natural source also would account for the relatively high concentrations of phosphorus in streams in these subunits compared to other subunits with similar phosphorus inputs (fig. 22). Total-phosphorus data for ground water were limited, and only two subunits were represented by more than four sites. Total-phosphorus concentrations in ground water generally were less than 0.1 mg/L for most sites. No relation was evident between total-phosphorus concentrations in surface or ground water and land use or nonpoint phosphorus inputs.

Bacteria in Surface and Ground Water

Pathogens were cited as the cause of impairment for 29 of the 109 impaired stream segments and also were identified as an issue for ground-water quality in the lower Tennessee River Basin by State water-quality agencies (Alabama Department of Environmental Management, 1996; Georgia Department of Natural Resources, 1996; Kentucky Natural Resources and Environmental Protection Cabinet, 1996; Mississippi Department of Environmental Quality, 1996; Tennessee Department of Environment and Conservation, 1996). Fecal coliform bacteria are used to identify contamination to water bodies by waste from warm-blooded animals. Fecal coliform bacteria generally are not disease-causing, but their detection can indicate the presence of other more dangerous pathogens. Of the fecal-indicator bacteria commonly used in water-quality assessments, data for fecal coliform were the most frequently reported in both STORET and WATSTORE for the period 1980-96 and are summarized in this report.

Median counts of fecal coliform were higher in surface water than in ground water for each subunit (fig. 25). The highest median counts in surface water were about 7,500 colonies per 100 milliliters (col./100 mL) in the Valley and Ridge and about 5,000 col./100mL in the Outer Nashville Basin; however, data were reported for only three sites in the Valley and Ridge. The typical range in counts of fecal coliform in surface water is less than 1 to 5,000 col./100 mL and between 200 to greater than 2,000,000 col./100 mL in fecal-contaminated surface water (Wilde and others, 1997). The criteria for protection of recreational water bodies in Tennessee is 1,000 col./100 mL in a single sample (U.S. Environmental Protection Agency, 1999). Median reported fecal coliform counts for the Inner and Outer Nashville Basin and Valley and Ridge were greater than

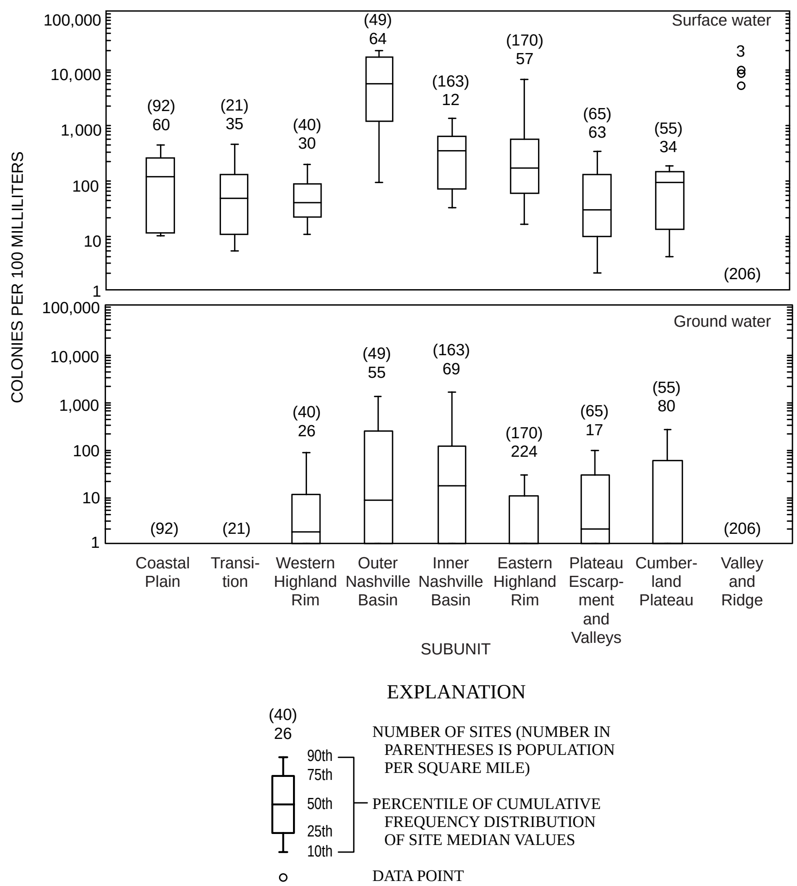

Figure 25. Counts of fecal coliform in surface and ground water by subunit in the lower Tennessee River Basin, 1980-96.

1,000 col./100 mL, suggesting that fecal contamination of surface water in these subunits is somewhat higher than in the remaining subunits. Median concentrations of fecal coliform in ground water were well below 200 col./100 mL in all subunits; however, no data were available for the Valley and Ridge. Median fecal coliform counts were highest for the Outer and Inner Nashville Basins and were lowest (less than 1 col./100 mL) for both the Coastal Plain and Transition; however, the number of sites with data from these subunits was very low.

Natural setting is an important factor affecting fecal-contamination of surface and ground water in the study unit. Fecal coliform counts in both surface and ground water generally were highest in subunits underlain by carbonate rocks, and especially the Ordovician carbonate rocks that have thin to absent regolith overlying bedrock. Sources of fecal contamination cited by State water-quality agencies include sanitary and combined sewer overflows, leaking septic systems, and livestock waste. The correlation of fecal counts with the distribution of these sources is not a straightforward analysis, because data are not available to estimate the distribution and magnitude of sewer overflows and leaking septic systems. Population and livestock densities were used as indicators of potential sources within each subunit and were compared to the rank order of fecal coliform counts (fig. 25). In general, higher median fecal coliform counts were related to a greater population and livestock density (figs. 20 and 25). Exceptions to this relation were the Outer Nashville Basin, which ranked sixth in both population and livestock density but ranked first in median fecal coliform counts; and the Cumberland Plateau ranked relatively low in fecal coliform counts in surface water but was ranked highest in livestock density. Fecal coliform counts in ground water from the Outer Nashville Basin also ranked high compared to the relative density of population and livestock.

SUMMARY

The lower Tennessee River Basin is one of 59 National Water-Quality Assessment study units in which water-quality assessments have been or are being conducted by the U.S. Geological Survey. The lower Tennessee River Basin study unit encompasses about 19,500 mi^2 and extends from Chattanooga, Tennessee, to Paducah, Kentucky. Geology and physiography were used to subdivide the study unit into nine subunits that represent areas of relative geologic and physiographic homogeneity. This subdivision provides framework in which natural variability in water quality can be quantified and the effects of human-related factors on water quality can be assessed. The boundaries for these subunits are similar to the ecoregion boundaries. The nine subunits delineated in order of size are the Western Highland Rim, Eastern Highland Rim, Coastal Plain, Outer Nashville Basin, Plateau Escarpment and Valleys, Cumberland Plateau, Transition, Inner Nashville Basin, and Valley and Ridge.

Much of the lower Tennessee River Basin is underlain by carbonate rocks, with smaller areas of unconsolidated sediments and siliciclastic rocks present in the western and eastern parts of the study unit, respectively. Most of the rock units in the study unit are undeformed and relatively flat-lying to gently dipping. Karst landforms, such as sinkholes, caves, and disappearing streams, are present in parts of the study unit underlain by carbonate rocks. Generally, the soils overlying bedrock in the study unit have moderate to slow infiltration rates.

The lower Tennessee River Basin lies within parts of the Coastal Plain, Interior Low Plateaus, and Appalachian Plateaus Physiographic Provinces. Relief is low to moderate in much of the study unit; high relief occurs between the Highland Rim and Cumberland Plateau Physiographic Sections of the Interior Low Plateaus and Appalachian Plateaus, respectively. Land-surface altitudes generally increase from about 500 ft above sea level in the west to more than 2,000 ft above sea level in the east.

The main stem of the Tennessee River is highly regulated with few free-flowing stream reaches. Six reservoirs are located on the main stem and many additional reservoirs are located on tributaries to the main stem. Mean-annual streamflow in the Tennessee River increases from about 35,900 to about 65,600 ft^3/s from Chattanooga, Tennessee, to Paducah, Kentucky. The Elk and Duck Rivers are the two largest tributaries and contribute about 26 percent of the streamflow gained in the study unit.

The Cretaceous sand, Pennsylvanian sandstone, Mississippian carbonate, and Ordovician carbonate aquifers account for most of the shallow ground-water flow in the study unit. Ground-water flow paths typically are short in these aquifers, and much of the recharge to the aquifers is discharged within the study unit. The shallow ground-water system generally is within 300 ft of land surface and flow is through unconsolidated sediments, solution openings in bedding planes and joints in bedrock, and in fractured bedrock. The Mississippian carbonate aquifer is the most productive in the study unit and is characterized by flow in solution openings. Estimates of the contribution of ground-water discharge to streamflow from the principal aquifers indicate that at least 50 percent of streamflow is contributed by ground-water discharge to streams.

Surface water is the principal source of water for both industrial use and public supply, and accounts for about 70 percent of the water used for drinking water. Much of surface water used is withdrawn from the main stem of the Tennessee River. Ground-water use is highest in the Eastern Highland Rim, where Huntsville, Alabama, the largest city in the study unit, uses ground water for about 40 percent of the water supply. Point-source discharges were estimated for 1995. The estimated total nitrogen input from wastewater discharges in the study unit was about 13,430 tons and the estimated total phosphorus load was 770 tons.

Land use in the study unit largely reflects the geomorphology of the basin and the distribution of people. Large forested areas are present in the Plateau Escarpment and Valleys, Transition, and Western Highland Rim where the topography has moderate to high relief. Forest land is the largest land use in the Coastal Plain, Cumberland Plateau, and Valley and Ridge as well. Pasture land is the dominant land use in the Inner and Outer Nashville Basin and the Eastern Highland Rim. Cultivated land constitutes 6 percent or less of the land use in all subunits except the Eastern Highland Rim, where about 16 percent of the land is cultivated. Urban and developed land is 1 percent or less of the land use in most subunits.

Cultural factors most likely to have a widespread effect on water quality in the lower Tennessee River Basin are related to animal and rowcrop agriculture. Corn, soybeans, cotton, and wheat were the primary crops grown in the study unit in 1992. The Eastern Highland Rim and Coastal Plain were the most intensively farmed subunits. Cotton acreage in the Eastern Highland Rim was the largest crop by subunit. About 42 million chickens, 0.9 million cattle, and 0.3 million hogs were produced in 1992. The number of chickens per square mile was highest in the Cumberland Plateau. Cattle production was most intense in the Inner and Outer Nashville Basin, and hogs were raised primarily in the Coastal Plain.

Nutrient inputs from agricultural activities and atmospheric deposition (nonpoint sources) were estimated for 1992. The estimated total nitrogen input from these sources was about 195,000 tons, with about 74 percent of the total contributed by fertilizer and livestock waste. On a per unit area basis, nitrogen inputs were highest in the Eastern Highland Rim. Nitrogen inputs from livestock waste were highest in the Cumberland Plateau, Inner and Outer Nashville Basin, and Valley and Ridge. Nitrogen inputs from fertilizer application were highest in the Eastern Highland Rim, Coastal Plain, and Inner Nashville Basin. About 14,500 tons of phosphorus were contributed to the study unit as fertilizer and 23,500 tons were produced by livestock in the study unit in 1992. On a per unit area basis, livestock waste was the larger source of phosphorus in most subunits. In the Eastern Highland Rim and Coastal Plain, fertilizer input was about the same or slightly more than inputs from livestock waste.

About 3.7 million pounds of pesticides (active ingredient) were applied to agricultural land in the study unit in 1992. The herbicides atrazine, monosodium methanearsonate (MSMA), 2,4-D, and metalochlor were used in the largest amount (more than 200,000 lb of each). Insecticides were used to a lesser extent and were applied primarily on cotton grown in the Eastern Highland Rim. About half of the pesticides used were applied to crops in the Eastern Highland Rim where about 538 lb of pesticides per square mile were applied.

Nutrient and fecal coliform data collected between 1980 and 1996 indicate that natural setting likely has as important an effect as cultural factors on surface- and ground-water quality in the lower Tennessee River Basin. These constituents represent water-quality issues for both surface and ground water in the lower Tennessee River Basin. Median nitrate concentrations were less than 1 mg/L for surface and ground water in all subunits except for the Eastern Highland Rim and Cumberland Plateau, where the nitrate concentration at the ninetieth percentile exceeded the maximum contaminant level for drinking water for nitrate (10 mg/L). In general, median concentrations of nitrogen species were highest in subunits where percentages of agricultural land use were highest. Median phosphorus concentrations in surface water were less than 1 mg/L in all subunits. The Inner and Outer Nashville Basin had the highest concentrations, probably a result of naturally occurring sources of phosphorus in phosphatic limestones in the Ordovician carbonate rocks. Available data for phosphorus concentrations in ground water were limited, but concentrations were generally less than 1 mg/L. Median counts of fecal coliform were higher in surface water than ground water. The highest median counts in surface water were in the Valley and Ridge (7,500 col./100 mL) and the Outer Nashville Basin (5,000 col./100 mL). Highest median counts in ground water were in the Inner and Outer Nashville Basin.

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