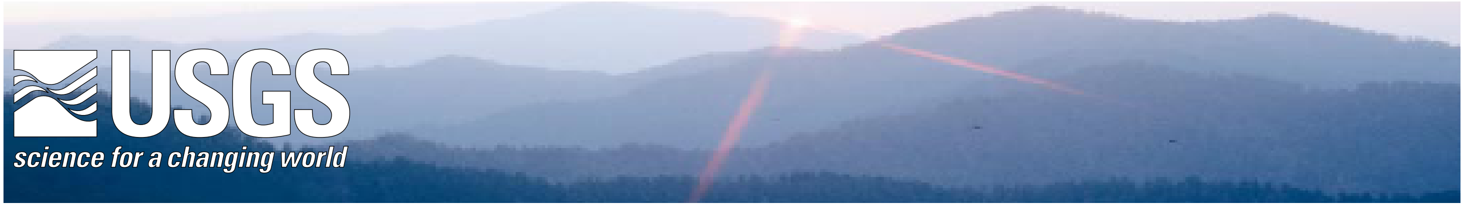
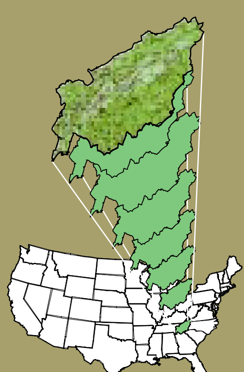


National Water-Quality Assessment Program—*Upper Tennessee River Basin Study Unit*

Phosphorus in Streams of the Upper Tennessee River Basin, 1970-93

by Gregory C. Johnson and M.W. Treece, Jr.

CONTENTS



U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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INTRODUCTION

In 1994, the U.S. Geological Survey (USGS) began an investigation to assess the water-quality conditions in the upper Tennessee River Basin. The investigation was implemented as part of the National Water-Quality Assessment (NAWQA) Program, which is designed to describe in a nationally consistent manner the status of and trends in the quality of a large representative part of the Nation's surface- and ground-water resources and to relate assessment of status and trends to the natural and human factors that affect the quality of water. When the NAWQA Program is fully implemented, water-assessment investigations will be ongoing in 60 study units across the Nation (Leahy and others, 1990). The general concepts of the NAWQA Program are outlined in a report by Hirsch and others (1988).

The upper Tennessee River Basin study unit (fig. 1) drains an area of about 21,390 square miles (mi^2), which includes the entire drainage of the Tennessee River and its tributaries upstream of the USGS gaging station at Chattanooga, Tennessee. The basin includes parts of Tennessee (11,500 mi^2), North Carolina (5,480 mi^2), Virginia (3,130 mi^2), and Georgia (1,280 mi^2). Four major river systems—Clinch/Powell, Holston, French Broad, and Little Tennessee—make up about 82 percent of the study unit. The basin includes parts of the Blue Ridge, Cumberland Plateau, and Valley and Ridge Physiographic Provinces.

Phosphorus is an essential nutrient for the metabolism of all living organisms and frequently limits the productivity of aquatic environments in terms of phytoplankton and macrophyte biomass. In freshwater aquatic environments, phosphorus enrichment can accelerate macrophyte and algal growth leading to eutrophication, unpleasant aesthetic conditions, disruption of the normal aquatic community composition, oxygen depletion as plants die and decay, and fishkills as oxygen is depleted. Eutrophic conditions near industrial and municipal water-withdrawal intakes also can cause water-supply problems, such as filter and pipeline clogging and unpleasant taste and odors.

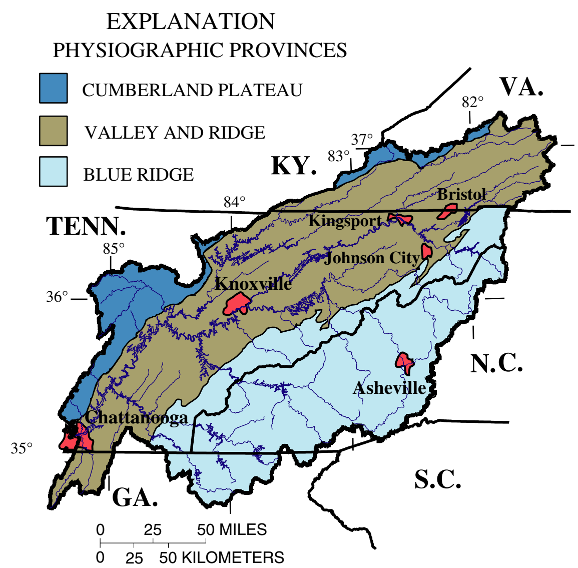

Figure 1. Upper Tennessee River Basin study unit.

Significant Findings

- Median total phosphorus concentrations for the period 1984-93 were less than 0.1 milligrams per liter at 65 of the 83 stations evaluated in the study unit.
- Highest total phosphorus concentrations were in the Hiwassee River Basin (near 2.0 milligrams per liter) and at West Chickamauga Creek near Chattanooga (1.45 milligrams per liter).
- Total phosphorus concentrations have not significantly changed since 1970 at 33 of the 42 stations examined; declines in total phosphorus concentrations were detected at 8 stations.
- Phosphorus concentrations decreased significantly at four of seven stations on the French Broad River after the phosphate detergent ban was imposed for North Carolina in 1988.
- The Tennessee River Basin between Watts Bar Dam and Chattanooga, excluding the Ocoee River Basin, accounted for over 65 percent of the total phosphorus load for only 16 percent of the total area of the study unit.
- Yields of total phosphorus were largest for the French Broad and Pigeon River Basins (1.19 and 0.88 pounds per acre per year, respectively).
- Total phosphorus concentrations were highest at stations with large agriculture and urban land uses.

Nashville, Tennessee
1998

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Phosphorus concentrations in surface water can be attributed to land use, geology, and the presence of point source discharges. The predominant land uses in the upper Tennessee River Basin study unit are forest and agriculture. Forest covers 64 percent of the basin, and agricultural land, predominantly pastureland, accounts for 27 percent. Most of the agricultural land is located in stream valleys and the more gently rolling areas of the Valley and Ridge Physiographic Province. Urban areas (6 percent), water bodies (2 percent), and mining operations (1 percent) account for the remainder of the land use in the basin.

This report presents results of analyses on available phosphorus data collected in the upper Tennessee River Basin by the USGS, the Tennessee Valley Authority (TVA), and State governmental data-collection agencies in Tennessee, North Carolina, Virginia, and Georgia. All data were retrieved from the U.S. Environmental Protection Agency (U.S. EPA) STORET and the USGS WATSTORE data bases. Phosphorous concentrations were most commonly reported as total phosphorus. Because most of the dissolved phosphorus concentrations were below the reporting limit, data analyses were limited to total phosphorus concentrations only.

SOURCES OF PHOSPHORUS

Phosphorus exists naturally in igneous rock and is frequently abundant in sediments. In natural waters, phosphorus occurs in the form of organic phosphorus, particulate inorganic phosphates, and dissolved organic and inorganic phosphates. Concentrations of total phosphorus in natural surface waters rarely are greater than 1 milligram per liter (mg/L) (Boyd, 1979), and dissolved phosphorus concentrations seldom exceed a few tenths of a milligram per liter (Hem, 1985). For example, a mean total phosphorus concentration of 0.01 mg/L was reported for samples collected in the Blue Ridge and eastern Piedmont Physiographic Provinces of North Carolina during 1973-78 (Simmons and Heath, 1982). Mean concentrations of total phosphorus ranged from 0.01 to 0.04 mg/L for selected streams in forested basins throughout North Carolina from 1986-88 (Caldwell, 1992). Mean total phosphorus concentrations in surface waters of agricultural drainages in central North Carolina, however, ranged from 0.55 to 1.4 mg/L from 1985-90 (Harned, 1994). In the Elk and Duck Rivers in Middle Tennessee from 1986-89, mean total phosphorus concentrations were 0.20 and 0.28 mg/L, respectively, and were attributed to runoff from phosphorus-rich soils and surface phosphate mines (Tennessee Valley Authority, 1991b).

Sources of phosphorus can originate from both point and nonpoint sources and can include agricultural fertilizers and manures, organic wastes in sewage and industrial effluent, and atmospheric deposition. Point sources usually discharge directly to surface

Cattle in northern East Tennessee

Sewage treament plant, Knoxville, Tennessee

waters from sources such as industrial and municipal wastewater facilities, and account for less than 50 percent of the stream loads of phosphorus in most watersheds in the United States (Puckett, 1995). Because acid-hydrolyzable phosphates added to detergents were identified as an important source of phosphorus in industrial and domestic sewage effluents, some states, including North Carolina and Virginia, imposed a ban on phosphate detergents in 1988 (Childress and Treece, 1996).

Although nonpoint sources, such as animal manure and chemical fertilizers, reach surface waters through runoff and may represent a potentially large phosphorus input, they probably contribute only a small part of the actual stream load (Puckett, 1995). Studies in the Southeastern United States indicate that only about one-third of the nonpoint-source inputs of phosphorus to surface water are immediately bioavailable (Wangsness and others, 1994). Statistical studies of water-quality trends suggest that increases in total phosphorus are associated with increases in livestock population densities and fertilized acreage.

Atmospheric inputs of phosphorus are not considered significant in the upper Tennessee River Basin and probably represent a minor source of phosphorus to watersheds in the region. Phosphorus-deposition rates are usually highest in major urban areas, less for agricultural areas, and mostly negligible in predominately forested areas (Robertson, 1996).

SPATIAL DISTRIBUTION OF PHOSPHORUS CONCENTRATIONS

Concentrations of total phosphorus in surface water were assessed using data collected at 83 stations in the upper Tennessee River Basin. Selection criteria were established to provide a data set consisting of as many stations as possible with current and frequent water-quality samples. Stations selected had data records for a 10-year period from 1984 to 1993 with at least 40 samples and no more than a 2-year gap in the data.

Median concentrations of total phosphorus ranged from less than 0.01 to 0.82 mg/L, and generally were low (less than 0.1 mg/L) for 65 of the 83 stations in the upper Tennessee River Basin. The low concentrations result from the predominance of forested land use in the study unit.

Stations with the greatest median concentrations were in mixed forest-agriculture-urban watersheds. Median phosphorus concentrations were highest at Oostanaula Creek (0.82 mg/L) in the Hiwassee River Basin and at a station on the Pigeon River (0.33 mg/L) (fig. 2). Elevated median concentrations (ranging from 0.18 to 0.30 mg/L) were recorded at Bear Creek in the upper Clinch River Basin, Cane Creek in the Hiwassee River Basin, Wolf Creek in the Middle Fork Holston River Basin, West Chickamauga Creek near

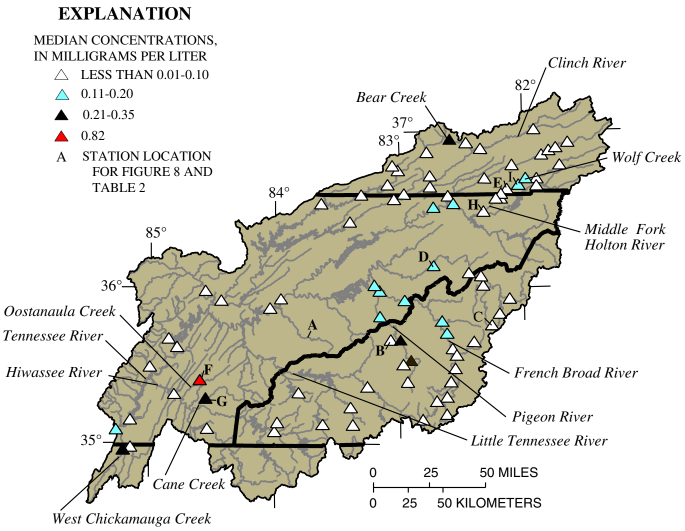


Figure 2. Distribution of median total phosphorus concentrations, 1984-93.

Chattanooga, and at several stations along the main stem of the French Broad and Pigeon Rivers.

Evaluation of total phosphorus concentrations at the 90th percentile identified stations where concentrations were more extreme (fig. 3). Stations on Oostanaula Creek and Cane Creek in the Hiwassee River Basin had 90th percentile concentrations near 2.0 mg/L, and stations on West Chickamauga Creek, Bear Creek, and the Pigeon River had 90th percentile concentrations of 1.45, 1.2, and 1.1 mg/L, respectively. These elevated concentrations likely can be attributed to wastewater discharges upstream of these stations.

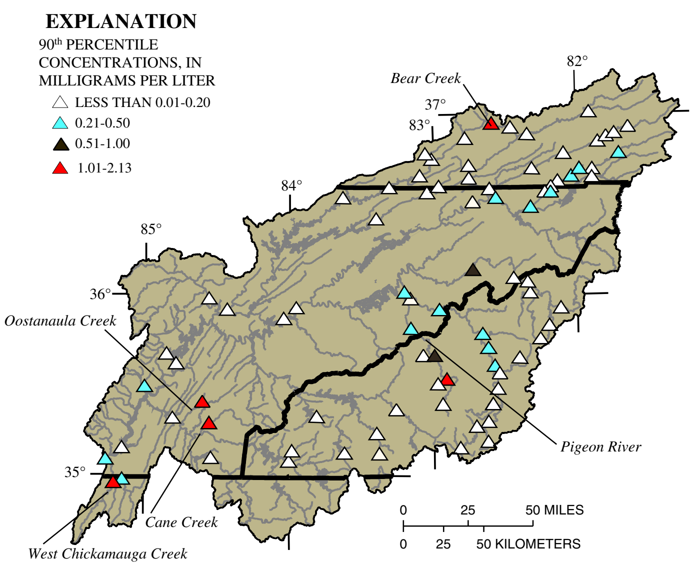


Figure 3. Distribution of 90th percentile of total phosphorus concentrations, 1984-93.

TRENDS IN PHOSPHORUS CONCENTRATIONS

Trend analyses were conducted for 42 stations in the study unit using the seasonal Kendall statistical test to detect changes in phosphorus concentrations for the period 1970 through 1993. For stations with streamflow data, concentrations were flow adjusted using a method of curve smoothing to remove the variability associated with streamflow (Helsel, 1993). A significance level (alpha) of 0.05 was used to show statistical significance of the trend test.

Results of the trend tests (fig. 4) indicated no trend in total phosphorus concentrations at 33 stations in the upper Tennessee River Basin. Total phosphorus concentrations increased at West Chickamauga Creek, which had relatively high concentrations for the entire period of record and drains a major industrial and urban setting. Total phosphorus concentrations decreased at eight stations across the basin. These stations receive drainage from watersheds dominated by forest and pasture, with only minor influence from development. Three of these stations, however, are located immediately downstream from wastewater discharges.

Improvements in municipal wastewater-treatment technology may be responsible for decreasing phosphorus trends and may explain the absence of increasing trends in areas experiencing urbanization and increased agricultural activities. Declines occurring after 1988 at some stations could be in response to upgraded treatment of municipal wastewater and the restricted use of phosphate detergents resulting from state-imposed regulations and voluntary reductions.

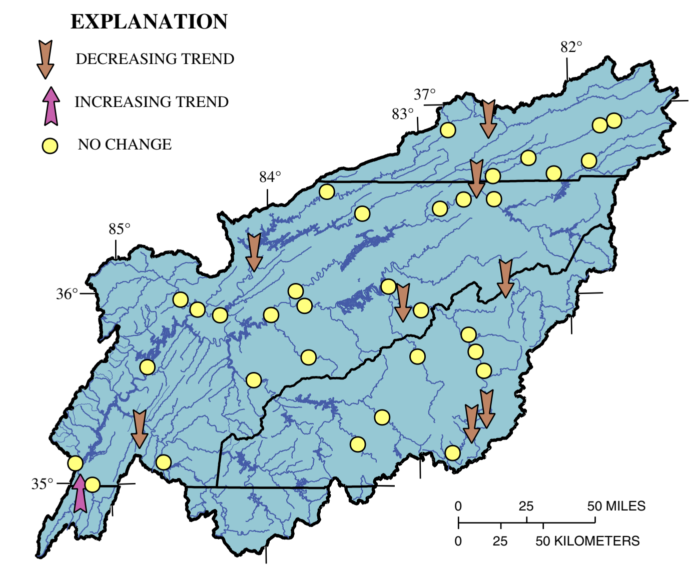


Figure 4. Trends in total phosphorus concentrations, 1970-93.

EFFECTS OF RESTRICTED USE OF PHOSPHATE DETERGENTS

The use of phosphate to increase the cleaning power of detergents began in the 1950's. As the public became more aware of the role of phosphorus in causing eutrophication in lakes, various actions were taken to restrict the use of phosphorus in detergents. The use of phosphates in detergent was banned in North Carolina and Virginia in 1988. In Tennessee, phosphate use was voluntarily reduced, but no ban was implemented. The effects of the restricted use of phosphates in commercial detergents on stream-water quality are not well documented.

Previous studies have indicated a decline in instream phosphorus loads and measured concentrations after the restrictions were imposed. Phosphorus loads in the Chattahoochee River, for example, decreased by 54 percent during 1988-93, while phosphorus discharges declined by 83 percent during the same period at the six largest wastewater-treatment facilities in Metropolitan Atlanta, Ga. (Wangsness and others, 1994). Phosphorus concentrations and loads in streams in the upper Cape Fear and upper Neuse River Basins of central North Carolina decreased by about 50 to 85 percent after the phosphate detergent ban (Childress and Treece, 1996).

The Wilcoxon rank-sum nonparametric statistical test was used to determine if the distribution of phosphorus concentrations for pre- and post-phosphate detergent ban (1980-87 and 1988-93) were statistically different using a 0.05 level of significance. The Wilcoxon rank-sum test compared differences in two grouped data sets separated by a discrete point in time, as opposed to the trend test which could indicate a more gradual change in conditions over time. Detecting temporal patterns in phosphorus concentrations resulting from the restricted use of phosphates is difficult because of long residence times and the phosphorus-trapping effects of reservoirs in the study unit.

The French Broad River is one of the few major tributaries to the Tennessee River that is not substantially influenced by reservoirs and has adequate data to reflect the implementation of the phosphate-detergent ban. Three stations on the French Broad River (fig. 5), downstream of Asheville, N.C. (Alexander, Marshall, and Newport), show a significant reduction in phosphorus levels after 1988. Two of these stations (Alexander and Marshall) are located less than 10 and 15 river miles downstream of a major municipal wastewater-treatment facility. Changes in phosphorus levels were not statistically significant, however, at the French Broad River at Asheville and Skyland. Within the vicinity of Asheville, the effects of the restricted use of phosphate detergents and upgraded treatment of municipal wastewater may have been offset by the increase in urban runoff and wastewater volume that accompanied development. Phosphorus levels were significantly reduced at the French Broad River at Blantyre, N.C., which is located 38 river miles upstream of Asheville and downstream of a mid-sized municipal wastewater-treatment facility. The French Broad River at Rosman, N.C., located in the upper part of the watershed, showed no change in total phosphorus levels because of minimal effect from upstream effluent discharge (fig. 5).

PHOSPHORUS LOADS AND YIELDS

Annual loads of phosphorus (fig. 6, table 1) were computed for stations located on major tributaries to the upper Tennessee River. Twenty stations were identified with adequate streamflow record and corresponding water-quality data for a common period of data from 1973 through 1993. Annual phosphorus loads were estimated using a constituent transport model that uses multiple regression to relate streamflow to the concentration of a water-quality constituent to derive loads (Cohn and others, 1989).

The average annual outflow load of total phosphorus from the upper Tennessee River Basin at Chattanooga was 13,500 pounds per day (lb/d) from 1973 through 1993. The French Broad River contributed 3,430 lb/d of phosphorus to the Tennessee River, while the Holston River added another 1,080 lb/d. The area between Watts Bar Dam and Chattanooga, excluding the Ocoee River Basin, contributed 8,820 lb/d of total phosphorus to the Tennessee River, accounting for over 65 percent of the total phosphorus load in only 16 percent of the total area of the upper Tennessee River Basin.

The fate of phosphorus in reservoirs depends on the physical characteristics of the reservoir (volume, surface area, depth, and hydraulic retention time) and its trophic state (Tennessee Valley Authority, 1991a). The tributary reservoirs with large storage capacity and long residence times efficiently trap both dissolved and sediment-bound phosphorus. Outflow loads of total phosphorus below Norris Lake on the Clinch River, for example, were only 37 percent of the inflow load from the Clinch and Powell Rivers. Load estimates for Holston River stations above and below Cherokee Lake indicate that the reservoir traps 46 percent of the total phosphorus load. In contrast, less trapping of phosphorus occurs in the main stem reservoirs, which are flow-through systems with little storage and low residence times. For example, outflow loads below Chickamauga Lake and Watts Bar Lake exceed the inflow loads, which can be attributed to low rates of phosphorus trapping and inputs from the ungaged areas adjacent to the reservoirs.

Yields of total phosphorus (loads per unit area for the upstream drainage area) were highest for the French Broad River Basin, particularly upstream from Marshall, N.C., and the Pigeon River Basin (table 1). Yields were lowest for stations immediately below dams: the Clinch River at Norris Dam and Melton Hill Dam, and the Little Tennessee River at Chilhowee Dam. The relatively low yield at the Holston River at Knoxville, Tenn., probably reflects the influence of Cherokee Lake. In addition, yields were low for areas with low percentages of agricultural land use: the Ocoee River at Parksville, Tenn., Cataloochee Creek at Cataloochee, N.C., the South Fork Holston River at Damascus, Va., and the Emory River at Oakdale, Tenn.

RELATION BETWEEN PHOSPHORUS CONCENTRATIONS AND LAND USE

The national watershed-based analysis by Puckett (1995) relating nonpoint and point sources of nutrients with regional and local land-use factors indicated that nutrient inputs to watersheds are dependent on variations in land-management practices as well as on the mixture of land use in the watershed. Although the effect of nonpoint sources on stream chemistry remains uncertain, recent studies have indicated that instream increases in total phosphorus are associated with increased livestock population densities and fertilized acreage.

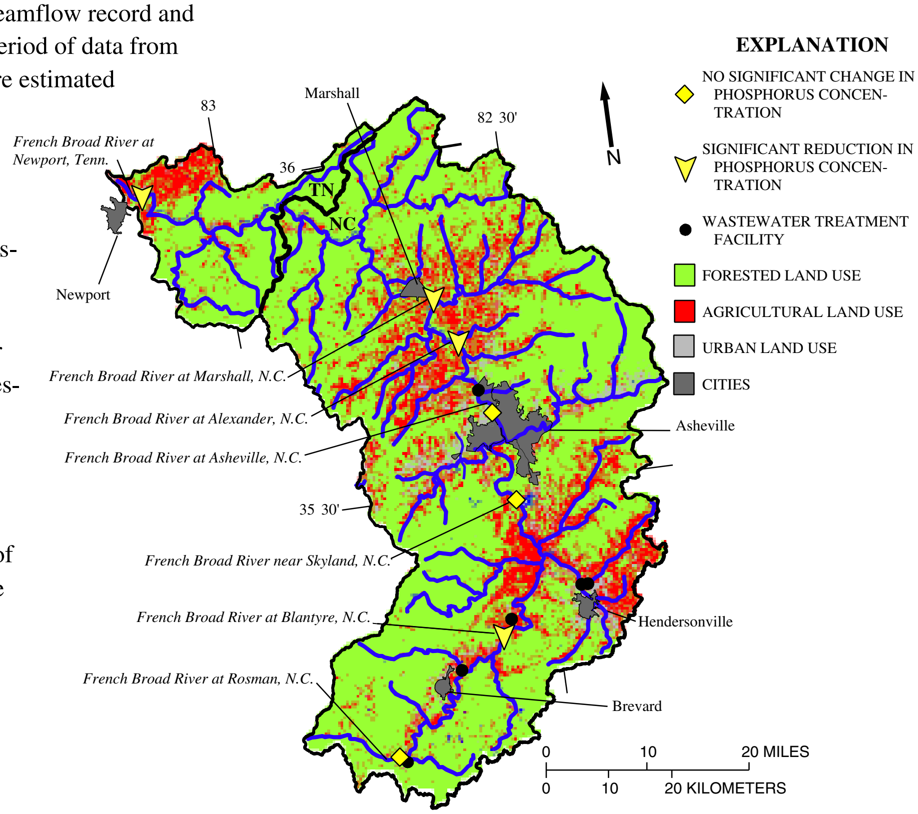


Figure 5. Results of comparison between pre- and post-phosphate detergent ban for total phosphorus concentrations at selected stations in the French Broad River Basin.

The relation between median total phosphorus concentrations and the percentage of land use was compared for 83 stations in the upper Tennessee River Basin. Statistical tests indicated that a significant relation existed between phosphorus concentrations and land use at a 0.05 level of significance (fig. 7). Concentrations were higher with increased agriculture and developed land use (figs. 7 and 8) and lower for stations with higher percentages of forested drainage areas. Median total phosphorus concentrations were compared for selected stations representing different land-use categories (fig. 8, table 2). Stations in forested watersheds had the lowest total phosphorus concentrations, whereas stations in urban and agricultural watersheds had the highest concentrations.

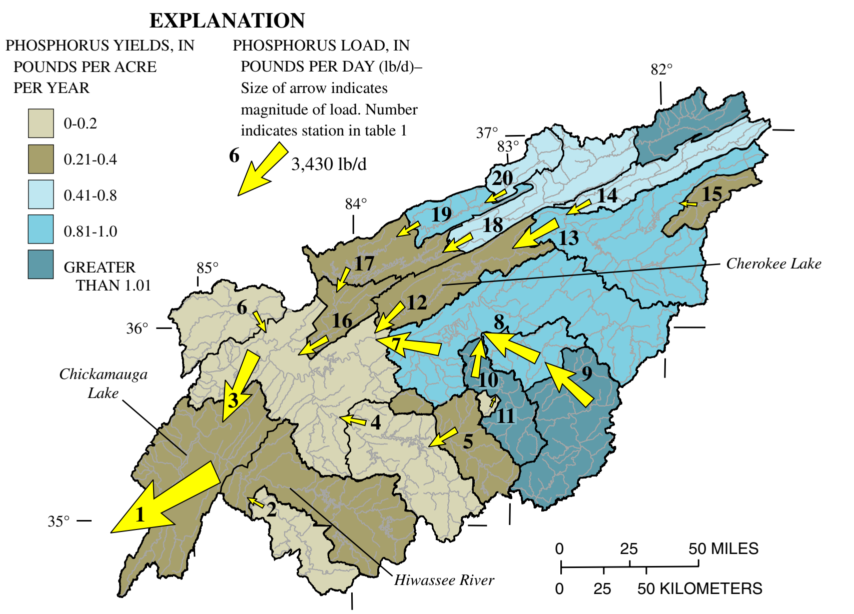


Figure 6. Mean annual total phosphorus loads and yields, 1973-93.

Table 1. Average annual phosphorus loads and yields for stations in the upper Tennessee River Basin, 1973-93

Map no. (fig. 6)	Station name	Drainage area, in square miles	Load, in pounds per day	Yield, in pounds per acre per year
1	Tennessee River at Chattanooga, Tenn.	21,390	13,500	0.36
2	Ocoee River at Parksville, Tenn.	595	103	0.10
3	Tennessee River at Watts Bar Dam, Tenn.	17,310	4,580	0.15
4	Little Tennessee River at Chilhowee Dam, Tenn.	1,987	345	0.10
5	Tuckasegee River at Bryson City, N.C.	665	602	0.52
6	Emory River at Oakdale, Tenn.	764	237	0.18
7	French Broad River near Knoxville, Tenn.	5,101	3,430	0.38
8	French Broad River at Newport, Tenn.	1,858	2,770	0.85
9	French Broad River at Marshall, N.C.	1,332	2,770	1.19
10	Pigeon River at Newport, Tenn.	666	1,030	0.88
11	Cataloochee Creek at Cataloochee, N.C.	49.2	14.1	0.16
12	Holston River at Knoxville, Tenn.	3,747	1,080	0.16
13	Holston River at Surgoinsville, Tenn.	2,874	2,010	0.40
14	North Fork Holston River at Gate City, Va.	672	368	0.31
15	South Fork Holston River at Damascus, Va.	301	87.7	0.17
16	Clinch River at Melton Hill Dam, Tenn.	3,343	607	0.10
17	Clinch River at Norris Dam, Tenn.	2,913	364	0.07
18	Clinch River at Tazewell, Tenn.	1,474	664	0.26
19	Powell River near Arthur, Tenn.	685	331	0.28
20	Powell River at Jonesville, Va.	319	202	0.36

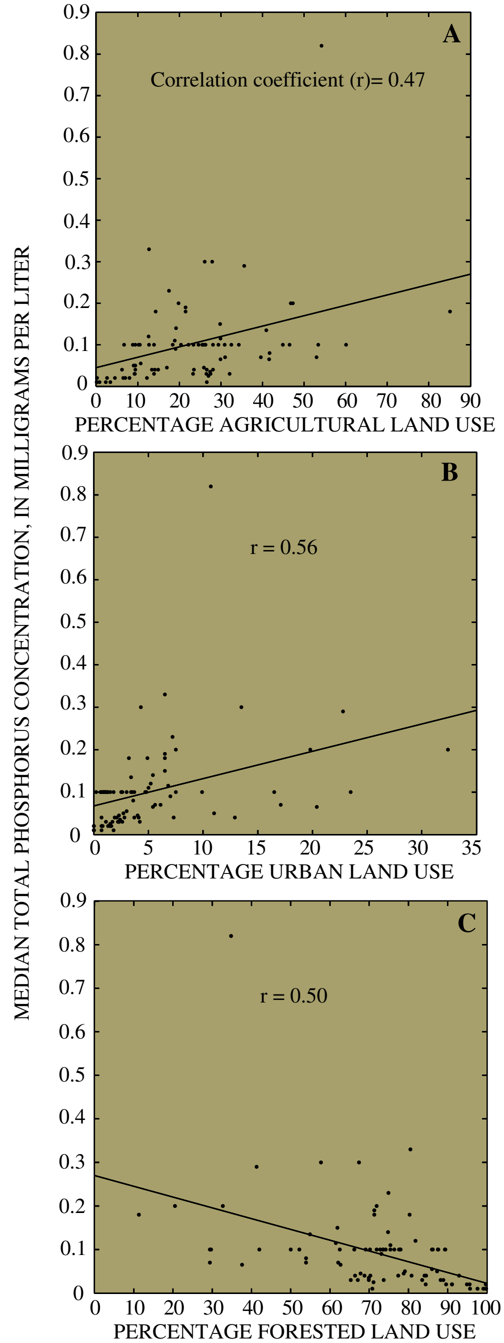
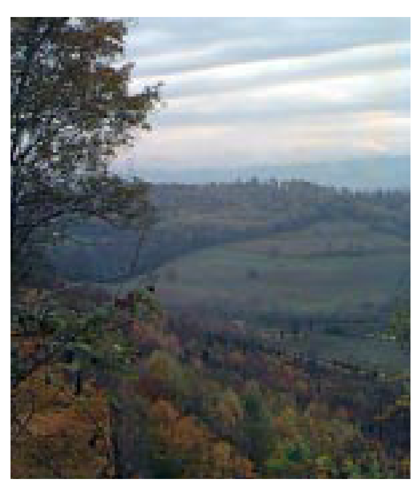


Figure 7. Relation of median total phosphorus concentration to (A) agricultural, (B) urban, and (C) forested land use.



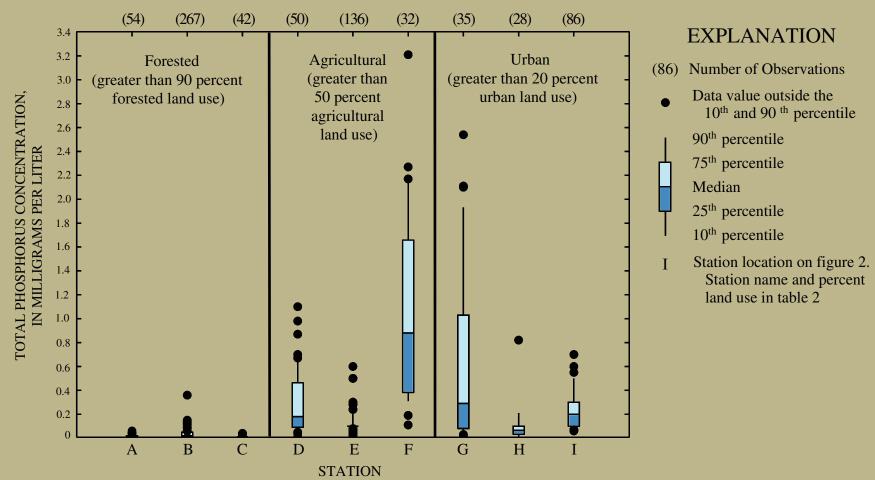


Figure 8. Distribution of total phosphorus concentrations for selected stations grouped by land-use type.

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Table 2. Land use for selected stations in the upper Tennessee River Basin

Station location (see fig. 2)	Station name	Percent forest	Percent agricultural	Percent urban	Percent other
A	Little River near Townsend, Tenn.	99.8	0.2	0	0
B	Cataloochee Creek Near Cataloochee, N.C.	99.8	0.2	0	0
C	South Toe River near Deep Gap, N.C.	99.8	0.2	0	0
D	Sinking Creek near Green Valley, Tenn.	11.4	85.2	3.3	0.1
E	Beaver Creek, upstream of Bristol, Tenn.	29.5	60.1	10.0	0.4
F	Oostanaula Creek at Longs Mill Road, Tenn.	34.9	54.2	10.7	0.2
G	Cane Creek at Carlock Road, Tenn.	41.3	35.7	22.8	0.2
H	Beaver Creek, downstream of Bristol, Tenn.	37.6	41.6	20.4	0.4
I	Wolf Creek at Green Springs, Va.	32.7	47.4	19.8	0.1

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