U.S. Department of the Interior
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Influence of Land Use and Open-Water Wetlands on Water Quality in the Lake Wallenpaupack Basin, Northeastern Pennsylvania

Water-Resources Investigations Report 98-4186

Prepared in cooperation with

THE PENNSYLVANIA STATE UNIVERSITY LAND ANALYSIS LABORATORY

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Conversion Factors, Abbreviated Water-Quality Units, and Vertical Datum

Length

inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

Area

acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer

Volume

cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meters per second per square kilometer

Mass

pound (lb)	0.4536	kilogram
pound per square mile (lb/mi^2)	0.1755	kilogram per square kilometer
ton	0.0972	megagram
ton per square mile (ton/mi^2)	0.3502	megagram per square kilometer

Temperature

Temperature conversions for degrees Fahrenheit (°F) and degrees Celsius (°C) are given in the following equations:

$$°C=5/9\ (°F-32)$$

$$°F=1.8\ \text{temp}\ °C+32$$

Other Abbreviations

Abbreviated water-quality units used in this report:

µm	micrometer
mg/L	milligrams per liter

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 both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

The recreational value of Lake Wallenpaupack, along with its proximity to the New York and New Jersey metropolitan areas, has resulted in residential development in parts of the watershed. Some of these developments encroach on existing ponds, lakes, and wetlands and result in the conversion of forest land to residential areas. Sediment and nutrients in runoff from these residential areas, and inputs from agricultural areas, sewage treatment plants, and atmospheric deposition, have had a significant effect on water quality in Lake Wallenpaupack.

Water-quality data collected in the Lake Wallenpaupack watershed from 1991 through 1994 indicate the influence of land use on water resources. Water samples collected from a forested undeveloped basin contained lower concentrations of suspended sediment, nitrogen, and total phosphorus than samples collected from the basins of Ariel Creek and Purdy Creek that drain areas having mixed land use with residential developments. Sediment yields were three to four times higher in the developed basins of Purdy and Ariel Creeks compared to the forested undeveloped basin. Annual yields for total nitrogen for Ariel Creek and Purdy Creek were between three to five times greater than yields from the forested basin. For the 1993 water year, the annual yield for dissolved nitrate plus nitrite (as nitrogen) from Ariel Creek Basin was 1,410 pounds per square mile, or about 60 times greater than the 24 pounds per square mile from the undeveloped basin. The total-phosphorus yield from the Ariel Creek Basin was 216 pounds per square mile for the 1994 water year. This was about three times greater than the 74 pounds per square mile from the forested basin. The total-phosphorus yield for the Purdy Creek Basin was 188 pounds per square mile for the 1994 water year, or 2.5 times greater than the yield from the undeveloped forested basin. Only slight differences were observed in dissolved orthophosphate phosphorus loadings between the basins. All three basins displayed seasonal differences in water quality. Most of the annual yield occurred during early spring as a result of snowmelt runoff.

Data collected from the Stevens Creek sites showed that an open-water wetland was very effective in removing sediment and total phosphorus but was not as effective in removing dissolved orthophosphate phosphorus and nitrogen. The wetland removed more than 96 percent of the sediment.

INTRODUCTION

Lake Wallenpaupack was constructed in 1923 as a water source for hydroelectric power generation. It is now owned by Pennsylvania Power and Light Company, Inc. (PP&L) and is still used for power generation during periods of peak demand. The watershed to the lake is 250 mi^2 and consists of agricultural, commercial, residential, and forested areas. The surface-water drainage system to Lake Wallenpaupack contains many small ponds, lakes, and wetlands.

Lake Wallenpaupack represents a large recreational resource in northeastern Pennsylvania (fig. 1). The recreational value of the lake, along with its proximity to the New York City metropolitan area, has resulted in residential development in parts of the watershed. Some developments result in the conversion of forest land to residential areas containing impervious roads, driveways, and rooftops. Sediment and nutrients from residential areas, agricultural land, sewage-treatment plants, and atmospheric deposition can have a significant effect on water quality of Lake Wallenpaupack.

In 1979, algal blooms in the lake resulted in numerous cases of algae-related afflictions such as allergic reactions and gastro-intestinal disorders (Browne, 1982).

In September 1979, the Lake Wallenpaupack Watershed Management District (LWWMD) was formed to manage water resources in the region and address the problem of nutrient loading to the lake. A study by Browne (1982) concluded that the lake was eutrophic, water quality in the lake had declined steadily since the early 1970’s, phosphorus was the limiting nutrient controlling algae growth, and a long-term study was needed to evaluate water quality in the basin. This investigation identified Ariel and Purdy Creeks as tributaries that provide substantial nutrient loads to Lake Wallenpaupack because of the high percentage of residential development and cropland in the basins. The study also noted that the Ariel and Purdy Creek Basins would have the greatest potential for future development.

To address the issues identified by Browne (1982) and the need for additional study, the U.S. Geological Survey (USGS), in cooperation with the Pennsylvania State University, Land Analysis Laboratory (LAL) (Department of Agronomy, College of Agricultural Sciences), conducted a water-resources investigation in the Lake Wallenpaupack watershed as part of a comprehensive study dealing with hydrology, water quality, and soils in the Lake Wallenpaupack Basin. The purpose of this investigation, which began in 1991, was to 1) compare sediment and nutrient transport in developed watersheds to a forested, undeveloped watershed and 2) to evaluate sediment and nutrient transport through open-water wetlands. Other investigators working on related projects are completing or have completed studies dealing with the sub-surface transport of septic leachate (Moul, 1994), streamflow and sediment transport modeling (Srinivasan, 1995), hydrologic and nutrient mass balance of small basins (Stiteler, 1998), and the effect of fragipans on hydrology and soil morphology in glacial till soils (Calmon, 1997).

To aid managers of the LWWMD in planning best-management practices, a watershed-based computer model that uses HSPF (Hydrologic Simulation

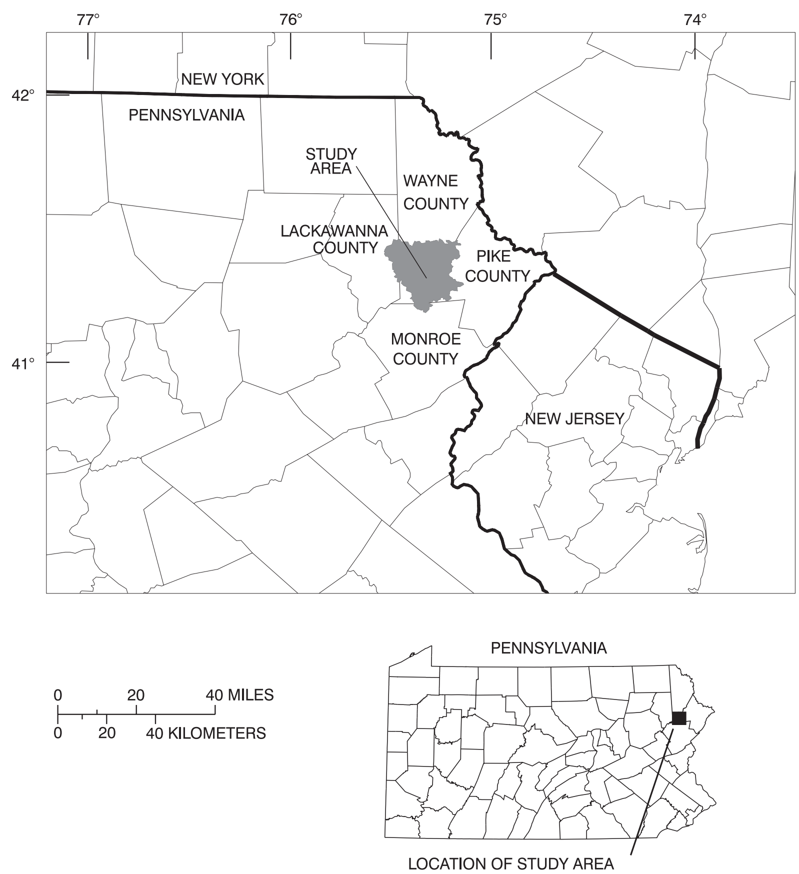


Figure 1. Location of Lake Wallenpaupack project study area.

Program-Fortran) has been developed for the basin by LAL (Srinivasan and others, 1998). The HSPF model (Johanson and others, 1980) is a comprehensive model for simulating a variety of hydrologic and sediment- and nutrient-transport processes from pervious and impervious land areas. The completed model, which was verified with hydrologic data collected from this investigation, provides a tool for planning responsible development throughout the Lake Wallenpaupack watershed.

Purpose and Scope

This report compares the concentrations and loads of suspended sediment and nutrients from mixed land-use basins in the Lake Wallenpaupack watershed that include wetlands, forest, agricultural land, and residential developments to those from a forested, undeveloped basin. The report also evaluates the effects of open-water wetlands on the transport of sediment and nutrients. Data analysis presented in the report covers the period October 1, 1992, through September 30, 1994, and attempts to quantify the hydrologic response of areas that substantially influence water quality in the Lake Wallenpaupack watershed. The data analysis was designed to provide calibration information for watershed-based computer models planned for the basin. Computers models provide a simulation tool for evaluating the hydrologic implications of altering current land-use conditions. A description of the study area, data-collection methods, and hydrologic analysis is included. Data presented in the report provide information to managers of the LWWMD for the development of management plans designed to protect water resources in the Lake Wallenpaupack watershed.

Approach

Five water-quality and streamflow-measurement stations were installed in the Lake Wallenpaupack Basin for measuring suspended-sediment and nutrient yields from different land uses and hydrologic settings (fig. 2) (table 1). Data from Ariel Creek and Purdy Creek were used to represent water quality in streams draining mixed land-use basins with residential development. Data from an unnamed tributary to Purdy Creek were used to represent water quality in streams draining forested, undeveloped basins. This basin has no identifiable external nutrient sources other than atmospheric inputs and was considered to represent a natural system characteristic of the region as a whole. Data from two sites on Stevens Creek, located at the inlet and outlet of an open-water wetland, were used to evaluate the surface-water transport of suspended sediment and nutrients through a wetland. Continuous precipitation and streamflow data were collected to develop water budgets. Analysis of water-quality samples collected at base flow and during stormflow were used to document chemical concentrations during these periods. Nutrient and sediment yields were calculated for each site to evaluate monthly and annual trends. A comprehensive database was developed for the project to archive data for the development of watershed-based computer models.

Acknowledgments

Special thanks are extended to Dr. Robert L. Cunningham for technical advice and encouragement throughout the project. The authors wish to acknowledge Chris Moul for his dedicated field work. The authors also thank the many landowners for providing access to private property during field data collection, especially Sando Parisi for providing access to the Stevens Creek sites, and the Lakeview Hunting Club for providing access to the site on the unnamed tributary to Purdy Creek. Finally, the authors would like to thank the PP&L and the LWWMD for their assistance in the design and implementation of the project.

Table 1. *Surface-water data-collection sites in the Lake Wallenpaupack Basin*
[mi^2, square miles]

Site number	U.S. Geological Survey station number	Station name	Drainage area (mi^2)
1	01431673	Ariel Creek near Ledgedale, Pa.	15.6
2	01431685	Purdy Creek at Lakeville, Pa.	8.18
3	01431683	Unnamed tributary to Purdy Creek near Lakeville, Pa.	.53
4	01431620	Stevens Creek near Sterling, Pa. (above wetland)	.81
5	01431621	Stevens Creek near Sterling, Pa. (below wetland)	.91

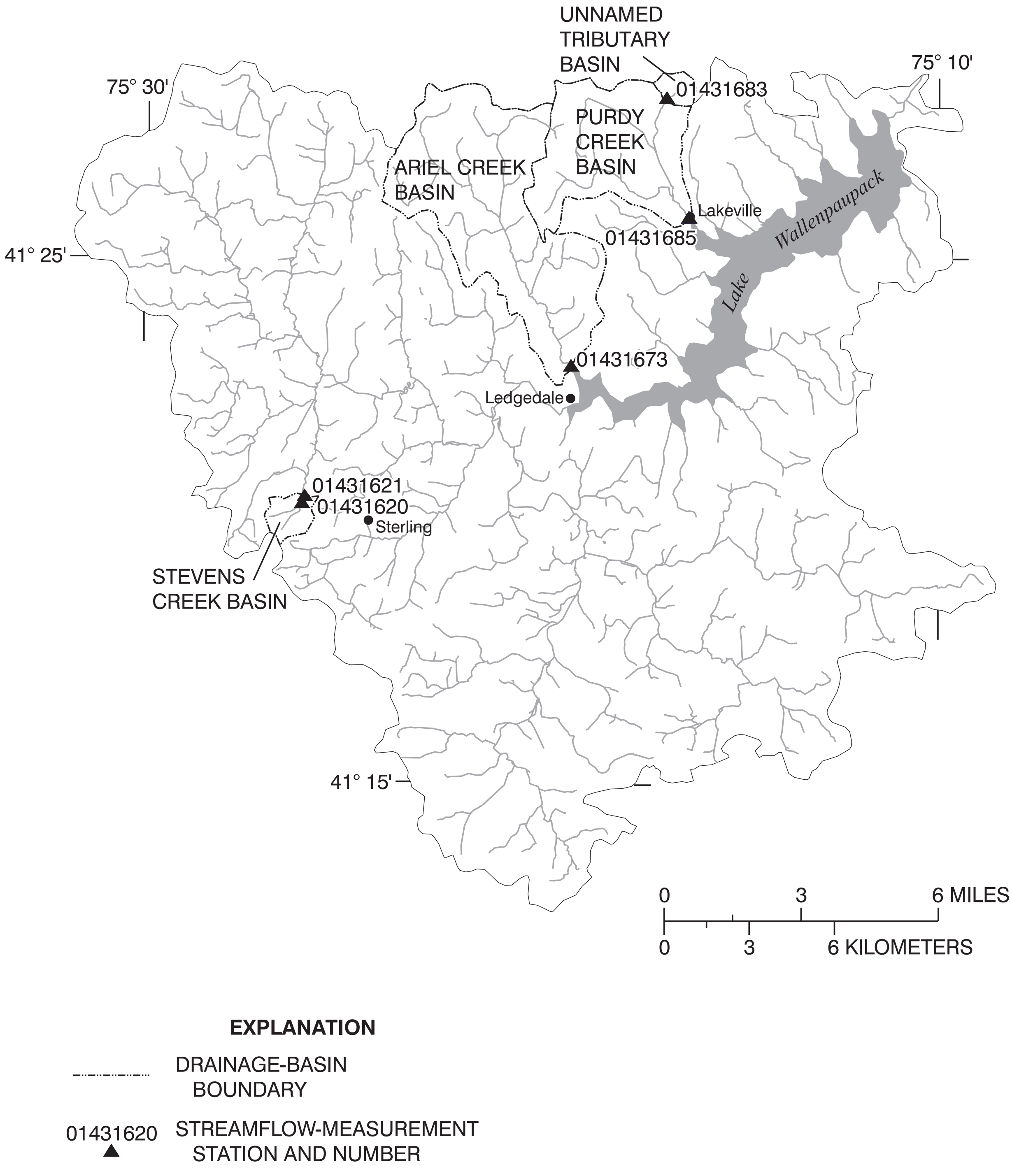


Figure 2. Lake Wallenpaupack project study area and monitoring sites.

DESCRIPTION OF STUDY AREA

Physical Setting

The Lake Wallenpaupack watershed lies in the Glaciated Plateau Section of the Appalachian Plateaus Physiographic Province in northeastern Pennsylvania. The dissected plateau is characterized by rolling, moderate relief with many broad flat uplands and the deranged drainage typical of glaciated areas. Wetlands and marshes are located throughout the watershed. Terminal moraines marking the southern boundary of the Late Wisconsin glaciation are approximately 40 mi south of the lake. Mixed hardwood and conifer forests cover approximately half of the watershed; the remainder is residential lots, farmland, and cleared fallow ground. Twenty-five tributaries of various sizes contribute streamflow to Lake Wallenpaupack, which was created by damming the largest of these—Wallenpaupack Creek.

Geology and Soils

The Lake Wallenpaupack watershed is underlain by Upper Devonian rocks of the Catskill Formation. The most notable feature of surficial geology is the presence of a blanket of glacial till of varying thickness over most of the landscape. Glacial outwash deposits are present in drainages and as terrace remnants. Extensive areas of the surface, especially in the higher elevations, are covered with small to large boulders or have exposed bedrock at the surface.

Soils in the area include the Arnot, Basher, Chippewa, Holly, Lordstown, Mardin, Morris, Norwich, Oquaga, Volusia, and Wellsboro series and, in the extensive wetlands, histosols Medihemists and Medifibrists (U.S. Department of Agriculture, 1985). The upper horizons of most soils are loams and sandy loams weathered from glacial till derived from the sandstone and shales of the Catskill Formation. These soils are pedogenically young; many are stony to extremely stony (U.S. Department of Agriculture, 1985). Extensive areas are poorly drained, frequently as a result of the presence of a fragipan. Fragipans are dense subsurface soil horizons that restrict the downward movement of roots and water. Nearly one third of Pennsylvania's landscape is covered by soils containing a fragipan; the largest concentration is in the glaciated regions (Ciolkosz and others, 1992). The depth of fragipans varies from 12 to 28 in. below the soil surface. The depth and thickness of fragipans are highly unpredictable and do not relate to slope, landform, or subbasin boundary.

Climate

In the Lake Wallenpaupack watershed, winters are cold and summers are moderately warm with occasional hot spells. Winter snowstorms are frequent. Precipitation is evenly distributed throughout the year and commonly is adequate for all crops typically grown in this area. The average daily temperature in summer is 18 °C; the average daily maximum is 26 °C. The average daily temperature in winter is -4 °C; the average daily minimum is -10 °C. Average yearly rainfall of 39.09 in. was calculated for the Lake Wallenpaupack area from data for a recent 10-year period (1980-90) from a National Weather Service (NWS) weather station at Hawley, Pa., near the northeast end of the lake.

Population

Northeastern Pennsylvania has experienced extensive development and population growth in the last two decades. The proximity of Lake Wallenpaupack to the densely populated New York City/Philadelphia corridor promotes the development of year-round and vacation homes. Pike County, which lies on the eastern side of the lake, experienced a population increase of 55 percent (from 18,000 to 28,000) from 1980 to 1990 (U.S. Department of Commerce, Bureau of the Census, 1994). In 1990, 18,000 vacation or weekend-use homes were in Pike County, equivalent to the number of housing units of all types in 1980 (U.S. Department of Commerce, Bureau of the Census, 1993). Wayne County, on the western side of the lake, is experiencing similar but somewhat slower growth. The population growth and watershed development coincides with a sharp decline in the farming industry. In Wayne County as a whole, the amount of farmland declined by 25 percent between 1978 and 1992, from 160,000 to 122,000 acres, and the number of working farms declined from 791 to 600 (U.S. Census Bureau, 1984; 1994).

INSTRUMENTATION, SAMPLING, AND ANALYTICAL TECHNIQUES

Data collection for hydrological studies is difficult because the variables measured frequently change rapidly and at irregular intervals. Storms are accompanied by major changes in streamflow, suspended sediment, and nutrient concentrations in streams. It is impossible to have scientific staff on site to collect the samples needed to document these changes. Therefore, remote capabilities with automatic samplers are required. The sections that follow outline the instrumentation and sampling protocols used to collect these critical data.

Precipitation

Precipitation data were collected at five sites at or near the streamflow-measurement stations. A tipping bucket rain gage in conjunction with digital recorders recorded precipitation at 15-minute intervals, which enabled the determination of the duration and intensity of storms and the daily, monthly, and annual precipitation totals. Precipitation data were estimated for periods of missing record by use of data from the NWS station at Hawley, Pa., which is 6 mi northeast of the study area. Snowfall and snow-accumulation data also were obtained from the NWS station at Hawley.

Streamflow

Stream stage (height) was recorded at each site at 15-minute intervals by use of a data-collection platform (DCP) equipped with satellite telemetry. V-notch weirs were installed in the small streams to create sampling pools and to stabilize the stream channel. Stage-streamflow relations were defined by making regular streamflow measurements by use of methods described by Buchanan and Somers (1969). Streamflow usually was measured with a current meter. Low-flow measurements were made at the weir by volumetric methods. Stream stages were converted to streamflow by use of methods described in Carter and Davidian (1968). Missing data at a site were estimated by comparing hydrographs from the operating stations in the study area. Missing data resulted from equipment failure that was detected through daily checks of the transmitted DCP data. The defective equipment was replaced usually within 24 hours. Streamflow data were used to calculate water budgets and nutrient and sediment loads.

Water Quality

Water samples were collected manually at the streamflow-measurement stations during base-flow periods at least once a month. An automatic sampler was used to collect stormwater samples at 30-minute intervals throughout a storm. The sampler was triggered by a computer program stored in the DCP that compares stage data from scan to scan. The sampler was triggered if the difference in stage between scans exceeded a preset threshold. To the extent possible, a five-sample subset of the samples collected by the automatic sampler during storm runoff was saved for laboratory analysis. The subset of samples used to represent the storm hydrograph included two samples during the rise, one sample at or near the peak, and two samples during the recession.

Water samples were collected by methods described in Guy and Norman (1970). Samples analyzed for dissolved constituents were filtered with a 0.45-µm filter. Nutrient analysis were performed by the USGS National Water-Quality Laboratory (NWQL) in Lakewood, Colo., for concentrations of dissolved nitrate plus nitrite, total ammonia plus organic nitrogen, dissolved ammonia, total phosphorus, and dissolved orthophosphate phosphorus. Nutrients were analyzed according to methods described by Skougstad and others (1979). Detection limits are listed in table 2. Samples were also collected for analysis of suspended-sediment concentrations. Concentrations of suspended sediment were determined at the USGS sediment laboratory in Lemoyne, Pa., by use of methods described by Guy (1969).

Quality Assurance

Quality-assurance measures were practiced throughout the study, both in field sampling and in laboratory analyses. Field samples were collected according to published methods. Sampling containers were obtained from the USGS Quality Water Service Unit in Ocala, Fla. These containers are pre-cleaned and quality assured at the Ocala facility. In addition, USGS field personnel participate in a USGS-operated National Field Quality Assurance program each year that tests

Table 2. *Nutrient laboratory analysis for surface-water samples*

Chemical constituent	U.S. Geological Survey parameter code	Detection limit
Dissolved nitrate plus nitrite (as nitrogen)[1]	00631	0.05
Total ammonia plus organic nitrogen (as nitrogen)[1]	00625	.20
Dissolved ammonia (as nitrogen)[1]	00608	.01
Total phosphorus (as phosphorus)[2]	00665	.01
Dissolved orthophosphate (as phosphorus)[3]	00671	.01

[1] All nitrogen compounds reported as N.
[2] All phosphorus compounds reported as P.
[3] Dissolved orthophosphate (as phosphorus) will be referred to as dissolved orthophosphate throughout the report.

abilities to correctly measure pH, specific conductance, temperature, and alkalinity.

Duplicate samples were collected on four occasions from Ariel Creek, on three occasions from Purdy Creek, once from Stevens Creek, and twice from the unnamed tributary to Purdy Creek and analyzed for the same nutrients as the routine samples. Most duplicate samples had the same concentration as the routine sample. The maximum deviation of duplicate samples from routine samples was 0.02 mg/L for phosphorus, 0.01 mg/L for ammonia nitrogen, 0.01 mg/L for nitrite plus nitrate nitrogen, 0.1 mg/L for ammonia plus organic nitrogen, and 0.11 mg/L for organic nitrogen.

Field-blank samples were collected and submitted for analysis on two occasions. Concentrations of nutrients in blank samples were less than detection limits except for ammonia and ammonia plus organic nitrogen. The concentration of ammonia in one sample was 0.01 mg/L, which is the detection limit. The second blank sample analyzed for ammonia had a concentration of less than the detection limit. The concentration of ammonia plus organic nitrogen in one blank sample was 0.7 mg/L. The second blank had a concentration of less than 0.2 mg/L, which is the detection limit.

Samples collected from an automatic sampler (which samples from a single point) may be biased for streams that are not completely mixed. Therefore, at each of the five stream-sampling locations used in this study, cross-sectional profiles of specific conductance and pH were measured. These profiles verified that each sampling site was well mixed. This is to be expected because the streams are small and turbulent.

Laboratory quality-control (QC) practices include analyses conducted according to published protocols, routine instrument maintenance, and participation in interlaboratory-comparison and performance-evaluation tests. The NWQL routinely scores very high in these tests. In addition, QC samples are analyzed at a minimum of 1 in every 10 samples. These QC samples include standard reference-water samples, laboratory duplicates (splits), standard solutions, blanks, and spikes. QC practices of the NWQL are documented in Pritt and Raese (1995).

In summary, these quality-assurance measures provide confidence that the data collected for the project are of high quality.

DATA ANALYSIS

Data analysis is critical for interpreting the findings of this study. Although the field-data-collection part of the study covered a period of 2 years, this is a short period of time to observe hydrological phenomena. Hydrological variability during the data-collection period was large. Therefore, careful data analysis is important for making sound interpretations. The sections that follow detail how the data were analyzed.

Water-Budget Calculations

Water budgets were calculated for each basin to evaluate the distribution of precipitation and to compare hydrologic conditions for the 1993 and 1994 water years. Assuming no ground-water transfer across basin boundaries and no change in ground-water storage, the annual water budget may be expressed as

$$P = R_s + R_g + ET, \qquad (1)$$

where P is precipitation,
R_s is surface runoff,
R_g is base flow, and
ET is evapotranspiration.

If the above assumptions are not met, the water-budget calculations may not represent actual field conditions. It was beyond the scope of this project to collect data to evaluate changes in storage, basin transfer of ground water, and evapotranspiration. Evapotranspiration was assumed to be the difference between total streamflow ($R_s + R_g$) and precipitation.

Surface runoff and base flow (fig. 3) were determined through hydrograph separation of total streamflow (Pettyjohn and Henning, 1979). Software developed by Sloto and Crouse (1996) was used to complete these calculations. The hydrograph-separation software included the fixed interval, sliding interval, and local minimum methods. Base flow calculated by the fixed interval and sliding interval methods were within 1 percent; the local minimum method calculated about 7 percent less base flow than the other methods. The fixed interval method was used for hydrograph separation in this investigation.

Descriptive Statistics

Basic descriptive statistics, including maximum, minimum, and median concentrations, were calculated by the use of standard statistical programs. To evaluate and compare chemical-concentration data from station to station, this information is presented in standard boxplots. Concentration data clustered near detection limits resulted in incomplete boxplots in some cases. The box-

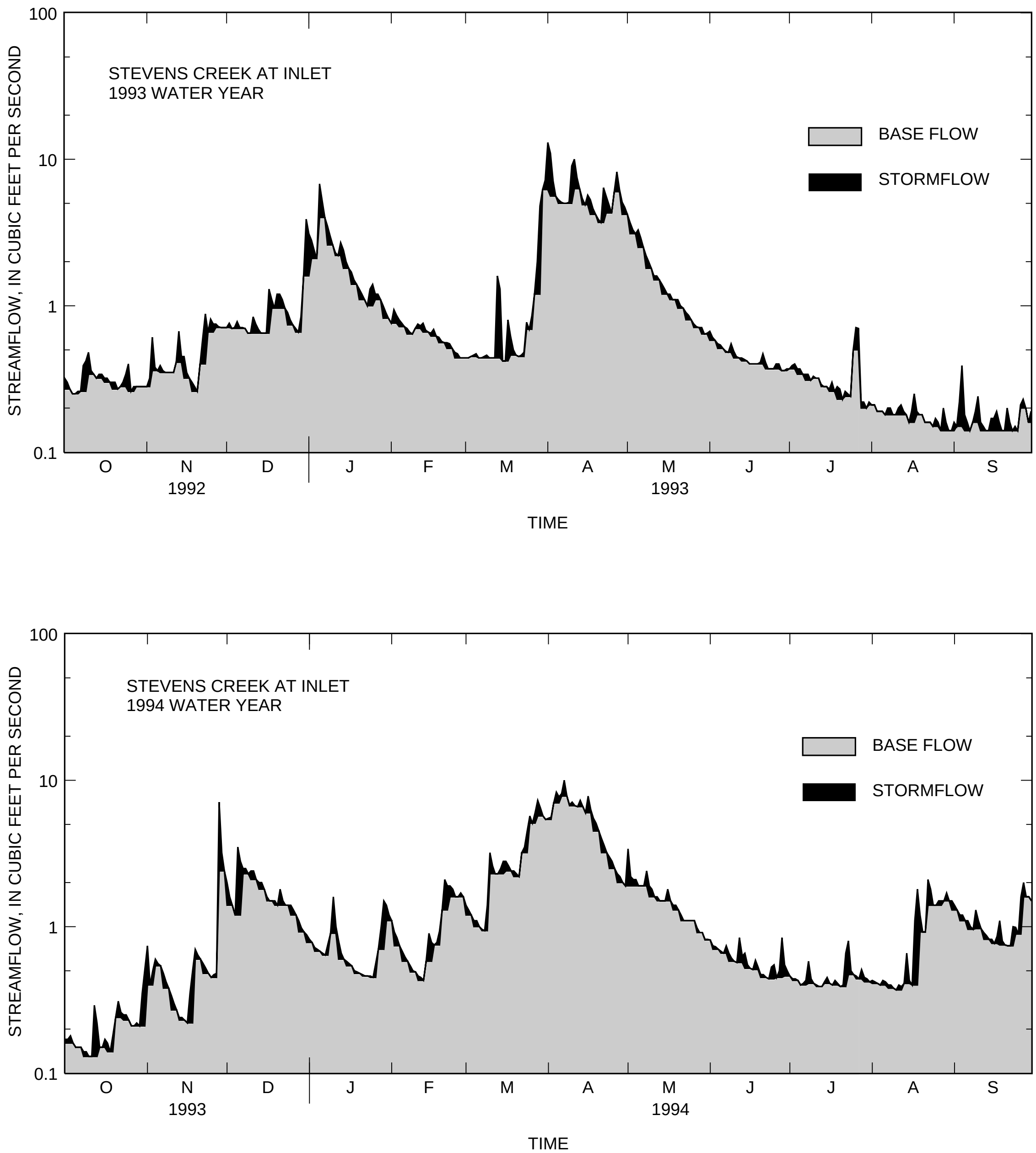


Figure 3. Hydrographs showing base-flow separation of streamflow for Stevens Creek.

plots provide a visual summary of over 200 separate chemical-concentration analyses at some sites.

Statistical Analysis

Statistical significance of differences in concentrations of nutrients and sediment measured at different sampling sites was determined through a paired sample analysis in order to remove any bias caused by differential sampling intensity at any single site. When comparing two sites, paired samples were determined by eliminating observations for which data were incomplete for both sites being evaluated. Paired differences in concentration were calculated from the paired samples by arbitrarily subtracting concentrations measured at one site from the other. The absolute values of the differences were evaluated for statistical significance by use of the nonparametric, Wilcoxon signed-rank test (Helsel and Hirsch, 1992) and MINITAB Release 11 statistical software. The null hypothesis of the test was that the median of the differences equaled 0.0, which, if not rejected, would indicate that the concentrations collected at the two sites were not significantly different. Separate statistical analyses were conducted for stormflow and base-flow nutrient samples. Separate stormflow and base-flow analyses were not conducted for sediment samples because most significant sediment concentrations were associated with stormflow samples.

The concentration data were pre-processed to group, or average, samples in order to create paired observations. This grouping was necessary because ideal paired samples were rarely available for several reasons. Automatic samplers commonly collected different numbers of samples at each site and at slightly different times throughout a storm event. Base-flow samples commonly were collected over a 2-day period because of the number and spacing of the sites, and sometimes additional base-flow samples were collected at individual sites.

Stormflow samples were grouped on a daily basis by calculating a flow-adjusted average daily concentration for each site by use of all samples collected for that day. Base-flow samples were grouped on a bimonthly basis by calculating a flow-adjusted average concentration for each site by use of all samples collected during the first or second half of an individual month. The paired observations, if they existed, were then matched, used to calculate paired differences, and used in the Wilcoxon signed-rank test.

Load Calculations

Annual loads of suspended sediment and nutrients were computed by use of a 7-parameter log-linear multiple regression model developed by Cohn and others (1989). The model was validated by Cohn and others (1992) with repeated split-sample studies. The model was used at nine monitoring stations for the Chesapeake Bay Nutrient Monitoring Program (Maryland Department of the Environment, 1992). The model is developed from measured streamflow and concentration data. Continuous daily mean streamflow data are used in the derived regression model to calculate mean daily chemical concentrations. The model is a multiple-regression equation of the form:

$$\ln[C] = \beta_o + \beta_1 \ln[Q/\bar{Q}] + \beta_2\{\ln[Q/\bar{Q}]\}^2 + \beta_3[T - \bar{T}] + \beta_4[T - \bar{T}]^2 + \beta_5 \sin[2\pi T] + \beta_6 \cos[2\pi T] + \varepsilon, \tag{2}$$

where *ln* is the natural logarithm function;

C is measured concentration, in milligrams per liter;

Q is measured streamflow, in cubic feet per second;

T is time, measured in decimal years;

$\bar{Q}$ and $\bar{T}$ are centering variables for discharge and time;

β_x are parameters estimated by ordinary least squares; and

ε is combined independent random error, assumed to be normally distributed with zero mean and variance σ_ε^2.

Mean daily concentrations predicted by the model are combined with mean daily streamflow to calculate daily loads as follows:

$$L_T = \sum_{t=1}^{T} \{C_{i,t} \times Q_t \times K\}, \tag{3}$$

where L_T is calculated load over time interval T for constituent *i*;

$C_{i,t}$ is predicted concentration of constituent *i* for day *t*, in milligrams per liter (calculated by the model);

Qt is measured mean daily streamflow for day *t*, in cubic feet per second; and

K is conversion factor $2.699 \times 10^{-3} \dfrac{\mathrm{s \times L \times ton}}{\mathrm{ft^3 \times mg \times d}}$,

where s is seconds, L is liters, ton is tons, ft^3 is cubic feet, mg is milligrams, and d is days.

(The model usually reports estimated loads in kilograms per day; for this study, the *K* listed above converts kilograms per day to tons per day.)

Data Archival

Time-series data from this investigation were archived in a USGS Watershed Data Management System (WDMS) database for the purpose of calibrating and verifying watershed models planned for the study area. A USGS utility program, ANNIE, was used to create and manipulate the WDMS database (Lumb and others, 1990). Data stored in the WDMS format can directly serve as model input and act as data storage for model output in watershed simulations. The WDMS database created for this project is listed in the Appendix.

INFLUENCE OF LAND USE ON WATER QUALITY

Development in the Lake Wallenpaupack Basin may be affecting water quality. The following sections give detailed findings from the study regarding effects of development on suspended sediment, nitrogen, and phosphorus.

Description of Monitoring Sites

Hydrologic and water-quality data collected from two mixed land-use basins and one undeveloped, forested basin were studied to analyze the effects of land use on water quality. Data from Ariel Creek (station 01431673) and Purdy Creek (station 01431685) represent basins with nutrient inputs from atmospheric, agricultural, and residential sources. The Ariel Creek Basin also has nutrient inputs from a sewage-treatment plant. Data from an unnamed tributary to Purdy Creek (station 01431683) represents an undeveloped, forested basin with outside inputs of nutrients only from atmospheric sources.

The Ariel Creek Basin has a drainage area of 15.6 mi^2. The drainage area of the Purdy Creek Basin is 8.18 mi^2. The forested basin is 0.53 mi^2 and is located in the headwaters of Purdy Creek Basin above any areas of agricultural and residential land use. Approximately 70 percent of the Ariel Creek and Purdy Creek Basins contain soils with fragipans. Most surface area is within the 3- to- 8-percent slope classification. The maximum and minimum elevations are 1,679 and 1,200 ft in Ariel Creek, and 1,595 and 1,204 ft in Purdy Creek. Relief of the undeveloped, forested basin is moderate, varying from an elevation of around 1,330 ft at the streamflow-measurement station to a high of 1,595 ft at the eastern side of the basin. Extensive areas of the surface, especially in the higher elevations, are covered with small to large boulders or have exposed bedrock at the surface.

Ariel Creek and Purdy Creek Basins contain significant areas of recent residential development. Land-use maps at a scale of 1:12,000 (fig. 4 and fig. 6) were prepared by use of USGS 1:40,000 black-and-white aerial photographs from April 1992 and 1:12,000 USGS Digital Orthophoto Quarter Quad (DOQQ) data (fig. 5 and fig. 7) for Wayne County, Pa. Land use in the Ariel Creek and Purdy Creek Basins is shown in table 3.

Land cover in the undeveloped, forested basin is dominated by mixed conifer and deciduous forest. A 14-acre wetland, vegetated by sedges, cattail, hummocky grasses, and some woody herbaceous plants, lies near the upper end of the basin. Much of the streamcourse between this headwater wetland and the streamflow-measurement station is also flanked by a forested riparian wetland. The 14-acre wetland is underlain by a soil containing a fragipan.

Hydrologic Conditions

Hydrographs of Ariel Creek, Purdy Creek, and the unnamed tributary reflect seasonal variations in streamflow, which is affected by precipitation and evapotranspiration. Although precipitation was distributed throughout the year, the greatest streamflows were during March and April from snowmelt runoff (fig. 8). A water budget developed for the three basins reflects the distribution of precipitation (table 4). Precipitation for the 1993 water year[1] at the Ariel Creek rain gage was 34 in., which is 13 percent lower than the recent 10-year average for the NWS rain gage at Hawley, Pa. Rainfall for the 1994 water year was 49 in. or 25 percent higher that the 10-year average at Hawley. Mean stormflow for the 1993 and 1994 water years was about 25 percent of total streamflow; base flow averaged 75 percent of total streamflow at all three basins. The unnamed tributary experienced several periods of no flow, especially during drought conditions in the 1993 water year.

[1] A water year begins on October 1 and ends on September 30.

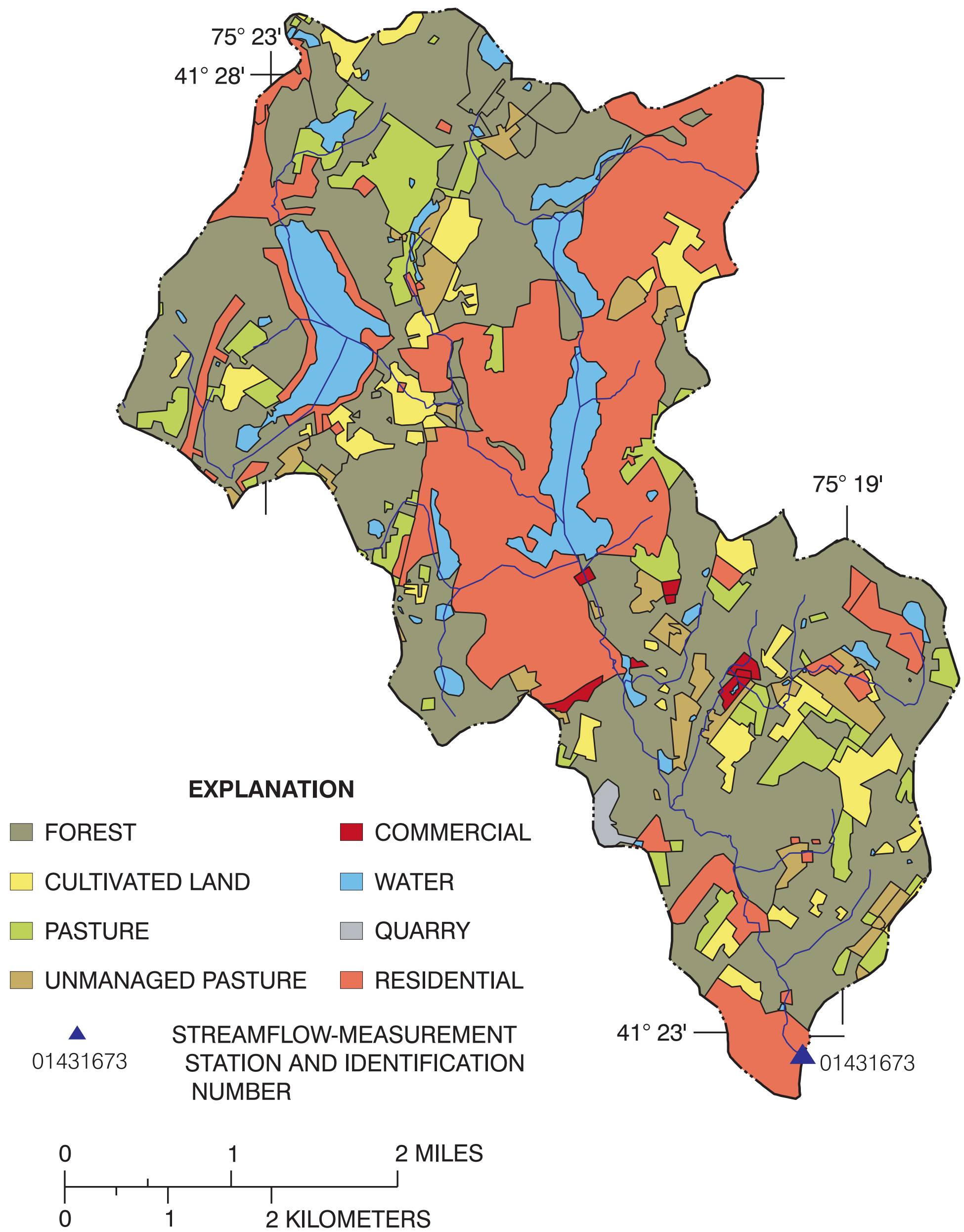


Figure 4. Land cover in the Ariel Creek Basin.

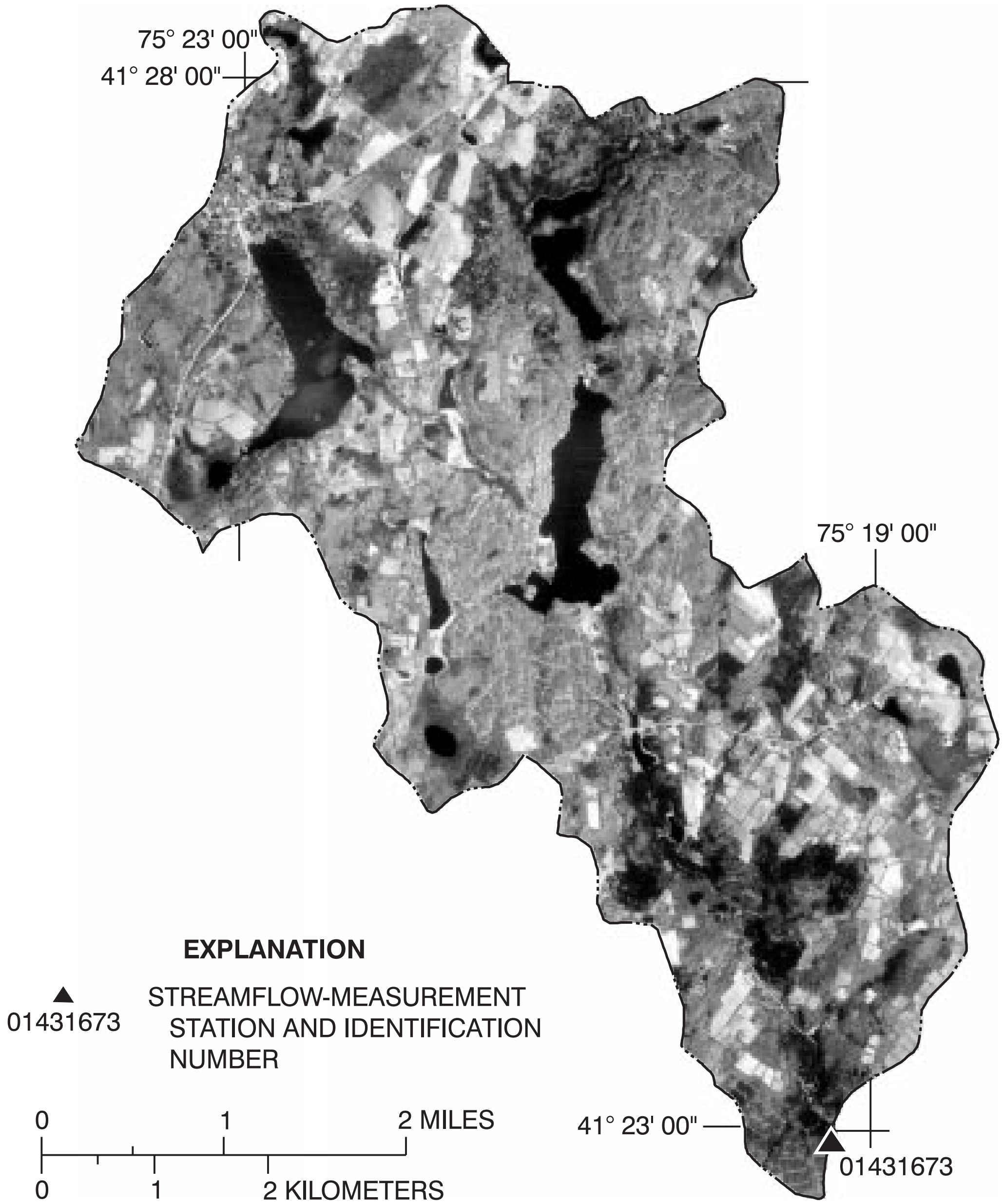


Figure 5. Digital orthophoto of the Ariel Creek Basin.

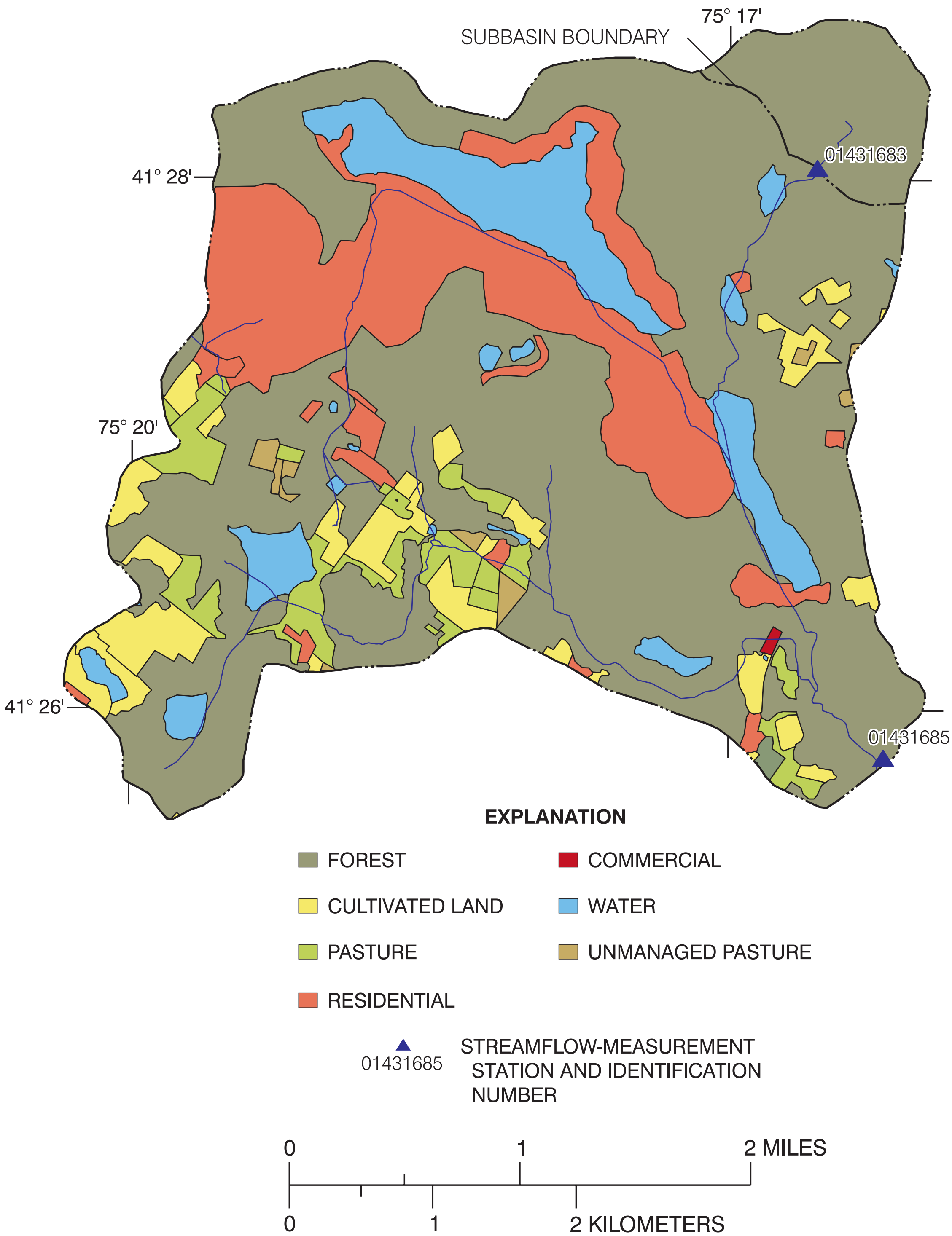


Figure 6. Land cover in the Purdy Creek Basin.

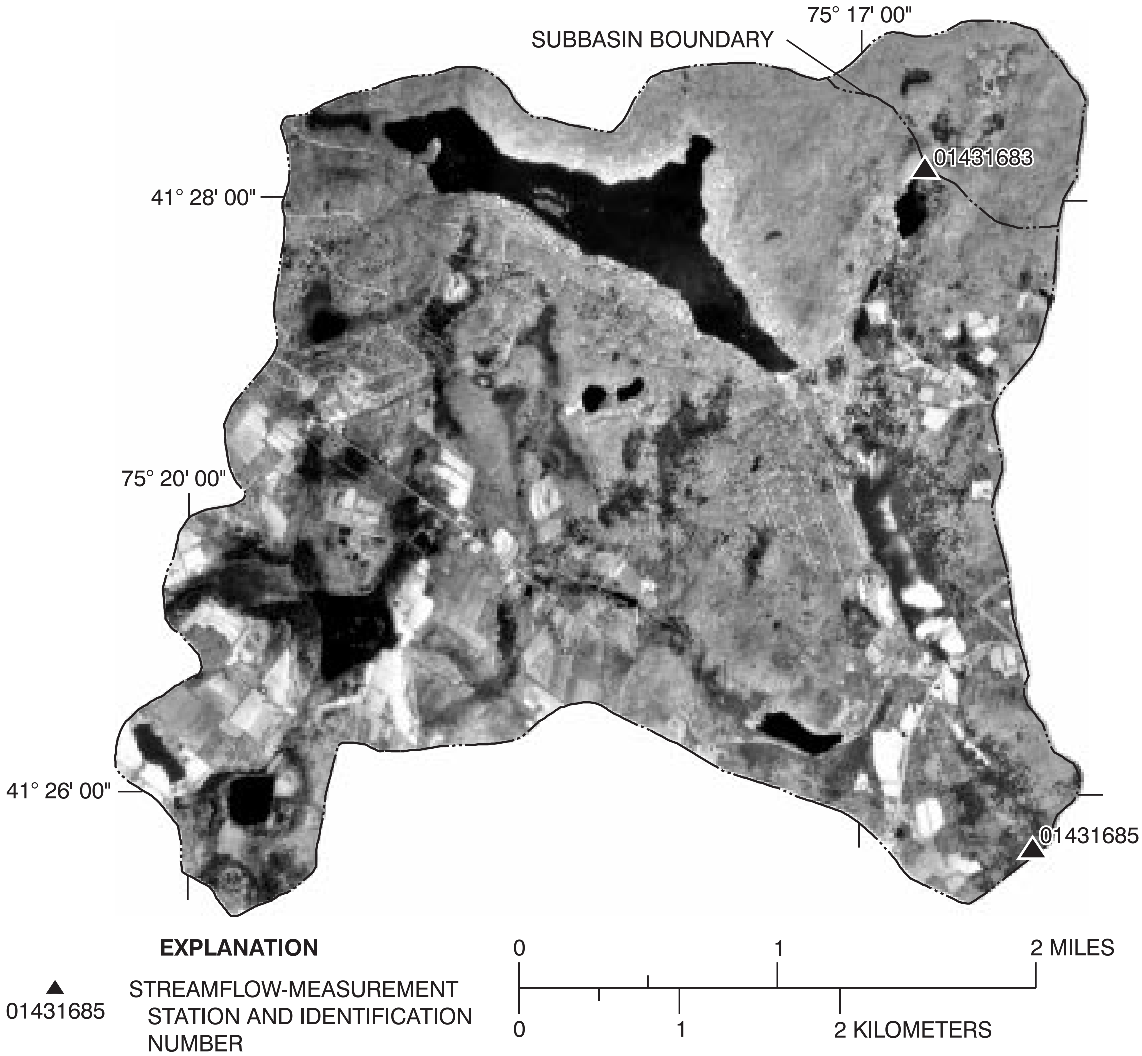
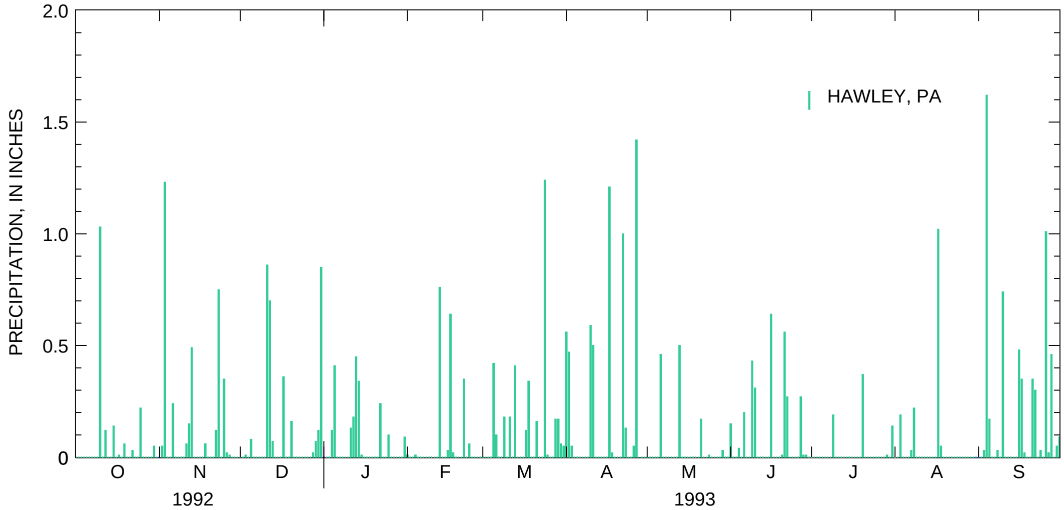
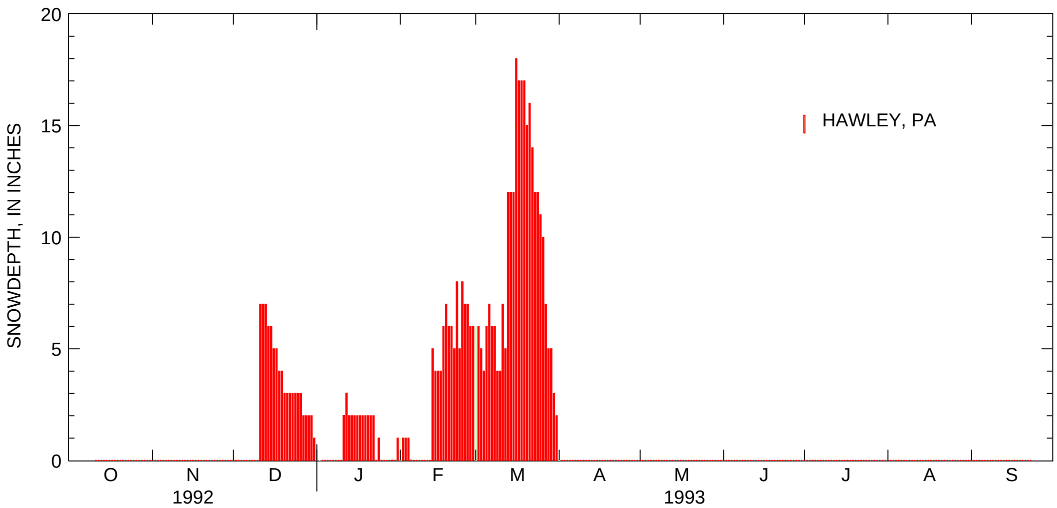


Figure 7. Digital orthophoto of the Purdy Creek Basin.

Table 3. *Land cover in the Ariel Creek and Purdy Creek Basins*

	Ariel Creek		Purdy Creek		Unnamed tributary	
	Square miles	Percentage	Square miles	Percentage	Square miles	Percentage
Forest	7.26	46.54	4.98	60.90	0.50	94.76
Cropland	1.14	7.33	.35	4.26	.00	.00
Pasture	1.89	12.14	.61	7.49	.00	.00
Residential	4.10	26.27	1.50	18.29	.00	.00
Commercial	.08	.49	.00	.06	.00	.00
Water	1.13	7.22	.74	8.99	.03	5.24





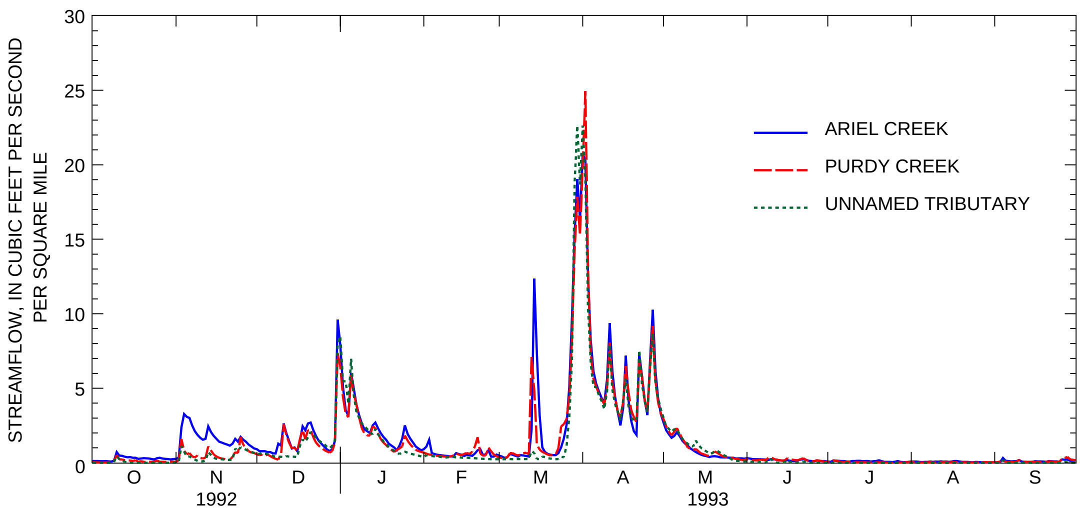


Figure 8. Streamflow hydrograph of Ariel Creek, Purdy Creek, and unnamed tributary, showing relation to precipitation and snowmelt at Hawley, Pa., 1993 water year.

Table 4. *Annual water budgets for Ariel Creek, Purdy Creek, and unnamed tributary basins for 1993 and 1994 water years*

Water year	Precipitation	Evapotranspiration		Total streamflow		Base flow[1]		Stormflow[1]	
	Inches	Inches	Percentage[2]	Inches	Percentage[2]	Inches	Percentage[3]	Inches	Percentage[3]
				Ariel Creek Basin					
1993	34.0	13.9	40.9	20.1	59.1	14.6	72.6	5.5	27.4
1994	49.0	25.3	51.6	23.7	48.4	18.6	78.5	5.1	21.5
Mean	41.5	19.6	47.2	21.9	52.8	16.6	75.8	5.3	24.2
				Purdy Creek Basin					
1993	34.0	16.5	48.5	17.5	51.5	12.6	72.0	4.9	28.0
1994	49.0	22.0	44.9	27.0	55.1	20.7	76.7	6.3	23.3
Mean	41.5	19.2	46.3	22.3	53.7	16.7	74.9	5.6	25.1
				Unnamed tributary basin					
1993	34.0	18.3	53.8	15.7	46.2	11.6	73.9	4.1	26.1
1994	49.0	26.4	53.9	22.6	46.1	17.0	75.2	5.6	24.8
Mean	41.5	22.4	54.0	19.1	46.0	14.3	74.9	4.8	25.1

[1] From hydrograph separation.
[2] Percentage of precipitation.
[3] Percentage of streamflow.

Water Quality

To evaluate the effects of land use on water quality, water samples were collected and analyzed for concentrations of suspended sediment and nutrients. The concentration data are summarized in the form of boxplots for the purpose of comparing the three study areas. The concentration and streamflow data also were used to calculate sediment and nutrient loads by use of the multiple regression model developed by Cohn and others (1989). Sediment and nutrient loads were calculated for the 1993 and 1994 water years. Sediment and nutrient loads in 1994 exceeded 1993 values at all stations because of greater streamflow. The increase in streamflow in 1994 was a result of an additional 10 in. of precipitation compared to conditions in 1993.

Suspended Sediment

Suspended-sediment concentrations are shown in figure 9. The median concentration of all samples collected at the forested basin was 2.0 mg/L. This compares to median concentrations of 11.0 and 9.0 mg/L for Ariel Creek and Purdy Creek, respectively. Maximum concentrations were during storms for all three basins.

These concentrations represent significant differences on the basis of the paired samples used in the Wilcoxon signed-rank test (table 5).

Suspended-sediment loads and yields were calculated for all three basins (table 6) (fig. 10). The 1994 suspended-sediment yield for the undeveloped basin was 15 ton/mi^2. This was about four times less than the 65 ton/mi^2 at Ariel Creek and 2.8 times less than the 39 ton/mi^2 at Purdy Creek. The highest monthly yields for all stations were during March and April for both years. Melting of the winter snowpack resulted in high streamflow. In 1994, suspended-sediment yields for March and April accounted for 67 percent, 57 percent, and 62 percent of the total annual yield for Ariel Creek, Purdy Creek, and the unnamed tributary, respectively. Total suspended-sediment load to Lake Wallenpaupack for the 2 years was 1,829 ton for Ariel Creek and 562 ton for Purdy Creek. The suspended-sediment load from the undeveloped basin was 16 ton for the 2-year period. The basins of Ariel Creek and Purdy Creek contain significant agricultural and urban land compared to the unnamed tributary. Exposed soil in these areas is easily eroded and contributes to the sedimentation in the stream and lake. Also, these basins contain impervious areas such as parking lots, roads, and rooftops. Rainfall on these surfaces creates accelerated storm runoff that can erode drainage channels and contribute to sedimentation problems.

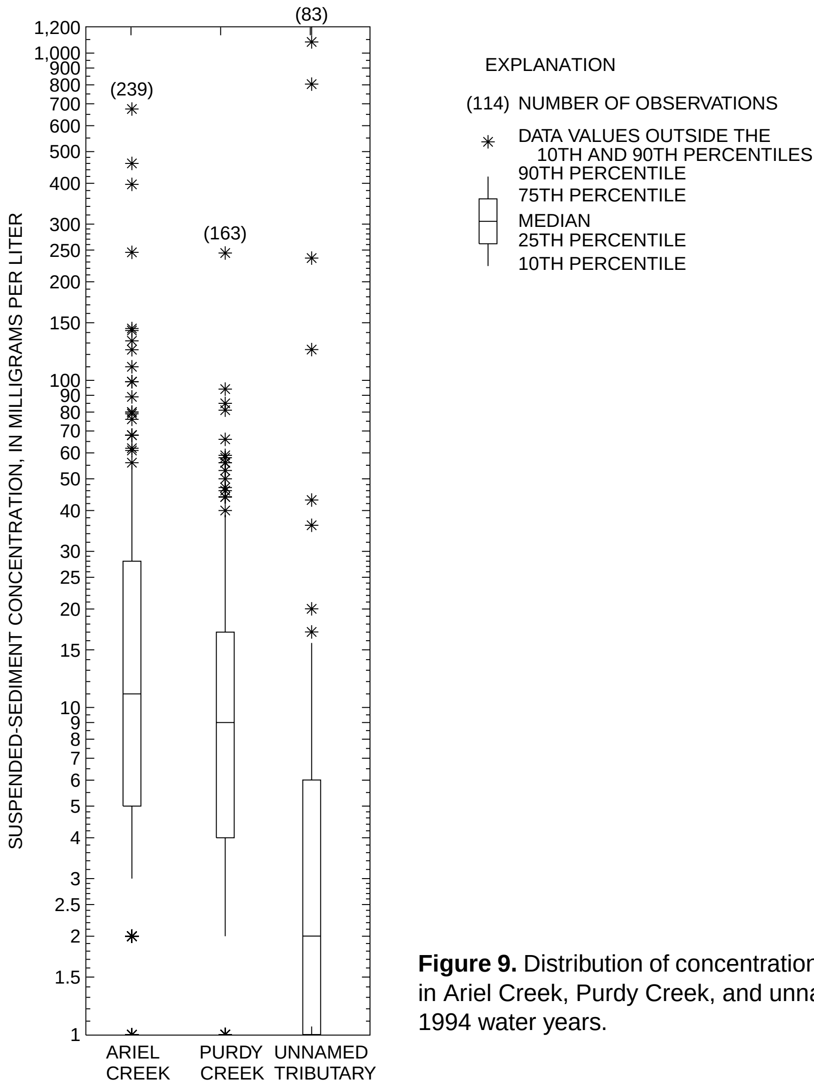


Figure 9. Distribution of concentrations of suspended sediment in Ariel Creek, Purdy Creek, and unnamed tributary,1993 and 1994 water years.

Table 5. *Median differences in sediment concentrations between Ariel Creek, Purdy Creek, and unnamed tributary*

[Median differences are in milligrams per liter; shaded values are statistically significant at the 95-percent confidence level based upon a Wilcoxon signed-rank test; n, number of paired samples where non-zero concentration differences were found]

Comparison	Sediment		Total number of paired samples
	Median	n	
Ariel - Purdy	5.15	62	66
Ariel - unnamed tributary	13.50	35	36
Purdy - unnamed tributary	11.61	27	27

Table 6. *Monthly and annual suspended-sediment loads for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years*

[Loads are in tons]

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
							1993 water year						
Ariel Creek	3.6	46	37	55	3.8	230	418	21	1.9	0.91	0.49	0.96	819
Purdy Creek	.48	4.6	12	21	1.7	58	131	8.2	.75	.11	.06	.53	240
Unnamed tributary	.05	.40	.67	1.2	.03	1.6	3.2	.40	.01	0	0	0	7.6
							1994 water year						
Ariel Creek	5.1	112	38	14	27	295	388	25	9.1	8.1	79	7.4	1,010
Purdy Creek	7.1	35	22	5.1	8.4	73	110	18	5.9	1.7	25	11	322
Unnamed tributary	.05	.58	.36	.04	.08	1.6	3.3	1.1	.23	.02	.38	.23	7.9

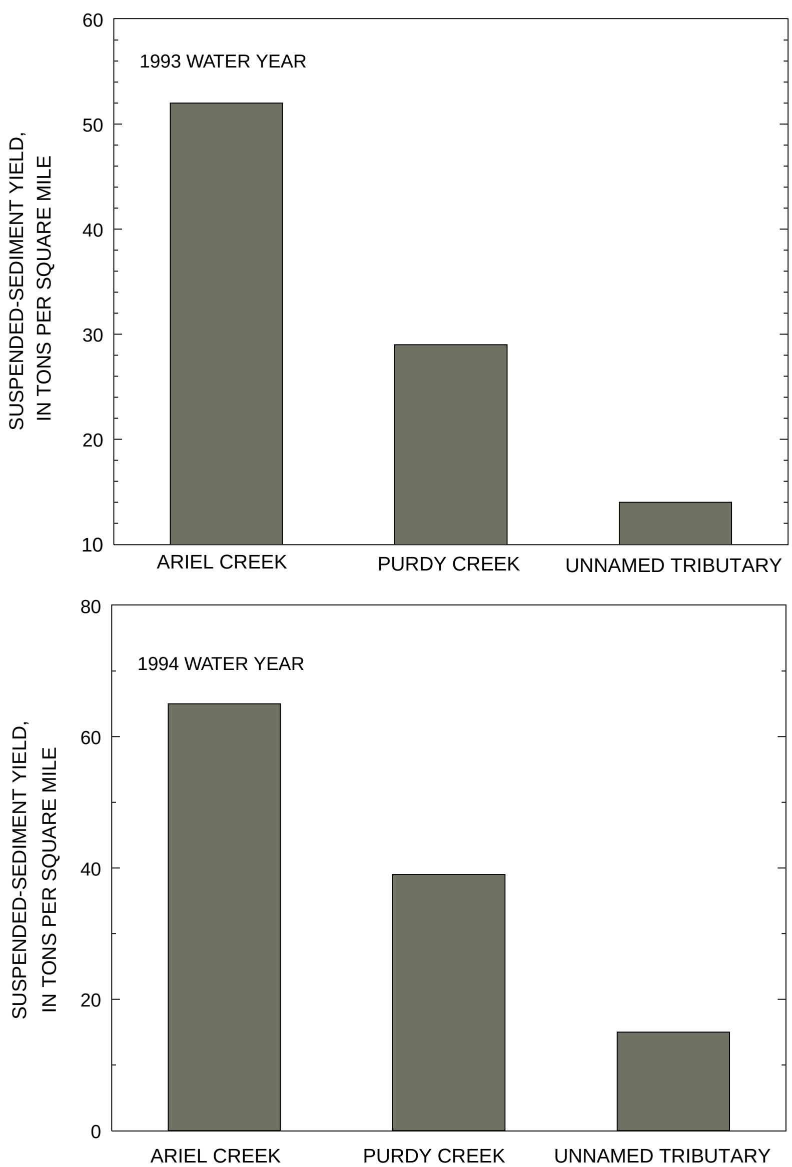


Figure 10. Annual yields of suspended sediment for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years.

Nitrogen

Concentration data for nitrogen species are shown on figure 11. Concentrations of total nitrogen ranged from 0.26 to 2.73 mg/L for Ariel Creek and 0.28 to 1.82 mg/L for Purdy Creek. In the forested basin, concentrations ranged from 0.20 to 3.50 mg/L. The median concentration of all samples collected at the forested site was 0.33 mg/L, compared to the median concentration of 0.87 mg/L at Ariel Creek and 0.70 mg/L at Purdy Creek. Base-flow and stormflow concentrations of total nitrogen were significantly higher in the Ariel Creek and Purdy Creek Basins compared to the unnamed tributary (table 7). Stormflow total-nitrogen concentrations at Ariel Creek and Purdy Creek did not differ significantly.

Median concentrations of dissolved nitrate plus nitrite in samples collected at the forested site were significantly lower than in samples collected at Ariel Creek and Purdy Creek during base-flow and stormflow conditions (table 7). The median concentration of 0.05 mg/L at the forested site was 10 times lower than the 0.46 mg/L median concentration at Ariel Creek and 5 times lower than the 0.28 mg/L median concentration at Purdy Creek. Nitrate plus nitrite concentrations ranged from 0.05 to 1.30 mg/L for Ariel Creek and 0.05 to 0.94 mg/L for Purdy Creek. Concentrations of nitrate plus nitrite in the forested basin ranged from 0.05 to 2.80 mg/L. The peak concentration of 2.80 mg/L in the forested basin was on September 3, 1993, at 2130 hours during a storm that followed a 2-month drought. Consecutive samples collected at 2200 hours and at 2230 hours contained nitrate plus nitrate concentrations of 1.90 mg/L and 1.30 mg/L, respectively.

Nitrogen export from the three study areas is shown in table 8 and figure 12. Annual yields for total nitrogen for Ariel Creek and Purdy Creek were between three and five times greater than yields from the undeveloped, forested basin. All three basins displayed seasonal differences. Most of the annual yield was during early spring as a result of high flows during snowmelt. The lowest monthly yields were during the summer months, the period of lowest streamflow volumes. The combined total load of nitrogen for the 1993 and 1994 water years was 86,600 lb for Ariel Creek, 44,700 lb for Purdy Creek, and 662 lb for the unnamed tributary. About 78 percent of the total nitrogen exported from the forested site was in the form of organic nitrogen. By comparison, organic nitrogen represented 40 percent and 49 percent of the total nitrogen exported from Ariel Creek and Purdy Creek, respectively.

Annual yields of dissolved nitrate plus nitrite from Ariel Creek and Purdy Creek were substantially greater than the annual yields from the undeveloped basin. Nitrate plus nitrite export represented 55 percent and 44 percent of the export of total nitrogen for Ariel Creek and Purdy Creek, respectively, and 4.4 percent for the forested site. Nitrogen in this form is more available for plant uptake than organic nitrogen and therefore represents a potential eutrophication problem to downstream water bodies. For the 1993 water year, the annual yield for dissolved nitrate plus nitrate from Ariel Creek Basin was 1,410 lb/mi^2 or about 60 times greater than the 24 lb/mi^2 from the undeveloped basin. During the 1994 water year, the yields of nitrate plus nitrite from the Ariel Creek and Purdy Creek Basins were more than 50 times the yield from the forested basin. The stream draining the undeveloped, forested basin was sampled at a point just upstream of residential and agricultural developments on Purdy Creek. The yield of dissolved nitrate plus nitrite at this point in the basin averaged 27 lb/mi^2 per year for the 1993 and 1994 water years. By comparison, the downstream location on Purdy Creek below the residential and agricultural developments averaged 1,220 lb/mi^2 per year. These differences may be attributed to excess nitrogen from agricultural fertilizers, animal waste, lawn fertilizers, and on-lot septic systems.

For the 1993 water year, the yields of dissolved ammonia nitrogen from the developed basins of Ariel Creek and Purdy Creek were about three times higher than yields from the undeveloped, forested basin. In 1993 and 1994, peak loads were during March and April for all three basins. In 1993 and 1994, loads of dissolved ammonia nitrogen for March and April accounted for about 62 percent of the total annual loads at all three stations. The total load to Lake Wallenpaupack from Ariel Creek and Purdy Creek was 5,060 lb and 3,720 lb, respectively, for the 2 years. The total load from the undeveloped basin was 79 lb during this period; 48 lb were during March and April.

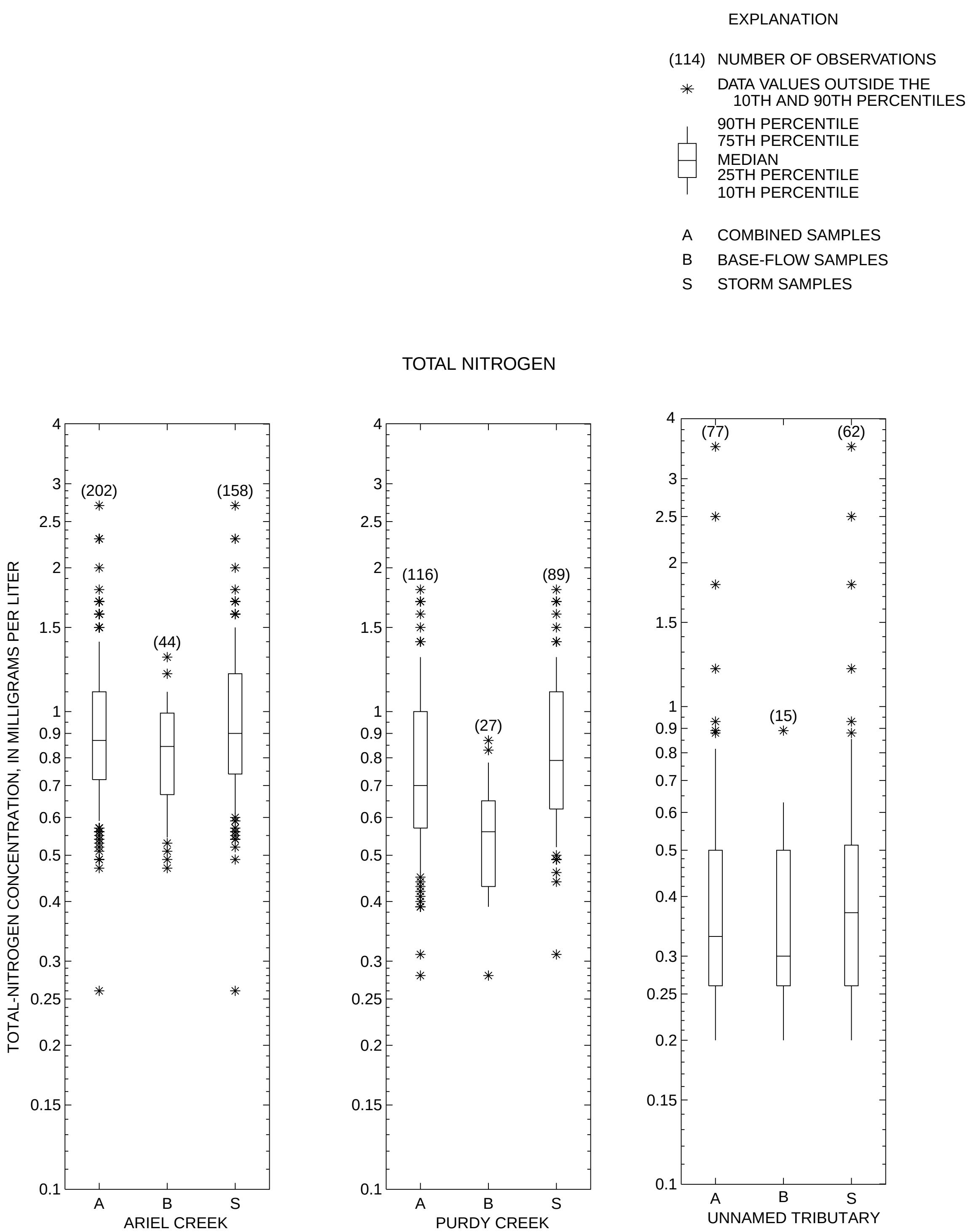


Figure 11. Distribution of concentrations of nitrogen species for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years.

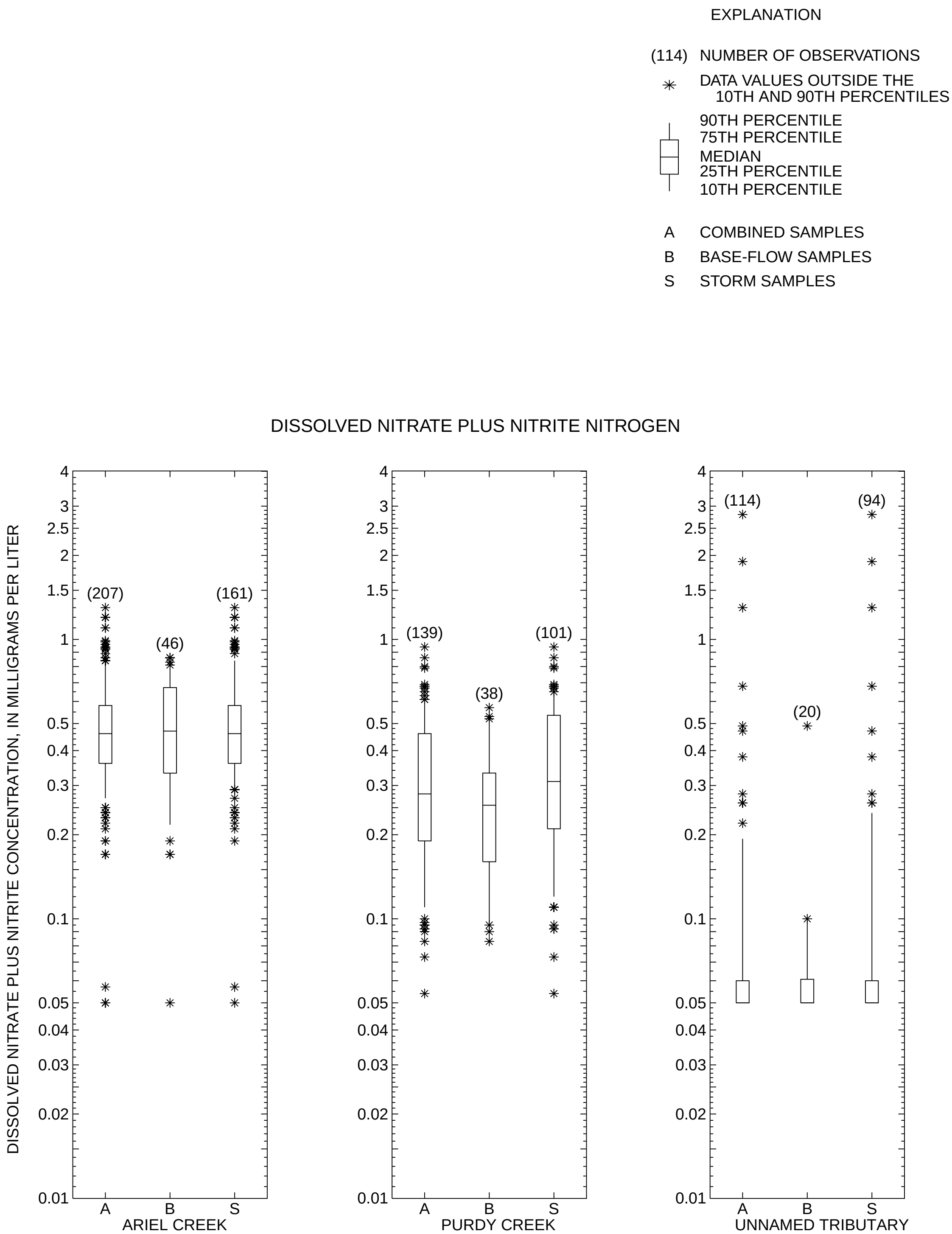


Figure 11. Distribution of concentrations of nitrogen species for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years—Continued.

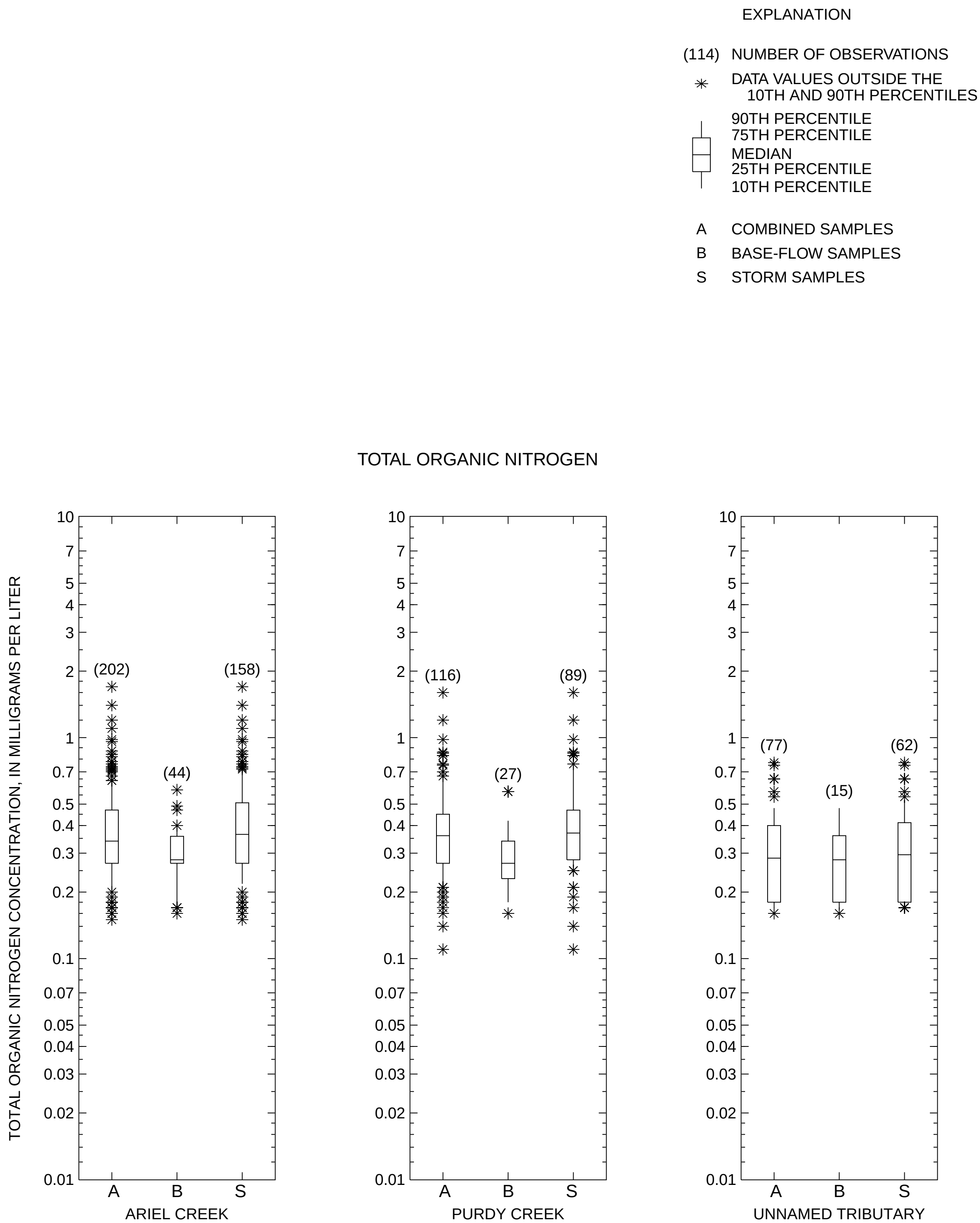


Figure 11. Distribution of concentrations of nitrogen species for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years—Continued.

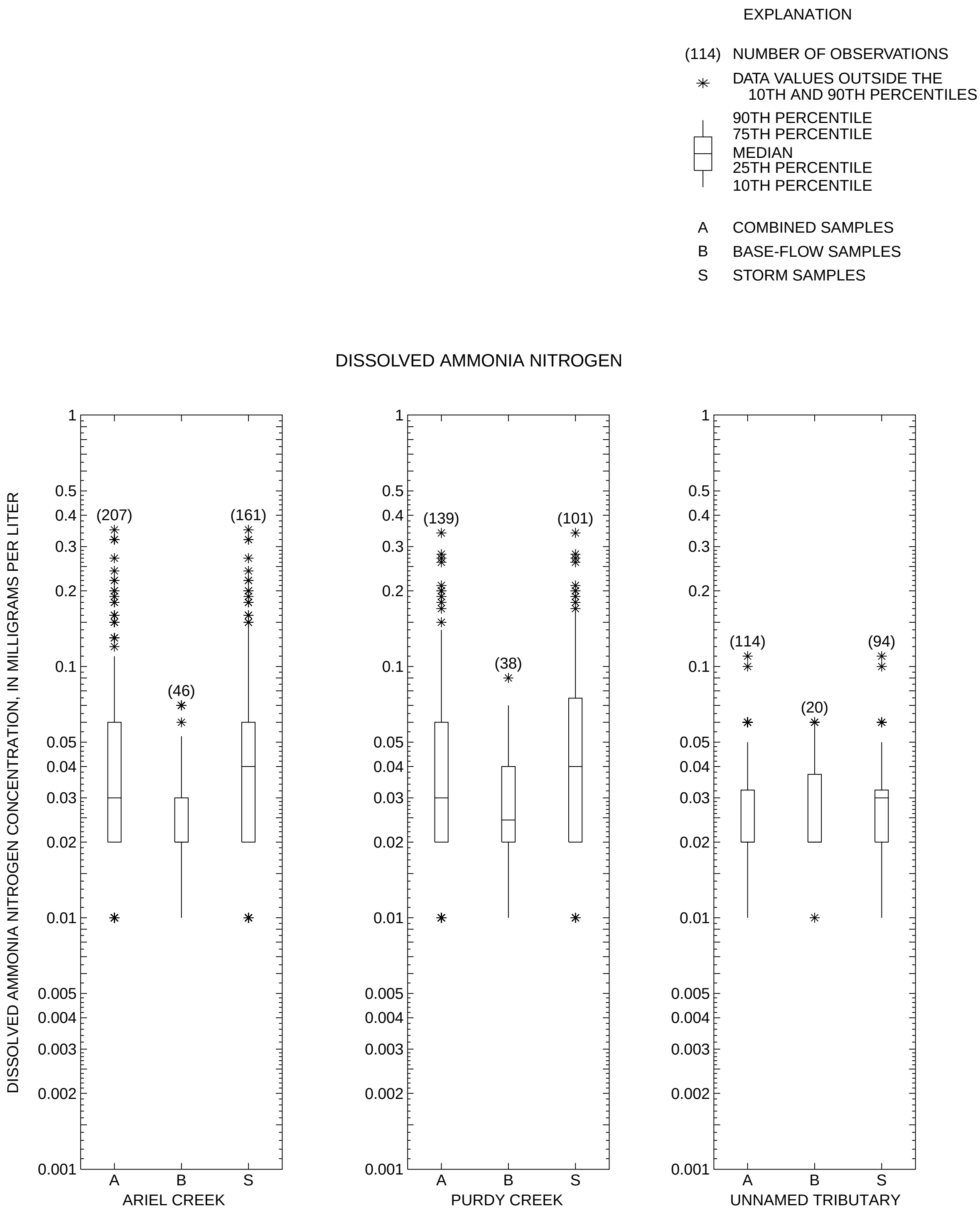


Figure 11. Distribution of concentrations of nitrogen species for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years—Continued.

Table 7. *Median differences in base-flow and stormflow nitrogen concentrations between Ariel Creek, Purdy Creek, and unnamed tributary*

[Median differences are in milligrams per liter; shaded values are statistically significant at the 95-percent confidence level on the basis of a Wilcoxon signed-rank test; n, number of paired samples where non-zero concentration differences were found]

Comparison	Total nitrogen		Nitrate plus nitrite		Organic nitrogen		Ammonia nitrogen		Total number of paired samples
	Median difference	n	Median difference	n	Median difference	n	Median difference	n	
Base flow									
Ariel - Purdy	0.277	25	0.216	25	0.055	22	0.000	14	25
Ariel - Unnamed tributary	.430	14	.360	14	.069	14	-.001	14	14
Purdy - Unnamed tributary	.196	13	.153	13	.040	13	.001	10	14
Stormflow									
Ariel - Purdy	.000	40	.017	39	-.014	37	-.012	37	40
Ariel - Unnamed tributary	.441	34	.314	34	.108	32	.009	28	34
Purdy - Unnamed tributary	.416	25	.265	25	.115	25	.020	23	25

Table 8. *Monthly and annual nitrogen loads for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Total-nitrogen load, in pounds													
1993 water year													
Ariel Creek	903	5,470	4,820	6,810	1,330	7,350	13,100	1,860	360	193	129	241	42,500
Purdy Creek	89	580	1,390	2,400	513	3,440	7,000	879	141	30	21	89	16,600
Unnamed tributary	2.3	15	20	30	2.4	40	112	30	1.8	0	0	.54	253
1994 water year													
Ariel Creek	923	5,600	4,710	2,530	2,950	10,300	10,900	1,820	732	676	2,320	644	44,100
Purdy Creek	628	2,130	2,480	1,200	1,640	6,750	8,080	2,020	623	250	1,330	977	28,100
Unnamed tributary	9.3	46	32	4.6	6.6	59	114	58	20	1.9	37	21	409
Dissolved nitrate plus nitrite load, in pounds													
1993 water year													
Ariel Creek	477	2,660	2,740	3,990	985	3,700	6,040	965	199	105	72	135	22,100
Purdy Creek	25	129	421	875	305	1,740	3,200	373	77	29	25	49	7,250
Unnamed tributary	.31	1.0	.67	.52	.17	.64	3.7	4.6	1.1	0	0	.23	13
1994 water year													
Ariel Creek	509	2,800	2,890	1,880	2,150	6,180	6,050	1,120	438	384	1,090	391	25,900
Purdy Creek	222	845	1,190	783	1,060	3,680	3,720	664	156	60	159	119	12,700
Unnamed tributary	1.2	1.5	.72	.16	.17	.73	1.9	3.5	2.4	.33	2.1	1.0	16
Total organic nitrogen load, in pounds													
1993 water year													
Ariel Creek	393	2,580	1,850	2,480	370	3,170	6,100	789	142	78	50	95	18,100
Purdy Creek	77	502	893	1,310	193	1,450	3,260	466	70	11	6.6	50	8,290
Unnamed tributary	1.7	12	17	26	2.0	33	88	21	1.1	0	0	.33	202
1994 water year													
Ariel Creek	373	2,500	1,670	722	872	3,830	4,490	689	302	301	1,330	278	17,400
Purdy Creek	428	1,220	1,150	413	531	2,410	3,270	1,090	449	192	1,590	1,090	13,800
Unnamed tributary	6.5	37	26	3.9	5.6	49	91	43	13	1.2	25	15	316
Dissolved ammonia nitrogen load, in pounds													
1993 water year													
Ariel Creek	32	219	248	396	74	652	1,050	95	17	9.2	6.3	9.8	2,800
Purdy Creek	3.6	24	84	181	59	316	561	61	8.9	2.1	1.5	4.1	1,310
Unnamed tributary	.08	.91	2.0	3.8	.49	5.5	13	2.8	.11	0	0	.02	29
1994 water year													
Ariel Creek	33	279	209	120	155	653	645	66	21	16	51	13	2,260
Purdy Creek	26	109	179	133	205	745	764	145	31	11	34	28	2,410
Unnamed tributary	.51	3.8	3.8	1.0	1.6	11	18	6.3	1.3	.10	1.4	.96	50

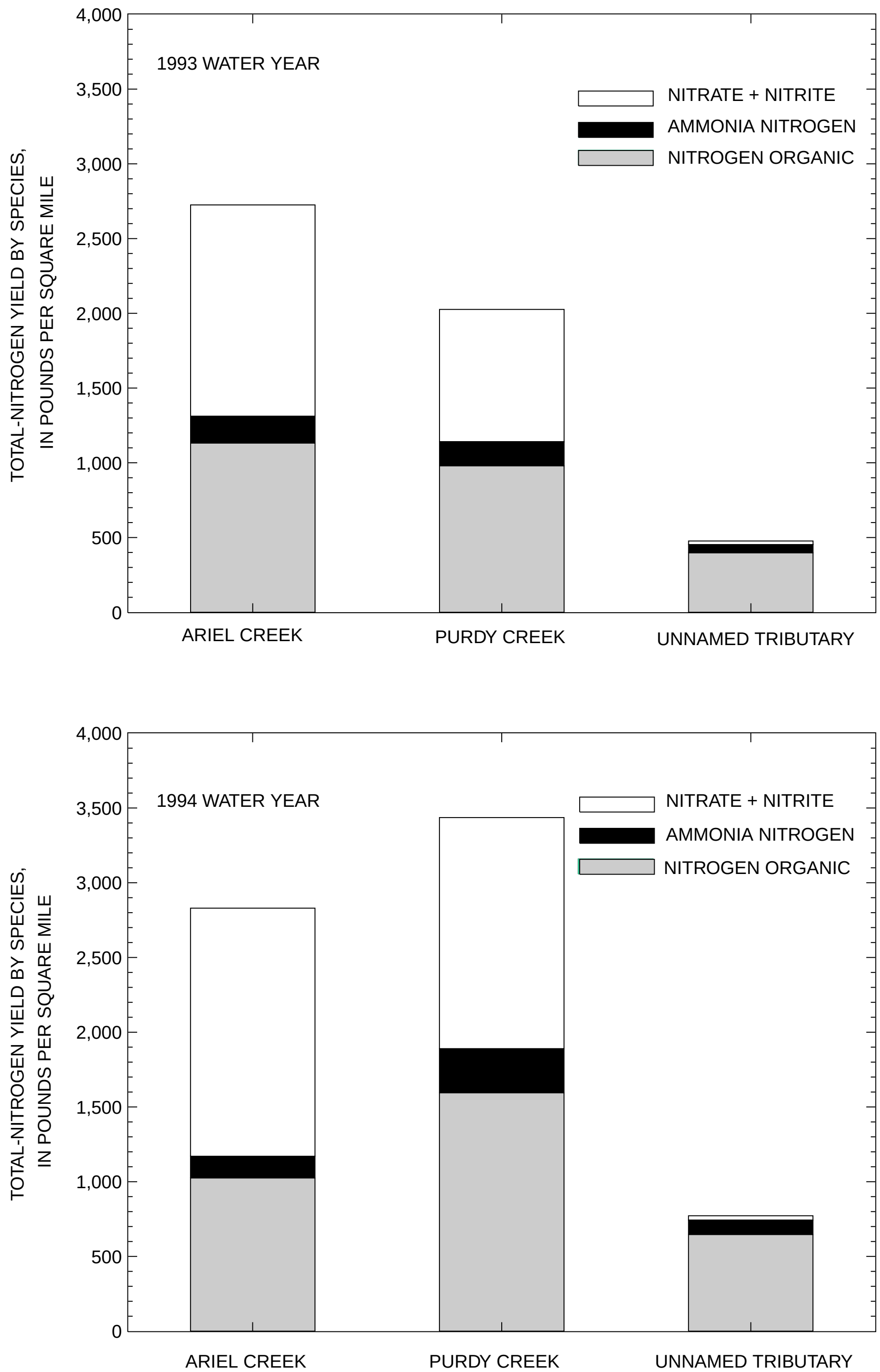


Figure 12. Annual total-nitrogen yields by species for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years.

Phosphorus

Phosphorus concentrations are shown in figure 13. The median concentration for total phosphorus in combined base-flow and stormflow samples for the forested basin was 0.02 mg/L. This compares to median concentrations of 0.04 and 0.03 mg/L for Ariel Creek and Purdy Creek, respectively. The median concentration of combined base-flow and stormflow samples for dissolved orthophosphate was 0.01 mg/L for the forested basin and 0.02 and 0.01 mg/L for Ariel Creek and Purdy Creek, respectively. Ariel Creek had significantly higher concentrations of total phosphorus during base flow compared to Purdy Creek and the forested basin (table 9). The forested basin had significantly lower concentrations of total phosphorus for stormflow compared to Ariel Creek and Purdy Creek.

Loads and yields of phosphorus compounds for all three basins are shown on table 10 and figure 14. The yield of total phosphorus from the Ariel Creek Basin was 216 lb/mi^2 for the 1994 water year. This was about three times greater than the 74 lb/mi^2 from the forested basin. The yield of total phosphorus for the Purdy Creek Basin was 188 lb/mi^2 for the 1994 water year, or 2.5 times greater than the yield from the forested basin.

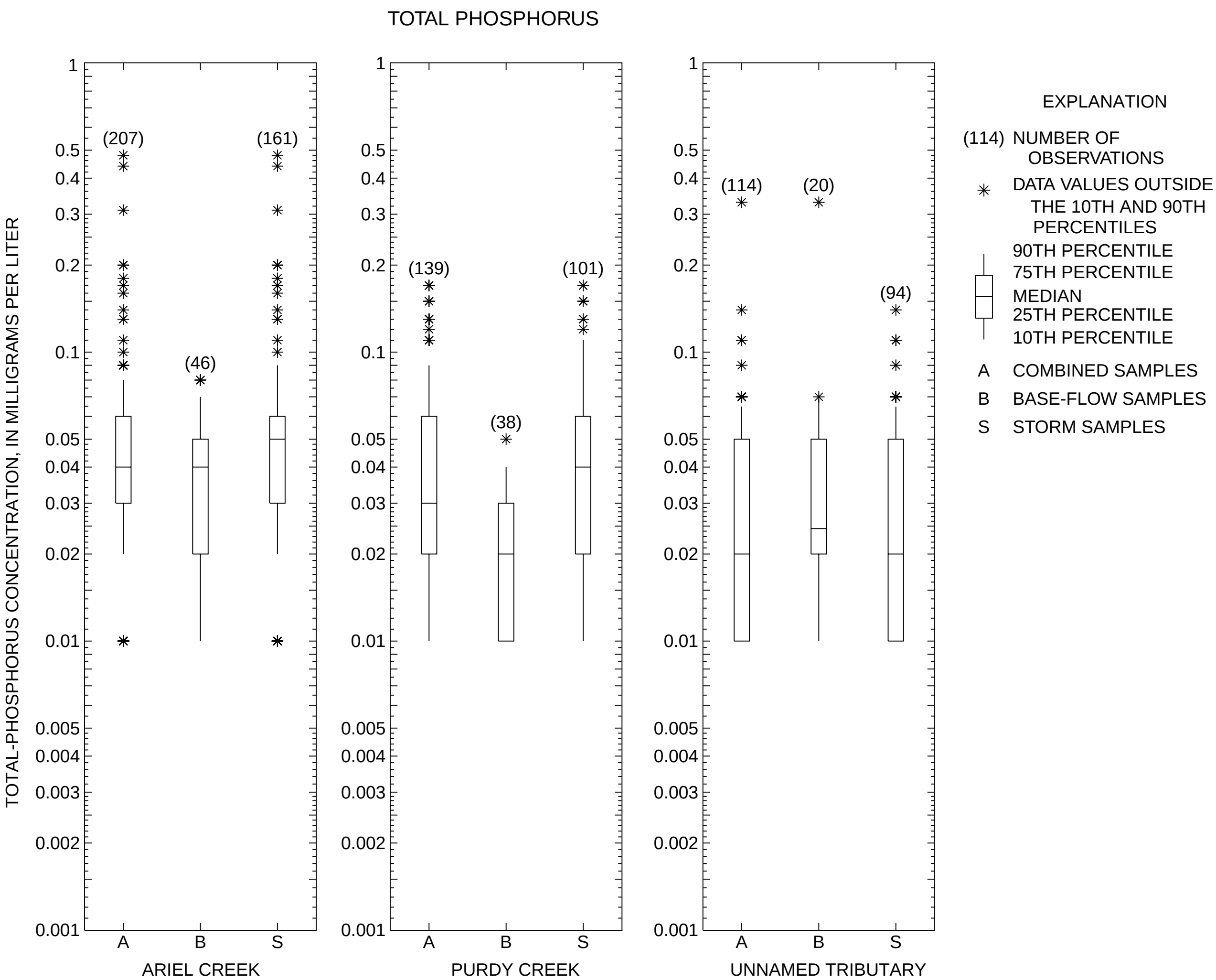


Figure 13. Distributions of concentrations of phosphorus compounds for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years.

Because a large fraction of total phosphorus transported by streams is bound to soil particles, yields of total phosphorus were directly related to sediment yields (tables 6 and 10). Adsorbed phosphorus (that part bound to sediment) is not immediately available for plant uptake. However, anaerobic lake-bottom environments and resuspension of sediments by wind- or boat-generated waves may make this bound form available to enter solution, especially as concentrations in lake-water fall. Orthophosphate yields per unit area were very similar in all three basins with no apparent effects from land use.

For the 2-year period, the basins of Ariel Creek and Purdy Creek yielded an average of 25 percent more orthophosphate in pounds per square mile than the undeveloped, forested basin. Total annual load of orthophosphate to Lake Wallenpaupack for the 2-year period was 1,530 and 598 lb for Ariel Creek and Purdy Creek, respectively. The total load from the forested basin was 34 lb. Phosphorus in the form of dissolved orthophosphate is readily available for plant uptake. Phosphorus in this form can accelerate plant growth, resulting in algae blooms and eutrophic conditions in lake ecosystems.

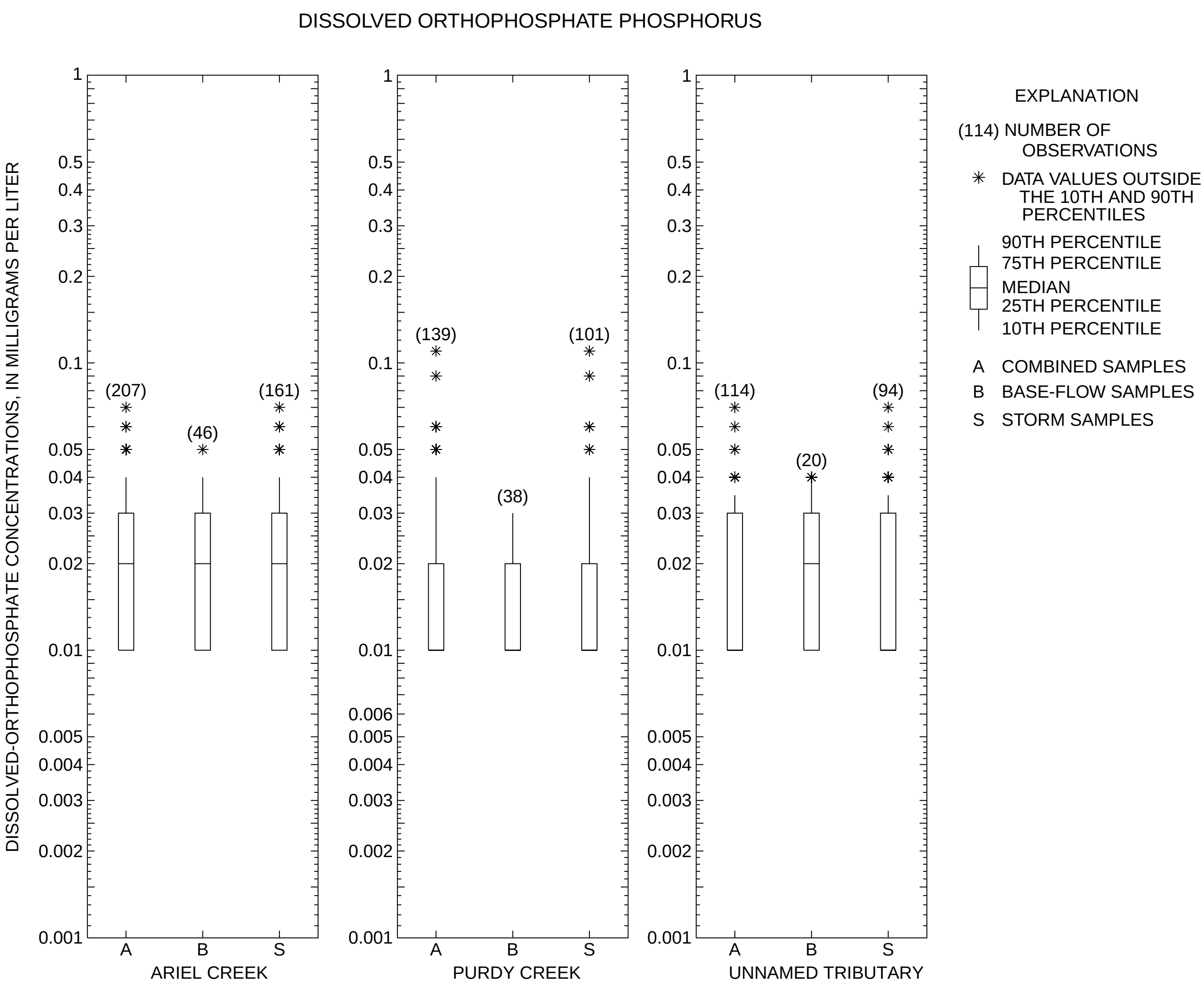


Figure 13. Distributions of concentrations of phosphorus compounds for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years—Continued.

Table 9. *Median differences in base-flow and stormflow phosphorus concentrations between Ariel Creek, Purdy Creek, and unnamed tributary*

[Median differences are in milligrams per liter; shaded values are statistically significant at the 95-percent confidence level on the basis of a Wilcoxon signed-rank test; n, number of paired samples where non-zero concentration differences were found]

Comparison	Total phosphorus		Orthophosphorus		Total number of paired samples
	Median difference	n	Median difference	n	
Base flow					
Ariel - Purdy	0.020	22	0.010	19	25
Ariel - unnamed tributary	.012	12	.000	8	14
Purdy - unnamed tributary	-.005	12	-.003	7	14
Stormflow					
Ariel - Purdy	.010	38	.000	28	40
Ariel - unnamed tributary	.025	31	.000	20	34
Purdy - unnamed tributary	.014	21	.000	14	25

Table 10. *Monthly and annual phosphorus loads for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Total-phosphorus load, in pounds													
1993 water year													
Ariel Creek	38	230	161	220	29	478	916	94	21	14	9.6	15	2,220
Purdy Creek	6.8	30	47	67	7.0	138	340	36	7.8	2.2	1.9	7.3	691
Unnamed tributary	.35	1.2	1.1	1.6	.07	3.6	11	3.1	.2	0	0	.07	22
1994 water year													
Ariel Creek	44	365	193	83	121	793	1,030	136	72	79	377	73	3,370
Purdy Creek	45	137	84	21	29	227	376	104	57	27	289	147	1,540
Unnamed tributary	.82	3.5	1.6	.12	.19	3.5	9.1	6.3	3.2	.31	7.8	3.0	39
Dissolved orthophosphate load, in pounds													
1993 water year													
Ariel Creek	9.3	44	41	61	16	110	214	36	11	7.5	5.7	7.9	563
Purdy Creek	2.8	8.3	15	24	5.0	51	112	14	4.3	2.47	2.5	4	246
Unnamed tributary	.08	.55	.84	1.3	.12	1.9	5.3	1.4	.09	0	0	.03	12
1994 water year													
Ariel Creek	20	98	76	44	56	229	266	50	25	23	59	17	962
Purdy Creek	13	36	30	11	14	75	101	23	9.6	5.2	21	13	352
Unnamed tributary	.51	2.7	2.0	.31	.43	3.5	6.3	3.0	.92	.08	1.5	.85	22

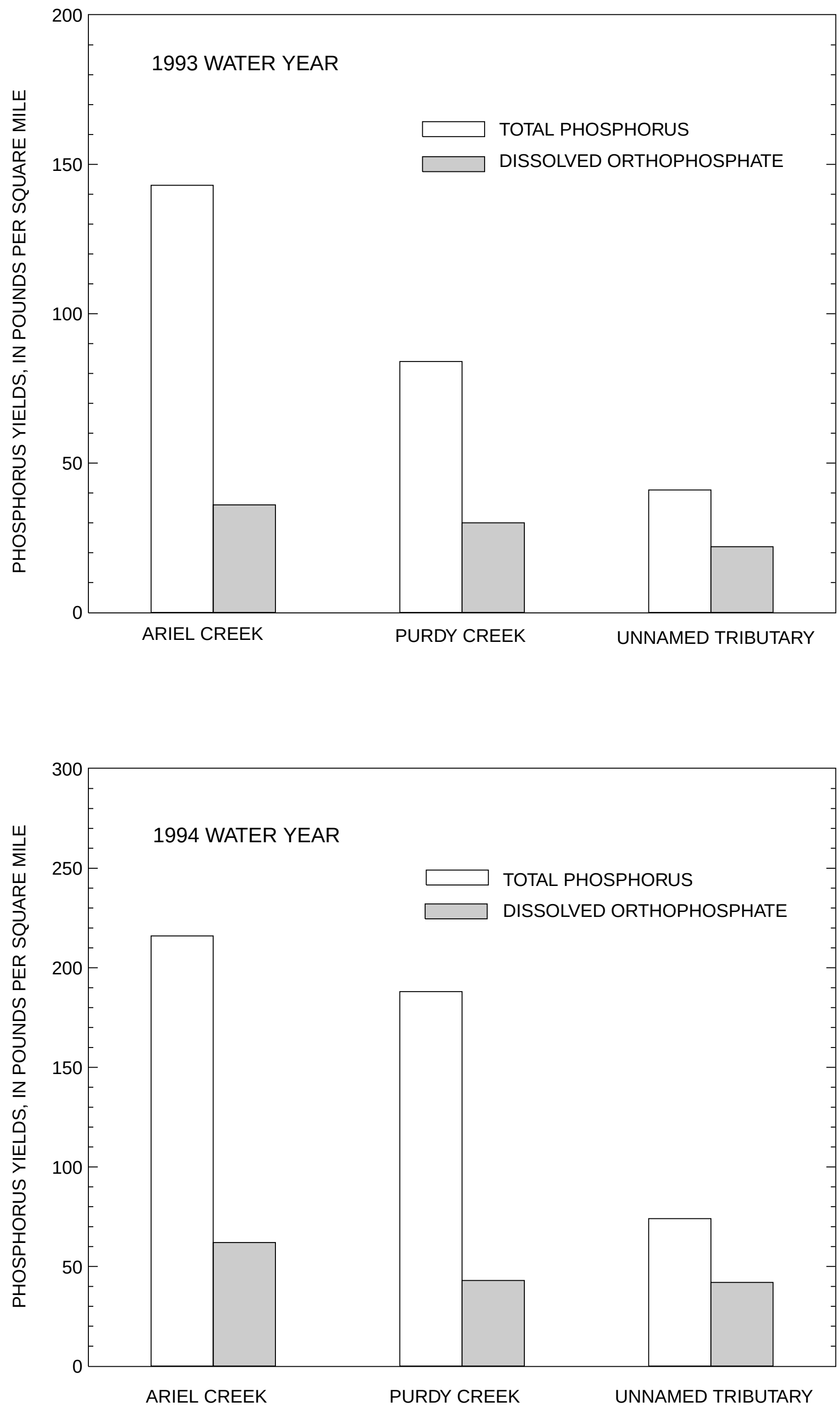


Figure 14. Annual phosphorus yields for Ariel Creek, Purdy Creek, and unnamed tributary, 1993 and 1994 water years.

INFLUENCE OF OPEN-WATER WETLANDS ON WATER QUALITY

Wetlands have been shown to improve water quality as water moves through them. In fact, wetlands and stormwater detention ponds are frequently used as management techniques to improve the quality of water draining from urban areas. The following sections report findings about the effect of a wetland in the Lake Wallenpaupack Basin, including an analysis of which contaminants are being removed by the wetland and which ones are not.

Description of Monitoring Sites

Hydrologic and water-quality data collected above and below an open-water wetland on Stevens Creek located in Sterling Township, Wayne County, were used to analyze the effects of open-water wetlands on the surface-water transport of sediment and nutrients. The wetland[2] along Stevens Creek is 10 acres in area, is 7 to 10 ft deep, and is mostly open water. Shallow areas of the wetland contain rooted vegetation. Streamflow-measurement stations were established on Stevens Creek at the inlet (USGS station 01431620) and outlet (USGS station 01431621) of the wetland. The inlet site was located in the free-flowing section of Stevens Creek just above the impounded area. The outlet site was located at the discharge point of an 18-in. culvert. The drainage area at the inlet was 0.81 mi^2 and at the outlet was 0.91 mi^2. Relief in the basin is moderate, with elevation ranging from a low of around 1,550 ft at the outlet to a high of around 2,020 ft at the top of the watershed. Bedrock outcrops are common in the upper elevations. Soils of the watershed are diverse and are mapped by the U.S. Department of Agriculture (1985) in descending order of area as Mardin, Swartswood, Wyoming, Oquaga, Lordstown, Norwich and Chippewa complex, Arnot complex (rock outcrop), Volusia, and Wellsboro Series. With the exception of the Wyoming Series, all these soils are formed in glacial till and are characterized as having a fragipan at depths ranging from 12 to 28 in. (U.S. Department of Agriculture, 1985). Wyoming soils formed in the water-sorted sands and gravels of kames, eskers and valley trains.

[2] Wetland refers to open-water wetland in this section of the report.

Land use in the Stevens Creek Basin was determined from aerial photographs and field reconnaissance as previously described. Land use for the basin is displayed on figure 15 and the digital orthophoto on figure 16. The percentage of each land-use type is listed in table 11. Although the basin is mostly forest land, 24 residences with on-lot septic systems provided a possible source for nutrients. Most houses are occupied year-round, and the population of the area in 1994 was 61. Several new homes are presently under construction. No industries of any sort are present in the study area.

Hydrologic Conditions

Streamflow hydrographs of Stevens Creek reflect seasonal variations in streamflow, which is affected by precipitation and evapotranspiration. Although precipitation was distributed throughout the year, the greatest streamflows were during March and April from snowmelt runoff (fig. 3). A water budget developed for the basin reflects the distribution of precipitation (table 12). Precipitation for the 1993 water year at the Stevens Creek rain gage was 35.7 in., which is 9 percent lower that the recent 10-year average for the NWS rain gage at Hawley. Rainfall for the 1994 water year was 50.8 in. or 30 percent higher than the 10-year average at Hawley. Mean stormflow for the 1993 and 1994 water years was about 13 percent of total streamflow; base flow averaged 87 percent. By comparison, base flow in the Ariel Creek and Purdy Creek Basins averaged 75 percent of total streamflow. These differences may be because of soil conditions, in particular the areal extent of fragipans. Wyoming soils derived from the glacial outwash deposits do not contain fragipans and this may allow for increased infiltration rates and ground-water recharge in the Stevens Creek Basin. Flow-duration curves of Ariel Creek, Purdy Creek, and Stevens Creek show the hydrologic differences in the basins (fig. 17). Stevens Creek maintains a sustained base flow even during prolonged periods of no precipitation. These hydrologic differences are important when calibrating hydrologic sections of watershed-based computer models and limit the utility for transferring parameters and coefficients between basin models.

Table 11. *Land cover in the Stevens Creek Basin*

	Stevens Creek at inlet		Stevens Creek at outlet	
	Square miles	Percentage	Square miles	Percentage
Forest	0.74	90.86	0.82	89.90
Pasture	.00	.11	.01	1.64
Residential	.03	3.68	.03	3.59
Water	.04	5.35	.05	5.68

Table 12. *Annual water budgets for the Stevens Creek Basin, 1993 and 1994 water years*

Water year	Precipitation	Evapotranspiration		Total streamflow		Base flow[1]		Stormflow[1]	
	Inches	Inches	Percentage[2]	Inches	Percentage[2]	Inches	Percentage[3]	Inches	Percentage[3]
1993	35.7	15.3	42.9	20.4	57.1	17.3	84.8	3.1	15.2
1994	50.8	26.2	51.6	24.6	48.4	21.9	89.0	2.7	11.0
Mean	43.3	20.8	48.0	22.5	52.0	19.6	87.1	2.9	12.9

[1] From hydrograph separation.
[2] Percentage of precipitation.
[3] Percentage of streamflow.

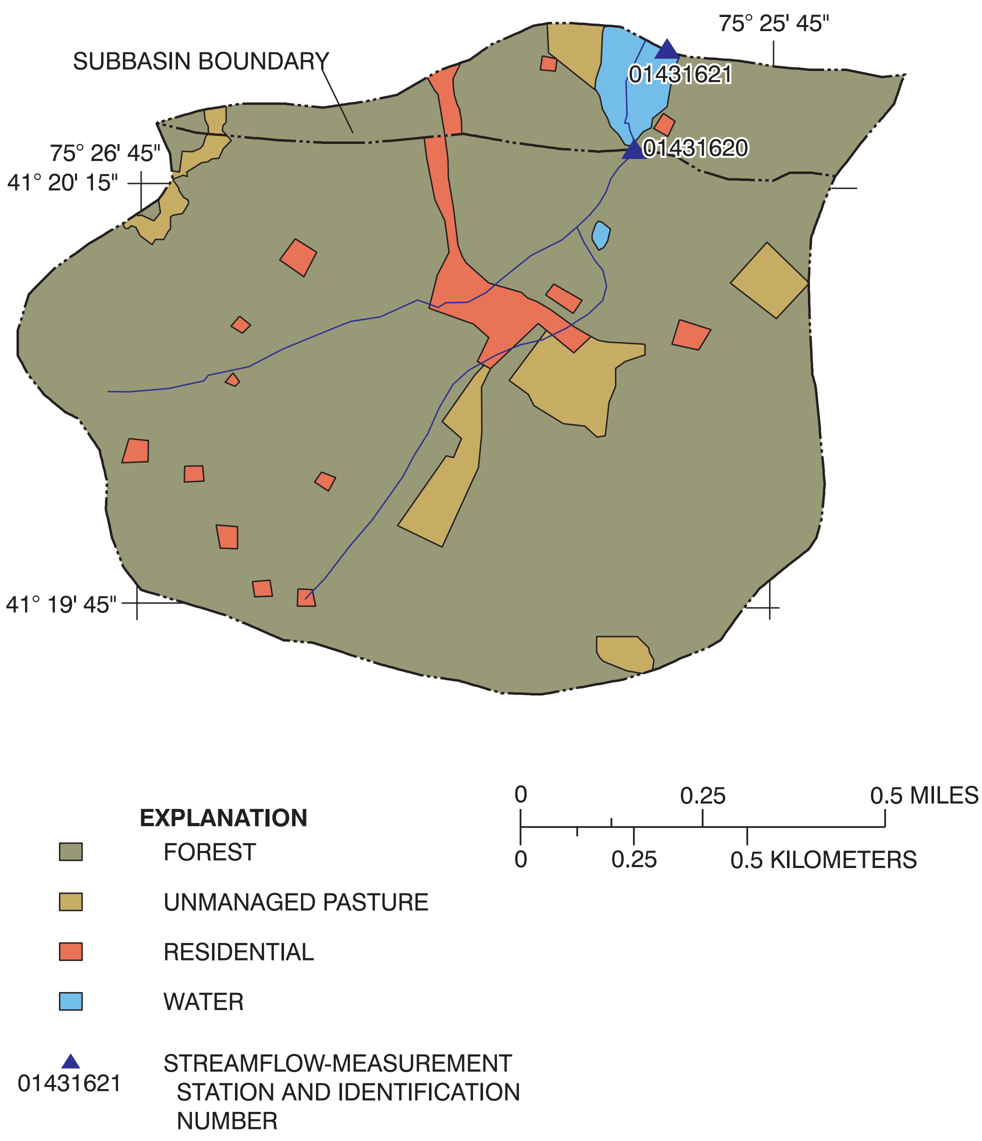


Figure 15. Land cover in the Stevens Creek Basin.

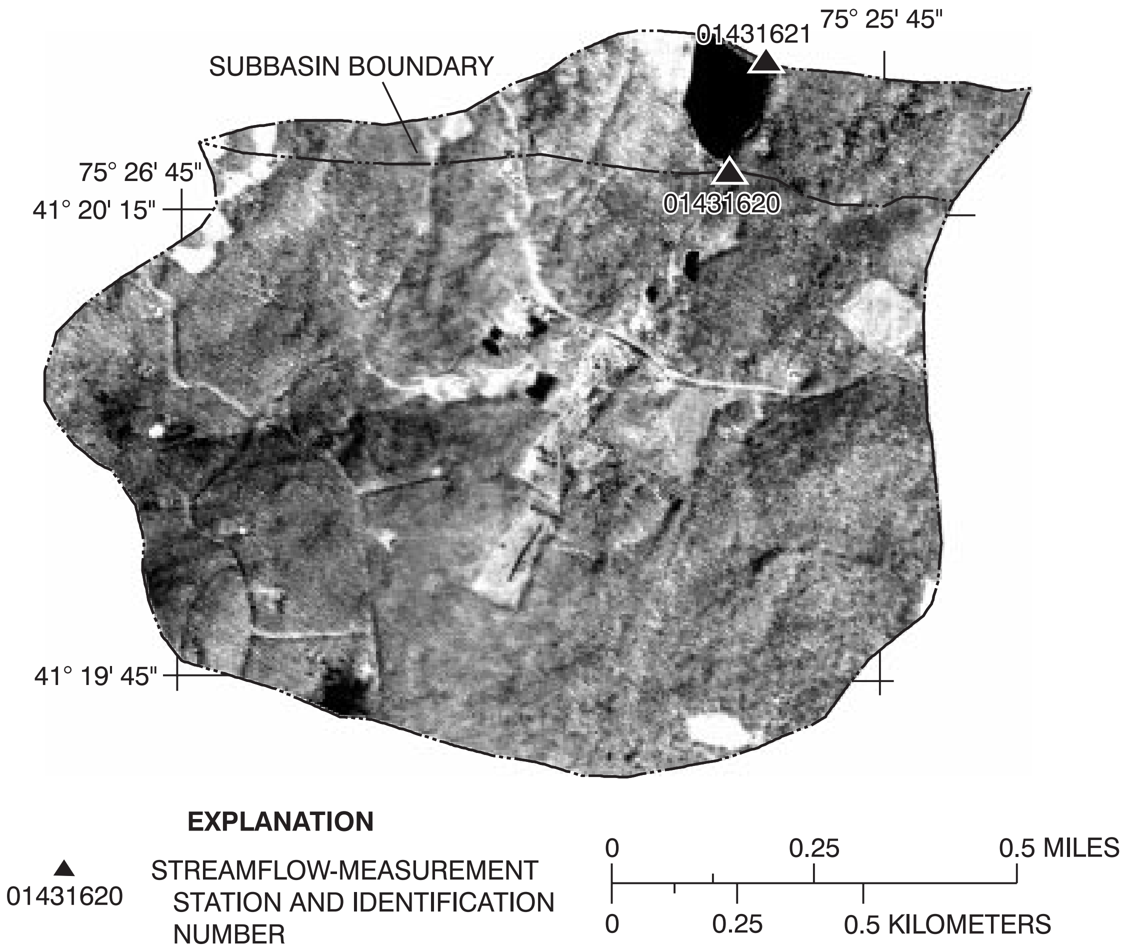


Figure 16. Digital orthophoto of the Stevens Creek Basin.

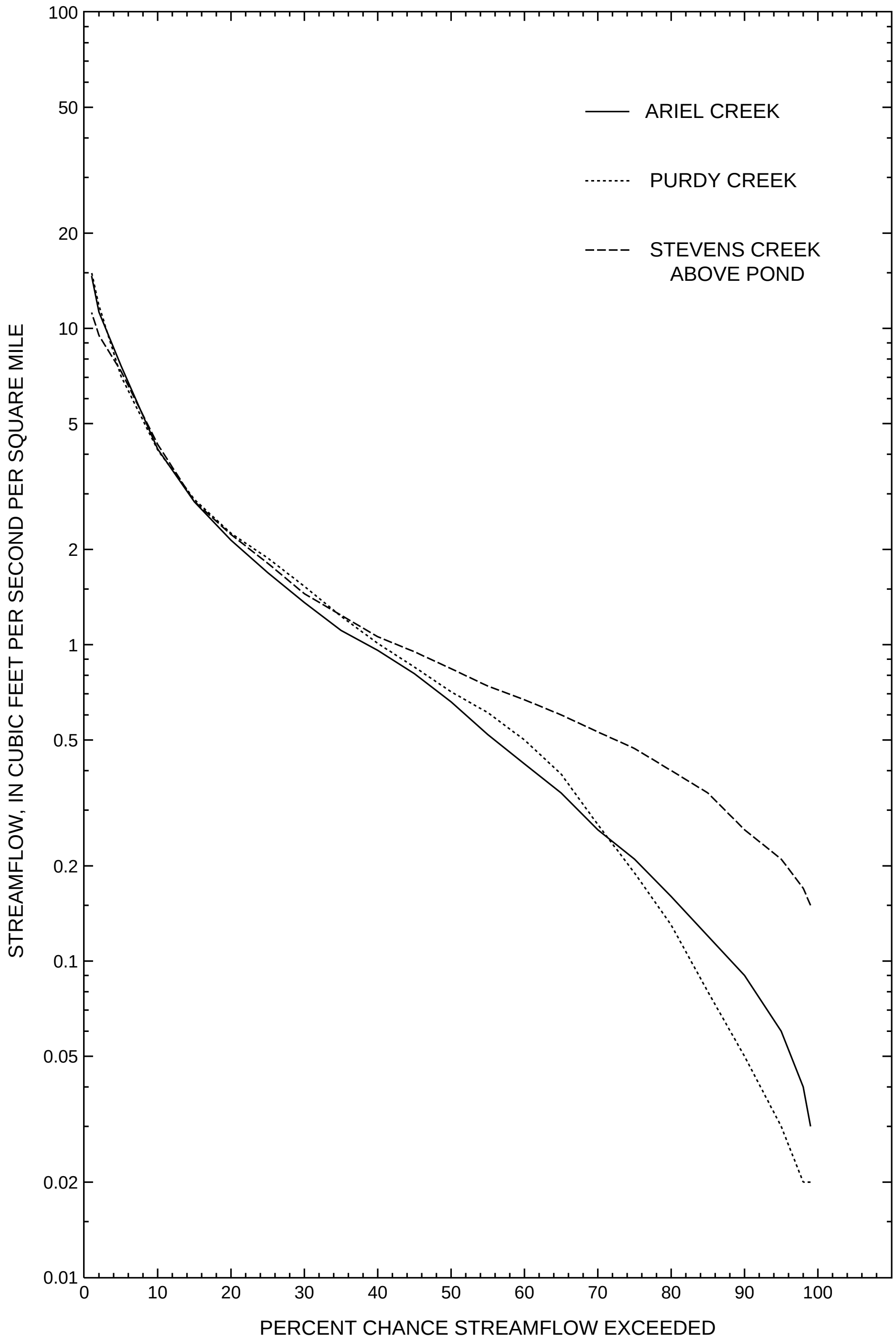


Figure 17. Flow-duration curves of Ariel Creek, Purdy Creek and Stevens Creek for the 1993 and 1994 water years.

Water Quality

Concentration data collected above and below the wetland for the 1993 and 1994 water years are summarized in the form of boxplots. The concentration and streamflow data also were used to calculate sediment and nutrient loads using the multiple-regression model developed by Cohn and others (1989). Calculated loads were used to evaluate the effectiveness of the wetland in removing sediment and nutrients from streamflow. Sediment and nutrient loads were calculated for the inflow and outflow stations for the 1993 and 1994 water years. Loads of all constituents sampled during the study were greater in 1994 because of an increase in streamflow from additional precipitation compared to 1993.

Suspended Sediment

The distribution of suspended-sediment concentrations is shown in figure 18. The median concentration of suspended sediment at the inlet was 14.0 mg/L compared to 3.0 mg/L at the outlet. Median concentrations of 31 paired samples were significantly higher at the inlet than at the outlet (table 13). The maximum sediment concentration recorded at the inlet was 7,910 mg/L compared to 208 mg/L at the outlet. Maximum concentrations were during storm events. A substantial amount of the sediment transported by Stevens Creek was deposited at the upper end of the wetland as the stream velocity decreased in the impounded area.

Table 13. *Median differences in sediment concentrations between Stevens Creek pond inlet and outlet*

[Median difference is in milligrams per liter; shaded values are statistically significant at the 95-percent confidence level based upon a Wilcoxon signed-rank test; n, number of paired samples where non-zero concentration differences were found]

Comparison	Sediment		Total number of paired samples
	Median	n	
Inlet-outlet	3.00	25	31

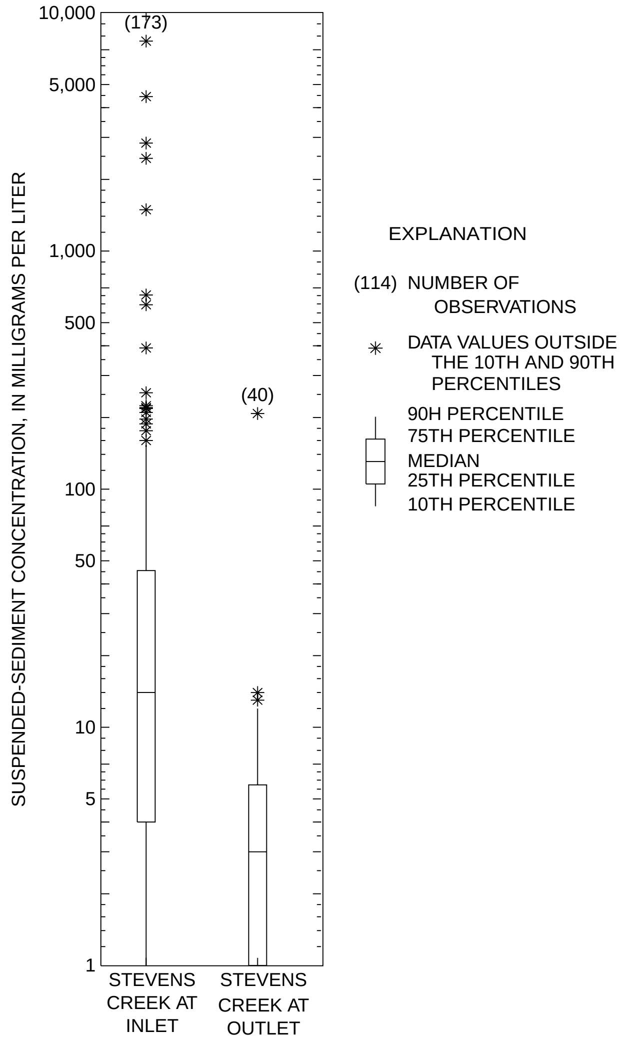
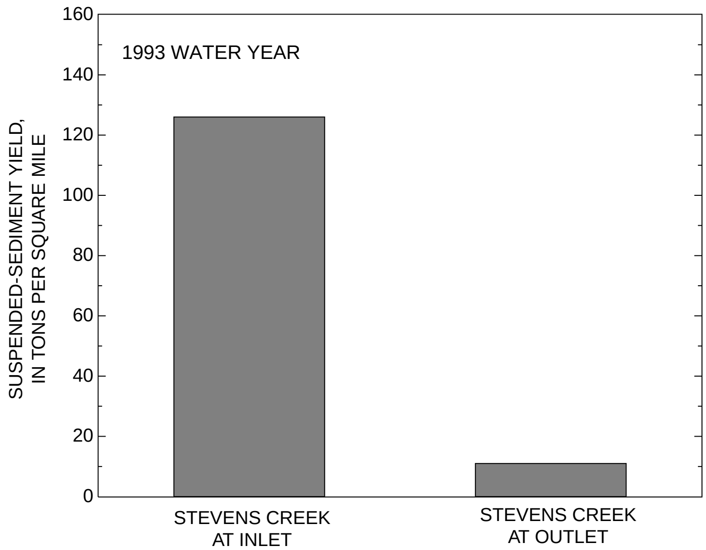


Figure 18. Distribution of concentrations of suspended sediment for Stevens Creek monitoring sites, 1993 and 1994 water years.

Suspended-sediment loads and yields are noted on table 14 and figure 19. During the 1993 and 1994 water year, 267 ton of suspended sediment were transported from the Stevens Creek Basin into the wetland. By comparison, the sediment load measured at the outlet was 13.5 ton for the 2-year period. The highest monthly yields were during March and April for both years because of high streamflow from melting of the winter snowpack. Over the 2-year period, the wetland reduced the input sediment load by 96 percent. This reduction indicates the important role that ponds and wetlands play in the water quality of Lake Wallenpaupack.

Table 14. *Monthly and annual suspended-sediment loads for Stevens Creek monitoring sites, 1993 and 1994 water years*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
						1993 water year							
Inlet site	0.72	0.74	1.6	7.4	0.12	4.5	74	8.3	1.1	1.8	0.7	0.68	102
Outlet site	.27	.61	1.3	3.2	.15	.43	3.3	.54	.11	.15	.1	.12	10
						1994 water year							
Inlet site	.49	17	9.9	.46	.58	13	60	6.3	2	2.7	29	24	165
Outlet site	.13	.75	.98	.10	.07	.31	.65	.11	.04	.03	.06	.04	3.3



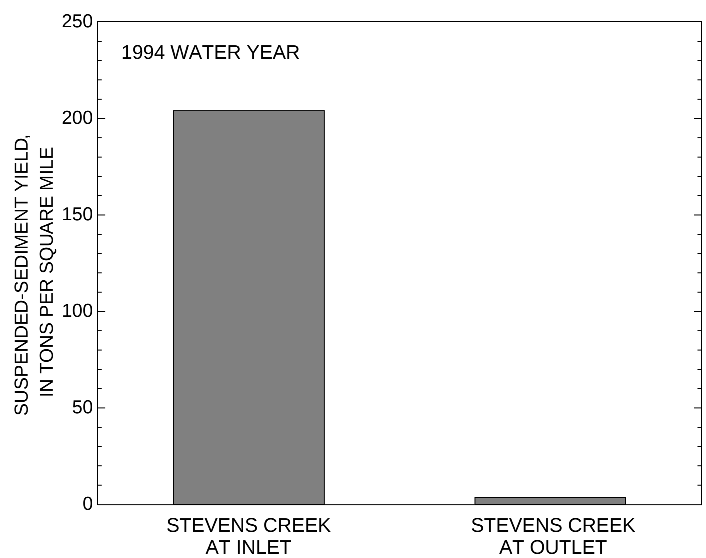


Figure 19. Annual yields of suspended sediment for Stevens Creek monitoring sites, 1993 and 1994 water years.

Nitrogen

The distribution of concentration data for nitrogen species is shown in figure 20. Concentrations of total nitrogen ranged from 0.50 to 3.99 mg/L for Stevens Creek at the inflow site and 0.26 to 1.34 mg/L at the outflow. Samples collected during storm events had higher concentrations of total nitrogen than samples collected during base flow. The median concentration of total nitrogen at the inflow was 1.00 mg/L compared to the median concentration of 0.56 mg/L at the outflow. Inlet concentrations of total nitrogen were significantly higher than outlet concentrations during base flow and stormflow conditions on the basis of paired samples (table 15).

Median concentrations of dissolved nitrate plus nitrate were significantly different for base flow and stormflow samples at the inflow and outflow (table 15). The median base-flow concentration of 0.10 mg/L measured at the outflow was 6.5 times less than the median base-flow concentration of 0.65 mg/L measured at the inflow. Nitrogen in this form of nitrate is available for plant uptake, and the increase in residence time during low-flow conditions potentially allows for increased utilization of this nutrient as well as denitrification.

The median concentrations of dissolved ammonia nitrogen were significantly higher at the outflow sites during base flow. This may be because of the flushing of ammonia accumulated in the wetland by mineralization of organic nitrogen.

Nitrogen export from Stevens Creek at the inflow and outflow stations is shown on table 16 and figure 21. Yields of total nitrogen at the inflow and outflow were not substantially different. The combined load of total nitrogen for the 1993 and 1994 water years was 5,580 lb at the inflow and 5,140 lb at the outflow. Organic nitrogen accounted for 23 and 17 percent of the total nitrogen export at the inflow and outflow stations, respectively. Decrease in levels of organic nitrogen between the inflow and outflow may be attributed to mineralization and loss of fine organic detritus to bottom sediments. Dissolved nitrate plus nitrite accounted for 76 and 88 percent of the total nitrogen export at the inflow and outflow stations, respectively. Yields of dissolved ammonia nitrogen accounted for 2.4 percent of the inflow total nitrogen and 4.5 percent of the outflow total nitrogen. Discrepancies in nitrogen loads are largely because of model calculations for concentration data at or below detection limits.

Table 15. *Median differences in base-flow and stormflow nitrogen concentrations between Stevens Creek pond inlet and outlet*

[Median differences are in milligrams per liter; shaded values are statistically significant at the 95-percent confidence level based upon a Wilcoxon signed-rank test; n, number of paired samples where non-zero concentration differences were found]

Comparison	Total nitrogen		Organic nitrogen		Nitrate plus nitrite		Ammonia nitrogen		Total number of paired samples
	Median difference	n	Median difference	n	Median difference	n	Median difference	n	
Base flow (inlet - outlet)	0.278	18	-0.079	16	0.403	18	-0.010	14	18
Stormflow (inlet - outlet)	1.010	24	-.678	24	.794	24	.000	17	24

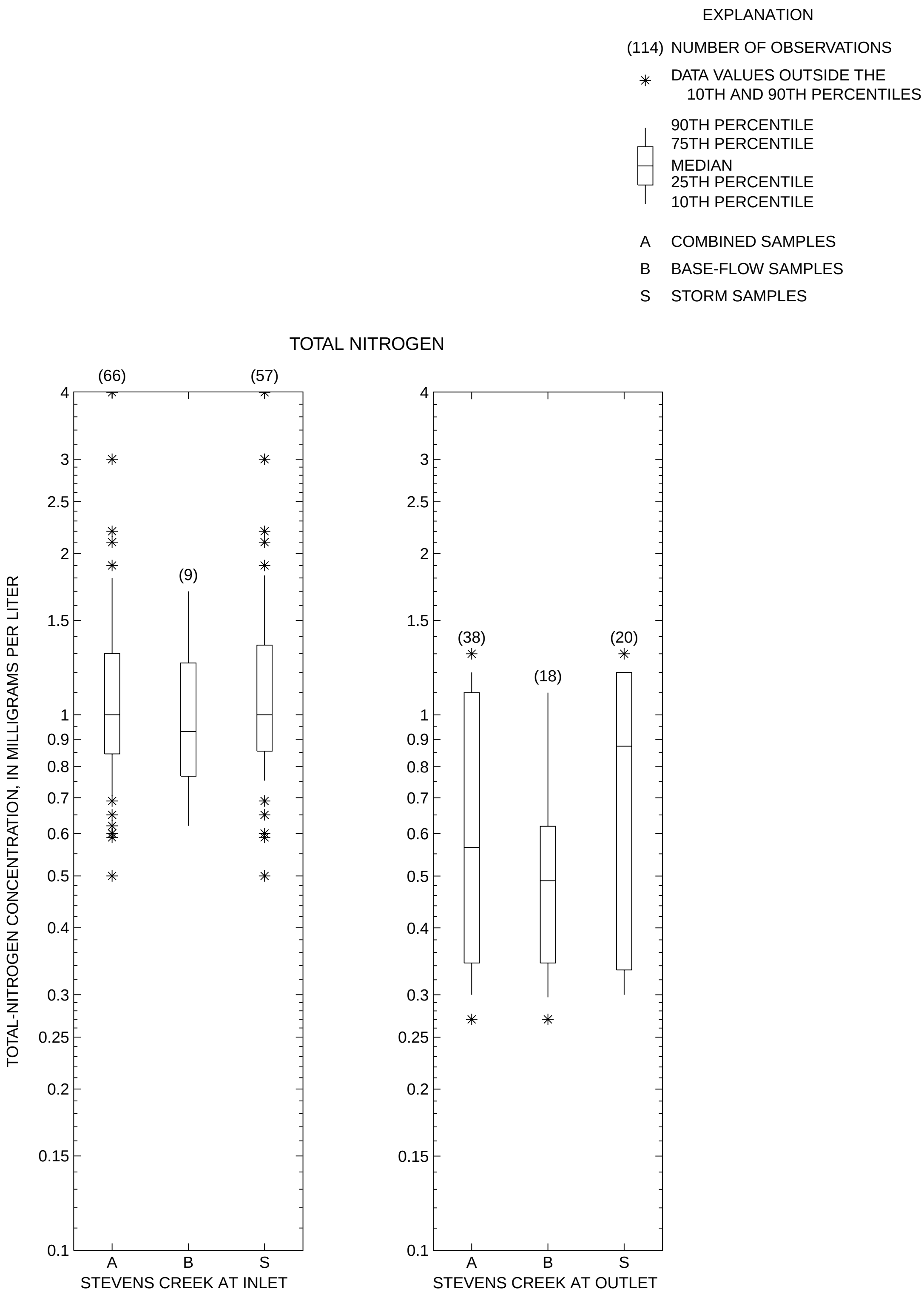


Figure 20. Distributions of concentrations of nitrogen species for Stevens Creek monitoring sites, 1993 and 1994 water years.

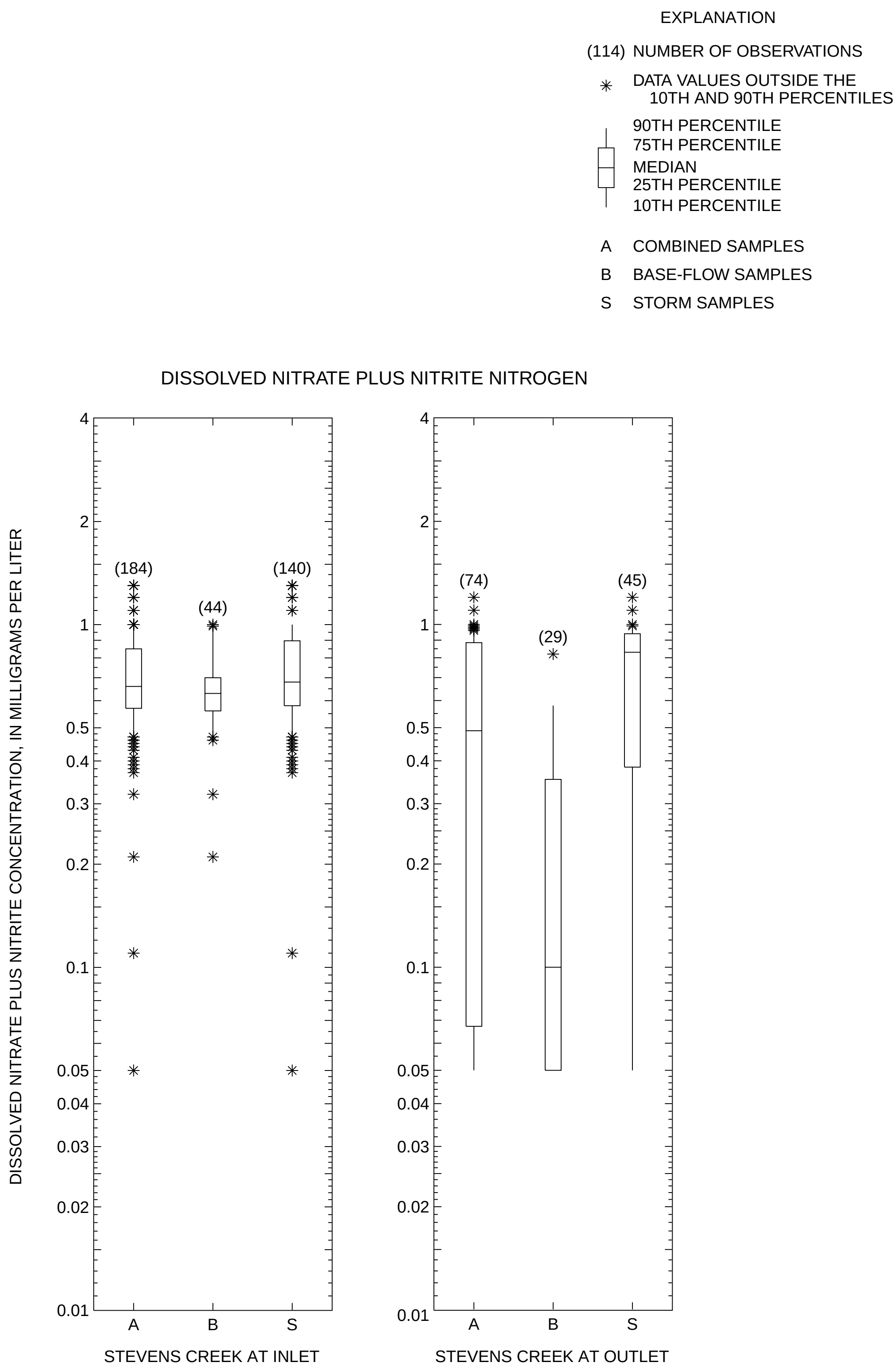


Figure 20. Distributions of concentrations of nitrogen species for Stevens Creek monitoring sites, 1993 and 1994 water years—Continued.

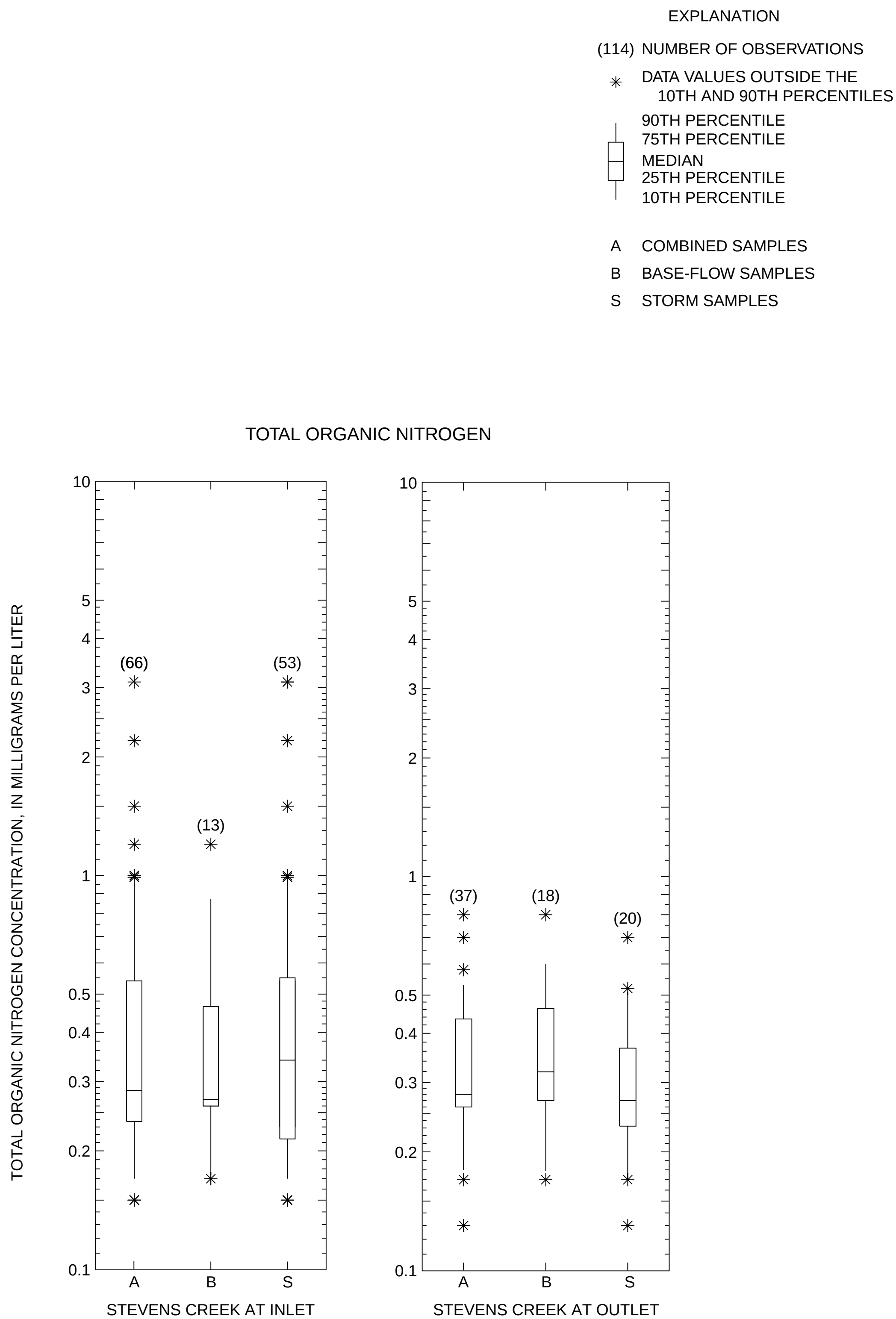


Figure 20. Distributions of concentrations of nitrogen species for Stevens Creek monitoring sites, 1993 and 1994 water years—Continued.

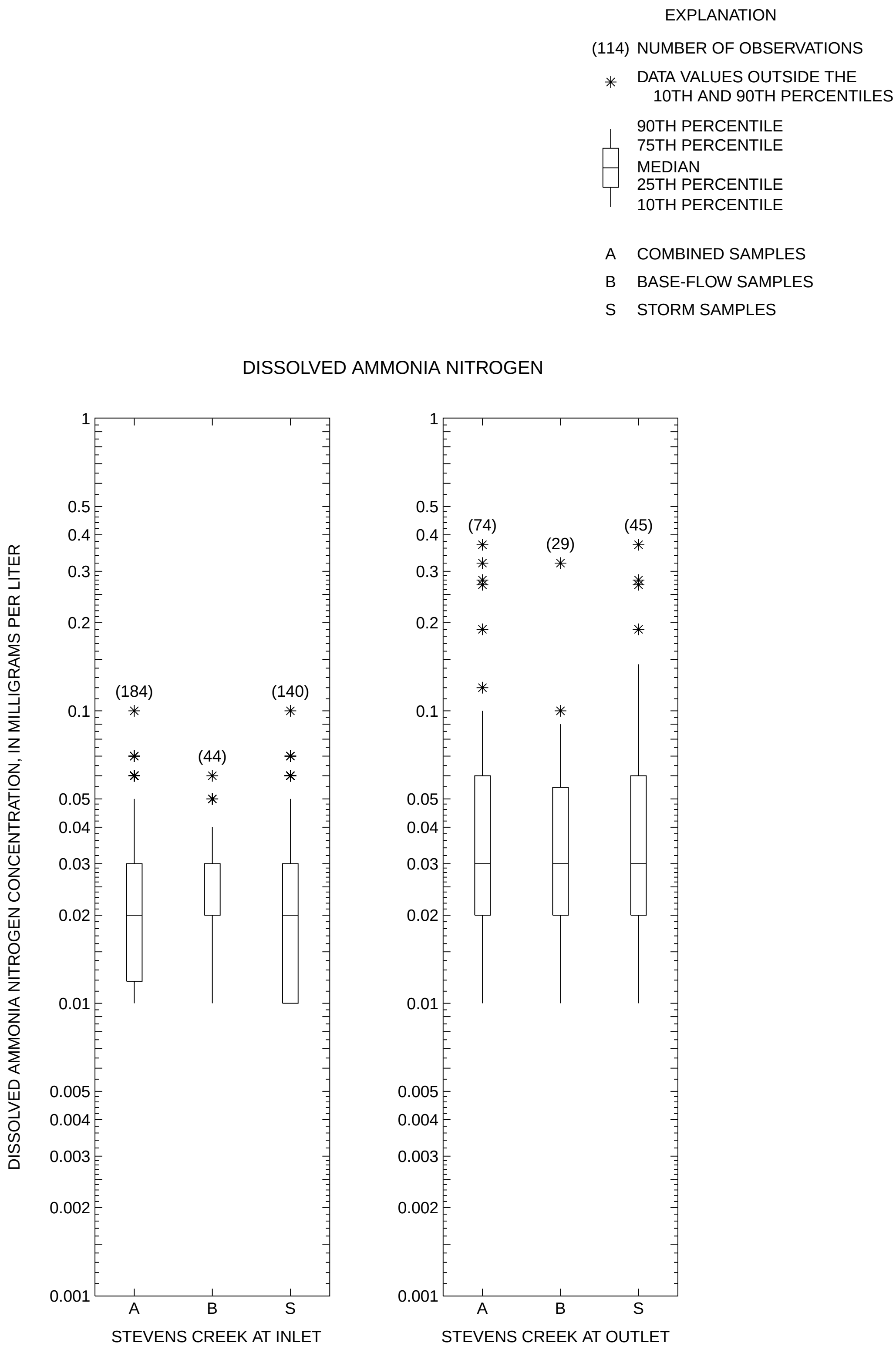


Figure 20. Distributions of concentrations of nitrogen species for Stevens Creek monitoring sites, 1993 and 1994 water years—Continued.

Table 16. *Monthly and annual nitrogen loads for Stevens Creek monitoring sites, 1993 and 1994 water years*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Total-nitrogen load, in pounds													
						1993 water year							
Inlet site	54	86	183	446	105	215	1,130	261	59	43	23	23	2,630
Outlet site	18	41	126	392	96	226	1,240	242	43	29	15	16	2,490
						1994 water year							
Inlet site	29	137	304	125	156	544	967	238	81	63	141	172	2,950
Outlet site	24	154	366	148	179	579	907	154	36	21	40	45	2,650
Dissolved nitrate plus nitrite load, in pounds													
						1993 water year							
Inlet site	31	56	133	348	106	206	967	214	48	32	18	17	2,180
Outlet site	4.6	22	123	511	109	254	1,190	201	15	6.0	1.5	1.7	2,440
						1994 water year							
Inlet site	23	96	221	111	140	429	686	150	45	29	49	55	2,040
Outlet site	4.0	81	296	129	192	591	701	99	11	3.9	9.2	11	2,130
Total organic nitrogen load, in pounds													
						1993 water year							
Inlet site	21	25	40	83	11	26	170	43	10	9.7	5.1	5.3	448
Outlet site	8.6	11	19	40	9.8	23	146	51	20	20	13	13	376
						1994 water year							
Inlet site	6.1	34	64	16	19	84	187	59	27	31	124	170	822
Outlet site	13	38	65	20	20	67	129	43	20	19	39	40	513
Dissolved ammonia nitrogen load, in pounds													
						1993 water year							
Inlet site	1.8	2.1	3.6	7.6	2.0	4.5	25	7.1	2.1	1.6	.85	.71	59
Outlet site	.38	1.0	3.1	8.9	3.7	8.4	40	15	4.6	3.5	2.0	2.0	92
						1994 water year							
Inlet site	.73	2.4	4.9	2.1	2.9	12	24	8.2	3.7	3.2	6.6	7.4	78
Outlet site	2.6	10	24	11	12	29	37	10	2.9	1.6	1.9	1.7	144

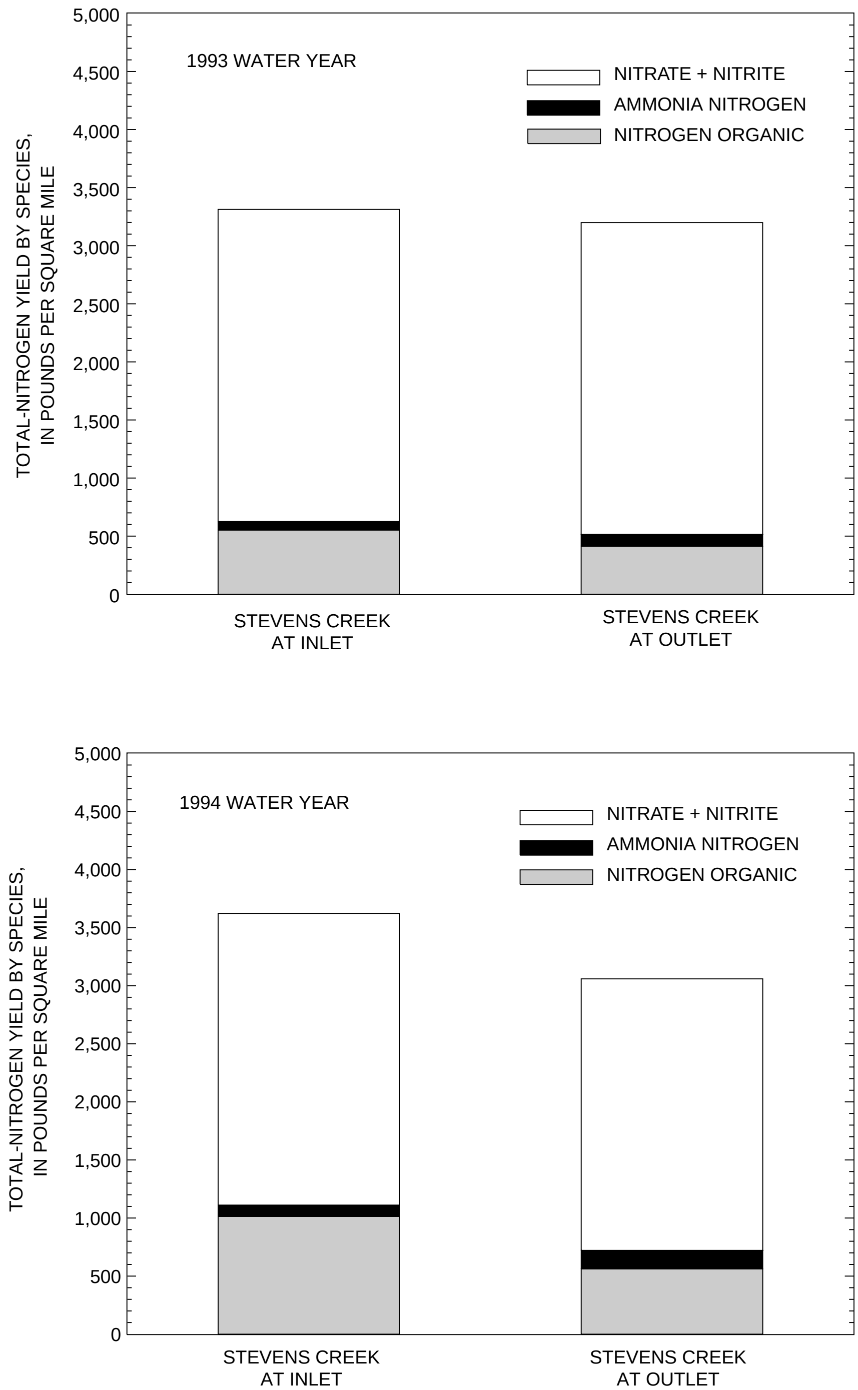


Figure 21. Annual total-nitrogen yields by species for Stevens Creek monitoring sites, 1993 and 1994 water years.

Phosphorus

Phosphorus concentrations are shown in the boxplots in figure 22. The median total phosphorus concentration at the inflow was 0.02 mg/L compared to 0.014 mg/L at the outflow. The inflow concentrations ranged from 0.01 to 0.60 mg/L. The outflow concentrations ranged from 0.01 to 0.04 mg/L. Median concentrations of dissolved orthophosphorus were 0.01 mg/L at the inflow and outflow stations. High concentrations of phosphorus were during storm events. The paired sample analysis showed no significant differences in total phosphorus or dissolved orthophosphate during base flow but showed significantly higher total phosphorus and dissolved orthophosphate at the inlet during stormflow conditions (table 17). This appears to be associated with higher sediment concentrations at the inlet during storm events. This indicates the effectiveness of the wetland as a sediment and sediment-adsorbed-phosphorus trap.

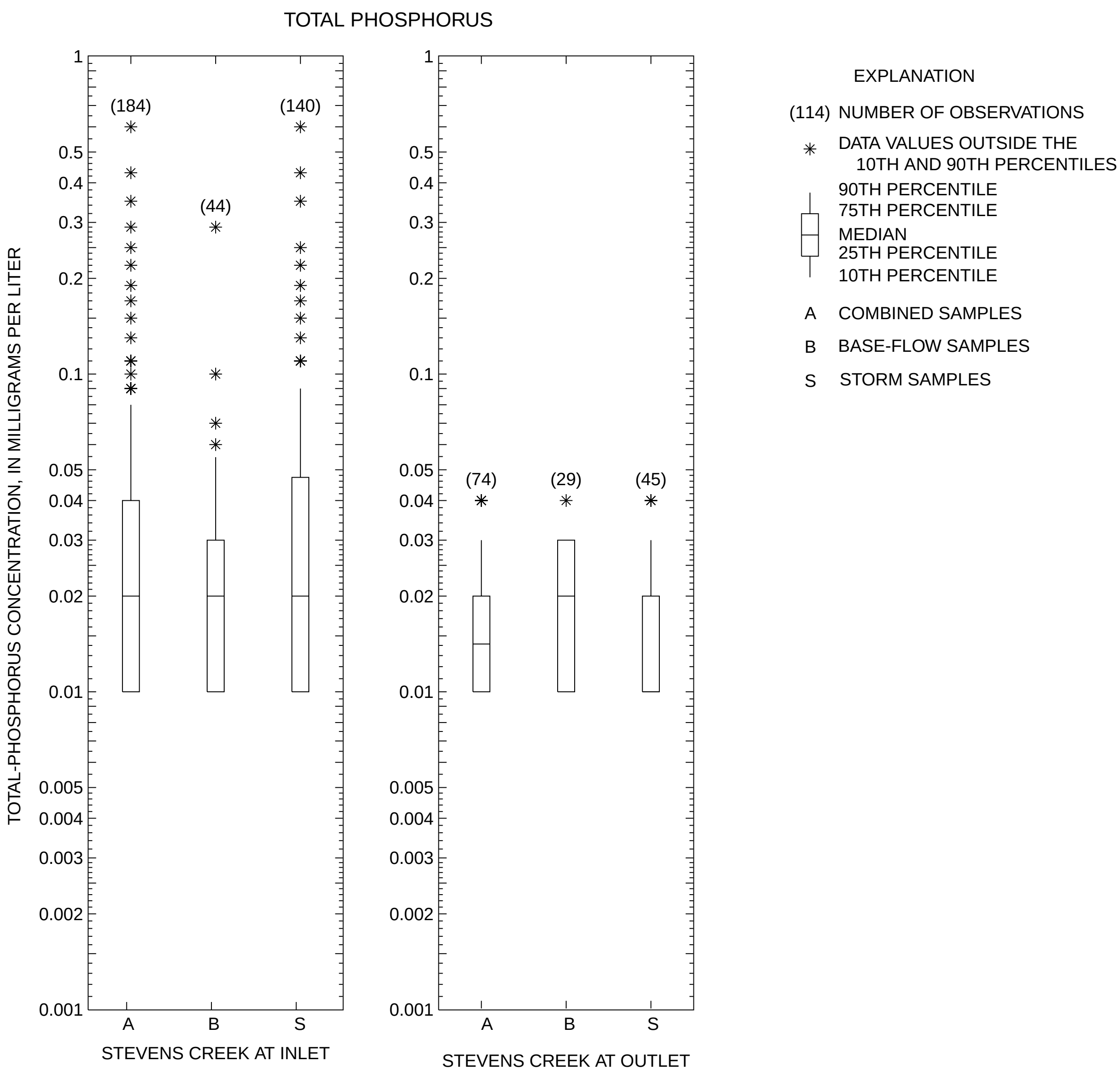


Figure 22. Distribution of concentrations of phosphorus compounds for Stevens Creek monitoring sites, 1993 and 1994 water years.

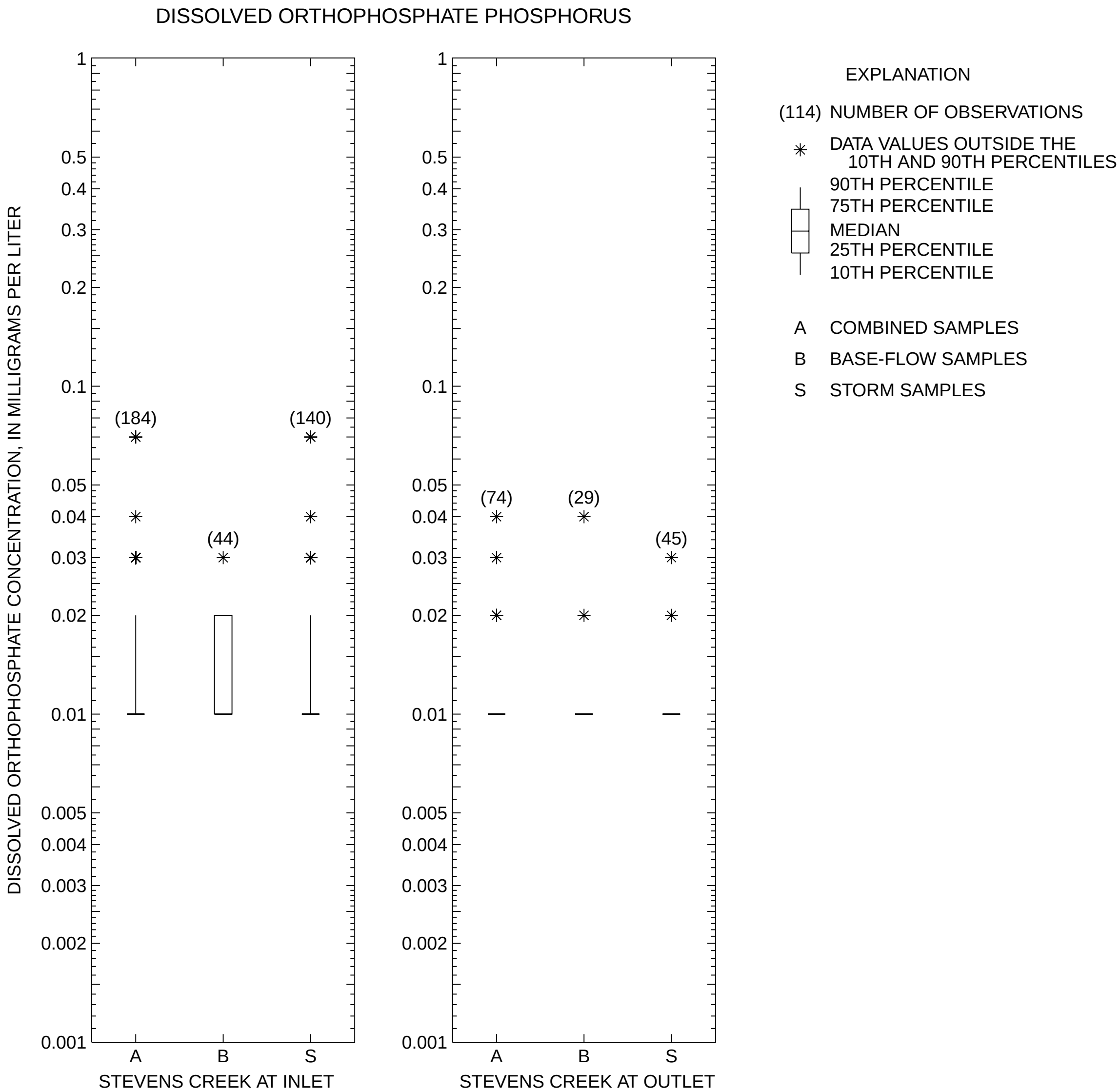


Figure 22. Distribution of concentrations of phosphorus compounds for Stevens Creek monitoring sites, 1993 and 1994 water years—Continued.

Table 17. *Median differences in base-flow and stormflow phosphorus concentrations between Stevens Creek pond inlet and outlet*

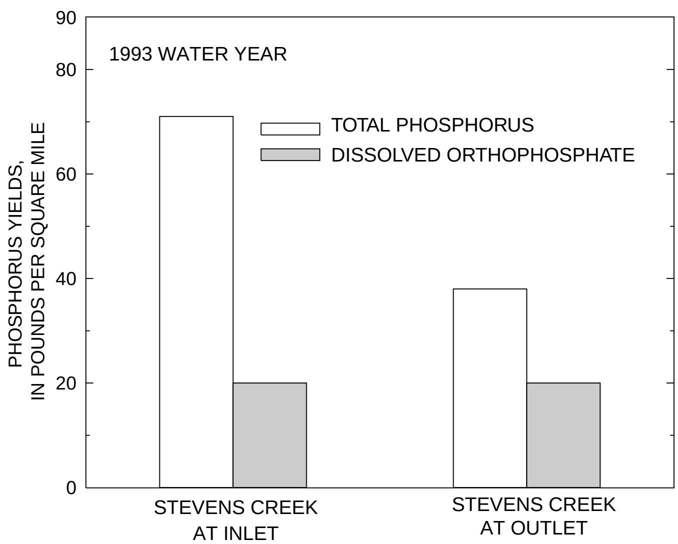
[Median differences are in milligrams per liter; shaded values are statistically significant at the 95-percent confidence level based upon a Wilcoxon signed-rank test; n, number of paired samples where non-zero concentration differences were found]

Comparison	Total phosphorus		Orthophosphorus		Total number of paired samples
	Median difference	n	Median difference	n	
Base flow (inlet - outlet)	-0.003	15	0.000	6	18
Stormflow (inlet - outlet)	.707	24	.012	24	24

Loads and yields of phosphorus compounds at the inflow and outflow are shown on table 18 and figure 23. The wetland appears to substantially reduce loads of total phosphorus. The load measured at the inflow for the 1993 and 1994 water years was 238 lb. The load of total phosphorus at the outflow for this period was 76 lb. The wetland reduced the load by 68 percent. Most of this reduction was probably caused by retention of sediment in the wetland. Yields of dissolved phosphorus at the inlet and outlet were not substantially different.

Table 18. *Monthly and annual phosphorus loads for Stevens Creek monitoring sites, 1993 and 1994 water years*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
						1993 water year							
Inlet site	1.8	2.0	3.1	7.5	0.64	2.9	27	6.8	1.7	2.0	1.0	1.0	58
Outlet site	.67	.90	1.6	3.6	.88	2.3	15	4.8	1.6	1.5	.84	.75	34
						1994 water year							
Inlet site	1.0	7.5	11	1.8	2.1	14	39	11	5.4	7.0	37	44	180
Outlet site	.74	2.4	4.4	1.4	1.6	6.1	12	4.0	1.7	1.4	2.9	2.8	42



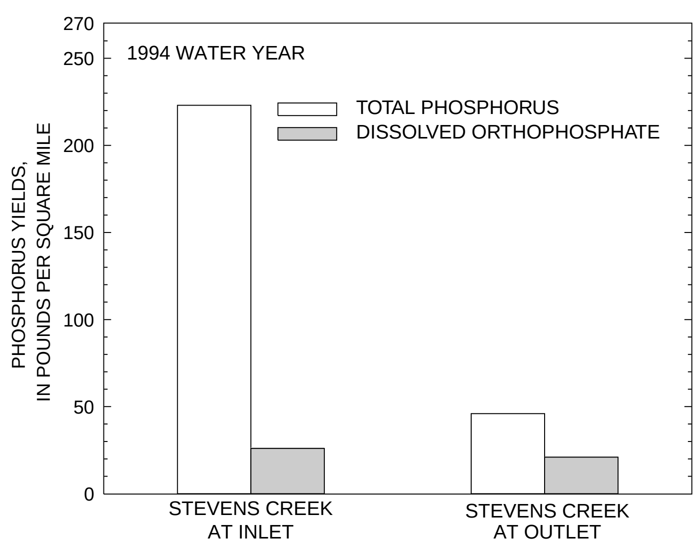


Figure 23. Annual phosphorus yields for Stevens Creek monitoring sites, 1993 and 1994 water years.

SUMMARY AND CONCLUSIONS

The recreational value of Lake Wallenpaupack along with its proximity to the New York/New Jersey metropolitan areas has resulted in accelerated residential development in parts of the watershed. Some developments encroach on existing ponds, lakes, and wetlands and result in the conversion of forest land to residential areas. Sediment and nutrients from these residential areas along with inputs from agriculture, sewage treatment plants, and atmospheric deposition have had a significant effect on the water quality of Lake Wallenpaupack.

Hydrologic and water-quality data were collected from five sites in the Lake Wallenpaupack Basin. Data from Ariel Creek and Purdy Creek were used to represent water quality in streams draining mixed land-use basins with residential development. Data from an unnamed tributary to Purdy Creek were used to represent water quality in streams draining undeveloped, forested basins. Two sites on Stevens Creek, located at the inlet and outlet of a wetland, were used to evaluate the transport of suspended sediment and nutrients through a wetland. Continuous precipitation and streamflow data were collected to develop water budgets. Analyses of water-quality samples were used to document chemical concentrations during base flow and stormflow. Nutrient and sediment yields were calculated for each site to evaluate monthly and annual variability.

Effects of land use on water quality in the Lake Wallenpaupack Basin were evident. Analysis of water-quality samples collected from the undeveloped, forested basin showed significantly lower concentrations of suspended sediment, total nitrogen, and total phosphorus than samples from the mixed land-use basins. Sediment yields were three to four times lower in the undeveloped, forested basin compared to the developed basins of Ariel and Purdy Creeks. The increased sediment yield probably is because of land disturbance associated with residential development and agriculture.

Annual yields for total nitrogen for the undeveloped, forested basin were between three to five times lower than yields from the developed basins of Ariel and Purdy Creeks. About 78 percent of the total nitrogen export from the forested site was in the form of organic nitrogen. By comparison, organic nitrogen represented 40 percent and 49 percent of the total nitrogen export for Ariel Creek and Purdy Creek, respectively. Annual yields of dissolved nitrate plus nitrite from the forested basin were significantly lower than the annual yields from the developed basins. Nitrate plus nitrite export represented 4.4 percent of the total nitrogen export for the forested site and 55 and 44 percent of the total nitrogen export for Ariel and Purdy Creeks, respectively. For the 1993 water year, the annual yield for dissolved nitrate plus nitrate from the forested basin was 24 lb/mi^2 or about 60 times lower than the 1,410 lb/mi^2 from the Ariel Creek Basin. All three basins displayed seasonal differences. Most of the annual yield was during early spring as a result of snowmelt.

Phosphorus loadings also are higher for the developed basins compared to the undeveloped basin. Most differences are because of phosphorus associated with sediment transport. The yield of total phosphorus from the Ariel Creek Basin was 216 lb/mi^2 for the 1994 water year. This was about 3.0 times greater than the 74 lb/mi^2 from the forested basin. The yield of total phosphorus for the Purdy Creek Basin was 188 lb/mi^2 for the 1994 water year or 2.5 times greater than the yield from the undeveloped basin.

Data collected from the Stevens Creek sites provided information on sediment and nutrient transport through a wetland. The wetland removed over 96 percent of the sediment that was carried into it with streamflow. Because much of the phosphorus entering the wetland was associated with stream sediment, the wetland was also very effective in reducing total phosphorus. The load of total phosphorus measured at the inflow for the 1993 and 1994 water years was 238 lb, whereas the load at the outflow for this period was 76 lb, a reduction of 68 percent. The wetland was not as effective in reducing dissolved orthophosphate or nitrogen loads.

Data from this study have been provided to the Pennsylvania State University for input into a watershed-based computer model. This model can be used by local environmental managers as a tool for making management decisions.

These findings suggest that prudent management of development in the Lake Wallenpaupack watershed is warranted. Development of forested areas results in increased suspended sediment, total nitrogen, and total phosphorus concentrations and yields. Dissolved nitrate plus nitrite yields are also larger in developed areas than in forested areas. Wetlands, with their ability to remove suspended sediment, may provide a useful management strategy for abating some of the effects of development.

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APPENDIX

Appendix.*—List of project datasets in the Watershed Data Management file system*

[WDM, Watershed Data Management; ft^3, cubic feet; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; lb, pounds; lb/mi^2, pounds per square mile; kg/day, kilograms per day; ton, tons; ton/mi^2, tons per square mile]

WDM ID	Begin date	End date	Station ID	Time code	Time step	Dataset description
110	1992/10/1	1994/9/30	Hawley	4	1	Measured daily precipitation—Hawley (NWS)—inches
115	1992/1/1	1994/9/30	Scranton	2	60	Climatic data—air temp (°C)—Scranton Airport
116	1992/1/1	1994/9/30	Scranton	2	60	Climatic data—dew point (°C)—Scranton Airport
117	1992/1/1	1994/9/30	Scranton	2	60	Climatic data—wind speed—Scranton Airport
118	1991/10/1	1994/9/30	Scranton	2	60	Climatic data—solar radiation—Scranton Airport
120	1992/5/1	1994/9/30	F. W. Dam	4	1	Measured daily pan evaporation—Francis E. Walter Dam—inches
200	1992/1/1	1994/9/30	Hawley	4	1	Measured daily snow depth—Hawley (NWS)—inches
1000	1992/10/1	1994/9/30	01431673	2	15	Precipitation data—inches
1100	1991/9/30	1994/9/30	01431673	2	60	Streamflow data—measured—instantaneous—ft^3/s
1110	1991/9/30	1994/9/30	01431673	2	60	Streamflow data—measured—instantaneous—inches
1200	1991/10/1	1994/9/30	01431673	4	1	Streamflow data—measured—daily mean—ft^3/s
1205	1992/10/1	1994/9/30	01431673	4	1	Streamflow data—measured—daily total—million ft^3
1210	1992/10/1	1994/9/30	01431673	4	1	Streamflow data—measured—daily mean—ft^3/s / mi^2
1220	1991/10/1	1994/9/30	01431673	4	1	Streamflow data—measured—daily sum—inches
1555	1992/10/1	1994/9/30	01431673	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly mean—kg/day
1556	1992/10/1	1994/9/30	01431673	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb
1557	1992/10/1	1994/9/30	01431673	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
1755	1992/10/1	1994/9/30	01431673	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly mean—kg/day
1756	1992/10/1	1994/9/30	01431673	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb
1757	1992/10/1	1994/9/30	01431673	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
1780	1992/10/1	1994/9/30	01431673	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly mean—kg/day
1781	1992/10/1	1994/9/30	01431673	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb
1782	1992/10/1	1994/9/30	01431673	5	1	Nitrogen total as n—estimated load (Cohn method)—monthly total—lb/mi^2
1805	1992/10/1	1994/9/30	01431673	5	1	Phosphorus total—estimated load (Cohn method)—monthly mean—kg/day
1806	1992/10/1	1994/9/30	01431673	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb
1807	1992/10/1	1994/9/30	01431673	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb/mi^2
1855	1992/10/1	1994/9/30	01431673	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly mean—kg/day
1856	1992/10/1	1994/9/30	01431673	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly total—lb
1857	1992/10/1	1994/9/30	01431673	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
1900	1992/10/1	1994/9/30	01431673	5	1	Suspended sediment total—estimated load (Cohn method)—monthly mean—kg/day
1901	1992/10/1	1994/9/30	01431673	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton
1902	1992/10/1	1994/9/30	01431673	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton/mi^2
1910	1992/10/1	1994/9/30	01431673	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly mean—kg/day
1911	1992/10/1	1994/9/30	01431673	5	1	Nitrogen-organic, total—estimated load(Cohn method)—monthly total—lb

WDM ID	Begin date	End date	Station ID	Time code	Time step	Dataset description
1912	1992/10/1	1994/9/30	01431673	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly total—lb/mi^2
2100	1992/9/30	1994/9/30	01431685	2	60	Streamflow data—measured—instantaneous—ft^3/s
2110	1992/9/30	1994/9/30	01431685	2	60	Streamflow data—measured—instantaneous—inches
2200	1992/10/1	1994/9/30	01431685	4	1	Streamflow data—measured—daily mean—ft^3/s
2205	1992/10/1	1994/9/30	01431685	4	1	Streamflow data—measured—daily total—million ft^3
2210	1992/10/1	1994/9/30	01431685	4	1	Streamflow data—measured—daily mean—ft^3/s / mi^2
2220	1992/10/1	1994/9/30	01431685	4	1	Streamflow data—measured—daily sum—inches
2555	1992/10/1	1994/9/30	01431685	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly mean—kg/day
2556	1992/10/1	1994/9/30	01431685	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb
2557	1992/10/1	1994/9/30	01431685	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
2755	1992/10/1	1994/9/30	01431685	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly mean—kg/day
2756	1992/10/1	1994/9/30	01431685	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb
2757	1992/10/1	1994/9/30	01431685	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
2780	1992/10/1	1994/9/30	01431685	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly mean—kg/day
2781	1992/10/1	1994/9/30	01431685	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb
2782	1992/10/1	1994/9/30	01431685	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb/mi^2
2805	1992/10/1	1994/9/30	01431685	5	1	Phosphorus total—estimated load (Cohn method)—monthly mean—kg/day
2806	1992/10/1	1994/9/30	01431685	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb
2807	1992/10/1	1994/9/30	01431685	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb/mi^2
2855	1992/10/1	1994/9/30	01431685	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly mean—kg/day
2856	1992/10/1	1994/9/30	01431685	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly total—lb
2857	1992/10/1	1994/9/30	01431685	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
2900	1992/10/1	1994/9/30	01431685	5	1	Suspended sediment total—estimated load (Cohn method)—monthly mean—kg/day
2901	1992/10/1	1994/9/30	01431685	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton
2902	1992/10/1	1994/9/30	01431685	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton/mi^2
2910	1992/10/1	1994/9/30	01431685	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly mean—kg/day
2911	1992/10/1	1994/9/30	01431685	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly total—lb
2912	1992/10/1	1994/9/30	01431685	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly total—lb/mi^2
3000	1991/9/30	1994/9/30	01431683	2	15	Precipitation data—inches
3100	1991/9/30	1994/9/30	01431683	2	60	Streamflow data—measured—instantaneous—ft^3/s
3110	1991/9/30	1994/9/30	01431683	2	60	Streamflow data—measured—instantaneous—inches
3200	1991/10/1	1994/9/30	01431683	4	1	Streamflow data—measured—daily mean—ft^3/s
3205	1992/10/1	1994/9/30	01431683	4	1	Streamflow data—measured—daily total—million ft^3
3210	1992/10/1	1994/9/30	01431683	4	1	Streamflow data—measured—daily mean—ft^3/s / mi^2

WDM ID	Begin date	End date	Station ID	Time code	Time step	Dataset description
3220	1992/10/1	1994/9/30	01431683	4	1	Streamflow data—measured—daily sum—inches
3555	1992/10/1	1994/9/30	01431683	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly mean—kg/day
3556	1992/10/1	1994/9/30	01431683	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb
3557	1992/10/1	1994/9/30	01431683	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
3755	1992/10/1	1994/9/30	01431683	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly mean—kg/day
3756	1992/10/1	1994/9/30	01431683	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb
3757	1992/10/1	1994/9/30	01431683	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
3780	1992/10/1	1994/9/30	01431683	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly mean—kg/day
3781	1992/10/1	1994/9/30	01431683	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb
3782	1992/10/1	1994/9/30	01431683	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb/mi^2
3805	1992/10/1	1994/9/30	01431683	5	1	Phosphorus total—estimated load (Cohn method)—monthly mean—kg/day
3806	1992/10/1	1994/9/30	01431683	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb
3807	1992/10/1	1994/9/30	01431683	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb/mi^2
3855	1992/10/1	1994/9/30	01431683	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly mean—kg/day
3856	1992/10/1	1994/9/30	01431683	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly total—lb
3857	1992/10/1	1994/9/30	01431683	5	1	Phosphorus-ortho, dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
3900	1992/10/1	1994/9/30	01431683	5	1	Suspended sediment total—estimated load (Cohn method)—monthly mean—kg/day
3901	1992/10/1	1994/9/30	01431683	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton
3902	1992/10/1	1994/9/30	01431683	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton/mi^2
3910	1992/10/1	1994/9/30	01431683	5	1	Nitrogen-organic,total—estimated load (Cohn method)—monthly mean—kg/day
3911	1992/10/1	1994/9/30	01431683	5	1	Nitrogen-organic,total—estimated load (Cohn method)—monthly total—lb
3912	1992/10/1	1994/9/30	01431683	5	1	Nitrogen-organic,total—estimated load (Cohn method)—monthly total—lb/mi^2
4000	1991/9/30	1994/9/30	01431620	2	15	Precipitation data—inches
4100	1991/9/30	1994/9/30	01431620	2	60	Streamflow data—measured—instantaneous—ft^3/s
4101	1991/9/30	1994/9/30	01431620	2	60	Streamflow data—measured—instantaneous—ft^3/s
4110	1991/9/30	1994/9/30	01431620	2	60	Streamflow data—measured—instantaneous—inches
4200	1991/10/1	1994/9/30	01431620	4	1	Streamflow data—measured—daily mean—ft^3/s
4205	1992/10/1	1994/9/30	01431620	4	1	Streamflow data—measured—daily total—million ft^3
4210	1992/10/1	1994/9/30	01431620	4	1	Streamflow data—measured—daily mean—ft^3/s / mi^2
4220	1992/10/1	1994/9/30	01431620	4	1	Streamflow data—measured—daily sum—inches
4555	1992/10/1	1994/9/30	01431620	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly mean—kg/day
4556	1992/10/1	1994/9/30	01431620	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb
4557	1992/10/1	1994/9/30	01431620	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
4755	1992/10/1	1994/9/30	01431620	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly mean—kg/day

***Appendix.**—List of project datasets in the Watershed Data Management file system—Continued*

WDM ID	Begin date	End date	Station ID	Time code	Time step	Dataset description
4756	1992/10/1	1994/9/30	01431620	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb
4757	1992/10/1	1994/9/30	01431620	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
4780	1992/10/1	1994/9/30	01431620	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly mean—kg/day
4781	1992/10/1	1994/9/30	01431620	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb
4782	1992/10/1	1994/9/30	01431620	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb/mi^2
4805	1992/10/1	1994/9/30	01431620	5	1	Phosphorus total—estimated load (Cohn method)—monthly mean—kg/day
4806	1992/10/1	1994/9/30	01431620	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb
4807	1992/10/1	1994/9/30	01431620	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb/mi^2
4855	1992/10/1	1994/9/30	01431620	5	1	Phosphorus ortho, dissolved—estimated load (Cohn method)—monthly mean—kg/day
4856	1992/10/1	1994/9/30	01431620	5	1	Phosphorus ortho, dissolved—estimated load (Cohn method)—monthly total—lb
4857	1992/10/1	1994/9/30	01431620	5	1	Phosphorus ortho, dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
4900	1992/10/1	1994/9/30	01431620	5	1	Suspended sediment total—estimated load (Cohn method)—monthly mean—kg/day
4901	1992/10/1	1994/9/30	01431620	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton
4902	1992/10/1	1994/9/30	01431620	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton/mi^2
4910	1992/10/1	1994/9/30	01431620	5	1	Nitrogen-organic,total—estimated load (Cohn method)—monthly mean—kg/day
4911	1992/10/1	1994/9/30	01431620	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly total—lb
4912	1992/10/1	1994/9/30	01431620	5	1	Nitrogen-organic,total—estimated load (Cohn method)—monthly total—lb/mi^2
5100	1991/9/30	1994/9/30	01431621	2	60	Streamflow data—measured—instantaneous—ft^3/s
5110	1991/9/30	1994/9/30	01431621	2	60	Streamflow data—measured—instantaneous—inches
5200	1992/10/1	1994/9/30	01431621	4	1	Streamflow data—measured—daily mean—ft^3/s
5205	1992/10/1	1994/9/30	01431621	4	1	Streamflow data—measured—daily total—million ft^3
5210	1992/10/1	1994/9/30	01431621	4	1	Streamflow data—measured—daily mean—ft^3/s / mi^2
5220	1992/10/1	1994/9/30	01431621	4	1	Streamflow data—measured—daily sum—inches
5555	1992/10/1	1994/9/30	01431621	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly mean—kg/day
5556	1992/10/1	1994/9/30	01431621	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb
5557	1992/10/1	1994/9/30	01431621	5	1	Nitrogen ammonia dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
5755	1992/10/1	1994/9/30	01431621	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly mean—kg/day
5756	1992/10/1	1994/9/30	01431621	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb
5757	1992/10/1	1994/9/30	01431621	5	1	Nitrogen NO_2+NO_3 dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
5780	1992/10/1	1994/9/30	01431621	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly mean—kg/day
5781	1992/10/1	1994/9/30	01431621	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb
5782	1992/10/1	1994/9/30	01431621	5	1	Nitrogen total as N—estimated load (Cohn method)—monthly total—lb/mi^2
5805	1992/10/1	1994/9/30	01431621	5	1	Phosphorus total—estimated load (Cohn method)—monthly mean—kg/day
5806	1992/10/1	1994/9/30	01431621	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb

Appendix.—*List of project datasets in the Watershed Data Management file system*—*Continued*

WDM ID	Begin date	End date	Station ID	Time code	Time step	Dataset description
5807	1992/10/1	1994/9/30	01431621	5	1	Phosphorus total—estimated load (Cohn method)—monthly total—lb/mi^2
5855	1992/10/1	1994/9/30	01431621	5	1	Phosphorus ortho, dissolved—estimated load (Cohn method)—monthly mean—kg/day
5856	1992/10/1	1994/9/30	01431621	5	1	Phosphorus ortho, dissolved—estimated load (Cohn method)—monthly total—lb
5857	1992/10/1	1994/9/30	01431621	5	1	Phosphorus ortho, dissolved—estimated load (Cohn method)—monthly total—lb/mi^2
5900	1992/10/1	1994/9/30	01431621	5	1	Suspended sediment total—estimated load (Cohn method)—monthly mean—kg/day
5901	1992/10/1	1994/9/30	01431621	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton
5902	1992/10/1	1994/9/30	01431621	5	1	Suspended sediment total—estimated load (Cohn method)—monthly total—ton/mi^2
5910	1992/10/1	1994/9/30	01431621	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly mean—kg/day
5911	1992/10/1	1994/9/30	01431621	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly total—lb
5912	1992/10/1	1994/9/30	01431621	5	1	Nitrogen-organic, total—estimated load (Cohn method)—monthly total—lb/mi^2