ESTIMATED LOADS OF SELECTED CONSTITUENTS FROM PERMITTED AND NONPERMITTED SOURCES AT SELECTED SURFACE-WATER-QUALITY STATIONS IN THE MUSCONETCONG, ROCKAWAY, AND WHIPPANY RIVER BASINS, NEW JERSEY, 1985-90

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
gallon (gal)	0.003785	cubic meter
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
pounds per day (lb/d)	0.4536	kilograms per day
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

Abbreviated water-quality units:

mg/L - milligrams per liter
BOD - biochemical oxygen demand, 5 days at 25 degrees Celsius
TOC - total organic carbon

ESTIMATED LOADS OF SELECTED CONSTITUENTS FROM PERMITTED AND NONPERMITTED SOURCES AT SELECTED SURFACE-WATER-QUALITY STATIONS IN THE MUSCONETCONG, ROCKAWAY, AND WHIPPANY RIVER BASINS, NEW JERSEY, 1985-90

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ABSTRACT

Surface-water-quality data from the cooperative sampling network maintained by the U.S. Geological Survey and the New Jersey Department of Environmental Protection for 1985-90 are summarized for stations in the Musconetcong, Rockaway, and Whippany River Basins. Four constituents are included in the analysis: biochemical oxygen demand (BOD), total nitrogen, total phosphorus, and total organic carbon (TOC). Contemporaneous streamflow estimates were used to calculate instream loads from constituent concentrations in water-quality samples. Loads from permitted point sources were estimated as the sum of reported loads of BOD, total nitrogen, and total phosphorus upstream from each station. TOC loads from permitted sources were not estimated because point-source release data were insufficient. The relative contribution of loads from permitted sources to the total instream loads differed markedly among the basins and between upstream and downstream locations within the basins. Some of these differences can be attributed to reservoir effects; others are related to the presence or absence of major permitted sources upstream from water-quality stations.

INTRODUCTION

The New Jersey Department of Environmental Protection (NJDEP) currently is implementing a program of nonpoint-source management throughout the State of New Jersey. Nonpermitted sources (defined in this report as all contaminant inputs to surface water from other than permitted wastewater releases) have been recognized by the NJDEP as a major factor affecting surface-water quality in the State. The NJDEP also has recognized that it needs to identify those surface waters that are significantly affected by nonpermitted sources in order to solve water-quality problems (New Jersey Department of Environmental Protection and Energy, 1993).

A study was conducted by the U.S. Geological Survey (USGS) in cooperation with the NJDEP to compare instream loads (defined in this report as the load, in pounds per day, computed from constituent concentrations in water-quality samples and contemporaneous streamflow estimates) of four water-quality constituents to streamflow and to permitted loads (defined in this report as loads released from permitted wastewater facilities) to assess the relative contribution of loads from permitted and nonpermitted sources. This evaluation was conducted for three drainage basins: the Musconetcong, Whippany, and Rockaway River Basins. Instream loads were computed from water-quality and streamflow data collected by the USGS and NJDEP. Ancillary data (such as land-use and population data) were used to assist in interpreting the results of this analysis.

Purpose and Scope

This report describes the results of an analysis of instream water quality and reported wastewater releases from permitted sources to determine the relative contribution of permitted and nonpermitted inputs to total instream loads of selected water-quality constituents at nine water-quality stations in the Musconetcong, Rockaway, and Whippany River Basins. The water-quality data used in the analysis were collected during 1985-90, and the permitted-source data used were reported during 1985-91.

Description of the Study Area

The study area includes three river basins--the Musconetcong, Rockaway, and Whippany--in northern New Jersey (fig. 1). The Musconetcong River flows from northeast to southwest into the Delaware River. The Whippany River flows into the Rockaway River, which then flows eastward to the Passaic River. Data describing the physiography, population, and land use in each of the three basins are listed in table 1.

Musconetcong River Basin

The Musconetcong River drains an area of 156 mi^2 that includes parts of Sussex, Warren, Hunterdon, and Morris Counties (fig. 1). The river is 42 mi long and flows from its headwaters at Lake Hopatcong to the Delaware River at Riegelsville. Major impoundments include Lake Hopatcong, Lake Shawnee, Lake Musconetcong, and Cranberry Reservoir.

The estimated population in the Musconetcong River Basin in 1990 was 77,100 (U.S. Bureau of the Census, 1991). The major population centers are in the upper part of the basin. Development is significant along the shores of Lakes Hopatcong and Musconetcong. The downstream parts of the basin are less developed and are mostly forested or used for agriculture (New Jersey Department of Environmental Protection, 1990).

Rockaway River Basin

The Rockaway River drains an area of 136 mi^2 that lies mostly within Morris County, with a small portion in Sussex County (fig. 1). This 39-mi-long river flows generally southeastward to its confluence with the Whippany River and continues eastward to its confluence with the Passaic River at Pine Brook. The small (less than 0.6 mi^2) area of the basin below the river's confluence with the Whippany River is not included in this study. The drainage basin includes many lakes and ponds, but the major impoundments are Green Pond, Longwood Lake, Boonton Reservoir, Taylortown Reservoir, Splitrock Reservoir, White Meadow Lake, and Lake Denmark.

The estimated population in the Rockaway River Basin in 1990 was 127,800 (U.S. Bureau of the Census, 1991). The distribution of land-use types in the basin is related to the topography. The upland areas are mostly forested, whereas the lowlands are primarily residential, commercial, and industrial (New Jersey Department of Environmental Protection, 1990).

Whippany River Basin

The Whippany River drains a 72-mi^2 area of Morris County and flows 18 mi to the Rockaway River (fig. 1). The estimated population in the Whippany River Basin in 1990 was 103,600 (U.S. Bureau of the Census, 1991). The land use in the Whippany River Basin is about one-half forest, wetlands, and barren land and one-half residential and commercial (New Jersey Department of Environmental Protection, 1990).

Previous Studies

Although the USGS, in cooperation with State and local agencies, began comprehensive water-quality studies in New Jersey in the early 1960's, the contribution of nonpoint sources to contamination in New Jersey streams is a much more recent water-quality issue. Two USGS nonpoint-source studies were done in the Coastal Plain of New Jersey--one in the Mill Creek Basin in Willingboro, Burlington County (Schornick and Fishel, 1980), and one in the Great Egg Harbor River Basin in Winslow Township, Camden County (Fusillo, 1981). The current study is the first investigation of the effect of nonpoint sources on surface-water quality conducted by the USGS in northern New Jersey.

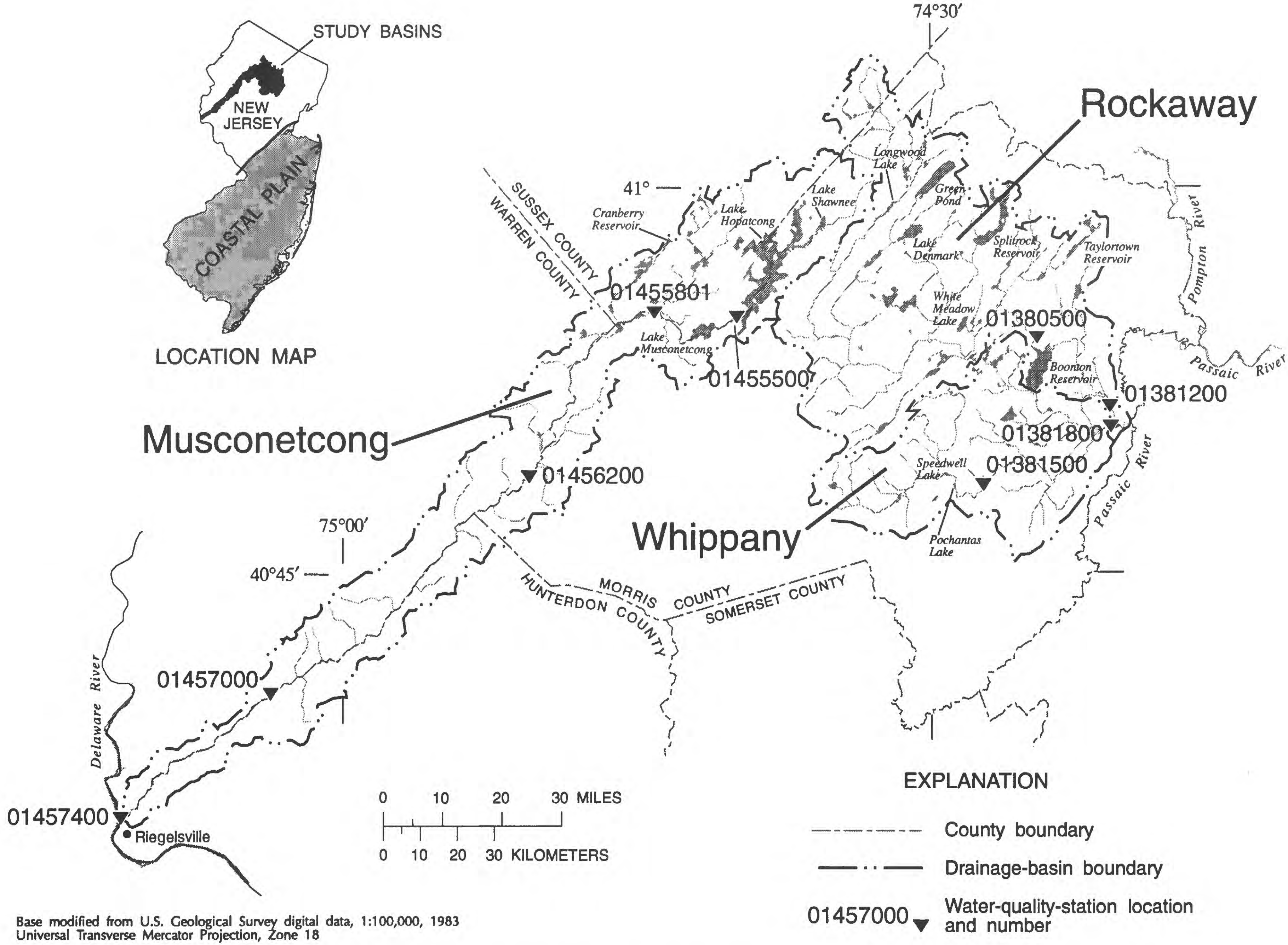

Figure 1. Location of the Musconetcong, Rockaway, and Whippany River Basins, New Jersey.

Table 1. Physical, land-use, and population data for the Musconetcong, Rockaway, and Whippany River Basins, New Jersey

	River basin		
	Musconetcong	Rockaway	Whippany
Area, in square miles	156	136	72
Average overland slope, in percent[1]	5.59	5.42	3.14
Estimated population[2]	77,100	127,800	103,600
Population density, in persons per square mile[2]	494	940	1,439
Land use/land cover, 1972, in percent[3]:			
Urban	10.8	28.5	54.6
Agricultural	26.8	3.1	2.2
Forested	56.3	60.6	30.0
Water	4.0	4.7	2.1
Wetlands	.5	2.2	8.3
Barren	1.6	.9	2.8
Landsat-based impervious land cover, 1985, in percent[4]	16.5	16.4	37.4

[1]Calculated from U.S. Geological Survey digital data (U.S. Geological Survey, 1987)
[2]Estimated from U.S. Bureau of the Census, 1991
[3]Calculated from U.S. Geological Survey digital data, (U.S. Geological Survey, 1986)
[4]Calculated from U.S. Geological Survey unpublished data (see text)

Gillespie and Schopp (1982) described flow characteristics of New Jersey streams. Statewide water-quality trends were identified by Hay and Campbell (1990). The surface-water hydrology of the Musconetcong River Basin was described by Hardison and Martin (1963), Kasabach (1966), and Parker and others (1964). Najarian Associates (1993) described the quality of water in the upper Musconetcong River Basin and presented model results that predict the potential effect of a new wasteload allocation for the river. The hydrologic system of the Rockaway River Basin has been described by Schaefer and others (1993), Geonics, Ltd. (1979), and Canace and others (1983). Rosensteel and Strom (1991) sampled stormwater near the confluence of the Passaic and Pompton Rivers and compared permitted to instream phosphorus loads. Anderson and Faust (1973) described the water-quality and streamflow characteristics of the Passaic River downstream from the current study area. Van Orden and Uchrin (1993a,1993b) simulated the dynamics of dissolved oxygen in the Whippany River.

A point-source-location and effluent-volume data base was developed by the National Oceanic and Atmospheric Administration from the U.S. Environmental Protection Agency's (USEPA) Permit Compliance System (PCS) data base (U.S. Department of Commerce, 1993). This data base was developed from information reported during 1991.

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METHODS FOR DETERMINING RELATIVE CONTRIBUTION FROM PERMITTED AND NONPERMITTED SOURCES TO TOTAL INSTREAM LOADS

The relative contribution of loads from permitted and nonpermitted sources to total instream loads was determined by compiling effluent-quality and -quantity data reported for permitted sources of wastewater and water-quality and streamflow data from USGS and NJDEP water-quality stations in the three study basins. The relation between the instream loads and the sum of the reported loads from permitted sources was used to determine whether or not the instream load was controlled mostly by inputs from permitted sources. In addition, the relation of instream load to streamflow was interpreted. Characteristics of each drainage basin (land use, population, and overland slope) were determined to aid in the qualitative interpretation of the water-quality data.

Determination of Loads from Permitted Sources

Reported effluent data for 1985 through 1991 were retrieved from the USEPA's PCS data base. The "extra" year of reports (1991) was included to ensure that sufficient point-source release data were available for the analysis. This data base includes site information, permit limits, and reported effluent characteristics (including water-quality and volume measurements). The effluent-characteristics data are entered into PCS from the Discharge Monitoring Reports (DMR's) filed with NJDEP periodically (commonly monthly or quarterly) by the owners of point-source discharge permits. The PCS data base is documented by the USEPA (U.S. Environmental Protection Agency, 1992a, 1992b).

Permitted sources included in the analysis were limited to those associated with discharges located within the study area for which data either were reported in the PCS or could be found in paper files at the NJDEP office in Trenton, N.J. (Susan Carson, New Jersey Department of Environmental Protection, oral commun., 1993).

Reported mean constituent concentrations and mean effluent volumes were analyzed statistically to determine median values for each permitted source. In many cases either no data were available or the available data obviously were problematic–for example, some effluent- volume values were reported in units of gallons per day rather than the expected million gallons per day. Where no valid concentration values were available, typical constituent concentrations developed by the National Oceanic and Atmospheric Administration's National Coastal Pollutant Discharge Inventory Program (U.S. Department of Commerce, 1990) were used. Questionable effluent values were checked against permit limits from the PCS or NJDEP paper files. Permitted sources that were classified by the NJDEP as releasing primarily noncontact cooling water or that were used only intermittently (for example, permits for discharge of stormwater runoff or water used for tank flushing) were excluded from the analysis. A list of permitted sources used in the analysis and their associated effluent volumes and calculated released loads are given in table 2.

Compilation of Water-Quality and Streamflow Data

The primary source of water-quality data used in this study is the streamflow- and water-quality-data cooperative network of USGS and NJDEP (Bauersfeld and others, 1992). The nine stations from which data were used in this study are shown in figure 1 and listed in table 3. Although two of these stations, Musconetcong River at Lockwood (01455801) and Rockaway River above Boonton (01380500), were not included in the sampling network during most of the study period (1985-90), results of analyses of additional water-quality samples collected by NJDEP were used.

Table 2. Estimated effluent flow and constituent loads from selected permitted sources in the Musconetcong, Rockaway, and Whippany River Basins, New Jersey, 1985-91

[Unless otherwise noted, effluent flow and constituent loads estimated from effluent quantity and concentration data reported in the U.S. Environmental Protection Agency Permit Compliance System data base. Abbreviations: NPDES, National Pollution Discharge Elimination System; MUA, Municipal Utility Authority; STP, Sewage Treatment Plant]

NPDES code	Facility name	Median flow, in million gallons per day	Median flow, in cubic feet per second	Load, in pounds per day: Biochemical oxygen demand	Load, in pounds per day: Total nitrogen	Load, in pounds per day: Total phosphorus
			Musconetcong River Basin			
NJ0004448	Warren Glenn Mill	2.360	3.65	326.9876	[1]27.5773	[1].0000
NJ0021369	Hackettstown MUA	1.553	2.40	156.8440	[1]145.1779	8.1663
NJ0027821	Musconetcong Sewerage Authority	1.005	1.55	164.4119	[1]93.9497	9.3111
NJ0028657	BP Performance Polymers, Inc.	.447	.69	[1]43.6520	[1].7462	[1]4.1040
NJ0004421	James River Paper Company, Inc.	.278	.43	29.5846	[1]3.2485	[1].0000
NJ0004812	Elastimold Division Amerace Corporation	.106	.16	[1]11.1478	[1]6.4586	[1].0885
NJ0028592	Diamond Hill Estates Sewage Company	.080	.12	36.8921	[1]7.4786	[1]4.6741
NJ0026212	Mt. Arlington Sanitation Corp.	.025	.04	.6260	[1]2.3371	.8305
NJ0023094	Garden State Truck Plaza	.023	.04	.9599	[1]2.1501	1.3438
NJ0076082	International Trade Center	.016	.02	.9655	[1]1.4957	.0481
NJ0021156	Consolidated School STP	[2].007	.01	.1169	[1].6544	.1052
NJ0021105	Arthur Stanlick School	.005	.01	.0835	[1].4674	.0121
NJ0022632	Byram Township Board Of Education	.005	.01	.3668	[1].4674	.0142
NJ0034975	Advanced Environmental Technology Corp.	.003	.00	[1].5985	[1].2804	[1].1753
NJ0026239	Our Lady of Lake Regional School	[2].0004	.00	.0100	[1].0374	[1].0063

Table 2. Estimated effluent flow and constituent loads from selected permitted sources in the Musconetcong, Rockaway, and Whippany River Basins, New Jersey, 1985-91 --continued

NPDES code	Facility name	Median flow, in million gallons per day	Median flow, in cubic feet per second	Load, in pounds per day		
				Bio-chemical oxygen demand	Total nitrogen	Total phosphorus
		Rockaway River Basin				
NJ0022349	Rockaway Valley Regional Sewerage Authority	8.616	13.33	243.7904	[1]805.4432	143.8291
NJ0030287	Montville Township MUA	2.160	3.34	603.9622	[1]201.9217	[1]126.2011
NJ0002500	Department of the Army	.408	.63	35.9272	[1]113.7412	[1].0000
NJ0002496	McWilliams Forge Company, Inc.	.222	.34	.0000	[1].0000	[1].0000
NJ0032808	Rockaway Town Square Mall	.109	.17	9.7802	[1]10.1896	[1]6.3685
NJ0026867	Jefferson Township -- White Rock	.078	.12	2.9297	[1]7.2916	.4232
NJ0001635	Howmet Turbine Components Corp.	.073	.11	.0000	[1]5.1791	[1].0000
NJ0026603	Randolph High School STP	.032	.05	.5342	[1]2.9914	[1]1.8696
NJ0021091	Jefferson High School	.017	.03	.2838	[1]1.5892	.0702
NJ0003077	Hewlett-Packard Co., Inc.	.012	.02	.2754	[1]2.1434	[1].1002
NJ0022802	White Meadow Lake	.0050	.01	.4215	[1].5926	[1].4173
NJ0030317	Montville Township MUA	[2].0047	.01	1.5594	[1].4394	[1].2746
		Whippany River Basin				
NJ0025496	Morristown STP	3.123	4.83	495.2640	[1]291.9451	47.7017
NJ0024902	Hanover Sewerage Authority	2.000	3.09	191.9725	[1]186.9645	[1]66.773
NJ0024911	Butterworth STP	1.706	2.64	258.4442	[1]159.4807	[1]57.242
NJ0026689	Greystone Park Psychiatric Hospital	.287	.44	25.0328	[1]80.0091	[1]5.749
NJ0003514	PPF Norda International, Inc.	.022	.03	.4076	[1]3.2869	[1]1.2303
NJ0071030	North American Phillips	.012	.02	[1]2.1434	[1].7312	[1].1002

[1]Value estimated by using typical concentrations from U.S. Department of Commerce (1990)

[2]Value estimated by using effluent quantity and quality data from paper files at the New Jersey Department of Environmental Protection

Table 3. Description of U.S. Geological Survey water-quality and streamflow-gaging stations in the Musconetcong, Rockaway, and Whippany River Basins, New Jersey

River basin	Station-identification number	Station name	Data type[1]	Period of record
Musconetcong	01455500	Musconetcong River at outlet of Lake Hopatcong	s,c,m	s: 1928-75 c,m: 1962, 1976-91
	01455801	Musconetcong River at Lockwood	c,m	1976-1991
	01456200	Musconetcong River at Beattystown	c,m	[2]1976-
	01457000	Musconetcong River near Bloomsburg	s,c,m	s: [2]1921- c,m: 1963-80, [2]1991-
	01457400	Musconetcong River at Riegelsville	c,m	[2]1976-
Rockaway	01380500	Rockaway River above Reservoir at Boonton	s,c	[2]1937-
	01381200	Rockaway River at Pine Brook	s,m	[2]1991-
Whippany	01381500	Whippany River at Morristown	s,c,m	s: [2]1921- c,m: [2]1962-
	01381800	Whippany River near Pine Brook	c,m	[2]1963-

[1]Data type: s, continuous streamflow; c, chemical; m, microbiological. (Chemical and microbiological data include instantaneous-streamflow measurements.)
[2]Stations are active as of October 1994

Five water-quality constituents were included in the study data base: chloride, biochemical oxygen demand (BOD), total phosphorus, total nitrogen, and total organic carbon (TOC). Chloride was included to confirm that the instream chloride load increased downstream and to identify the presence of major withdrawals. A conservative constituent such as chloride is not removed or added to the stream by biological or chemical processes within the stream. Therefore, changes in chloride load can be assumed to result from water inputs or withdrawals. In the absence of withdrawals, the instream load either stays the same or increases downstream. Values of instantaneous streamflow estimated at the time the water-quality samples were collected also were retrieved. Results of water-quality analyses of two samples were deleted from the data base because concurrent streamflow data were unavailable and one total-phosphorus concentration was deleted because it clearly was outside the reasonable range of concentrations recorded at that site over the period of record. Constituent concentrations are plotted as a function of instantaneous streamflow in figures 5 through 8 and 10 through 17 (farther on).

Continuous streamflow data are available for four of the nine water-quality stations--Musconetcong River at outlet of Lake Hopatcong (10455500), Musconetcong River near Bloomsburg (01457000), Rockaway River above the reservoir at Boonton (01380500), and Whippany River at Morristown (01381500). Flow-duration curves were developed for these stations to estimate the percent-exceedance streamflow values used in figures 5 through 8 and 10 through 17.

Estimation of Instream Constituent Loads

Instream loads were calculated for each measurement of each of the five constituents by multiplying the concentration by the instantaneous streamflow and applying unit conversions to yield an instream load in pounds per day, as follows:

$$\text{load (lb/d)} = \text{concentration (mg/L)} \times \text{streamflow (ft}^3\text{/s)} \times 2.20462 \times 10^{-6}\ \text{lb/mg} \times 86{,}400\ \text{s/d} \times 28.316\ \text{L/ft}^3.$$

Concentrations given as less than a laboratory reporting limit (for example, a reported total-phosphorus concentration of <0.02 mg/L) were included in the boxplots (fig. 4) and scatter plots (figs. 5-17) as the reporting limit. Loads calculated from concentrations that were reported as "less-than" values therefore represent a maximum possible instream load at the time that the particular water-quality sample was collected.

Interpretation Of Relations Between Load And Streamflow

If permitted sources are assumed to contribute constituents to a stream at a constant rate independent of streamflow, loads would remain constant with increasing streamflow if the constituent load is contributed mostly from these sources. If the load component from nonpermitted sources is large, however, loads would increase sharply with increasing streamflow, because the nonpermitted load presumably would include loads that are contributed only during periods of high streamflow, such as the load in overland runoff resulting from a large storm. Constituent concentration cannot be related to streamflow in this way, however; although a very low constituent concentration may not appear to indicate a large constituent input to the stream, at high-flow conditions a low concentration actually can represent a high instream load.

Three hypothetical streamflow-load relations are shown in figure 2. The crosses in the plot illustrate the case of constant instream load at all flow conditions, indicating little or no contribution to instream load from nonpermitted sources. The circles in the plot illustrate a gradual increase in instream load with increasing streamflow, indicating the dominance of the load from nonpermitted sources. The squares illustrate the most common case of a fairly constant instream load that increases above a threshold of streamflow as overland runoff contributes constituents to the stream, indicating that nonpermitted sources are important contributors to the instream load only during high-flow conditions.

The instream load also can be affected by contributions from ground water and stream sediment. Ground-water inputs are unlikely to affect surface-water quality during high flow conditions but, in some hydrologic systems, the scour of stream sediment could complicate the interpretation of the data significantly. Rosensteel and Strom (1991) collected water-quality samples from the Pompton and Passaic Rivers during storms and found that most of the observed increase in the load of total phosphorus at high flows was attributable to the dissolved fraction of the phosphorus load, indicating that the load contributed by sediment scour probably was significant.

Determination of Drainage-Basin Characteristics

In order to facilitate development of qualitative relations between instream loads and drainage-basin characteristics, land use, population, and overland slope were determined for each drainage basin. The results of these analyses are shown in table 1.

Population was determined from population estimates obtained from 1990 census data (U.S. Bureau of the Census, 1991).

Land use was determined from 1972 USGS land-use/land-cover data (U.S. Geological Survey, 1986). Areas assigned to each of the different land-use categories were aggregated to obtain a value for each land-use type as a percentage of the land area in each basin.

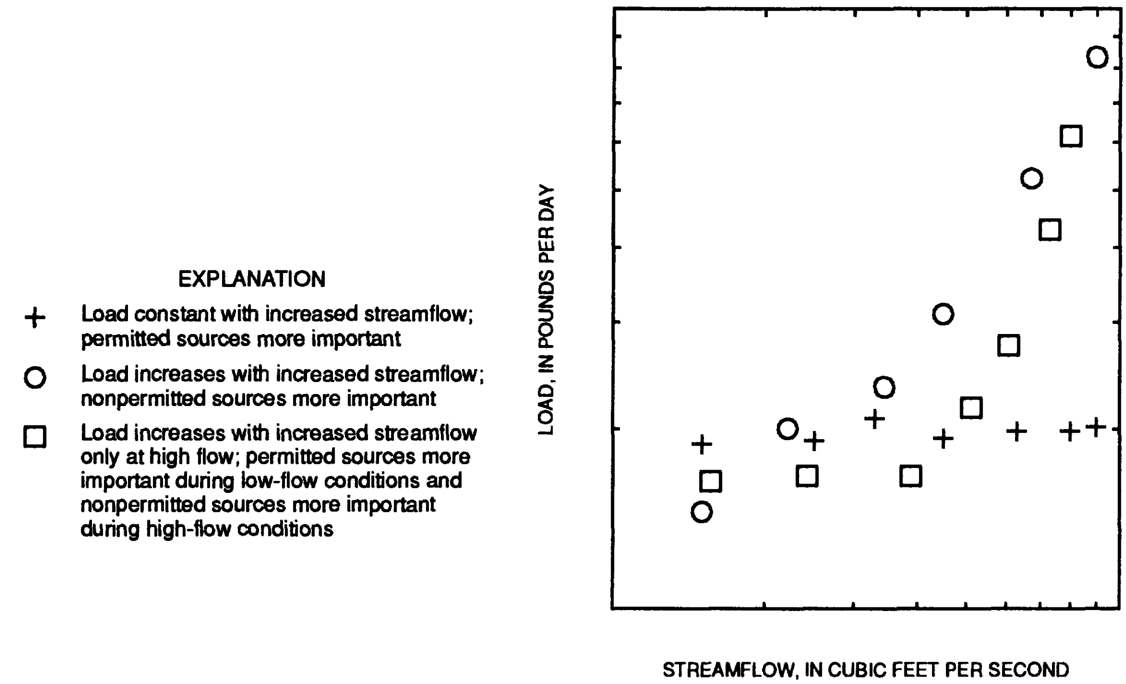


Figure 2. Hypothetical logarithmic plot of expected load-streamflow relations for streams strongly affected by permitted and nonpermitted sources of constituent load.

Unpublished estimates of impervious land cover as a percentage of the total basin area were developed from Landsat satellite data acquired on August 27, 1985. Because this information has not been field-checked, it can be used only for qualitative comparisons.

Slope statistics for the three basins were calculated from 1:250,000-scale digital elevation data (U.S. Geological Survey, 1987) to make a qualitative comparison of topography among the three basins.

ESTIMATED LOADS OF SELECTED CONSTITUENTS FROM PERMITTED AND NONPERMITTED SOURCES

Loads of all five constituents included in the study data base were used in the analysis. In the discussion below, the results of analysis of chloride data are followed by boxplots and a table describing instream and permitted loads and scatter plots showing concentration-streamflow and load-streamflow relations. The scatter plots include flow-duration information for stations where continuous-record streamflow data are available.

Chloride

Boxplots of chloride loads for eight of the nine stations in the three study basins are shown in figure 3. No chloride data were available for the Musconetcong River near Bloomsburg station (01457000). Loads of chloride, a conservative constituent, increased downstream in all but two instances.

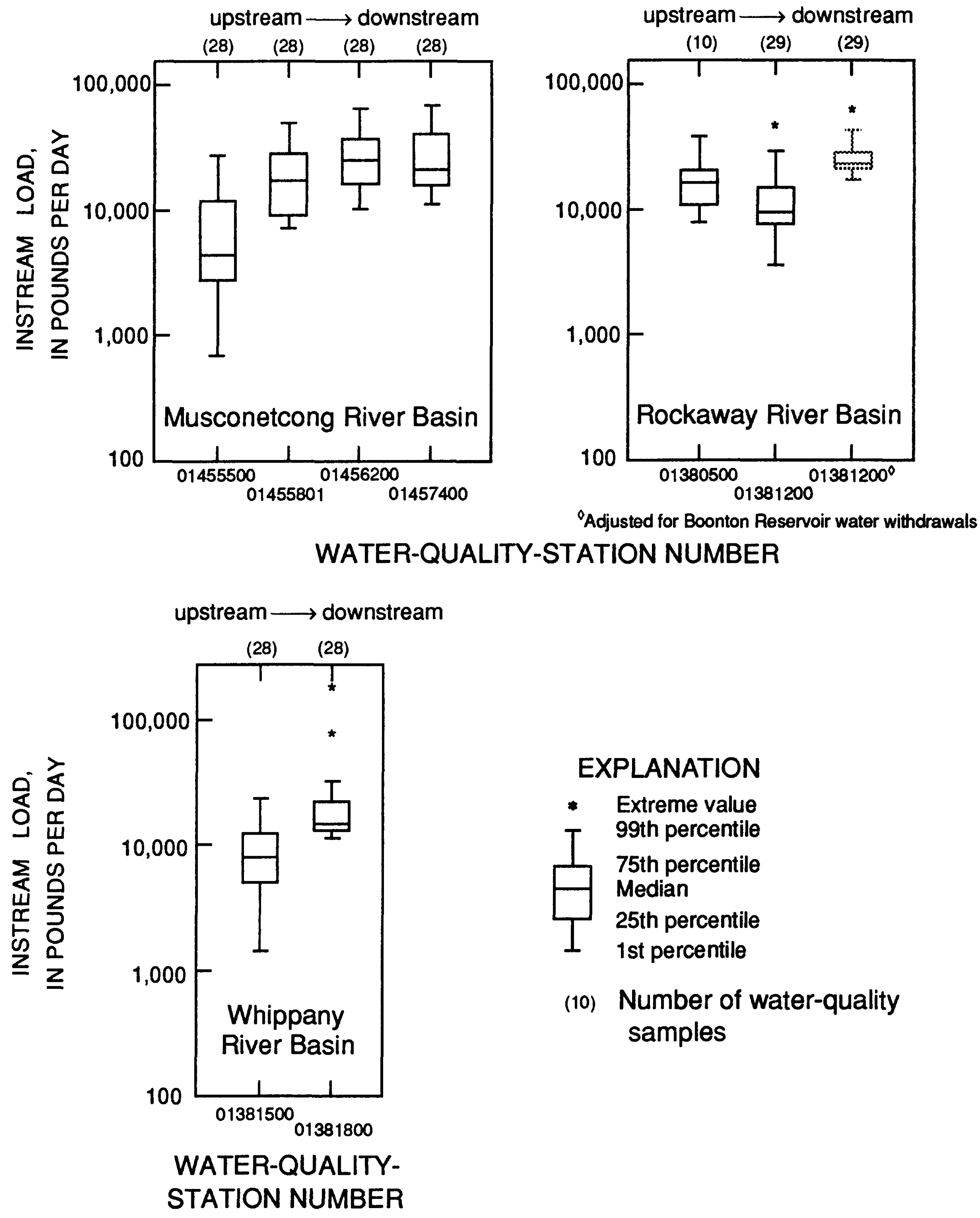


Figure 3. Chloride loads at water-quality stations in the Musconetcong, Rockaway, and Whippany River Basins, 1985-90.

In the Musconetcong River Basin, the median chloride load decreased slightly from the station at Beattystown (01456200) to the station farther downstream at Riegelsville (01457400). The decrease is small; the median load at the upstream station (01456200) is within the interquartile range of the chloride loads at the downstream station. The decrease could be explained by several factors: (1) error in streamflow measurements, (2) non-contemporaneous water-quality measurements, (3) the presence of a diversion of water around the water-quality station at Riegelsville (although it is unclear whether the diversion was active during 1985-90), and (4) possible exchange of water (with different chloride concentrations) between the ground- and surface-water systems.

In the Rockaway River Basin, the chloride load decreased downstream from the Rockaway River station at Boonton (01380500) to the station at Pine Brook (01381200), probably as a result of withdrawals from Boonton Reservoir for public water supply above the downstream station. The chloride loads at the downstream station were adjusted by adding the estimated chloride load in the withdrawal (estimated from the 1985-90 median chloride concentration of 31.5 mg/L at the upstream station and a 1985-90 mean withdrawal rate of 82 ft^3/s (Bauersfeld and others, 1991)); the adjusted boxplot shows the expected range of chloride loads at the downstream station without public-supply withdrawals. Because the adjusted results show that the chloride load increased downstream, instream loads of the other constituents calculated from concentration and instantaneous-streamflow measurements can be interpreted with confidence. The same adjustment factor (82 ft^3/s multiplied by the 1985-90 median constituent concentration) subsequently was applied to the estimated permitted BOD, nitrogen, and phosphorus loads at the Pine Brook (01381200) station.

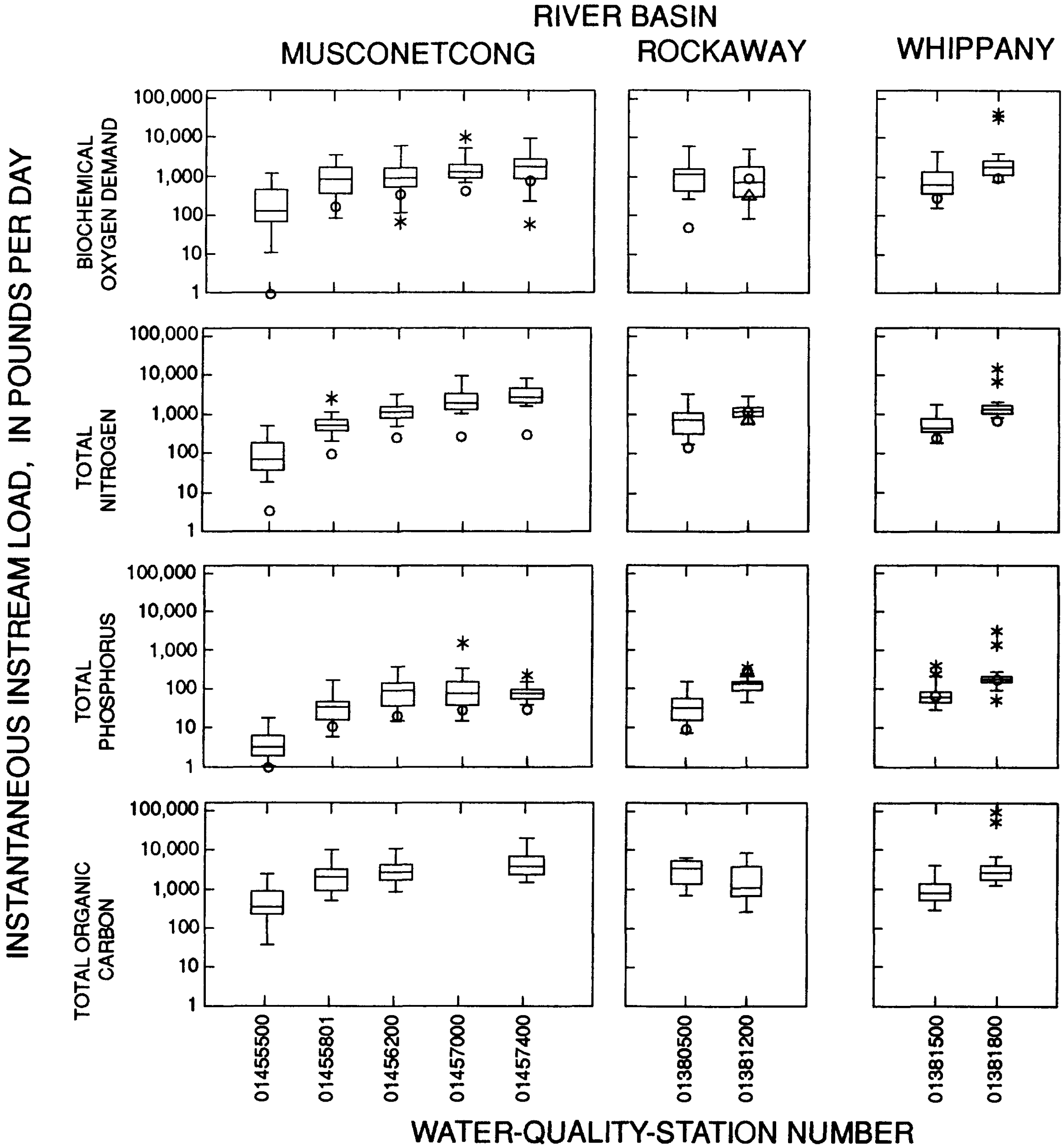
Biochemical Oxygen Demand, Nitrogen, Phosphorus, and Organic Carbon

The distributions of instream constituent loads in the three study basins are shown in figure 4. Estimated total median loads of three of the constituents (BOD, total nitrogen, and total phosphorus) from permitted point sources upstream from the water-quality station are plotted as circles. The load data shown in figure 4 are summarized in table 4. Because no reliable estimates of the permitted TOC load from permitted sources were available, permitted loads of this constituent are not plotted in figure 4 or included in table 4. Loads from permitted sources are assumed to be conservative and are not adjusted for degradation or decay of constituents. The permitted load that actually contributes to the instream load is undoubtedly smaller than the total load released to the stream from permitted sources because constituents are likely to be removed from the stream through physical, chemical, and biological processes.

Musconetcong River Basin

In the Musconetcong River Basin, instream loads of all four constituents increased downstream (fig. 4). The instream loads at the uppermost station, Musconetcong River at outlet of Lake Hopatcong (01455500), were much lower than those at the other stations, probably as a result of the small input from permitted sources upstream and the station's location directly downstream from a reservoir. During the long residence time of water in a reservoir, particulate constituents can be removed biologically or can sink and be incorporated into bottom sediments. Therefore, instream loads at this station would be expected to be low. At all of the stations, the estimated total median permitted load was smaller than the median instream load--in all cases less than 45 percent of the median instream load--indicating that the bulk of the instream load is contributed by nonpermitted sources. This hypothesis is supported by the observation that changes in the permitted loads from upstream to downstream stations do not closely mimic the changes in the distribution of instream loads.

Instream concentrations and loads of the four constituents at the Musconetcong River stations are plotted in figures 5 through 9. The sample-concentration plots show constituent concentrations over a range of flow conditions at each station. Flow-duration data are available for two of the stations and are shown across the top of the plots for those stations. The flow-duration data for the stations located at the outlet of Lake Hopatcong and at Bloomsburg show that, at least for these two stations, the water-quality samples represent a large range of flow conditions, from low flow to high flow.



EXPLANATION

o Estimated total median load from permitted point sources upstream from the water-quality station (1985-91). Load of total organic carbon from permitted point sources not available.

△ Estimated total median load adjusted for withdrawals from Boonton Reservoir (see text and table 4).

Figure 4. Instream loads at water-quality stations in the Musconetcong, Rockaway, and Whippany River Basins, New Jersey, 1985-91.

Table 4. Estimated total permitted load and median instream load at water-quality stations in the Musconetcong, Rockaway, and Whippany River Basins, New Jersey, 1985-90

River	Location	Station-identification number	Biochemical oxygen demand	Total nitrogen	Total phosphorus
			Estimated total permitted load, in pounds per day		
Musconetcong	at outlet of Lake Hopatcong	01455500	0.8	3.5	1.0
	at Lockwood	01455801	167.2	99.7	10.5
	at Beattystown	01456200	335.2	251.3	18.8
	near Bloomsburg	01457000	415.7	259.6	27.6
	at Riegelsville	01457400	773.2	292.5	28.9
Rockaway	above reservoir at Boonton	01380500	50.2	143.7	9.2
	at Pine Brook	01381200	899.5	1151.5	279.6
	at Pine Brook	[1]01381200	324.5	735.8	266.3
Whippany	at Morristown	01381500	285.6	240.2	63.1
	near Pine Brook	01381800	973.3	722.4	178.8
			Median instream load[2], in pounds per day		
Musconetcong	at outlet of Lake Hopatcong	01455500	125.7	69.8	2.9
	at Lockwood	01455801	828.5	521.0	33.3
	at Beattystown	01456200	902.4	1,132.7	90.0
	near Bloomsburg	01457000	1,279.1	1,877.0	75.7
	at Riegelsville	01457400	1,734.6	2,696.8	74.4
Rockaway	above reservoir at Boonton	01380500	1,118.4	712.9	32.2
	at Pine Brook	01381200	694.2	1,141.3	132.8
Whippany	at Morristown	01381500	608.4	428.3	59.8
	near Pine Brook	01381800	1,721.6	1,352.2	177.1
			Total permitted load expressed as a percentage of median instream load		
Musconetcong	at outlet of Lake Hopatcong	01455500	0.6	5.0	34.5
	at Lockwood	01455801	20.2	19.1	31.5
	at Beattystown	01456200	37.1	22.2	20.9
	near Bloomsburg	01457000	32.5	13.8	36.3
	at Riegelsville	01457400	44.6	10.8	38.8
Rockaway	above reservoir at Boonton	01380500	4.5	20.2	28.6
	at Pine Brook	01381200	129.6	100.9	210.5
	at Pine Brook	[1]01381200	46.7	64.5	200.5
Whippany	at Morristown	01381500	46.9	56.1	105.5
	near Pine Brook	01381800	56.5	53.4	101.0

[1]Total reported load adjusted for load removed by water-supply withdrawal from Boonton Reservoir

[2]Load calculated from concentration and discharge data collected by the U.S. Geological Survey and the New Jersey Department of Environmental Protection

Instream loads of BOD increased with streamflow (fig. 5), indicating an instream load dominated by input from nonpermitted sources. Many of the BOD concentrations were recorded as below the laboratory reporting limit, and are plotted as open triangles on both the concentration and load plots in figure 5. The slope of the load-streamflow relation for the station at Riegelsville is less steep and the data points are more scattered than at the other stations. This may be a result of BOD input from permitted sources; this station shows the largest permitted BOD load expressed as a percentage of median instream load (44.6 percent). Nevertheless, this percentage indicates that nonpermitted sources contribute more of the instream load of BOD than permitted sources.

The instream loads of total nitrogen (fig. 6) demonstrate a similar pattern of strongly increased load at high flow, which indicates that nonpermitted sources are more important contributors to the instream load than permitted sources. The permitted total-nitrogen loads at each water-quality station (fig. 4, table 4) are all less than 25 percent of the median instream total-nitrogen load, again indicating that permitted sources are less important contributors to instream load than nonpermitted sources in the Musconetcong River Basin.

Relations of total-phosphorus concentration and load to streamflow for the Musconetcong River Basin stations are shown in figure 7. At four of the five stations (all stations except Riegelsville), total-phosphorus loads increased markedly with increased streamflow, indicating that nonpermitted sources contribute most of the instream load. At the Riegelsville station, loads increased only slightly with increased streamflow. Because no major permitted sources of total phosphorus are present between the station at Riegelsville and the next station upstream at Bloomsburg, this relation probably is not caused by a large input from permitted sources. Instead, the absence of the expected increase in load at high flow may result from the presence of limestone in the downstream part of the basin (Kasabach, 1966). Limestone areas are less likely than areas underlain by other types of bedrock to generate overland runoff during storms, because precipitation commonly percolates directly into fractures and solution channels in the limestone rather than running overland (and transporting sediment) to streams.

The load data from the Beattystown station fall into two clusters that correspond to different time periods. The change in the relation between total-phosphorus load and streamflow with time at this station is shown in figure 8a. Loads clearly were higher during 1985-87 than during 1989-90. This change may reflect improvements in the quality of effluent released from upstream permitted sources. The Hackettstown Municipal Utility Authority sewage-treatment facility is located less than 0.5 mi upstream from this station. Reported loads from the PCS data base (fig. 8b) indicate that upgrades to the facility in 1988 reduced the mean input of total phosphorus to the stream. This reduction in total-phosphorus input to the stream apparently reduced the instream load at low flow; however, the instream loads at high flow for the two time periods (fig. 8a) do not differ markedly.

TOC loads increased significantly with increased streamflow, indicating that the instream load of TOC is controlled mostly by input from nonpermitted sources (fig. 9).

Rockaway River Basin

The distributions of instream constituent loads in the Rockaway River Basin are shown in figure 4 and summarized in table 4. The upstream station, Rockaway River above Reservoir at Boonton (01380500), is 1.8 mi upstream from Boonton Reservoir. The downstream station, Rockaway River at Pine Brook (01381200), is 1.0 mi upstream from the confluence of the Rockaway and Whippany Rivers (Bauersfeld and others, 1992). Permitted loads of each of the constituents except TOC at the Pine Brook station (fig. 4 and table 4) were adjusted for surface-water withdrawals from Boonton Reservoir, which decrease both streamflow and constituent load in the river. The adjustment was made by using the 1985-90 mean withdrawal rate of 82 ft^3/s (Bauersfeld and others, 1992) multiplied by the 1985-90 median concentration at the upstream station at Boonton. Unadjusted permitted loads are plotted as circles and adjusted permitted loads are plotted as triangles in figure 4.

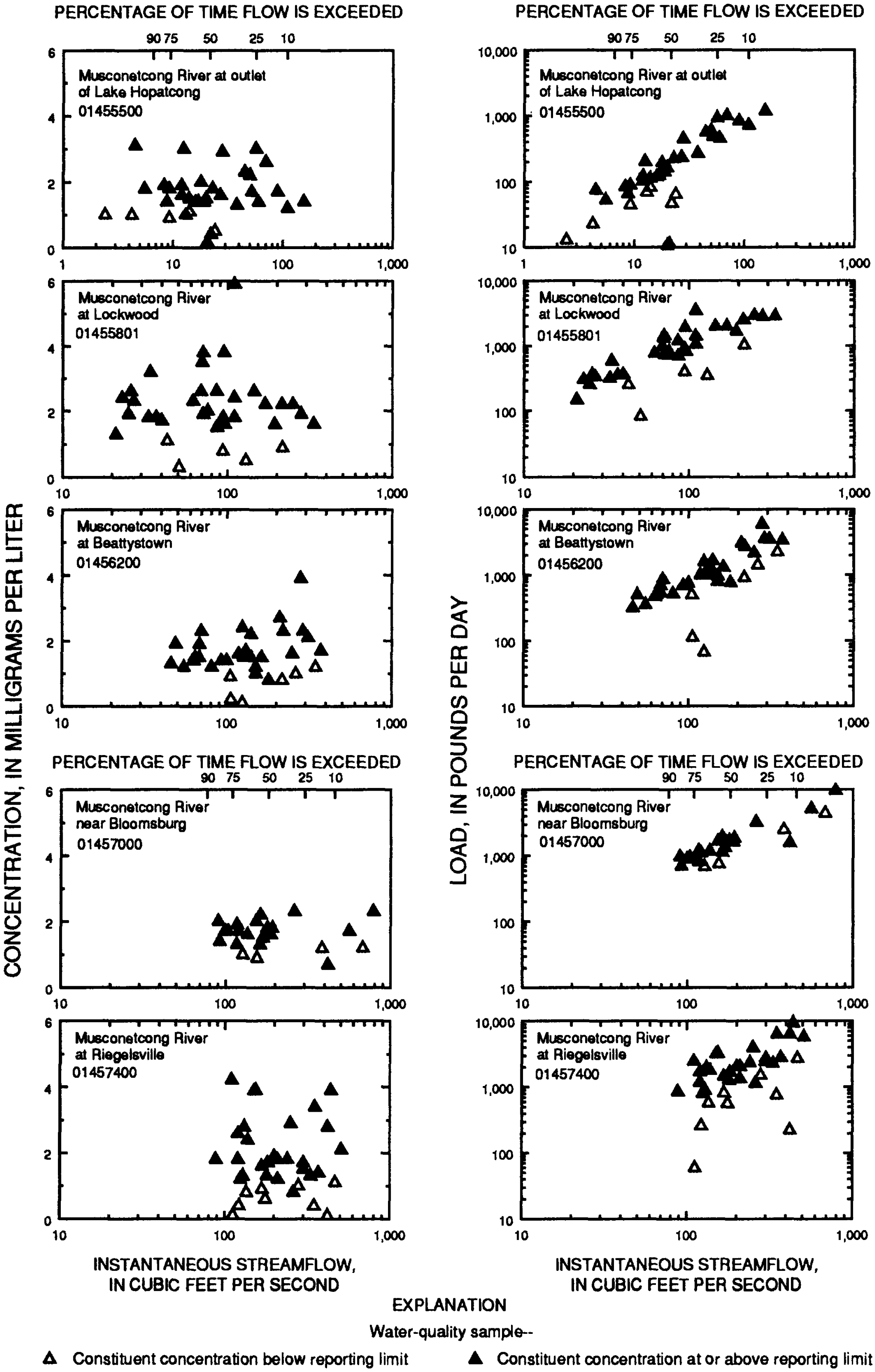


Figure 5. Relation of instream concentration and load of biochemical oxygen demand to instantaneous streamflow at water-quality stations in the Musconetcong River Basin, New Jersey, 1985-91.

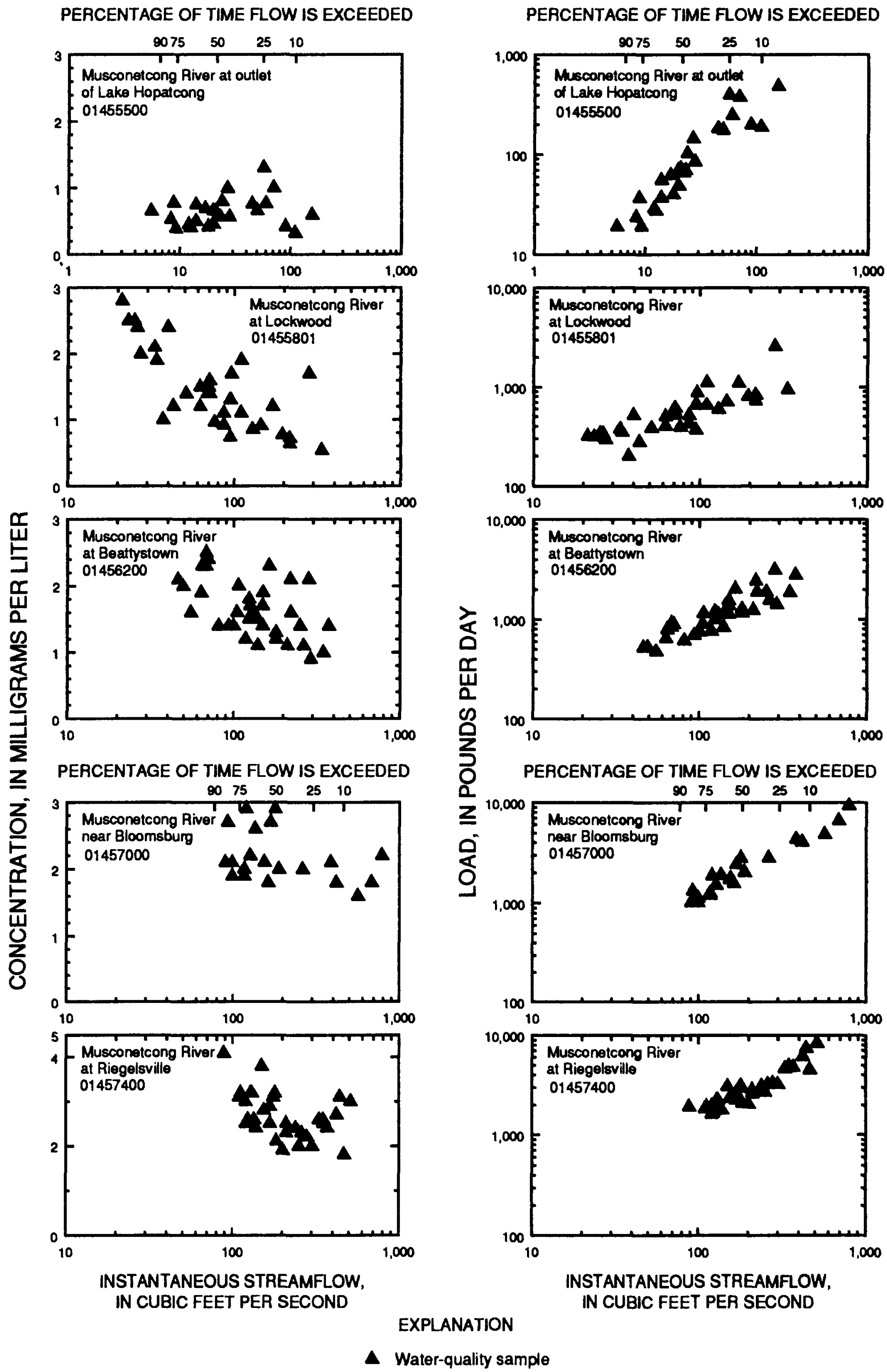


Figure 6. Relation of instream concentration and load of total nitrogen to instantaneous streamflow at water-quality stations in the Musconetcong River Basin, New Jersey, 1985-91.

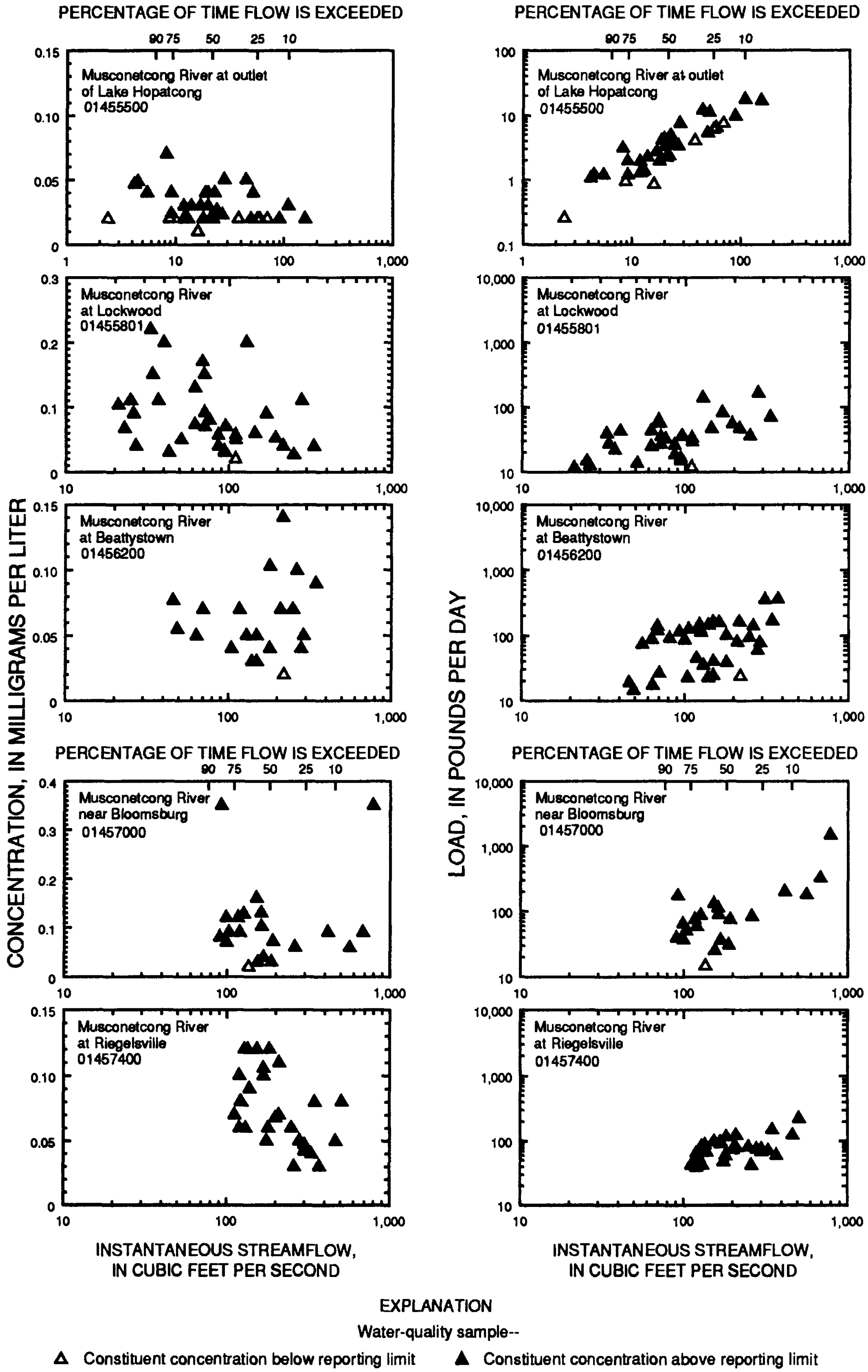


Figure 7. Relation of instream concentration and load of total phosphorus to instantaneous streamflow at water-quality stations in the Musconetcong River Basin, New Jersey, 1985-91.

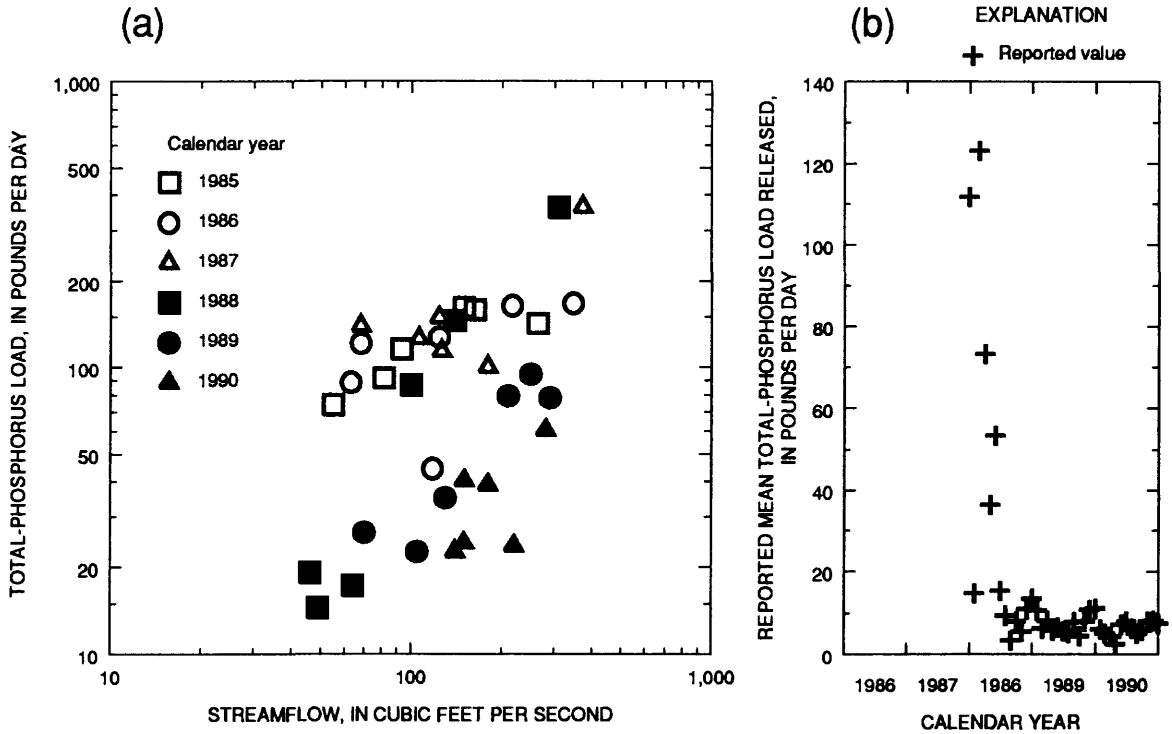


Figure 8. (a) Relation of total-phosphorus load to streamflow, Musconetcong River at Beattystown (01456200), New Jersey, and (b) reported mean monthly total-phosphorus loads released from the sewage-treatment plant operated by Hackettstown Municipal Utility Authority 0.5 miles upstream. (Data from U.S. Environmental Protection Agency Permit Compliance System data base.)

The median instream BOD and TOC loads decreased from the upstream to the downstream station, whereas loads of total nitrogen and total phosphorus increased greatly. Estimated total median loads of BOD, total nitrogen, and total phosphorus from permitted sources also increased from the upstream to the downstream station. Permitted loads of total phosphorus were much larger than the median instream load at the Pine Brook station, indicating that the load of total phosphorus from permitted sources probably makes up most of the instream load of this constituent at the Pine Brook station. Although it appears unreasonable, it is possible for the permitted load of total phosphorus to be twice the instream load because much of the load contributed by permitted sources is removed from the stream by physical, chemical and biological processes before it reaches the Pine Brook station.

Instream concentrations and loads of the four constituents at the Rockaway River stations are plotted in figures 10 through 13. Flow-duration data are available only for the upstream station and are indicated along the top axis of the plots.

Instream loads of all four constituents increased with streamflow in the Rockaway River Basin, although at the Pine Brook station, total-nitrogen and total-phosphorus loads increased less markedly with streamflow than BOD and TOC loads. This indicates that although nonpermitted sources contribute loads of all four constituents to the instream loads at both stations, total-nitrogen and total-phosphorus instream loads at Pine Brook include a significant component from permitted sources. The load-discharge relations indicate that the strong increase noted above in the median instream loads of total nitrogen and total phosphorus from the upstream to the downstream station was caused by the input of loads from permitted sources between the two stations.

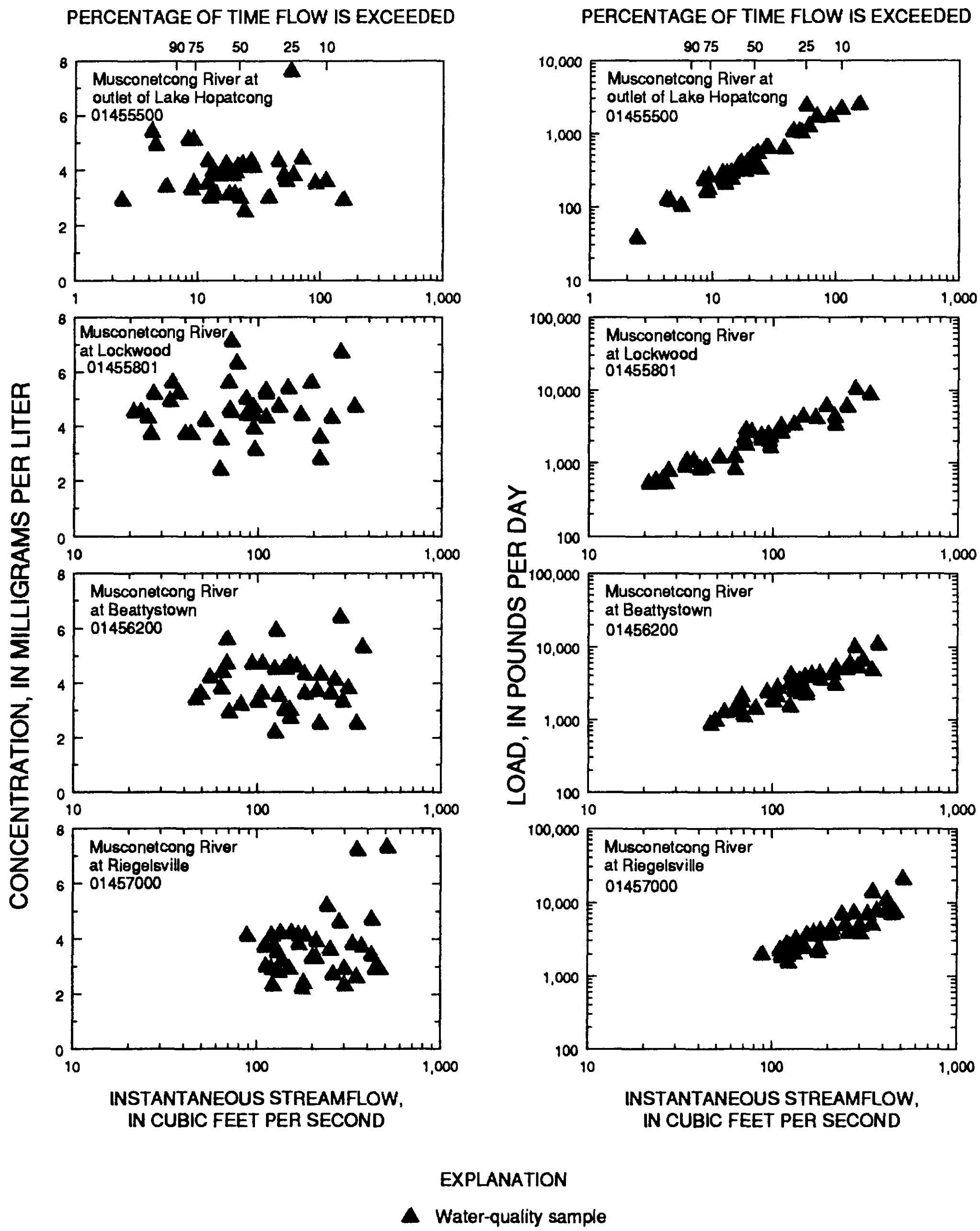


Figure 9. Relation of instream concentration and load of total organic carbon to instantaneous streamflow at water-quality stations in the Musconetcong River Basin, New Jersey, 1985-91. (No data were available and no plot is shown for Musconetcong River near Bloomsburg.)

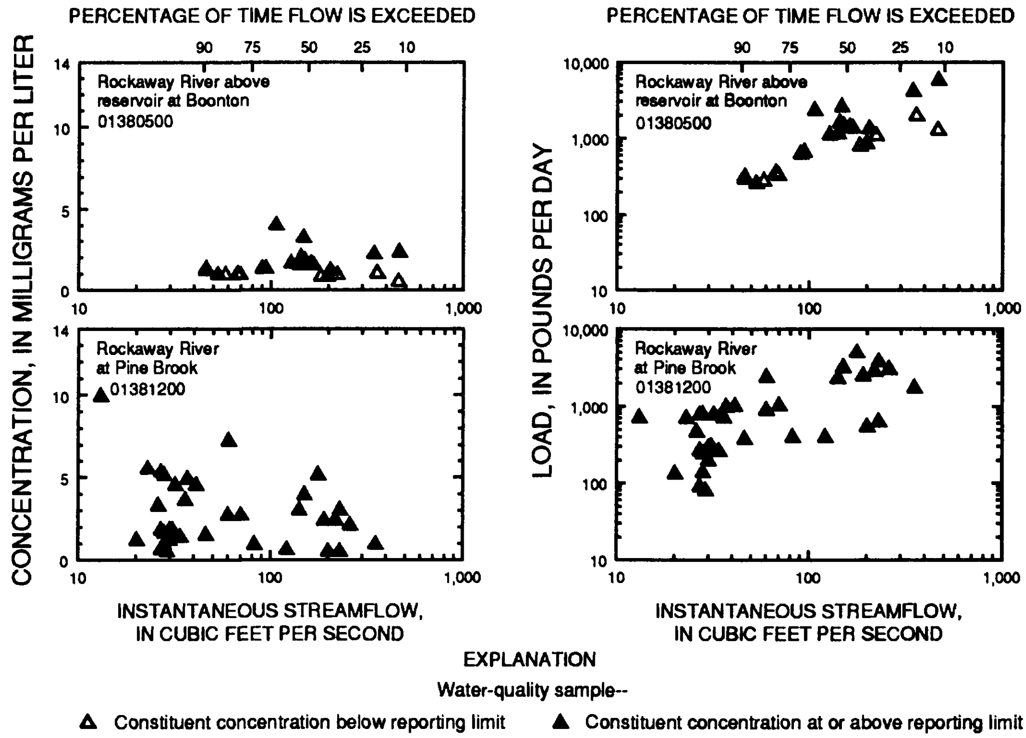


Figure 10. Relation of instream concentration and load of biochemical oxygen demand to instantaneous streamflow at water-quality stations in the Rockaway River Basin, New Jersey, 1985-91.

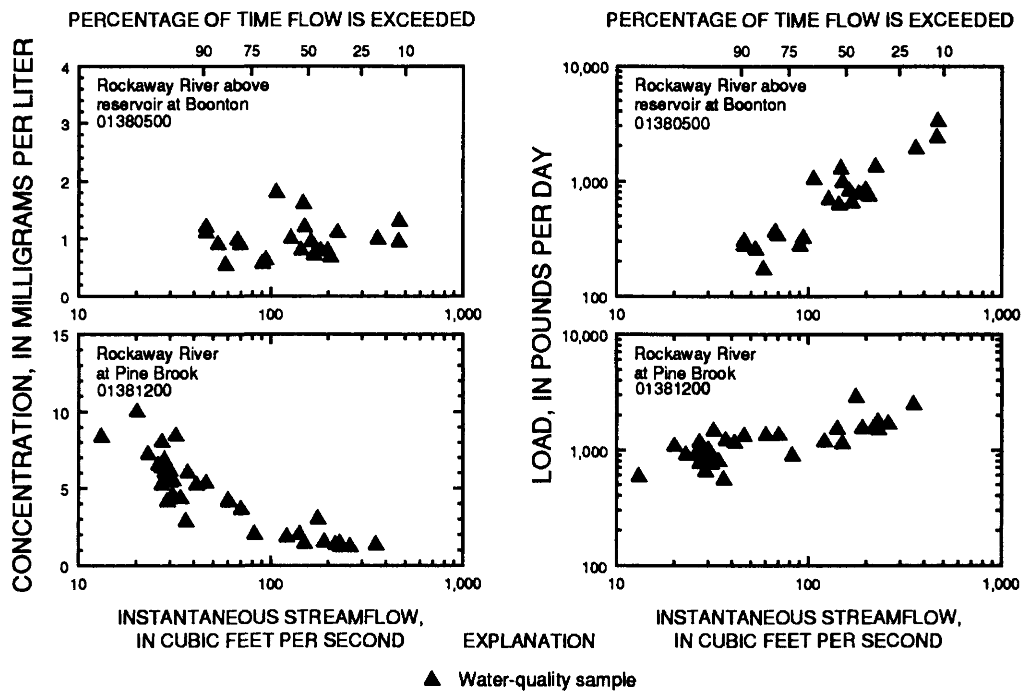


Figure 11. Relation of instream concentration and load of total nitrogen to instantaneous streamflow at water-quality stations in the Rockaway River Basin, New Jersey, 1985-91.

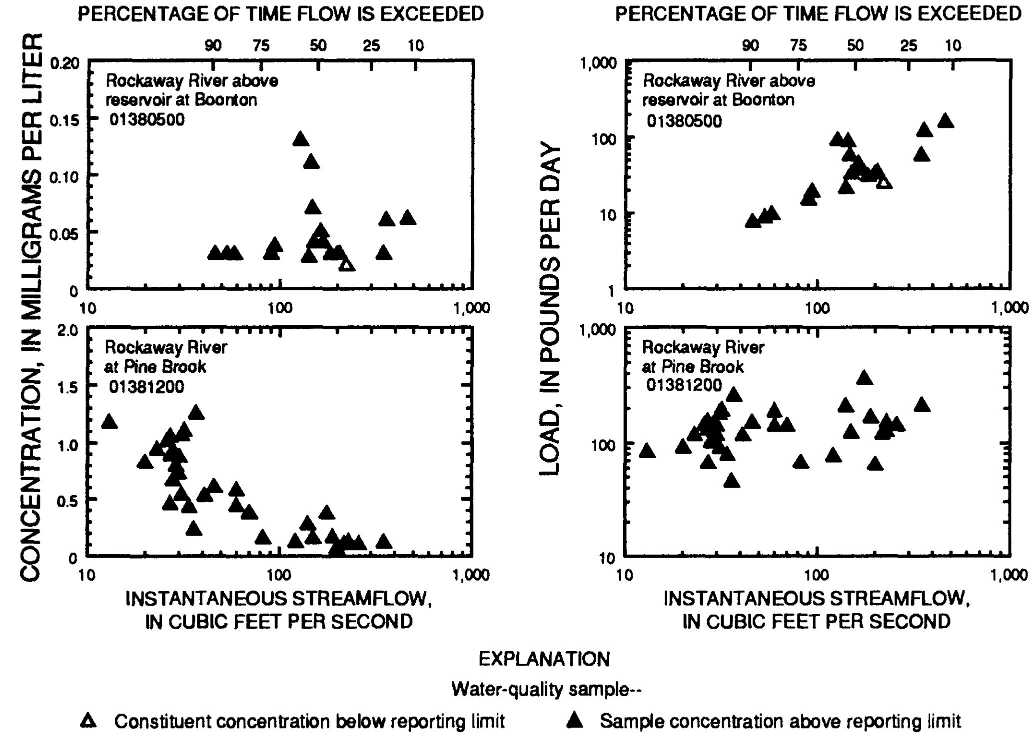


Figure 12. Relation of instream concentration and load of total phosphorus to instantaneous streamflow at water-quality stations in the Rockaway River Basin, New Jersey, 1985-91.

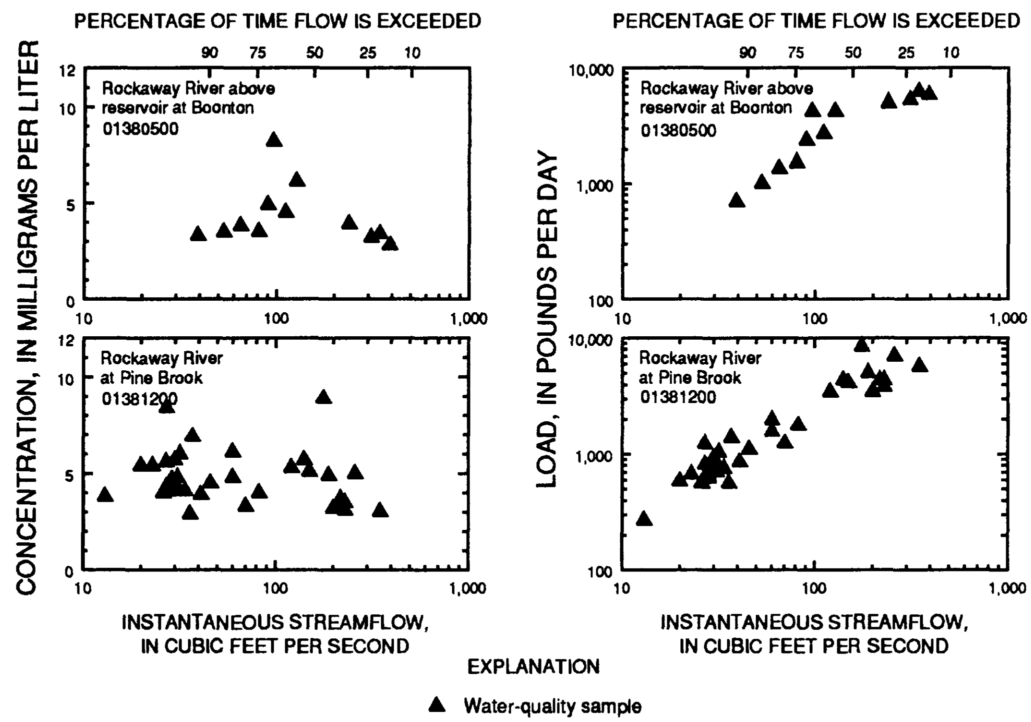


Figure 13. Relation of instream concentration and load of total organic carbon to instantaneous streamflow at water-quality stations in the Rockaway River Basin, New Jersey, 1985-91.

Whippany River Basin

Estimated permitted loads and instream loads at the two Whippany River stations are shown in figure 4 and listed in table 4. The upstream station, Whippany River at Morristown (01381500), is directly downstream from two impoundments of the Whippany River, Pocohantas and Speedwell Lakes. The downstream station, Whippany River near Pine Brook (01381800), is 0.4 mi upstream from the confluence with the Rockaway River (Bauersfeld and others, 1992).

Loads of all four constituents increased from the upstream to the downstream station (fig. 4). The 25th-percentile instream-load values for BOD and total nitrogen exceeded the estimated total median loads from permitted sources (plotted as circles) at both stations, indicating an important nonpermitted-source contribution for those constituents. Permitted loads of total phosphorus, in contrast, were equal to or greater than the instream loads, indicating a larger input of this constituent from permitted sources. Because of the lake effect (described above in the discussion of the Musconetcong River Basin), however, a large amount of particulate phosphorus probably is removed from the Whippany River above the upstream station. Therefore, the permitted load of total phosphorus plotted in figure 4 for the upstream station (01381500) probably is much larger than the actual load contributed by permitted sources.

Instream concentrations and loads of the four constituents at the Whippany River stations are plotted in figures 14 through 17. Flow-duration data are available only for the upstream station and are indicated along the top axis of the plots.

All the plots for the downstream station near Pine Brook show two extremely high flow events during which loads also were very high. The instream loads estimated from these two water-quality samples, collected on April 16, 1986, and October 28, 1987, were much higher than those in the other samples in the data set, indicating that loads from nonpermitted sources were very high during these events. The actual source of this load, however, could have been either nonpermitted sources or violations of permits (for example, failure of a wastewater-treatment plant caused by stormwater flowing into the sewerage system). The following interpretations, therefore, consider only the water-quality samples collected during more typical flow conditions.

BOD, total-nitrogen, and total-phosphorus loads increased with increasing streamflow at the Morristown station and remained relatively constant with increasing streamflow near Pine Brook (figs. 14-16). This indicates that nonpermitted sources are more important contributors to the instream load at the Morristown station and permitted sources are more important contributors to the instream load at the station near Pine Brook. Instream loads of TOC, however, increased with increasing streamflow at both stations (fig. 17), indicating that the nonpermitted load of TOC is a major component of the instream load even in the lower part of the basin near Pine Brook.

SUMMARY AND CONCLUSIONS

This report summarizes the quality of surface water during 1985-90 with respect to four constituents--biochemical oxygen demand, total nitrogen, total phosphorus, and total organic carbon--at nine water-quality-sampling stations in three river basins in northern New Jersey over a range of flow conditions, and characterizes the major wastewater inputs to the rivers above these stations. The comparison of instream water-quality data from the nine stations and permitted-source data shows that the lower reaches of the rivers generally carry larger instream loads than the upper reaches, and that the difference often is not solely attributable to inputs from permitted sources. Where the load from permitted sources is much less than the total observed instream load, the instream load can be assumed to be derived mostly from nonpermitted sources, including overland runoff and other nonpoint sources of constituent load.

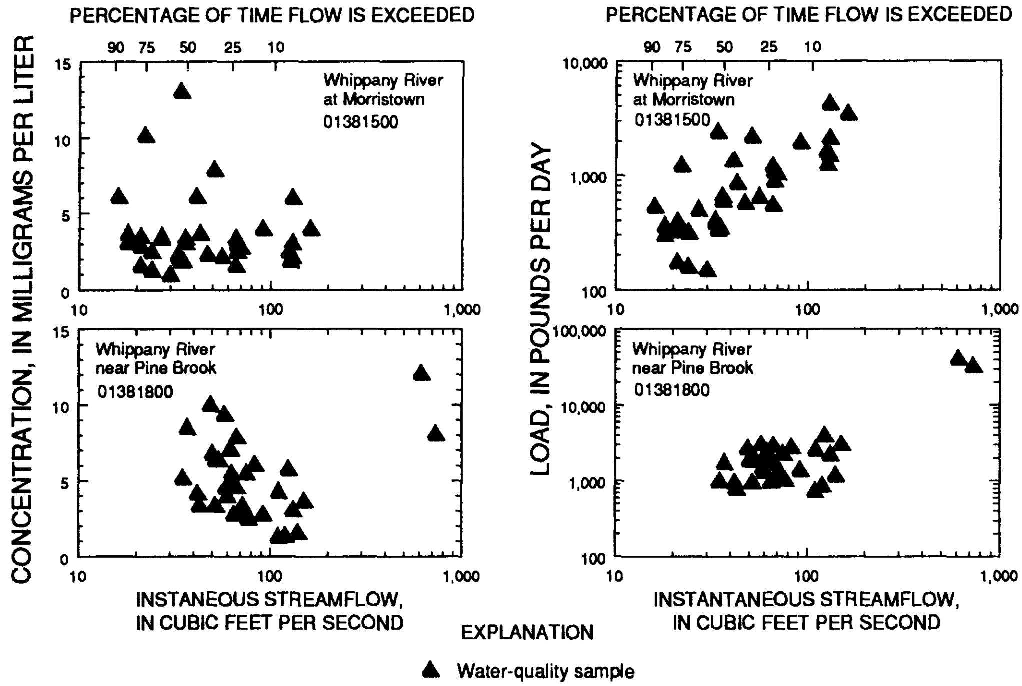


Figure 14. Relation of instream concentration and load of biochemical oxygen demand to instantaneous streamflow at water-quality stations in the Whippany River Basin, New Jersey, 1985-91.

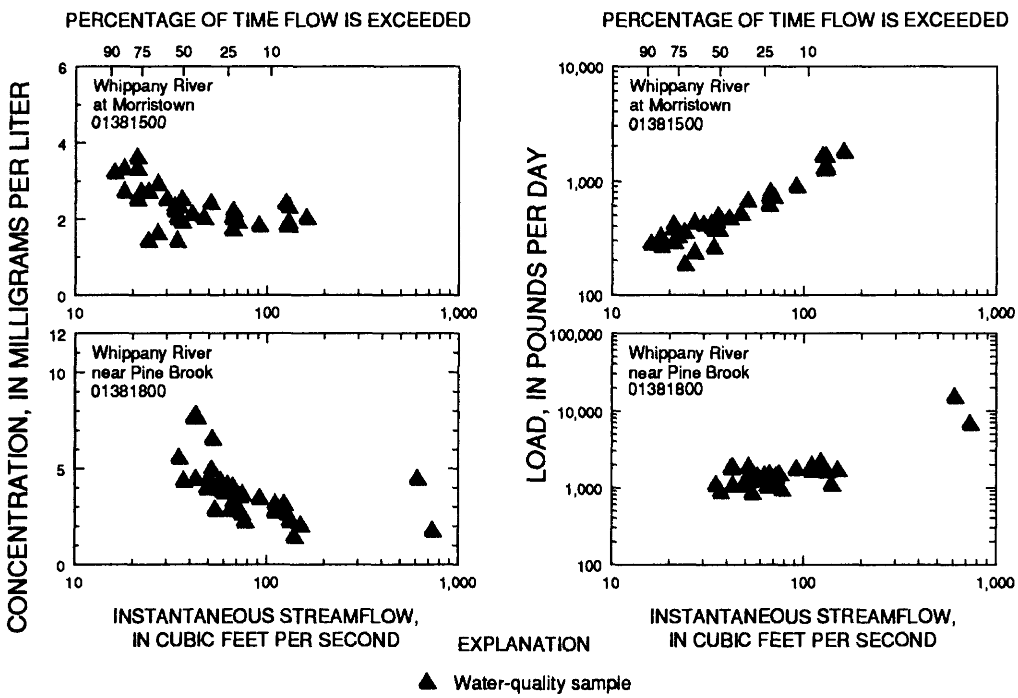


Figure 15. Relation of instream concentration and load of total nitrogen to instantaneous streamflow at water-quality stations in the Whippany River Basin, New Jersey, 1985-91.

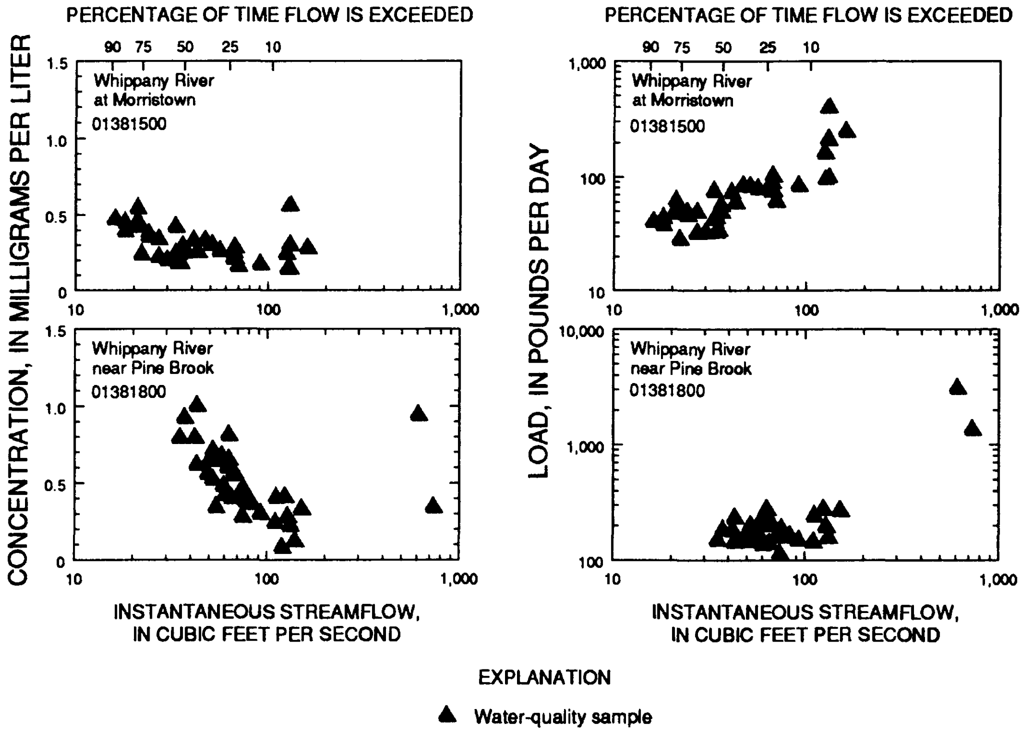


Figure 16. Relation of instream concentration and load of total phosphorus to instantaneous streamflow at water-quality stations in the Whippany River Basin, New Jersey, 1985-91.

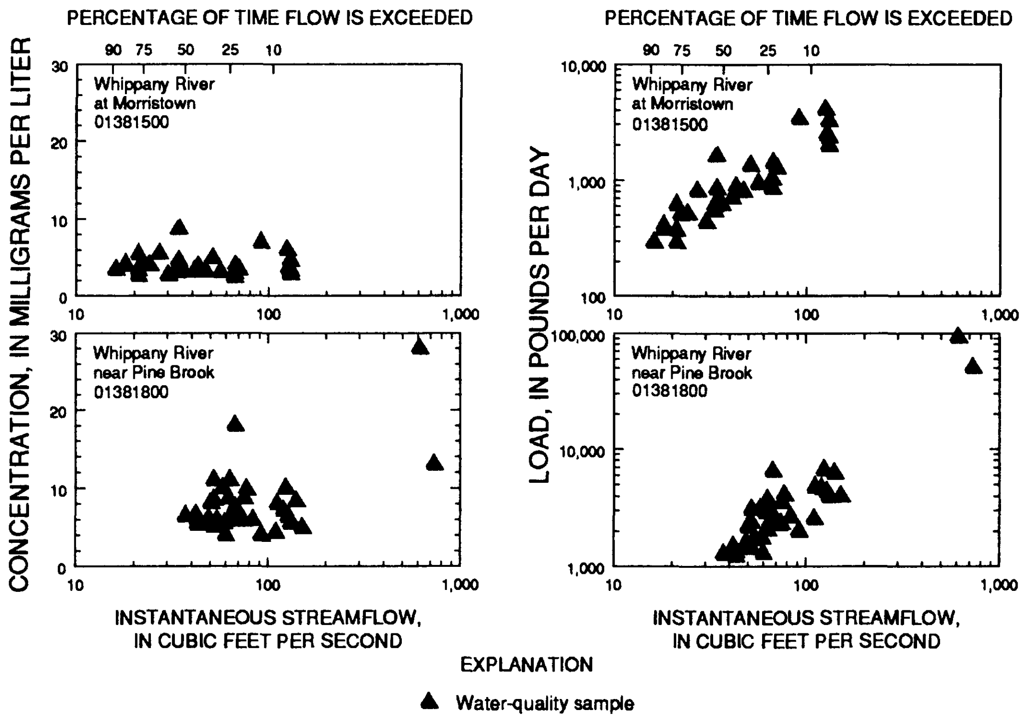


Figure 17. Relation of instream concentration and load of total organic carbon to instantaneous streamflow at water-quality stations in the Whippany River Basin, New Jersey, 1985-91.

If permitted point sources are assumed to contribute constituents to the stream at a nearly constant rate independent of streamflow, load-streamflow relations can be used to evaluate the relative contribution of inputs from permitted and nonpermitted sources to the instream constituent loads. In general, conclusions drawn from interpretation of these relations agree with those reached by comparison of permitted and instream loads. Examination of water-quality data in this way can be used as a helpful screening tool to indicate where additional study may be needed to address water-quality problems effectively. For example, instream loads of biochemical oxygen demand, total nitrogen, and total organic carbon in the Musconetcong River Basin appear to be derived largely from nonpermitted sources. Further study is needed to identify the sources (for example, storm sewers or runoff from suburban or agricultural areas) in order to improve water quality.

The lack of data on wastewater discharges reported in the U.S. Environmental Protection Agency's Permit Compliance System was an impediment to this analysis. The Permit Compliance System data base was designed for monitoring compliance with regulatory requirements on certain kinds of wastewater-generating facilities and not specifically for water-quality planning and management. Because estimation of effluent volumes and effluent sampling is expensive and time-consuming, information on many constituents important to supporting fisheries, water supply, or recreational uses of waterways (such as the constituents included in this study) commonly is not required in wastewater-permit-compliance reports.

Although accurate, detailed data on point-source loads are helpful in evaluating stream-water quality, the goal of water-quality management is to control the instream contaminant concentration and load, to which nonpermitted sources can be important contributors. A long-term water-quality record can be used to evaluate relative contributions of inputs from permitted and nonpermitted sources to total instream contaminant load over a range of flow conditions.

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