U.S. Department of the Interior
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RELATIONS OF SURFACE-WATER QUALITY TO STREAMFLOW IN THE RARITAN RIVER BASIN, NEW JERSEY, WATER YEARS 1976-93

Water-Resources Investigations Report 99-4045

Prepared in cooperation with the

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

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West Trenton, New Jersey

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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
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
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pounds per day (lb/d)	0.4536	kilograms per day
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram

Temperature given in degrees Fahrenheit (°F) and Celsius (°C) can be converted to degrees Celsius (°C) and Kelvin (°K) by the following equations:

$$°C = 5/9 \times (°F-32)$$
$$°K = 273.15 + °C$$

Water-quality abbreviations

µm	- micrometer
s/d	- seconds per day
mg/L	- milligrams per liter
µg/L	- micrograms per liter
MPN/100mL	- most probable number of bacteria per 100 milliliters
ALK	- alkalinity
HARD	- hardness
TOC	- total organic carbon
SS	- suspended sediment
DS	- dissolved solids
NA	- dissolved sodium
CL	- dissolved chloride
DO	- dissolved oxygen
FDO	- fraction of dissolved oxygen at saturation
TP	- total phosphorus
TN	- total nitrogen
NO32	- total nitrate plus nitrite
NO2	- total nitrite
TAON	- total ammonia plus organic nitrogen
NH4	- total ammonia
B	- total boron
PB	- total lead
BACT	- fecal coliform bacteria

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ABSTRACT

Relations of water quality to streamflow were determined for 18 water-quality constituents at 21 surface-water stations within the drainage area of the Raritan River Basin for water years 1976-93. Surface-water-quality and streamflow data were evaluated for trends (through time) in constituent concentrations during high and low flows, and relations between constituent concentration and streamflow, and between constituent load and streamflow, were determined. Median concentrations were calculated for the entire period of study (water years 1976-93) and for the last 5 years of the period of study (water years 1989-93) to determine whether any large variation in concentration exists between the two periods. Medians also were used to determine the seasonal Kendall's tau statistic, which was then used to evaluate trends in concentrations during high and low flows.

Trends in constituent concentrations during high and low flows were evaluated to determine whether the distribution of the observations changes through time for intermittent (nonpoint storm runoff) or constant (point sources and ground water) sources, respectively. High- and low-flow trends in concentrations were determined for some constituents at 13 of the 21 water-quality stations; 8 stations have insufficient data to determine trends. Seasonal effects on the relations of concentration to streamflow are evident for 16 of the 18 constituents. Negative slopes of relations of concentration to streamflow, which indicate a decrease in concentration at high flows, predominate over positive slopes because of the dilution of instream concentrations by storm runoff.

The slopes of the regression lines of load to streamflow were determined in order to show the relative contributions to the instream load from constant (point sources and ground water) and intermittent sources (storm runoff). Greater slope values indicate larger contributions from storm runoff to instream load, which most likely indicate an increased relative importance of nonpoint sources. The slopes of load-to-streamflow relations along a stream reach that tend to increase in a downstream direction indicate the increased relative importance of contributions from storm runoff. The slopes of load-to-streamflow relations increase in the downstream direction for alkalinity at North Branch Raritan and Millstone Rivers, for some or all of the nutrient species at South Branch and North Branch Raritan Rivers, for hardness at South Branch Raritan River, for dissolved solids at North Branch Raritan River, for dissolved sodium at Lamington River, and for suspended sediment and dissolved oxygen at Millstone River. Likewise, the slopes of load-to-streamflow relations along a stream reach that tend to decrease in a downstream direction indicate the increased relative importance of point sources and ground-water discharge. The slopes of load-to-streamflow relations decrease in the downstream direction for dissolved solids at Raritan and Millstone Rivers; for dissolved sodium, dissolved chloride, total ammonia plus organic nitrogen, and total ammonia at South Branch Raritan, Raritan, and Millstone Rivers; for dissolved oxygen at North Branch Raritan and Lamington Rivers; for total nitrite at Lamington, Raritan, and Millstone Rivers; for total boron at South Branch Raritan and Millstone Rivers; for total organic carbon at North Branch Raritan River; for suspended sediment and total nitrogen at Raritan River; and for hardness, total phosphorus, and total lead at Millstone River.

INTRODUCTION

The New Jersey Department of Environmental Protection (NJDEP) has initiated an innovative watershed approach to water-quality management in order to attain State-mandated goals for the quality of surface water (New Jersey Department of Environmental Protection, 1989). Water quality will be assessed and management practices will be executed on the basis of factors that adversely affect quality, such as nonpoint source contributions, headwaters destruction, and habitat degradation, within the watershed or basin. This approach requires evaluation of the effects of point- and nonpoint-source contributions on the quality of surface water within a watershed. To facilitate the assessment of surface-water quality, the State is divided into four regions on the basis of watershed-management issues and hydrogeologic boundaries defined by the U.S. Geological Survey (USGS) (fig. 1).

The USGS, in cooperation with the NJDEP, has developed a watershed-based method for relating water quality to streamflow to assess the relative contributions of constant (point sources and ground-water discharge) and intermittent (nonpoint storm runoff) sources of constituents to New Jersey streams in all four watershed regions. The initial study was conducted for the Passaic region, which comprises the Hackensack, Passaic, Elizabeth, and Rahway River Basins (Buxton and others, 1998a). The other regions consist of (1) the Wallkill River and upper Delaware River Basins; (2) the Raritan River Basin; and (3) the Atlantic Coastal, lower Delaware River, and Delaware Bay Basins.

Purpose and Scope

This report presents the results of analyses for 18 water-quality constituents in samples collected at 21 surface-water-quality stations within the Raritan River Basin (referred to as the study area) during water years[1] 1976-93 (October 1, 1975, through September 30, 1993). Relations between each of the 18 constituents and streamflow at the 21 stations over the period of record were determined by testing for trends in the concentrations of constituents during low and high flows. Qualitative values of contributions from constant (point sources and ground water) and intermittent (nonpoint storm runoff) sources are estimated statistically by examining the relations between concentrations of constituents and streamflow, and between load and streamflow.

Results of analyses are presented in three ways--in tables for each station with median concentrations, the regression slopes of concentration and load to streamflow, and the directions of the trends in concentrations during low and high flows for all constituents; in schematics for each constituent showing regional trends in concentrations during low and high flows and the slopes of load to streamflow; and in graphs for each constituent, by station, showing relations of concentration to streamflow, load to streamflow, and trends in concentrations during low and high flows.

[1] A water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends.

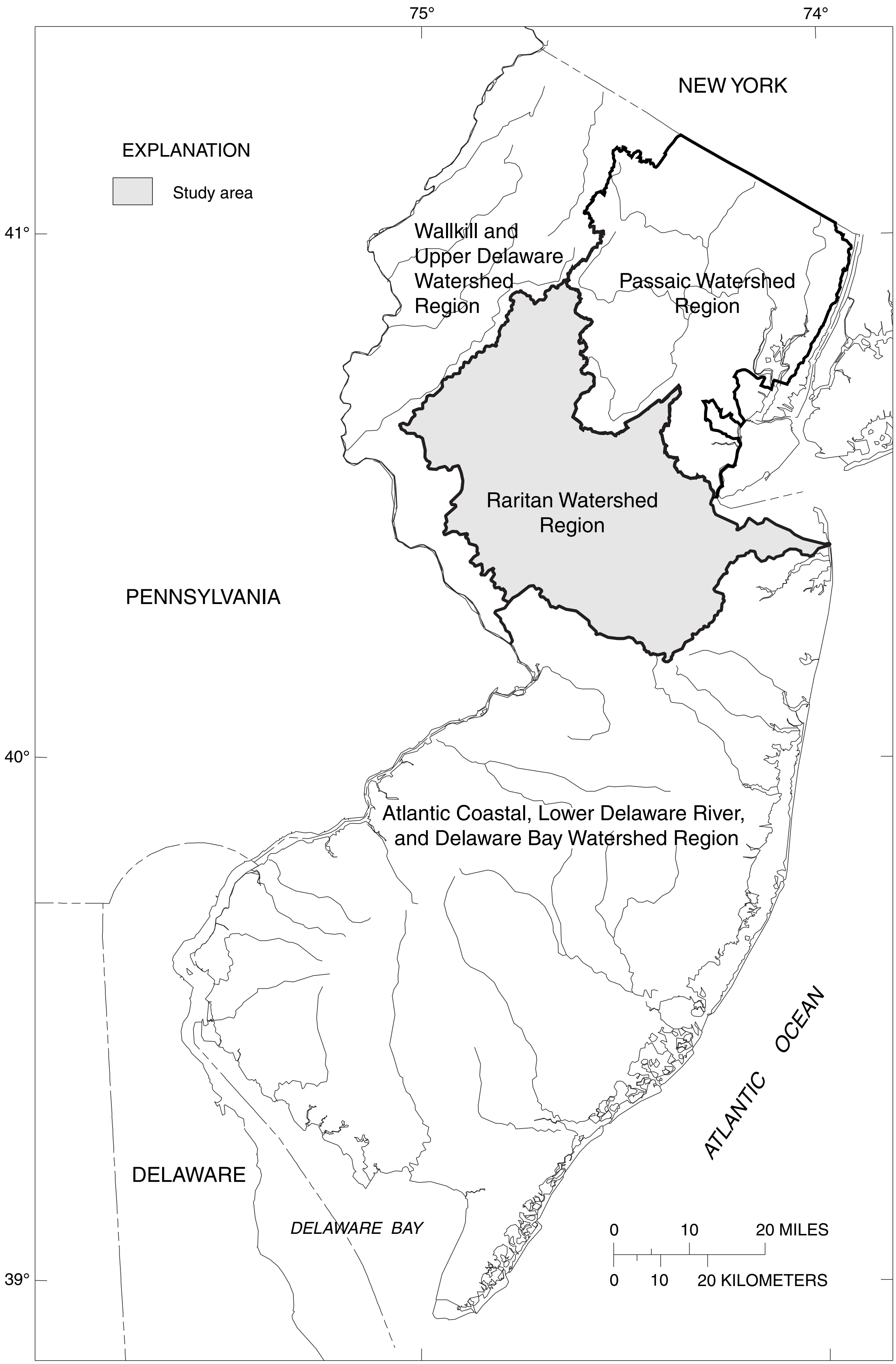

Figure 1. Four watershed regions in New Jersey.

Approach

A river receives constituents from point and nonpoint sources within the contributing drainage basin. Point sources are discrete, identifiable origins of constituents, such as permitted discharges from municipal- and industrial-wastewater treatment facilities, that contribute water to a stream at a constant rate, independent of streamflow conditions. Constituents from more diffuse, nonpoint sources are transported to the river by storm runoff from agricultural, residential, and urban areas and impervious surfaces (highways and parking lots), and by ground water that could contain effluent from leaking underground-storage tanks, septic systems, and landfills. Storm runoff, composed of overland runoff (water that flows overland when precipitation exceeds the infiltration rate) and interflow (infiltrated water that moves in a horizontal direction in the lower permeable subsoil), contributes to a stream intermittently, depending on storm intensity and frequency, and only during high flows (Chow, 1964; Novotny and Chesters, 1981). Ground-water discharge to a stream is almost constant; although the rate of discharge varies slightly with season and precipitation rate. Instream concentrations of constituents are a summation of the contributions from constant (point sources and ground-water discharge) and intermittent (storm runoff) sources.

The magnitude, or steepness, of the slope of the regression line between constituent loads and streamflow indicates the relative contributions of constant and intermittent sources at a river location. The steeper the slope, the greater the contribution from nonpoint sources during increased streamflow. If the contributions to instream load are mainly from point sources and ground water, instream load will remain constant with increasing streamflow, and the regression slope of load to streamflow will be approximately zero (fig. 2). If, however, storm runoff contributes a disproportionate amount of material to instream load, instream load will increase with increasing streamflow, and the regression slope of load to streamflow will be greater than zero (fig. 2). A steep slope does not imply that contributions from constant sources are unimportant, but only that intermittent sources contribute more to instream load during high flows than do constant sources. Price and Schaefer (1995) used this approach (steepness of the load-to-streamflow regression line) to assess the relative contributions of permitted and nonpermitted sources in the Musconetcong, Rockaway, and Whippany River Basins. An idealized example of the relation of load to streamflow is shown in figure 3. For site 01380500, Rockaway River above the reservoir at Boonton, the slope of the regression line is steeper (the estimated total median load from permitted point sources upstream was approximately 100 lbs/d) than the slope for site 01381200, Rockaway River at Pine Brook (the estimated median load from permitted point sources was approximately 1,000 lbs/d). In the example, the relative importance of nonpoint sources is greater at station 01380500 than at site 01381200, and the relative importance of point sources is greater at site 01381200 than at site 01380500.

Concentrations of constituents cannot be related to streamflow in this way because contributions from storm runoff are flow dependent, and a small concentration can represent a large instream load during high-flow conditions. If constituents are contributed to a stream mostly from constant sources, then instream concentrations will be diluted during periods of high flow. If, however, storm runoff contributes significant amounts of constituents to a stream, then the extent of dilution during periods of high flow will be reduced. The use of loads (mass per time) instead of concentrations (mass per volume) removes the influence of changing streamflow (volume per time) on instream constituent amounts (Buxton and others, 1998a).

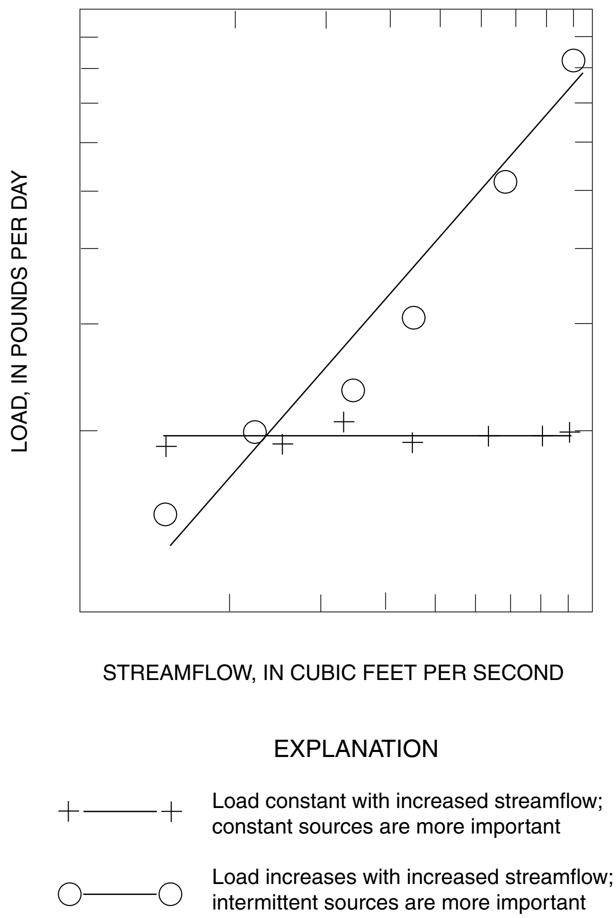

Figure 2. Hypothetical logarithmic plot of expected load-to-streamflow relations for a stream strongly affected by constant (point source and ground water) and intermittent (nonpoint storm runoff) sources.

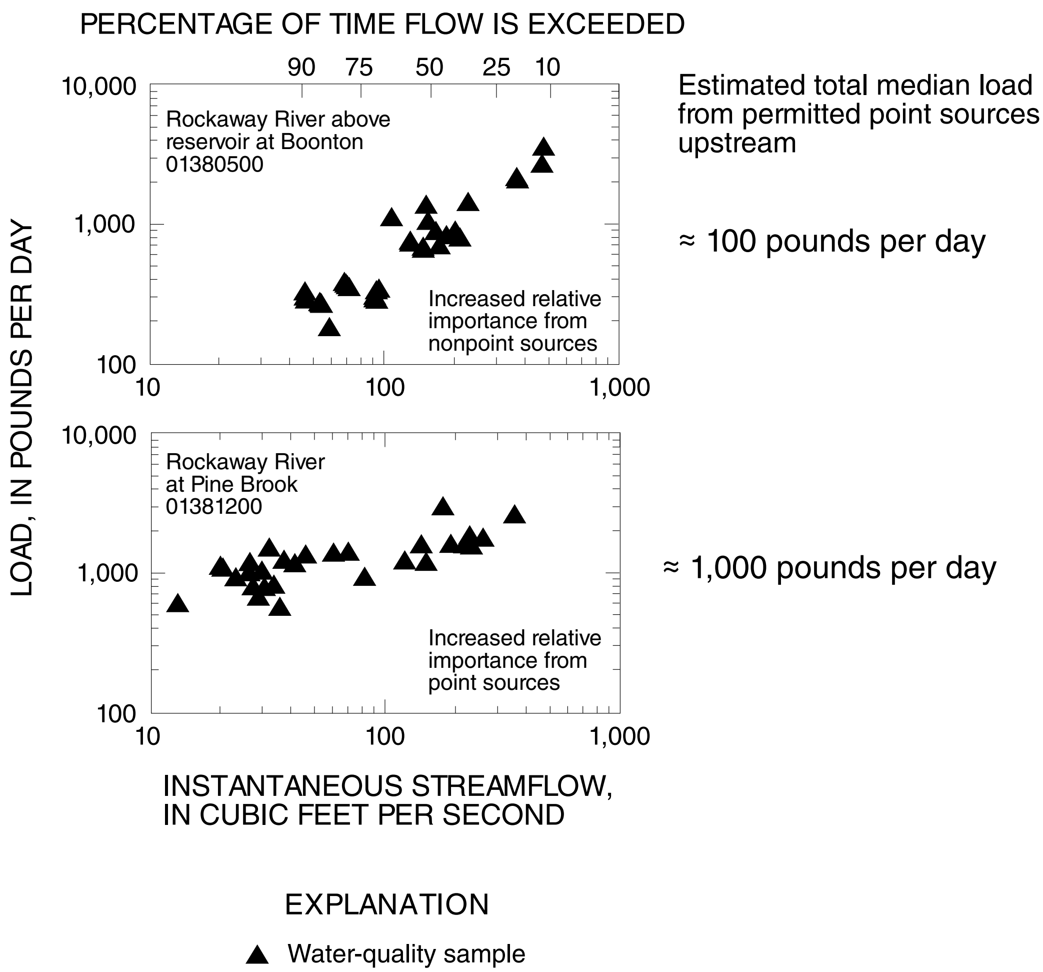

Figure 3. Relation of instream load of total nitrogen to instantaneous streamflow at water-quality stations in the Rockaway River Basin, New Jersey, 1985-91.

The instream load also can be affected by contributions from ground water and streambed sediment. Ground-water contributions to streams during low flow can be significant, but are less likely to affect surface-water quality during high-flow conditions when ground-water contributions are diluted. In some hydrologic systems, the scour of streambed sediment during high flows can contribute to the instream load. Rosensteel and Strom (1991) collected water 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.

Comparisons of trends in constituent concentrations during high and low flows can indicate changes through time in the contributions from intermittent and constant sources, respectively. Positive trends during high flows indicate an increase in the storm runoff contributions through time, whereas negative trends indicate a decrease in the storm runoff contributions. Positive trends during low flows indicate an increase in the contributions from point sources or ground water or both through time, whereas negative trends indicate a decrease in the contributions from point sources and (or) ground water.

The study involved several phases of multidisciplinary activity starting with the selection of the surface-water-quality stations (table 1), constituents, and the period of record. Water-quality and instantaneous-streamflow data were retrieved from the National Water Information System (NWIS) data base (Hutchison, 1975), which is maintained by the USGS. The water-quality and instantaneous-streamflow data underwent extensive quality-assurance procedures.

The data base created for this study was maintained with the Statistical Analysis System (SAS), a statistically based integrated software system that provides data access, management, analysis, and presentation. With SAS, median concentrations and relations of surface-water quality to streamflow were determined for each constituent at each station. The types of relations analyzed are concentration to streamflow, load to streamflow, and concentration trends during low- and high-flow conditions.

Graphs, schematics, and tables were generated to show the statistical results. Results are presented in the text first by basin and compared with the impairment index generated by the NJDEP's Ambient Biomonitoring Network (AMNET) biological assessment, then by constituent. Results of the three surface-water quality to streamflow analyses are presented graphically by constituent for each station in appendixes 1-18[2].

Previous Studies

Water-quality studies have been conducted in New Jersey by the USGS, in cooperation with State and local agencies, since the early 1960's. Three more recent USGS studies report the effects of nonpoint source contamination on New Jersey streams. Schornick and Fishel (1980) reported the effect of storm runoff on the surface-water quality of the Mill Creek Basin in Willingboro, Burlington County. Fusillo (1981) reported the effects of suburban residential development on surface- and ground-water quality in the upper Great Egg Harbor River Basin in

[2] Appendixes 1-18 containing median concentrations and relations of surface-water quality to streamflow are available on a CD-ROM; contact the New Jersey District Office of the USGS in West Trenton, N.J., for more information or to obtain copies of the CD-ROM.

Table 1. Description of, years of record for, and mean annual flow at, selected stations in the Raritan River Basin, New Jersey

[ND, no data for site; mi^2, square miles; ft^3/s, cubic feet per second; WY, water year]

Station number	Station name	Latitude/ longitude	Drain-age area in mi^2	Daily streamflow record (water years)	Mean annual flow in ft^3/s (period of record)
[1]01396280	South Branch Raritan River at Middle Valley	404540/744918	47.6	ND	ND
[1]01396535	So. Branch Raritan River at Arch St., at High Bridge	403949/745352	68.8	ND	ND
[1]01396588	Spruce Run near Glen Gardner	404041/745506	15.5	ND	ND
01396660	Mulhockaway Creek at Van Syckel	403851/745809	11.8	1977-93	20.0
01397000	So. Branch Raritan River at Stanton	403421/745210	147.0	1904-93	247.0
[1]01397400	So. Branch Raritan River at Three Bridges	403101/744812	181.0	ND	ND
01398000	Neshanic River at Reaville	402818/744942	25.7	1931-93	36.8
[1]01398260	North Branch Raritan River near Chester	404616/743734	7.6	ND	ND
[1]01399120	North Branch Raritan River at Burnt Mills	403809/744056	63.8	ND	ND
01399500	Lamington (Black) River near Pottersville	404339/744350	32.8	1922-93	56.0
[1]01399700	Rockaway Creek at Whitehouse	403749/744411	37.1	ND	ND
[1]01399780	Lamington River at Burnt Mills	403804/744113	100.0	ND	ND
01400500	Raritan River at Manville	403318/743502	490.0	1904-93	773.0
[1]01400540	Millstone River near Manalapan	401544/742513	7.4	ND	ND
[1]01400650	Millstone River at Grovers Mill	401919/743631	43.4	ND	ND
01401000	Stony Brook at Princeton	401959/744056	44.5	1954-93	64.7
[1]01401600	Beden Brook near Rocky Hill	402452/743902	27.6	ND	ND
01402000	Millstone River at Blackwells Mills	402830/743434	258.0	1922-93	377.0
[1,2]01403300	Raritan River at Queens Bridge, at Bound Brook	403334/743141	804.0	ND	ND
[1]01405302	Matchaponix Brook at Mundy Ave, at Spotswood	402322/742255	44.1	ND	ND
[1]01405340	Manalapan Brook at Federal Rd, near Manalapan	401746/742353	20.9	ND	ND

[1] Water-quality station only

[2] NASQAN station

Winslow Township, Camden County. Price and Schaefer (1995) reported estimated loads of selected constituents in the Musconetcong, Rockaway, and Whippany River Basins in northern New Jersey.

Several previous studies address surface-water issues in the river basins investigated in this study. Anderson and George (1966) reported the results of a statewide reconnaissance study of the water-quality characteristics of New Jersey streams. Anderson and Faust (1974) described the water quality and streamflow characteristics of the Raritan River Basin. George (1963) studied sedimentation in the Stony Brook Basin, and Mansue and Anderson (1974) described the effects of land use and retention practices on the sediment yields in the Stony Brook Basin. Bettendorf (1967) discussed the floods on the Millstone River and Stony Brook near Princeton, New Jersey. Ivahnenko and Buxton (1994) discussed the presence of pesticides from agricultural runoff in the Raritan River, Millstone River, and Matchaponix Brook, and Buxton and Dunne (1993) reported on water-quality data for the Millstone River at Weston, New Jersey.

Several USGS studies were conducted to evaluate surface-water characteristics and water-quality trends in New Jersey. Low-flow characteristics and flow durations of New Jersey streams were reported by Gillespie and Schopp (1982). Hay and Campbell (1990) identified statewide water-quality trends in New Jersey streams. Robinson and Pak (1993) summarized the water quality of selected New Jersey streams for water years 1987-89. Statewide monthly statistical summaries of surface-water temperatures during 1955-93 were presented by Reed and Hunchak-Kariouk (1995). Relations of surface-water quality to streamflow were presented for the Hackensack, Passaic, Elizabeth, and Rahway River Basins in Buxton and others (1998a), for the Atlantic Coastal Plain, Lower Delaware River, and Delaware Bay Basins in Hunchak-Kariouk and others (1998), and for the Wallkill and Upper Delaware River Basins in Buxton and others (1998b).

Acknowledgments

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Description of the Study Area

The Raritan River Basin is in central New Jersey and includes the Raritan River, South and North Branch Raritan Rivers, and 10 major tributaries (fig. 4). The mainstem of the Raritan River originates at the confluence of the South and North Branches at Raritan, New Jersey, flows for 35 miles in an easterly direction, and discharges into Raritan Bay (Bartlett, 1984). The South Branch Raritan River is 51 miles long from its source in Budd Lake to the mainstem. The North Branch Raritan River originates as a spring-fed stream in Morris County and flows south for about 23 miles to its confluence with the South Branch. The Raritan River drainage basin covers about 1,105 mi^2, making it the largest river basin located entirely within the State, and includes parts of seven New Jersey counties--Morris, Union, Middlesex, Somerset, Hunterdon, Mercer, and Monmouth. Major tributaries to the Raritan River include Spruce Run, Mulhockaway Creek, Neshanic River, Lamington River, Rockaway Creek, Millstone River, Stony Brook, Beden Brook, Matchaponix Brook, and Manalapan Brook. The major impoundments in the basin are Spruce

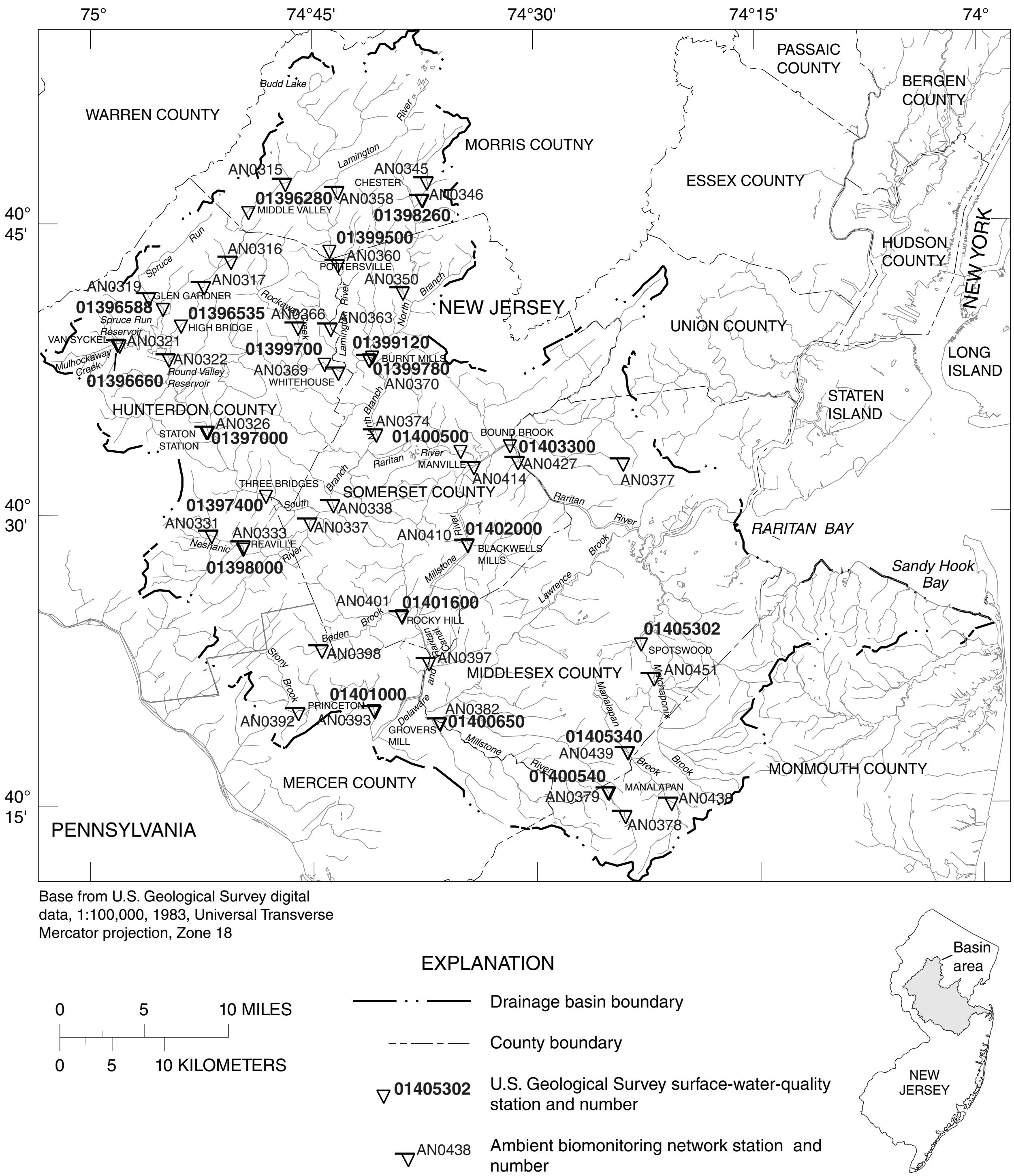


Figure 4. Locations of surface-water-quality stations and ambient biomonitoring network stations in the Raritan River Basin, New Jersey.

Run Reservoir, Budd Lake, and Round Valley Reservoir. Mean annual flow for water years 1904 to 1993 is estimated to be 773 ft^3/s at the surface-water gaging station on the Raritan River at Manville (01400500) (Bauersfeld and others, 1994).

Twenty-one water-quality stations are located in the Raritan River Basin (table 1). Two water-quality stations are located on the mainstem; the station on the Raritan River at Queens Bridge, at Bound Brook (01403300) is a NASQAN station. Four water-quality stations are located on the South Branch Raritan River, and three water-quality stations are located on the Millstone River. Two water-quality stations are located on each of the North Branch Raritan River and the Lamington River. One water-quality station is located on each of Spruce Run, Mulhockaway Creek, Neshanic River, Rockaway Creek, Stony Brook, Beden Brook, Matchaponix Brook, and Manalapan Brook. The period of record for water-quality-data collection for each station is shown in figure 5.

Land use along the mainstem of the Raritan River is primarily urban and suburban with some industrial and commercial centers. Land use along the South Branch Raritan River is mostly agricultural, but suburban and industrial development is increasing at a rapid rate. Land use along the North Branch Raritan River is primarily rural with woodlands and agricultural lands. Commercial and residential areas are scattered along the North Branch Raritan River, and development is increasing along major roads. Land use in the Millstone River area is primarily suburban with scattered agricultural areas. Some development is present in the upper part of the area (New Jersey Department of Environmental Protection and Energy, 1993).

METHODS OF STUDY

The following section describes the methods and criteria used for the selection of constituents, sites, and data sources. Methods for data preparation, quality assurance, and statistical analyses are described.

Selection of Constituents, Sites, and Data Sources

Constituents were chosen on the basis of their usefulness as indicators of the quality of the surface water and usefulness in developing effective surface-water-quality management practices. The 18 constituents selected include aggregate water properties (properties that include concentrations of several different chemical species), major ions, dissolved oxygen, nutrients, metals, and bacteria (table 2).

The basin contains 21 water-quality stations (table 1) with data from water years 1976-93 that are part of the USGS/NJDEP Cooperative Ambient Surface Water Quality Network; one of these water-quality stations is part of the National Stream Quality Accounting Network (NASQAN). Nine of the stations also are operated as surface-water gaging stations. These stations were chosen on the basis of the locations and periods of record.

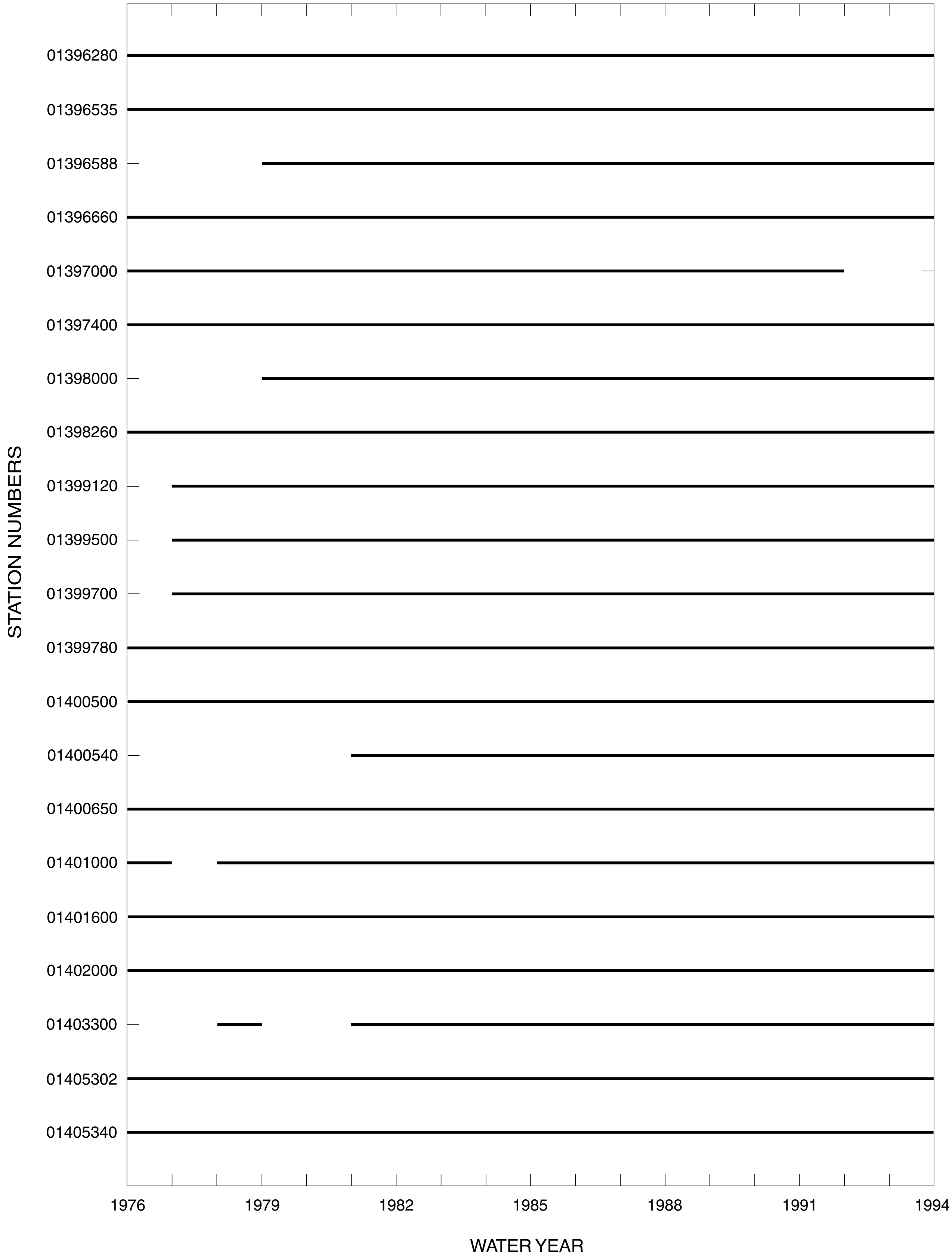


Figure 5. Period of record (at least one measurement per year) of water-quality data for selected stations in the Raritan River Basin, New Jersey, for water years 1976-93. (Station names are given in table 1.)

Table 2. Selected constituents and reporting units

[mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium; Cl, chloride; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters]

Constituent	Reporting unit
Alkalinity	mg/L as $CaCO_3$
Hardness[1]	mg/L as $CaCO_3$
Total organic carbon[1]	mg/L as C
Suspended sediment	mg/L
Dissolved solids	mg/L
Dissolved sodium	mg/L as Na
Dissolved chloride	mg/L as Cl
Dissolved oxygen	mg/L
Fraction of dissolved oxygen at saturation[1]	Percent
Total phosphorus	mg/L as P
Total nitrogen[1]	mg/L as N
Total nitrate plus nitrite	mg/L as N
Total nitrite	mg/L as N
Total ammonia plus organic nitrogen	mg/L as N
Total ammonia	mg/L as N
Total boron	µg/L as B
Total lead	µg/L as Pb
Fecal coliform bacteria	MPN/100 mL

[1] Values of constituent or property are calculated.

Water-quality and streamflow data were retrieved from the NWIS data base. Water-quality data for water years 1976-93 are available for 12 stations; partial records are available for the other 9 stations (fig. 5). Streamflow data are available for six water-quality stations for water years 1976-93 and for one water-quality station for water years 1977-93.

<u>Data Preparation</u>

Water-quality and instantaneous-streamflow data retrieved from the NWIS data base were reviewed extensively for accuracy and were maintained in a SAS data base. Values of dissolved nitrate plus nitrite and dissolved nitrite were substituted for values of total nitrate plus nitrite and total nitrite where the latter were missing. This substitution is appropriate because nitrate and nitrite are anions that are poorly absorbed to mineral surfaces and, therefore, are present in ambient water almost exclusively as dissolved species (Hem, 1985). Where both dissolved and total concentration values were available for nitrate plus nitrite and nitrite, little or no difference was observed.

Water-Quality Data

Values for the fraction of dissolved oxygen at saturation and concentrations of hardness, total organic carbon, and total nitrogen were calculated.

The fraction of dissolved oxygen at saturation is the ratio of the measured dissolved-oxygen concentration to the dissolved-oxygen concentration at saturation, in percent, computed by using the following equation:

$$FDO = 100 \left[\frac{DO}{DOsat}\right], \qquad (1)$$

where

FDO = fraction of dissolved oxygen at saturation;

DO = dissolved oxygen concentration, in milligrams per liter; and

DO_{sat} = dissolved oxygen at saturation, in milligrams per liter.

The following evaluation by R.F. Weiss (R.J. Pickering, U.S. Geological Survey, written commun., 1981) was used to calculate the concentration of dissolved oxygen at saturation:

$$DO_{sat} = A_1 + A_2 \frac{100}{T} + A_3 \ln\frac{T}{100} + A_4 \frac{T}{100} + S\left[B_1 + B_2\frac{T}{100} + B_3 \left(\frac{T}{100}\right)^2\right] , \qquad (2)$$

where

$\ln$ = natural logarithm;

DO_{sat} = dissolved oxygen at saturation;

A_1 = 173.4292;

A_2 = 249.6339;

A_3 = 143.3483;

A_4 = 21.8492;

B_1 = 0.033096;

B_2 = 0.014259;

B_3 = 0.001700;

T = temperature, in degrees Kelvin; and

S = salinity, in grams per kilogram.

The concentration of total hardness, expressed as calcium carbonate in milligrams per liter (mg/L as $CaCO_3$), was calculated as follows:

$$\text{Total hardness} = 2.497\,[\text{Ca}] + 4.118\,[\text{Mg}], \qquad (3)$$

where

Ca is the dissolved calcium concentration, in milligrams per liter, and

Mg is the dissolved magnesium concentration, in milligrams per liter.

Some total organic carbon concentrations were calculated as the sum of the dissolved and particulate organic carbon concentrations; all are expressed as carbon in milligrams per liter (mg/L as C). The concentration of total nitrogen was calculated as the sum of the total nitrate plus nitrite and total ammonia plus organic nitrogen concentrations; all are expressed as nitrogen in milligrams per liter (mg/L as N).

Estimated loads were calculated for each of 16 constituents (no loads were calculated for the fraction of dissolved oxygen at saturation or fecal coliform bacteria) by multiplying the concentration by the instantaneous streamflow and applying unit conversions to yield an instream load in pounds per day, as follows:

$$\text{load (lb/d)} = \text{concentration (mg/L)} \times \text{streamflow (ft}^3\text{/s)} \times 2.20462 \times 10^{-6}\ \text{lb/mg} \times 86{,}400\ \text{s/d} \times 28.316\ \text{L/ft}^3. \qquad (4)$$

When concentrations are in micrograms per liter, the conversion is

$$\text{load (lb/d)} = \text{concentration } (\mu g/L) \times \text{streamflow } (ft^3/s) \times 2.20462 \times 10^{-9} \text{ lb}/\mu g \times 86{,}400 \text{ s/d} \times 28.316 \text{ L}/ft^3. \quad (5)$$

Steps were taken to ensure consistent data quality because of the long period over which the data were collected. Water-quality data for the period of record, water years 1976 to 1993, were reviewed to identify any obvious data inconsistencies (that is, data outliers), because of changes in laboratory remark codes, reporting levels, analytical methods, project data-entry protocols, project data-quality review protocols, sample preservation, and sample processing. Many of these factors were known to have changed over the 18-year period of record; this may have affected the quality of the data (in this study, only data outliers were of concern). Breidt and others (1991) reported finding similar water-quality-data anomalies in this period of record. This review resulted in the removal from the data base of less than 1 percent of the original data set. Most of the corrections (removal) were for field measurements made prior to 1985 and for data that had been entered into the data base manually from paper records.

No attempt was made to identify data-biasing effects on the median values. The data review was performed prior to statistical analysis and interpretation. Data in the 0.025 and 0.975 percentiles for each station were candidates for being data outliers. In addition, plots of constituent concentrations by month, as well as constituent concentrations as a function of streamflow, were visually inspected for potential outliers. Data were evaluated by month of sample collection to determine whether a value was a seasonal outlier and by discharge to determine whether the value was an outlier because it was affected by dilution during high flow. In addition, changes in laboratory reporting remark codes and censoring limits were reviewed. The analytical method used for the years in which the censored data were collected was determined from tables reported by Friedman and Fishman (1989) and Fishman and others (1994), and the analytical method lower-reporting limit was checked against those reported for that analytical method in Skougstad and others (1979), Fishman and Friedman (1989), and Wershaw and others (1987). The outliers were evaluated by considering:

(1) concentrations of related constituents in the same sample,
(2) the constituent concentration at sites upstream or downstream,
(3) the effects of an early or late change of season,
(4) the number of measurements for the month or season,
(5) the presence of point-source discharges upstream from the sampling site,
(6) the possibility of constituent inputs from seasonal nonpoint-source runoff,
(7) streamflow regulation,
(8) the streamflow discharge, and
(9) surrounding geology and physiographic province.

Outliers were deleted only if no plausible explanation based on the factors listed above was found.

Streamflow Data

Instantaneous-streamflow values were used when available to calculate instream loads; when those values were not available, an estimated daily mean value was used. Continuous streamflow records from gages were available for nine water-quality stations and were used to determine instantaneous streamflows. For the 12 stations with no streamflow data, a correlation with an adjacent gaging station was developed, and a daily mean streamflow was estimated from the correlation.

As with the water-quality data, steps were taken to ensure consistent data quality because of the long period over which the data were collected. Streamflow data for the period of record, water years 1976 to 1993, were reviewed to identify any apparent or obvious data inconsistencies (that is, data outliers), many of which were due to data entry errors. The review was performed prior to statistical analysis and interpretation. This review resulted in the removal from the data base of less than 2 percent of the original data set.

Streamflow data from each surface-water-quality monitoring station were regressed on daily mean values from the NWIS data base to ensure that the values were consistent. Residuals of plots of streamflow as a function of gage height, and streamflow at adjacent or nearby continuous-record stations, were evaluated. Outliers were identified as those values with studentized residuals larger than an absolute value of 2 and were further evaluated by considering:

(1) the time of sample collection,
(2) upstream flow regulation, and
(3) streamflow at nearby stations.

If no plausible explanation for the apparent inconsistency of a data point (an outlier), based on the factors listed above, was found, the daily mean values were used. These new values were double-checked by plotting them on a graph of field specific conductance as a function of flow duration. Specific conductance would be expected to be inversely proportional to streamflow, except during times of snow melt. The measurement of specific conductance is independent of the measurement of streamflow.

Flow-Duration Data

Flow durations for each water-quality station were retrieved as data from WATSTORE (National Water Data Storage and Retrieval System), as output from computer simulations using MOVE.1 (Maintenance of Variance Extension, Type 1) (Hirsch, 1982), and as drainage area adjustments from nearby surface-water gaging stations (table 3).

Flow-duration tables were developed by using the Daily Value Statistics (DVSTAT) computer program in the WATSTORE data base for 7 of the 21 surface-water-quality stations that had continuous streamflow records. Flow-duration curves show the percentage of time that a particular discharge is exceeded, and a flow-duration point is a discharge value, in cubic feet per second, interpolated from a duration table for a particular percentage of time. For the purpose of this study, the 25-percent duration point was used to determine high-flow conditions, and the 75-percent duration point was used to determine the low-flow conditions. The resulting values for each station are shown in table 3.

Base-flow relations were determined for 12 of the 21 water-quality gaging stations by correlating instantaneous low-flow discharge at the partial-record station with the mean daily discharge at a nearby "index" continuous-record gaging station. A streamflow record extension technique, MOVE.1, was used to develop the correlations (Hirsch, 1982). MOVE.1 was used

Table 3. Estimated flow-duration values of mean daily discharge and data source for surface-water-quality stations in the Raritan River Basin, N.J.

[ft^3/s, cubic feet per second; %, percent; WATSTORE, National Water Data Storage and Retrieval System; MOVE.1, Maintenance of Variance Extension, Type 1; Drainage Area, adjusted on basis of drainage area from nearby surface-water gages]

Station number	Flow duration values of mean daily discharge, in ft^3/s		Source
	25%	75%	
01396280	102	35.7	MOVE.1
01396535	162	49.1	MOVE.1
01396588	22.9	5.7	MOVE.1
01396660	21.8	6.7	WATSTORE
01397000	289	101	WATSTORE
01397400	314	105	MOVE.1
01398000	34.5	3.5	WATSTORE
01398260	16.1	3.7	MOVE.1
01399120	130	34.4	MOVE.1
01399500	73.7	24.1	WATSTORE
01399700	57.3	16.5	MOVE.1
01399780	193	55.6	MOVE.1
01400500	853	235	WATSTORE
01400540	13.2	5.0	MOVE.1
01400650	93.6	24.9	Drainage area
01401000	60.7	6.3	WATSTORE
01401600	55.0	4.7	MOVE.1
01402000	396	101	WATSTORE
01403300	1,320	307	Drainage area
01405302	93.1	29.9	MOVE.1
01405340	29.6	12.2	MOVE.1

because it was adequate for the purposes of this study, in which flow duration was used only to divide streamflow data into groups of high, moderate, and low ranges for trend analysis. The relations are made in the following form:

$$LQ_{PR} = u_{PR} + \left(\frac{S_{PR}}{S_{CR}}\right)[LQ_{CR} - u_{CR}], \tag{6}$$

where

LQ_{PR} = the base-10 logarithm of the partial-record streamflow,

u_{PR} = the mean of the logarithms of partial-record streamflow,

S_{PR} = the standard deviation of logarithms of partial-record streamflow,

LQ_{CR} = the base-10 logarithm of the index continuous-record streamflow,

u_{CR} = the mean of the logarithms of the index continuous-record streamflows, and

S_{CR} = the standard deviation of logarithms of the index continuous-record streamflow.

The flow-duration values for partial-record stations 01403300, Raritan River at Queens Bridge, at Bound Brook, and 01400650, Millstone River at Grovers Mill, were estimated using drainage area adjustments from nearby surface-water gaging stations (table 3).

Statistical Analyses

Concentration measurements were selected for use in the analyses only if they had an associated, nonzero value of streamflow (instantaneous or estimated); only one observation per constituent per day was used. Concentration values were reported as “uncensored,” “less-than,” and “greater-than”. Concentrations of constituents other than fecal coliform bacteria were either uncensored or less-than values; some measurements of fecal coliform bacteria were greater-than values.

Median concentrations and relations of surface-water quality to streamflow were determined for each constituent and station. The following types of relations of surface-water quality to streamflow are presented graphically by constituent for each station in appendixes 1-18: concentration to streamflow, load to streamflow, and trends in concentrations during low and high flows.

Calculation of Medians

Medians were calculated for measurements made during two periods--the entire period of study (water years 1976-93) and the last 5 years of the period of study (water years 1989-93). The method of calculation depended upon whether the data set contained censored values. For data sets with only uncensored data, the values were ranked, and the median was calculated as the 50th percentile. For data sets with less-than values but no greater-than values, medians were calculated by using the adjusted maximum likelihood method described in Cohn (1988) and in Helsel and Cohn (1988). If the data set contained either an insufficient number of observations needed to use this method or contained great-than values, the median was determined by manually ranking and identifying the 50th percentile value.

Determination of Relations of Surface-Water Quality to Streamflow

The processes used to determine relations between concentration and streamflow, relations between load and streamflow, and trends in concentrations during high and low flows are described in this section.

Relations of concentration to streamflow

Water quality is strongly influenced by biological activity, which is seasonal; therefore, relations between concentration and streamflow were developed by using (1) all measurements, (2) growing-season measurements only, and (3) nongrowing-season measurements only. The growing season in New Jersey is from April 1 through October 31; the nongrowing season is from November 1 through March 31. The dates for the growing and nongrowing seasons were based on the average times of the first and final frosts in New Jersey (Ruffner and Bair, 1977). All relations take the following form:

$$\log(CONC) = SLOPE \times \log(FLOW) + INT \text{ ,} \qquad (7)$$

where

log = base-10 logarithm;

CONC = constituent concentration, in indicated units;

SLOPE = the slope of the relation;

FLOW = streamflow, in cubic feet per second; and

INT = the intercept of the relation.

These relations were developed by using Tobit regression (Cohn, 1988), which includes less-than values. For Tobit regression in this report, greater-than values were considered to be uncensored. Where there were no less-than values, this method resulted in the same values of SLOPE and INT as those calculated by ordinary least-squares regression. A goodness-of-fit value such as the correlation coefficient is not presented; the Tobit method does not generate such a value.

A relation of water quality to streamflow at a given station was developed only if at least nine uncensored concentration values were available. T.A. Cohn (U.S. Geological Survey, written commun., 1995) noted that at least nine uncensored values were needed to use the Tobit method with two unknowns. Nine uncensored values were sometimes insufficient to calculate statistically significant results.

A relation using all measurements is reported only if the value of SLOPE was different from zero at the 0.05 level of significance; otherwise, a SLOPE of “0” is reported. A “not determined” value of SLOPE is reported if the data were insufficient to conduct the analysis. A value of INT was calculated only if the value of SLOPE was different from zero.

Each set of seasonal relations was developed and reported by using the methods just described if an analysis of covariance (described below) indicated that the seasonal relations were different from one another at the 0.05 level of significance. The analysis of covariance was conducted only if there were at least nine uncensored measurements during each season.

The analysis of covariance followed the approach in Helsel and Hirsch (1992), except that Tobit regression was used in place of ordinary least-squares regression. The analysis determined whether a complex model with a seasonal component was significantly better than a simple model without a seasonal component. The simple model is given in equation 7; the complex model is given in equation 8:

$$\log(CONC) = [SLOPE_1 \times \log(FLOW) + INT_1] + [SLOPE_2 \times \log(FLOW) + INT_2 \times I] \ , \quad (8)$$

where

log = base-10 logarithm;

$CONC$ = constituent concentration, in indicated units;

$FLOW$ = streamflow, in cubic feet per second;

I = an index for season (I = 0 for the nongrowing season, and I = 1 for the growing season);

$SLOPE_1$ = the slope for the nongrowing season;

INT_1 = the intercept for the nongrowing season;

$SLOPE_2$ = the difference between the growing- and nongrowing-season slopes; and

INT_2 = the difference between the growing- and nongrowing-season intercepts.

A test statistic different from that used by Helsel and Hirsch (1992) was calculated because of the use of Tobit regression in the analysis of covariance (T.A. Cohn, written commun., 1995). The value, X, was determined from the results of the simple and complex models, then compared to the value of the chi-square distribution with 2 degrees of freedom and a 0.05 level of significance. If the value of X equalled or exceeded the corresponding value of chi-square distribution, the seasonal relations differed from one another in SLOPE or INT or both. Whether SLOPE was different or INT was different was not determined. The value of X was calculated as follows:

$$X = -2 \times \ln[(LKHD_S)/(LKHD_C)] \ , \quad (9)$$

where

X = the test statistic,

ln = natural logarithm,

$LKHD_S$ = the likelihood of the simple relation, and

$LKHD_C$ = the likelihood of the complex relation.

The detection level of each constituent at each station is required to conduct Tobit regression. The detection limits for constituents with only uncensored values were determined by considering the method of analysis and the smallest concentration measured at all stations. These values (table 4) are either equal to the smallest less-than value or slightly less than the smallest uncensored value measured at all stations during water years 1976-93.

Relations of load to streamflow

The relation of load to streamflow was developed by using the same procedures as those used to develop the relation of concentration to streamflow for all measurements. Loads were not determined for fraction of dissolved oxygen at saturation and fecal coliform bacteria. For each constituent and station, the detection limit was set equal to the smallest uncensored load measured at the station. The load relation takes the following form:

$$\log(LOAD) = SLOPE \times \log(FLOW) + INT \qquad (10)$$

where

log = base-10 logarithm;

$LOAD$ = constituent load, in pounds per day;

$SLOPE$ = the slope of the relation;

$FLOW$ = streamflow, in cubic feet per second; and

INT = the intercept of the relation.

A smoothed relation of load to streamflow is shown for a constituent at each station at which there were 10 or more values. This relation was determined by using the SM smoothing routine in SAS (SAS Institute, Inc., 1990, p. 416).

Trends in concentrations during low and high flows

Trends in concentrations during low and high flows were tested to determine whether the probability distribution from which the observations come increased or decreased during water years 1976-93. The 75-percent and 25-percent values of the flow durations were used to divide the measurements for each station into a low- or high-flow group, respectively. Concentrations during low flows were designated as those measured at streamflows less than or equal to the daily

Table 3. Estimated detection limits for selected constituents measured in the Raritan River Basin, N.J., water years 1976-93

[mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; C, carbon; Na, sodium; Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters]

Constituent	Estimated detection limit
Alkalinity, mg/L as $CaCO_3$	1
Hardness, mg/L as $CaCO_3$	10
Total organic carbon, mg/L as C	.2
Suspended sediment, mg/L	1
Dissolved solids, mg/L	10
Dissolved sodium, mg/L as Na	1
Dissolved chloride, mg/L as Cl	1
Dissolved oxygen, mg/L	.5
Fraction of dissolved oxygen at saturation, %	5
Total phosphorus, mg/L as P	.01
Total nitrogen, mg/L as N	.1
Total nitrate plus nitrite, mg/L as N	.05
Total nitrite, mg/L as N	.002
Total ammonia plus total organic nitrogen, mg/L as N	.03
Total ammonia, mg/L as N	.01
Total boron, µg/L as B	10
Total lead, µg/L as Pb	1
Fecal coliform bacteria, MPN/100 mL	2

mean streamflow that was exceeded 75 percent of the time; concentrations during high flows were designated as those measured at streamflows greater than the daily mean streamflow that was exceeded 25 percent of the time.

For both the low- and high-flow data sets, trend tests were conducted only if there was at least one measurement in each data set consisting of not less than four of the six water years in each one-third of the period of study (18 years). This requirement followed a recommendation made in Helsel and Hirsch (1992) that there be no less than 20 percent of the total measurements in each one-third of the period being tested for trends. Therefore, 12 was the minimum number of low- or high-flow measurements used in a test. Fewer data could have been tested for trends. The fewer the data, however, the less likely it is that the measured concentrations represent conditions during the period tested and, therefore, the less likely that the results of the trend test are accurate.

The seasonal Kendall's tau method (Hirsch and others, 1982) was used to examine the data for trends. For both the low- and high-flow data sets, the test was run on the median of the measured concentrations for each water year because of variations in sampling frequency (Hirsch and others, 1982). The test statistic, tau, was calculated from the relative sizes of the annual median concentrations, then tested to see whether it was significantly different from zero. For this report, a trend is indicated if the value of tau was significantly different from zero at the 0.05 level. Seasonality was not included in the test.

A value of SLOPE is reported for constituent concentrations during either low or high flows if a trend was indicated. The value of SLOPE is the median of the slopes of all pairs of annual median concentrations. A SLOPE value of "0" is reported if sufficient data were available for a trend test but a trend was not indicated; a "not determined" value is reported if there were insufficient data for a test. The units of SLOPE are units of concentration per year.

No value is reported for the intercept of the relation showing the trend of concentration through time. An intercept value is calculated by the trend test only for the purpose of showing the trend in a plot.

Multiple trend tests were conducted on data sets with censored values; the censored values were set at their minimum and maximum possible values. Two tests were conducted on data sets with less-than values but no greater-than values--one with the less-than values set to the reporting limit and one with the less-than values set to zero. Two tests were conducted on data sets with greater-than values but no less-than values--one with the greater-than values set to the reporting limit and one with the greater-than values set to 10^7 (a value greater than all reported uncensored values). Four tests were conducted on data sets with both less-than and greater-than values--one with each of the permutations of the greater-than and less-than values discussed above.

For each data set with censored values, the results are reported only for the trend relation with the least significant value for tau. Because of the uncertainty in censored data, a significant trend slope is reported only if a slope is determined when the censored data are set equal to both their minimum and maximum values.

RELATIONS OF SURFACE-WATER QUALITY TO STREAMFLOW

An understanding of the relation of surface-water quality to streamflow is important for assessment of the relative contributions of point sources, ground water, and storm runoff to instream loads. Point sources (permitted discharges) release constituents to a stream at a relatively constant rate, independent of the receiving streamflow conditions. Ground-water contributions to a stream are somewhat constant, varying slightly with season and precipitation rate. Storm runoff contributions to a stream are intermittent, depending on storm intensity and frequency, and occur only during high flows. Instream constituent concentrations are a summation of the contributions from these constant (point source and ground water) and intermittent (storm runoff) sources (Buxton and others, 1998a).

To describe the relation of surface-water quality to streamflow, the data analyses are presented in three ways. First, three aspects of the relation of surface-water quality to streamflow (concentration to streamflow, load to streamflow, and trends in concentrations during low and high flows) are presented graphically by constituent for each station in appendixes 1-18 (on CD-ROM). Second, the data analyses are presented by basin in the text; tables for each station list the median concentrations, the regression slopes of concentration and load to streamflow, and the directions of the trends in concentrations during low and high flows for all constituents along with the AMNET impairment status at and near the station. Third, relations are presented in schematics showing the regional trends in concentrations during low and high flows and the slopes of load to streamflow by constituent.

Appendixes 1-18 illustrate the relations of surface-water quality to streamflow by constituent for each station with three graphs. Figure 6 is an example page from appendix 6. The first graph shows the relation of concentration to streamflow. Plots of concentration to streamflow indicate how instream constituent concentrations vary with streamflow, but do not indicate the relative contributions of constant and intermittent sources. Data for stations on streams draining developed areas show the most scatter, especially for inorganic constituents such as sodium, chloride, and hardness. Relations between concentration and streamflow were developed by using (1) all measurements, (2) only measurements collected during the growing season, and (3) only measurements collected during the nongrowing season. Growing-season measurements are shown with open symbols and nongrowing-season measurements are shown with crisscross symbols. Different symbols are used to show uncensored and censored values. For each group of measurements, the number of observations and values of slope and intercept are listed, and a regression line is shown when the slope of concentration to streamflow is different from zero at the 0.05 significance level. A seasonal dependency is indicated when the relations of concentration to streamflow for the growing- and nongrowing-season measurements are different. The 75 and 25 percentiles of the flow duration also are indicated.

The second graph in figure 6 shows the relation of load to streamflow. The regression slope of load to streamflow indicates the relative contributions of constant and intermittent sources to the instream load. The steeper the slope, the greater the contribution during increased streamflow from storm runoff (intermittent sources). Relations between load and streamflow were developed using all measurements. Different symbols are used to show uncensored and censored values. The number of observations and values of slope and intercept are shown, and a regression line is drawn when the slope is different from zero at the 0.05 significance level. A smoothed relation between load and streamflow is shown when there are 10 or more observations. The 75 and 25 percentiles of the flow duration also are indicated.

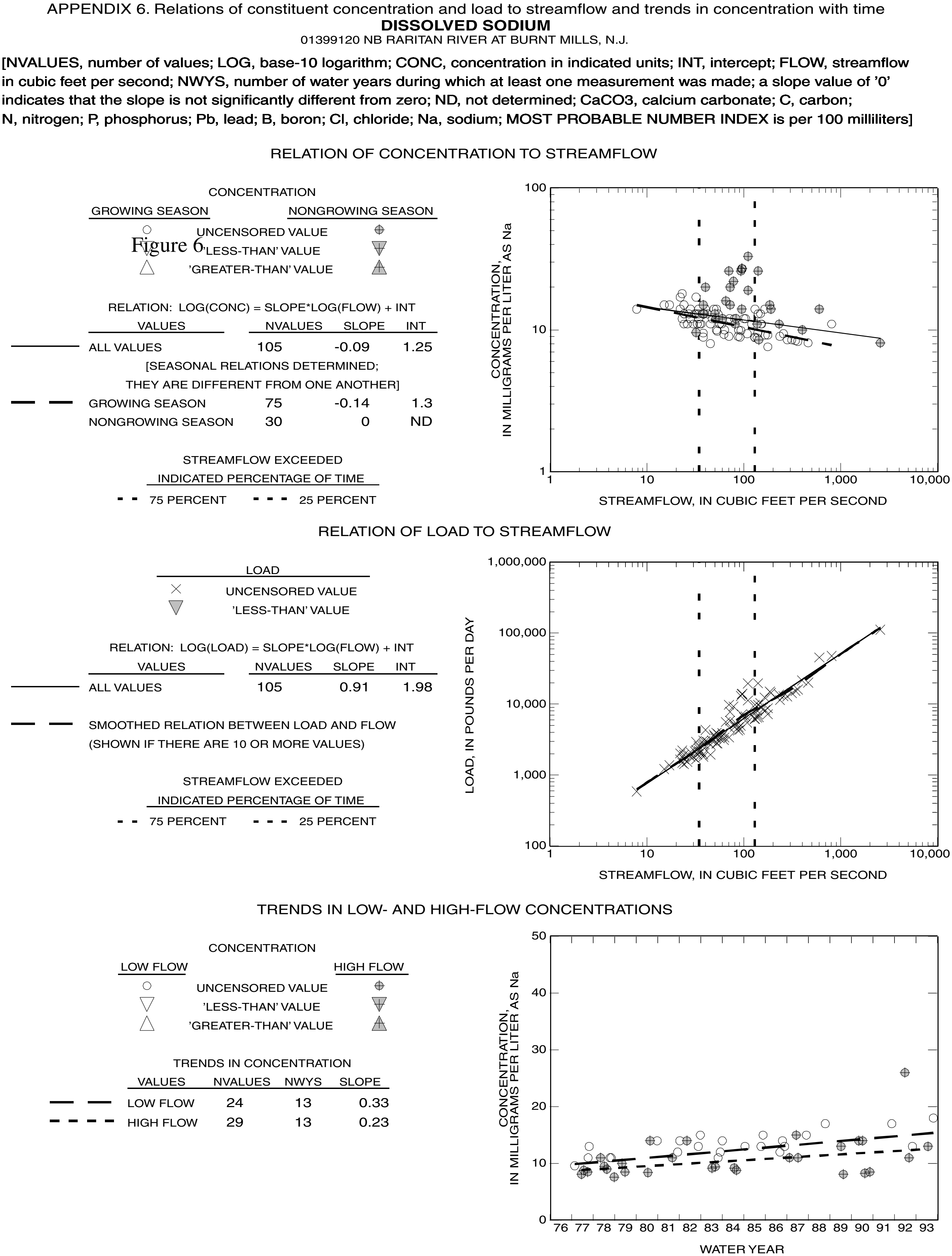


Figure 6. Example page from Appendix 6 of graphs showing relation of concentration to streamflow, relation of load to streamflow, and trends in low- and high-flow concentrations for dissolved sodium at a station on the North Branch Raritan River at Burnt MIlls, New Jersey, for water years 1976-93. (Available on CD-ROM)

The third graph in figure 6 shows the trends in concentrations during low and high flows. Trends in constituent concentrations during high and low flows can indicate changes through time in the contributions from intermittent and constant sources, respectively. Positive trends during high flows indicate an increase in the storm runoff contributions through time, whereas negative trends indicate a decrease in the storm runoff contributions. Positive trends during low flows indicate an increase in the contributions from point sources and ground water through time, whereas negative trends indicate a decrease in the contributions from point sources and ground water. Measurements during low flows are shown with open symbols, and measurements during high flows are shown with crisscross symbols. Different symbols are used to show uncensored and censored values. The number of observations and water years during which at least one measurement was made is shown for each group of measurements. Trends are indicated by regression lines and slope values when the seasonal Kendall tau value is significant.

Analysis of Relations by Basin

Median concentrations, regression slopes of concentration and load to streamflow, and directions of the trends in concentrations during low and high flows for each constituent are presented in tables 5 through 25. Constituents that show seasonal dependency (the relations of concentration to streamflow for the growing and nongrowing seasons are different) and the 1993 AMNET impairment status in the vicinity (at and within five miles upstream and downstream) of the surface-water-quality station also are listed. Median concentrations were calculated for two periods, the entire period of study (water years 1976-93) and the last five years of the period of study (water years 1989-93) to provide a visual comparison of water quality to the AMNET impairment status. In tables 5 through 25, the directions of trends in concentrations during low and high flows are represented by +, -, 0, and NA symbols. Results of statistical tests are discussed for each river basin. One- to four-letter abbreviations are used for each water-quality constituent throughout the discussion. (See Conversions Factors and Abbreviated Water-Quality Units, p. ix).

Slopes of load to streamflow for each constituent are divided into three ranges in order to describe the relative contributions of constant (point source and ground water) and intermittent (storm runoff) sources to instream load. High-range slopes are greater than or equal to 75 percent of the interval between the minimum and maximum slopes for each constituent at each site. For stations with slopes in the high range, a larger contribution from storm runoff to instream load occurs than at other sites, indicating an increased relative importance of nonpoint sources at these sites. Moderate-range slopes are greater than 25 percent and less than 75 percent of the interval between the minimum and maximum slopes. Low-range slopes are less than or equal to 25 percent of the interval between the minimum and maximum slopes. For stations with slopes in the low range, a smaller contribution from storm runoff to instream load occurs than at other sites, indicating an increased relative importance of continuous sources at these sites. For constituents with large slopes of load to streamflow (greater than 0.8), however, storm runoff is most likely the more significant contributor to instream loads, even for stations with load slopes in the low range.

In 1992, the Bureau of Water Monitoring of the NJDEP reactivated the AMNET to monitor benthic-macroinvertebrate populations at 457 stations in the major drainage basins in New Jersey. The objective of this biomonitoring program is to provide long-term, basin-wide, biological data for surface water (New Jersey Department of Environmental Protection, 1995). Stations will be monitored every 5 to 6 years, a realistic temporal lag between the cessation and recovery of a biological community from a perturbation. Biomonitoring uses instream populations of benthic macroinvertebrates as indicators of the quality of the surface water. Species of the instream macroinvertebrate community occupy distinct niches based on their tolerance to environmental conditions; these communities can change as environmental conditions change. Benthic-community biological impairment is indicated by (1) the absence of contaminant-sensitive macroinvertebrate taxa, (2) excessive dominance by certain taxon, (3) low overall taxa richness, or (4) perceptible shifts in community structure relative to a reference condition.

The NJDEP sampling techniques and biometric assessments were modified from U.S. Environmental Protection Agency protocols which integrate community, population, and functional parameters into one easily understood evaluation of biological integrity (New Jersey Department of Environmental Protection, 1995). The integrated assessment results at each station were given an AMNET impairment status rating of non-impaired—the benthic community is comparable to communities found in other undisturbed streams within the region and is characterized by a maximum taxa richness, balanced taxa groups, and good representation of intolerant individuals; moderately impaired—the macroinvertebrate richness and community balance are reduced and intolerant taxa are absent because of taxa composition changes; or severely impaired—the benthic community has dramatically changed and macroinvertebrates are dominated by a few tolerant taxa. When used together with chemical and physical monitoring, benthic macroinvertebrate monitoring is a good indicator of stream quality and possible sources of impairment.

South Branch Raritan River Basin

Seven surface-water-quality stations are located in the South Branch Raritan River Basin. Four stations are located along the South Branch Raritan River, and one station each is located on Spruce Run, Mulhockaway Creek, and Neshanic River.

South Branch Raritan River

The four stations located along the South Branch Raritan River are 01396280 at Middle Valley; 01396535 at Arch Street, at High Bridge; 01397000 at Stanton Station; and 01397400 at Three Bridges. The 5-year medians are smaller than the period-of-record medians for NO2 and NH4 at station 01396280; 5-year and period-of-record medians are similar for all other constituents (table 5a). At station 01396535 the 5-year medians are smaller than the period-of-record medians for B, PB, and NH4, and the 5-year median is larger than the period-of-record median for BACT (table 6a). The 5-year median is smaller than the period-of-record median for NH4 at station 01397000; 5-year and period-of-record medians are similar for all other constituents (table 7a). The 5-year medians are smaller than the period-of-record medians for NH4 and BACT at station 01397400; 5-year and period-of-record medians are similar for all other constituents (table 8a). The regression slopes of concentration to streamflow show seasonal dependency for ALK, TOC, NA, CL, DO, TP, NO32, NH4, and BACT at station 01396280; for ALK, TOC, SS, NA, CL, DO, TP, NO32, and BACT at station 01396535; for DO, TN, NO32, NO2, NH4, and BACT at station 01397000; and for ALK, NA, CL, DO, TN, NO32, NO2, and BACT at station 01397400.

The regression slopes of load to streamflow for DO and NH4 at station 01396280 are the largest for these constituents in the study area. The load slopes for HARD and TP at station 01396280, and for DO and PB at station 01397000, are the smallest for these constituents in the

Table 5a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01396280, South Branch Raritan River at Middle Valley, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	60	(27)	60	(73)	0.760	*	0.500	NA	NA
Hardness, mg/L as CaCO3	86	(27)	79	(98)	-.359		.641	NA	+
Total organic carbon, mg/L as C	2.9	(25)	3.0	(96)	.217	*	1.217	NA	-
Suspended sediment, mg/L	5	(11)	6	(20)	.849		1.849	NA	NA
Dissolved solids, mg/L	143	(26)	134	(96)	-.163		.837	NA	0
Dissolved sodium, mg/L as Na	13	(27)	12	(98)	0	*	1.022	NA	0
Dissolved chloride, mg/L as Cl	25	(27)	20	(98)	0	*	1.055	NA	0
Dissolved oxygen, mg/L	11.2	(26)	11.1	(96)	0	*	1.027	NA	0
Fraction of dissolved oxygen at saturation, %	106	(22)	104	(91)	-.053		ND	NA	0
Total phosphorus, mg/L as P	.06	(22)	.09	(66)	-.629	*	.370	NA	NA
Total nitrogen, mg/L as N	2.2	(27)	1.9	(88)	-.205		.795	NA	0
Total nitrate plus nitrite, mg/L as N	1.78	(27)	1.53	(91)	-.299	*	.701	NA	0
Total nitrite, mg/L as N	.013	(27)	.020	(86)	-.269		.731	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.37	(27)	.46	(97)	0		1.198	NA	-
Total ammonia, mg/L as N	.04	(27)	.08	(87)	.294	*	1.294	NA	0
Total boron, µg/L as B	20	(5)	20	(16)	0		1.027	NA	NA
Total lead, µg/L as Pb	2	(5)	3	(18)	0		1.224	NA	NA
Fecal coliform bacteria, MPN/100 ml	330	(25)	230	(94)	0	*	ND	NA	0

Table 5b. 1993 AMNET impairment status in the vicinity of water-quality station 01396280, South Branch Raritan River at Middle Valley, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0315	None	AN0316
Impairment status	Non-impaired	ND	Non-impaired

Table 6a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01396535, South Branch Raritan River at Arch Street, at High Bridge, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY							
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	61	(27)	63	(75)	0.750	*	0.557	NA	NA
Hardness, mg/L as CaCO3	86	(27)	82	(104)	-.344		.656	NA	+
Total organic carbon, mg/L as C	2.6	(26)	2.8	(100)	.163	*	1.162	NA	0
Suspended sediment, mg/L	4	(11)	6	(23)	.683	*	1.683	NA	NA
Dissolved solids, mg/L	140	(27)	131	(102)	-.165		.835	NA	+
Dissolved sodium, mg/L as Na	11	(27)	10	(104)	0	*	1.025	NA	0
Dissolved chloride, mg/L as Cl	21	(27)	17	(104)	0	*	1.048	NA	0
Dissolved oxygen, mg/L	11.2	(26)	10.5	(101)	.083	*	1.083	NA	0
Fraction of dissolved oxygen at saturation, %	104	(22)	102	(97)	-.026		ND	NA	0
Total phosphorus, mg/L as P	.06	(24)	.08	(70)	-.269	*	.730	NA	NA
Total nitrogen, mg/L as N	1.9	(27)	1.7	(91)	0		.945	NA	NA
Total nitrate plus nitrite, mg/L as N	1.50	(27)	1.30	(95)	-.143	*	.857	NA	NA
Total nitrite, mg/L as N	.014	(26)	.015	(87)	0		.956	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.30	(27)	.40	(99)	.202		1.202	NA	-
Total ammonia, mg/L as N	.04	(27)	.08	(90)	0		1.202	NA	-
Total boron, µg/L as B	<10	(5)	20	(17)	0		0	NA	NA
Total lead, µg/L as Pb	1	(5)	3	(18)	.686		1.686	NA	NA
Fecal coliform bacteria, MPN/100 ml	230	(25)	160	(100)	.520	*	ND	NA	0

Table 6b. 1993 AMNET impairment status in the vicinity of water-quality station 01396535, South Branch Raritan River at Arch Street, at High Bridge, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0317	None	AN0322
Impairment status	Non-impaired	ND	Non-impaired

Table 7a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01397000, South Branch Raritan River at Stanton Station, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	58	(11)	59	(12)	0.380		0.664	NA	NA
Hardness, mg/L as CaCO3	75	(12)	73	(64)	-.194		.806	NA	NA
Total organic carbon, mg/L as C	3.2	(11)	4.4	(30)	0		.992	NA	NA
Suspended sediment, mg/L	5	(11)	5	(38)	1.439		2.439	NA	NA
Dissolved solids, mg/L	124	(11)	123	(30)	-.126		.874	NA	NA
Dissolved sodium, mg/L as Na	11	(12)	9	(67)	0		.942	NA	NA
Dissolved chloride, mg/L as Cl	18	(13)	14	(68)	0		.920	NA	NA
Dissolved oxygen, mg/L	12.2	(20)	11.6	(107)	0	*	1.016	NA	0
Fraction of dissolved oxygen at saturation, %	104	(20)	103	(103)	-.045		ND	NA	0
Total phosphorus, mg/L as P	.06	(21)	.07	(57)	0		.865	NA	NA
Total nitrogen, mg/L as N	1.7	(21)	1.7	(96)	0	*	1.026	NA	0
Total nitrate plus nitrite, mg/L as N	1.37	(21)	1.20	(101)	0	*	.954	NA	0
Total nitrite, mg/L as N	.021	(21)	.022	(94)	-.191	*	.808	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.41	(21)	.54	(106)	.187		1.186	NA	0
Total ammonia, mg/L as N	.04	(21)	.10	(88)	0	*	1.065	NA	0
Total boron, µg/L as B	20	(3)	20	(3)	ND		ND	NA	NA
Total lead, µg/L as Pb	2	(5)	2	(36)	0		0	NA	NA
Fecal coliform bacteria, MPN/100 ml	80	(21)	110	(108)	.926	*	ND	NA	0

Table 7b. 1993 AMNET impairment status in the vicinity of water-quality station 01397000, South Branch Raritan River at Stanton Station, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0322	AN0326	AN0329
Impairment status	Non-impaired	Non-impaired	Non-impaired

Table 8a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01397400, South Branch Raritan River at Three Bridges, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	61	(27)	60	(71)	0.540	*	0.692	NA	NA
Hardness, mg/L as CaCO3	83	(27)	81	(101)	-.240		.760	NA	0
Total organic carbon, mg/L as C	3.5	(26)	3.4	(97)	0		1.080	NA	0
Suspended sediment, mg/L	6	(11)	8	(22)	0		1.758	NA	NA
Dissolved solids, mg/L	138	(26)	139	(99)	-.180		.820	NA	0
Dissolved sodium, mg/L as Na	15	(27)	13	(103)	-.175	*	.825	NA	0
Dissolved chloride, mg/L as Cl	22	(27)	18	(103)	-.105	*	.895	NA	+
Dissolved oxygen, mg/L	10.9	(27)	10.7	(104)	0	*	1.045	NA	0
Fraction of dissolved oxygen at saturation, %	106	(24)	103	(101)	-.033		ND	NA	0
Total phosphorus, mg/L as P	.12	(27)	.12	(98)	0		.837	NA	+
Total nitrogen, mg/L as N	2.2	(27)	1.9	(93)	0	*	1.012	NA	NA
Total nitrate plus nitrite, mg/L as N	1.44	(27)	1.28	(95)	0	*	.966	NA	NA
Total nitrite, mg/L as N	.028	(27)	.027	(86)	0	*	.850	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.69	(27)	.60	(101)	0		1.087	NA	0
Total ammonia, mg/L as N	.06	(27)	.12	(92)	0		.991	NA	NA
Total boron, µg/L as B	35	(6)	30	(19)	-.826		0	NA	NA
Total lead, µg/L as Pb	1	(6)	2	(22)	0		1.446	NA	NA
Fecal coliform bacteria, MPN/100 ml	170	(25)	330	(100)	0	*	ND	NA	0

Table 8b. 1993 AMNET impairment status in the vicinity of water-quality station 01397400, South Branch Raritan River at Three Bridges, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0326	AN0329	AN0338
Impairment status	Non-impaired	Non-impaired	Non-impaired

study area. The load slopes for B at stations 01396535 and 01397400 are zero, which is the smallest for this constituent in the study area. Load slopes are in the high range for TOC, NA, CL, TAON, and NH4 at station 10396280; for TOC, NA, CL, TAON, NH4, and PB at station 01396535; for SS and TAON at station 01397000; and for PB at station 01397400, indicating greater contributions of these constituents from storm runoff relative to that at other sites in the study area. The load slopes for HARD, TP, TN, and NO32 increase in the downstream direction, indicating an increase in the relative contributions of these constituents from storm runoff along the South Branch Raritan River. The load slopes for NA, CL, TAON, NH4, and B decrease in the downstream direction.

Insufficient data are available to determine trends for all constituents during low flows at all stations on the South Branch Raritan River. Trends in concentrations during high flows are positive for HARD at station 01396280; for HARD and DS at station 01396535; and for CL and TP at station 01397400, indicating an increase in the contribution of these constituents from storm runoff through time. Trends in concentrations during high flows are negative for TOC and TAON at station 01396280 and for TAON and NH4 at station 01396535, indicating a decrease in the contributions of these constituents from storm runoff through time. The trends in concentrations during high flows are insignificant for DS, NA, CL, DO, FDO, TN, NO32, NH4, and BACT at station 01396280; for TOC, NA, CL, DO, FDO, and BACT at station 01396535; and for DO, FDO, TN, NO32, TAON, NH4, and BACT at station 01397000.

The AMNET impairment status is non-impaired upstream and downstream from stations 01396280 (table 5b) and 01396535 (table 6b). The AMNET impairment status is non-impaired at, upstream from, and downstream from stations 01397000 (table 7b) and 01397400 (table 8b).

Spruce Run

For the one station on Spruce Run, station 01396588 near Glen Gardner, the 5-year median is smaller than the period-of-record median for NH4; 5-year and period-of-record medians are similar for all other constituents (table 9a). The regression slopes of concentration to streamflow for ALK, TOC, CL, DO, NO32, TAON, and BACT show seasonal dependency. Regression slopes of load to streamflow are in the low range for SS, DO, and B; in the moderate range for HARD, DS, NA, CL, TP, TN, NO32, NH4, and PB; and in the high range for ALK, TOC, NO2, and TAON. Insufficient data are available for all constituents to determine trends in concentrations during low and high flows. The AMNET impairment status upstream from station 01396588 is non-impaired (table 9b).

Mulhockaway Creek

For the one station on Mulhockaway Creek, station 01396660 at Van Syckel, the 5-year and period-of-record medians differ only slightly for all constituents (table 10a). The regression slopes of concentration to streamflow show seasonal dependency for ALK, HARD, TOC, NA, CL, DO, NO32, NO2, and BACT. The regression slope of load to streamflow is in the low range for SS, indicating a smaller contribution of this constituent from storm runoff relative to other sites in the study area. The load slope for B is zero; this is the lowest load slope for B in the study area. The regression slopes of load to streamflow for all other constituents fall within the moderate to high range. Insufficient data are available for all constituents at this station to determine trends in concentrations during low flows. During high flows, the trend direction is positive for NA and CL, indicating an increase in the contribution of these constituents from

Table 9a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01396588, Spruce Run near Glen Gardner, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY		1976-93 WY						
	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	33	(27)	30	(74)	0.580	*	0.803	NA	NA
Hardness, mg/L as CaCO3	55	(27)	50	(83)	-.121		.879	NA	NA
Total organic carbon, mg/L as C	2.1	(25)	2.2	(81)	.191	*	1.190	NA	NA
Suspended sediment, mg/L	3	(11)	3	(19)	0		1.227	NA	NA
Dissolved solids, mg/L	101	(27)	101	(84)	-.062		.938	NA	NA
Dissolved sodium, mg/L as Na	9	(27)	9	(83)	-.047		.953	NA	NA
Dissolved chloride, mg/L as Cl	15	(27)	13	(83)	0	*	.989	NA	NA
Dissolved oxygen, mg/L	11.4	(27)	10.4	(84)	0	*	1.032	NA	NA
Fraction of dissolved oxygen at saturation, %	106	(24)	104	(80)	-.030		ND	NA	NA
Total phosphorus, mg/L as P	.06	(23)	.06	(55)	0		.998	NA	NA
Total nitrogen, mg/L as N	1.5	(27)	1.4	(79)	.086		1.086	NA	NA
Total nitrate plus nitrite, mg/L as N	1.31	(27)	1.05	(81)	0	*	1.001	NA	NA
Total nitrite, mg/L as N	.006	(27)	.008	(78)	.181		1.181	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.28	(27)	.36	(82)	.257	*	1.257	NA	NA
Total ammonia, mg/L as N	.04	(27)	.08	(78)	0		1.068	NA	NA
Total boron, µg/L as B	10	(6)	11	(17)	0		1.003	NA	NA
Total lead, µg/L as Pb	1	(6)	2	(18)	0		.693	NA	NA
Fecal coliform bacteria, MPN/100 ml	220	(25)	220	(81)	0	*	ND	NA	NA

Table 9b. 1993 AMNET impairment status in the vicinity of water-quality station 01396588, Spruce Run near Glen Gardner, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0319	None	None
Impairment status	Non-impaired	ND	ND

Table 10a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01396660, Mulhockaway Creek at Van Syckel, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	50	(27)	48	(74)	0.750	*	0.710	NA	NA
Hardness, mg/L as CaCO3	70	(27)	66	(104)	-.216	*	.784	NA	0
Total organic carbon, mg/L as C	2.1	(27)	2.2	(102)	.229	*	1.228	NA	-
Suspended sediment, mg/L	1	(11)	4	(32)	0		1.189	NA	NA
Dissolved solids, mg/L	113	(27)	112	(102)	-.125		.875	NA	0
Dissolved sodium, mg/L as Na	8	(27)	7	(104)	0	*	.987	NA	+
Dissolved chloride, mg/L as Cl	14	(27)	10	(104)	0	*	1.029	NA	+
Dissolved oxygen, mg/L	10.8	(27)	10.4	(104)	.057	*	1.057	NA	0
Fraction of dissolved oxygen at saturation, %	104	(22)	100	(97)	0		ND	NA	0
Total phosphorus, mg/L as P	.04	(23)	.03	(69)	0		1.302	NA	NA
Total nitrogen, mg/L as N	1.3	(26)	1.3	(88)	0		1.025	NA	0
Total nitrate plus nitrite, mg/L as N	1.04	(26)	.97	(93)	-.071	*	.929	NA	0
Total nitrite, mg/L as N	.007	(27)	.008	(85)	.291	*	1.291	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.25	(27)	.32	(100)	.212		1.212	NA	0
Total ammonia, mg/L as N	.04	(27)	.07	(89)	0		1.161	NA	NA
Total boron, µg/L as B	10	(5)	10	(20)	-.642		0	NA	NA
Total lead, µg/L as Pb	1	(5)	2	(23)	0		1.107	NA	NA
Fecal coliform bacteria, MPN/100 ml	230	(25)	230	(100)	0	*	ND	NA	0

Table 10b. 1993 AMNET impairment status in the vicinity of water-quality station 01396660, Mulhockaway Creek at Van Syckel, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	None	AN0321	None
Impairment status	ND	Non-impaired	ND

storm runoff through time, and negative for TOC, indicating a decrease in the contribution of TOC from storm runoff through time. Trends are insignificant for HARD, DS, DO, FDO, TN, NO32, TOAN, and BACT. The AMNET impairment status is non-impaired at station 01396660 (table 10b).

<u>Neshanic River</u>

For the one station on the Neshanic River, station 01398000 at Reaville, the 5-year medians are smaller than the period-of-record medians for SS and NH4 (table 11a). The 5-year median is larger than the period-of-record median for BACT. The regression slopes of concentration to streamflow show seasonal dependency for ALK, HARD, TOC, SS, TP, NO32, TAON, and BACT. The regression slopes of load to streamflow are in the low range for TOC, DS, and TAON. The regression slopes for TOC and TAON are the minimum values for these constituents at all stations in the study area. The regression slope of load to streamflow for TN is the maximum value for this constituent for all stations in the study area. The slopes for all other constituents are in the moderate to high range. Insufficient data are available for all constituents to determine trends in concentrations during low and high flows. The AMNET impairment status downstream from and at station 01398000 is moderately impaired, and upstream is non-impaired (table 11b).

North Branch Raritan River Basin

Five surface-water-quality stations are located in the North Branch Raritan River Basin. Two stations are located along the North Branch Raritan River, two are located on the Lamington River, and one is located on Rockaway Creek.

<u>North Branch Raritan River</u>

The two stations on the North Branch Raritan River are 01398260 near Chester and 01399120 at Burnt Mills. The 5-year medians are smaller than the period-of-record medians for TP, TN, TAON, and NH4 at station 01398260 (table 12a) and for SS and NH4 at station 01399120 (table 13a). The 5-year median is larger than the period-of-record median for BACT at both stations. The regression slopes of concentration to streamflow show seasonal dependency for TOC, NA, CL, DO, FDO, TP, TN, and BACT at station 01398260 and for HARD, TOC, SS, DS, NA, CL, DO, FDO, NO32, and BACT at station 01399120.

The regression slope of load to streamflow for NO32 and NO2 are the smallest for these constituents in the study area. The regression slopes of load to streamflow are in the low range for DS and all six nutrient species at station 01398260 and for TOC and DO at station 01399120. The regression slopes of load to streamflow are in the high range for PB at station 01398260 and for ALK, NO2, NH4, and PB at station 01399120. All other load slopes are in the moderate range. The load slopes of ALK, DS, and all six nutrient species increase in the downstream direction, indicating an increase in the relative contributions of these constituents from storm runoff along the North Branch Raritan River. The load slopes of TOC and DO decrease in the downstream direction.

Insufficient data are available to determine trends for all constituents during low and high flows at station 01398260. Trends in concentrations during low flows are positive for HARD, DS, NA, and CL at station 01399120, indicating an increase in the relative contributions of these

Table 11a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01398000, Neshanic River at Reaville, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY		1976-93 WY						
	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	57	(27)	60	(75)	0.890	*	0.706	NA	NA
Hardness, mg/L as CaCO3	116	(26)	116	(85)	-.198	*	.802	NA	NA
Total organic carbon, mg/L as C	3.7	(27)	3.5	(84)	0	*	.956	NA	NA
Suspended sediment, mg/L	3	(11)	6	(42)	.549	*	1.549	NA	NA
Dissolved solids, mg/L	198	(27)	214	(83)	-.151		.849	NA	NA
Dissolved sodium, mg/L as Na	17	(27)	18	(86)	-.094		.906	NA	NA
Dissolved chloride, mg/L as Cl	28	(26)	31	(85)	0		.947	NA	NA
Dissolved oxygen, mg/L	12.4	(26)	12.3	(83)	.086		1.086	NA	NA
Fraction of dissolved oxygen at saturation, %	102	(24)	107	(78)	0		ND	NA	NA
Total phosphorus, mg/L as P	.05	(27)	.06	(60)	.114	*	1.114	NA	NA
Total nitrogen, mg/L as N	2.3	(27)	2.2	(83)	.311		1.311	NA	NA
Total nitrate plus nitrite, mg/L as N	1.89	(27)	1.60	(85)	.630	*	1.630	NA	NA
Total nitrite, mg/L as N	.014	(27)	.020	(78)	0		1.021	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.50	(27)	.56	(83)	0	*	.947	NA	NA
Total ammonia, mg/L as N	.04	(27)	.08	(79)	0		1.112	NA	NA
Total boron, µg/L as B	40	(4)	40	(16)	0		.684	NA	NA
Total lead, µg/L as Pb	2	(4)	3	(16)	0		.824	NA	NA
Fecal coliform bacteria, MPN/100 ml	1,100	(25)	700	(81)	0	*	ND	NA	NA

Table 11b. 1993 AMNET impairment status in the vicinity of water-quality station 01398000, Neshanic River at Reaville, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0331	AN0333	AN0337
Impairment status	Non-impaired	Moderately impaired	Moderately impaired

Table 12a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01398260, North Branch Raritan River near Chester, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY		1976-93 WY							
	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	41	(27)	40	(74)	0.590		0.683	NA	NA
Hardness, mg/L as CaCO3	66	(27)	62	(98)	-.255		.745	NA	NA
Total organic carbon, mg/L as C	3.0	(27)	3.3	(97)	0	*	1.056	NA	NA
Suspended sediment, mg/L	2	(11)	3	(21)	0		1.519	NA	NA
Dissolved solids, mg/L	149	(27)	136	(99)	-.142		.857	NA	NA
Dissolved sodium, mg/L as Na	15	(27)	15	(98)	-.095	*	.905	NA	NA
Dissolved chloride, mg/L as Cl	31	(27)	26	(99)	0	*	.952	NA	NA
Dissolved oxygen, mg/L	10.4	(26)	10.2	(99)	.103	*	1.103	NA	NA
Fraction of dissolved oxygen at saturation, %	101	(24)	96	(94)	.067	*	ND	NA	NA
Total phosphorus, mg/L as P	.15	(26)	.24	(70)	-.505	*	.495	NA	NA
Total nitrogen, mg/L as N	2.0	(27)	2.3	(88)	-.314		.686	NA	NA
Total nitrate plus nitrite, mg/L as N	1.54	(27)	1.30	(91)	-.494		.504	NA	NA
Total nitrite, mg/L as N	.017	(27)	.032	(82)	-.746	*	0	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.46	(27)	.89	(94)	0		1.008	NA	NA
Total ammonia, mg/L as N	.07	(27)	.30	(87)	0		.915	NA	NA
Total boron, µg/L as B	40	(5)	40	(17)	-.377		.619	NA	NA
Total lead, µg/L as Pb	2	(5)	2	(20)	.543		1.542	NA	NA
Fecal coliform bacteria, MPN/100 ml	230	(25)	130	(98)	.558	*	ND	NA	NA

Table 12b. 1993 AMNET impairment status in the vicinity of water-quality station 01398260, North Branch Raritan River near Chester, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0345	AN0346	AN0350
Impairment status	Non-impaired	Non-impaired	Non-impaired

Table 13a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01399120, North Branch Raritan River at Burnt Mills, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	51	(27)	49	(74)	0.680		0.734	NA	NA
Hardness, mg/L as CaCO3	72	(27)	71	(104)	-.179	*	.820	+	0
Total organic carbon, mg/L as C	3.6	(27)	3.4	(100)	0	*	1.010	0	0
Suspended sediment, mg/L	3	(11)	7	(52)	1.084	*	2.084	NA	NA
Dissolved solids, mg/L	138	(26)	134	(104)	-.132	*	.868	+	0
Dissolved sodium, mg/L as Na	13	(27)	12	(105)	-.088	*	.912	+	+
Dissolved chloride, mg/L as Cl	25	(27)	21	(105)	0	*	.938	+	0
Dissolved oxygen, mg/L	10.8	(27)	11.1	(98)	0	*	1.030	NA	0
Fraction of dissolved oxygen at saturation, %	100	(24)	106	(92)	-.036	*	ND	NA	0
Total phosphorus, mg/L as P	.08	(26)	.09	(66)	0		.901	NA	NA
Total nitrogen, mg/L as N	1.3	(27)	1.4	(88)	0		.962	NA	0
Total nitrate plus nitrite, mg/L as N	.89	(27)	.90	(94)	-.069	*	.931	NA	0
Total nitrite, mg/L as N	.016	(27)	.018	(82)	.143		1.143	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.35	(27)	.46	(98)	0		1.035	-	0
Total ammonia, mg/L as N	.04	(27)	.07	(87)	0		1.203	0	NA
Total boron, µg/L as B	55	(6)	55	(16)	-.625		.372	NA	NA
Total lead, µg/L as Pb	2	(6)	2	(18)	.537		1.539	NA	NA
Fecal coliform bacteria, MPN/100 ml	790	(25)	330	(93)	0	*	ND	NA	0

Table 13b. 1993 AMNET impairment status in the vicinity of water-quality station 01399120, North Branch Raritan River at Burnt Mills, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	None	None	AN0374
Impairment status	ND	ND	Non-impaired

constituents from point sources and ground water through time. The trend in concentrations during low flows is negative for TAON at station 01399120, indicating a decrease in the relative contribution of TAON from point sources and ground water through time. The trends are insignificant for TOC and NH4 during low flows. During high flows trends in concentrations are positive for NA, indicating an increase in the relative contribution from storm runoff through time at station 01399120, and insignificant for HARD, TOC, DS, CL, DO, FDO, TN, NO32, TAON, and BACT.

The AMNET impairment status is non-impaired at, upstream, and downstream from station 01398260 (table 12b). The AMNET impairment status is non-impaired downstream from station 01399120 (table 13b).

Lamington River

The two stations located on the Lamington River are station 01399500 near Pottersville and station 01399780 at Burnt Mills. The 5-year median is smaller than the period-of-record median for NH4 at station 01399500 (table 14a) and is larger than the period-of-record median for B at both stations (tables 14a and 15a). The regression slopes of concentration to streamflow show seasonal dependency for ALK, TOC, SS, NA, CL, DO, TN, and NO32 at station 01399500, and for ALK, TOC, NA, CL, DO, TN, NO32, and BACT at station 01399780.

The regression slope of load to streamflow for DS at station 01399500 is the smallest for this constituent in the study area, and B has a slope of zero at both stations. The regression slopes of load to streamflow are in the low range for DS, NA, CL, and B at station 01399500 and for DS, CL, DO, and B at station 01399780. The load slopes are in the high range for ALK, NO2, and NH4 at station 01399500 and for ALK and PB at station 01399780. All other load slopes are in the moderate range. The load slope of NA increases in the downstream direction, indicating an increase in the relative contribution of NA from storm runoff along the Lamington River. The load slopes of DO, NO2, and NH4 decrease in the downstream direction.

Trends in concentrations during low flows are insignificant for TOC, DO, FDO, TN, NO32, TAON, NH4, and BACT at station 01399500. All other constituents at both stations have insufficient data to determine trends. Trends in concentrations during high flows are positive for CL at both stations, indicating an increase in the relative contributions of CL from storm runoff through time. The trend is negative for TAON at station 01399500, indicating a decrease in the relative contribution of TAON from strom runoff through time. Trends during high flows are insignificant for HARD, TOC, DS, NA, DO, TN, NO32, NH4, and BACT at station 01399500 and for HARD, TOC, DS, NA, DO, FDO, TAON, and BACT at station 01399780. The AMNET impairment status is non-impaired upstream and downstream from station 01399500, and at and upstream from station 01399780 (table 14b and 15b).

Rockaway Creek

For the one station on Rockaway Creek, station 01399700 at Whitehouse, the 5-year and period-of-record medians are similar for all constituents (table 16a). The regression slopes of concentration to streamflow show seasonal dependency for ALK, TOC, NA, CL, DO, TP, TN, NO32, NO2, and BACT. The regression slopes of load to streamflow are in the low range for DS, DO, and NO32; in the moderate range for HARD, TOC, SS, NA, CL, TN, NO2, TAON, B, and PB; and in the high range for ALK, TP, and NH4. Insufficient data are available for all constitu-

Table 14a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01399500, Lamington River near Pottersville, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY Median concentration		1976-93 WY Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	46	(26)	47	(73)	0.560	*	0.706	NA	NA
Hardness, mg/L as CaCO3	67	(27)	60	(100)	-.250		.749	NA	0
Total organic carbon, mg/L as C	4.2	(26)	4.6	(98)	.137	*	1.137	0	0
Suspended sediment, mg/L	4	(11)	5	(29)	.842	*	1.843	NA	NA
Dissolved solids, mg/L	135	(27)	131	(97)	-.206		.794	NA	0
Dissolved sodium, mg/L as Na	17	(27)	16	(99)	-.195	*	.805	NA	0
Dissolved chloride, mg/L as Cl	32	(27)	25	(100)	-.183	*	.816	NA	+
Dissolved oxygen, mg/L	10.6	(27)	10.2	(102)	.074	*	1.074	0	0
Fraction of dissolved oxygen at saturation, %	102	(24)	100	(95)	0		ND	0	NA
Total phosphorus, mg/L as P	.05	(27)	.08	(70)	0		.818	NA	NA
Total nitrogen, mg/L as N	1.2	(27)	1.3	(85)	0	*	.972	0	0
Total nitrate plus nitrite, mg/L as N	.71	(27)	.75	(89)	-.126	*	.873	0	0
Total nitrite, mg/L as N	.008	(27)	.009	(85)	.231		1.231	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.41	(27)	.51	(95)	.133		1.133	0	-
Total ammonia, mg/L as N	.03	(27)	.07	(89)	0		1.192	0	0
Total boron, µg/L as B	50	(5)	30	(12)	-.606		0	NA	NA
Total lead, µg/L as Pb	1	(5)	2	(12)	ND		ND	NA	NA
Fecal coliform bacteria, MPN/100 ml	70	(25)	70	(99)	0		ND	0	0

Table 14b. 1993 AMNET impairment status in the vicinity of water-quality station 01399500, Lamington River near Pottersville, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0358	None	AN0360
Impairment status	Non-impaired	ND	Non-impaired

Table 15a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01399780, Lamington River at Burnt Mills, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY		1976-93 WY						
	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	55	(26)	51	(73)	0.620	*	0.706	NA	NA
Hardness, mg/L as CaCO3	74	(26)	68	(110)	-.214		.786	NA	0
Total organic carbon, mg/L as C	3.4	(24)	3.7	(97)	0	*	1.100	NA	0
Suspended sediment, mg/L	5	(11)	9	(38)	.839		1.838	NA	NA
Dissolved solids, mg/L	128	(25)	125	(111)	-.155		.845	NA	0
Dissolved sodium, mg/L as Na	13	(26)	12	(112)	-.169	*	.831	NA	0
Dissolved chloride, mg/L as Cl	22	(26)	16	(112)	-.179	*	.821	NA	+
Dissolved oxygen, mg/L	11.2	(26)	10.5	(108)	0	*	1.037	NA	0
Fraction of dissolved oxygen at saturation, %	100	(22)	101	(99)	0		ND	NA	0
Total phosphorus, mg/L as P	.08	(25)	.08	(68)	0		.894	NA	NA
Total nitrogen, mg/L as N	1.4	(25)	1.4	(83)	0	*	1.000	NA	NA
Total nitrate plus nitrite, mg/L as N	.92	(26)	.85	(99)	0	*	.901	NA	NA
Total nitrite, mg/L as N	.012	(26)	.010	(93)	0		.898	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.34	(25)	.49	(95)	0		1.142	NA	0
Total ammonia, mg/L as N	.05	(26)	.06	(86)	0		1.106	NA	NA
Total boron, µg/L as B	50	(4)	20	(13)	-.560		0	NA	NA
Total lead, µg/L as Pb	3	(4)	3	(15)	.587		1.587	NA	NA
Fecal coliform bacteria, MPN/100 ml	250	(24)	260	(94)	.422	*	ND	NA	0

Table 15b. 1993 AMNET impairment status in the vicinity of water-quality station 01399780, Lamington River at Burnt Mills, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0363	AN0370	None
Impairment status	Non-impaired	Non-impaired	ND

Table 16a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01399700, Rockaway Creek at Whitehouse, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	54	(26)	53	(72)	0.760	*	0.704	NA	NA
Hardness, mg/L as CaCO3	72	(27)	72	(112)	-.199		.801	NA	0
Total organic carbon, mg/L as C	2.6	(24)	2.8	(99)	.134	*	1.134	NA	0
Suspended sediment, mg/L	7	(11)	8	(153)	.762		1.762	NA	NA
Dissolved solids, mg/L	126	(26)	122	(110)	-.169		.831	NA	0
Dissolved sodium, mg/L as Na	10	(27)	9	(112)	-.112	*	.888	NA	+
Dissolved chloride, mg/L as Cl	15	(27)	12	(113)	-.100	*	.900	NA	+
Dissolved oxygen, mg/L	10.0	(26)	10.2	(106)	0	*	1.042	NA	+
Fraction of dissolved oxygen at saturation, %	96	(22)	101	(98)	0		ND	NA	0
Total phosphorus, mg/L as P	.12	(26)	.11	(69)	0	*	1.078	NA	NA
Total nitrogen, mg/L as N	1.7	(27)	1.7	(88)	-.108	*	.892	NA	NA
Total nitrate plus nitrite, mg/L as N	1.33	(27)	1.20	(103)	-.396	*	.604	NA	+
Total nitrite, mg/L as N	.015	(27)	.015	(93)	-.180	*	.820	NA	0
Total ammonia plus organic nitrogen, mg/L as N	.33	(27)	.42	(98)	0		1.071	NA	0
Total ammonia, mg/L as N	.05	(27)	.06	(87)	.245		1.245	NA	0
Total boron, µg/L as B	20	(5)	30	(19)	0		.812	NA	NA
Total lead, µg/L as Pb	2	(5)	3	(21)	0		1.174	NA	NA
Fecal coliform bacteria, MPN/100 ml	490	(25)	330	(93)	0	*	ND	NA	0

Table 16b. 1993 AMNET impairment status in the vicinity of water-quality station 01399700, Rockaway Creek at Whitehouse, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0366	None	AN0369
Impairment status	Non-impaired	ND	Non-impaired

ents to determine trends in concentrations during low flows. Trends in concentrations during high flows are positive for NA, CL, DO, and NO32 and insignificant for HARD, TOC, DS, FDO, NO2, TAON, NH4, and BACT. The AMNET impairment status upstream and downstream from station 01399700 is non-impaired (table 16b).

Raritan River Basin

The two surface-water-quality stations on the mainstem of the Raritan River--stations 01400500 at Manville and 01403300 at Queens Bridge, at Bound Brook--have similar 5-year and period-of-record medians for all constituents except SS (tables 17a and 18a). At station 01400500, the 5-year median is smaller than the period-of-record median for SS. The regression slopes of concentration to streamflow for ALK, TOC, SS, DS, NA, CL, DO, TP, TN, NO32, and BACT at station 01400500, and ALK, HARD, DS, CL, DO, TN, and NO32 at station 01403300 show seasonal dependency.

The regression slope of load to streamflow for CL at station 01403300 is the smallest for this constituent in the study area. The load slopes are in the low range for DO at station 01400500 and for DS, NA, CL, DO, and TAON at station 01403300. The load slopes are in the high range for ALK, SS, TN, NO2, and B at station 01400500 and for ALK at station 01403300. All other load slopes are in the moderate range. The load slopes of SS, DS, NA, CL, TN, NO2, and TAON decrease in the downstream direction, indicating a decrease in the relative contribution of these constituents from storm runoff along the mainstem of the Raritan River.

Insufficient data are available to determine trends for all constituents during low flows at both stations. Trends in concentrations during high flows are insignificant for HARD, TOC, DS, NA, CL, DO, FDO, TAON, and BACT at station 01400500; insufficient data are available to determine trends for all other constituents at this station. Insufficient data are available to determine trends for all constituents during high flows at station 01403300. The AMNET impairment status is moderately impaired downstream from station 01400500 (table 17b), and upstream and downstream from station 01403300 (table 18b).

Millstone River Basin

Five surface-water-quality stations are located in the Millstone River Basin. Three are on Millstone River, and one each is on Stony Brook and Beden Brook.

Millstone River

The three stations located along the Millstone River are 01400540 near Manalapan (table 19a), 01400650 at Grovers Mills (table 20a), and 01402000 at Blackwells Mills (table 21a). The 5-year and period-of-record medians for most constituents differ slightly at these stations. The largest differences are for TP at station 01400650, and for NH4 and PB at station 01402000 where the period-of-record medians are larger than the 5-year medians. The regression slopes of concentration to streamflow show seasonal dependency for ALK, TOC, NA, CL, DO, TP,TN, NO32, and TAON at station 01400540; for ALK, HARD, TOC, DS, NA, CL, DO, FDO, TP, TN, NO32, NO2, TAON, NH4, and BACT at station 01400650; and for TOC, NA, CL, DO, FDO, NO2, and BACT at station 01402000. The regression slopes of load to streamflow for HARD,

Table 17a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01400500, Raritan River at Manville, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY Median concentration		1976-93 WY Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	54	(27)	54	(74)	0.660	*	0.736	NA	NA
Hardness, mg/L as CaCO3	81	(27)	79	(108)	-.196		.804	NA	0
Total organic carbon, mg/L as C	3.2	(25)	3.4	(102)	0	*	1.099	NA	0
Suspended sediment, mg/L	6	(11)	12	(46)	1.415	*	2.415	NA	NA
Dissolved solids, mg/L	136	(27)	135	(107)	-.124	*	.876	NA	0
Dissolved sodium, mg/L as Na	13	(27)	12	(109)	-.125	*	.875	NA	0
Dissolved chloride, mg/L as Cl	21	(27)	17	(109)	-.095	*	.905	NA	0
Dissolved oxygen, mg/L	10.0	(27)	10.0	(108)	0	*	1.028	NA	0
Fraction of dissolved oxygen at saturation, %	107	(27)	101	(106)	-.054		ND	NA	0
Total phosphorus, mg/L as P	.07	(25)	.09	(105)	0	*	1.041	NA	NA
Total nitrogen, mg/L as N	1.6	(27)	1.6	(98)	.240	*	1.240	NA	NA
Total nitrate plus nitrite, mg/L as N	1.10	(27)	1.08	(100)	.285	*	1.285	NA	NA
Total nitrite, mg/L as N	.016	(26)	.017	(79)	0		1.118	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.41	(27)	.53	(106)	0		1.118	NA	0
Total ammonia, mg/L as N	.05	(27)	.07	(95)	0		1.091	NA	NA
Total boron, µg/L as B	40	(5)	40	(17)	0		1.167	NA	NA
Total lead, µg/L as Pb	4	(5)	3	(17)	0		1.243	NA	NA
Fecal coliform bacteria, MPN/100 mL	130	(23)	130	(101)	.940	*	ND	NA	0

Table 17b. 1993 AMNET impairment status in the vicinity of water-quality station 01400500, Raritan River at Manville, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	None	None	AN0377
Impairment status	ND	ND	Moderately impaired

Table 18a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01403300, Raritan River at Queens Bridge, at Bound Brook, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	48	(20)	44	(50)	0.690	*	0.776	NA	NA
Hardness, mg/L as CaCO3	75	(20)	81	(50)	-.214	*	.786	NA	NA
Total organic carbon, mg/L as C	ND	(0)	3.2	(4)	ND		ND	NA	NA
Suspended sediment, mg/L	10	(20)	11	(49)	.566		1.566	NA	NA
Dissolved solids, mg/L	147	(19)	150	(49)	-.186	*	.814	NA	NA
Dissolved sodium, mg/L as Na	16	(20)	17	(51)	-.245		.755	NA	NA
Dissolved chloride, mg/L as Cl	22	(20)	24	(50)	-.192	*	.808	NA	NA
Dissolved oxygen, mg/L	11.2	(20)	10.4	(51)	0	*	1.041	NA	NA
Fraction of dissolved oxygen at saturation, %	102	(20)	100	(51)	-.034		ND	NA	NA
Total phosphorus, mg/L as P	.20	(20)	.23	(51)	-.278		.722	NA	NA
Total nitrogen, mg/L as N	2.6	(20)	2.7	(49)	-.119	*	.881	NA	NA
Total nitrate plus nitrite, mg/L as N	1.80	(20)	1.80	(50)	-.133	*	.867	NA	NA
Total nitrite, mg/L as N	.020	(19)	.020	(21)	0		.924	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.70	(20)	.80	(50)	0		.953	NA	NA
Total ammonia, mg/L as N	.13	(17)	.16	(29)	0		.968	NA	NA
Total boron, µg/L as B	ND	(0)	ND	(0)	ND		ND	NA	NA
Total lead, µg/L as Pb	ND	(0)	6	(4)	ND		ND	NA	NA
Fecal coliform bacteria, MPN/100 ml	ND	(0)	ND	(0)	ND		ND	NA	NA

Table 18b. 1993 AMNET impairment status in the vicinity of water-quality station 01403300, Raritan River at Queens Bridge, at Bound Brook, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0414	None	AN0428
Impairment status	Moderately impaired	ND	Moderately impaired

Table 19a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01400540, Millstone River near Manalapan, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY		1976-93 WY						
	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	9	(27)	10	(72)	0.400	*	0.527	NA	NA
Hardness, mg/L as CaCO3	31	(27)	30	(72)	0		.978	NA	NA
Total organic carbon, mg/L as C	2.7	(25)	3.2	(70)	0	*	1.048	NA	NA
Suspended sediment, mg/L	6	(11)	6	(11)	0		1.001	NA	NA
Dissolved solids, mg/L	78	(26)	72	(68)	.054		1.054	NA	NA
Dissolved sodium, mg/L as Na	6	(27)	6	(72)	0	*	1.044	NA	NA
Dissolved chloride, mg/L as Cl	14	(27)	12	(72)	0	*	1.052	NA	NA
Dissolved oxygen, mg/L	9.2	(27)	9.2	(72)	0	*	1.046	NA	NA
Fraction of dissolved oxygen at saturation, %	89	(25)	91	(66)	-.041		ND	NA	NA
Total phosphorus, mg/L as P	.07	(27)	.09	(58)	0	*	1.167	NA	NA
Total nitrogen, mg/L as N	1.9	(27)	1.8	(70)	.118	*	1.118	NA	NA
Total nitrate plus nitrite, mg/L as N	1.50	(27)	1.34	(72)	0	*	1.054	NA	NA
Total nitrite, mg/L as N	.011	(27)	.011	(67)	.190		1.189	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.37	(27)	.44	(70)	.206	*	1.205	NA	NA
Total ammonia, mg/L as N	.08	(27)	.08	(70)	.272		1.270	NA	NA
Total boron, µg/L as B	20	(5)	20	(15)	.462		1.462	NA	NA
Total lead, µg/L as Pb	1	(5)	2	(15)	0		1.892	NA	NA
Fecal coliform bacteria, MPN/100 ml	70	(25)	100	(70)	0		ND	NA	NA

Table 19b. 1993 AMNET impairment status in the vicinity of water-quality station 01400540, Millstone River near Manalapan, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0378	AN0379	None
Impairment status	Moderately impaired	Non-impaired	ND

Table 20a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01400650, Millstone River at Grovers Mill, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY		1976-93 WY						
	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	15	(27)	15	(75)	0.160	*	0.804	NA	NA
Hardness, mg/L as CaCO3	47	(27)	45	(106)	-.064	*	.936	NA	NA
Total organic carbon, mg/L as C	4.1	(26)	5.0	(101)	.078	*	1.078	NA	NA
Suspended sediment, mg/L	10	(11)	12	(18)	.334		1.333	NA	NA
Dissolved solids, mg/L	118	(27)	112	(103)	-.061	*	.939	NA	NA
Dissolved sodium, mg/L as Na	15	(27)	14	(106)	-.078	*	.922	NA	NA
Dissolved chloride, mg/L as Cl	22	(27)	20	(106)	0	*	.993	NA	NA
Dissolved oxygen, mg/L	7.9	(27)	7.2	(106)	.132	*	1.132	NA	NA
Fraction of dissolved oxygen at saturation, %	82	(26)	75	(105)	.071	*	ND	NA	NA
Total phosphorus, mg/L as P	.18	(25)	.31	(78)	-.154	*	.846	NA	NA
Total nitrogen, mg/L as N	4.3	(24)	3.9	(94)	-.176	*	.824	NA	NA
Total nitrate plus nitrite, mg/L as N	3.17	(25)	2.52	(96)	-.311	*	.689	NA	NA
Total nitrite, mg/L as N	.035	(25)	.044	(78)	-.289	*	.710	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	1.24	(24)	1.25	(103)	0	*	1.023	NA	NA
Total ammonia, mg/L as N	.60	(25)	.50	(94)	0	*	1.235	NA	NA
Total boron, µg/L as B	50	(5)	40	(18)	0		.830	NA	NA
Total lead, µg/L as Pb	4	(4)	5	(18)	0		1.252	NA	NA
Fecal coliform bacteria, MPN/100 ml	230	(23)	220	(101)	0	*	ND	NA	NA

Table 20b. 1993 AMNET impairment status in the vicinity of water-quality station 01400650, Millstone River at Grovers Mill, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	None	AN0382	AN0397
Impairment status	ND	Moderately impaired	Moderately impaired

Table 21a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01402000, Millstone River at Blackwells Mills, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY	1976-93 WY				
Constituent	Median concentration	Median concentration	Regression slope of concentration to streamflow	Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	37 (11)	37 (11)	0.860	0.704	NA	NA
Hardness, mg/L as CaCO3	69 (12)	67 (62)	-.204	.796	NA	NA
Total organic carbon, mg/L as C	5.1 (9)	5.7 (31)	0 *	1.058	NA	NA
Suspended sediment, mg/L	11 (11)	16 (22)	.430	1.430	NA	NA
Dissolved solids, mg/L	150 (11)	144 (34)	-.125	.875	NA	NA
Dissolved sodium, mg/L as Na	20 (12)	15 (64)	-.195 *	.805	NA	NA
Dissolved chloride, mg/L as Cl	26 (13)	20 (66)	-.153 *	.847	NA	NA
Dissolved oxygen, mg/L	9.4 (21)	8.4 (106)	.130 *	1.130	NA	NA
Fraction of dissolved oxygen at saturation, %	92 (21)	82 (104)	.058 *	ND	NA	NA
Total phosphorus, mg/L as P	.20 (19)	.28 (59)	-.404	.596	NA	NA
Total nitrogen, mg/L as N	3.0 (21)	3.1 (98)	-.135	.865	NA	NA
Total nitrate plus nitrite, mg/L as N	1.92 (21)	2.02 (100)	-.178	.822	NA	NA
Total nitrite, mg/L as N	.022 (21)	.030 (92)	-.126 *	.874	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.73 (21)	1.04 (106)	0	.963	NA	NA
Total ammonia, mg/L as N	.09 (21)	.20 (94)	0	1.088	NA	NA
Total boron, µg/L as B	85 (4)	80 (5)	ND	ND	NA	NA
Total lead, µg/L as Pb	2 (6)	6 (39)	0	.777	NA	NA
Fecal coliform bacteria, MPN/100 ml	170 (21)	220 (107)	.456 *	ND	NA	NA

Table 21b. 1993 AMNET impairment status in the vicinity of water-quality station 01402000, Millstone River at Blackwells Mills, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	None	AN0410	AN0414
Impairment status	ND	Moderately impaired	Moderately impaired

DS, NA, B, and PB at station 01400540 and for ALK at station 01400650 are the largest for these constituents at all stations in the study area. The load slope of SS is smaller at station 01400540 than at any other station in the study area. The regression slopes of load to streamflow increase in the downstream direction for ALK, SS, and DO and decrease in the downstream direction for HARD, DS, NA, CL, TP, NO2, TAON, NH4, B, and PB. At all three stations, insufficient data are available to determine trends in concentrations during low and high flows.

The AMNET impairment status is non-impaired at station 01400540 and moderately impaired upstream from the station (table 19b). The AMNET impairment status for station 01400650 is moderately impaired at and downstream from the station (table 20b), and the AMNET impairment status at and downstream from station 01402000 is moderately impaired (table 21b).

Stony Brook

For the one station on Stony Brook, station 01401000 at Princeton, the 5-year and period-of-record medians are similar for all constituents (table 22a). The regression slopes of concentration to streamflow for ALK, HARD, TOC, DS, NA, CL, DO, FDO, TN, NO32, and BACT show seasonal dependency. The regression slopes of load to streamflow are in the low range for TOC, SS, CL, and NH4: in the moderate range for HARD, DS, NA, TP, TAON, B, and PB; and in the high range for ALK, DO, TN, NO32, and NO2. The load slopes of DO and NO32 are the largest for these constituents at all stations in the study area. Insufficient data are available for all constituents at this station to determine trends in concentrations during low and high flows. The AMNET impairment status at and upstream from station 01401000 is moderately impaired (table 22b).

Beden Brook

For the one station on Beden Brook, station 01401600 near Rocky Hill, the 5-year and period-of-record medians differ slightly for all constituents except B; the 5-year median for B is the larger of the two values (table 23a). The regression slopes of concentration to streamflow for ALK, TOC, NA, Cl, DO, TP, NO32, NO2, NH4, and BACT show seasonal dependency. The regression slopes of load to streamflow are in the low to moderate range for all constituents except ALK, which is in the high range. The load slope of NH4 is the smallest for NH4 at all stations in the study area. The trends in concentrations during low flows are positive for NA and CL, negative for TAON, and insignificant for HARD, TOC, DS, DO, FDO, and BACT. Insufficient data are available to determine trends in concentrations during high flows. The AMNET impairment status at and upstream from station 01401600 is moderately impaired (table 23b).

South River Basin

Two surface-water-quality stations located in the South River Basin are included in this study. One is on Matchaponix Brook, and the other is on Manalapan Brook.

Table 22a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01401000, Stony Brook at Princeton, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

Constituent	1989-93 WY		1976-93 WY						
	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	55	(27)	47	(80)	0.780	*	0.760	NA	NA
Hardness, mg/L as CaCO3	72	(27)	68	(93)	-.144	*	.856	NA	NA
Total organic carbon, mg/L as C	4.1	(25)	4.2	(90)	0	*	.995	NA	NA
Suspended sediment, mg/L	3	(11)	3	(24)	0		1.140	NA	NA
Dissolved solids, mg/L	130	(27)	128	(90)	-.108	*	.892	NA	NA
Dissolved sodium, mg/L as Na	16	(27)	14	(93)	-.174	*	.826	NA	NA
Dissolved chloride, mg/L as Cl	21	(27)	19	(93)	-.160	*	.840	NA	NA
Dissolved oxygen, mg/L	12.7	(27)	11.0	(88)	.152	*	1.152	NA	NA
Fraction of dissolved oxygen at saturation, %	110	(27)	105	(88)	.082	*	ND	NA	NA
Total phosphorus, mg/L as P	.06	(27)	.07	(60)	0		.918	NA	NA
Total nitrogen, mg/L as N	.9	(27)	1.0	(86)	.285	*	1.284	NA	NA
Total nitrate plus nitrite, mg/L as N	.51	(27)	.54	(91)	.764	*	1.764	NA	NA
Total nitrite, mg/L as N	.009	(27)	.008	(73)	.197		1.197	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.43	(27)	.50	(87)	0		1.034	NA	NA
Total ammonia, mg/L as N	.05	(27)	.06	(81)	0		.935	NA	NA
Total boron, µg/L as B	50	(3)	50	(16)	0		.960	NA	NA
Total lead, µg/L as Pb	1	(3)	2	(16)	0		.678	NA	NA
Fecal coliform bacteria, MPN/100 ml	110	(23)	170	(81)	0	*	ND	NA	NA

Table 22b. 1993 AMNET impairment status in the vicinity of water-quality station 01401000, Stony Brook at Princeton, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0392	AN0393	None
Impairment status	Moderately impaired	Moderately impaired	ND

Table 23a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01401600, Beden Brook near Rocky Hill, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	50	(27)	41	(79)	0.750	*	0.762	NA	NA
Hardness, mg/L as CaCO3	72	(27)	69	(114)	-.206		.794	0	NA
Total organic carbon, mg/L as C	3.8	(26)	4.2	(111)	0	*	1.000	0	NA
Suspended sediment, mg/L	5	(11)	5	(23)	0		1.113	NA	NA
Dissolved solids, mg/L	127	(27)	130	(111)	-.182		.818	0	NA
Dissolved sodium, mg/L as Na	14	(27)	12	(114)	-.200	*	.800	+	NA
Dissolved chloride, mg/L as Cl	20	(27)	16	(114)	-.185	*	.814	+	NA
Dissolved oxygen, mg/L	10.4	(26)	10.0	(113)	.077	*	1.077	0	NA
Fraction of dissolved oxygen at saturation, %	103	(26)	97	(110)	0		ND	0	NA
Total phosphorus, mg/L as P	.12	(27)	.13	(80)	-.293	*	.707	NA	NA
Total nitrogen, mg/L as N	1.9	(27)	1.9	(97)	0		1.034	NA	NA
Total nitrate plus nitrite, mg/L as N	1.35	(27)	1.27	(107)	.054	*	1.054	NA	NA
Total nitrite, mg/L as N	.026	(27)	.024	(84)	-.251	*	.749	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.51	(27)	.60	(105)	0		.967	-	NA
Total ammonia, mg/L as N	.05	(27)	.08	(94)	-.148	*	.852	NA	NA
Total boron, µg/L as B	100	(2)	55	(14)	-.230		.768	NA	NA
Total lead, µg/L as Pb	3	(2)	3	(15)	0		1.020	NA	NA
Fecal coliform bacteria, MPN/100 ml	200	(25)	240	(106)	0	*	ND	0	NA

Table 23b. 1993 AMNET impairment status in the vicinity of water-quality station 01401600, Beden Brook near Rocky Hill, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0398	AN0401	None
Impairment status	Moderately impaired	Moderately impaired	ND

Matchaponix Brook

For the one station on Matchaponix Brook, station 01405302 at Mundy Avenue, the 5-year medians are smaller than the period-of-record medians for TAON, NH4, and PB (table 24a). The regression slopes of concentration to streamflow show seasonal dependency for TOC, NA, CL, DO, FDO, and NO2. The regression slopes of load to streamflow are in the low range for ALK, DS, NA, CL, TN, and NO32; in the moderate range for HARD, TOC, NO2, TAON, NH4, B, and PB; and in the high range for SS, DO, and TP. The load slope of SS is the largest for SS in the study area. The load slopes of ALK, NA, and TN are the smallest for these constituents in the study area. Trends in concentrations during low flows are positive for HARD, DS, NA, CL, FDO, TN, and NO32; negative for TOC, TAON, and NH4; and insignificant for DO and BACT. Insufficient data are available to determine trends during high flows. The AMNET impairment status upstream from station 01405302 is moderately impaired (table 24b).

Manalapan Brook

For the one station on Manalapan Brook, station 01405340 at Federal Road, near Manalapan, the 5-year medians are smaller than the period-of-record medians for NH4 and BACT (table 25a). The regression slopes of concentration to streamflow show seasonal dependency for ALK, HARD, TOC, NA, CL, DO, TP, NO32, NO2, TAON, and BACT. The regression slopes of load to streamflow are in the low range for SS; in the moderate range for ALK, TOC, DS, NA, CL, DO, TP, NO32, NO2, TAON, and B; and in the high range for HARD, TN, NO2, and NH4. Trends in concentrations during low flows are positive for NA and CL; negative for TAON and NH4; and insignificant for HARD, TOC, DS, DO, TP, TN, NO32, and BACT. Trends in concentrations during high flows are positive for NA and CL and insignificant for HARD, TOC, DS, DO, FDO, TAON, and BACT. The AMNET impairment status is severely impaired at station 01405340 and moderately impaired upstream (table 25b).

Analysis of Relations by Constituent

Schematics of the trends in concentrations during low and high flows and the values of the slopes of load to streamflow are shown for each constituent. Schematics depicting the slopes of load to streamflow are presented for each constituent except dissolved oxygen saturation and fecal coliform bacteria because loads were not calculated for these two constituents. The 01 prefix and any extraneous ending zeros have been removed from station numbers on the schematics and in the text that follows. Schematics are not drawn to scale. Only results from stations with sufficient data for analysis are discussed. Eight of the 21 water-quality stations have insufficient data for all constituents to determine trends in concentrations during high and low flows.

In the schematics showing trends of concentrations during low and high flows, symbols are used to indicate a positive (increasing concentrations), negative (decreasing concentrations), or no (insignificant change in concentrations) trend (figs. 9-26). Trends in concentrations during high and low flows indicate trends in contributions from intermittent (storm runoff) and constant (point sources and ground water) sources, respectively. Trends in concentrations during high flows indicate changes in the relative contributions from nonpoint sources because storm runoff contributes to a stream during high flows. Trends in concentrations during low flows indicate changes in the relative contributions from point sources and ground water because storm runoff does not contribute to a stream during low flows.

Table 24a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01405302, Matchaponix Brook at Mundy Avenue, at Spotswood, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY	1976-93 WY				
Constituent	Median concentration	Median concentration	Regression slope of concentration to streamflow	Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	7 (27)	5 (74)	0.310	0.374	NA	NA
Hardness, mg/L as CaCO3	60 (28)	52 (95)	-.214	.785	+	NA
Total organic carbon, mg/L as C	3.0 (28)	3.4 (94)	0 *	1.038	-	NA
Suspended sediment, mg/L	3 (11)	6 (20)	1.517	2.517	NA	NA
Dissolved solids, mg/L	156 (26)	142 (92)	-.202	.797	+	NA
Dissolved sodium, mg/L as Na	16 (28)	16 (96)	-.254 *	.745	+	NA
Dissolved chloride, mg/L as Cl	26 (28)	24 (96)	-.158 *	.842	+	NA
Dissolved oxygen, mg/L	8.0 (28)	8.1 (94)	.136 *	1.136	0	NA
Fraction of dissolved oxygen at saturation, %	85 (28)	84 (89)	.062 *	ND	+	NA
Total phosphorus, mg/L as P	.05 (28)	.07 (71)	0	1.202	NA	NA
Total nitrogen, mg/L as N	4.4 (25)	3.8 (84)	-.372	.628	+	NA
Total nitrate plus nitrite, mg/L as N	3.82 (27)	2.91 (89)	-.474	.526	+	NA
Total nitrite, mg/L as N	.009 (28)	.013 (84)	-.286 *	.714	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.48 (25)	.93 (90)	0	1.040	-	NA
Total ammonia, mg/L as N	.14 (28)	.25 (91)	0	1.085	-	NA
Total boron, µg/L as B	60 (6)	50 (20)	-.331	.669	NA	NA
Total lead, µg/L as Pb	3 (6)	8 (21)	0	1.006	NA	NA
Fecal coliform bacteria, MPN/100 ml	60 (26)	50 (93)	0	ND	0	NA

Table 24b. 1993 AMNET impairment status in the vicinity of water-quality station 01405302, Matchaponix Brook at Mundy Avenue, at Spotswood, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0451	None	None
Impairment status	Moderately impaired	ND	ND

Table 25a. Median concentrations, relations of concentration and load to streamflow, and directions of concentration trends for selected water-quality constituents at water-quality station 01405340, Manalapan Brook at Federal Road, near Manalapan, N.J.

[Number in parenthesis is the number of available data; WY, water years; mg/L, milligrams per liter; CaCO3, calcium carbonate; C, carbon; Na, sodium, Cl, chloride; %, percent; P, phosphorus; N, nitrogen; µg/L, micrograms per liter; B, boron; Pb, lead; MPN/100 mL, most probable number per 100 milliliters. Regression slopes and trend directions are zero when the slope is not different from zero at the 0.05 significance level; * indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level); +, positive trend direction; -, negative trend direction; NA, insufficient data for analysis; ND, undetermined value]

	1989-93 WY		1976-93 WY						
Constituent	Median concentration		Median concentration		Regression slope of concentration to streamflow		Regression slope of load to streamflow	Low-flow trend direction	High-flow trend direction
Alkalinity, mg/L as CaCO3	8	(27)	7	(73)	0.200	*	0.523	NA	NA
Hardness, mg/L as CaCO3	33	(26)	34	(90)	-.078	*	.921	0	0
Total organic carbon, mg/L as C	3.0	(27)	3.4	(92)	0	*	1.063	0	0
Suspended sediment, mg/L	7	(11)	8	(19)	0		1.293	NA	NA
Dissolved solids, mg/L	84	(27)	79	(89)	0		.968	0	0
Dissolved sodium, mg/L as Na	7	(27)	6	(92)	0	*	.940	+	+
Dissolved chloride, mg/L as Cl	15	(27)	12	(93)	0	*	.944	+	+
Dissolved oxygen, mg/L	9.8	(27)	9.6	(93)	.072	*	1.072	0	0
Fraction of dissolved oxygen at saturation, %	94	(26)	95	(87)	0		ND	NA	0
Total phosphorus, mg/L as P	.08	(27)	.08	(92)	0	*	.993	0	NA
Total nitrogen, mg/L as N	1.5	(26)	1.5	(88)	.169		1.169	0	NA
Total nitrate plus nitrite, mg/L as N	1.11	(26)	.90	(90)	.339	*	1.339	0	NA
Total nitrite, mg/L as N	.010	(26)	.010	(80)	.214	*	1.214	NA	NA
Total ammonia plus organic nitrogen, mg/L as N	.33	(27)	.48	(93)	0	*	1.074	-	0
Total ammonia, mg/L as N	.06	(27)	.11	(90)	0		1.247	-	NA
Total boron, µg/L as B	10	(5)	25	(12)	0		.801	NA	NA
Total lead, µg/L as Pb	2	(5)	2	(13)	ND		ND	NA	NA
Fecal coliform bacteria, MPN/100 ml	50	(25)	80	(92)	0	*	ND	0	0

Table 25b. 1993 AMNET impairment status in the vicinity of water-quality station 01405340, Manalapan Brook at Federal Road, near Manalapan, N.J.

[AMNET, Ambient Biomonitoring Network; WQ, water-quality. Upstream from WQ station is within five miles upstream from the WQ station; at WQ-station location is within 0.5 miles upstream or downstream from the WQ station; downstream from WQ station is within five miles downstream from the WQ station; ND, undetermined impairment status]

	Upstream from WQ station	At WQ-station location	Downstream from WQ station
AMNET station	AN0438	AN0439	None
Impairment status	Moderately impaired	Severely impaired	ND

The steepness of the slope of load to streamflow at a site indicates the relative contributions to the instream load from constant and intermittent sources relative to that at other sites in the study area. The larger the contribution from storm runoff, the larger the slope will be because the load will increase with increasing streamflow. Likewise, the larger the contribution from constant sources, the smaller the slope will be because the instream load will be constant with increasing streamflow. In the schematics, symbols are used to indicate the range category of the slope at each station. Filled circles represent stations with slopes in the high range, hashed circles represent stations with slopes in the moderate range, and quartered circles represent stations with slopes in the low range. Open circles indicate stations for which slopes could not be determined because of insufficient data. Only results from stations with slopes in either the high or low range are discussed.

An increase in the magnitude of the slope in the downstream direction along a stream would indicate an increase in the relative contribution to the instream load from the storm runoff and would be evident if the order of circles proceeded from quartered to hashed to solid in the downstream direction. Likewise, a decrease in the magnitude of the slope in the downstream direction along a stream would indicate an increase in the relative contribution to the instream load from point sources and ground water and would be evident if the order of circles proceeded from solid to hashed to quartered in the downstream direction.

Alkalinity

Alkalinity, an aggregate property of water, is a measure of the capacity of water to neutralize acids and is the sum of all the titratable bases in solution (Eaton and others, 1995). The carbonate contributors to alkalinity, carbonate and bicarbonate, result from the dissociation of dissolved carbon dioxide. The important noncarbonate contributors to alkalinity include hydroxides, silicates, borates, phosphates, and organic ligands, especially acetate and propionate. In many surface-water bodies, alkalinity is primarily a function of carbonate, bicarbonate, and hydroxide, and represents their combined concentrations. Alkalinity measurements are important in the evaluation and control of potable water and wastewater processes, including chemical coagulation, water softening, corrosion control, and buffer capacity evaluation. In surface water that supports extensive algal blooms, consumption of carbon dioxide by algae for photosynthesis causes an increase in pH due to a shift in the forms of alkalinity, although there is no change in the total alkalinity (Sawyer and McCarty, 1978). Alkalinity in excess of alkaline-earth element concentrations could make water unsuitable for irrigation. Carbonate concentrations can be estimated from alkalinity measurements and used to compute the ion balance when checking water analyses.

Relation of trends in concentration to flow conditions

Insufficient data are available to determine trends in alkalinity during low and high flows at all stations in the study area (figs. 7a and 7b).

Relation of load to streamflow

The range categories of regression slopes of alkalinity load to streamflow are depicted in figure 7c. The slopes range from 0.374 at station 405302 on Matchaponix Brook (table 24a) to 0.804 at station 40065 on Millstone River (table 20a). Slopes are in the high range at the downstream station on North Branch Raritan River (39912); the stations on Spruce Run (396588),

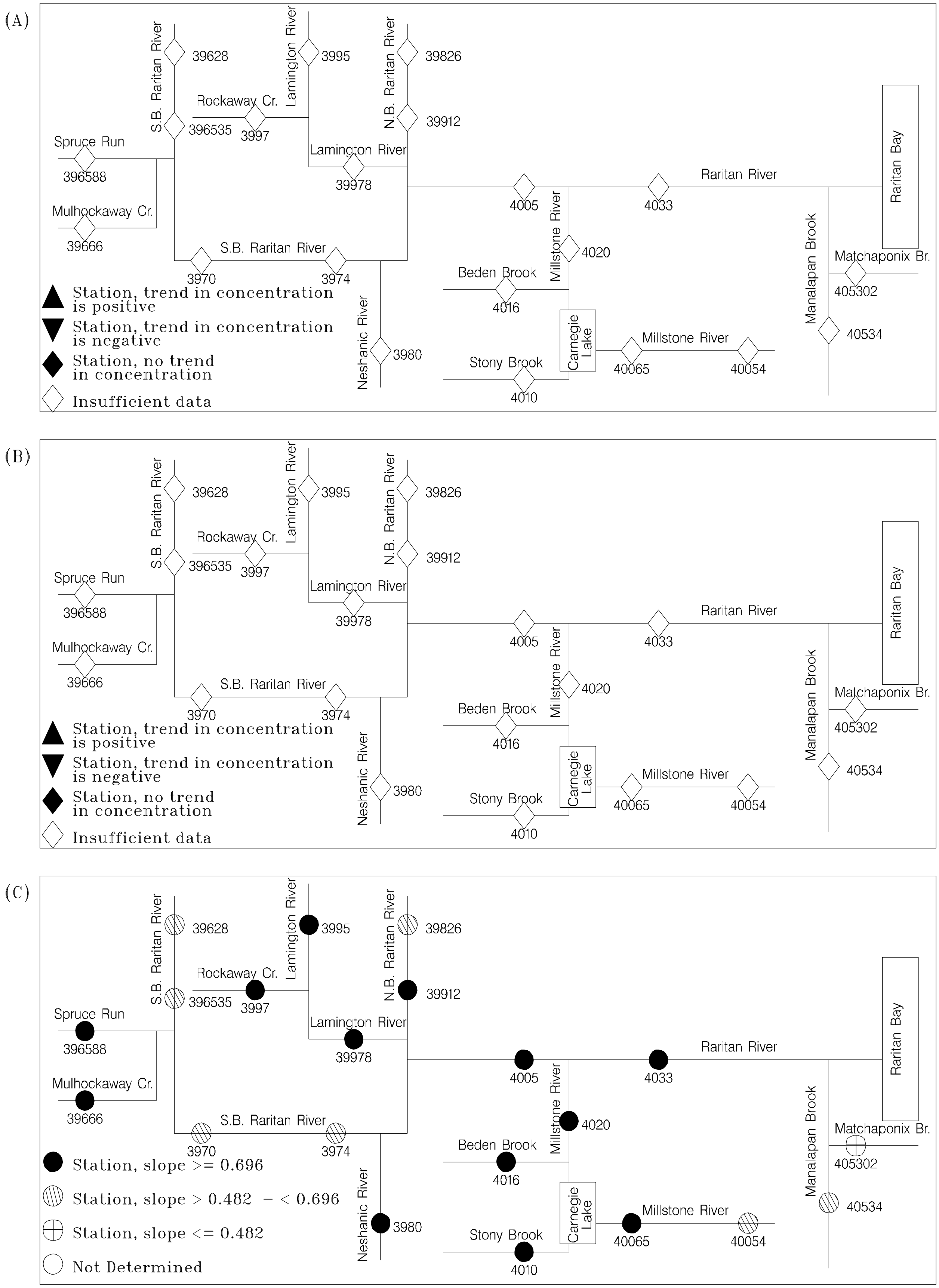


Figure 7. Trends in alkalinity concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of alkalinity load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

Mulhockaway Creek (39666), Neshanic River (3980), Rockaway Creek (3997), and Stony (4010) and Beden (4016) Brooks; the two stations on Lamington River (3995 and 39978); the downstream stations on Millstone River (40065 and 4020); and both stations on Raritan River (4005 and 4033). At these sites, the contributions to instream alkalinity loads from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. Slopes are in the low range at the one station on Matchaponix Brook (405302) where the contributions to instream alkalinity loads from point sources and ground water are larger and less influenced by storm runoff than at other sites in the study area.

Hardness

Hardness, an aggregate property of water, is an important consideration in determining the suitability of water for domestic and industrial uses. Hardness, historically described as a measure of the capacity of water to precipitate soap, is commonly caused by divalent metallic cations, namely calcium, magnesium, strontium, ferrous iron, and manganous ions (Sawyer and McCarty, 1978). Other polyvalent cations also can precipitate soap, but they often are in complex forms, frequently with organic constituents, and their role in water hardness may be minimal and difficult to define (Eaton and others, 1995). Cation concentrations can be estimated from hardness measurements and used to compute the ion balance when checking water analyses.

Calcium and magnesium, the major contributors to hardness, are often the major cations in surface water. Calcium is the most abundant of the alkaline-earth elements and is a major constituent of many common rock minerals; it is an essential element for plant and animal life. Calcium geochemical behavior is governed by the availability of soluble calcium-containing minerals, solution- and gas-phase equilibria that involve carbon dioxide species, and the availability of sulfur in the form of sulfate (Hem, 1985). Calcium also participates in cation-exchange equilibria at aluminosilicate and other mineral surfaces. Calcium salts used for deicing highways can be carried to surface water with storm runoff and melting snow. Magnesium is an alkaline-earth element and is essential in plant and animal nutrition. The water chemistry of calcium and magnesium is similar; however, the geochemical behavior is different. The cation-exchange behavior of magnesium is similar to that of calcium.

Relation of trends in concentration to flow conditions

The trends in hardness concentrations during high flows are positive at the two upstream stations on South Branch Raritan River (39628 and 396535), indicating an increase in the contribution from storm runoff through time at these stations (fig. 8a). Hardness concentrations during high flows show no trends at the station on Mulhockaway Creek (39666); the farthest downstream stations on South Branch (3974) and North Branch (39912) Raritan Rivers; the stations on Lamington River (3995 and 39978), Rockaway Creek (3997), and Manalapan Brook (40534); and the upstream station on Raritan River (4005). The trends in hardness concentrations during low flows are positive at the downstream station on North Branch Raritan River (39912) and at station 405302 on Matchaponix Brook, indicating an increase in the contribution from point sources and ground water through time at these stations (fig. 8b). Hardness concentrations during low flows show no trends at the stations on Beden (4016) and Manalapan (40534) Brooks.

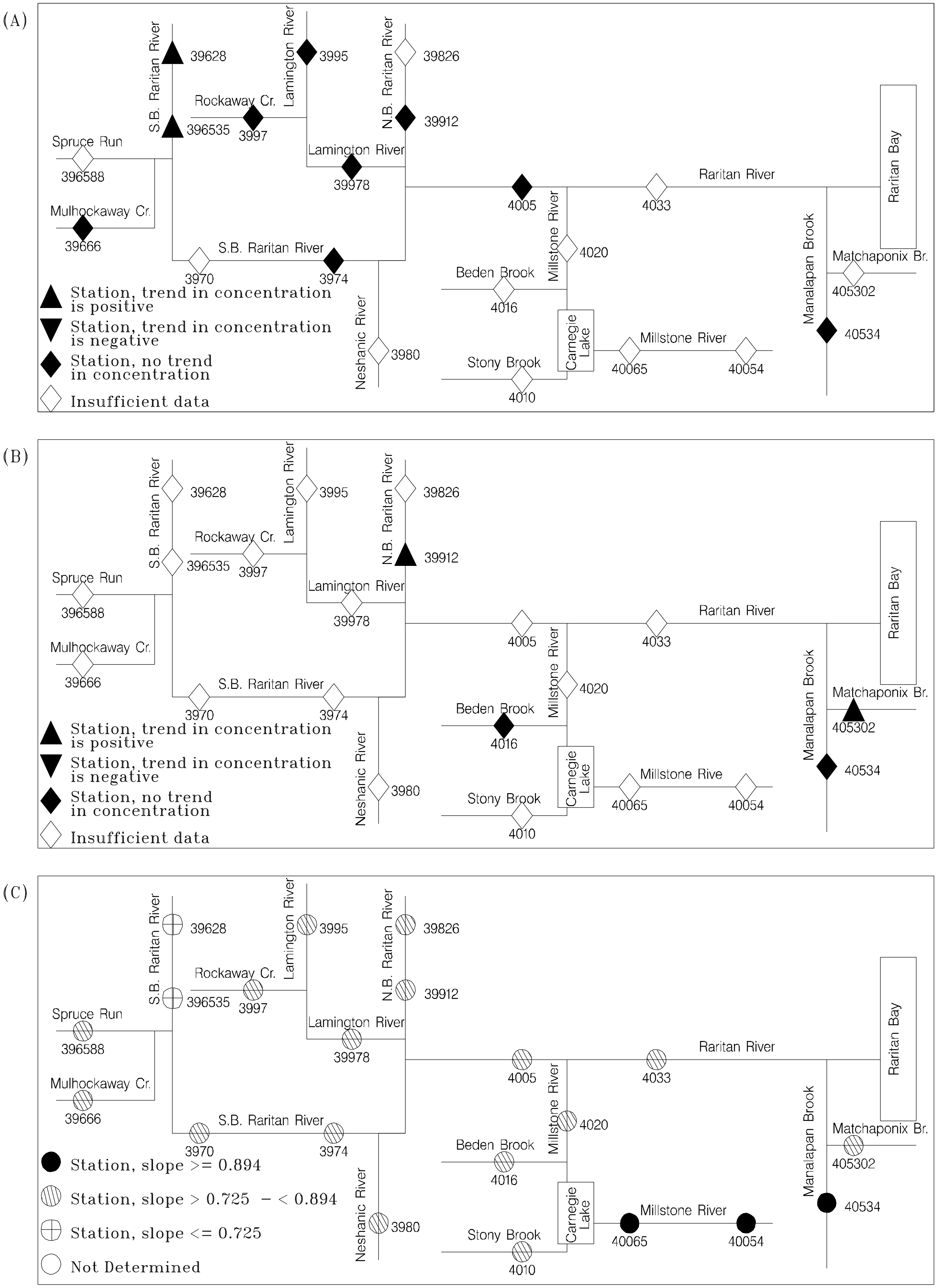


Figure 8. Trends in hardness concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of hardness load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

Relation of load to streamflow

The range categories of regression slopes of hardness load to streamflow are depicted in figure 8c. The slopes range from 0.641 at the farthest upstream station on South Branch Raritan River (39628) (table 5a) to 0.978 at the farthest upstream station on Millstone River (40054) (table 19a). Slopes are in the high range at the upstream stations on Millstone River (40054 and 40065) and the one station on Manalapan Brook (40534). At these sites, the contributions to instream hardness load from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. Slopes are in the low range at the two farthest upstream stations on South Branch Raritan River (39628 and 396535) where the contributions to instream hardness loads from point sources and ground water are larger and less influenced by storm runoff than at other sites. Slopes at stations on the South Branch Raritan River increase in the downstream direction, indicating an increase in the contributions from storm runoff along the river.

Total Organic Carbon

The concentration of total organic carbon (TOC), an aggregate property of water, is a measure of the organic compounds in various oxidation states in surface water (Eaton and others, 1995). TOC concentrations in most surface water are small compared to dissolved inorganic solute concentrations. Although the presence of organic compounds in surface water can cause an oxygen demand as organisms decompose the compounds, a measure of TOC does not represent a measure of other organically bound elements, such as nitrogen and hydrogen, or inorganics that can contribute to the oxygen demand as measured by the biochemical or chemical oxygen demands.

The methods used to measure TOC analyze fractions of total carbon. These fractions are defined as inorganic carbon, the carbonate, bicarbonate, and dissolved carbon dioxide removed from solution gas stripping under specified conditions; TOC, all carbon atoms covalently bonded in organic molecules; dissolved organic carbon (DOC), the fraction of TOC that passes through a 0.45 µm-pore-diameter filter; particulate organic carbon (POC), the fraction of TOC that is retained by a 0.45 µm-pore-diameter filter; volatile organic carbon (VOC), the fraction of TOC removed from an aqueous solution by gas stripping under specified conditions; and non-purgeable organic carbon, the fraction of TOC not removed by gas stripping. In most surface water, the VOC contribution to TOC is negligible. When not directly measured, TOC concentration is calculated as the sum of the DOC and POC concentrations.

Relation of trends in concentration to flow conditions

The trends in TOC concentrations during high flows are positive at the farthest upstream station on South Branch Raritan River (39628) and the one station on Mulhockaway Creek (39666), indicating an increase in the contribution from storm runoff through time at these stations (fig. 9a). TOC concentrations during high flows show no trend at the second (396535) and farthest downstream (3974) stations on South Branch Raritan River; the downstream station on North Branch Raritan River (39912); the stations on Lamington River (3995 and 39978), Rockaway Creek (3997), and Manalapan Brook (40534); and the upstream station on Raritan River (4005). TOC concentrations during low flows are negative at the one station on Matchaponix Brook (405302), indicating a decrease in the contributions from point sources and

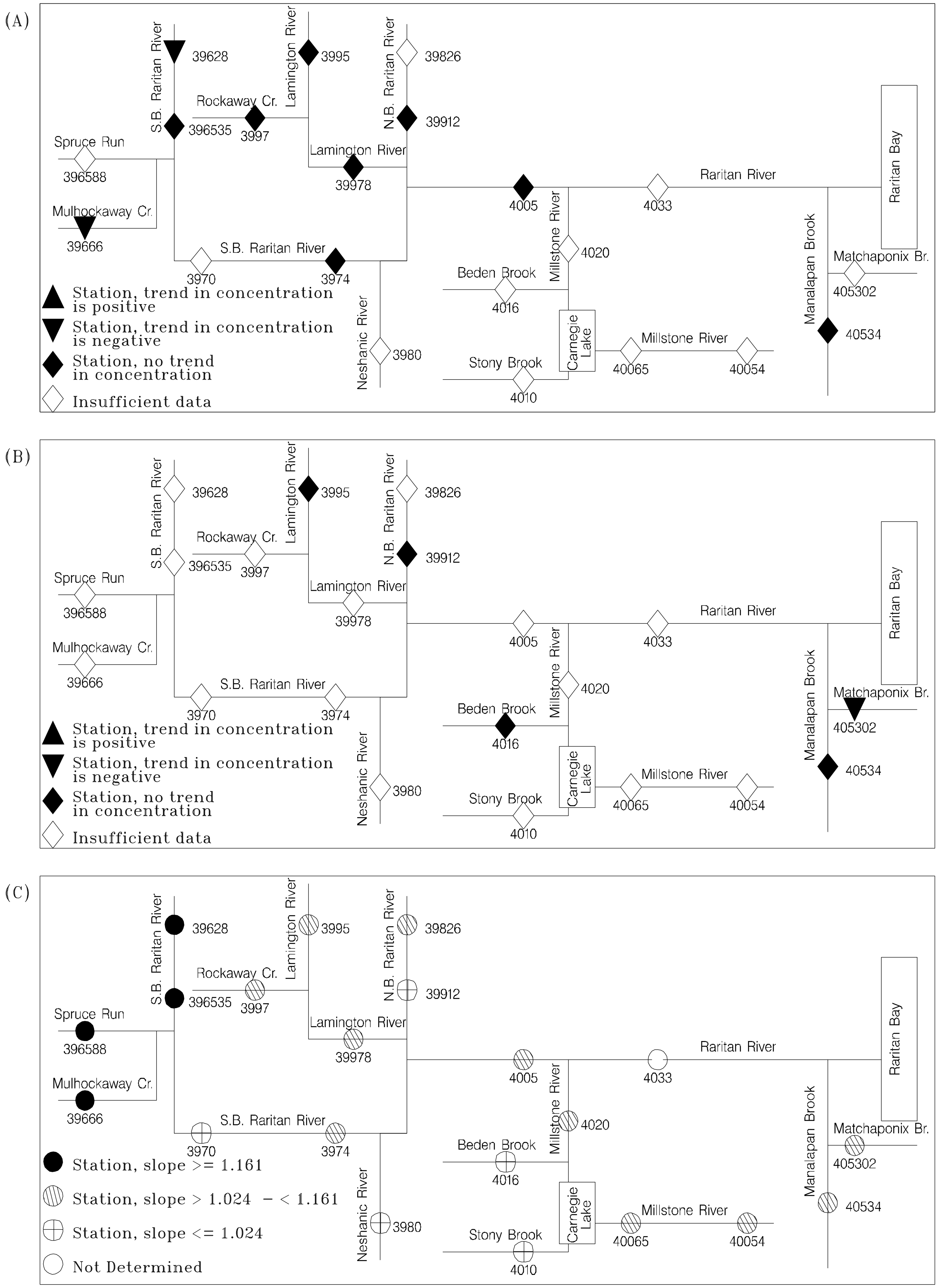


Figure 9. Trends in total organic carbon concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total organic carbon load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

ground water through time at this station (fig. 9b). TOC concentrations during low flows show no trend at the downstream station on North Branch Raritan River (39912), the upstream station on Lamington River (3995), and the stations on Beden (4016) and Manalapan (40534) Brooks.

Relation of load to streamflow

The range categories of regression slopes of TOC load to streamflow are depicted in figure 9c. The slopes range from 0.956 at station 3980 on the Neshanic River (table 11a) to 1.228 at the station 39666 on the Mulhockaway Creek (table 10a). Insufficient data are available to determine the slope at the downstream station on Raritan River (4033). Slopes are in the high range at the two upstream stations on South Branch Raritan River (39628 and 396535), and the stations on Spruce Run (396588) and Mulhockaway Creek (39666). At these sites, the contributions to instream TOC load from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. Slopes are in the low range at the third downstream station on South Branch Raritan River (3970), the downstream station on North Branch Raritan River (39912), and the stations on Neshanic River (3980) and Stony (4010) and Beden (4016) Brooks. At these sites, however, the contributions to instream TOC loads from constant sources probably are relatively insignificant because the load-to-streamflow slopes are large (greater than 0.8). Storm runoff most likely is the dominant contributor of TOC in the study area because the load-to-streamflow slopes at all stations are large.

Suspended Sediment

Suspended sediment, an aggregate property of water, is the part of total solids that is retained by a filter under specified conditions; its concentration is determined by the weight of the dry residue remaining after evaporation of the volatile part of a sample aliquot by heating to 105 °C (Eaton and others, 1995). Large concentrations of suspended sediments in surface water could inhibit light penetration to bottom-dwelling macrophytes and create esthetically unsatisfactory conditions for such purposes as swimming. Some metals, nutrients, and organic compounds can associate with the surface of suspended sediment and be transported with the suspended sediment in surface water. Suspended sediment concentration is the velocity-weighted concentration of suspended sediment in the sampled zone (from the water surface to a constant approximately 0.3 feet above the bed) (Bauersfeld and others, 1994). Generally, the primary source of suspended sediment in a stream is from erosion, streambed scour, and overland runoff during storm events.

Relation of trends in concentration to flow conditions

Insufficient data are available to determine trends in suspended sediment concentrations during high and low flows at all stations in the study area (figs. 10a and 10b).

Relation of load to streamflow

The range categories of regression slopes of suspended sediment load to streamflow are depicted in figure 10c. The slopes range from 1.001 at the farthest upstream station (40054) on Millstone River (table 19a) to 2.517 at station 405302 on Matchaponix Brook (table 24a). Load-to-streamflow slopes are larger for suspended sediments than for any other constituent at all stations. During high flows, the stream velocity can become sufficient to scour the streambed,

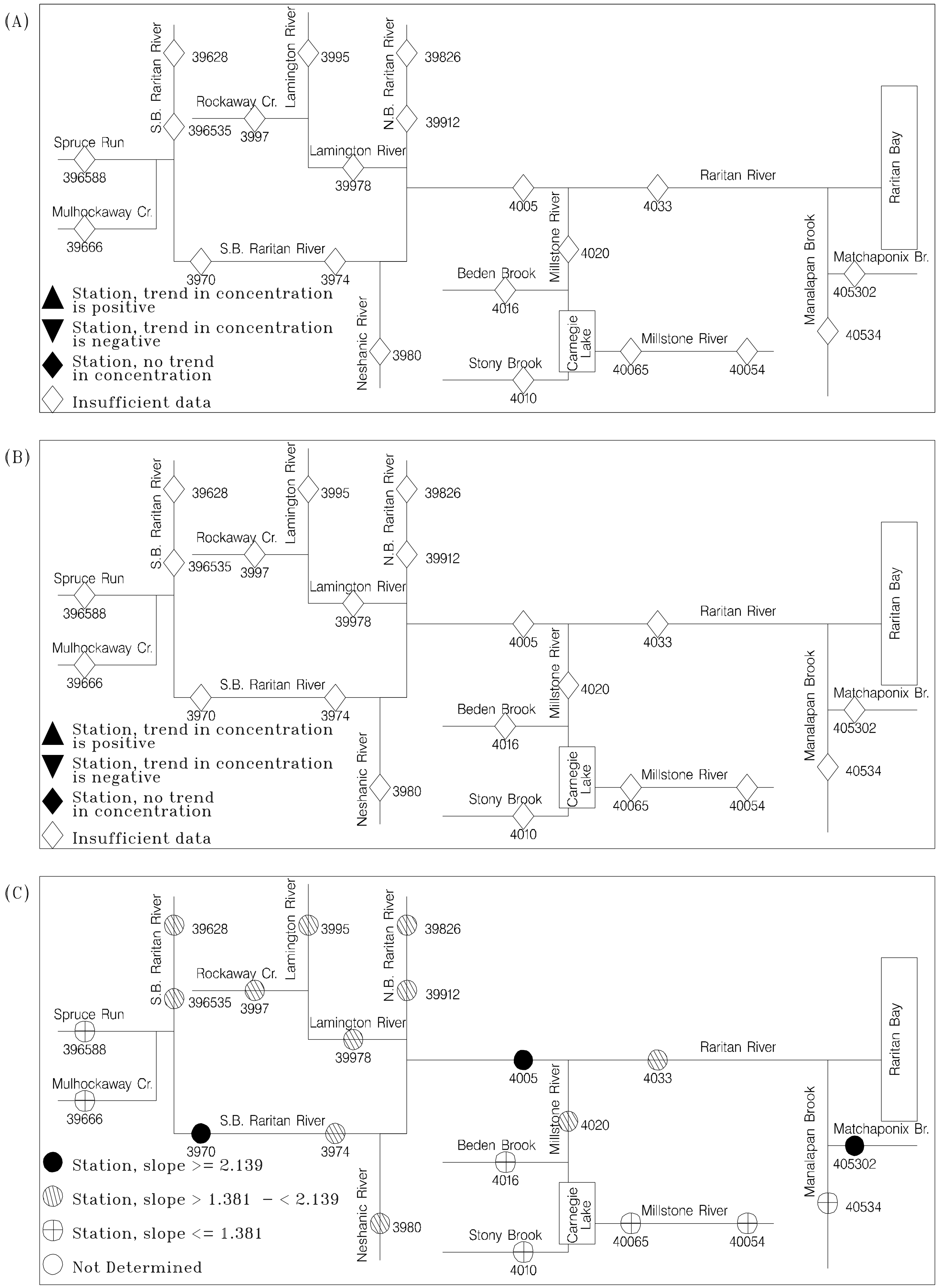


Figure 10. Trends in suspended sediment concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of suspended sediment load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

thereby, making the streambed an additional source of measured instream load. The influence of streamflow velocity on the magnitude of the load-to-streamflow slope ideally is considered when evaluating the influence of point sources and storm runoff.

Slopes are in the high range at the third downstream station on South Branch Raritan River (3970), the upstream station on Raritan River (4005), and the one station on Matchaponix Brook (405302). At these stations, the relative contributions to instream suspended sediment loads from storm runoff are larger than at other sites and less influenced by point sources and ground water. Slopes are in the low range at the stations on Spruce Run (396588) and Mulhockaway Creek (39666), the upstream stations on Millstone River (40054 and 40065), and the stations on Stony (4010) and Beden (4016) Brooks. At these sites, however, the contribution to instream suspended sediment loads from constant sources probably are relatively insignificant because the load-to-streamflow slopes are large (greater than 0.8). Storm runoff most likely is the dominant contributor of suspended sediment in the study area because the load-to-streamflow slopes at all stations are large.

Dissolved Solids

Dissolved solids, an aggregate property of water, is the part of total solids that passes through a filter of 0.45-µm (or smaller) nominal pore size under specified conditions; its concentration is determined by the weight of the dry residue remaining after evaporation of the volatile part of a sample aliquot by heating to 180 °C, the residue-upon-evaporation method (Eaton and others, 1995). All carbonates and bicarbonates will break down when heated, but organic matter will be only partially volatilized and not completely removed. Water with large concentrations of dissolved solids generally has an inferior palatability and may induce diarrhea. Salts used for deicing highways can be carried to surface water by storm runoff and melting snow and can contribute to the dissolved solids load. The dissolved solids concentration can be compared to the computed ion balance when checking a water analysis.

Relation of trends in concentration to flow conditions

The trend in dissolved solids concentration during high flows is positive at the second farthest downstream station on South Branch Raritan River (396535), indicating an increase in the contribution from storm runoff through time at this station (fig. 11a). Dissolved solids concentrations during high flows show no trends at the farthest upstream (39628) and downstream (3974) stations on South Branch Raritan River; the downstream station on North Branch Raritan River (39912); the stations on Mulhockaway Creek (39666), Lamington River (3995 and 39978), Rockaway Creek (3997), and Matchaponix Brook (40534); and the upstream station on the Raritan River (4005). The trend in dissolved solids concentrations during low flows is positive at the downstream station on North Branch Raritan River (39912) and the station on Manalapan Brook (405302), indicating an increase in the contribution from point sources and ground water through time at these sites (fig. 11b). Concentrations of dissolved solids during low flows show no trend at the stations on Beden (36777) and Manalapan (40534) Brooks.

Relation of load to streamflow

The range categories of regression slopes of dissolved solids load to streamflow are depicted in figure 11c. The slopes range from 0.794 at station 3995 on Lamington River (table 14a) to 1.054 at the farthest upstream station on Millstone River (40054) (table 19a), the only

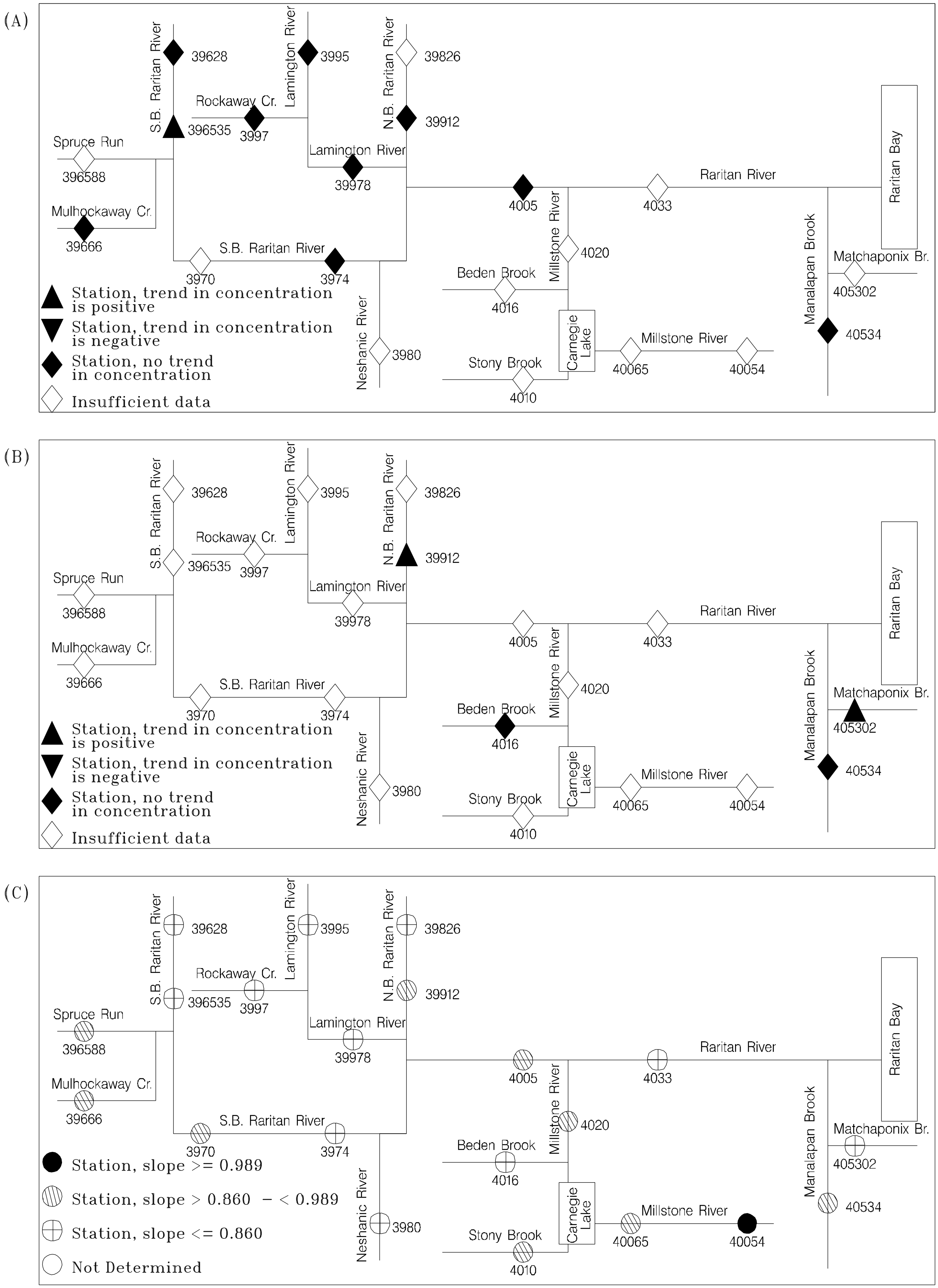


Figure 11. Trends in dissolved solids concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of dissolved solids load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

station with a slope in the high range. Contributions to instream dissolved solids loads from storm runoff are larger and less influenced by point sources and ground water at station 40054 on Millstone River than at other sites in the study area. Slopes are in the low range at the two farthest upstream (39628 and 396535) and the farthest downstream (3974) stations on South Branch Raritan River; the upstream station on North Branch Raritan River (39826); the stations on Neshanic (3980) and Lamington (3995 and 39978) Rivers, Rockaway Creek (3997), and Beden (4016) and Matchaponix (405302) Brooks; and the downstream station on Raritan River (4033). At these sites, the contributions to instream dissolved solids loads from point sources and ground water are larger and less influenced by storm runoff than at other sites in the study area. Slopes at stations on North Branch Raritan River increase in the downstream direction, indicating an increase in the contribution from storm runoff along the river. Slopes at stations on Millstone and Raritan Rivers decrease in the downstream direction, indicating a decrease in the contributions from storm runoff along the river.

Dissolved Sodium

Sodium is present in most surface water. The ratio of sodium to total cations is important in agriculture and human pathology. Sodium tends to remain in solution, when dissolved from rocks by weathering, and not form precipitates that can maintain low sodium concentrations. Sodium is retained by adsorption on mineral surfaces, especially by minerals with high cation-exchange capacities, such as clays. Cation exchange processes in fresh water systems tend to extract divalent ions from solution and replace then with monovalent ions, especially sodium (Hem, 1985). Sodium salts used for deicing highways can be carried to surface water with storm runoff and melting snow. The reuse of water for irrigation commonly leaves a residual that is much greater in sodium concentration than was the original water.

Relation of trends in concentration to flow conditions

The trends in sodium concentrations during high flows are positive at the one station on Mulhockaway Creek (39666), the downstream station on North Branch Raritan River (39912), the one station on Rockaway Creek (3997), and the one station on Manalapan Brook (40534). Contributions from storm runoff increase through time at these stations (fig. 12a). Sodium concentrations during high flows show no trends at the two farthest upstream (39628 and 396535) and farthest downstream (3974) stations on South Branch Raritan River, the stations on Lamington River (3995 and 39978), and the upstream station on Raritan River (4005). Sodium concentrations during low flows are positive at the downstream station on North Branch Raritan River (39912) and the stations on Beden (4016), Matchaponix (405302), and Manalapan (40534) Brooks (fig. 12b). Contributions from point sources and ground water increase through time at these sites.

Relation of load to streamflow

The range categories of regression slopes of dissolved sodium load to streamflow are depicted in figure 12c. The slopes range from 0.745 at station (405302) on Matchaponix Brook (table 24a) to 1.044 at the farthest upstream station on Millstone River (40054) (table 19a). The slopes are in the high range at the two farthest upstream stations on South Branch Raritan River (39628 and 396535), the one station on Mulhockaway Creek (39666), and the farthest upstream station on Millstone River (40054). At these stations, the contributions to instream sodium loads from storm runoff are larger and less influenced by point sources and ground water than at other

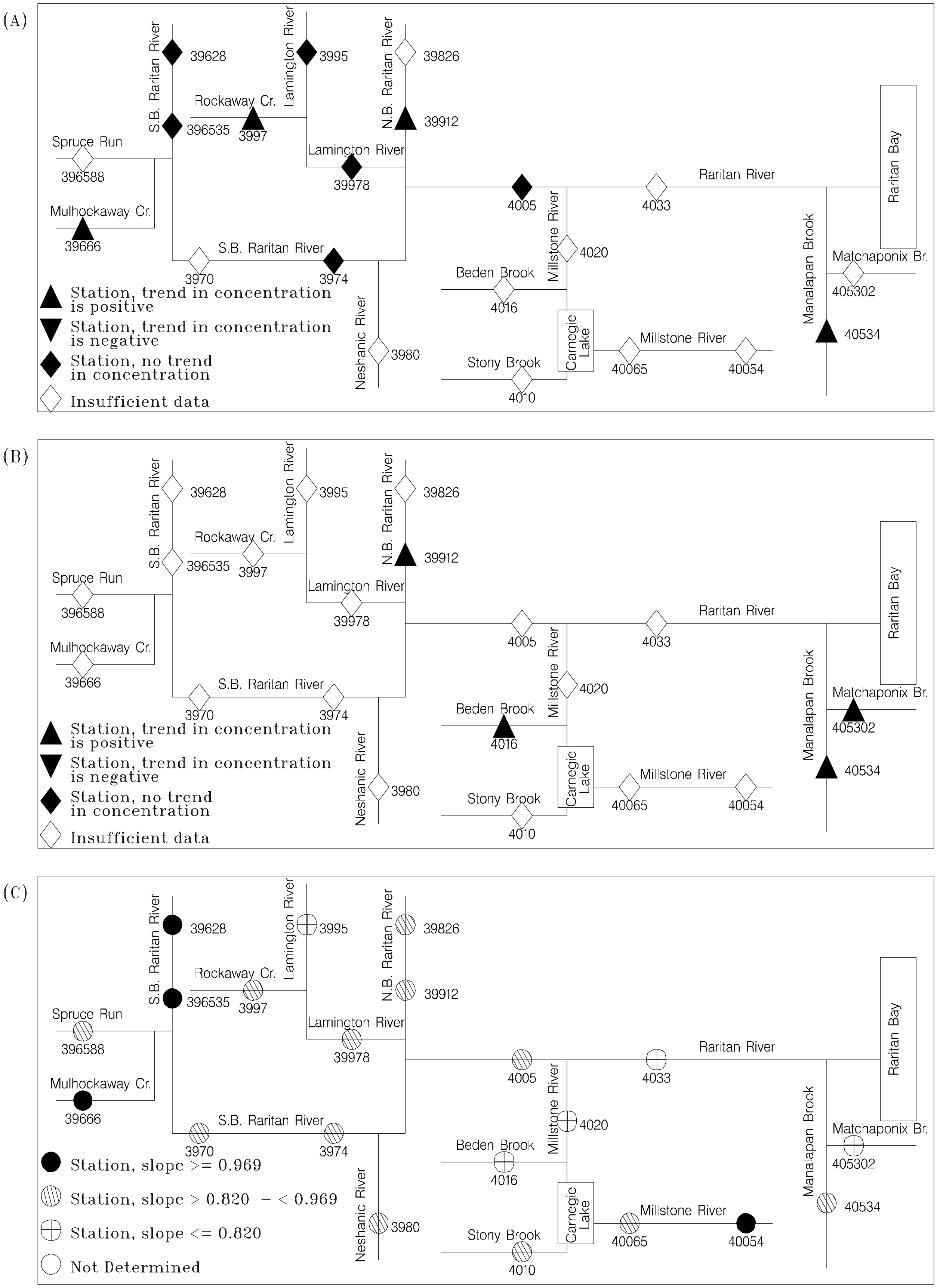


Figure 12. Trends in dissolved sodium concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of dissolved sodium load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

sites in the study area. The slopes are in the low range at the upstream station on Lamington River (3995), the stations on Beden (4016) and Matchaponix (405302) Brooks, and the downstream stations on the Millstone (4020) and Raritan (4033) Rivers. At these stations, the contributions to instream sodium loads from point sources and ground water are larger and less influenced by storm runoff than at other sites in the study area. Slopes at stations on South Branch Raritan, Millstone, and Raritan Rivers decrease in the downstream direction, indicating a decrease in the contributions from storm runoff along the river.

Dissolved Chloride

Chloride is present in all surface water, but usually in low (<10 mg/L) concentrations. Chloride ions do not significantly enter into oxidation or reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed onto mineral surfaces, and play few vital biochemical roles (Hem, 1985). Conservative constituents such as chloride move through a stream system mainly by physical processes (water inputs and withdrawals). Chloride is present in various rock types in concentrations lower than that of any of the other major constituents of ambient water. In most streams, chloride concentrations are smaller than those of sulfate or bicarbonate. Exceptions occur where streams receive inflows of ground water or industrial wastewater containing large concentrations of chloride, or are affected by oceanic tides. Chloride salts used for deicing highways can be carried to surface water by storm runoff and melting snow.

Relation of trends in concentration to flow conditions

The trends in chloride concentrations during high flows are positive at the one station on Mulhockaway Creek (39666), the farthest downstream station on South Branch Raritan River (3974), and the stations on Lamington River (3995 and 39978), Rockaway Creek (3997), and Manalapan Brook (40534). Contributions from storm runoff increase through time at these sites (fig. 13a). Chloride concentrations during high flows show no trends at the two farthest upstream stations on South Branch Raritan River (39628 and 396535) and the downstream station on North Branch Raritan River (39912). The trends in chloride concentrations during low flows are positive at the downstream station on North Branch Raritan River (39912) and the stations on Beden (4016), Matchaponix (405302), and Manalapan (40534) Brooks (fig. 13b). Contributions from point sources and ground water increase through time at these sites.

Relation of load to streamflow

The range categories of regression slopes of chloride load to streamflow are depicted in figure 13c. The slopes range from 0.808 at the downstream station on Raritan River (4033) (table 18a) to 1.055 at the farthest upstream station on South Branch Raritan River (39628). The slopes are in the high range at the two upstream stations on South Branch Raritan River (39628 and 396535), the one station on Mulhockaway Creek (39666), and the two upstream stations on Millstone River (40054 and 40065). At these stations, the contributions to instream chloride loads from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The slopes are in the low range at the stations on Lamington River (3995 and 39978) and Stony (4010), Beden (4016), and Matchaponix (405302) Brooks, and the downstream stations on Millstone (4020) and Raritan (40330) Rivers. At these sites, however, the contribution to instream chloride loads from constant sources probably are relatively insignificant

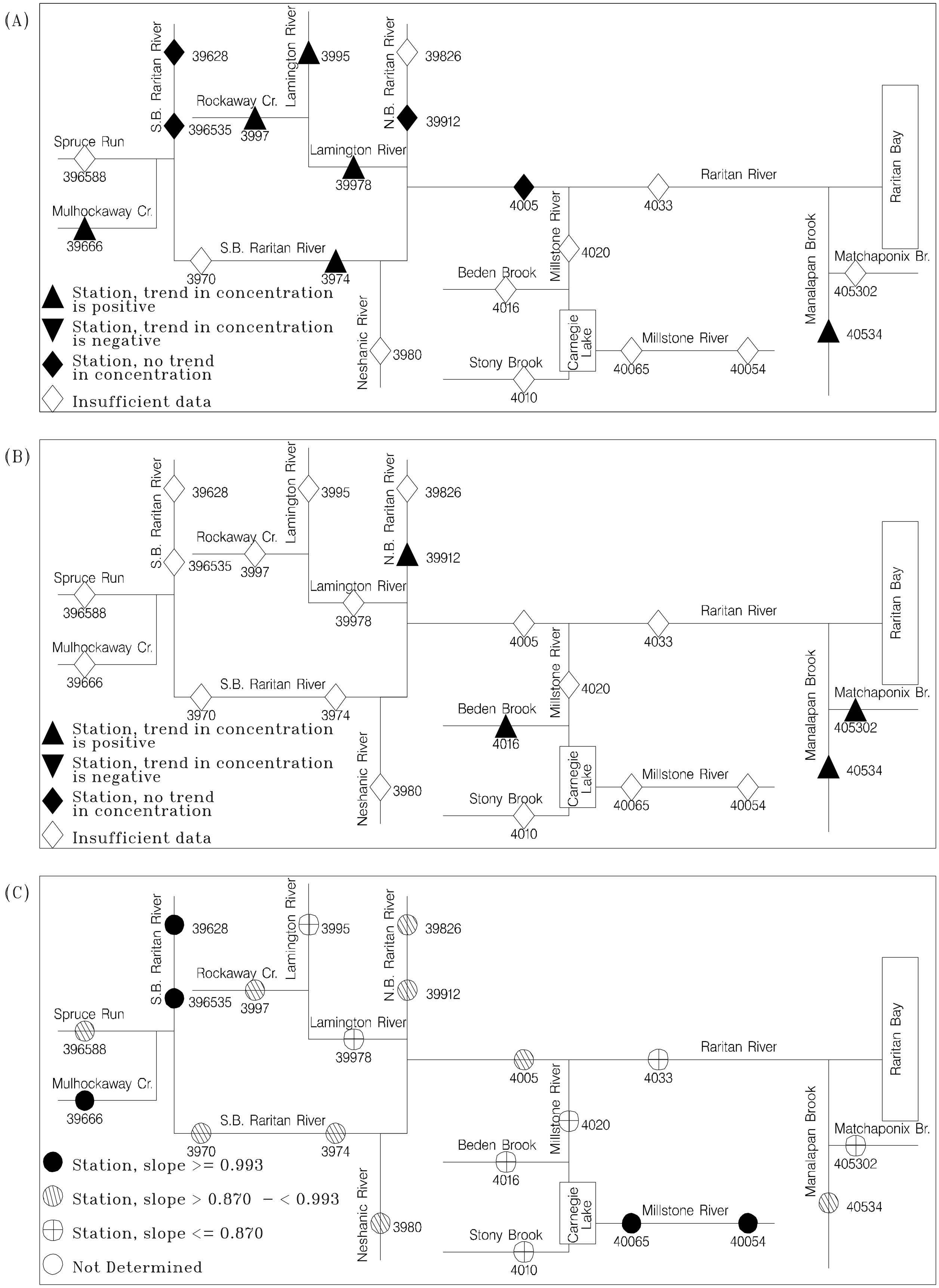


Figure 13. Trends in dissolved chloride concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of dissolved chloride load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

because the load-to-streamflow slopes are large (greater than 0.8). Storm runoff most likely is the dominant contributor of chloride in the study area because the load-to-streamflow slopes at all stations are large.

Dissolved Oxygen

Dissolved oxygen (DO) concentrations in surface water depend on the physical, chemical, and biochemical activities occurring in the water body and are a function of water temperature, atmospheric pressure, and concentrations of other solutes. The higher forms of aquatic life require oxygen for survival, and the measurement of DO is used widely to evaluate the biochemistry of surface water (Hem, 1985). Photosynthesis and water turbulence are important mechanisms that replenish DO consumed by organic matter. Oxygen supersaturation can occur in slow moving systems in winter and when photosynthesizing biota are abundant during the summer. The presence of organic compounds in surface water can cause oxygen demand. Positive trends and steep slopes of load to streamflow can indicate improved water quality.

Relation of trends in concentration to flow conditions

The trend in dissolved oxygen concentrations during high flows is positive at the one station on the Rockaway Creek (3997) (fig. 14a). Dissolved oxygen concentrations during high flows show no trend at all stations on South Branch Raritan River (39628, 396535, and 3974), the station on Mulhockaway Creek (39666), the downstream station on North Branch Raritan River (39912), the stations on Lamington River (3995 and 39978), the upstream station on Raritan River (4005), and the one station on Manalapan Brook (40534). Dissolved oxygen concentrations during low flows show no trend at the upstream station on Lamington River (3995) and the stations on Beden (4016), Matchaponix (405302), and Manalapan (40532) Brooks (fig. 14b).

Relation of load to streamflow

The range categories of regression slopes of dissolved oxygen load to streamflow are depicted in figure 14c. The range of slopes is narrow, ranging from 1.016 at the third downstream station on South Branch Raritan River (3970) (table 7a) to 1.152 at station 4010 on Stony Brook (table 22a). Slopes are in the high range at the station on Stony Brook (4010) and the two downstream stations on Millstone River (40065 and 4020). The slopes are in the low range at the farthest upstream station (39628) and two farthest downstream (3970 and 3974) stations on the South Branch Raritan River, the stations on Spruce Run (396588) and Rockaway Creek (3997), the downstream stations on North Branch Raritan (39912) and Lamington (39978) Rivers, the farthest upstream station on Millstone River (40054), and both stations on Raritan River (4005 and 4033).

Fraction of Dissolved Oxygen at Saturation

The fraction of dissolved oxygen at saturation is the ratio of the measured DO concentration to the maximum DO concentration possible in the water. The maximum DO concentration possible is a function of atmospheric pressure, water temperature, and specific conductance of the water sample. Values are determined from published equations. The

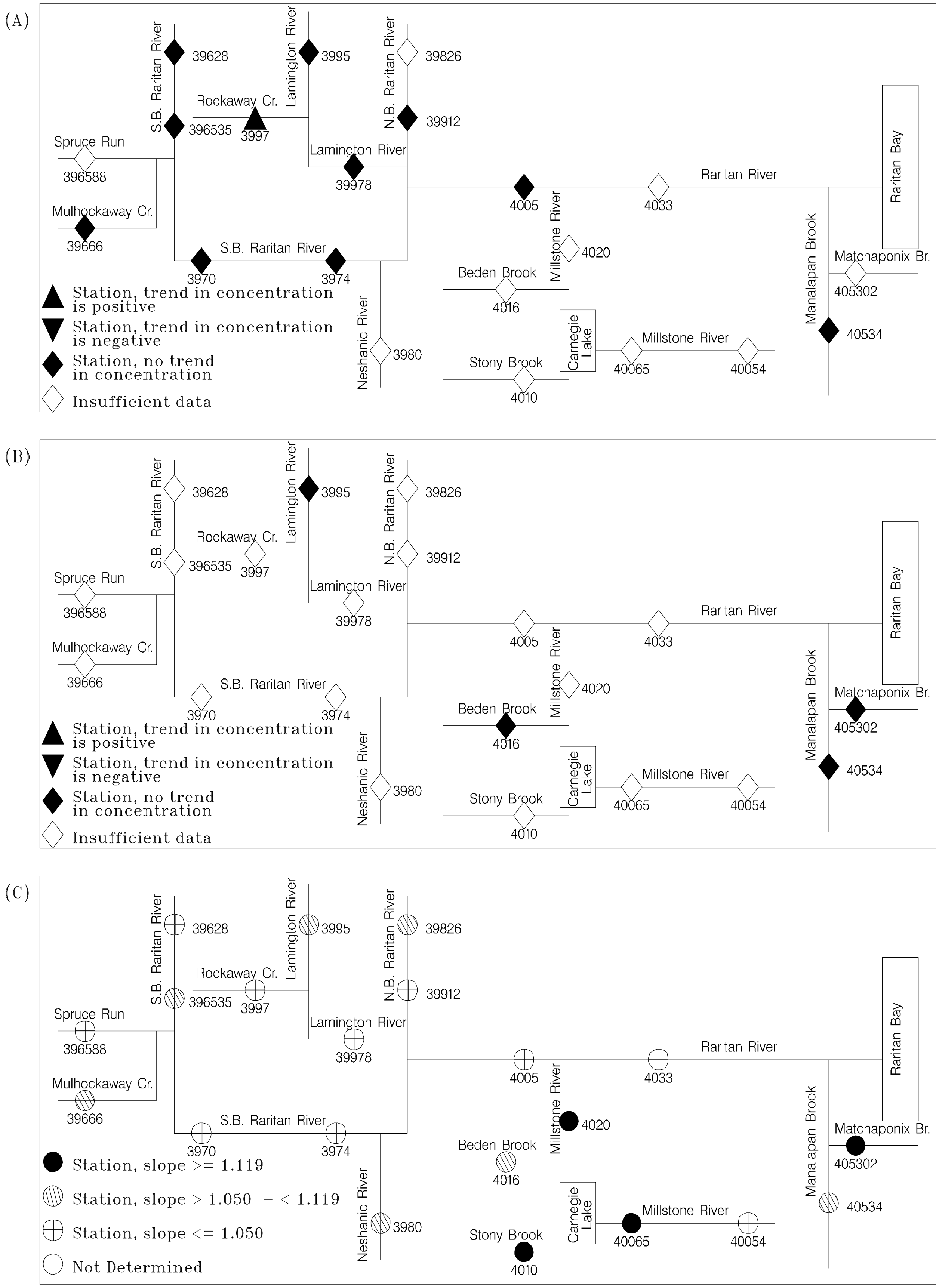


Figure 14. Trends in dissolved oxygen concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of dissolved oxygen load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

calculation of the fraction of dissolved oxygen at saturation removes the effect of temperature on oxygen solubility so that the effects of photosynthesis on DO concentration are easier to evaluate. Loads of percent dissolved oxygen saturation were not calculated.

Relation of trends in concentration to flow conditions

No trends are apparent for fraction of dissolved oxygen at saturation during high flows at all stations on South Branch Raritan River (39628, 396535, 3970, and 3974), the downstream station on North Branch Raritan River (39912), the stations on Rockaway Creek (3997) and Manalapan Brook (40534), the downstream station on Lamington River (39978), and the upstream station on Raritan River (4005) (fig. 15a). The trend in fraction of dissolved oxygen at saturation during low flows is positive at the one station on the Matchaponix Brook (405302). No trends are apparent at the upstream station on the Lamington River (3995) and the one station on Beden Brook (4016) (fig. 15b).

Total Phosphorus

Phosphorus is present in surface water as orthophosphates, condensed phosphates (pyro-, meta-, and other polyphosphates), and organically bound phosphates (Sawyer and McCarty, 1978). Phosphates are found in solution, associated with particles, in detritus, and in the bodies of aquatic organisms. They are derived from a variety of sources and are relatively immobile in soils and sediments (Hem, 1985). Phosphorus is a rather common element in igneous rock and is fairly abundant in sediment. Orthophosphates applied to agricultural or residential land as fertilizers can be carried into surface water with storm runoff. Phosphorus is an essential nutrient and can limit the primary productivity of a water body. Primary productivity is a measure of the rate at which new organic matter is formed and accumulated through photosynthetic and chemosynthetic activity of producer organisms (chiefly, green plants) (Bauersfeld and others, 1994). The addition of phosphorus to surface water from storm runoff and the discharge of treated wastewater, agricultural drainage, or certain industrial wastes to the water can stimulate the growth of photosynthetic aquatic micro- and macro-organisms in nuisance quantities.

Relation of trends in concentration to flow conditions

The trend of total phosphorus concentrations during high flows is positive at the downstream station on South Branch Raritan River (3974), indicating an increase in the contribution from storm runoff through time at this station (fig. 16a). The concentrations of total phosphorus show no trends during low flows at the one station on the Manalapan Brook (40534) (fig. 16b).

Relation of load to streamflow

The range categories of regression slopes of total phosphorus load to streamflow are depicted in figure 16c. The slopes range from 0.370 at the farthest upstream station on South Branch Raritan River (39628) (table 5a) to 1.302 at station 39666 on Mulhockaway Creek (table 10a). The slopes are in the high range at the stations on the Mulhockaway Creek (39666), Neshanic River (3980), Rockaway Creek (3997), and Matchaponix Brook (405302), and the farthest upstream station on Millstone River (40054). At these stations, the contributions to instream total phosphorus loads from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. Slopes are in the low range at the upstream

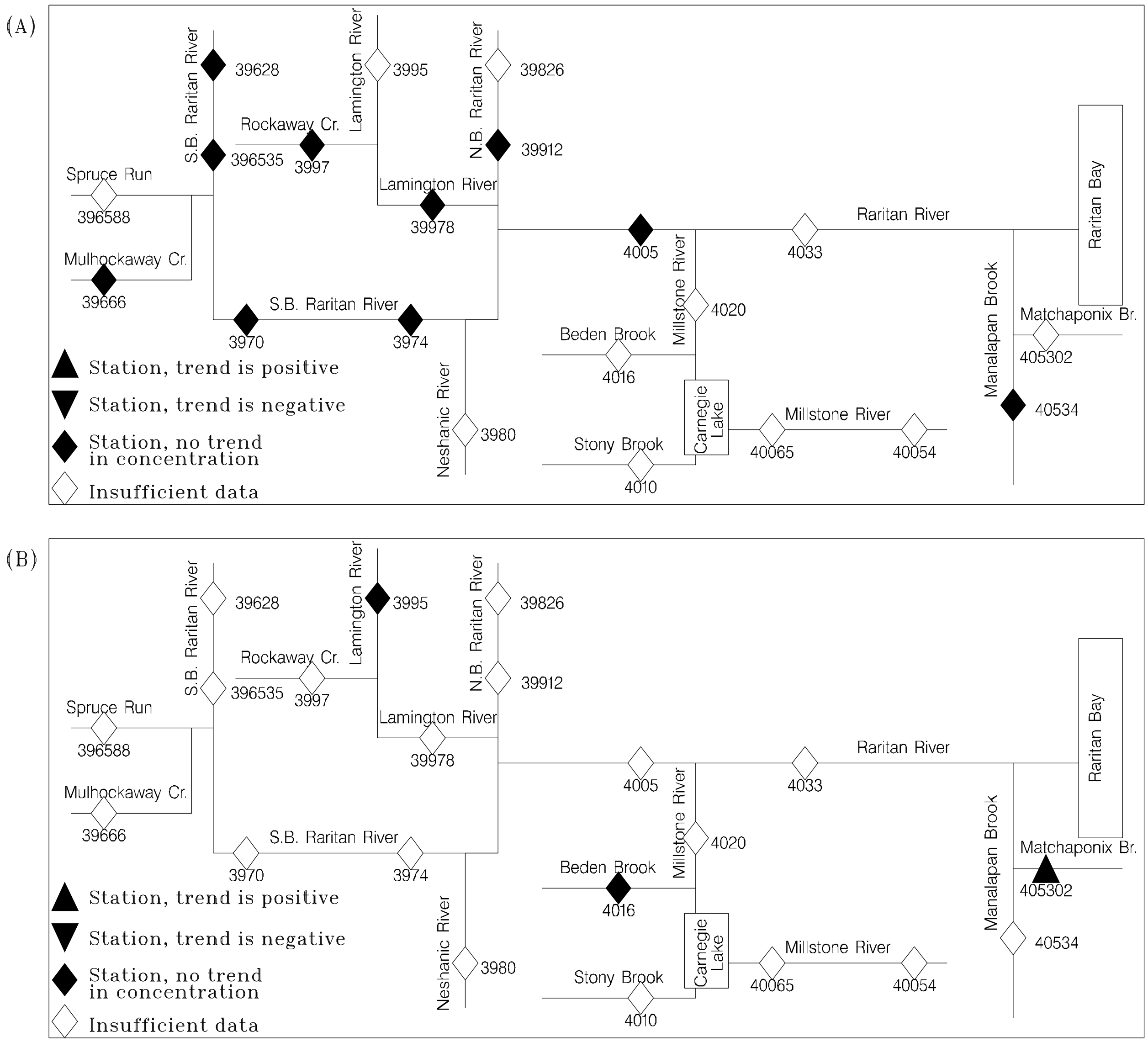


Figure 15. Trends in fraction of dissolved oxygen at saturation during (A) high- and (B) low-flow conditions at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

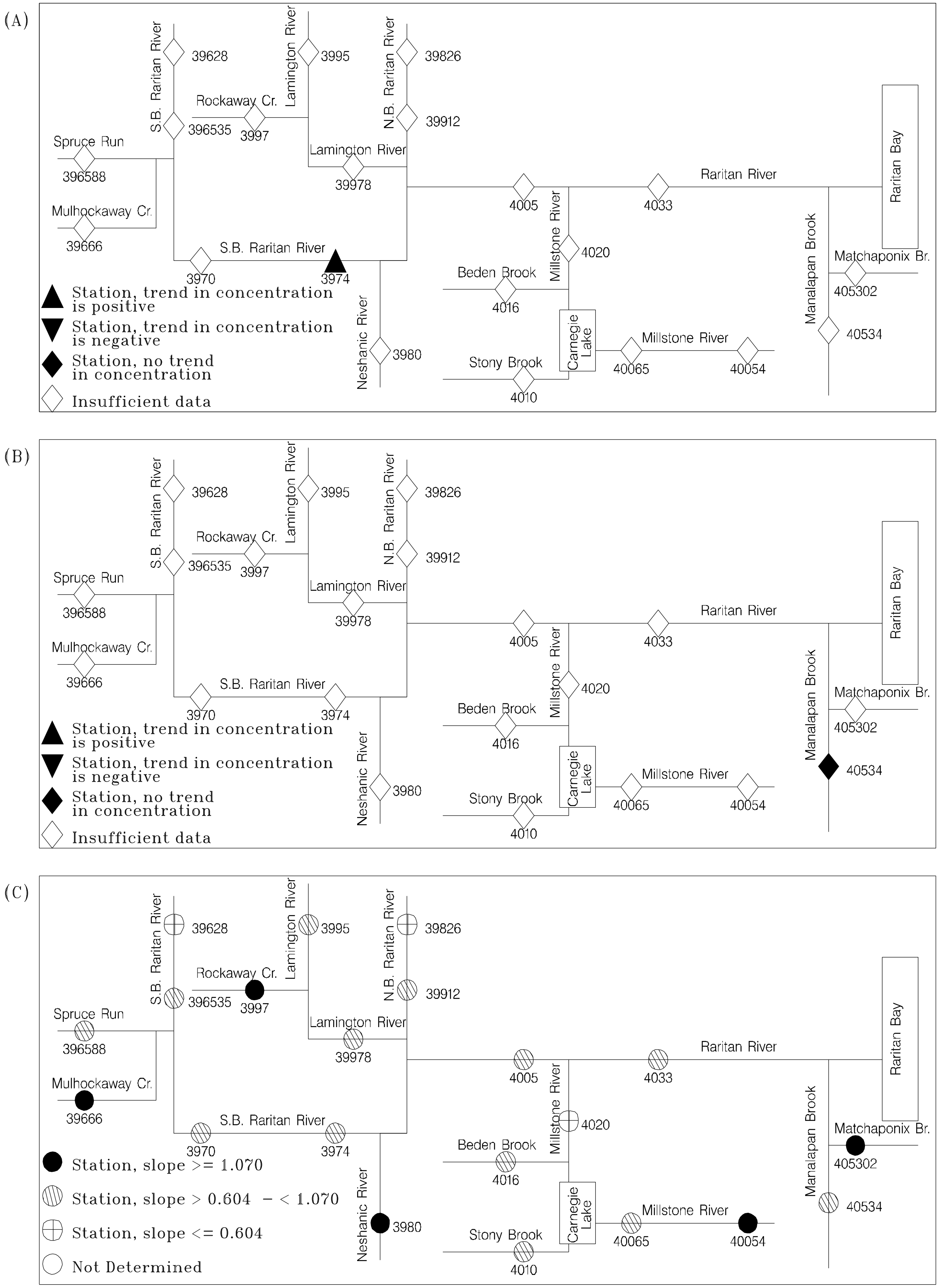


Figure 16. Trends in total phosphorus concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total phosphorus load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

stations on South Branch (39628) and North Branch (3983) Raritan Rivers and the farthest downstream station on Millstone River (4020). At these sites, the contributions to instream total phosphorus loads from point sources and ground water are larger and less influenced by storm runoff than at other sites in the study area. Slopes at stations on South Branch and North Branch Raritan Rivers increase in the downstream direction, indicating an increase in the contributions from storm runoff along the rivers. Slopes at stations on Millstone and Raritan Rivers decrease in the downstream direction, indicating a decrease in the contributions from storm runoff along the rivers.

Total Nitrogen

Nitrogen is an essential element for plant and animal growth; however, sufficiently large concentrations of certain nitrogen species can adversely affect the quality of surface water by causing excess algal growth (eutrophication) or toxicity to aquatic and terrestrial animals. Important forms of nitrogen in surface water are, in order of decreasing oxidation state, nitrate, nitrite, ammonia, and organic nitrogen. The cycling of nitrogen is mainly controlled by biological processes. Nitrogen enters aquatic environments from fertilizers, agricultural wastes, decomposition of organic matter, atmospheric deposition, biotic fixation, and ambient soils and rocks. Ground water and storm runoff are important sources of nitrate and ammonia to surface water. High concentrations of nitrate and nitrite can reduce the oxygen-carrying capacity of hemoglobin in warm-blooded animals. Un-ionized ammonia can be toxic to aquatic organisms.

Relation of trends in concentration to flow conditions

The concentrations of total nitrogen show no trends during high flows at the farthest upstream (39628) and third farthest downstream (3970) stations on South Branch Raritan River, the stations on Mulhockaway Creek (39666) and Lamington River (3995), and the downstream station on North Branch Raritan River (39912) (fig. 17a). During low flows, the trend in total nitrogen concentrations is positive at the station on the Matchaponix Brook (405302), indicating an increase in the contributions from point sources and ground water through time at this station (fig. 17b). Total nitrogen concentrations during low flows show no trend at the stations on Lamington River (3995) and Manalapan Brook (40532).

Relation of load to streamflow

The range categories of regression slopes of total nitrogen load to streamflow are shown in figure 17c. The slopes range from 0.628 at station 405302 on Matchaponix Brook (table 24a) to 1.311 at station 3980 on Neshanic River (table 11a). Slopes are in the high range at the stations on Neshanic River (3980), Stony (4010) and Manalapan (40534) Brooks, and the upstream station on Raritan River (4005). At these sites, the contributions to instream total nitrogen loads from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The slope is in the low range at the upstream stations on South Branch (39628) and North Branch (3982) Raritan Rivers and the one station on Matchaponix Brook (405302). At these sites, the contributions to the instream total nitrogen load from point sources and ground water are larger and less influenced by storm runoff than at other sites in the study area. Slopes at stations on South Branch and North Branch Raritan Rivers increase in the downstream direction, indicating an increase in the contributions from storm runoff along the rivers. Slopes at stations on the Raritan River decrease in the downstream direction, indicating a decrease in the contributions from storm runoff along the river.

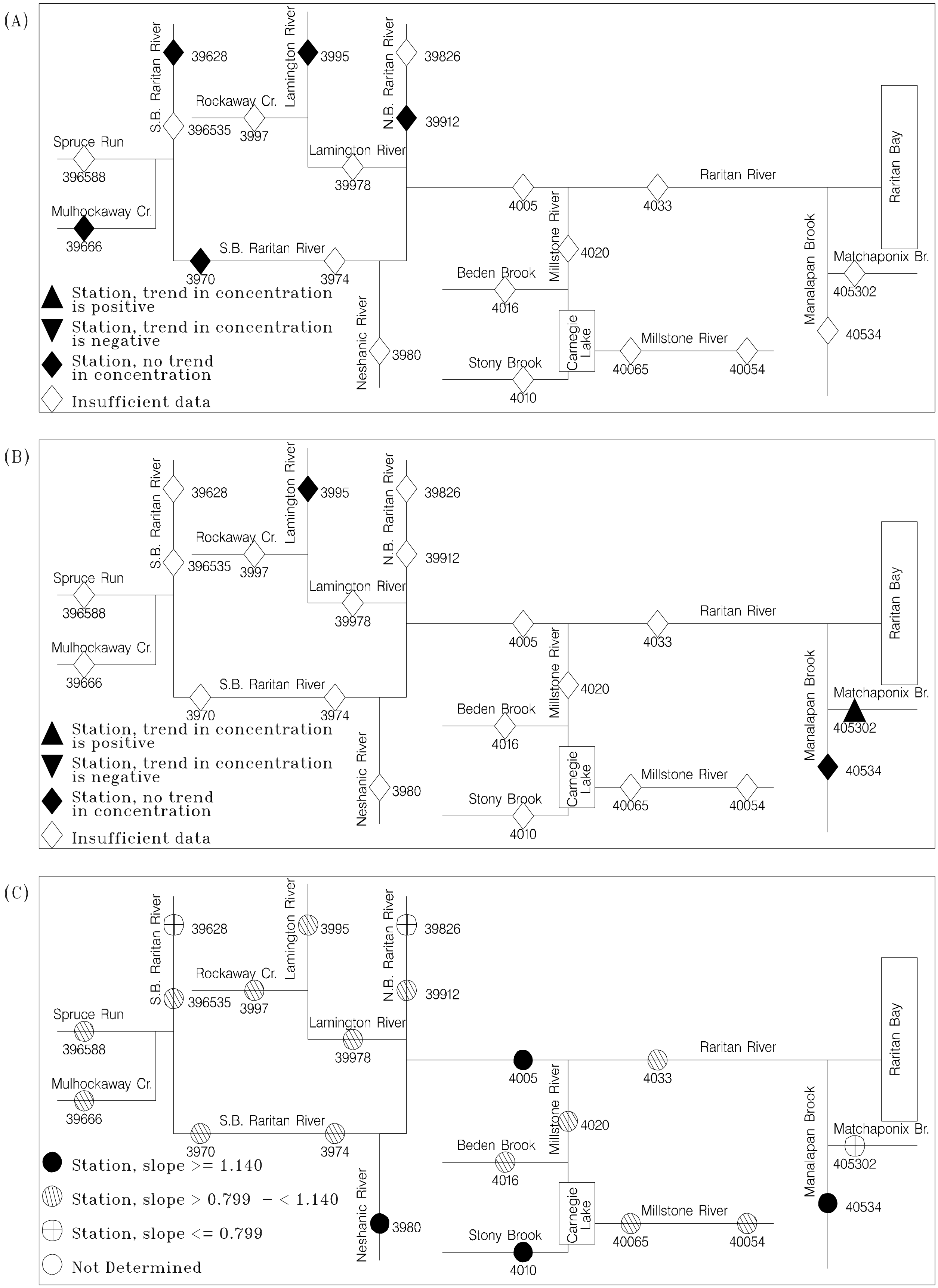


Figure 17. Trends in total nitrogen concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total nitrogen load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

Total Nitrate Plus Nitrite

Total oxidized nitrogen concentration is the sum of the nitrate and nitrite concentrations. Nitrite is an intermediate oxidation state of nitrogen. Nitrite is usually present in trace amounts in surface water because it is rapidly oxidized to nitrate and is generally considered to be an indicator of the presence of sewage or organic waste (low DO conditions). Nitrite can enter surface water in discharge from wastewater-treatment plants and water-reuse systems in fish culture facilities where the nitrification process to reduce ammonia concentrations is impaired (Rand and Petrocelli, 1985). Nitrite is the etiologic agent of methemoglobinemia in humans and fish. Under specific conditions, nitrite is involved in the formation of some carcinogenic nitrosamines. Nitrate is an essential nutrient for many photosynthetic autotrophs and, in some cases, has been identified as the growth-limiting nutrient. It is present generally in trace amounts in surface water, but can attain high levels in some ground-water systems (Hem, 1985). Nitrate fertilizers applied to agricultural and residential land, then carried to surface water by storm runoff and ground water, can stimulate the growth of photosynthetic aquatic micro- and macro-organisms. Nitrate is considerably less toxic to aquatic organisms than are ammonia and nitrite; however, in excess amounts (>10 mg/L), nitrate contributes to methemoglobinemia in small children and fish.

<u>Relation of trends in concentration to flow conditions</u>

The trend in total nitrate plus nitrite concentrations during high flows is positive at the one station on the Rockaway Creek (3997), indicating an increase in the contribution from storm runoff through time at this station (fig. 18a). The concentrations of total nitrate plus nitrite show no trends during high flows at the farthest upstream station (39628) and third farthest downstream (3970) station on South Branch Raritan River, the stations on Mulhockaway Creek (39666) and Lamington River (3995), and the downstream station on North Branch Raritan River (39912). The trend in total nitrate plus nitrite concentrations during low flows is positive at the station on Matchaponix Brook (405302), indicating an increase in the contributions from point sources and ground water through time at this site (fig. 18b). Discharge from wastewater-treatment plants in which the organic nitrogen is almost entirely oxidized can result in increased nitrate plus nitrite concentrations in the receiving streams. Also during low flows, the concentrations of total nitrogen show no trends at the upstream station on Lamington River (3995) and the one station on the Manalapan Brook (40534).

<u>Relation of load to streamflow</u>

The range categories of regression slopes of total nitrate plus nitrite load to streamflow are depicted in figure 18c. The slopes range from 0.504 at the upstream station on North Branch Raritan River (39826) (table 12a) to 1.764 at station 4010 on Stony Brook (table 22a). Slopes are in the high range at the stations on Neshanic River (3980) and Stony Brook (4010) where the contributions to instream total nitrate plus nitrite loads from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The slope is in the low range at the upstream stations on South Branch (39628) and North Branch (39862) Raritan Rivers, the stations on the Rockaway Creek (3997) and Matchaponix Brook (405302), and the second farthest downstream station on the Millstone River (40065). At these sites, the contributions to instream total nitrate plus nitrite loads from point sources and ground water are

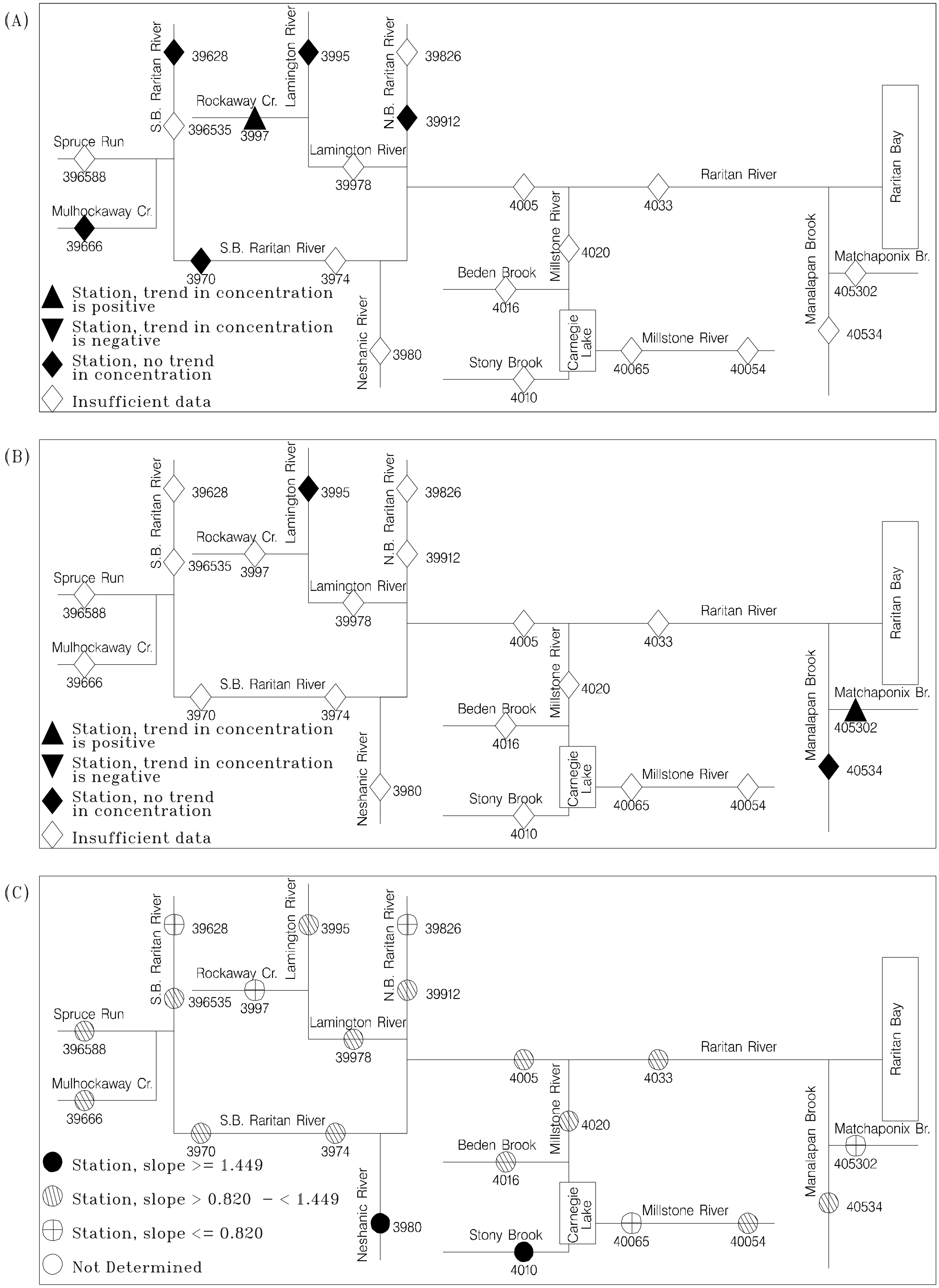


Figure 18. Trends in total nitrate plus nitrite concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total nitrate plus nitrite load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

larger and less influenced by storm runoff than at other sites in the study area. Slopes at stations on South Branch and North Branch Raritan Rivers increase in the downstream direction, indicating an increase in the contributions from storm runoff along the rivers.

Total Nitrite

Nitrite is an intermediate oxidation state of nitrogen, both in the oxidation of ammonia to nitrate and in the reduction of nitrate. Nitrite species are unstable in aerated water and are generally considered to be indicators of the presence of sewage or organic waste (low DO conditions). Nitrite is the etiologic agent of methemoglobinemia.

Relation of trends in concentration to flow conditions

During high flows, no trend was determined at the one station on the Rockaway Creek (3997) (fig. 19a). Insufficient data are available to determine trends in total nitrite concentrations during low flows at all stations in the study area (fig. 19b).

Relation of load to streamflow

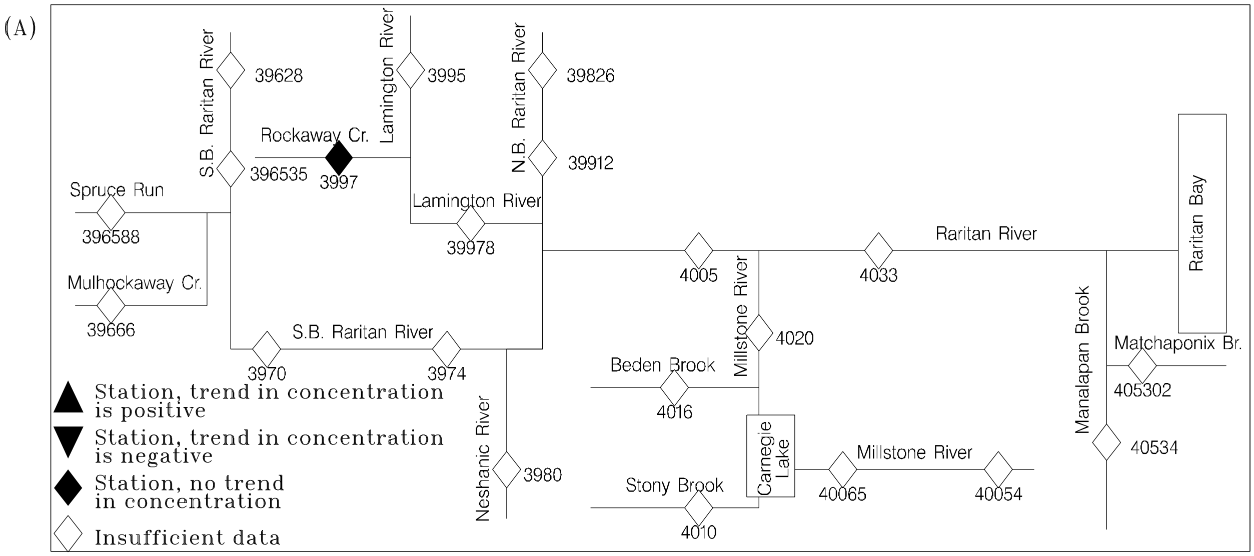
The range categories of regression slopes of total nitrite load to streamflow are depicted in figure 19c. The slopes range from zero at the upstream station on North Branch Raritan River (39826) (table 12a) to 1.291 at station 39666 on Mulhockaway Creek (table 10a). The slopes are in the high range at the stations on Spruce Run (396588), Mulhockaway Creek (39666), Neshanic River (3980), North Branch Raritan River (39912), Millstone River (40054), Stony Brook (4010), and Manalapan Brook (40534), and the upstream stations on Raritan River (4005) and Lamington River (3995). At these sites, the contributions to instream total nitrite loads from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The slope is in the low range at the upstream station on North Branch Raritan River (39826) where the contribution to instream total nitrite loads from storm runoff is smaller and more influenced by point sources and ground water than at other sites in the study area.

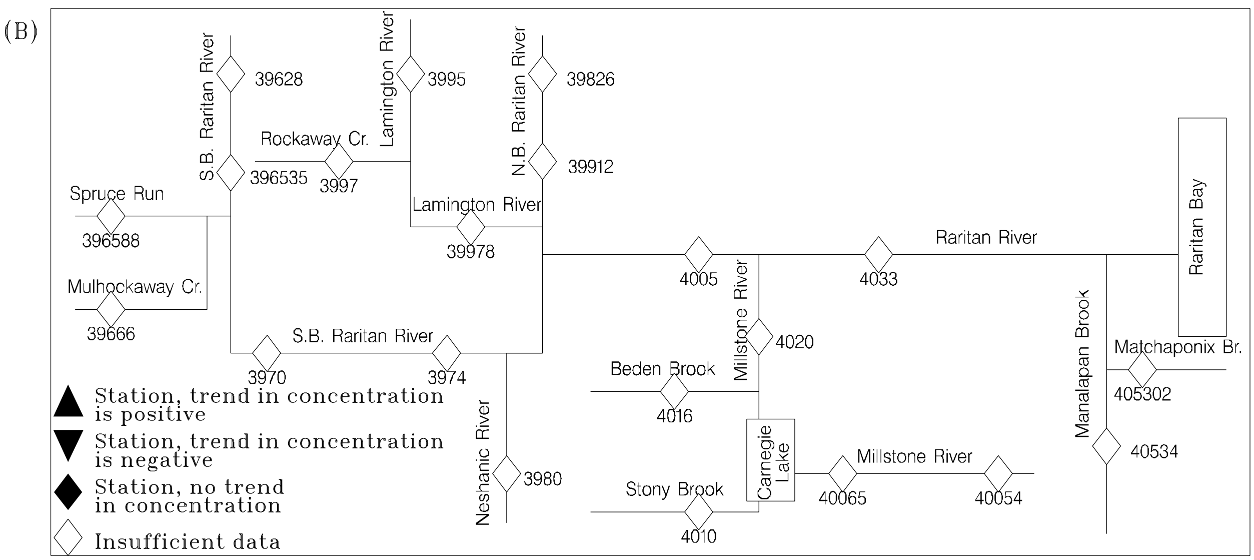
Total Ammonia Plus Organic Nitrogen

Organic nitrogen is defined as organically bound nitrogen in the tri-negative oxidation state. It includes natural materials, such as proteins and peptides, nucleic acids, and urea, and numerous synthetic organic materials, but does not include all organic nitrogen compounds. Ammonia is produced by the deamination of organic nitrogen-containing compounds. Ammonia can enter surface water dissolved in wastewater effluent, storm runoff, and rain. Temperature, pH, and ionic strength control the speciation of ammonia in surface water. The un-ionized form of ammonia is toxic to fish. The total ammonia plus organic nitrogen concentrations are determined together by the kjeldahl method (Eaton and others, 1995).

Relation of trends in concentration to flow conditions

The trends in total ammonia plus organic nitrogen concentrations during high flows are negative at the two upstream stations on South Branch Raritan River (39628 and 396535) and the upstream station on Lamington River (3995), indicating a decrease in the contribution from storm runoff through time at these stations (fig. 20a). The concentrations of total ammonia plus organic





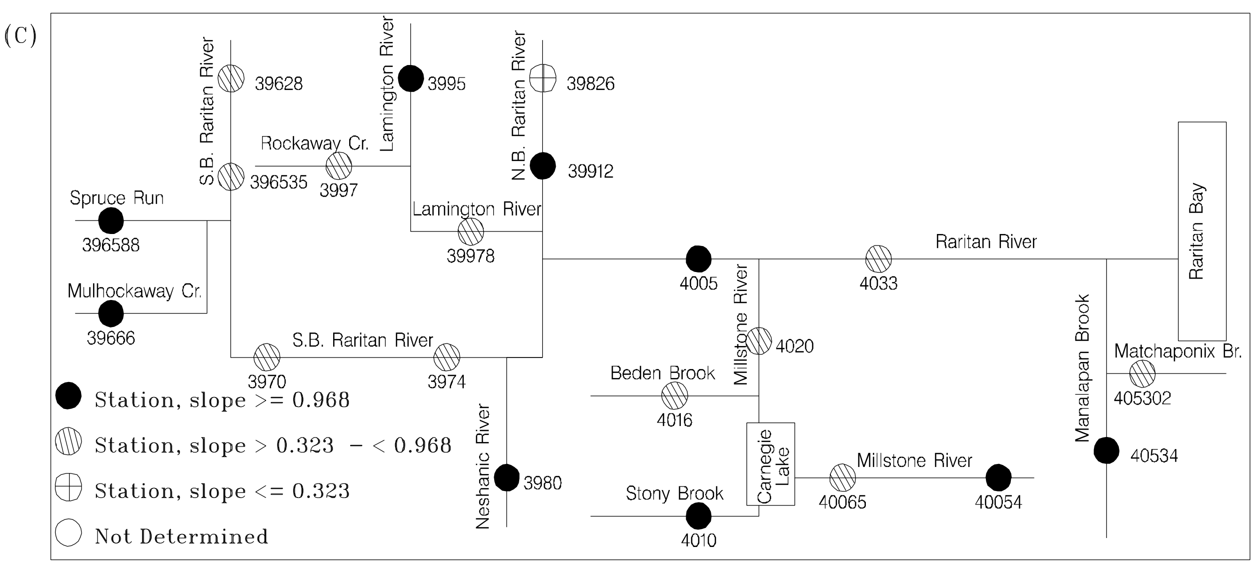


Figure 19. Trends in total nitrite concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total nitrite load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

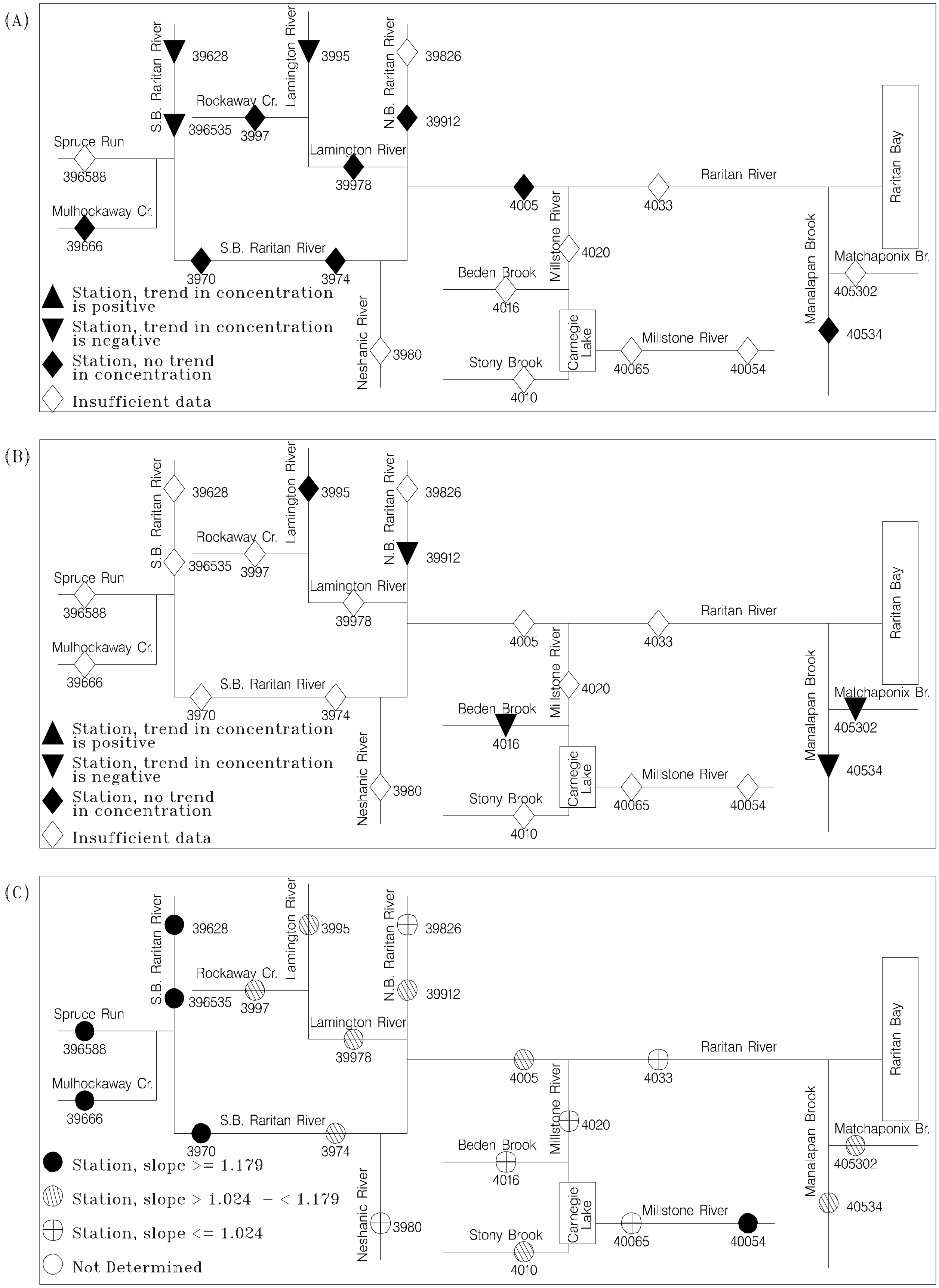


Figure 20. Trends in total ammonia plus organic nitrogen concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total ammonia plus organic nitrogen load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

nitrogen during high flows show no trends at the two farthest downstream stations on South Branch Raritan River (3970 and 3974); the downstream station on North Branch Raritan River (39912); the stations on Mulhockaway Creek (39666), Rockaway Creek (3997), and Lamington River (39978); and the upstream station on Raritan River (4005). The trends in total ammonia plus organic nitrogen concentrations during low flows are negative at the downstream station on North Branch Raritan River (39912) and the stations on the Beden (4016), Matchaponix (405302), and Manalapan (40532) Brooks (fig. 20b). The contributions from point sources and ground water decreased through time at these stations. The concentrations of total ammonia plus organic nitrogen during low flows show no trend at the upstream station on Lamington River (3995).

<u>Relation of load to streamflow</u>

The range categories of regression slopes of total ammonia plus total organic nitrogen load to streamflow are depicted in figure 20c. The slopes range from 0.947 at station 3980 on Neshanic River (table 11a) to 1.257 at station 396588 on Spruce Run (table 9a). The slopes are in the high range at the three farthest upstream stations on South Branch Raritan River (39628, 396535, and 3970), the stations on Spruce Run (396588) and Mulhockaway Creek (39666), and the upstream station on Millstone River (40054). At these sites, the contributions to instream loads from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The slopes are in the low range at the stations on Neshanic River (3980) and Beden Brook (4016), the upstream station on North Branch Raritan River (39826), and the downstream stations on Millstone (40065 and 4020) and Raritan (4033) Rivers. At these sites, however, the contributions to instream total ammonia plus total organic nitrogen loads from constant sources probably are relatively insignificant because the load-to-streamflow slopes are large (greater than 0.8). Storm runoff most likely is the dominant contributor of total ammonia plus total organic nitrogen in the study area because the load-to-streamflow slopes at all stations are large.

Total Ammonia

Ammonia is produced largely by deamination of organic nitrogen-containing compounds and by hydrolysis of urea. Ammonia can enter surface water by wet deposition with industrial, municipal, and agricultural waterwaste and runoff, especially from areas treated with ammonia fertilizers. At some water-treatment plants, ammonia is added to react with chlorine to form a combined chlorine residual. Contributions of ammonia to surface water from ground water are usually small because ammonia can adsorb to soil particles and clays and does not leach from soils (Hem, 1985).

The toxicity of ammonia to fish is dependent on its speciation. Un-ionized ammonia is considered to be the toxic form to aquatic organisms (Rand and Petrocelli, 1985). The relative concentrations of ionized (NH_4^+) and un-ionized (NH_3) ammonia are a function of the pH, temperature, and ionic strength of the aqueous solution. When the pH, temperature, and total ammonia concentration are measured in a solution, the relative concentrations of NH_3 and NH_4^+ can be calculated. Decreased dissolved oxygen concentrations can cause an increase in ammonia toxicity.

Relation of trends in concentration to flow conditions

The trend in total ammonia concentrations during low flows is negative at the second farthest downstream station on South Branch Raritan River (396535), indicating a decrease in the contribution from storm runoff through time at this station (fig. 21a). The total ammonia concentrations during high flows show no trends at the farthest upstream (39628) and third farthest downstream (3970) stations on South Branch Raritan River, the upstream station on Lamington River (3995), and the station on Rockaway Creek (3997) (fig. 21a). The trends in total ammonia concentrations during low flows are negative at the stations on Matchaponix (405302) and Manalapan (40534) Brooks, indicating a decrease in the contribution from point sources and ground water through time at these stations (fig. 21b). Total ammonia concentrations during low flows show no trends at the downstream station on North Branch Raritan River (39912) and the upstream station on the Lamington River (3995).

Relation of load to streamflow

The range categories of regression slopes of total ammonia load are depicted in figure 21c. The slopes range from 0.852 at station 4016 on the Beden Brook (table 23a) to 1.294 at the farthest upstream station on South Branch Raritan River (39628) (table 5a). The slopes are in the high range at the two farthest upstream stations on the South Branch Raritan River (39628 and 396535); the downstream station on North Branch Raritan River (39912); the upstream station on Lamington River (3995); the stations on Rockaway Creek (3997) and Manalapan Brook (40534); and the two upstream stations on Millstone River (40054 and 40065). At these sites, the contributions to instream total ammonia load from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The slopes are in the low range at the upstream station on North Branch Raritan River (39826) and the stations on Stony (4020) and Beden (4016) Brooks. At these sites, however, the contributions to instream total ammonia loads from constant sources probably are relatively insignificant because the load-to-streamflow slopes are large (greater than 0.8). Storm runoff most likely is the dominant contributor of total ammonia in the study area because the load-to-streamflow slopes at all stations are large. Slopes at stations on South Branch Raritan and Millstone Rivers decrease in the downstream direction, indicating a decrease in the contributions from storm runoff along the rivers. Slopes on North Branch Raritan River increase in the downstream direction, indicating an increase in the contributions from storm runoff along the river.

Total Boron

Boron is a minor constituent in most surface water. Small amounts of boron are essential for plant growth. Boron minerals are present in some igneous rocks; water in volcanic areas and thermal springs may contain considerable concentrations of boron (Hem, 1985). Boron from the cleaning agent, sodium tetraborate (borax), can be present in surface water as a result of the release of treated sewage and industrial-use water.

Relation of trends in concentration to flow conditions

Insufficient data are available to determine trends in boron concentrations during high and low flows at all stations in the study area (figs. 22a and b).

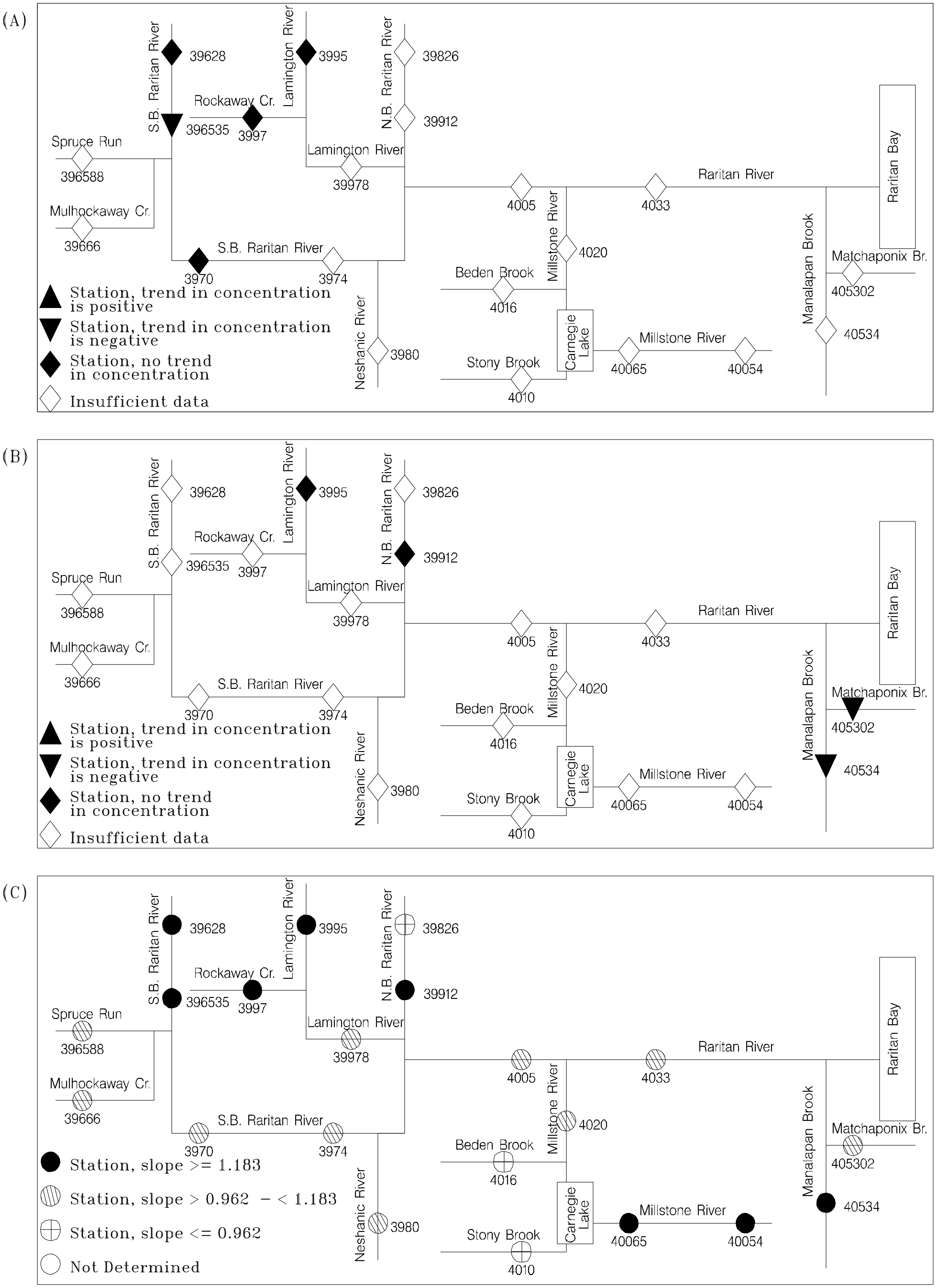


Figure 21. Trends in total ammonia concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total ammonia load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

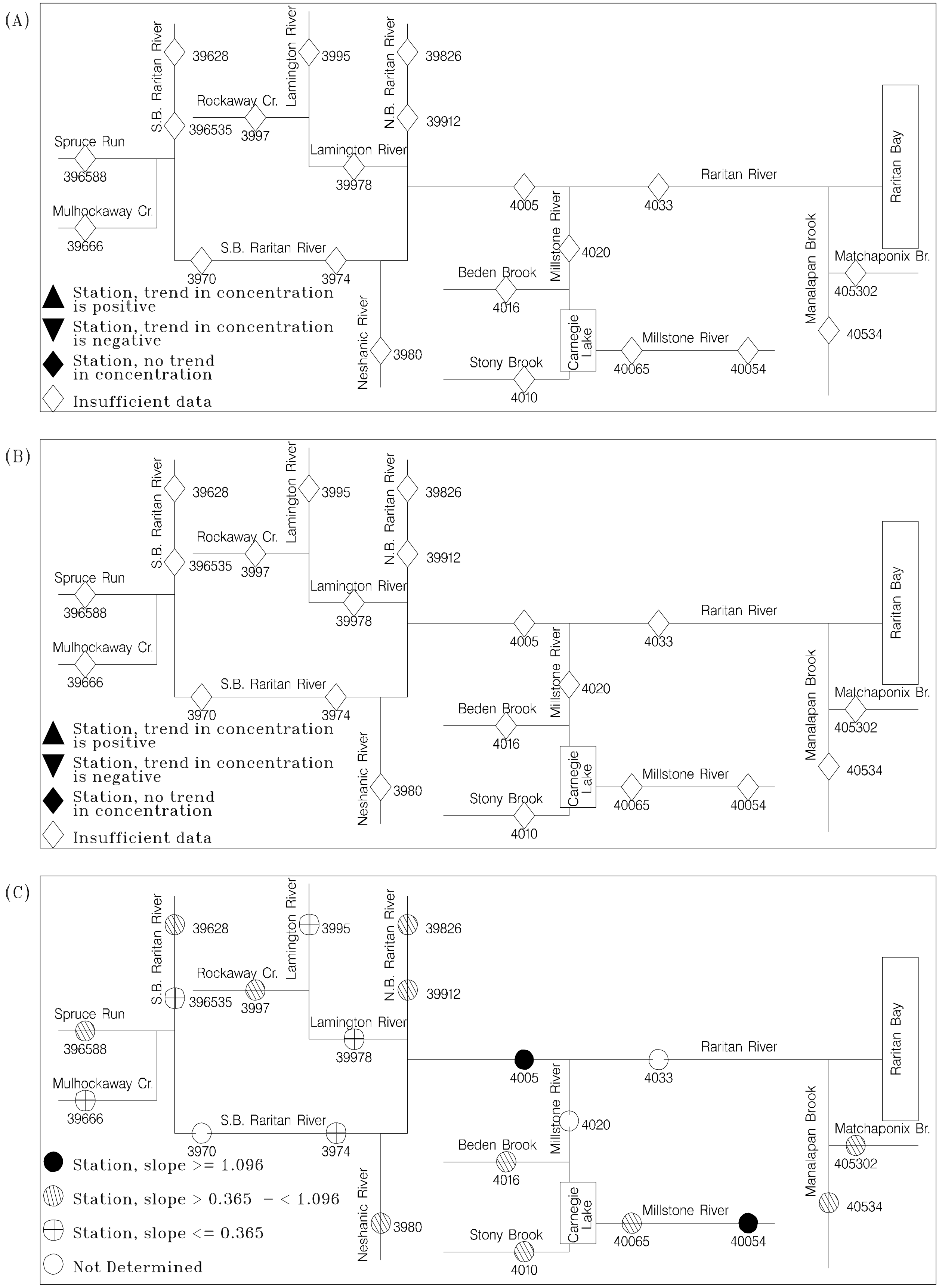


Figure 22. Trends in total boron concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total boron load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

Relation of load to streamflow

The range categories of regression slopes of total boron to streamflow are depicted in figure 22c. Insufficient data are available to determine slopes at three stations--3970 on South Branch Raritan River, 4020 on Millstone River, and 4033 on Raritan River. The slopes range from zero at two stations on South Branch Raritan River (396535 and 3974), two stations on Lamington River (39978 and 3995), and one station on Mulhockaway Creek (39666) to 1.462 at the farthest upstream station on Millstone River (40054). The slopes are in the high range at station 40054 on Millstone River and station 4005 on Raritan River, indicating that contributions to instream boron load from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The five stations with zero slopes have slopes in the low range, indicating that the contributions to instream total boron loads from point sources and ground water are larger and less influenced by storm runoff at these sites than at other sites in the study area.

Total Lead

Lead is occasionally present in surface water in trace amounts, which can be toxic to aquatic organisms. Lead is widely dispersed in sedimentary rocks; however, its mobility is low (Hem, 1985). The many uses of lead have dispersed the element throughout the environment. Dry fallout and rain-out of particulate lead is probably a factor of major importance in the circulation of the element. Concentrations of lead in rain and snow are greater in areas subject to substantial air pollution than in more remote areas. Storm runoff is a potential source of lead in surface water.

Relation of trends in concentration to flow conditions

Insufficient data are available to determine trends in lead concentrations during high and low flows at all stations in the study area (figs. 23a and 23b).

Relation of load to streamflow

The range categories of regression slopes of total lead to streamflow are depicted in figure 23c. Insufficient data are available to determine slopes at three stations--3995 on Lamington River, 40534 on Manalapan Brook, and the downstream station on Raritan River (4033). The slopes range from zero at the third farthest downstream station on South Branch Raritan River (3970) (table 7a) to 1.892 at the farthest upstream station on Millstone River (40054) (table 19a). The slopes are in the high range at the second farthest upstream station (396535) and the farthest downstream station (3974) on South Branch Raritan River, station 39978 on Lamington River, both stations on North Branch Raritan River (39826 and 39912), and the farthest upstream station on Millstone River (40054). At these sites, contributions to instream total lead load from storm runoff are larger and less influenced by point sources and ground water than at other sites in the study area. The slope is in the low range at the third farthest downstream station on South Branch Raritan River (3970) where the contributions to instream total lead loads from point sources and ground water are larger and less influenced by storm runoff than at other sites in the study area.

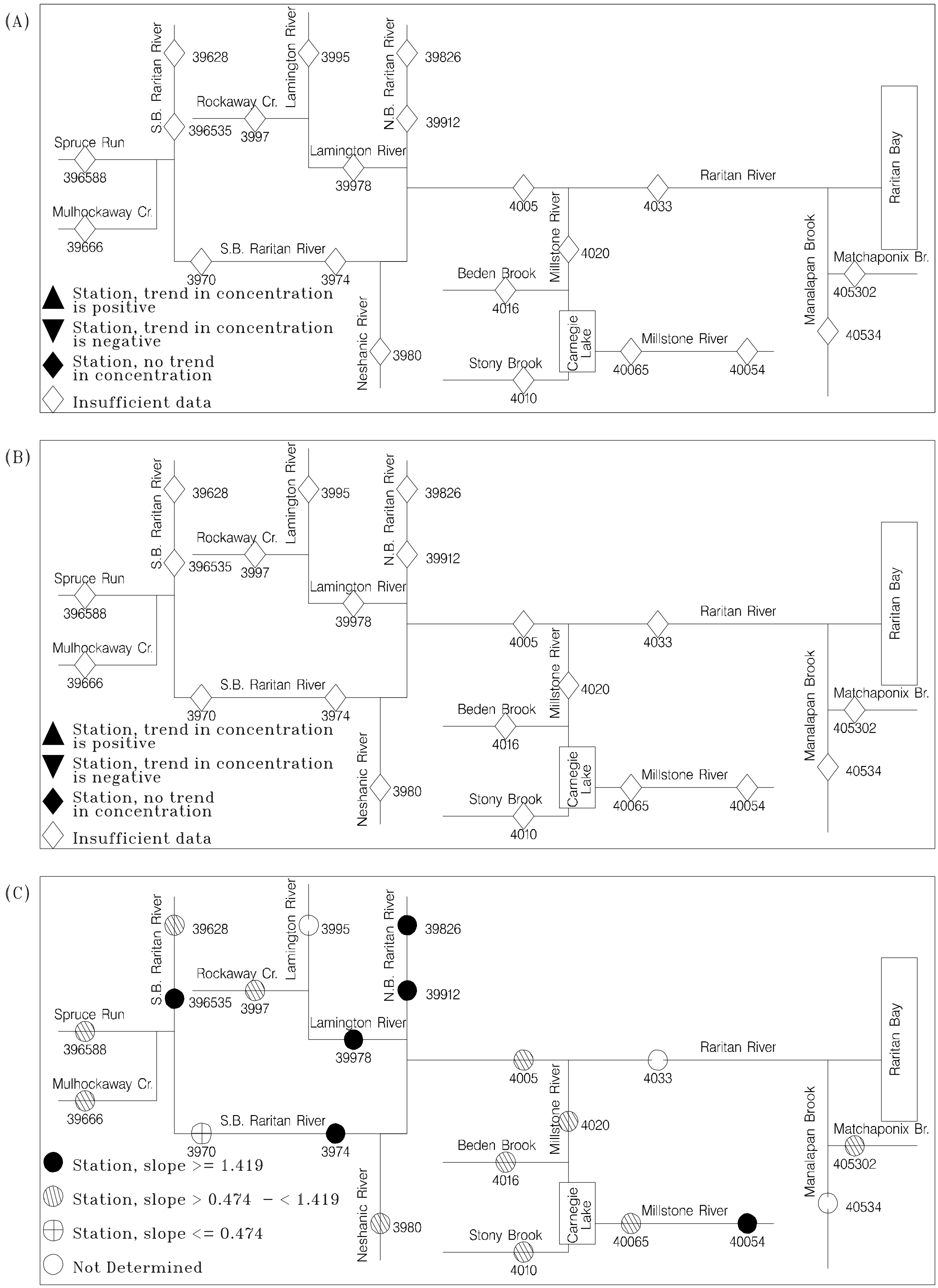


Figure 23. Trends in total lead concentrations during (A) high- and (B) low-flow conditions, and (C) relative slope of total lead load to streamflow at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

Fecal Coliform Bacteria

Fecal coliform bacteria are present in the intestine and feces of warm-blooded animals. The presence of high numbers of fecal coliform bacteria in surface water can indicate the recent release of untreated wastewater or the presence of animal feces, or both. These organisms also can indicate the presence of pathogens that are harmful to humans. High numbers of fecal coliform bacteria can render surface water unfit for some uses, such as swimming and fishing. Fecal coliform bacteria are often used as indicators of the sanitary quality of the water (Eaton and others, 1995). For laboratory purposes, fecal coliform bacteria are defined as all organisms that produce blue colonies within 24 hours when incubated at 44.5 °C ± 0.2 °C on M-FC medium (nutrient medium for bacterial growth) (Bauersfeld and others, 1994).

Relation of trends in concentration to flow conditions

The fecal coliform bacteria concentrations during high flows show no trends at all stations on South Branch Raritan River (39628, 396535, 3970, and 3974); the stations on Mulhockaway Creek (39666), Lamington River (3995 and 39978), Rockaway Creek (3997), and Manalapan Brook (40534); the downstream station on North Branch Raritan River (39912); and the upstream station on Raritan River (4005) (fig. 24a). The fecal coliform bacteria concentrations during low flows show no trends at the stations on Lamington River (3995) and Beden (4016), Matchaponix (405302), and Manalapan (40534) Brooks (fig. 24b).

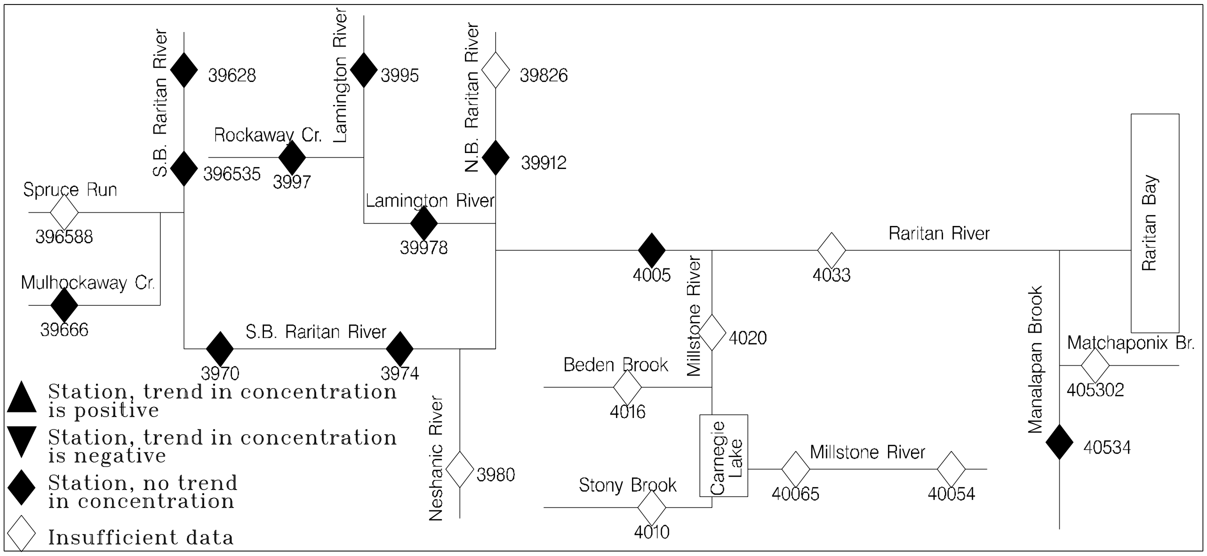
COMPARISON OF RESULTS

Positive trends in constituent concentrations through time during low flows indicate increasing constant-rate source contributions for HARD and DS at stations 39912 on North Branch Raritan River and 405302 on Matchaponix Brook; for NA and CL at stations 39912, 405302, 4016 on Beden Brook, and 40534 on Manalapan Brook; and for FDO, TN, and NO32 at station 405302 (table 26). Negative trends during low flows indicate decreasing constant-rate source contributions for TOC at station 405302; for TAON at stations 39912, 4016, 405302 and 40534; and for NH4 at stations 405302 and 40534 (table 26).

Positive trends during high flows indicate increasing intermittent source contributions for HARD at stations 39628 and 396535 on South Branch Raritan River; for DS at station 396535; for NA at stations 39666 on Mulhockaway Creek, 39912 on North Branch Raritan River and 3997 on Rockaway Creek, and 40534; for CL at stations 39666 on Mulhockaway Creek, 3974 on South Branch Raritan River, 3997 on Rockaway Creek, 3995 and 39978 on Lamington River, and 40534; for DO at station 3997; for TP at station 3974; and for NO32 at station 3997 (table 27). Negative trends during high flows indicate decreasing intermittent source contributions for TOC at stations 39628 and 39666; for NH4 at station 396535; and for TAON at stations 39628, 396535, and 3995 (table 27).

Negative trends in TOAN and NH4 during low flows could result from an improvement in wastewater treatment during which the oxidized species of nitrogen are formed. NO32 shows positive trends during low flows at station 405302 on Matchaponix Brook, a further indication of the improving conditions of surface-water quality. Positive trends in low and high flows for NA and CL could be caused by an increase in road-salt application (Hay and Campbell, 1990, and Robinson and others,1996).

(A)



(B)

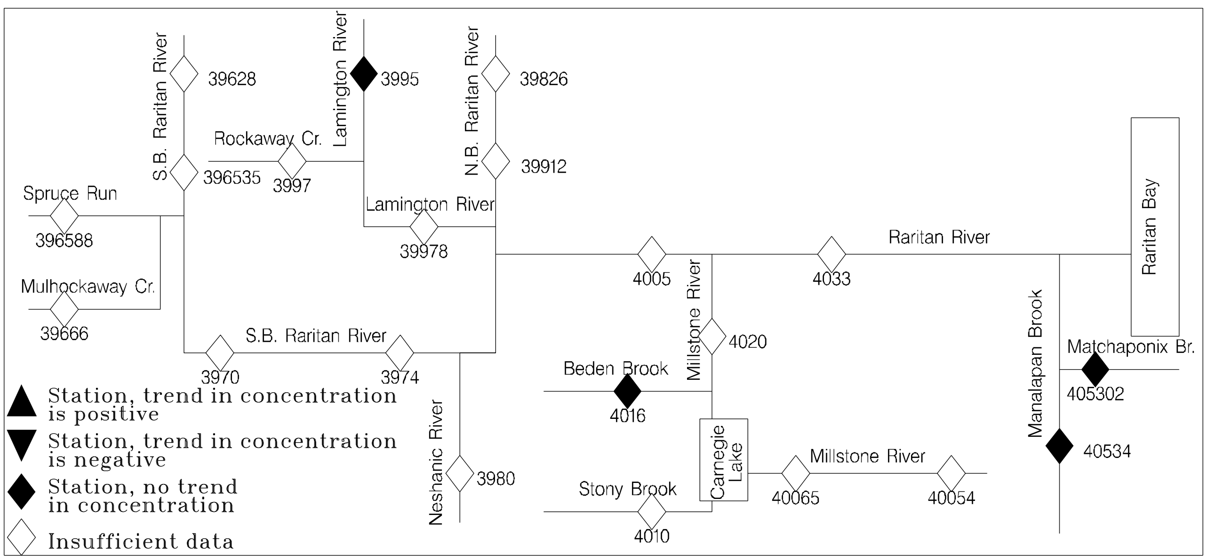


Figure 24. Trends in fecal coliform bacteria concentrations during (A) high- and (B) low-flow conditions, and at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93.

Table 26. Concentration trends during low flows at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93

[USGS, U.S. Geological Survey; No., number; ALK, alkalinity; HARD, hardness; TOC, total organic carbon; SS, suspended sediment; DS, dissolved solids; NA, sodium; CL, chloride; DO, dissolved oxygen; FDO, fraction of dissolved oxygen at saturation; TP, total phosphorus; TN, total nitrogen; NO32, nitrate plus nitrite; NO2, nitrite; TAON, total ammonia plus organic nitrogen; NH4, ammonia; B, boron, PB, lead; BACT, fecal-coliform bacteria; ↑, positive trend; ↓, negative trend; ↔, no trend (slope is not significant at the 0.05 level); -, insufficient data for analysis; --, no total]

River basin	USGS station number	ALK	HARD	TOC	SS	DS	NA	CL	DO	FDO	TP	TN	NO32	NO2	TAON	NH4	B	PB	BACT	No. of constituents with a positive trend	No. of constituents with a negative trend	No. of constituents with no trend
South Branch Raritan	01396280	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
	01396535	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Spruce Run	01396588	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Mulhockaway	01396660	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
South Branch Raritan	01397000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
	01397400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Neshanic	01398000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
North Branch Raritan	01398260	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
	01399120	-	↑	↔	-	↑	↑	↑	-	-	-	-	-	-	↓	↔	-	-	-	4	1	2
Lamington	01399500	-	-	↔	-	-	-	-	↔	↔	-	↔	↔	-	↔	↔	-	-	↔	0	0	8
Rockaway	01399700	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Lamington	01399780	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Raritan	01400500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Millstone	01400540	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
	01400650	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Stony	01401000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Beden	01401600	-	↔	↔	-	↔	↑	↑	↔	↔	-	-	-	-	↓	-	-	-	↔	2	1	6
Millstone	01402000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Raritan	01403300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Matchaponix	01405302	-	↑	↓	-	↑	↑	↑	↔	↑	-	↑	↑	-	↓	↓	-	-	↔	7	3	2
Manalapan	01405340	-	↔	↔	-	↔	↑	↑	↔	-	↔	↔	↔	-	↓	↓	-	-	↔	2	2	8
No. of stations with a positive trend		0	2	0	0	2	4	4	0	1	0	1	1	0	0	0	0	0	0	--	--	--
No. of stations with a negative trend		0	0	1	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0	--	--	--
No. of stations with no trend		0	2	4	0	2	0	0	4	2	1	2	2	0	1	2	0	0	4	--	--	--

Table 27. Concentration trends during high flows at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93

[USGS, U.S. Geological Survey; No., number; ALK, alkalinity; HARD, hardness; TOC, total organic carbon; SS, suspended sediment; DS, dissolved solids; NA, sodium; CL, chloride; DO, dissolved oxygen; FDO, fraction of dissolved oxygen at saturation; TP, total phosphorus; TN, total nitrogen; NO32, nitrate plus nitrite; NO2, nitrite; TAON, total ammonia plus organic nitrogen; NH4, ammonia; B, boron, PB, lead; BACT, fecal-coliform bacteria; ↑, positive trend; ↓, negative trend; ↔, no trend (slope is not significant at the 0.05 level); -, insufficient data for analysis; --, no total]

River basin	USGS station number	ALK	HARD	TOC	SS	DS	NA	CL	DO	FDO	TP	TN	NO32	NO2	TAON	NH4	B	PB	BACT	No. of constituents with a positive trend	No. of constituents with a negative trend	No. of constituents with no trend
South Branch Raritan	01396280	-	↑	↓	-	↔	↔	↔	↔	↔	-	↔	↔	-	↓	↔	-	-	↔	1	2	9
	01396535	-	↑	↔	-	↑	↔	↔	↔	↔	-	-	-	-	↓	↓	-	-	↔	2	2	6
Spruce Run	01396588	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Mulhockaway	01396660	-	↔	↓	-	↔	↑	↑	↔	↔	-	↔	↔	-	↔	-	-	-	↔	2	1	8
South Branch Raritan	01397000	-	-	-	-	-	-	-	↔	↔	-	↔	↔	-	↔	↔	-	-	↔	0	0	7
	01397400	-	↔	↔	-	↔	↔	↑	↔	↔	↑	-	-	-	↔	-	-	-	↔	2	0	8
Neshanic	01398000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
North Branch Raritan	01398260	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
	01399120	-	↔	↔	-	↔	↑	↔	↔	↔	-	↔	↔	-	↔	-	-	-	↔	1	0	10
Lamington	01399500	-	↔	↔	-	↔	↔	↑	↔	-	-	↔	↔	-	↓	↔	-	-	↔	1	1	9
Rockaway	01399700	-	↔	↔	-	↔	↑	↑	↑	↔	-	-	↑	↔	↔	↔	-	-	↔	4	0	8
Lamington	01399780	-	↔	↔	-	↔	↔	↑	↔	↔	-	-	-	-	↔	-	-	-	↔	1	0	8
Raritan	01400500	-	↔	↔	-	↔	↔	-	↔	↔	-	-	-	-	↔	-	-	-	↔	0	0	8
Millstone	01400540	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
	01400650	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Stony	01401000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Beden	01401600	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Millstone	01402000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Raritan	01403300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Matchaponix	01405302	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Manalapan	01405340	-	↔	↔	-	↔	↑	↑	↔	↔	-	-	-	-	↔	-	-	-	↔	2	0	7
No. of stations with a positive trend		0	2	0	0	1	4	6	1	0	1	0	1	0	0	0	0	0	0	--	--	--
No. of stations with a negative trend		0	0	2	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	--	--	--
No. of stations with no trend		0	8	8	0	9	6	3	10	10	0	5	5	1	8	4	0	0	11	--	--	--

Insufficient data are available for 8 of the 21 water-quality stations--396588, 3980, 39826, 40054, 40065, 4010, 4020, and 4033--to determine trends in concentrations during both high and low flows. The lack of water-quality data during low and high flows at many of the stations is due, in part, to the conservative method used in this study. This method ensured that only data collected during base flow and stormflow were used to determine trends. If additional data were collected or the data-collection schedule were changed to accommodate sampling during a full range of flow conditions, and if different flow durations were used to group the data so that more of the data were included, a greater number of significant trends might be identified. (All data used in this study are available in appendixes on CD-ROM for further site-by-site comparisons of visual trends.)

Relations of concentration to streamflow show that concentrations decrease with increasing flows (dilution); therefore, negative concentration slopes predominate. A significant seasonal dependency (a total of 10 more stations per constituent) is evident for ALK, TOC, NA, CL, DO, TP, TN, NO32, NO2, and BACT (table 28). Seasonal dependency is not evident at any station for B or PB. DO shows seasonal dependency at 20 stations, possibly because of its relation to bioactivity in surface water. NA and CL most likely show seasonal dependency because of road salting; NA and CL also have an effect on the seasonality of DS. NO2 makes up only a small part of the TN concentration; it is less seasonally dependent than NO32 and more seasonally dependent than TAON or NH4.

Slopes of load-to-streamflow relations along river reaches in this study generally remain constant or decrease in a downstream direction for most constituents, indicating the increased relative importance of point sources and ground water. The exception, increasing slopes in the downstream direction or the increased relative importance of storm runoff, occurs for DS on North Branch Raritan River and Lamington Creek; for ALK on North Branch Raritan and Millstone Rivers; for some or all of the nutrient species on South and North Branches Raritan River; for SS and DO on Millstone River; and for HARD on South Branch Raritan River.

Overall, for SS, DS, CL, and NO32, more slopes are in the low range than the high range, indicating an increased relative importance of point sources and ground water for these constituents (tables 29 and 30). Slopes are generally in the low range at stations on North Branch Raritan River (39826), Beden Brook, and Matchaponix Brook, indicating an increased relative importance of point sources and ground water. Millstone River (40054) and Mulhockaway Creek have only one low range slope each, but have a significant number of high range slopes, indicating an increased relative importance of nonpoint sources at these sites. The load-to-streamflow slopes are larger for SS than for any other constituent at all stations, indicating the greater importance of storm runoff than point sources and ground water. At high flows, streambed scour adds to the instream load, complicating the analyses of point source and storm runoff influences on SS.

In general, for the nutrients more slopes are in the high range than the low range, indicating an increased relative importance of nonpoint sources (table 30). The station on Neshanic River (3980) and the downstream station on Millstone River (40054) have the most high range slopes for nutrients. A significant number of low range slopes with a value of zero or few high range slopes are evident for the upstream station on North Branch Raritan River (39826), the station on Beden Brook (4016), and the station on Matchaponix Brook (405302), indicating the increased relative importance of point sources and ground water.

Table 28. Seasonal dependency at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93

[USGS, U.S. Geological Survey; No., number; ALK, alkalinity; HARD, hardness; TOC, total organic carbon; SS, suspended sediment; DS, dissolved solids; NA, sodium; CL, chloride; DO, dissolved oxygen; FDO, fraction of dissolved oxygen at saturation; TP, total phosphorus; TN, total nitrogen; NO32, nitrate plus nitrite; NO2, nitrite; TAON, total ammonia plus organic nitrogen; NH4, ammonia; B, boron; PB, lead; BACT, fecal-coliform bacteria; S indicates seasonal dependency (the slope and (or) intercept of growing (April through October) and non-growing (November through March) season data were different at the 0.05 significance level; -, no seasonal dependency or insufficient data for analysis; --, no total]

River basin	USGS station number	ALK	HARD	TOC	SS	DS	NA	CL	DO	FDO	TP	TN	NO32	NO2	TAON	NH4	B	PB	BACT	No. of constituents with seasonal dependency
South Branch Raritan	01396280	S	-	S	-	-	S	S	S	-	S	-	S	-	-	S	-	-	S	9
	01396535	S	-	S	S	-	S	S	S	-	S	-	S	-	-	-	-	-	S	9
Spruce Run	01396588	S	-	S	-	-	-	S	S	-	-	-	S	-	S	-	-	-	S	7
Mulhockaway	01396660	S	S	S	-	-	S	S	S	-	-	-	S	S	-	-	-	-	S	9
South Branch Raritan	01397000	-	-	-	-	-	-	-	S	-	-	S	S	S	-	S	-	-	S	6
	01397400	S	-	-	-	-	S	S	S	-	-	S	S	S	-	-	-	-	S	8
Neshanic	01398000	S	S	S	S	-	-	-	-	-	S	-	S	-	S	-	-	-	S	8
North Branch Raritan	01398260	-	-	S	-	-	S	S	S	S	S	-	-	S	-	-	-	-	S	8
	01399120	-	S	S	S	S	S	S	S	S	-	-	S	-	-	-	-	-	S	10
Lamington	01399500	S	-	S	S	-	S	S	S	-	-	S	S	-	-	-	-	-	-	8
Rockaway	01399700	S	-	S	-	-	S	S	S	-	S	S	S	S	-	-	-	-	S	10
Lamington	01399780	S	-	S	-	-	S	S	S	-	-	S	S	-	-	-	-	-	S	8
Raritan	01400500	S	-	S	S	S	S	S	S	-	S	S	S	-	-	-	-	-	S	11
Millstone	01400540	S	-	S	-	-	S	S	S	-	S	S	S	-	S	-	-	-	-	9
	01400650	S	S	S	-	S	S	S	S	S	S	S	S	S	S	S	-	-	S	15
Stony	01401000	S	S	S	-	S	S	S	S	S	-	S	S	-	-	-	-	-	S	11
Beden	01401600	S	-	S	-	-	S	S	S	-	S	-	S	S	-	S	-	-	S	10
Millstone	01402000	-	-	S	-	-	S	S	S	S	-	-	-	S	-	-	-	-	S	7
Raritan	01403300	S	S	-	-	S	-	S	S	-	-	S	S	-	-	-	-	-	-	7
Matchaponix	01405302	-	-	S	-	-	S	S	S	S	-	-	-	S	-	-	-	-	-	6
Manalapan	01405340	S	S	S	-	-	S	S	S	-	S	-	S	S	S	-	-	-	S	11
No. of stations with seasonal dependency		16	7	18	5	5	17	19	20	6	10	10	18	10	5	4	0	0	17	--

Table 29. Maximum, minimum, and spread of load-to-streamflow slopes for selected constituents at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93

[USGS, U.S. Geological Survey; ALK, alkalinity; HARD, hardness; TOC, total organic carbon; SS, suspended sediment; DS, dissolved solids; NA, sodium; CL, chloride; H, high-slope category; L, low-slope category; -, moderate-slope category; ND, not determined; --, no total]

River basin	USGS station number	ALK	HARD	TOC	SS	DS	NA	CL	Number of constituents with high slopes	Number of constituents with low slopes
South Branch Raritan	01396280	-	L	H	-	L	H	H	3	2
	01396535	-	L	H	-	L	H	H	3	2
Spruce Run	01396588	H	-	H	L	-	-	-	2	1
Mulhockaway	01396660	H	-	H	L	-	H	H	4	1
South Branch Raritan	01397000	-	-	L	H	-	-	-	1	1
	01397400	-	-	-	-	L	-	-	0	1
Neshanic	01398000	H	-	L	-	L	-	-	1	2
North Branch Raritan	01398260	-	-	-	-	L	-	-	0	1
	01399120	H	-	L	-	-	-	-	1	1
Lamington	01399500	H	-	-	-	L	L	L	1	3
Rockaway	01399700	H	-	-	-	L	-	-	1	1
Lamington	01399780	H	-	-	-	L	-	L	1	2
Raritan	01400500	H	-	-	H	-	-	-	2	0
Millstone	01400540	-	H	-	L	H	H	H	4	1
	01400650	H	H	-	L	-	-	H	3	1
Stony	01401000	H	-	L	L	-	-	L	1	2
Beden	01401600	H	-	L	L	L	L	L	1	5
Millstone	01402000	H	-	-	-	-	L	L	1	2
Raritan	01403300	H	-	ND	-	L	L	L	1	3
Matchaponix	01405302	L	-	-	H	L	L	L	1	4
Manalapan	01405340	-	H	-	L	-	-	-	1	1
Number of stations with high slopes		13	3	4	3	1	4	5	--	--
Number of stations with low slopes		1	2	5	7	11	5	7	--	--
Maximum slope		0.80	0.98	1.23	2.52	1.05	1.04	1.06	--	--
Minimum slope		.37	.64	.95	1.00	.79	.75	.81	--	--
Spread between maximum and minimum slopes		.43	.34	.27	1.52	.26	.30	.25	--	--

Table 30. Maximum, minimum, and spread of load-to-streamflow slopes for selected nutrients at surface-water-quality stations in the Raritan River Basin, N.J., water years 1976-93

[USGS, U.S. Geological Survey; TP, total phosphorus; TN, total nitrogen; NO32, nitrate plus nitrite; NO2, nitrite; TAON, total ammonia plus organic nitrogen; NH4, ammonia; H, high-slope category; L, low-slope category; -, moderate-slope category; --no total]

River basin	USGS station number	TP	TN	NO32	NO2	TAON	NH4	Number of constituents with high slopes	Number of constituents with low slopes
South Branch Raritan	01396280	L	L	L	-	H	H	2	3
	01396535	-	-	-	-	H	H	2	0
Spruce Run	01396588	-	-	-	H	H	-	2	0
Mulhockaway	01396660	H	-	-	H	H	-	3	0
South Branch Raritan	01397000	-	-	-	-	-	-	0	0
	01397400	-	-	-	-	-	-	0	0
Neshanic	01398000	H	H	H	H	L	-	4	1
North Branch Raritan	01398260	L	L	L	L	L	L	0	6
	01399120	-	-	-	H	-	H	2	0
Lamington	01399500	-	-	-	H	-	H	2	0
Rockaway	01399700	H	-	L	-	H	H	3	1
Lamington	01399780	-	-	-	-	-	-	0	0
Raritan	01400500	-	H	-	H	-	-	2	0
Millstone	01400540	H	-	-	H	H	H	4	0
	01400650	-	-	L	-	L	H	1	2
Stony	01401000	-	H	H	H	-	L	3	1
Beden	01401600	-	-	-	-	L	L	0	2
Millstone	01402000	L	-	-	-	L	-	0	2
Raritan	01403300	-	-	-	-	L	-	0	1
Matchaponix	01405302	H	L	L	-	-	-	1	2
Manalapan	01405340	-	H	-	H	-	H	3	0
Number of stations with high slopes		5	4	2	9	6	8	--	--
Number of stations with low slopes		3	3	5	1	6	3	--	--
Maximum slope		1.30	1.31	1.76	1.29	1.26	1.29	--	--
Minimum slope		.37	.63	.50	0	.95	.85	--	--
Spread of maximum and minimum slopes		.49	.68	1.26	1.29	.31	.44	--	--

SUMMARY

The U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, investigated the quality of surface water in the Raritan River Basin during water years 1976-93. After selection of the appropriate surface-water-quality stations, constituents, and period of record, the water-quality data, instantaneous streamflow data, and flow durations were compiled and checked for accuracy. A project data base was maintained, and statistical parameters, such as median constituent concentrations, slopes of regression for load to streamflow and concentration to streamflow, and trends in constituent concentrations through time were determined. Eighteen water-quality constituents at 21 surface-water-quality stations were investigated. The relative contributions of constant and intermittent sources of water-quality constituents were evaluated by testing for trends in concentrations during low and high flows, and qualitative values of source contributions were estimated by statistically defining the relations between concentration and streamflow, and load and streamflow.

Results of trend analysis can indicate the relative contributions of constant-rate and intermittent sources to stream-water quality through time within a basin. A trend in concentrations during high-flow conditions can indicate increasing or decreasing intermittent source contributions through time, and a trend in concentrations during low-flow conditions can indicate increasing or decreasing constant-source contributions through time. A conservative method was used to determine trends during low and high flows. The use of flow duration values covering a greater range would possibly allow additional significant trends to be determined.

The slopes of regression lines of load to streamflow were grouped into low (less than or equal to 25 percent of the interval between the minimum and maximum slopes of each constituent), medium (great than 25 percent to less than 75 percent of the slope interval), and high (greater than or equal to 75 percent of the slope interval) ranges in order to compare sites by constituent. At sites with slopes in the high range, contributions to instream loads from storm runoff probably are larger than at other sites in the study area, indicating an increased relative importance of intermittent (nonpoint storm runoff) source contributions. At sites with slopes in the low range, contributions to instream loads from intermittent sources probably are smaller than at other sites in the study area, indicating an increased relative importance of constant (point sources and ground water) source contributions. For constituents with large slopes of load to streamflow, such as total organic carbon, suspended sediment, chloride, total ammonia plus organic nitrogen, and total ammonia, storm runoff is most likely the significant contributor to instream loads, even for stations with load slopes in the low range. Constituent concentrations cannot be related to streamflow in the same way as load because contributions from storm runoff are flow dependent.

Trends in concentrations during low flows are positive (increasing constant-rate source contributions) at one station for fraction of dissolved oxygen at saturation, total nitrogen, and total nitrate plus nitrite; at two stations for hardness and dissolved solids; and at four stations for dissolved sodium and dissolved chloride. Trends during low flows are negative (decreasing constant-rate source contributions) at four stations for total ammonia plus organic nitrogen, at two stations for total ammonia, and at one station for total organic carbon.

Trends in concentrations during high flows are positive (increasing intermittent source contributions) at one station for dissolved solids, dissolved oxygen, total phosphorus, and total nitrate plus nitrite; at two stations for hardness; at four stations for dissolved sodium; and at six

stations for dissolved chloride. Trends are negative (decreasing intermittent source contributions) at one station for total ammonia, at two stations for total organic carbon, and at three stations for total ammonia plus organic nitrogen.

Insufficient data are available to determine trends in concentrations for high- and low-flow conditions at 8 of the 21 water-quality stations. Trends tests were conducted only if there was at least one measurement in each period of not less than four of the six water years in each one-third of the period of study (18 years); a lack of data results in no trend.

Concentration-to-streamflow relations indicate seasonal dependency at one or more stations for 16 of the 18 constituents. Seasonal dependency is not indicated for total boron or lead. Slopes for hardness, suspended sediment, and dissolved sodium are negative at most stations. Slopes for dissolved chloride are almost equally divided between negative slopes and zero slopes (zero indicates the slope is not different from zero at the 0.05 significance level). Slopes are negative for total nitrate plus nitrite at eleven stations; for fraction of dissolved oxygen at saturation at nine stations; for total boron at eight stations; for total phosphorus, total nitrogen, and total nitrite at seven stations; and for total ammonia at one station. Slopes for alkalinity are positive at all stations. Slopes for dissolved oxygen and suspended sediment are almost equally divided between positive slopes and zero slopes. Slopes for total organic carbon, total ammonia plus organic nitrogen, total lead, and fecal coliform bacteria at most stations are zero; slopes are positive for total organic carbon at seven stations, for total ammonia plus organic nitrogen and fecal coliform bacteria at six stations, and for total lead at four stations. Slopes are positive for total nitrite at eight stations, for total nitrogen at six stations, for fraction of dissolved oxygen at saturation and total nitrate plus nitrite at five stations, for total ammonia at three stations, and for total phosphorus and total boron at one station.

For most constituents load-to-streamflow relations at stations along a river reach remain constant or decrease in a downstream direction, indicating smaller contributions from intermittent sources than from constant-rate sources. The slopes increase in the downstream direction for alkalinity at North Branch Raritan and Millstone Rivers; for total phosphorus, total nitrogen, total nitrate plus nitrite at South Branch Raritan River; for dissolved solids at North Branch Raritan River; for dissolved sodium at Lamington River; and for suspended sediment and dissolved oxygen at Millstone River.

The relation of load to streamflow provides a qualitative estimate of the relative contributions of nonpoint storm runoff and ground water, and point sources, to surface-water quality, and represents preliminary results for the total maximum daily load process for the State's watersheds. The results of this study, along with identification of constant-rate sources, additional water-quality data collected during low and high flows, and ground-water data (water-quality data, water levels, flow rates, and travel times) could facilitate a more detailed analysis of the overall hydrology of these river basins.

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