EVALUATION OF STREAMFLOW, WATER QUALITY, AND PERMITTED AND NONPERMITTED LOADS AND YIELDS IN THE RARITAN RIVER BASIN, NEW JERSEY, WATER YEARS 1991-98

By Robert G. Reiser

U.S. Geological Survey

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CONVERSION FACTORS AND WATER-QUALITY ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
mile per hour (mi/h)	1.609	kilometer per hour
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

CONVERSION FACTORS AND WATER-QUALITY ABBREVIATIONS--Continued

<u>Water-quality abbreviations</u>:

µg	-micrograms	NO_3+NO_2	-Nitrate plus nitrite
mg	-milligrams	BOD	-biological oxygen demand
µg/L	-micrograms per liter	TSS	-total suspended solids
mg/L	-milligrams per liter	TOC	-total organic carbon
TKN	-total ammonia plus organic nitrogen	VOC	-volatile organic compound
TDS	-total dissolved solids		

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ABSTRACT

Seventeen water-quality constituents were analyzed in samples collected from 21 surface-water sampling sites in the Raritan River Basin during water years 1991-97. Loads were computed for seven constituents. Thirteen constituents have associated instream water-quality standards that are used as reference levels when evaluating the data. Nine of the 13 constituents did not meet water-quality reference levels in all samples at all sites. The constituents that most commonly failed to meet the water-quality reference levels in the 801 samples analyzed were total phosphorus (greater than 0.1 mg/L (milligrams per liter) in 32 percent of samples), fecal coliform bacteria (greater than 400 counts/100 milliliters in 29 percent), hardness (less than 50 mg/L in 21 percent), pH (greater than 8.5 or less than 6.5 in 17 percent), and water temperature in designated trout waters (greater than 20 degrees Celsius in 12 percent of samples). Concentrations of chloride, total dissolved solids, nitrate plus nitrite, and sulfate did not exceed water-quality reference levels in any sample. Results from previous studies on pesticides and volatile organic compounds in streamwater during 1996-98, and organic compounds and trace elements in sediments during 1976-93, were summarized for this study. Concentrations of pesticides in some samples exceeded the relevant standards.

Water-quality data varied significantly as season and streamflow changed. Concentrations or values of 12 constituents were significantly higher in the growing season than in the nongrowing season at 1 to 21 sites, and concentrations of 6 constituents were significantly higher in the nongrowing season at 1 to 21 sites. Concentrations or values of seven constituents decreased significantly with increased streamflow, indicating a more significant contribution from base flow or permitted sources than from runoff. Concentrations or values of four constituents increased with increased flow, indicating a more significant contribution from runoff than from base flow or permitted sources. Phosphorus concentrations increased with flow at two sites with no point sources and decreased with flow at five sites with four or more permitted point sources. Concentrations of five constituents did not vary significantly with changes in streamflow at any of the sites.

Concentrations of constituents differed significantly between sites. The sites with the most desirable values for the most constituents were Mulhockaway Creek, Spruce Run, Millstone River at Manalapan, Manalapan Brook, and Lamington River at Pottersville. The sites with the least desirable values for the most constituents were Millstone River at Blackwells Mills, Matchaponix Brook, Raritan River at Bound Brook, Neshanic River, and Millstone River at Grovers Mill.

The total instream loads of seven constituents–total ammonia plus organic nitrogen (TKN), biochemical oxygen demand (BOD), total dissolved solids (TDS), nitrate plus nitrite (NO3+NO2), total organic carbon (TOC), total phosphorus, and total suspended solids (TSS)--were analyzed at low, median, and high flows. The quantities of total instream load that originated from facilities with permits issued by the New Jersey Department of Environmental Protection to discharge effluent to streams (permitted sources) and from other sources (nonpermitted sources)

were estimated for each sampling site. TOC and TSS loads primarily were contributed by nonpermitted sources at all flows. BOD and TDS loads primarily were contributed by nonpermitted sources at median and high flows. At low flow, permitted sources contributed more than one-third of the TDS load at 10 sites and more than one-third of the BOD load at 3 sites. Permitted sources contributed more than one-third of the total phosphorus load at 15 and 14 sites at low and median flows, respectively. Permitted sources accounted for more than one-third of total instream load of NO3+NO2 at low- and median-flow conditions at nearly half of the sampling sites.

Samples from the Raritan River at Bound Brook site represent a composite of water that drains nearly three-quarters of the Raritan River Basin, including effluent from 70 permitted point sources. Contributions by permitted sources at the Bound Brook sampling site for each of the seven constituents ranged from 4 to 56 percent of total instream load at median flow. Permitted sources accounted for 4 percent of TSS, 10 percent of TOC, 14 percent of BOD, 22 percent of TDS, 35 percent of TKN, 45 percent of total phosphorus, and 56 percent of NO3+NO2 loads.

Nonpermitted yields were related to environmental factors such as land use, soils, lithology, basin shape, and hydrology. Total phosphorus and TSS yields most strongly correlated with the soils, lithology, and slope associated with the Coastal Plain. At low flow, increases in BOD yield most strongly correlated with increases in septic-system density and other factors related to urban areas. At median and high flows, correlations were strongest between decreases in BOD yield and increases in the percentages of soil types and lithology characteristic of the Coastal Plain in the drainage area upstream from the site. Increases in TKN yields most strongly correlated with decreases in slope and percent of forested land at high flow and with increases in basin elongation associated with streams at low flow in the New England Physiographic Province. Nonpermitted TDS yields most strongly correlated with septic-system density and with soils and lithology associated with the New England Physiographic Province. Nonpermitted yields of NO3+NO2 most significantly correlated with septic-system density and soil permeability at low flow. No significant correlations were observed at high flow. Nonpermitted TOC yield correlated most significantly with increases in factors related to urban land uses and soil permeability.

INTRODUCTION

The Clean Water Act (CWA) is a 1977 amendment to the Federal Water Pollution Control Act enacted by Congress in 1972 to address the issue of water quality in our Nation's waterways (U.S. Environmental Protection Agency, 1992). One of the goals of the legislation is to improve water quality in streams to a fishable and swimmable status. Initial efforts for improving the water quality of streams focused on implementing best-available-technology to treat effluent from municipal wastewater-treatment plants (point-source discharges) by requiring advanced treatment. Use of this technology reduced the amount of nutrients, total suspended solids (TSS), biochemical oxygen demand, heavy metals, and other contaminants discharged to streams.

The effort to upgrade permitted point-source discharges has led to substantial improvements in the quality of many streams during the first 20 years of the CWA. The improvements to water quality were a result of regulating the amount and quality of point-source effluent so that there was sufficient instream dilution at low-flow conditions to meet water-quality goals. For many streams, improving the quality of point-source effluent without improving nonpoint sources of contamination was not sufficient to attain fishable and swimmable status. During the first 20 years of the CWA, nonpoint sources of contamination were rarely evaluated (Jarrell, 1999). Beginning in the late 1980's, the U.S. Environmental Protection Agency (USEPA) and state agencies began to evaluate point- and nonpoint sources of contamination on a basin basis (Jarrell, 1999).

The New Jersey Department of Environmental Protection (NJDEP) regulates the effluent discharged by municipal and industrial facilities into New Jersey streams. These permitted point source discharges are monitored and controlled by the New Jersey Pollutant Discharge Elimination System (NJPDES), a program implemented by NJDEP (NJDEP, 1997). The NJDEP implements the permitting program through the authority of the New Jersey Water Pollution Control Act (State of New Jersey, 1977), the Federal Clean Water Act (U.S. Environmental Protection Agency, 1992), and the USEPA's National Pollutant Discharge Elimination System (U.S. Environmental Protection Agency, 2002).

The New Jersey Department of Environmental Protection (NJDEP) has implemented a watershed management approach to characterize water quality and assess the effects of permitted and nonpermitted loads on surface-water quality in New Jersey. This study to characterize and assess the water resources in the three watershed management areas (areas 8, 9, and 10) that constitute the Raritan River Basin--North and South Branch Raritan River (area 8), Lower Raritan River (area 9), and Millstone River (area 10)--was conducted by the U.S. Geological Survey (USGS), in cooperation with the New Jersey Water Supply Authority (NJWSA) (fig. 1). Goals of this project are the characterization and assessment of surface-water quality in the study area, quantification of instream loads, estimation of the relative contributions of permitted and nonpermitted sources to instream loads in the freshwater nontidal sections of the basin, and the evaluation of the relation of basin characteristics to nonpermitted yields.

The 17 constituents evaluated in this study by using data collected during water years 1991 through 1997 are among the most important for characterizing the water quality and health of streams in the basin. Sources of instream loads of eight constituents were investigated by estimating relative contributions of permitted and nonpermitted source loads to total instream loads along stream reaches throughout the study area. This study of loads is a screening tool for determining which constituents and which stream reaches may need further study for development of total maximum daily loads (TMDLs). A TMDL is the amount of a constituent load that a water body can receive and still meet water-quality standards--the quality of water that supports a particular use. Results from this study can be used by water-resources managers for watershed management planning and for assessing models that simulate alternative strategies for the implementation of TMDLs for streams in the Raritan River Basin.

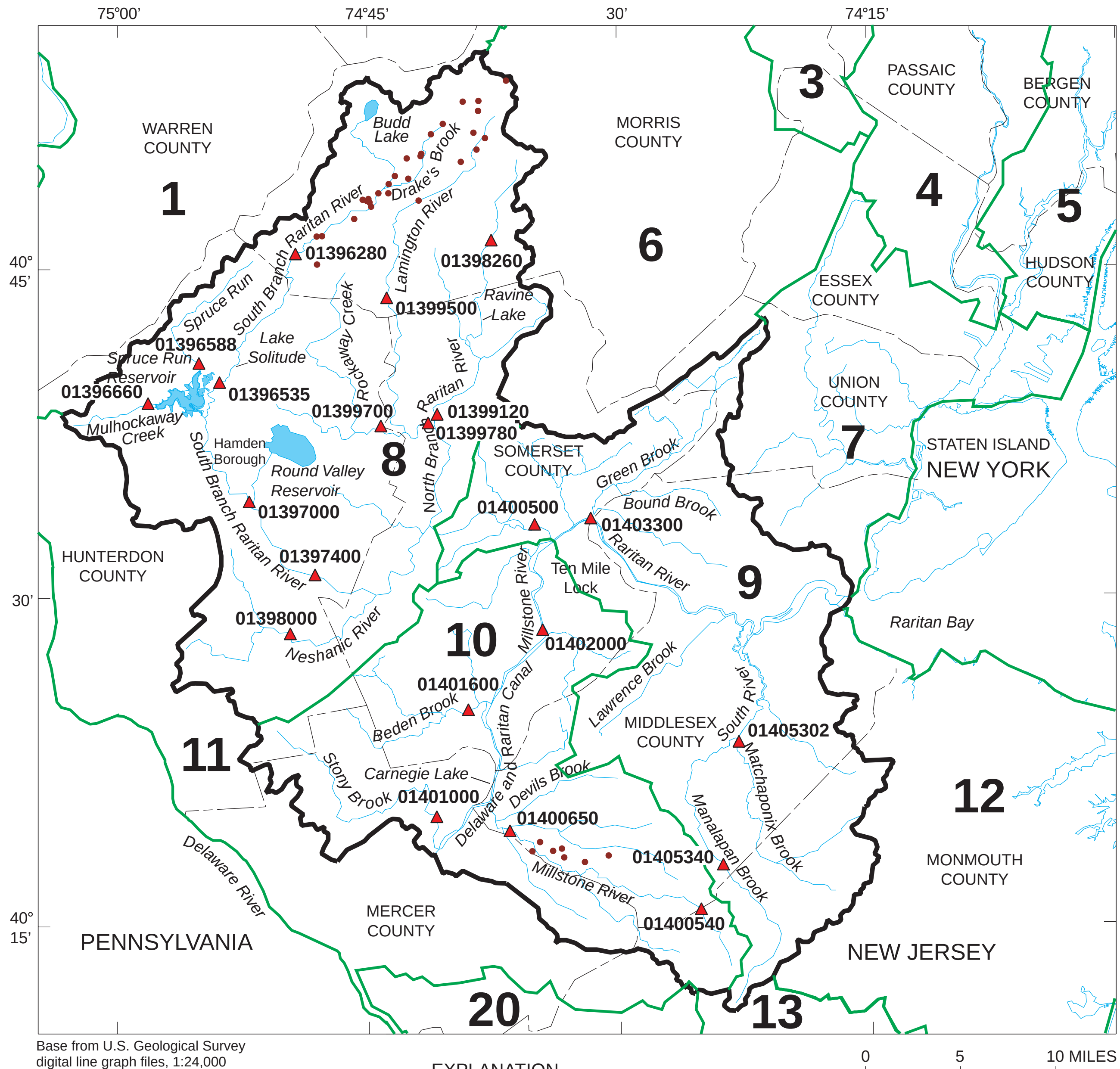
Purpose and Scope

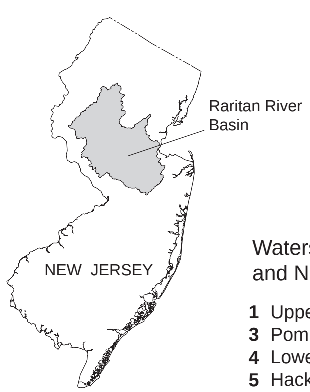
This report documents the results of the analyses for 17 water-quality constituents in 801 samples collected at 21 surface-water sampling sites in the Raritan River Basin during water years[1] 1991 through 1997. This evaluation of water quality includes statistical analysis of the water-quality data; analysis of data on constituent concentrations, pH, water temperature, and fecal coliform bacteria counts in relation to water-quality reference levels; comparisons of data between sites; analysis of changes in constituent concentrations, pH, water temperature, and fecal coliform bacteria by season and flow condition; and an investigation of trends over time at each site.

In addition to the results of analyses for the 17 constituents, results of analyses for other constituents reported in previous studies are summarized in this report. This summary includes results from recent studies on pesticides and volatile organic compounds in surface water, and trace elements and organic compounds in streambed sediments. Results from other recent studies on trends and relations of water quality to streamflow also are summarized to give a more comprehensive evaluation of water-quality conditions in the nontidal parts of streams in the Raritan River Basin.

This report also describes the results of the analysis of loads of eight constituents that characterize the water quality and health of streams in the Raritan River Basin. Water-quality and streamflow data collected at 21 surface-water

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





EXPLANATION

Basin boundary

Watershed Management area boundary

01396660 Surface-water sampling site and identification number (siteid)

Shallow well

Watershed Management Area Number and Name

1 Upper Delaware River
3 Pompmton, Pequannock, Wanaque, Ramapo
4 Lower Passaic, Saddle
5 Hackensack, Pascack
6 Upper Passaic, Whippany, Rockaway
7 Elizabeth, Rahway, Woodbridge
8 North & South Bracnh Raritan
9 Lower Raritan, South River, Lawrence Brook
10 Millstone River
11 Central Delaware Tributaries
12 Monmouth Watersheds
13 Barnegat Bay Watersheds
20 Crosswicks Creek

Siteid	Station name
01396280	South Branch Raritan River at Middle Valley
01396535	South Branch Raritan River at Arch St. at High Bridge
01396588	Spruce Run near Glen Gardner
01396660	Mulhockaway Creek at Van Syckel
01397000	South Branch Raritan River at Stanton
01397400	South Branch Raritan River at Three Bridges
01398000	Neshanic River at Reaville
01398260	North Branch Raritan River near Chester
01399120	North Branch Raritan River at Burnt Mills
01399500	Lamington River near Pottersville
01399700	Rockaway Creek at Whitehouse
01399780	Lamington River at Burnt Mills
01400500	Raritan River at Manville
01400540	Millstone River near Manalapan
01400650	Millstone River at Grovers Mill
01401000	Stony Brook at Princeton
01401600	Beden Brook near Rocky Hill
01402000	Millstone River at Blackwells Mills
01403300	Raritan River at Bound Brook
01405302	Matchaponix Brook at Mundy Ave. at Spotswood
01405340	Manalapan Brook at Federal Rd. near Manalapan

Figure 1. Location of surface-water sampling sites in the Raritan River Basin of New Jersey.

sampling sites during water years 1991 through 1997 are used for computation of instream loads and yields (load per unit area). The evaluation of loads and yields includes a statistical summary of loads and yields at each site, comparisons between sites, a comparison of ground-water quality and surface-water quality at low flow, estimates of mean annual loads contributed by ground water at selected sites, relations of nonpermitted yields to basin characteristics, and evaluation of the effects of changes in permitted source loads on trends in total instream loads.

The tables and figures presented in this report summarize much of the statistical analysis of the water-quality data. Maps show locations of surface-water sampling sites and New Jersey Pollutant Discharge Elimination System (NJPDES) sites, median values of constituents distributed across the study area, and variability of data at each site with changes in season and streamflow. Land-use gradient plots show relations of median values to land use. The stacked bar charts present the total instream load for each of the constituents and the permitted and nonpermitted loads that constitute the total instream load at low, median, and high flow conditions. Tables present water-quality data and statistical summaries for surface-water sampling sites and NJPDES sites, water-quality reference levels, the percentage of samples that do not meet those levels, and loads and yields, including the amount contributed by permitted and nonpermitted sources at the three flow conditions. Appendixes include distributions of 17 constituents shown in box plots, water-quality standards, percentage of samples that do not meet the standards, and cumulative probability curves, which show the percentage of samples below a given value.

Description of Study Area

The Raritan River Basin comprises an area of 1,105 mi^2 in central and northern New Jersey. It is the largest drainage basin entirely within the State of New Jersey (fig. 1). The major subbasins are the Millstone River (287 mi^2), South Branch (S.B.) Raritan River (279 mi^2), North Branch (N.B.) Raritan River (190 mi^2), South River (133 mi^2), Bound Brook (65 mi^2), and Lawrence Brook (46.3 mi^2). The basin drains all or parts of 100 municipalities in Hunterdon, Mercer, Middlesex, Monmouth, Morris, Somerset, and Union Counties. The major impoundments in the basin are Spruce Run Reservoir, Round Valley Reservoir, and Budd Lake. Spruce Run (completed in 1963 with 33,750 acre-ft or 11,000 million gallons of storage capacity) is an on-stream water-supply reservoir, whereas Round Valley (completed in 1966 with 168,700 acre-ft or 55,000 million gallons of storage capacity) is an off-stream pumped-storage reservoir (U.S. Geological Survey, 1986). Spruce Run releases water to S.B. Raritan River, and Round Valley Reservoir releases water to the N.B. and S.B. of the Raritan River.

The Raritan River Basin drains an area spanning three physiographic provinces. Northern parts of the N.B. and S.B. Raritan Rivers are in the New England Province. This area is underlain predominantly by Precambrian granite, gneiss, and small amounts of marble. These rocks are resistant to erosion and form a hilly upland dissected by the deep, steep-sided valleys of major streams. The entire Bound Brook subbasin and a large part of the N.B. and S.B. Raritan River subbasins are within the Piedmont Physiographic Province, a broad lowland that contains ridges underlain by interbedded sandstone, shale, conglomerate, basalt, and diabase. The South River, Lawrence Brook, and much of the Millstone River subbasins are within the Coastal Plain Physiographic Province. The Coastal Plain is mainly flat and is underlain by unconsolidated layers of sand, silt, and clay (New Jersey Department of Environmental Protection and Energy, 1992).

Twenty-one water-quality stations throughout the basin that are part of the USGS/NJDEP cooperative network were sampled during water years 1991-97; data from these sites were used for this study (fig. 1; table 1). Twelve sites are used to monitor drainage basins located entirely in one province--five in the New England Province, four in the Coastal Plain Province, and three in the Piedmont Province. Eight sites are used to monitor streamflow in two provinces. The Raritan River at Bound Brook site monitors streamflows that

Table 1. Characteristics of U.S. Geological Survey/New Jersey Department of Environmental Protection network surface-water sampling sites in the Raritan River Basin, N.J., 1991-97 water years

[USGS, U.S. Geological Survey; Flow record: C, continuous record; P, partial record. 1996 land-use data from New Jersey Department of Environmental Protection. Population density from 1990 census. Surface-water classification: NT, nontrout; TM, trout maintanance; TP, trout production; AMNET, Ambient Biomonitoring Network; AMNET biological impairment status (NJDEP, 1995): N, nonimpaired; M, moderate; S, severe; mi^2, square mile; --, no data]

USGS station number	Station name	Drainage area (mi^2)	Flow record	Historical period of water-quality record	Number of point sources upstream from site	Surface-water classification	AMNET biological impairment status	Land use (in percent) Urban	Agriculture	Forest	Water	Wetland	Barren	Population density (per mi^2)
01396280	South Branch Raritan River at Middle Valley, NJ	47.7	P	1964-65, 1967, 1976-97	7	TP	N	29.1	11.9	40.1	1.8	16.0	1.08	623
01396535	South Branch Raritan River at Arch Street at High Bridge, NJ	68.8	P	1976-97	7	TM	N	28.1	13.6	42.5	1.5	13.4	.9	537
01396588	Spruce Run near Glen Gardner, NJ	15.3	P	1979-97	1	TP	N	17.2	19.6	52.8	.4	9.3	.7	257
01396660	Mulhockaway Creek at Van Syckel, NJ	11.8	C	1976-98	1	TM	N	23.6	19.8	42.9	.3	12.5	1.0	174
01397000	South Branch Raritan River at Stanton, NJ	147	C	1960-81,1991-97	13	TM	N	24.6	20.8	40.6	2.5	10.6	.9	405
01397400	South Branch Raritan River at Three Bridges, NJ	181	P	1976-97	15	NT	N	25.7	20.9	38.3	4.0	10.3	.8	407
01398000	Neshanic River at Reaville, NJ	25.7	C	1957,1962, 1979-98	0	NT	M	23.9	41.5	22.2	.2	12	.1	305
01398260	North Branch Raritan River near Chester, NJ	7.57	P	1964-65, 1967, 1976-97	1	TP	N	38.7	5.3	44.6	.4	10.7	.2	569
01399120	North Branch Raritan River at Burnt Mills, NJ	63.8	P	1964, 1976-97	6	NT	N	28.0	19.5	45.8	.7	5.4	.64	364
01399500	Lamington River near Pottersville, NJ	32.8	C	1977-97	4	TM	N	29.4	11.3	40.6	1.9	15.3	1.54	609
01399700	Rockaway Creek at Whitehouse, NJ	37.1	P	1977-97	3	NT	N	27.0	23.1	43.6	.9	4.7	.67	226
01399780	Lamington River at Burnt Mills, NJ	100	P	1964, 1976-98	10	NT	N	23.8	22.9	42.9	1.2	8.5	.82	322
01400500	Raritan River at Manville, NJ	490	C	1923-25, 1959, 1962-73, 1976-97	37	NT	M	28.1	24.6	35.2	2.0	9.3	.75	425
01400540	Millstone River near Manalapan, NJ	7.37	P	1960-64, 1981-97	0	NT	N	16.0	36.6	24.0	.7	19.6	3.14	251
01400650	Millstone River at Grovers Mill, NJ	43.4	P	1976-94, 1996-98	4	NT	M	21.7	32.2	16.1	.7	27.9	1.34	751
01401000	Stony Brook at Princeton, NJ	44.5	C	1956-75, 1978-98	4	NT	M	24.7	22.5	37.2	.9	13.8	.92	315
01401600	Beden Brook near Rocky Hill, NJ	27.6	P	1959-63, 1976-97	3	NT	M	21.0	24.8	39.2	.4	13.7	1.06	274
01402000	Millstone River at Blackwells Mills, NJ	258	C	1962-69, 1973, 1976-80, 1991-98	28	NT	M	29.3	24.1	23.3	1.1	20.6	1.54	568
01403300	Raritan River at Queens Bridge at Bound Brook, NJ	804	P	1964-69, 1971-73, 1978, 1981-98	70	NT	M	29.6	24.0	30.2	1.7	13.4	1.11	517
01405302	Matchaponix Brook at Mundy Avenue at Spotswood, NJ	44.1	P	1976-97	3	NT	M	43.2	10.2	16.4	.4	28.0	1.87	1,220
01405340	Manalapan Brook at Federal Road near Manalapan, NJ	20.9	P	1976-97	0	NT	S	24.0	25.3	19.2	.9	30.0	.67	199
				Summary of subbasins in study area										
	Raritan River study area	1,104	--	--	73		--	35.7	19.2	26.6	1.9	15.2	1.4	939
	Millstone River sub-basin	281	--	--	31		--	30.7	24.5	22.0	1.1	19.9	1.6	648
	South Branch Raritan River sub-basin	278	--	--	19		--	25.7	28.0	32.6	2.7	10.2	.7	363
	North Branch Raritan sub-basin	189	--	--	17		--	28.4	20.8	41.5	1.0	7.6	.8	381
	South River sub-basin	133	--	--	3		--	37.4	10.2	21.1	1.5	27.2	2.5	1,215

originate in all three provinces (fig. 2). All sites are on streams classified by NJDEP as freshwater (New Jersey Department of Environmental Protection, 1998). Fourteen sites are on streams with a nontrout designation. Four sites are in trout-production waters, and three sites are in trout-maintenance waters (New Jersey Department of Environmental Protection, 1998).

Municipal and industrial point-source discharges occur in all the major subbasins. The Neshanic River at Reaville, Manalapan Brook at Federal Road near Manalapan, and Millstone River near Manalapan are the only surface-water sampling sites without any permitted point sources upstream. Raritan River at Queens Bridge at Bound Brook integrates flow from the S.B. Raritan, N.B. Raritan, and Millstone River subbasins; 76 industrial and municipal point sources are upstream from these sites.

Basin Characteristics

Basin characteristics can contribute to the variability in water quality in streams throughout the study area. Three general categories of characteristics were considered in an analysis of nonpermitted yields: (1) anthropogenic factors, (2) soil and geologic features, and (3) hydrologic characteristics. Basin characteristics such as basin shape, topographic gradient, land use, population density, impervious surface area, lithology, soil characteristics, stream flashiness, road density, and density of septic systems are considered in this analysis. The effect of each characteristic on nonpermitted loads varies among constituents as flow conditions change in the stream. Basin characteristics were derived from geographic information system (GIS) coverages and 1990 census data (U.S. Bureau of the Census, 1991).

Land use is derived from a GIS coverage developed from 1995-97 digital infrared aerial photos (N.J. Department of Environmental Protection, 2000) using the Anderson method of classification (Anderson and others, 1976). Land use is characterized on the basis of percentages of urban, agriculture, forested, wetland, open water, and barren land for each subbasin. Urban land use was classified further as either residential or commercial/industrial. Percentages of urban and agricultural land use were added to get the percentage of total developed land. The percentages of forested, wetland, open water, and barren land were added to get the percentage of total undeveloped land. The amount of land covered by impervious surfaces also was obtained from the GIS coverage.

Most of the drainage basins upstream from the 21 sampling sites were characterized as having mixed land uses (fig. 2). The drainage basin upstream from the site at Spruce Run at Glen Gardner is the only basin with a single land-use type that represents more than 50 percent of the basin. Spruce Run is 52.8 percent forested (table 1). The areas with the most intense urban land use are along the mainstem of the Raritan River, in the Bound Brook subbasin, and in the lower reaches of the Lawrence Brook and South River subbasins. Areas with the highest percentages of forested land use are in the upper reaches of the N.B. and S.B. Raritan River subbasins. Areas with the highest percentages of agricultural land uses are in the S.B. Raritan River and Millstone River subbasins. Areas with the highest percentages of wetlands are in the Millstone and South River subbasins.

Physical characteristics of the basin were derived from USGS GIS coverages of basin boundaries and stream channels, and from geology and digital elevation maps. Slope of the basin, basin elongation, and length of perennial streams per square mile were variables considered in the development of the multivariate models used in this study. Basin elongation refers to the shape of the basin. The more rotund the basin, the lower the value of basin elongation. The lithology of the basin was categorized by the percentage of igneous, metamorphic, and sedimentary bedrock and unconsolidated sediments. Soil characteristics were derived from the Soil Survey Geographic (SSURGO) database (U.S. Department of Agriculture, 1995). Lithology and soil characteristics, including hydrologic soils group, soil drainage classification, vertical and horizontal permeability, and percentage of sand, silt, and clay, were used to explain differences in basin

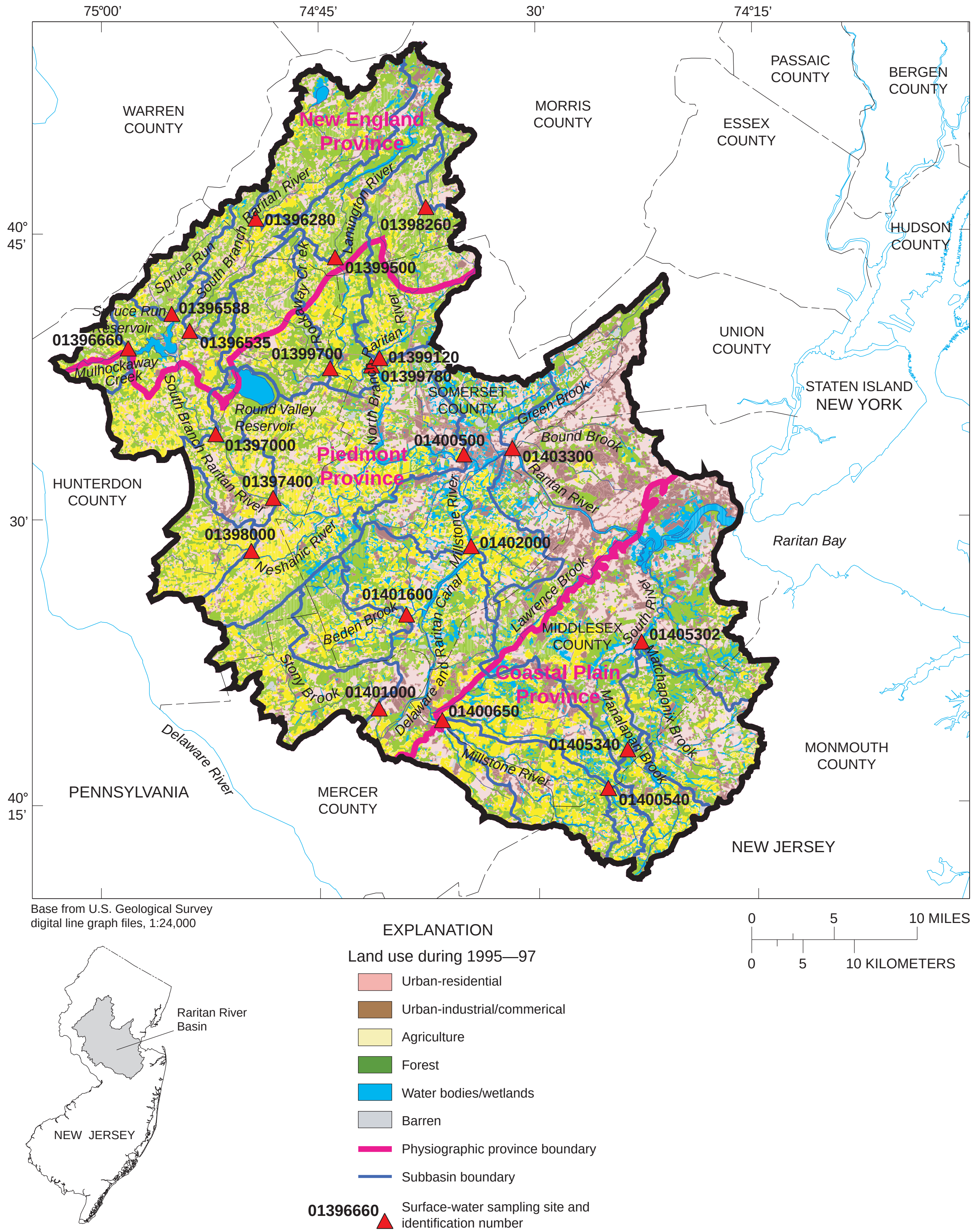


Figure 2. Land use, physiographic provinces, and subbasins in the Raritan River Basin, N.J.

characteristics between physiographic provinces. Hydrologic soils groups are based on the depth and texture of the whole soil profile (U.S. Department of Agriculture, 1995). The four soil groups used in this study are classes A through D. Class A soils are deep and well drained, Classes B and C have intermediate properties, and Class D soils have slow infiltration rates and are associated with high water table or a shallow depth to an impervious layer (U.S. Department of Agriculture, 1995).

Streamflow variability was the hydrologic feature used for comparative purposes. Streamflow per unit drainage area was not used in the correlation or multiple regression analysis because flow is used in the compution of load and yield. The responsiveness of streamflow varies throughout the study area because of differences in substrate, slope, and drainage area. Flow duration statistics were used to measure this variability. The flow duration refers to the percentage of time a mean daily flow is equaled or exceeded. The ratios of 25^{th} to 75^{th} and 10^{th} to 90^{th} flow duration measure the differences between periods of high and low flow and were used as measures of flashiness. Regulation of streamflow from Spruce Run and Round Valley Reservoirs reduces flashiness on the S.B. Raritan River and mainstem Raritan River. In this study area, the sites with the highest values of flashiness are those sites with small drainage areas in the Piedmont Province. Streamflows at these sites decrease more dramatically during dry periods than streamflows in similar-sized basins in other physiographic provinces.

Streamflow at sampling sites on the S.B. Raritan River and on the mainstem Raritan River downstream from Spruce Run and Round Valley Reservoirs is regulated by releases of water from the reservoirs and by water diverted into the reservoirs. Spruce Run Reservoir stores water from the Mulhockaway Creek and Spruce Run and releases water to the S.B. Raritan River for public water supply for municipalities downstream. Round Valley Reservoir stores water diverted from the S.B. Raritan River and releases water as needed for public water supply downstream to the S.B. Raritan River and the Rockaway Creek in the N.B. Raritan River Basin.

Data from the 1990 census (U.S. Bureau of the Census, 1991) on population, housing units, and septic systems were used to compute population density, housing density, and septic-system density in each basin. The percentages of sewered and nonsewered areas in each subbasin were derived from a GIS coverage available from NJDEP. A GIS coverage of roads was used to compute total road length per square mile in each subbasin. This variable was used to estimate the quantity of road salt used.

Previous Studies

Water quality, streamflow, and time-of-travel data for the basin were characterized for 1955-72 by Anderson and Faust (1974). Streamflows decreased during the period. In general, water quality was suitable for most industrial, domestic, and recreational uses, except along the mainstem Raritan River downstream from the Raritan River at Manville sampling site. Maximum observed concentrations of orthophosphates, phenolic materials, and fecal coliform bacteria increased during the study period. Dissolved oxygen decreased and BOD increased in the Raritan River downstream from the Raritan River at Manville sampling site. Comparisons of water-quality data from the late 1920's with data from 1955-72 indicate that concentrations of sulfate, chloride, nitrate, and dissolved solids increased significantly during the period.

Relations of water quality to streamflow were determined for 18 water-quality constituents at 21 surface-water stations within the Raritan River Basin for the years 1976-93 (Buxton and others, 1999). Stormwater runoff was determined to be the most likely contributor of instream loads of total organic carbon (TOC), suspended sediment, chloride, total ammonia plus organic nitrogen (TKN), and total ammonia. Trends in concentrations and loads during high- and low-flow periods were evaluated. Median concentrations during 1989-93 were compared to the median values during 1976-93.

Trend tests were conducted by Hickman and Barringer (1999) on data for 24 water-quality constituents at 83 surface-water sampling sites in New Jersey, including 21 stations in the Raritan River Basin for 1986-95. The trends in the concentrations of constituents at stream sites were analyzed for statistical association with drainage basin characteristics (Robinson and others, 1996).

The relative contribution of point-source loads to total instream loads at seven sites in the Musconetcong, Rockaway, and Whippany River Basins was evaluated by Price and Schaefer (1995). Data on BOD, total nitrogen, total phosphorus, and TOC in samples collected during 1985-90 in each basin were studied. Differences between sites were attributed to the presence or absence of major point sources and the regulation of streamflow by reservoirs.

Two recent studies on volatile organic compounds (VOCs) focused on the presence and distribution of VOCs in streams in New Jersey. The presence and variability of 86 VOCs in streams in New Jersey and Long Island, New York, including 12 stations in the Raritan River Basin, were evaluated from data collected during January 27-30, 1997, from stations chosen to represent an urban land-use gradient (O'Brien and others, 1998). The presence and seasonal variability of VOCs at seven stations, including four stations in the Raritan River Basin, that were sampled routinely from April 1996 through April 1997 were evaluated in a second study (Reiser and O'Brien, 1998).

The presence and differences in concentrations of 85 pesticides in 7 New Jersey streams, including 4 in the Raritan River Basin, were determined from the evaluation of data collected routinely from April 1996 through June 1998 (Reiser, 1999). Differences in concentrations during the study period were evaluated by season, streamflow, and land use. Another study focused on the presence and distribution of pesticides at 50 stream sites, including 9 stations in the Raritan River Basin, using data collected June 9-18, 1997 (Reiser and O'Brien, 1999). Stations were chosen to represent the gradient of land uses in the study area, and analyses focused on the relation of concentrations to land use.

Data on the presence and distribution of trace elements in bed sediment in New Jersey streams during 1976-93, including data from more than 40 sites in the Raritan River Basin, were evaluated by O'Brien (1997). Median arsenic and manganese concentrations at sites in the Raritan River Basin were among the highest in New Jersey. The relation of concentrations to basin characteristics was evaluated. Data on the presence and distribution of chlorinated organic compounds in bed sediment in New Jersey streams during 1976-93, including data from 41 sites in the Raritan River Basin, were evaluated by Stackelberg (1997). Median concentrations and detection frequencies of organic carbon and the six most frequently detected compounds in samples from the Raritan River Basin were not extremely high or low compared to those from other basins in New Jersey.

An Ambient Biomonitoring Network (AMNET) biological impairment status was assigned to 457 stream sites in New Jersey by NJDEP in 1993 (New Jersey Department of Environmental Protection, 1995). The AMNET rating is based on the benthic-macroinvertebrate population at the stream site. Species of the instream macroinvertebrate community occupy distinct niches based on their tolerance to environmental conditions. An integrated assessment of the benthic community results in an impairment status for each site. The three possible ratings are (1) 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 species; (2) moderately impaired --the macroinvertebrate richness and community balance are reduced and intolerant taxa are absent; or (3) severely impaired-- the benthic community has dramatically changed and macroinvertebrates are dominated by a few tolerant taxa (Buxton and others, 1999). Chemical and physical data along with biological impairment status are good indicators of stream quality. Water-quality data give an indication of possible causes of macroinvertebrate impairment.

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METHODS OF STUDY

The methods used to select surface-water sampling sites, water-quality constituents, and permitted point-source discharges to be studied are described in this section. Methods for data review, analysis, computation of instream loads and yields, and presentation of the results are documented.

Water-Quality Data

The water-quality and streamflow data used in this study were collected primarily from the USGS/NJDEP cooperative network of sites (Reed and others, 1998). Most of the 21 sites in the Raritan River Basin have continuous records of data that were collected routinely five times a year during 1991-97 (table 1). A smaller number of samples were collected at the S.B. Raritan River at Stanton site and Millstone River at Grovers Mill and at Blackwell Mills sites than at the other sites, and during part of the study period, fewer constituents were analyzed in samples collected from the Raritan River at Bound Brook. Only one sample was collected at sites S.B. Raritan River at Stanton and Millstone River at Blackwell Mills in 1991. No samples were collected at Millstone River at Grover's Mill in 1995. At Raritan River at Bound Brook, a few constituents were not analyzed for during the entire study period; BOD was not analyzed for during 1992-94, TOC during 1991-94; and total ammonia during 1993-95. Samples were collected for fecal coliform bacteria four times a year during 1991-95 and five times a year during 1996-97.

Water-quality samples collected for the USGS/NJDEP cooperative network were analyzed at USGS and New Jersey Department of Public Health and Environmental (NJDPHE) Laboratories. Samples for BOD and fecal coliform bacteria were analyzed at the USGS New Jersey District laboratory or at the NJDPHE laboratory. Samples for nutrients were analyzed at the NJDPHE or at the USGS National Water Quality laboratory (NWQL) in Arvada, Colorado. Sediment samples were analyzed in the USGS laboratory in Iowa City, Iowa. All other samples were analyzed at the USGS laboratory in Arvada, Colorado.

The study period 1991-97 was chosen to allow for an adequate amount of data for statistical analysis. Beginning in 1998, the network of USGS/NJDEP cooperative sites was changed, and many of the sites included in this study were no longer sampled. The data collected at these sites during the study period include field characteristics such as pH, dissolved oxygen, specific conductance, and water temperature; alkalinity; and constituents analyzed for in the laboratory such as nitrogen species, phosphorus, eight major ions, hardness, fecal coliform bacteria, TSS, total dissolved solids (TDS), dissolved organic carbon, and suspended organic carbon. Additional samples were collected at Neshanic River at Reaville, Stony Brook, and Raritan River at Bound Brook during 1996-97 for the USGS Long Island/New Jersey National Water Quality Assessment (LINJ NAWQA) project.

Point-source effluent quality and quantity were derived primarily from the NJDEP discharge monitoring report (DMR) database (TRC Omni Environmental Corporation, 2001). Some facilities that discharge effluent do not submit data for the NJDEP DMR database for several of the constituents studied. Additional data were obtained from these facilities by TRC Omni Environmental Corporation (also called Omni). Some facilities do not collect samples for analysis of all constituents studied. Concentrations of these constituents were estimated by Omni from data that were collected at those facilities during a different period, from other facilities with similar operations of effluent treatment, or from scientific literature (TRC Omni Environmental Corporation, 2001).

Selection of Constituents

Seventeen constituents (table 2) considered important indicators of water quality in the Raritan River Basin were chosen for analysis. Sufficient data are available for these constituents during the study period 1991-97 to complete a statistical analysis. The constituents chosen for analysis are alkalinity as calcium carbonate ($CaCO_3$), TKN, BOD, chloride, dissolved oxygen, fecal coliform bacteria, hardness, NO3+NO2, pH, sodium, sulfate, TOC, total phosphorus, TDS, TSS, un-ionized ammonia, and water temperature. Nine of these constituents were chosen for analysis because of existing instream water-quality criteria (New Jersey Department of Environmental Protection, 1998). Eight of these constituents were chosen for analysis of loads--TKN, BOD, chloride, NO3+NO2, TOC, total phosphorus, TDS, and TSS. State of New Jersey instream surface water-quality or State of New Jersey drinking-water maximum contaminant levels (MCLs) have been determined for 13 of the 17 constituents (New Jersey Department of Environmental Protection, 1989 and 1998). The surface-water-quality standards for New Jersey streams represent a quality of water that supports a particular use. Instream water-quality or drinking-water standards have not been determined for alkalinity, BOD, TKN, and TOC.

Alkalinity level is important in evaluating drinking-water and wastewater processes, including chemical coagulation, water softening, corrosion control, and buffering capacity (Buxton and others, 1999). The alkalinity of a solution is defined as the capacity of the solutes contained in the solution to react with and neutralize acid (Hem, 1985). Alkalinity is the sum of all titratable bases, including carbonate, bicarbonate, hydroxides, silicates, borates, phosphates, and organic ligands (Buxon and others, 1999). Carbonate and bicarbonate concentrations constitute most of the alkalinity in most surface-water bodies. When an extensive algal bloom occurs, consumption of carbon dioxide by algae for photosynthesis causes an increase in pH as a result of a shift in the forms of alkalinity, although no change occurs in the total alkalinity (Sawyer and McCarty, 1978).

TKN represents the reduced part of total nitrogen in a stream. High ammonia concentration is a concern of water purveyors because of increased treatment costs. Organic nitrogen and ammonia are instream oxygen consumers and indicators of ecosystem health. These nitrogen constituents oxidize in streams causing reduced dissolved oxygen levels. No New Jersey instream water-quality standards have been determined for TKN.

Un-ionized ammonia concentrations were calculated from total ammonia concentrations provided by the NWQL laboratory, and pH and water temperature were measured in the field. The following equation was provided by Kevin Berry (New Jersey Department of Environmental Protection, written commun., 1999) to determine un-ionized ammonia concentrations from sampled data.

$$\text{Un-ionized ammonia-N} = [100/[1+ \text{antilog}((0.09018+2729.92/T)-pH)]*(NH_3)/100], \quad (1)$$

where T is water temperature in degrees Kelvin (^oK) (^oK = 273.15 + degrees Celsius), and NH_3 is ammonia-N.

Un-ionized ammonia concentrations were analyzed to assess water-quality conditions in the basin. Ammonia is soluble in water. The toxicity of an aqueous solution of ammonia is attributed to the un-ionized (NH_3) component (Schornick and Fischel, 1980). It is an important compound in biological processes and is produced as a normal biological degradation product (Schornick and Fischel, 1980). The surface water-quality standard for un-ionized ammonia is 0.05 mg/L in nontrout streams and 0.02 mg/L in trout streams (New Jersey Department of Environmental Protection, 1998). Samples collected from the USGS/NJDEP network sites are analyzed for dissolved and total ammonia. The un-ionized ammonia was computed by use of the concentration of total ammonia, pH, and water temperature. Un-ionized ammonia has

Table 2. Water-quality constituents analyzed for in samples from 21 sites in Raritan River Basin, N.J., and detection frequencies

Constituent or characteristic	Detection frequency (in percent)
Alkalinity, as CaCO3	99.9
Ammonia, un-ionized	58.4
Ammonia + organic nitrogen, total	98.7
Biochemical Oxygen Demand (5-day)	61.2
Chloride	100
Dissolved Oxygen	100
Dissolved solids, total	100
Fecal Coliform Bacteria	87.6
Hardness	100
Nitrate + nitrite	99.9
Organic carbon, total	100
pH	100
Phosphorus, total	92.0
Sodium	100
Sulfate	100
Suspended solids, total	95.7
Water temperature	100

the lowest frequency of detection of the 17 constituents at sampling sites in the basin (table 2). In previous studies, un-ionized ammonia exceeded water-quality standards in four stream reaches in the basin (New Jersey Department of Environmental Protection, 1997).

BOD was chosen for study because it is a measure of potential oxygen consumption and a good measure of stress to the stream ecosystem. BOD is a measure of the amount of dissolved oxygen consumed during a 5-day period of incubation at 20 ^{o}C. Oxygenated water is added to the sample, enhancing the ability of microorganisms to decompose organic matter in the water and consume oxygen in the process. BOD can be used to evaluate the biodegradable organic load in a quantitative way (Hem, 1985). No water-quality standard has been determined for BOD.

Chloride has a State of New Jersey secondary MCL drinking-water and surface-water standard of 250 mg/L (New Jersey Department of Environmental Protection, 1989; Shelton and Lance, 1997; and New Jersey Department of Environmental Protection, 1998). Most of the highest concentrations in surface water are caused by runoff from deicing salts applied to roads. Chloride is a conservative constituent that can be used to assure the quality of a mass balance model. Conservative constituents, such as chloride, are not removed or added to the stream by biological or chemical processes. The chloride load stays the same or increases as water moves downstream in gaining streams. Changes in load are caused by discharges or withdrawals from the stream or stream reaches that lose flow to ground water.

Dissolved oxygen is a direct measurement of the water quality of the river. The concentration of dissolved oxygen in streams depends on physical, chemical, and biological characteristics of the water body. Warm temperatures, the presence of organic compounds, and biological and chemical activity reduce the amount of dissolved oxygen in water. Turbulence, photosynthesis, and low temperature increase the amount of dissolved oxygen in water. Dissolved oxygen concentrations exhibit a diurnal fluctuation in response to photosynthesis and the respiration of algae and other aquatic plants. Dissolved oxygen concentrations were below water-quality standards in some samples from the Millstone and N.B. Raritan Rivers (New Jersey Department of Environmental Protection, 1998). Three New Jersey surface-water standards have been determined for dissolved oxygen. Dissolved oxygen must be greater than the instream standards at all times: (1) greater than 4 mg/L in nontrout waters, (2) greater than 5 mg/L in waters classified as trout maintenance, and (3) greater than 7 mg/L in waters classified as trout production (New Jersey Department of Environmental Protection, 1998).

TDS is an important constituent to purveyors and water users because high concentrations of TDS can cause changes to the taste of water and could have undesirable effects for hospitals, industrial facilities, and stream ecosystems. TDS exerts osmotic pressure on water-purification systems and stream ecosystems. TDS concentrations have increased over time at some locations in the basin (Hickman and Barringer, 1999). The drinking-water MCL and instream standard is 500 mg/L (New Jersey Department of Environmental Protection, 1989).

Fecal coliform bacteria levels are a measure of the sanitary quality of water. Fecal coliform bacteria can indicate untreated wastewater and animal feces. High numbers of fecal coliform bacteria can cause streams to be unsuitable for swimming. Previous studies detected fecal coliform levels that exceeded the established criteria at all sites evaluated in the basin (New Jersey Department of Environmental Protection, 1997). Two surface-water standards have been determined for fecal coliform bacteria. Levels should not exceed a geometric mean of 200 colonies per 100 mL or 400 colonies per 100 mL in more than 10 percent of total samples collected in a 30-day period (New Jersey Department of Environmental Protection, 1998).

Hardness is computed typically by multiplying the sum of the milliequivalents per liter of calcium and magnesium by 50 (Hem, 1985) and is reported as CaCO3 in mg/L. The drinking-water standard for hardness is greater than 50 mg/L and less than 250 mg/L (New Jersey Department of Environmental Protection, 1989; Shelton and Lance, 1997). Water with hardness concentrations that do not meet these standards is undesirable to consumers because it results in higher soap consumption and scale formation in pipes and hot water heaters. Hardness, therefore, is a concern of water purveyors. Another water-quality concern is the inverse relation of hardness to the solubility of heavy metals. As hardness increases, the solubility of heavy metals decreases. Concentrations of calcium and magnesium and all other divalent cations contribute to hardness concentrations (Buxton and others, 1999).

NO3+NO2 represents the oxidized forms of nitrogen in the stream. The drinking-water MCL for NO3+NO2 is 10 mg/L (New Jersey Department of Environmental Protection, 1989; Shelton and Lance, 1997). NO3+NO2 can enter surface water from wastewater-treatment plants. It is a primary nutrient of rooted aquatic plants and algae. Nitrate is found in surface water at much higher levels than nitrite, which is rapidly oxidized to nitrate. Nitrate is considerably less toxic to aquatic organisms than are ammonia and nitrite; however, in excess amounts (greater than 10 mg/L), nitrate contributes to methemoglobinemia in small children (Buxton and others, 1999).

TOC is a direct measure of organic content in the water column of a stream. Increased levels may indicate a potential for forming disinfection by-products in drinking water. Data on concentrations of specific forms of organic carbon, such as chloroform and other disinfection by-products, and other VOCs, are not routinely collected throughout the basin. These constituents generally are detected in low concentrations (O’Brien and others, 1997). A fraction of TOC is assimilable carbon used as a nutrient by microorganisms and contributes to BOD. In combination with TKN, it is an indicator of ecosystem health. TOC can be an indicator of nonpoint-source contamination or a poorly controlled process in a sewage-treatment plant. No drinking-water or surface-water standards have been determined for TOC.

The New Jersey surface-water standard for pH is greater than 6.5 and less than 8.5 (New Jersey Department of Environmental Protection, 1998). The pH of water is a measure of the negative logarithm of the hydrogen ion concentration. Values less than 7 are considered acidic, and values greater than 7 are considered basic. The pH of water can exhibit diurnal fluctuation in response to the respiration rates of algae and other aquatic plants. The aquatic life in a stream is affected by the pH. Typically, the pH of streamwater in the Coastal Plain part of the Raritan River Basin is lower than the pH of water from streams in the Piedmont and New England Physiographic Provinces.

Total phosphorus concentrations are important to stream health. Total phosphorus is a primary nutrient for algae and aquatic plants and can stimulate excessive plant and algal growth. Exceedances of the 0.1 mg/L surface-water standard are common throughout the Raritan River Basin. “Phosphorus as total phosphorus standard shall not be exceeded in any stream; unless it can be demonstrated that total phosphorus is not a limiting nutrient and will not render the waters unsuitable for the designated uses” (New Jersey Department of Environmental Protection, 1998). For the purposes of this study, a concentration of 0.1 mg/L is used as a reference point in all streams studied. A second surface-water standard of 0.05 mg/L was determined for lakes and reservoirs and for streams at the point of entry to these water bodies (New Jersey Department of Environmental Protection, 1998). Phosphates are found in solution and attached to particulates. Phosphorus is a common element in igneous rock and is fairly abundant in sediments (Buxton and others, 1999). Orthophosphorus is applied to agricultural land, lawns, and gardens and can be washed into streams in runoff. Phosphorus also enters streams from wastewater-treatment plants.

TSS, which is regulated, may be one of the more important indicators of nonpoint-source contamination. The health of stream ecosystems is affected by high concentrations of TSS, which also is a concern for water purveyors. The primary sources of TSS in streams are storm runoff, instream erosion, and resuspension. A poorly controlled process in a sewage-treatment plant and algae blooms also can cause an increase in TSS concentrations. The surface-water standards are 40 mg/L in nontrout waters and 25 mg/L in trout waters (New Jersey Department of Environmental Protection, 1998).

Sodium concentrations were evaluated to determine whether there were exceedances of the 50 mg/L New Jersey secondary MCL drinking-water standard (New Jersey Department of Environmental Protection, 1989, Shelton and Lance, 1997). Sodium tends to remain in solution when dissolved from weathering rocks and not form precipitates that can maintain low sodium concentrations (Buxton and others, 1999). Cation-exchange processes in freshwater systems tend to extract divalent ions from solution and replace them with monovalent ions, especially sodium (Hem, 1985). Also, sodium salts used for deicing roads can be transported to streams in runoff.

Sulfate concentrations were evaluated to determine whether there were exceedances of the 250 mg/L surface-water and drinking-water standards (New Jersey Department of Environmental Protection, 1989; Shelton and Lance, 1997; and New Jersey Department of Environmental Protection, 1998). Sulfur is widely distributed in reduced form in igneous and sedimentary rocks as metallic sulfides. When sulfide minerals undergo weathering in contact with aerated water, the sulfur is oxidized to yield sulfate ions (Hem, 1985). Combustion of fuels also can be a major source of sulfates in streams. High concentrations of sulfate affect the taste of drinking water and may cause laxative effects.

Water temperature influences the chemical and biological processes in a stream. The amount of sunlight, rainfall, air temperature, and ground-water discharge to a stream, and thermal point sources all influence the water temperature of a stream. New Jersey surface-water standards for stream temperatures vary according to stream classification. In trout-production waters, properly treated wastewater effluent should not deviate more than 0.6 ^{o}C from the ambient temperature (New Jersey Department of Environmental Protection, 1998). In trout-maintenance waters, properly treated wastewater effluent should not cause ambient temperature to increase more than 1.1^{o} C or should not cause water temperature to exceed 20 ^{o}C. In nontrout waters, no heat may be added which would cause temperatures to deviate more than 2.8 ^{o}C from ambient temperatures, or exceed 27.8 ^{o}C for small mouth bass or yellow perch waters, or 30 ^{o}C for other nontrout waters (New Jersey Department of Environmental Protection, 1998). For the purpose of this study, a reference point of 20^{o} C for trout production and trout-maintenance waters and a reference point of 27.8 ^{o}C for nontrout waters were used to evaluate streams with elevated water temperature.

Quality Assurance of Data

Quality-assurance samples were collected to evaluate the reliability and reproducibility of the data. Three types of quality-assurance samples were collected -- blanks, replicate and spikes. Field equipment blanks and concurrent replicate samples are routinely collected for all major ions and nutrients analyses.

Split spiked samples were collected along with the VOC and pesticide ambient samples collected by the LINJ NAWQA. Spiked samples were used to evaluate potential bias and the ability of the analytical method to recover analytes (Reiser, 1999).

All instream water-quality data from 1991-97 were reviewed extensively for quality-assurance purposes and entered into a database for data manipulation and statistical analysis. Data on 20 constituents were plotted in relation to streamflow to observe seasonal differences. Data on some constituents were compared with data on other constituents. As a result of the review, less than 0.1 percent of the values were changed or removed from the database. Most of the corrections were made to field readings or data that had been entered into the database manually from paper copies.

Missing values of total NO3+NO2 were replaced with values of dissolved NO3+NO2. Little difference is observed when both values are present for a sample. NO3+NO2 is present in water almost exclusively as dissolved species (Hem, 1985). Total organic carbon was calculated by adding suspended organic carbon to dissolved organic carbon. Missing values of total TSS were substituted with values of total suspended sediment.

Instantaneous-flow data associated with each sample were checked by plotting the flows in relation to gage height, by plotting flows in relation to mean daily flow when available, and by using regression analysis to identify data outliers. Large residuals from regression analysis were evaluated for possible errors. Thirty-one of 801 flow measurements or estimates associated with the samples collected during 1991 through 1997 were revised.

Statistical Methods

Water samples were categorized by the season and the hydrologic condition in which they were collected. The growing season is April through October, and the nongrowing season is November through March. The dates for defining these seasons are based on the average times of the first and final frosts in New Jersey (Ruffner and Bair, 1977). All samples were grouped into one of two flow categories, low flow or high flow. A low-flow sample is defined as a sample collected when the streamflow was less than the 7-year (1991-97) median flow at the site. A high-flow sample is defined as a sample collected when the streamflow was greater than the 7-year (1991-97) median flow.

Detection frequencies were computed for each constituent (table 2). Water-quality data that consist of concentrations of constituents reported as less than analytical detection limit set by the laboratory are considered censored data or nondetections. In some cases data on fecal coliform bacteria that are greater than the analytical detection limit are considered censored data or nondetections. One or more of the data points for alkalinity, unionized ammonia, TKN, BOD, fecal coliform, NO2+NO3, total phosphorus, and TSS are censored. Nonparametric methods of statistical analysis were used on the data sets with censored values to more accurately study the data.

Percentiles show the percentage of samples with results that are less than a particular value. These statistics were used to analyze the distribution of concentrations and loads in a data set. Percentiles of censored data sets were computed using a maximum likelihood estimation method developed by Helsel and Cohn (1988). With this method the censored values contain nearly as much information for estimating percentiles as would the same observations had the detection limit been below them (Helsel and Cohn, 1988). Medians of highly censored constituents shown on maps and used for comparisons to land use are derived from this method. The medians and percentiles shown in boxplots were not estimated with this procedure. The boxplots (shown farther on in this report) only show the distribution of data greater than the detection limit. Percentiles were used to summarize the data and to make comparisons at each site and among sites by season and flow condition. The inner quartile range (IQR) was used to measure the variability of data. It is a measure of the range of the central 50 percent of the data and is defined as the 75th percentile minus the 25th percentile (Helsel and Hirsch, 1992). IQR was used instead of variance or standard deviation because it is not influenced by outliers or non-normal distributions.

The Wilcoxan rank sum test was used to test for differences in the means of two data sets. It is the nonparametric equivalent to a t-test. It was used to compare growing season to nongrowing season data and to compare data collected at high-flow conditions to data collected at low-flow conditions. The null hypothesis (H_0) states that medians of the data are equal in each season or flow condition. The alternate hypothesis states that the median from one group of data differs from the other. A p-value of less than or equal to 0.05 was used to define a significant difference between groups. A p-value this low minimizes the chance that a difference occurred by chance alone.

One-way analysis of variance (ANOVA) was applied to the ranks of concentrations to determine whether median concentrations varied among sites by season and flow condition, and whether concentrations at a single site varied by season and flow condition. The null hypothesis (H_0) states that median concentrations are equal at each site. The alternate hypothesis states that the median concentration from at least one site differs from the others. If the null hypothesis was rejected, Tukey's test was used to determine which pairs of median concentrations were significantly different at the 0.05 level. By selecting a p-value less than 0.05, there is a 95 percent or greater chance that the difference is truly significant. Tukey's groups are represented by letters A through K on the boxplots. Sites in group A have the highest median concentration, and those in groups B through K have successively lower rank concentrations. Sites containing one or more of the same letters do not differ significantly (Helsel and Hirsch, 1992). Two-way ANOVA was applied to ranks of concentrations to simultaneously test the significance of season, flow condition, and season as a function of flow as factors that contribute to concentrations in streams. Season as a function of flow includes comparisons of median concentrations at high flow in the growing and nongrowing seasons, and at low flow in the growing and nongrowing seasons.

Regression techniques were used to evaluate concentration and load. Relations between instantaneous streamflow and concentration, and instantaneous flow and load were analyzed for each of the sites. Tobit regression uses censored data to develop the relation. Constituents detected in more than 50 percent of the samples from a site were analyzed by use of Tobit regression (Cohn, 1988). BOD data were censored for 53 to 56 percent of the samples from Millstone River near Manalapan, Matchaponix Brook at Spotswood, and Manalapan Brook near Manalapan. Results from Tobit regression at these sites are considered less reliable than at sites with fewer than 50 percent of the samples censored. The relation was considered to be significant if the slope of the regression line was different from zero at the 0.05 level of significance. A base-10 logarithm transformation of streamflow and concentration was used to normalize the data before using Tobit regression. Median concentrations of the 17 constituents were evaluated in relation to land use at the 21 sites by using least squares linear regression (Ott, 1988).

Multivariate regression techniques were used to estimate velocities and nonpermitted yields by developing linear relations with basin characteristics. Data for each variable were normalized in order to obtain the best linear relation. The Shapiro-Wilk statistic (SAS Institute, Inc., 1995) was used to test for normality in the data set of each variable. Data were normalized using various transformations to make the data more symmetric and linear. In some cases, the raw data were normally distributed and, therefore, no transformation was needed. Variables that could not be normalized were dropped from the analysis. Pearson correlation analyses also were performed to determine interaction between the basin characteristics.

Pearson correlation analysis was used to examine the relation between (1) nonpermitted yield and (2) velocity and independent variables, and the relation between the independent variables. A strong linear relation is shown between variables when the test yields a high correlation coefficient and a low probability level of significance. A significant relation between independent variables indicates the possibility that these correlated variables measure the same effect on the dependant variable and, if used together in a model, may increase instability in coefficient estimates (SAS Institute Inc., 1995). This is referred to as multicollinearity. Multicollinearity between variables was examined by use of the variance inflation factor (VIF) test.

The VIF is defined as $1/(1-R^2)$. Each variable in a model is associated with a VIF value. Any variables associated with a VIF that exceed the defined number are more closely related to other independent variables than they are to the dependant variable (SAS Institute Inc., 1995). Only models with variables associated with a VIF less than $1/(1-R^2)$ were considered in this analysis.

A procedure in SAS System for Regression called the R-square selection method was used to summarize information on the estimated coefficients from many different models. The method was used to assist in selecting a suitable subset of variables for a final model (SAS Institute Inc., 1995). The models were evaluated by looking at statistics that describe the model's prediction quality and multicollinearity—R-square value, Mallows C(P), Press statistic, and VIF. The best models showed the best combination of low Mallows C(P), Press statistic, standard error as measured by the coefficient of variation, and VIF and had high R-square values. A low Mallows C(P) and a low VIF were the statistics most influential in choosing a model. Mallows C(P) is a measure of the total squared error of a model (SAS Institute Inc., 1995).

A stepwise forward regression procedure was another approach used to choose the best model (SAS Institute Inc., 1995). This method starts with the best univariate model and adds variables one by one that result in the largest increase in R-square. Variables with a greater than 5 percent probability level of significance were removed from the model. The models chosen by this method were not necessarily the best, as defined by the statistics that describe the model's prediction quality and multicollinearity. Models were selected on the basis of the summary from the R-square selection method, the analysis of multicollinearity, and the stepwise procedure.

Trend tests by Hickman and Barringer (1999) were conducted on constituent concentration data collected during 1986-95 for the same 21 sites studied for this analysis by use of Seasonal Kendall test on uncensored data sets (Helsel and Hirsch, 1992) and by Tobit regression on censored data sets. Trends tests were performed on all constituents included in this study except TSS. Results from Hickman and Barringer (1999) are summarized in this report for all constituents. The Seasonal Kendall test was performed on TSS data for this analysis. All censored values were given a value of 0.50 mg/L or one-half the censored value.

Trend tests were conducted for this study on concentration data collected during 1991-97 by use of the Seasonal Kendall test (Helsel and Hirsch, 1992). This is a nonparametric test designed for water-quality data that are not normally distributed. The test also accounts for seasonal variability in the data by comparing data collected in the same season. The test was performed on two sets of data (1) all data and (2) data collected at low-flow conditions. The test was performed for all constituents with and without censored data. For censored values in the data set, one-half the censored value was substituted. A significant trend exists if the test statistic tau is significantly different from zero at the 0.05 confidence level.

Computation of Instream Loads and Yields

Instream loads were computed for each sample by multiplying the instantaneous streamflow value by the concentration and applying unit conversions to give a value of load in pounds per day by using the following formula:

$$\text{Load (lb/d)} = \text{Concentration (mg/L)} \times \text{streamflow } (\text{ft}^3/\text{s}) \times 2.20462 \times 10^{-6} \text{ lb/mg} \times 86{,}400 \text{ s/d} \times 28.316 \text{ L/ft}^3 \qquad (2)$$

Instantaneous yields (loads per unit area) were computed by dividing load by drainage area above the sampling site. This area-normalized load was used to eliminate some of the bias inherent in studying loads at sites with different sized drainage areas. Streamflows and loads are generally higher at sites with larger drainage areas. This method, however, does not eliminate all the variability in loads between sites caused by differences in drainage areas because the flow per unit area varies across the study area. Flows per square mile are highest in the New England province and lowest in the Piedmont province. Runoff is a higher percentage of total streamflow in the Piedmont province than in the other provinces because of the presence of shallow soils with low permeability.

Loads and yields computed from concentrations that are reported as less than the laboratory detection limit are listed in this report as a "less than" value. The probability plotting procedure described in the "Statistical Methods" section was used to estimate medians and other percentiles of censored constituent data used in this analysis.

Permitted Load

Effluent-flow and concentration data from permitted point sources categorized as minor or major, and as municipal or industrial, were included in this study. Discharges of non-contact cooling water, stormwater, and discharges from temporary cleanup sites were excluded.

The contribution of permitted load to total instream load was computed at the sampling sites for each year from 1991-97. The permitted component of instream-load that reaches the sampling point is dependent on four factors: (1) the amount of load discharged to the stream, (2) the distance between the discharge point and the sampling point, (3) the average velocity through the stream reach, and (4) the attenuation rate of the constituent. Stream velocities and distances along stream reaches were computed by USGS, and data on flow, constituent concentrations and load discharged to the stream, and attenuation rates were provided by TRC Omni Corporation (2001).

Nonpermitted Load

Nonpermitted load is defined as all instream loads not attributable to permitted point sources. Nonpermitted loads were computed at three flow conditions--high, median, and low--by subtracting permitted load from the total instream load at each sampling site. Estimates of nonpermitted loads at sampling sites with a high percentage of permitted loads could be underestimated because permitted loads dominate the system. Estimates of permitted loads for some constituents are equal to the total instream load at some sampling sites in close proximity to permitted point sources.

The nonpermitted yields discussed in this report were estimated for growing season conditions by use of attenuation rates at 20 ^{o}C, unless otherwise stated. An equation was provided by TRC Omni Environmental Corporation (2001) to correct the attenuation rate coefficients for different water temperatures (TRC Omni Environmental Corporation, 2001). The equation and comparisons of constituent yields between the growing season and nongrowing season are summarized in the section "Adjustment for Attenuation Rates."

Estimation of Time of Travel

Time of travel (TOT) was estimated for stream reaches without any TOT data. Results of the following three estimation methods were compared: (1) a prediction equation developed by the USGS (Jobson, 1996), (2) a modification of that prediction equation, and (3) a new prediction equation based on velocities in the study area and seven explanatory variables. No TOT studies were done on the 21 small streams in the study area that receive discharges from permitted point sources. Sixteen of these streams are located in the Piedmont and New England Physiographic Provinces, and 5 are located in the Coastal Plain. The drainage areas of these tributaries range in size from 2.93 mi^2 (Cuckles Brook) to 50.0 mi^2 (Beden Brook).

Jobson (1996) compiled velocities and hydraulic data for more than 980 sub-reaches of about 90 rivers in the United States, representing a wide range of river sizes, slopes, and geomorphic features. Data on four explanatory variables were available for a sufficient number of reaches for regression analysis with velocity. The variables included drainage area (A_d), reach slope (S), mean annual river discharge (A), and discharge of the event studied (Q).

The prediction equation (3) developed by Jobson (1996) has an R-square value of 0.70. The equation accounts for 70 percent of the variation in velocity. It was used to compute stream velocity at the 90th, 50th, and 25th percentile flow durations for all reaches in the subbasin. The velocities predicted along reaches with existing TOT data were used for comparative purposes. Velocities were converted to English units for this study.

$$\text{Velocity} = 0.094 + 0.0143 \times (D'_a)^{0.919} \times (Q'_a)^{-0.469} \times S^{0.159} \times Q/D_a, \qquad (3)$$

where

Q is the instantaneous streamflow, in cubic meters per second;

Q_a is the annual average flow, in cubic meters per second;

Q'_a is equal to Q/Q_a ;

D_a is the average drainage area of the stream reach, in square kilometers;

g is acceleration of gravity;

D'_a is equal to $D_a^{1.25} \times g^{0.5} / Q_a$; and

S is slope, in meters per meter.

Drainage areas were derived from GIS coverages and from USGS quadrant maps that contain the original delineated drainage-basin divides. Mean annual discharge and 90th, 50th, and 25th percentile flows were computed from mean daily streamflow data for all continuous-record gaging stations. Estimates of these flow statistics were computed at low-flow partial-record sites by use of MOVE1 correlation analysis. A drainage-area adjustment (flow per square mile) technique was used to estimate flows on streams with no flow data available. The flow at nearby sites was divided by drainage area to get an average flow per square mile for the area studied.

A GIS coverage was used to compute distances and slopes along stream reaches. Distances were derived from the USGS National hydrologic data set coverage. Distances were computed from point sources to stream confluences, point sources to sampling sites, and between sampling sites. Elevation data were derived from digital elevation maps. The USGS National Elevation data set with 30-meter grid spacing was used to compute the elevation at point-source locations, sampling sites, and stream confluences. Slopes were computed from these data.

Estimation of Velocities

Velocities computed from TOT data from previous studies were compared with velocities estimated with the Jobson regression equation (2). In general, the Jobson method underestimated high velocities and overestimated low velocities in the Raritan River Basin. It did not accurately predict the full range of average velocities for the reaches in the basin. At 90th percentile flows, average velocities from the TOT studies ranged from 0.20 ft/s for Drakes Brook tributary to the S.B. Raritan River to 0.8 ft/s for the S.B. Raritan River. Velocities from the Jobson method ranged from 0.35 ft/s to 0.55 ft/s. The average percentage difference for all reaches showed that velocities from the Jobson method were 4.2 percent higher than velocities from TOT studies. The largest differences between computed velocities from TOT studies and estimated velocity from the Jobson method at the 90^{th} percentile flow ranged from -39 percent to +126 percent.

At 50th percentile flows, average velocities from the TOT studies ranged from 0.40 ft/s for Drakes Brook tributary to the S.B. Raritan River to 1.3 ft/s for the S.B. Raritan River and mainstem Raritan River. Average velocities from the Jobson method ranged from 0.4 ft/s to 0.65 ft/s. On average for all reaches, the Jobson method underestimated velocities at the 50^{th} percentile flows by 32 percent. The largest difference between velocities at the 50^{th} percentile from TOT studies and the Jobson method along a reach was -56 percent to +28 percent. The average difference was -32 percent. At 25th percentile flows, average reach velocities from TOT studies ranged from 0.68 ft/s for Matchaponix Brook to 2.0 ft/s for the Lamington and mainstem Raritan Rivers. Flows along all reaches were underestimated, from -67 percent to -29 percent. The average difference was -51 percent.

The Jobson method for estimating stream velocities was modified to improve the fit of estimated velocities to the TOT data for the Raritan River Basin. A least squares linear regression equation was developed for velocities computed from TOT studies in the Raritan River Basin and the variables used in Jobson's equation. Velocity was regressed against a dimensionless variable created by multiplying the variables from the Jobson method $[(D'_a)^{0.919} \times (Q'_a)^{-0.469} \times S^{0.159} \times Q/D_a]$. As a result, the equation is essentially the same, except the slope and constant differ from those in equation (3).

$$\text{Velocity} = -0.0487 + 0.0569\,[(D'_a)^{0.919} \times (Q'_a)^{-0.469} \times S^{0.159} \times Q/D_a\,] \qquad (4)$$

The modified method was better at predicting the variability in velocities throughout the basin; however, percentage differences were still large.

Selection of Regression Methods

Seven explanatory variables were considered in an exploratory analysis to find the regression model with the best ability to predict velocity. A linear relation was developed between TOT velocity and seven explanatory variables. The seven variables were chosen because the data were available for all reaches studied, and the variables were found to relate significantly to velocity in the study by Jobson (1996). The variables used in the analysis are event flow (Q), average flow (Q_a), drainage area (D_a), and the four variables used in the Jobson regression equation (Q/Qa, Q/D_a, slope, and $D_a^{1.25} \times 9.81^{0.5}/Q_a$). A log transformation of the explanatory variables and velocity resulted in a better model with higher R-square value, lower Mallow's C(P) and smaller residuals.

Pearson correlation analysis was used to examine the relations between velocity and each independent variable and the relations among independent variables. All seven independent variables were significantly related ($p<0.05$) to velocity. This indicates that each variable was useful in estimating velocity. A comparison of pairs of independent variables indicated some pairs have high correlation coefficients and a low probability level of significance. Highly correlated variables were not used in the same model.

The R-square selection method was used to summarize information on the estimated coefficients from the seven-variable model to determine a suitable subset of variables for a final model (SAS Institute, Inc., 1995). A two-variable model appeared to be the best choice. The four best two-variable models were evaluated by looking at statistics that describe the model's prediction quality and multicollinearity: R-square value, Mallows C(P), PRESS statistic, and VIF. The two-variable models showed the best combination of low Mallow's C(P), PRESS statistic, and low statistic standard error as measured by the coefficient of variation, low VIF, and a high R-square value. A low Mallow's C(P) and low VIF were the statistics most influential in choosing a model.

A stepwise regression procedure was the second approach used to choose the best models (SAS Institute Inc., 1995). This method starts with the best univariate model and adds variables one by one that result in the largest increase in R-square. Variables with a greater than 5 percent probability level of significance were removed from the model. The models chosen by this method were not necessarily the best as defined by the statistics that describe the model's prediction quality and multicollinearity. Models were selected on the basis of the summary from the R-square selection method, analysis of multicollinearity, and the stepwise method.

Two models were developed for predicting velocity in the Raritan River Basin. One model was chosen to predict velocity along reaches in the Piedmont and New England Physiographic Provinces, and a second model was chosen to predict velocities along reaches in the Coastal Plain. The first model was developed using data from 37 TOT studies on stream reaches with less than a 50-mi^2 drainage area in the New England province. TOT studies along smaller stream reaches were chosen because all stream reaches for which velocities would be estimated are less than 50 mi^2. Three of the two-variable models were similar statistically and resulted in similar predictions. A model that uses the variable flow divided by drainage area and average flow was found to generate velocities that resulted in slightly lower differences between estimated velocities and actual TOT study velocities. This was the two-variable model with the lowest Mallow's C(P), lowest VIF, lowest PRESS statistic, and highest R-square. This model predicts velocities more accurately than those predicted by the Jobson method or the Jobson method with modifications. Model equation (5) was used to predict stream velocities along 17 tributaries to the N.B and S.B. Raritan Rivers, Lamington River, Millstone River, and mainstem Raritan River in the New England and Piedmont Physiographic Provinces. For this equation, r^2 equals 0.81.

$$\text{Velocity} = 0.352 \times Q/D_a^{\,0.743948} \times Q_a^{\,0.191575} \quad (5)$$

Equation (5) was better at estimating the ranges in velocities throughout the New England and Piedmont parts of the basin than the equation from the Jobson method. At 90th percentile flows, average estimated velocities from equation (5) ranged from 0.25 ft/s to 0.80 ft/s along reaches in the basin, whereas velocities from TOT studies ranged from to 0.20 to 0.80 ft/s. The largest differences between measured velocities along a reach from TOT studies and those estimated from this equation ranged from -29 percent to +39 percent. At 50th percentile flows, average estimated velocities ranged from 0.47 to 1.26 ft/s, whereas velocities from TOT studies ranged from 0.40 to 1.5 ft/s. The largest differences between measured velocities along a reach from TOT studies and those estimated with this method ranged from -20 percent to +36 percent. At 25th percentile flows, estimated velocities ranged from 0.79 to 1.96 ft/s, and measured velocities from TOT studies ranged from 0.68 to 2.00 ft/s. The largest differences in estimated velocities along a reach ranged from -16 percent to +36 percent. On average for all reaches, this method produced estimates that were within 4.8 percent of measured velocities at the 90th percentile flow, 6.9 percent at the 50th percentile, and 7.2 percent at the 25th percentile.

A second model was developed to estimate velocities on four tributaries to the Millstone River in the Coastal Plain. The tributaries are located upstream from Carnegie Lake. Too few TOT data were available for the Coastal Plain part of the study area to develop a model for the area. Only three TOT studies included the Coastal Plain part of the study area. One study was of a Millstone River reach that averages 60 mi^2 in length, and the other two studies were of the Matchaponix Brook along reaches that are about 26 and 27 mi^2. The results from the three TOT studies from the Coastal Plain were added to those from the 37 TOT studies used in the model for the stream reaches in New England and Piedmont provinces. The results of these 40 TOT studies were used to develop model equation (6).

A two-variable model using the variables (1) flow divided by drainage area and (2) average flow was found to have the best fit with measured velocity. This model estimated velocities along the Millstone River more accurately than did the Jobson method and modified Jobson. This model, however, does not improve upon the Jobson estimates of velocity along the Matchaponix Brook. The second model, equation (6), estimates velocities more accurately than the first model of Coastal Plain streams.

The model equation (6) was used to predict stream velocities in four tributaries to the Millstone River. For this equation, r^2 equals 0.75.

$$\text{Velocity} = 0.3505 \times Q/D_a^{\,0.696969} \times Q_a^{\,0.192168} \quad (6)$$

The velocities estimated from the equations were compared to velocities measured in the three TOT studies on the Matchaponix Brook and Millstone River. At 90th percentile flow, the velocities estimated for three reaches, from point sources to the sampling site, ranged from -35 to +30 percent. At 50th percentile flow, estimates ranged from -8 to +46 percent. At 25th percentile flow, velocities ranged from +2.1 to +59 percent. The estimated velocities along the Millstone River reach upstream from Carnegie Lake, which were included in a TOT study, ranged from -30 percent at 90th percentile flow to +2.1 percent at 25th percentile flow.

The estimated velocities for Millstone River tributaries compared favorably to velocities measured with flow meters along those streams. Streamflow measurements are available for USGS sampling sites on all tributaries in the Millstone River where point sources discharge, except Devils Brook (fig. 1).

Correlation Analysis and Multiple Regression Analysis

Three general categories of characteristics were considered in this analysis: (1) anthropogenic factors, (2) soil and geologic features, (3) and hydrology and basin features. Correlation analysis and multiple regression analysis were used to analyze relations between nonpermitted yield and basin characteristics at the 21 sites studied. Correlation analysis measured the strength of the association between the nonpermitted yield at each flow condition and individual environmental variables. Multiple regression was used to evaluate the effect of multiple environmental variables on each nonpermitted yield. Multiple regression also was used to analyze all the explanatory variables and to select those that best explain the variability in nonpermitted yields.

Forty-one explanatory variables were considered in an exploratory analysis to find a regression model with the best ability to estimate nonpermitted yields. All variables were tested for normality. The data for 15 of the variables were normally distributed. Data for 21 of the other variables were normalized by using various transformations to reduce variability and to make the data more symmetric and linear. Five other variables could not be normalized. Flashiness, a measure of streamflow variability, could not be fit to a normal distribution by use of standard transformations (log, square root, and raising to various powers). Flashiness, however, was considered likely to be associated with the variability in nonpermitted yield, and the data were fit to a different distribution. Two measures of flashiness, the ratio of 25^{th} to 75^{th} percentile flow and the ratio of 10^{th} to 90^{th} percentile flow, were fit to a Pareto distribution (Werckman and others, 2001) when no transformation was found to fit the data to a normal distribution. The five variables that could not be normalized-- percentages of Coastal Plain, New England, and Piedmont provinces and the percentage of metamorphic and unconsolidated bedrock in each subbasin-- were dropped from the multiple regression analysis. Each of these variables was correlated with other explanatory variables used to explain differences in physiographic provinces. Barren land and open water constitute a small percentage of land use in the study area. The percentages do not differ much between sites, so these variables were dropped from the multiple regression analysis.

Pearson correlation analysis was used to examine the relation between nonpermitted yield and each independent variable and the relation between independent variables. Thirty-seven of the 41 variables were significantly related ($p<0.05$) to nonpermitted yield of at least one constituent at one or more flow conditions. This indicates that each of these variables could be useful in estimating nonpermitted yield. Only stream density and percentages of urban, commercial/industrial, and total undeveloped land uses were not related to nonpermitted yields. Although the statistics show that the percentage of urban land and the percentage of total undeveloped land were not significantly correlated to yields, other indicators of those types of land use were correlated to nonpermitted yields. For example, impervious surface area and forested land, indicators of urban and undeveloped land uses, respectively, correlated with nonpermitted yields of various constituents. The 12 variables not included in the discussion of correlation results are the three physiographic provinces; metamorphic and unconsolidated bedrock; one measure of flashiness; percentages of barren land, residential land, and water; horizontal permeability; and percentages of sewered and non-sewered areas.

A comparison of pairs of independent variables made with the correlation analysis indicated that some pairs have high correlation coefficients and a low probability level of significance, which indicates a strong linear relation between these independent variables. This increases the possibility that correlated variables measure the same effect on nonpermitted yield (multicollinearity) and, if used together in a model, could increase instability in coefficient estimates (SAS Institute, Inc., 1995). This is referred to as multicollinearity and, in the multiple regression procedure, is measured by computing the VIF. Variables with low VIF do not show multicollinearity.

Correlations between independent explanatory variables that describe different factors make it more difficult to come to conclusions about the major features that contribute to variation in nonpermitted yields in the basin. Basin characteristics that describe land use were correlated with characteristics that describe soils, lithology, and slope. Forested land use is positively correlated with soil group B, excessively well-drained soil, metamorphic and igneous bedrock, and slope, all features of the New England province. Forested land use is negatively correlated with well-drained soil, soil group A, and unconsolidated bedrock, all features of the Coastal Plain province. Urban land use is positively correlated with soil group D. Agriculture is negatively correlated with soil group D, excessively well-drained soil, and igneous and metamorphic bedrock, and is positively correlated with well-drained soil.

Any variables that are associated with a VIF and exceed the definition ($1/1-R^2$) are more closely related to other independent variables than they are to the dependant variable (SAS Institute, Inc., 1995). Only models with a VIF less than the value of $1/(1-R^2)$ were considered in this analysis.

A procedure in SAS called the R-square selection method was used to summarize information on the estimated coefficients from many different models. The method was used to assist in selecting a suitable subset of variables for a final model (SAS, Institute, Inc., 1995). The models were evaluated by looking at the statistics that describe the model's prediction quality and multicollinearity--R-square value, Mallow's C(P), PRESS statistic, and VIF. The best models showed the best combination of low Mallow's C(P), PRESS statistic, standard error as measured by the coefficient of variation and VIF, and a high R-square. A low Mallow's C(P) and a low VIF were the statistics most influential in choosing a model.

The R-square selection method was applied to four subsets of variables to allow the program to run more efficiently. The variables chosen for each of the four subsets were combined, and the R-square selection method was rerun. The variables selected by this procedure were analyzed further for collinearity by analyzing correlation results. If explanatory variables correlated with one another, the variable with the smallest partial R-square value was dropped.

A stepwise regression procedure was the final approach used to choose the best model (SAS Institute Inc., 1995). The step-forward method starts with the best univariate model and adds variables one by one that result in the largest increase in R-square. Variables with a greater than 5 percent probability level of significance were removed from the model. The models chosen by this method were not necessarily the best as defined by the statistics that describe the model's prediction quality and multicollinearity. In some cases, the explanatory variables in the models chosen by use of the stepwise procedure were correlated. In those cases, the variable with the least influence --the lowest partial R-square value--was removed. Models were selected on the basis of the summary from the R-square selection method, analysis of multicollinearity, and the stepwise procedure.

A linear model was developed for basin characteristics and nonpermitted yields of all constituents at each of the three flow conditions. The only constituent without a significant model at each flow condition was NO3+NO2 at high flow. The models of nonpermitted yields at low-flow conditions predict the basin characteristics that most affect the quality of streams at base-flow conditions. The results of models of nonpermitted yields at high flow indicate the basin characteristics that have the greatest effect on the quality of the stream during storm runoff.

The estimates of attenuated permitted yields at some sites at low and median flow were nearly equal to or in some cases greater than the estimate of total yield in the stream. This resulted in the nonpermitted yields estimated for some constituents to be biased low because of the predominance of permitted yields at these sites. Nonpermitted yields at these sites were compared with nonpermitted yields at sites that drain basins with similar characteristics but without permitted point sources. In almost all cases, those sites with greater than 50 percent of the total instream yield originating from permitted sources had much lower estimated nonpermitted yields than at those sites without any permitted point-source yields. Consequently, those sites with greater than 50 percent of the total instream yield originating from permitted sources were not used in the multiple regression analysis. This only affected some of the constituents at low and median flows. The constituents most affected were NO3+NO2 and total phosphorus at low flow. The models of total phosphorus and NO3+NO2 at low flow included nonpermitted yields from only 9 and 11 sites, respectively. The small number of data points in these models makes the results less reliable. Censoring this data could result in statistically significant regressions that may not be valid for the sampling sites removed from the model.

EVALUATION OF STREAMFLOW

Streamflow was measured at each of the 21 surface-water sampling sites studied in the Raritan River Basin. Instantaneous streamflow was determined for the mean time of each sample from ratings that relate the continuously recorded water-level elevation (stage) during sample collection to streamflow. Seven of the 21 sites have a continuous 15-minute record of streamflow. The other 14 sites have a staff gage for recording stage at the time a sample is collected. Instantaneous streamflow measurements are made periodically to develop a stage-discharge rating curve. The stage-discharge rating curve is used to convert the staff reading to a discharge. Streamflow measurements also are used to correlate flow with mean daily streamflows at nearby continuous-record gaging stations to estimate flow at certain stages or during times when the rating curve is not reliable. A measurement or estimate of streamflow is needed at the time the sample is collected for computation of loads.

Streamflow data can be used to develop a flow-duration curve that summarizes the magnitude and frequency of flow at each site (Searcy, 1959). Flow and water quality at a particular flow duration can be compared between sites. A flow-duration curve is a cumulative frequency curve that shows the percentage of time that specified mean daily flow was equaled or exceeded at each of the sampling sites during 1991-97 (table 3). For the purpose of this study, loads were examined at the 90^{th}-, 50^{th}-, and 25^{th}-percentile flow duration, streamflows defined as low, median, and high flow, respectively.

Flow durations at the sites with continuous streamflow records were computed with the Daily Value Statistics (DVSTAT) computer program associated with the USGS database WATSTORE. The 7-day 10-year low-flow statistic (MA7CD10) also was computed at each site with a continuous record of streamflow. The MA7CD10 flow was computed from the streamflow record for the entire period at all sites except for the sites on S.B. Raritan River at Stanton and Three Bridges, and the sites on the Raritan River at Manville and Bound Brook. Streamflow records registered after streamflow regulation began in September 1963 for Spruce Run and Round Valley Reservoirs were used to compute MA7CD10 flow at these sites.

Correlation procedures and streamflow records for nearby gaging stations were used to estimate flow duration and MA7CD10 flow at the 14 sites without a continuous record of streamflow. A streamflow record extension technique, maintenance of variance extension (MOVE1), was used to develop a correlation between instantaneous flow at the sampling site and mean daily flow at a nearby continuous-record gaging station (Hirsch, 1982). A log transformation of flow was used to normalize the data before the relation was developed. This technique is preferred for estimating low- to median-flow conditions. The accuracy of the MOVE1 method was tested at the seven gaging stations with continuous records at various flow durations. Estimates of flows at the 25th percentile were within 10 percent of the

Table 3. Streamflow statistics of mean daily discharge, sampled flows, and total permitted point-source discharge at each sampling site in the Raritan River Basin, N.J.

[Flows are in cubic feet per second. Flow durations and mean annual flows are based on streamflow records from 1991 through 1997. *, before adjustment for withdrawal. Permitted point source discharge is average total discharge to streams upstream from the site during 1991-97.]

Station number and stream name	Total permitted point-source discharge	Streamflow statistics (1991-97)					Number of samples	Sampled streamflow		
		Mean annual flow	Flow duration values of mean daily discharge							
			25 percent	Median	75 percent	90 percent		Mini-mum	Median	Maxi-mum
01396280 S.B. Raritan River	1.5	89	100	65	40	29	35	25	66	300
01396535 S.B. Raritan River	1.5	142	170	98	57	40	37	34	110	600
01396588 Spruce Run	.04	26	33	17	8.7	5.7	37	3	17	325
01396660 Mulhockaway Ck	.004	19.8	21	12.8	7.0	4.1	37	2.8	11	203
01397000 S.B. Raritan River	3.6	275	300	180	133	105	35	76	187	1,430
01397400 S.B. Raritan River	8.2	300	330	190	140	110	35	93	240	1,490
01398000 Neshanic River	0	46	37	14.9	4.1	1.5	56	.5	15.5	1,500
01398260 N.B. Raritan River	0.7	12.8	15	9.2	4.3	3.0	35	2.1	9	30
01399120 N.B. Raritan River	3.2	133	140	75	27	23	35	10	75	220
01399500 Lamington River	3.7	58.6	74	45	27	16	37	8.9	47	280
01399700 Rockaway Creek	0.9	48.6	58	33	19	13	35	11	42	280
01399780 Lamington River	4.7	201	210	117	62	39	37	23	112	2,600
01400500 Raritan River	16.1	821	870	460	280	220	35	207	459	3,870
01400540 Millstone River	0	10.5	12	7.2	4.3	3.2	35	3.7	9.8	34
01400650 Millstone River	5.1	75	92	49	27	18	30	8	48.5	200
01401000 Stony Brook	.5	73.4	63	23	6.9	2.8	59	1.3	22	5,810
01401600 Beden Brook	.9	62.7	54	19	5.1	2.0	37	1.2	15	391
01402000 Millstone River	23	384	407	208	110	73	31	46	204	2770
01403300 Raritan River	*65	1,190	1,250	590	280	180	56	140	840	14,300
01405302 Matchaponix Brook	7.3	61.6	74	42	27	18	35	17	40	600
01405340 Manalapan Brook	0	23.2	26	16	10	8.0	35	6.5	17	66

values computed from the daily flow record. Estimates of flows higher than the 25[th] percentile were found to have a larger standard error than was acceptable for this study. A test for base-flow conditions excludes high-flow measurements from the correlation. The flow duration values for Raritan River at Bound Brook and for Millstone River at Grovers Mill were estimated using drainage area adjustments from nearby gaging stations. The MOVE1 method was used to estimate instantaneous flow at the time of sample collection at some sites with a poor stage-discharge rating.

Samples were collected at each site five times a year at regularly scheduled intervals throughout the year. The sampling schedule was not designed to allow the collection of samples at targeted flow conditions. Samples were collected at all sites over the range of approximately 10- to 90-percent flow duration. Some sites were sampled during flows that exceeded the 1 percent duration, and other sites were sampled during flows as low as approximately 98-percent duration (table 3). Most of the samples collected at high flows were collected during a receding limb of a storm hydrograph. Samples were collected randomly and were not collected throughout a storm. No samples were collected at any site at flows as low as the MA7CD10 flow (table 3).

Streamflow Characteristics

Streamflows throughout the study area vary according to physiographic province, soils, bedrock, topography, reservoirs, impervious surfaces, and other characteristics of the basin. Streamflows in the Piedmont part of the study area are the most variable. Streams in this area have the lowest flows per square mile during base-flow conditions. The flow per square mile at the 90th percentile flow duration (low flow) is less than 0.10 ft^3/mi^2 in the Neshanic River, Stony Brook, and Beden Brook subbasins. The flow per square mile (yield) in the upper part of the S.B. Raritan River subbasin is 0.60 ft^3/mi^2. The highest yield at 90th percentile flow duration is 0.71 ft^3/mi^2 at S.B. Raritan River at Stanton. Flow at this site is augmented by releases from Spruce Run Reservoir during low-flow conditions. Flow per square mile at the 25[th] percentile flow duration (high flow) varied from 1.2 ft^3/mi^2 at Manalapan Brook to 2.5 ft^3/mi^2 at S.B. Raritan River at High Bridge. Flow per square mile was highest at sites on the S.B. Raritan and Lamington Rivers at each flow duration.

Base flow provides from 38 to 75 percent of mean annual streamflow at gaging stations in the study area (CH2M Hill, Metcalf & Eddy, Inc., 1992). Base flow accounts for a smaller component of total annual streamflow in streams in the Piedmont than in streams in the New England and Coastal Plain Physiographic Provinces. Base flow accounts for an average of 70 percent of mean annual flow at five gages in the New England province; 42 percent of mean annual flow at six gages in the Piedmont province; and 62 percent of mean annual flow at three gages in the inner Coastal Plain part of the Raritan River Basin. Runoff is a higher percentage of total streamflow in the Piedmont province than in the other provinces because of the presence of shallow soils with low permeability.

Differences in flow per unit area between physiographic provinces have an effect on constituent yields that are computed by dividing load by drainage area. Yields normalize the load at sites with different size drainage areas. When the flow per square mile differs between sites with similar drainage areas, yields differ as a function of flow. Constituent yields were affected more by differences in flow per square mile at low flow than at high flow.

Streamflows vary as a function of season. Highest monthly mean flows occur in spring and lowest monthly mean flows occur in fall. Six of the seven sampling sites with stream gages have highest mean monthly flows in March and lowest mean monthly flows in October. Mulhockaway Creek, the site with the smallest drainage area, has the lowest monthly flow in August and the highest monthly flow in April.

Streamflows at some of the sampling sites are regulated by releases of water from reservoirs and from the Delaware and Raritan Canal, and by major water withdrawals for municipal supply. Spruce Run Reservoir releases water to S.B. Raritan River, and Round Valley releases water to the S.B. Raritan River and Rockaway Creek in the N.B. Raritan River Basin. Streamflow at sampling sites on the S.B. Raritan River downstream from Spruce Run Reservoir, Rockaway Creek, Lamington River at the mouth, and the mainstem Raritan River is controlled by reservoir releases. Water is pumped into Round Valley Reservoir from S.B. Raritan River at Hamden and released to the S.B. Raritan River and Rockaway Creek to supplement releases from Spruce Run Reservoir during periods of low flow. The Delaware and Raritan Canal diverts water from the Delaware River Basin into the Raritan River Basin. The canal runs through the study area but affects flow only at the sampling site at Raritan River at Bound Brook. The mean daily flow in the canal coming into the Raritan River Basin at the basin divide, as recorded by the Delaware and Raritan Canal at Port Mercer gaging station, was 134 ft^3/s during 1990-97. Water is diverted from the canal at Ten Mile Lock into the Millstone River near the confluence with the Raritan River. The mean daily flow diverted from the canal to the Millstone River during 1991-97 was 18.9 ft^3/s. Approximately 170 ft^3/s was withdrawn from the Raritan River for water supply 3.1 miles upstream from the sampling site at Raritan River at Bound Brook.

Comparison of Recent Streamflow Data to Historical Streamflow and Precipitation Data

The statistics of mean daily streamflow at the seven sites with continuous streamflow records for 1991-97 (table 3) were compared to the long-term flow statistics for those sites. The long-term statistics for S.B. Raritan River at Stanton and for Raritan River at Manville were based on streamflow data for 1964-98. Earlier records of flow at these sites do not reflect the Spruce Run Reservoir releases that began in September 1963.

In general, flows were slightly higher during 1991-97 than for the whole period of record. The median flow during 1991-97 was 2 to 13 percent higher at S.B. Raritan River at Stanton, Neshanic River, Lamington River, and Millstone River sites, which have continuous streamflow records, than for the whole period of record. Median flow was the same at Stony Brook, 1 percent lower at Mulhockaway Creek, and 2 percent lower at Raritan River at Manville. The median flow at Raritan River at Bound Brook, as estimated from data for the Raritan River below Calco Dam at Bound Brook gage, during 1991-97 was 5 percent lower than the median for 1964-98.

Runoff was higher during 1991-97 at the five sites with continuous streamflow records for drainage areas less than 400 mi^2 and lower at the two sites for drainage areas greater than 400 mi^2 than runoff for the long-term period of record. The highest mean daily flows, those exceeded only 1 percent of the time, were higher at all sites during 1991-97 except at the two sites with the largest drainage areas, Raritan River at Manville and Raritan River at Bound Brook. The flow at the 1-percent flow duration was 9 percent lower at the Manville site and 15 percent lower at the Raritan River at Bound Brook site. Neshanic River had the largest increase in flow at the 1-percent flow duration, 18 percent from the 1922-98 period to the 1991-97 period.

Base flow was higher during 1991-97 at the five sites with continuous streamflow records for drainage areas greater than 30 mi^2 and lower at the two sites for drainage areas less than 30 mi^2. The lowest mean daily flows, those exceeded 99 percent of the time, were higher at all sites except the Mulhockaway and Neshanic River sites. The 99-percentile flow duration increased 29 to 54 percent at S.B. Raritan River at Stanton, Raritan River at Manville, Stony Brook, Millstone River and Raritan River at Bound Brook sites. The 99-percent flow duration decreased slightly from 2.4 to 2.2 ft^3/s at Mulhockaway Creek and decreased from 0.27 to 0.01 ft^3/s at Neshanic River. The Neshanic River gage recorded no flow at the site for 28 consecutive days in August and September 1995. In 1966, no flow passed the site on 33 days; the longest consecutive period of no flow was for 11 days. Also in 1965 no flow passed the site for 5 consecutive days. The occurrence of days with no flow in 1995 rivals the 1965-66 period; however, the extreme low end of the flow duration curve shows a sharper drop in flow during 1991-97 than during earlier periods. Extreme low flows during dry periods in late summer have occurred with greater frequency in the 1990's than during earlier periods of record. This may be an indication that water tables in the area are dropping.

Monthly precipitation records from the National Oceanic and Atmospheric Administration's National Climatic Data Center were used to compare precipitation during 1991-97 to long-term periods of record (National Oceanic and Atmospheric Administration, 2000). The average annual precipitation in northern New Jersey climate division 1, which includes the Piedmont, New England, and Valley and Ridge Physiographic Provinces, during 1991-97 is close to long-term averages. Precipitation averaged 47.1 inches per year in New Jersey climate division 1 during 1991-97. Average annual precipitation from 1960-99 averaged 47.4 inches, and the average from 1895-1999 was 46.0 inches. The average annual precipitation in southern New Jersey climate division 2, which includes most of the New Jersey Coastal Plain, was 45.9 inches during 1991-97. Annual averages for this climatic division during 1960-99 and 1895-1999 were 44.6 and 44.3 inches, respectively.

EVALUATION OF WATER QUALITY

Major Ions, Nutrients, and Field Characteristics

Data on major ions, nutrients, and field characteristics at the 21 USGS/NJDEP cooperative network sites were evaluated for the period 1991-97. These data included pH, dissolved oxygen, water temperature, alkalinity, and constituents analyzed for in the laboratory, such as NO3+NO2, TKN, total phosphorus, chloride, sodium, sulfate, hardness, TSS, TDS, TOC, BOD, and fecal coliform bacteria. This section includes summaries on comparisons of data to reference levels, trend analyses, analyses of variability of data at each site with changes in season and flow condition, a comparative rating of water-quality between sites, the relation of TSS to other constituents, and analyses of the variability of data at each site with land use.

Water-Quality Standards

Water-quality standards establish the goals and policies underlying the management of New Jersey's waters (New Jersey Department of Environmental Protection, 1997). Numeric criteria are set by the NJDEP to protect public health and welfare and to enhance the quality of water. The Federal Clean Water Act (U.S. Environmental Protection Agency, 1992) requires, wherever attainable, that instream water-quality standards should provide for protection and propagation of fish, shellfish and wildlife and to provide for recreation in and on the water (New Jersey Department of Environmental Protection, 1997). Drinking-water standards are set by the USEPA and NJDEP. These standards, known as maximum contaminant levels (MCL's) are the maximum permissible levels allowed in public drinking water (U.S. Environmental Protection Agency, 1996). The standards apply to treated water that will be delivered to public water-supply users. USEPA and NJDEP MCLs for instream and drinking-water standards are used in this study as reference levels for instream constituent concentrations.

New Jersey instream water-quality standards have been determined for 10 of the 17 constituents analyzed for. TDS, NO3+NO2, and sodium have only drinking-water standards. The instream standard in New Jersey of 10 mg/L applies to nitrate only. The MCL's for these constituents were used as reference levels in the absence of instream water-quality standards. Standards have not been established for alkalinity, BOD, TKN, and TDS. Standards for dissolved oxygen, TSS, un-ionized ammonia, and water temperature are stricter for trout waters than for nontrout waters. In addition, the standard for dissolved oxygen is stricter for trout production streams (>7 mg/L) than that for trout maintenance streams (>5 mg/L). The instream water-quality standards for New Jersey streams represent a quality of water that supports a particular use. When criteria are met, water quality, in general, will be acceptable for the designated use (New Jersey Department of Environmental Protection, 1998).

The New Jersey instream water-quality standards for some of the constituents studied do not apply to instantaneous values derived from one sample and, therefore, are used simply as a level of reference for evaluating water-quality conditions in the study area. The un-ionized ammonia standard of 0.02 mg/L for trout sites and 0.05 mg/L for nontrout sites is for a 24-hour average concentration. The standard for fecal coliform bacteria is that the count is to exceed neither a geometric mean of 200/100 mL nor 400/100 mL in 10 or more percent of the total number of samples collected in a 30-day period (New Jersey Department of Environmental Protection, 1998). For water temperature, thermal alterations from point-source discharges should not raise the ambient stream temperature more than 0.6 to 2.8 ^{o}C (degrees Celsius), or to a temperature that is higher than the maximum level consistent with the protection of aquatic life. The instream standards for these constituents were used only as reference levels for evaluating water-quality conditions in the study area. The instream standards for total phosphorus, TSS, TDS, dissolved oxygen, and pH apply to the quality in the stream at all times.

The percentages of samples from trout and nontrout streams that do not meet the established reference levels are listed in tables B1 and B2 by site, and the percentages of samples from all sites are listed by flow condition and season**.** The percentage of samples that exceed the reference level at each site during high-flow and low-flow conditions are listed in tables B1 and B2 for nontrout and trout streams, respectively. The percentage of samples that do not meet reference levels is presented by site in cumulative probability plots (figs. C1-C17). The cumulative probability plots show the percentage of values at each site that is less than a given concentration, fecal coliform bacteria count, or temperature. Horizontal lines across the plots represent established water-quality or drinking-water standards. The intersection of the cumulative probability line with the horizontal line that represents the standard indicates the percentage of values that meet the reference level. The exception is dissolved oxygen (fig. C-5); the intersection of the lines indicates the percentage of values that do not meet the reference level. Each sampling site had at least one sample with a value that did not meet a reference level.

The most common exceedances were for total phosphorus, fecal coliform bacteria, and hardness. Total phosphorus concentrations were greater than the reference level of 0.1 mg/L in 32 percent of samples or 42 percent of samples at nontrout sites and 10.6 percent of samples at trout sites. Fecal coliform counts were greater than the reference level of 400 counts/100mL in 29 percent of all samples, and hardness values exceeded the reference level of less than 50 mg/L in 20.7 percent of samples. No samples collected during the study period contained concentrations that exceeded the standards for chloride, TDS, NO3+NO2, or sulfate. The reference level for fecal coliform in streams states that the count is not to exceed a geometric mean of 200 counts/100mL (table B3) and is not to exceed 400 counts/100mL in more than 10 percent of samples collected during a 30-day period (tables B1-B2).

Phosphorus.--Concentrations of total phosphorus exceeded 0.1 mg/L in 97 percent of the samples from the Millstone River site at Blackwells Mills, in 70 percent from Millstone River at Grovers Mill, in 86 percent from Raritan River at Bound Brook, and in 60 percent from S.B. Raritan River at Three Bridges (fig. C12). Less than 20 percent of samples from Matchaponix Brook and all the sites in the N.B. and S.B. Raritan River subbasins, except Rockaway Creek and S.B. Raritan River at Three Bridges, exceeded the 0.1 mg/L reference level for phosphorus. Mulhockaway River at Van Syckel was the only site with no samples that exceeded 0.10 mg/L. More than 50 percent of samples collected at seven sites during low flow and at four sites during high flow exceeded 0.10 mg/L (tables B1 and B2).

Concentrations of total phosphorus exceeded the reference level of 0.05 mg/L set for lakes, reservoirs, and streams at the point of entry to these waterbodies in more than 70 percent of samples at 10 sites (table B1). More than 50 percent of samples exceeded the 0.05-mg/L reference level at 15 sites during low flow and 11 sites during high flow. The 0.05-mg/L reference level for lakes and streams at the point of entry to lakes could be a concern for the Mulhockaway Creek, Spruce Run, Stony Brook, and Millstone River at Grovers Mill sites because the Mulhockaway Creek and Spruce Run sites are a short distance upstream from Spruce Run Reservoir and the Stony Brook and Millstone River at Grover's Mill sites are upstream from Carnegie Lake (fig. 1). The samples that exceed the 0.05-mg/L limit at Mulhockaway Creek, Spruce Run, Stony Brook, and Millstone River account for 18, 32, 67, and 97 percent of the samples, respectively (tables B1 and B2). At Mulhockaway Creek, 25 percent of samples exceeded the reference level at high flow and 11 percent exceeded the reference level at low flow. At Spruce Run, 42 percent of low-flow samples and 27 percent of high-flow samples exceeded the limit. At Millstone River at Grovers Mill, 100 percent of low-flow samples and 93 percent of high-flow samples exceeded 0.05 mg/L. At Stony Brook, 71 percent of high-flow samples and 63 percent of low-flow samples exceeded 0.05 mg/L.

Fecal coliform bacteria.--Neshanic River at Reaville was the only site where more than 50 percent of samples exceeded the reference level of 400 colonies/100mL (fig. C7). Matchaponix Brook and Manalapan Brook had the fewest samples with values greater than 400 counts/100mL, 8.6 and 11 percent, respectively (fig. C7). Five sites had more than 50 percent of samples greater than 400 colonies/100 mL at low flow. At high-flow conditions, only Neshanic River had more than 50 percent of samples with values greater than 400 colonies/100 mL (table B1). At low flows, more than 50 percent of samples from the S.B. Raritan River site contained more than 400 colonies/100 mL (table B2).

The geometric mean of fecal coliform counts for all data at a site exceeded the New Jersey surface-water reference level of 200 counts/100mL at six sites (table B3). A geometric mean of 200 counts/100mL was exceeded in samples from four sites during low flow and from seven sites during high flow. The highest geometric mean during high- and low-flow conditions occurred at the Neshanic River site. The lowest geometric means at high flow were 31.6 counts/100mL at Matchaponix Brook and 36.9 counts/100mL at Manalapan Brook. The lowest geometric means at low flow were 54.7 counts/100mL at Lamington River at Pottersville and 63.3 counts/100mL at S.B. Raritan River at Stanton. The geometric mean is 218 counts/100mL for all growing season samples from all sites in the basin and 82.7 counts/100 mL for all nongrowing season samples. Lower geometric mean counts in the nongrowing season could be related to lower water temperatures. The geometric mean from all low-flow samples from all sites is 171 counts/100 mL and for all high-flow samples, 126 counts/100 mL.

Hardness.--Hardness concentrations were less than the 50- to 250-mg/L reference level in all samples from sites at Manalapan Brook and Millstone River at Manalapan, and more than 50 percent of samples from sites at Millstone River at Grovers Mill and Stony Brook at Princeton contained concentrations less than the reference level (fig. C8). All samples with concentrations less than 50 mg/L from 17 of the 21 sites were collected during high-flow conditions. Samples with hardness concentrations less than 50 mg/L that were collected at low-flow conditions were from three Coastal Plain sites and the Raritan River at Bound Brook site (tables B1 and B2). In 35 percent of samples from Neshanic River, concentrations were greater than 100 mg/L, the highest percentage of samples at any site (fig. C8). No samples exceeded the upper limit of 250 mg/L.

Water temperature.--Water temperature at the seven sites designated as trout waters exceeded the instream reference level of 20 ^{o}C in 30 of 249 samples or 12 percent of all samples (fig. C17). At least one water-temperature measurement at each of the seven sites in trout waters exceeded 20 ^{o}C. All temperatures greater than the reference level were measured during the growing season. Seventy percent of the temperatures greater than the instream reference level were measured at flows less than the median. Only one measurement each at Lamington River near Pottersville and N.B. Raritan River near Chester were greater than 20 °C. Twenty-six percent of water-temperature measurements at S.B. Raritan River at Stanton exceeded 20 °C, the largest percentage at any of the sites designated as trout waters (table B2). The reference level of 27.8 °C for nontrout waters was not exceeded at any site. More than half of the water-temperature measurements exceeded 20 °C during low-flow conditions at the Raritan River sites at Manville and Bound Brook and Millstone River at Blackwells Mills.

pH.--Measurements of pH did not meet the surface-water reference level of greater than 6.5 or less than 8.5 in 17 percent of all samples collected in the study area (tables B1 and B2). Differences in pH occurred between sites in the Coastal Plain and those in the Piedmont and New England Physiographic Provinces (fig. 2). Values of pH for all samples from the N.B. and S.B. of the Raritan River that did not meet reference levels were greater than 8.5. Values for samples from the mainstem Millstone River and South River subbasin that did not meet reference levels were less than 6.5. No samples collected from Millstone River at Grovers Mill or Millstone River at Blackwells Mill sites, affected by point-source effluent, were less than 6.5 (figure C11). More than 50 percent of pH measurements made at the Manalapan Brook and Matchaponix Brook Coastal Plain sites during high flows were less than 6.5. All pH measurements were greater than 7.0 at sites in the N.B. and S.B. Raritan River and Raritan River mainstem subbasins (fig. C11). All pH measurements at Coastal Plain sites were less than 8.0.

Total suspended solids.--TSS concentrations exceeded the reference level of 25 mg/L in 2.0 percent of the samples collected at the seven sites located at streams designated as trout waters. At least one sample each from four of the seven sites exceeded the reference level, all at high flows (table B2). No samples from Mulhockaway Creek, Spruce Run, and N.B. Raritan River near Chester exceeded the reference level (fig. C15).

Concentrations of TSS exceeded the reference level of 40 mg/L in 7.6 percent of all samples from the 14 sites designated as nontrout waters (table B1). Samples from 8 of the 14 sites exceeded the reference level at least once. For the sites on Manalapan Brook near Manalapan, Matchaponix Brook at Spotswood, and Millstone River at Grovers Mill, all of which drain areas exclusively in the Coastal Plain, no sample contained a concentration of TSS that exceeded 30 mg/L (fig. C15). The sites with the highest percentages of samples that exceeded the reference level for nontrout water were at Raritan River at Bound Brook, Stony Brook at Princeton, and Neshanic River at Reaville. At high-flow conditions, concentrations in 32 percent of samples from Stony Brook and 24 percent of samples from Raritan River at Bound Brook exceeded 40 mg/L. Millstone River at Blackwells Mills was the only site at which concentrations in samples collected at low flow exceeded the 40-mg/L reference level. This could have been caused by algal blooms because all the samples were collected in summer months.

Dissolved oxygen.--Dissolved oxygen concentrations met the reference level for trout maintenance waters and for trout production waters at all sites with these designations. Only one sample contained a dissolved oxygen concentration less than the 4-mg/L reference level for nontrout waters, a sample from Millstone River at Grovers Mill collected during low flow in the summer. No samples contained dissolved oxygen concentrations less than 7.8 mg/L at trout production sites or less than 7.7 mg/L at trout maintenance sites. Thirty-two of the 42 samples with concentrations less than 7 mg/L were collected during low-flow conditions. The Millstone River subbasin has the highest percentage of samples with concentrations less than 7.0 mg/L (fig. C5).

Sodium.--Sodium concentrations exceeded the secondary drinking-water MCL of 50 mg/L in 5.2 percent of samples. Five of the seven sites designated as trout streams had at least one sample that exceeded 50 mg/L. All of these samples were collected during high flows in the nongrowing season (table B2). Samples from 9 of the 14 nontrout sites exceeded the reference level of 50 mg/L; samples from five of these sites exceeded the reference level during both high and low flows. Millstone River at Manalapan had by far the highest percentage of exceedances--43 percent compared to less than 9 percent of samples at the other sites. Fifty-eight percent of samples collected at the Millstone River at Manalapan site during low flows contained concentrations that exceeded 50 mg/L (table B1). No permitted point sources exist in this subbasin. All samples collected at sites in the N.B. Raritan River subbasin and the Raritan River mainstem had concentrations less than 40 mg/L (fig. C13).

Un-ionized ammonia.--Un-ionized ammonia did not exceed the reference level of 0.05 mg/L for nontrout waters at any site (fig. C16). Only one sample from the site at S.B. Raritan River at Stanton contained concentrations that exceeded the 0.02-mg/L reference level for streams classified as trout waters (table B2). The sample was collected at low-flow conditions during the growing season. Four samples from nontrout streams exceeded 0.02 mg/L. Three were collected from Raritan River at Bound Brook during low-flow conditions in the summer and one during high-flow conditions in the growing season.

Other constituents.--The reference level for NO3+NO2 is 10.0 mg/L. The highest NO3+NO2 concentration, 10.1 mg/L, was present in a sample from Matchaponix Brook collected during low flow in July 1993. No samples collected during the study period exceeded the reference level for chloride (250 mg/L), TDS (500 mg/L), or sulfate (250 mg/L) (figs. C4, C6, and C14). The highest chloride concentration, 190 mg/L, was present in a sample collected from Neshanic River during high flow in the winter. The highest TDS concentration, 448 mg/L, was present in a sample collected from Neshanic River during low flow in June. The highest concentration of sulfate, 96 mg/L, was present in a sample collected from Neshanic River during low flow in September 1997.

Exceedance of Reference Levels

Constituents that did not meet water-quality reference levels were evaluated by season. All samples that exceeded the reference levels for dissolved oxygen, un-ionized ammonia, and water temperature were collected in the growing season (tables B1 and B2). Fecal coliform bacteria counts were highest in the growing season. Forty-six percent of growing season samples exceeded 400 counts/100mL, and only 13 percent of nongrowing season samples exceeded that limit. The percentages of samples that exceeded the total phosphorus and TSS reference levels were only slightly higher in the growing season than in the nongrowing season. The percentage of samples with hardness concentrations less than the reference level was slightly higher in the nongrowing season than the growing season. The percentage of samples that exceeded the reference levels for pH and sodium were the same in both seasons.

Constituents that did not meet water-quality reference levels also were evaluated by flow condition. Dissolved oxygen, fecal coliform bacteria, total phosphorus, un-ionized ammonia, and water temperatures did not meet the reference level in a higher percentage of samples collected at low-flow than at high-flow conditions (figs. B1-B2). TSS and sodium concentrations greater than the reference level and hardness concentrations less than the reference level were more common during high-flow conditions. Measurements of pH greater than the reference level of 8.5 were more common during low-flow conditions and those less than the reference level of 6.5 were more common during high-flow conditions. The percentage of samples collected during high and low flow at each site that did not meet the reference levels are presented in tables B1 and B2.

Trends in Water-Quality Characteristics

Trends for the 17 constituents discussed in this report are summarized from three previous USGS studies and from trends tests for this study (water years 1991-97). The results of trends tests for 16 of the 17 constituents for 1986 through 1995 are summarized from Hickman and Barringer (1999). Results from a study by Buxton and others (1999) of trends for 13 of the 17 constituents at high and at low flows during 1976-93 also are summarized. Trends in constituents measured during 1975-86 at 13 sites in the Raritan Basin were analyzed for statistical association with drainage-basin characteristics by Robinson and others (1996). Results from trends tests performed for this study on water-quality data collected at all flows during 1991-97 and on water-quality data collected at low flow only during 1991-97 for the eight constituents analyzed for loads are presented in table 4.

The results for 16 of the 17 constituents for the period 1986 through 1995 are derived from Hickman and Barringer (1999). A trend test was not performed on TSS data from the 1986-95 dataset used by Hickman and Barringer (1999). Trends were observed for at least one constituent at each site, and a trend was observed for each constituent at one or more sites. Trend tests for total ammonia and total organic nitrogen were performed separately. No trend tests were performed for un-ionized ammonia.

The results of trend tests on nutrients--ammonia, organic nitrogen, and phosphorus-- are consistent with the expected decrease in these nutrient concentrations in treated wastewater discharged from wastewater-treatment plants as a result of upgrades to plants (Hickman and Barringer, 1999). Trends for total ammonia were downward at all 21 sites. Trends for total organic nitrogen were downward at 17 sites, and trends for total phosphorus were downward at 11 sites. All decreases in total phosphorus concentrations occurred at stations downstream from wastewater-treatment plants, whereas concentrations at sites without upstream wastewater-treatment plants did not change significantly. The decreases in ammonia and organic nitrogen, however, have occurred at some sites whether or not they were downstream from wastewater-treatment plants. NO3+NO2 increased at four sites, but decreases did not occur at any sites. This also is consistent with upgrades to wastewater-treatment processes, which oxidize the reduced species of nitrogen in the effluent, thereby, decreasing concentrations of ammonia and increasing concentrations of NO3+NO2.

The results of trend tests on dissolved inorganic constituents--chloride, TDS, hardness, and sodium--show increased concentrations at 8, 3, 10, and 11 sites, respectively, across the basin. No significant decreases in these constituent concentrations were observed. Increases occurred at sites with and without upstream wastewater-treatment plants. These increases could be caused by changes in basin land use or other basin characteristics. Sulfate was the only dissolved constituent to show significant decreases at six sites. The concentration of sulfate increased at one site. The other sites had no significant changes in sulfate concentrations.

Upward trends in pH and total alkalinity occurred at slightly less than half the stations. Five sites showed significant upward trends in alkalinity and pH. No downward trends were observed for either constituent. Total organic carbon concentrations decreased at four of the seven sites located in the S.B. Raritan River subbasin, the N.B. Raritan River at Chester, and at the Millstone River at Grovers Mill. No significant increases were observed for these sites. BOD decreased at two sites and increased at one site. Fecal coliform count decreased at one site and showed no change at others. Water temperature decreased at three sites during 1991-97 and showed no change at others. No significant change was observed in TSS concentrations at any site. Results of trend tests on streamflow at the time of sampling indicated downward trends at Spruce Run, Mulhockaway Creek, Lamington River near Pottersville, Stony Brook, and Beden Brook. Streamflows at time of sampling did not significantly increase at any sites during 1986-95.

Results of trend tests by Buxton and others (1999) on constituents sampled during high and low flows are summarized here for 13 of the 17 constituents included in this study. The tests were performed on data sets consisting of long-term data from 1976 through 1993. High-flow samples are those samples collected at flows that are exceeded only 25 percent of the time. Low-flow samples are those samples collected at conditions that are less than or equal to the streamflow that occurs 75 percent of the time. Concentration data were not tested if data were available for fewer than 4 of the 6 years in each one-third of the period of study (18 years). Twelve was the minimum number of low- or high-flow measurements used in a test (Buxton and others, 1999). Positive trends during low-flow conditions indicate increases in concentrations from ground water and (or) point sources. Positive trends during high-flow conditions indicate increases in concentrations from storm runoff.

Trends for chloride and sodium concentrations were positive during high flows at 6 and 4, respectively, of 21 sites (Buxton and others, 1999). Trends for both constituents also were positive at four sites during low-flow conditions. TKN concentrations showed the most decreases at sites during both high and low flows, three and four, respectively. Trends for hardness were positive at two sites during high flow and two during low flow. Trends for ammonia and organic carbon were negative at three sites. Trends for dissolved oxygen, NO3+NO2, and total phosphorus were positive at one or two sites. No significant trends were determined for TSS and fecal coliform at high- or low-flow conditions. Alkalinity and BOD were not tested at any sites because of insufficient data.

Trend tests on concentration data from 1991-97 for this report were applied only to the eight constituents used in load analysis. Results from trends tests performed for this study on constituent-concentration data from 1991-97 showed similar but fewer significant trends than results from Hickman and Barringer (1999) and Buxton and others (1999) (table 4). The only exception was NO3+NO2. The other two studies showed upward trends at two and at four sites, respectively, with no significant decreases in concentrations. In this study, four sites showed a significant downward trend, and no sites showed upward trends. All significant trends for NO3+NO2, TKN, total phosphorus, and TOC are downward trends. Trends for chloride and TDS were upward, except at Neshanic River where there was a downward trend. BOD increased at one site, and TSS did not significantly change at any site.

Trends in the concentrations of 13 chemical constituents and 2 physical properties measured during 1975-86 at 60 sites, including 13 in the Raritan Basin, were evaluated for statistical association with drainage-basin characteristics (Robinson and others, 1996). Urbanized subbasins were associated with increasing concentrations of sodium, chloride, magnesium and pH. Trends in TDS, especially sodium and chloride, were strongly associated with application rates of road deicing salts. Upward trends in dissolved oxygen were associated with effluent discharged by nonmunicipal wastewater-treatment facilities. Trends in BOD and nutrients showed little association with the amount of effluent discharged to streams. Downward trends in total ammonia at sites influenced by agricultural land use seem to indicate that changes in nonpoint sources could have greater effects on streams than changes in effluent discharge.

For all sites with significant trends in chloride and TDS, the trends were upward, except for the Neshanic River site where the trends were downward. The upward trend in chloride concentrations at Mulhockaway Creek (fig. 3) from 10 mg/L in 1991 to 20 mg/L in 1997 is typical of chloride trends observed at other sites (table 4). Significant trends were observed when concentration data from all samples were tested and when only data from samples collected during low flow were tested. An example of the plots generated for each constituent at each site for the analysis of trends, the relation of concentration to flow, and the relation of load to flow is shown in figure 3.

The results from the 1991-97 trends tests show an upward trend in concentrations of BOD, chloride, and TDS at some of the sites with highest concentrations. The upward trends indicate that concentrations at these sites could exceed reference levels in the future. Concentrations of BOD increased at Stony Brook at Princeton, the site with the second highest median concentration (1.7 mg/L) in samples collected during 1991-97. No instream or drinking-water reference level has been established for BOD. Chloride concentrations increased at N.B. Raritan River at Chester, the site with the highest median concentration (38 mg/L) in

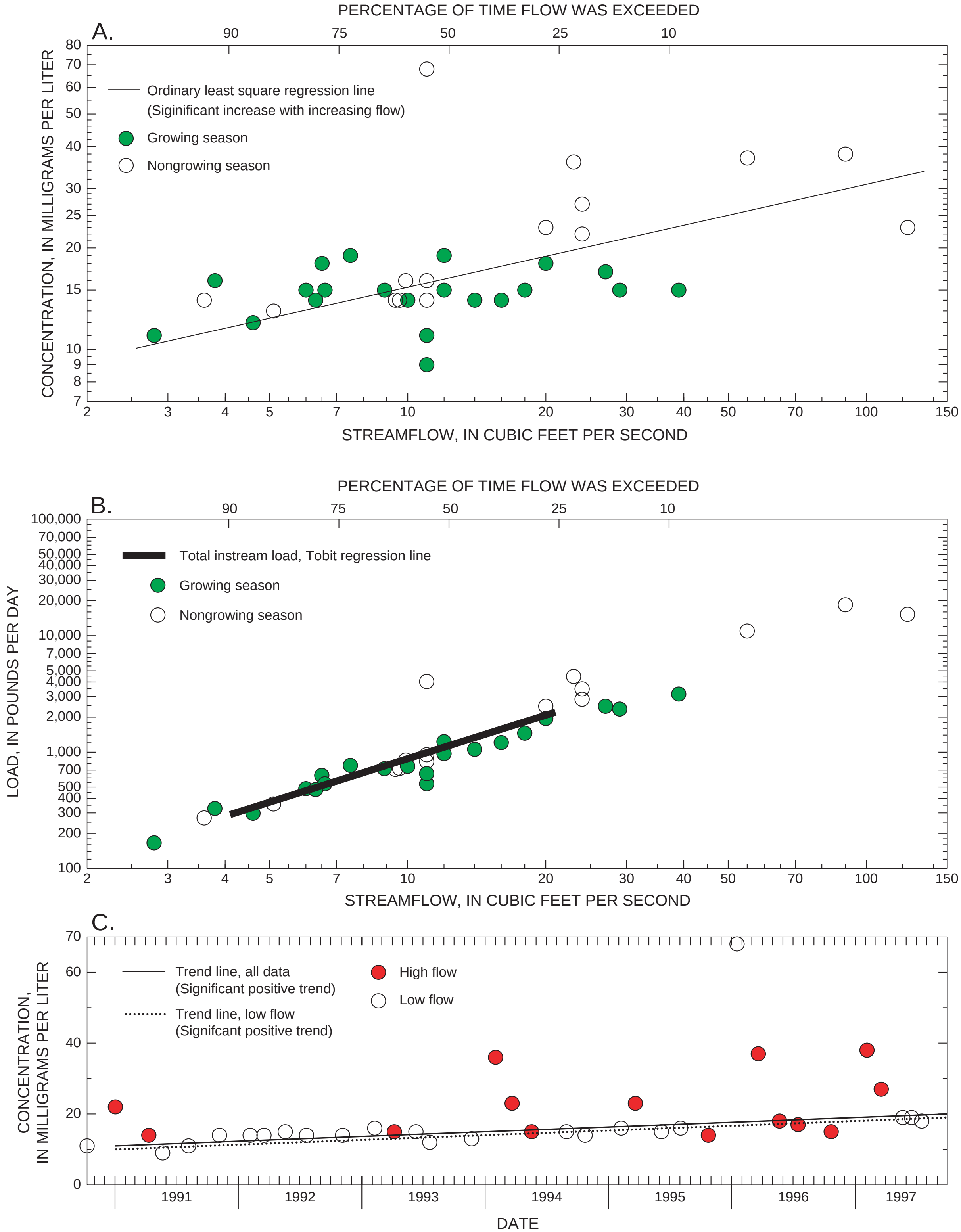


Figure 3. Relation of chloride concentrations and load to streamflow (A, B) and trends in concentrations at low and high flows (C) Mulhockaway Creek near Van Syckel (01396660), N.J.

Table 4. Summary of trend slopes from Seasonal Kendall tests performed for selected constituents and flow at time of sampling at 21 surface-water sampling sites in the Raritan River Basin, N.J., 1991-97 water years

[Slopes indicate change in units per year; **+**, positive slope indicates values increased with time; **-**, negative slope indicates concentration decreases with time; --, no significant change; mg/L, milligrams per liter; ft^3/s, cubic feet per second]

Station number	Station name	Ammonia + organic nitrogen (mg/L)		Biochemical oxygen demand (mg/L)		Chloride (mg/L)		Total dissolved solids (mg/L)		Nitrate + nitrite (mg/L)		Total organic carbon (mg/L)		Total phosphorus (mg/;L)		Total suspended solids (mg/L)		Sampled streamflow (ft^3/s)	
		All flows	Low flow	All flows	Low flow	All flows	Low flow	All flows	Low flow	All flows	Low flow	All flows	Low flow	All flows	Low flow	All flows	Low flow	All flows	Low flow
01396280	S.B. Raritan River	--	--	--	--	+0.11	+0.13	--	+0.38	--	--	--	--	--	--	--	--	--	--
01396535	S.B. Raritan River	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-0.30
01396588	Spruce Run	--	--	--	--	+.05	--	--	--	-0.08	--	--	--	--	--	--	--	--	--
01396660	Mulhockaway Ck	--	-0.03	--	--	+.13	+.14	--	+.28	-.04	--	--	-0.02	--	--	--	--	--	--
01397000	S.B. Raritan River	-0.04	-.03	--	--	+.10	--	--	--	--	--	--	--	-0.01	--	--	--	--	--
01397400	S.B. Raritan River	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01398000	Neshanic River	-.05	-.09	--	--	--	-.77	-0.13	-.19	--	--	--	--	-.05	-0.06	--	--	--	--
01398260	N.B. Raritan River	--	--	--	--	+.20	--	--	--	--	--	--	--	-.01	-.05	--	--	--	--
01399120	N.B. Raritan River	-.06	--	--	--	+.20	+.18	--	--	--	--	-0.03	--	-.01	--	--	--	--	--
01399500	Lamington River	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01399700	Rockaway Creek	--	--	--	--	--	--	--	--	-.07	--	--	--	--	--	--	--	--	--
01399780	Lamington River	--	--	--	--	--	--	--	--	-.05	--	--	--	-.08	--	--	--	--	--
01400500	Raritan River	--	--	--	--	+.12	+.13	--	--	--	--	--	--	-.05	--	--	--	--	--
01400540	Millstone River	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01400650	Millstone River	--	--	--	--	--	--	--	--	--	--	--	--	--	-.03	--	--	--	--
01401000	Stony Brook	--	--	+0.02	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01401600	Beden Brook	-.04	--	--	--	--	--	--	--	--	--	-.02	--	-.01	--	--	--	--	--
01402000	Millstone River	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01403300	Raritan River	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01405302	Matchaponix Brook	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01405340	Manalapan Brook	--	--	--	--	+.13	+.16	+.22	+.28	--	--	--	--	--	--	--	--	--	--

the study area. The second highest chloride concentration was recorded (150 mg/L) for S.B. Raritan River at Middle Valley; concentrations at this site increased significantly. If an upward trend continues, samples collected at high flows could approach concentrations of 250 mg/L, the instream reference level. TDS increased at S.B. Raritan River at Middle Valley, the site with the highest concentration recorded (334 mg/L). If the trend continues, concentrations during high flow could approach the instream reference level of 500 mg/L.

Relation of Constituent Values to Season and Flow

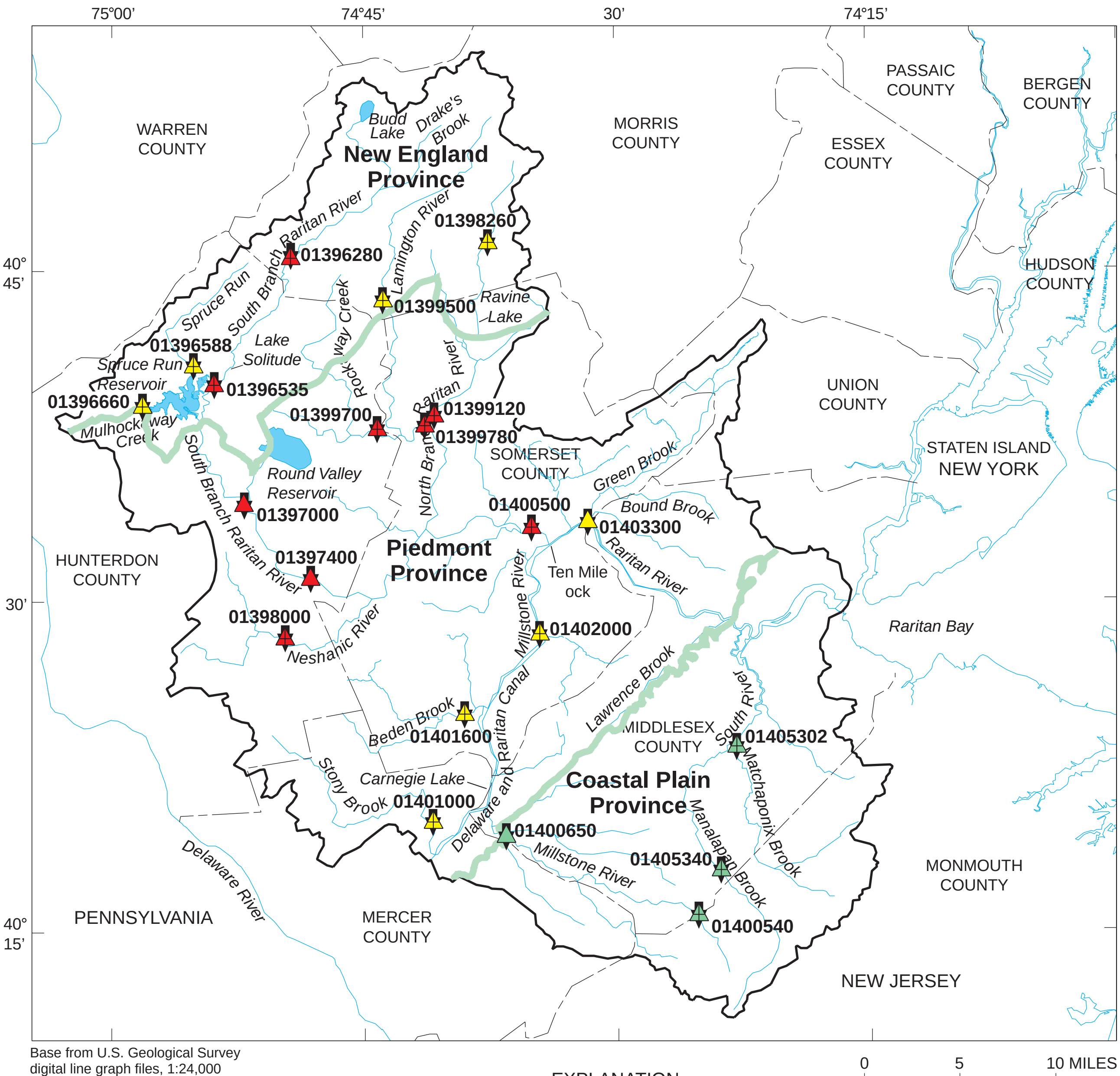
The streamflow condition and season of the year were found to affect the water quality of streams in the Raritan River Basin. Concentrations can increase or decrease with an increase in streamflow, depending on the source of the constituent. Seasonal changes, such as water temperature, frozen soils, and human activities, also affect concentrations in streams.

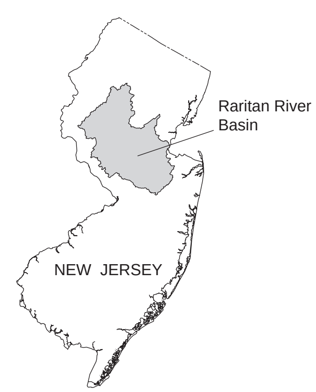
Concentrations of 15 constituents, fecal coliform counts, and water temperature were compared at each site by season, flow, and season as a function of flow to explain variability in the data. Significant differences in levels of constituents between seasons were found for each constituent at one or more sites. Significant changes in levels of all constituents in streams, except BOD, were observed as flow in the stream changed. A test also was performed to see whether the significant differences in concentrations were related to a change in flow as a function of season. In most instances, differences in concentration were not related to changes in flow in a single season. In most cases, when significant differences in concentration occurred between flow conditions, the differences were not limited to a single season, and differences in concentrations between seasons were not limited to a single flow condition.

The results of these analyses are presented in tables showing summary statistics and significant differences by season and flow condition (tables 5-21). The same summary also is presented on maps of the basin (figs. 4-20). A summary of the distributions of constituents at each site and a comparison between sites is presented in boxplots (figs. A1-A17) and in cumulative probability plots (figs. C1-C17).

Alkalinity.--Alkalinity as concentration of CaCO3 was significantly lower in the Coastal Plain part of the study area (headwaters of the Millstone River and South River subbasins) than in the Piedmont and New England Physiographic Provinces (N.B. and S.B. Raritan River and tributaries to the Millstone River) (fig. 4 and fig. A1). At three of the four sites in the Coastal Plain--Millstone River at Manalapan, Matchaponix Brook, and Manalapan Brook—concentrations of CaCO3 were significantly lower than at other sites. Median concentrations at these sites ranged from 7.1 to 8.6 mg/L. The median at Millstone River at Grovers Mill was slightly higher, 18.5 mg/L. Medians at the other stations ranged from 33 to 60 mg/L. The highest concentrations were detected in the S.B. Raritan River subbasin during low-flow conditions in summer. The lowest concentration (<1.0 mg/L) was detected at Matchaponix Brook during low flow in winter (table 5). Concentrations less than 3.0 mg/L were measured in samples from Matchaponix Brook, Manalapan Brook, and Millstone River at Manalapan.

Concentrations of CaCO3 were significantly higher at low flow than at high flow at each site (table 5). This indicates that runoff is diluting the buffering capacity of the water. The significant decrease in alkalinity concentrations at high flow at all sites was not great enough to cause the significant decrease in pH observed at high flow at nine sites. Concentrations were also significantly higher in the growing season at 16 of the 21 sites than in the nongrowing season. The increases during the growing season could be caused by algal growth (Hem, 1985). Concentrations at 19 of the 21 sites were lowest during high-flow conditions in the nongrowing season. The interaction of flow and season is a significant factor in explaining differences in concentrations at 11 of the 21 sites. Concentrations were highest at low flow in the growing season.





Siteid	Alkalinity
01396280	56.00
01396535	60.50
01396588	33.00
01396660	50.00
01397000	55.00
01397400	60.00
01398000	55.00
01398260	45.00
01399120	53.00
01399500	45.00
01399700	60.00
01399780	59.00
01400500	54.00
01400540	8.65
01400650	18.50
01401000	47.00
01401600	45.50
01402000	35.00
01403300	45.00
01405302	7.20
01405340	7.10

Figure 4. Median alkalinity concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 5. Statistical summary of and differences in alkalinity concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data from 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season; NS, not significant; <, less than]

		Alkalinity, as $CaCO_3$										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration			Median concentration			
Station number	Station name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Statistically significant	Low flow	High flow	Significant difference with flow	
01396280	S.B. Raritan River	35	33.0	56.0	100	66	52	G	75	47	LO	G@LO
01396535	S.B. Raritan River	36	35.0	60.5	101	77	57	G	82	53	LO	G@LO
01396588	Spruce Run	36	20.0	33.0	45.0	37	27	G	41	29	LO	G@LO
01396660	Mulhockaway Ck	36	24.0	50.0	84.0	58	47	G	60	42	LO	G@LO
01397000	S.B. Raritan River	31	29.0	55.0	80.0	56	52	NS	61	50	LO	--
01397400	S.B. Raritan River	35	18.0	60.0	87.0	61	56	NS	72	56	LO	--
01398000	Neshanic River	53	22.0	55.0	98.0	62	44	G	70	43	LO	G@LO
01398260	N.B. Raritan River	35	24.0	45.0	58.0	48	34	G	50	36	LO	G@LO
01399120	N.B. Raritan River	35	22.0	53.0	73.0	56	45	G	62	43	LO	--
01399500	Lamington River	35	23.0	45.0	63.0	50	34	G	50	34	LO	G@LO
01399700	Rockaway Creek	34	26.0	60.0	84.0	66	45	G	72	52	LO	G@LO
01399780	Lamington River	35	28.0	59.0	82.0	62	43	G	66	44	LO	G@LO
01400500	Raritan River	35	27.0	54.0	73.0	62	51	G	62	48	LO	--
01400540	Millstone River	34	2.70	8.65	15.0	10	5.1	G	12	8.2	LO	G@LO
01400650	Millstone River	30	7.00	18.5	49.0	20	18	NS	26	16	LO	--
01401000	Stony Brook	56	14.0	47.0	78.0	49	41	G	56	36	LO	--
01401600	Beden Brook	36	17.0	45.5	78.0	52	36	G	53	32	LO	--
01402000	Millstone River	31	15.0	35.0	52.0	39	32	G	40	30	LO	--
01403300	Raritan River	53	20.0	45.0	63.0	45	44	NS	52	41	LO	--
01405302	Matchaponix Brook	33	<1.0	7.20	28.0	9.5	3.5	NS	12	3.2	LO	--
01405340	Manalapan Brook	35	2.00	7.10	13.0	8.9	4.7	G	9.8	6.2	LO	G@LO

Results of Tobit regression analysis indicated that concentrations of $CaCO3$ significantly decreased as flow increased at all sites. The slope of the regression line (-0.72) for Matchaponix Brook indicates that this site has the sharpest decrease in concentration as flow increases.

Ammonia plus organic nitrogen.--Median concentrations of TKN were highest at the two most downstream sites on mainstem Millstone River (01400650; 01402000) and at Raritan River at Bound Brook (0.50-0.54 mg/L) (fig. A2, table 6). In general, concentrations were highest in the Millstone River subbasin (fig. 5). The highest individual concentrations (greater than 2 mg/L) were measured at Millstone River at Grovers Mill, Stony Brook, and Matchaponix Brook at low flow in the winter months and at Neshanic River at high flow in July. Concentrations at Mulhockaway Creek were significantly lower than at all the other sites.

TKN concentrations were significantly higher during the growing season at seven sites (table 6). Concentrations were significantly higher during low flow at Beden Brook and Raritan River at Manville and significantly higher at high flow at Stony Brook. In general, concentrations at 13 sites were highest at high flow during the growing season. The interaction of high flow and growing season was a significant factor in explaining variability only at the Raritan River at Bound Brook and Stony Brook sites (table 6). No significant differences in concentrations were observed between seasons or flow conditions at the other 11 sites.

Results of the Tobit regression indicated that concentrations significantly changed at only six sites as flow increased. Beden Brook was the only site at which concentrations significantly decreased as flow increased. Concentrations significantly increased as flow increased at five sites--Matchaponix Brook, Manalapan Brook, S.B. Raritan River at Stanton, Stony Brook, and Raritan River at Bound Brook.

Biochemical oxygen demand.--Median concentrations of BOD were highest at Millstone River at Blackwells Mills, Stony Brook, and S.B. Raritan River at Three Bridges (1.7 to 1.8 mg/L) (table 7 and fig. A3). The lowest median concentrations occurred at three of the four Coastal Plain sites (fig. 6)--Manalapan Brook, Matchaponix Brook, and Millstone River at Manalapan. Concentrations at Matchaponix Brook were significantly lower than those at the three sites with the highest concentrations.

Concentrations at all sites did not vary much between seasons and flow conditions. No sites had significantly different concentrations at different flow conditions (table 7). Rockaway Creek was the only site where concentrations varied by season. Concentrations were significantly higher in the growing season. The highest instantaneous concentrations were 11 mg/L at Raritan River at Manville at low flow in November 1991 and 7.2 mg/L at Millstone River at Grovers Mill at low flow in February 1992. The interaction of flow and season was not a significant factor in explaining variability in concentrations at any sites.

Results of the Tobit regression indicated that Stony Brook was the only site to have a significant relation between instantaneous flow and concentration. Concentrations increased as flow increased.

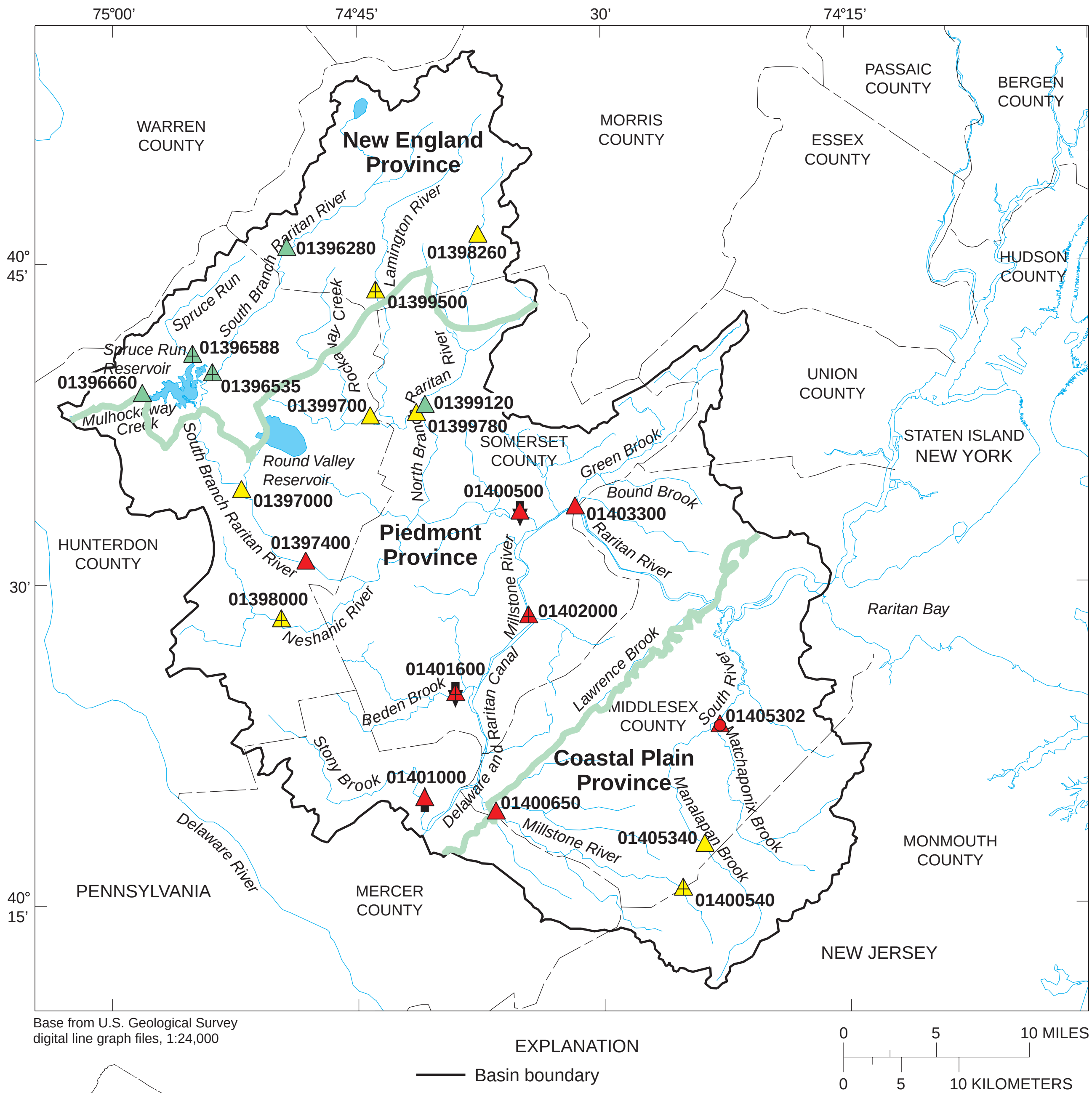
Chloride.--Median concentrations of chloride were highest at N.B. Raritan River at Chester and Lamington River at Pottersville (38 and 36 mg/L, respectively) (fig. A4, table 8). Median concentrations were lowest at Millstone River at Manalapan, Mulhockaway Creek, and Spruce Run (14, 15, and 17 mg/L, respectively). Highest instantaneous concentrations ranging from 110 to 190 mg/L occurred during high-flow conditions in the winter months at five sites.

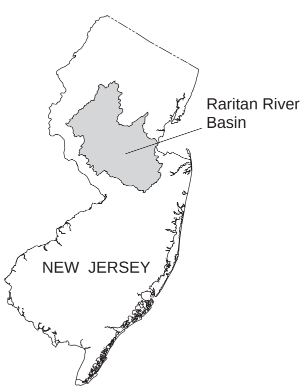
Median concentrations at 13 sites were highest at high flow during the nongrowing season. Median concentrations were significantly higher during the nongrowing season than the growing season at four sites (table 8). For all sites, the lowest median concentrations occurred during the growing season; median concentrations at 15 sites were lowest at high flow during the growing season. Concentrations at three sites were

Table 6. Statistical summary of and differences in total ammonia plus organic nitrogen concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; <, less than the laboratory detection limit; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow)]

		Total ammonia plus organic nitrogen										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration			Median concentration			
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	
01396280	S.B. Raritan River	35	0.03	0.29	1.00	0.30	0.20	--	0.23	0.30	--	--
01396535	S.B. Raritan River	34	.04	.20	1.30	.26	.18	G	.20	.20	--	--
01396588	Spruce Run	35	<.03	.17	.90	.20	.12	G	.16	.18	--	--
01396660	Mulhockaway Ck	36	<.03	.14	.92	.17	.14	--	.13	.15	--	--
01397000	S.B. Raritan River	31	.12	.30	1.80	.30	.30	--	.28	.30	--	--
01397400	S.B. Raritan River	35	.11	.39	1.10	.38	.42	--	.44	.37	--	--
01398000	Neshanic River	55	<.03	.30	2.10	.40	.20	G	.30	.27	--	--
01398260	N.B. Raritan River	35	.06	.30	1.40	.32	.25	--	.30	.26	--	--
01399120	N.B. Raritan River	35	<.03	.27	.67	.30	.24	--	.30	.22	--	--
01399500	Lamington River	36	.14	.30	.77	.34	.30	G	.32	.30	--	--
01399700	Rockaway Creek	35	.05	.30	1.00	.30	.30	--	.32	.30	--	--
01399780	Lamington River	35	.11	.30	1.10	.30	.28	--	.30	.30	--	--
01400500	Raritan River	35	.07	.38	.76	.44	.30	--	.43	.25	LO	--
01400540	Millstone River	35	.15	.30	.73	.39	.20	G	.24	.30	--	--
01400650	Millstone River	28	.20	.50	3.10	.53	.53	--	.56	.53	--	--
01401000	Stony Brook	58	.08	.40	3.00	.50	.34	--	.36	.50	HI	--
01401600	Beden Brook	36	<.03	.39	.83	.51	.30	G	.46	.30	LO	--
01402000	Millstone River	31	.26	.54	1.60	.68	.50	G	.56	.50	--	--
01403300	Raritan River	53	.30	.50	1.50	.60	.40	--	.50	.50	--	--
01405302	Matchaponix Brook	31	<.03	.40	2.10	.40	.40	--	.40	.41	--	--
01405340	Manalapan Brook	35	<.03	.30	.60	.33	.25	--	.30	.30	--	--





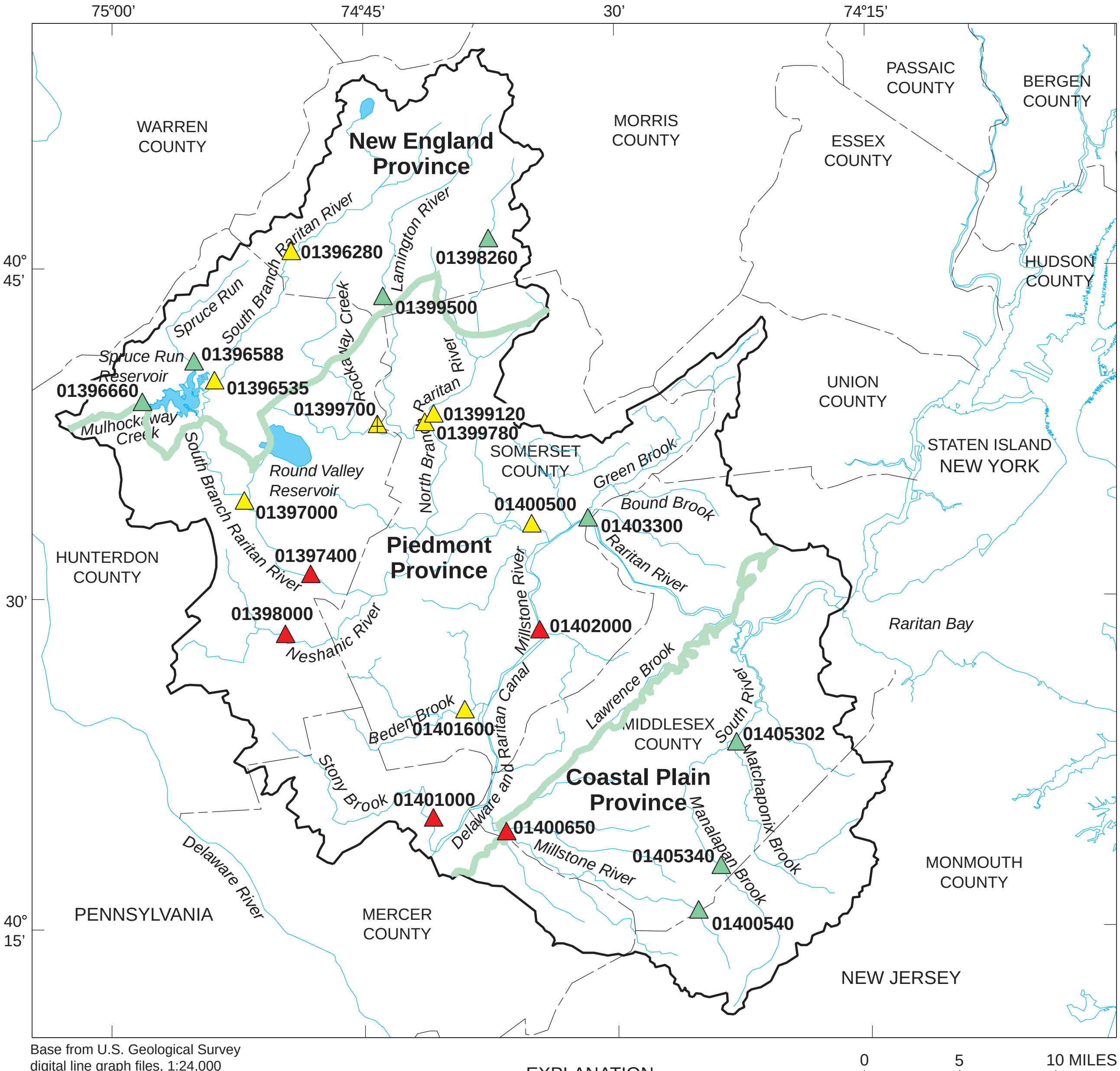
Siteid	Total ammonia plus organic nitrogen
01396280	0.29
01396535	0.20
01396588	0.17
01396660	0.14
01397000	0.30
01397400	0.39
01398000	0.30
01398260	0.30
01399120	0.27
01399500	0.30
01399700	0.30
01399780	0.30
01400500	0.38
01400540	0.30
01400650	0.53
01401000	0.40
01401600	0.39
01402000	0.54
01403300	0.50
01405302	0.40
01405340	0.30

Figure 5. Median total ammonia plus organic nitrogen concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97

Table 7. Statistical summary of and differences in biochemical oxygen demand concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; <, less than the laboratory detection limit; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October)]

		Biological oxyen demand										
						Seasonal comparison			Flow comparison			
		Statistical summary of all data				Median concentration			Median concentration			
Station number	Station name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	Flow and season interaction (highest median)
01396280	S.B. Raritan River	35	<1.0	1.3	4.4	1.1	1.3	--	<1.0	1.4	--	--
01396535	S.B. Raritan River	35	<1.0	1.4	3.2	1.4	1.5	--	1.0	1.5	--	--
01396588	Spruce Run	35	<1.0	1.2	3.3	1.0	1.5	--	1.2	1.2	--	--
01396660	Mulhockaway Creek	34	<1.0	1.0	2.6	1.2	<1.0	--	1.0	1.0	--	--
01397000	S.B. Raritan River	31	<1.0	1.5	3.9	1.6	1.4	--	1.5	1.4	--	--
01397400	S.B. Raritan River	35	<1.0	1.7	6.0	1.5	1.9	--	1.6	1.7	--	--
01398000	Neshanic River	35	<1.0	1.6	5.3	1.6	1.1	--	1.6	1.0	--	--
01398260	N.B. Raritan River	34	<1.0	1.0	2.8	1.2	<1.0	--	1.3	<1.0	--	--
01399120	N.B. Raritan River	35	<1.0	1.5	5.5	1.6	1.2	--	1.2	1.5	--	--
01399500	Lamington River	34	<1.0	1.2	2.4	<1.0	1.3	--	1.2	1.0	--	--
01399700	Rockaway Creek	35	<1.0	1.3	4.9	1.2	<1.0	G	1.4	1.3	--	--
01399780	Lamington River	35	<1.0	1.5	4.2	1.5	1.4	--	1.5	1.5	--	--
01400500	Raritan River	33	<1.0	1.4	3.6	1.4	<1.0	--	1.5	1.0	--	--
01400540	Millstone River	35	<1.0	<1.0	3.2	1.1	<1.0	--	1.4	<1.0	--	--
01400650	Millstone River	29	<1.0	1.6	7.2	1.6	1.2	--	1.6	1.6	--	--
01401000	Stony Brook	34	<1.0	1.7	4.3	1.8	1.6	--	1.8	1.4	--	--
01401600	Beden Brook	34	<1.0	1.4	2.8	1.4	1.3	--	1.5	1.2	--	--
01402000	Millstone River	31	<1.0	1.8	5.0	1.8	1.8	--	1.6	1.9	--	--
01403300	Raritan River	13	<1.0	1.2	2.9	1.6	<1.0	--	1.5	1.1	--	--
01405302	Matchaponix Brook	33	<1.0	<1.0	1.9	<1.0	1.1	--	1.0	<1.0	--	--
01405340	Manalapan Brook	34	<1.0	<1.0	2.8	1.0	<1.0	--	<1.0	1.1	--	--



Siteid	Biochemical oxygen demand
01396280	1.30
01396535	1.40
01396588	1.20
01396660	1.03
01397000	1.50
01397400	1.70
01398000	1.60
01398260	1.12
01399120	1.50
01399500	1.16
01399700	1.30
01399780	1.50
01400500	1.40
01400540	1.03
01400650	1.60
01401000	1.70
01401600	1.35
01402000	1.80
01403300	1.20
01405302	1.00
01405340	0.96

Figure 6. Median biochemical oxygen demand concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 8. Statistical summary of and differences in chloride concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April- October); NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November- March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Chloride										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration		Significant seasonal difference	Median concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	35	16.0	27.0	150	27	28	--	27	28	--	--
01396535	S.B. Raritan River	36	13.0	22.5	55	22	24	NG	22	24	HI	--
01396588	Spruce Run	36	12.0	17.5	24	17	18	--	18	17	--	--
01396660	Mulhockaway Ck	36	9.0	15.0	68	15	16	--	14	18	HI	--
01397000	S.B. Raritan River	31	13.0	22.0	38	22	22	--	22	22	--	--
01397400	S.B. Raritan River	35	15.0	29.0	58	29	30	--	30	27	--	--
01398000	Neshanic River	54	12.0	22.0	190	22	27	--	21	23	--	--
01398260	N.B. Raritan River	35	25.0	38.0	74	37	42	--	41	38	--	G@LO
01399120	N.B. Raritan River	35	16.0	31.0	62	29	33	NG	29	33	HI	NG@HI
01399500	Lamington River	36	21.0	36.0	50	34	38	--	36	34	--	--
01399700	Rockaway Creek	35	12.0	18.0	34	18	18	--	20	17	--	--
01399780	Lamington River	35	15.0	27.0	50	25	27	--	27	25	--	NG@HI
01400500	Raritan River	35	17.0	24.0	71	25	24	--	24	26	--	--
01400540	Millstone River	35	11.0	14.0	31	13	15	NG	14	14	--	--
01400650	Millstone River	30	11.0	24.0	78	22	26	NG	24	24	--	--
01401000	Stony Brook	56	7.5	24.0	110	24	22	--	24	20	LO	--
01401600	Beden Brook	36	14.0	24.0	76	23	24	--	24	21	--	G@LO
01402000	Millstone River	31	15.0	27.0	110	26	30	--	28	27	--	NG@HI
01403300	Raritan River	53	8.6	28.0	58	29	27	--	33	25	LO	--
01405302	Matchaponix Brook	34	11.0	31.5	130	29	32	--	36	26	LO	--
01405340	Manalapan Brook	35	11.0	18.0	36	16	20	--	18	18	--	--

significantly higher at high flows and at three sites were significantly higher at low flows (fig. 7).

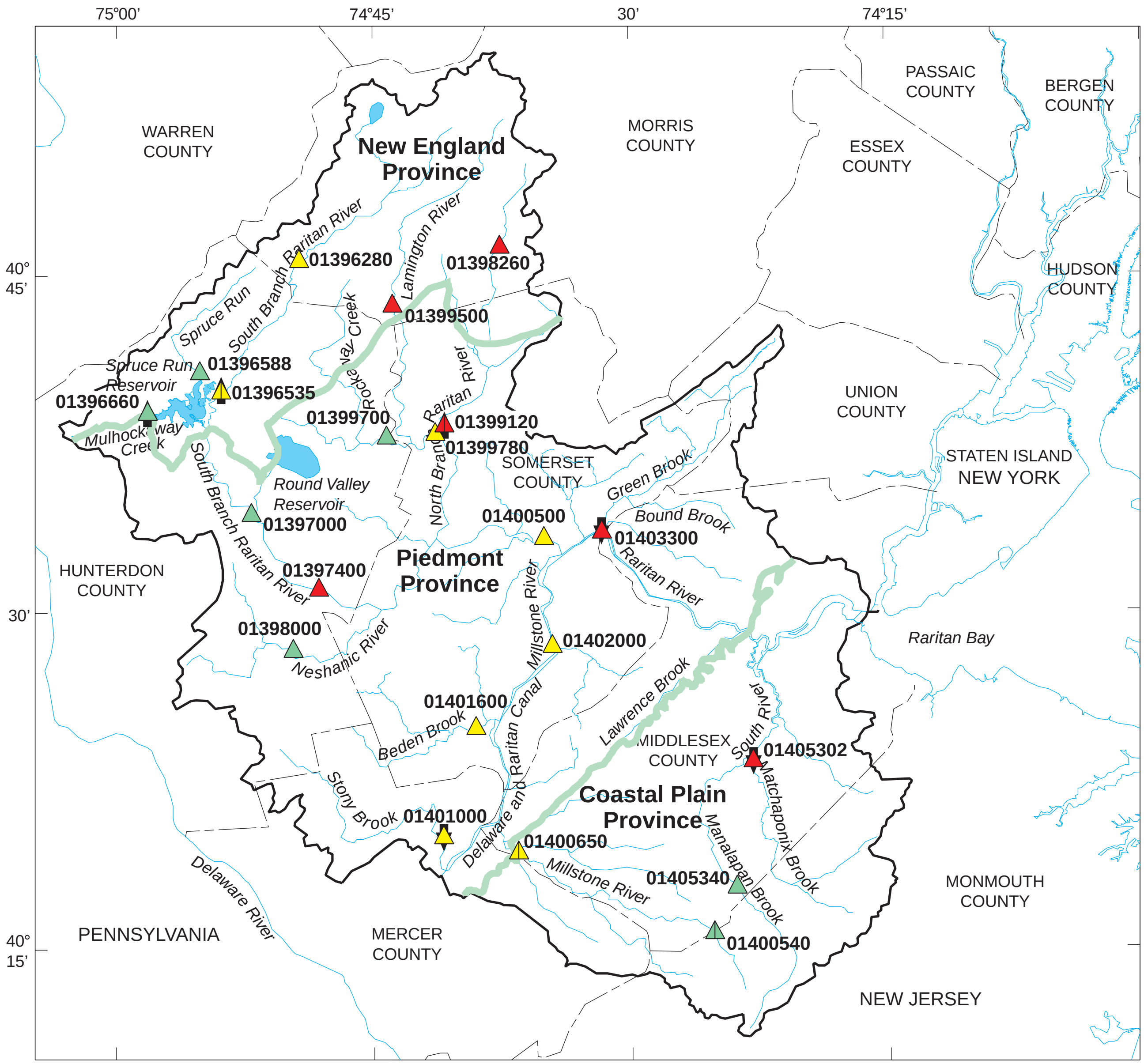
There is no dominant factor that relates to the variability of chloride concentrations in streams in the Raritan River Basin when season, flow, and interactions of both variables are studied together in a 2-way ANOVA. The interaction of season and flow was a significant factor in explaining variability of concentrations at five sites. High flow in the nongrowing season was the significant factor in determining highest concentrations at three sites--N.B. Raritan River at Burnt Mills, Lamington River at Burnt Mills, and Millstone River at Blackwells Mills (table 8). Low flow in the growing season was the significant variable that defined when the highest concentrations of chloride occurred at two sites--N.B. Raritan River at Chester and Beden Brook. At N.B. Raritan River at Burnt Mills, concentrations increased with flow during the nongrowing season and decreased with flow during the growing season. No significant differences in concentrations were observed between seasons or flow conditions at nine sites.

Results of Tobit regression indicated that chloride concentrations were significantly related to instantaneous flow at seven sites. Concentrations significantly increased as flow increased at three sites--Mulhockaway Creek, S.B. Raritan River at Stanton, and Beden Brook. The slope of the regression line is steepest for Mulhockaway Creek, indicating that concentrations increased more with increased flow at this site than at the other sites (fig. 3). All concentrations greater than 18 mg/L were in samples collected at flows greater than 10 ft^3/s during the nongrowing season. For four sites, including Stony Brook, Raritan River at Bound Brook, Matchaponix Brook, and Manalapan Brook, concentrations of chloride decreased as flow increased. An example of the plots generated for each constituent at each site for the analysis of concentration in relation to flow is shown in figure 3.

Dissolved oxygen.--Median concentrations of dissolved oxygen were fairly uniform across the study area (8.9-12.1 mg/L) (fig. A5, table 9). Concentrations at S.B. Raritan River at Middle Valley, Neshanic River, and N.B. Raritan River at Burnt Mills were significantly higher than at Lamington River at Burnt Mills, Millstone River sites at Grovers Mill and Blackwells Mills, and Matchaponix Brook (table 9). The lowest median values were calculated for sites in the Coastal Plain--Millstone River at Blackwells Mills and Raritan River at Bound Brook (fig. 8). The lowest instantaneous measurements were made at the Millstone River sites at Grovers Mill and Blackwells Mills, and at Neshanic River at Reaville at low flows during the growing season (table 9). The lowest value detected, 2.9 mg/L, was at Millstone River at Blackwells Mills at low flow in August. The highest values detected,18.2 and 17.5 mg/L, were at Stony Brook and Neshanic River at high flow in April.

Season along with the subsequent change in stream temperature is the dominant factor that causes the variability of dissolved oxygen concentrations in streams in the Raritan River Basin when season, flow, and interaction of both variables are studied together. All sites had significantly higher concentrations of dissolved oxygen during the nongrowing season. Median concentrations were highest at all sites at high flow; however, the concentrations at 10 sites were significantly higher at high flow than at low flow. Season and flow were both significant explanatory variables for the changes in concentrations at ten sites. The interaction of season and flow as an explanatory variable was a significant factor in defining variability in concentrations of dissolved oxygen at two sites--S.B. Raritan River at Middle Valley and Mulhockaway Creek (table 9). The median concentration of samples collected at low flow during the nongrowing season was significantly higher than the median concentration of samples collected during other season and flow conditions.

Results of the Tobit regression indicate that dissolved oxygen concentrations significantly increased as flow increased at 12 sites. No sites showed a decrease in concentration with increased flow. Season along with the subsequent change in stream temperature is the dominant factor that causes the variability of dissolved oxygen concentrations in streams.



Base from U.S. Geological Survey digital line graph files, 1:24,000

EXPLANATION

Basin boundary

Physiographic province boundary

Median concentration, in milligrams per liter

14 — 22

22.5 — 27

27.5 — 38

Season change

No change

Significantly higher in growing season (Apr.—Oct.)

Significantly higher in non-growing season (Nov.—Mar.)

Flow change

Significantly higher at low flow (below median flow)

Significantly higher at high flow (above median flow)

01396660 Surface-water sampling site number (siteid)

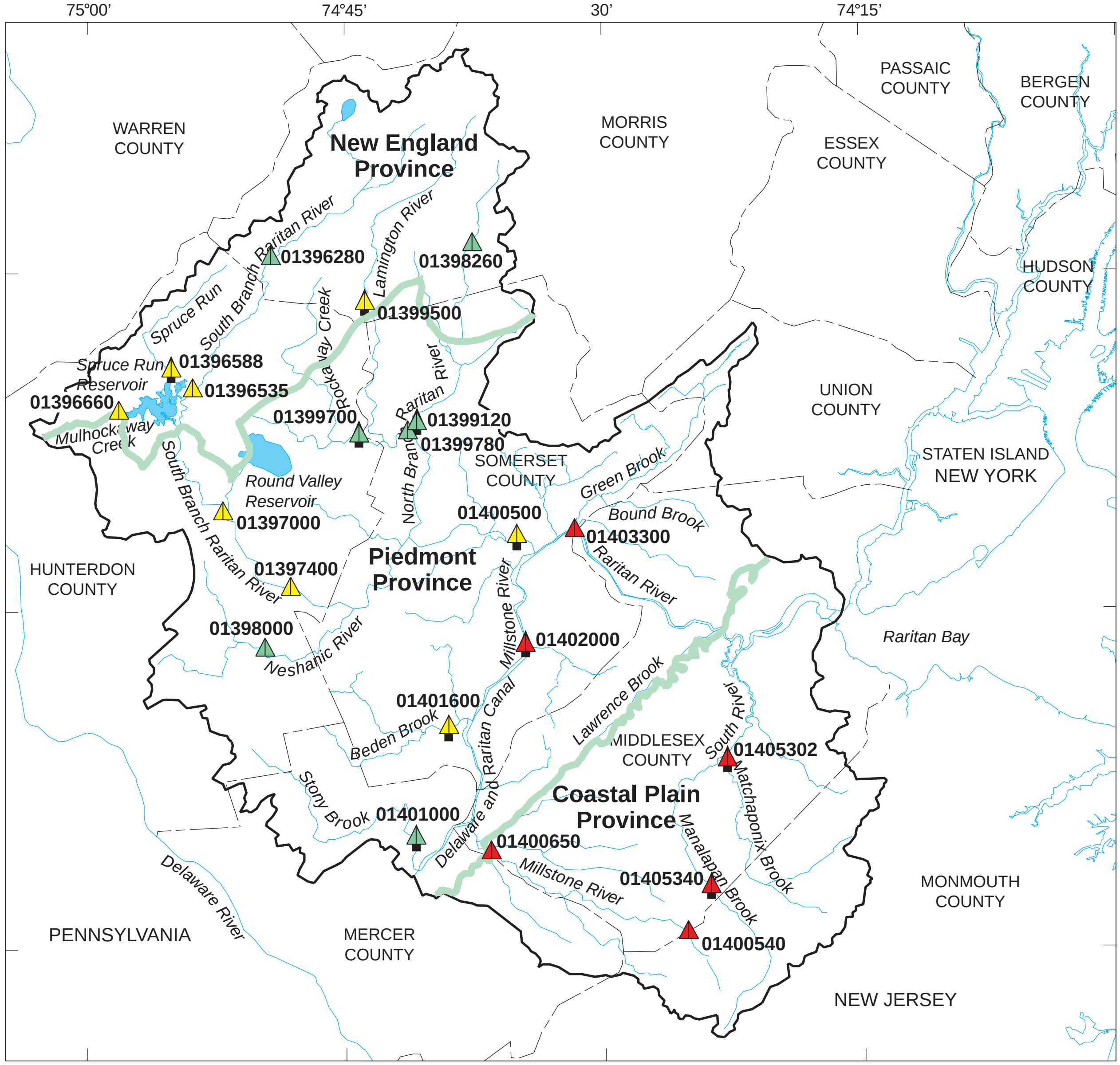
Siteid	Chloride
01396280	27.00
01396535	22.50
01396588	17.50
01396660	15.00
01397000	22.00
01397400	29.00
01398000	22.00
01398260	38.00
01399120	31.00
01399500	36.00
01399700	18.00
01399780	27.00
01400500	24.00
01400540	14.00
01400650	24.00
01401000	24.00
01401600	24.00
01402000	27.00
01403300	28.00
01405302	31.50
01405340	18.00

Figure 7. Median chloride concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 9. Statistical summary of and differences in dissolved oxygen concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November- March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Dissolved oxygen										
		Statistical summary of all data				Seasonal comparison			Flow comparison			
						Median concentration			Median concentration			
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	Flow and season interaction (highest median)
01396280	S.B. Raritan River	35	8.10	11.3	15.4	9.8	14	NG	12	11	--	NG@LO
01396535	S.B. Raritan River	36	8.50	10.8	15.6	9.7	13	NG	10	12	--	--
01396588	Spruce Run	36	8.80	10.9	15.6	9.9	13	NG	9.8	12	HI	--
01396660	Mulhockaway Ck	36	7.70	10.8	15.6	9.6	14	NG	10	11	--	NG@LO
01397000	S.B. Raritan River	31	8.20	10.3	15.8	9.8	14	NG	10	12	--	--
01397400	S.B. Raritan River	35	7.80	10.5	16.4	9.6	13	NG	10	12	--	--
01398000	Neshanic River	50	5.40	12.1	17.5	11	14	NG	11	13	--	--
01398260	N.B. Raritan River	34	8.40	11.3	15.0	9.3	13	NG	10	12	--	--
01399120	N.B. Raritan River	35	8.20	11.0	14.9	10	14	NG	10	13	HI	--
01399500	Lamington River	36	7.80	10.9	16.0	9.6	14	NG	10	12	HI	--
01399700	Rockaway Creek	35	6.50	11.6	14.6	9.7	13	NG	9.4	12	HI	--
01399780	Lamington River	37	7.70	11.7	15.1	10	14	NG	11	13	--	--
01400500	Raritan River	35	6.60	10.3	15.5	8.8	13	NG	9.6	13	HI	--
01400540	Millstone River	35	7.50	10.0	14.1	8.7	12	NG	9.6	10	--	--
01400650	Millstone River	30	2.90	9.5	13.2	7.0	11	NG	7.9	10	--	--
01401000	Stony Brook	53	6.00	11.0	18.2	9.5	13	NG	10	13	HI	--
01401600	Beden Brook	34	5.50	10.5	15.5	9.0	13	NG	9.1	13	HI	--
01402000	Millstone River	31	4.40	8.9	13.9	6.5	12	NG	6.4	11	HI	--
01403300	Raritan River	52	6.10	9.8	16.0	8.4	12	NG	9.6	10	--	--
01405302	Matchaponix Brook	35	6.00	9.3	13.5	7.9	11	NG	8.4	10	HI	--
01405340	Manalapan Brook	35	7.80	10.1	15.1	9.2	12	NG	8.8	11	HI	--



Base from U.S. Geological Survey digital line graph files, 1:24,000

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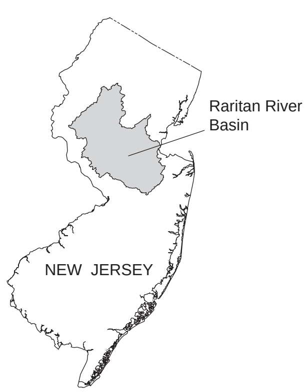


EXPLANATION

Basin boundary
Physiographic province boundary

Median concentration, in milligrams per liter

8.9 — 10.1
10.2 — 10.9
11.0 — 12.2

Season change

No change
Significantly higher in growing season (Apr.—Oct.)
Significantly higher in non-growing season (Nov.—Mar.)

Flow change

Significantly higher at low flow (below median flow)
Significantly higher at high flow (above median flow)

01396660 Surface-water sampling site number (siteid)

Siteid	Dissolved oxygen
01396280	11.3
01396535	10.8
01396588	10.8
01396660	10.9
01397000	10.3
01397400	10.5
01398000	12.1
01398260	11.2
01399120	11.0
01399500	10.9
01399700	11.6
01399780	11.7
01400500	10.3
01400540	10.0
01400650	9.5
01401000	11.0
01401600	10.5
01402000	8.9
01403300	9.8
01405302	9.3
01405340	10.1

Figure 8. Median dissolved oxygen concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Dissolved solids, total.--Concentrations of TDS were significantly higher at low-flow conditions than at high-flow conditions at 17 sites (table 10). Median concentrations at low flow were higher than at high flow at all sites. The highest concentration measured was 448 mg/L for the Neshanic River at low flow. Some of the highest TDS concentrations in instantaneous samples occurred, however, at high flows in winter. The second highest concentration recorded was 334 mg/L for S.B. Raritan River at Middle Valley at high flow in January. Chloride and sodium also were high in the same sample and contributed to high TDS as a result of runoff containing de-icing salts. Although the highest TDS concentrations were measured at high flow in winter, the highest median concentrations occurred at each site at low flow. The lowest concentrations in a sample were measured at high flow during the growing season. Samples collected at high flow during the growing season at Stony Brook and Millstone River at Manalapan contained TDS concentrations of 56 and 57 mg/L, respectively.

Median concentrations were compared between seasons at each site. Manalapan Brook was the only site with a significant seasonal difference; higher concentrations were measured during the nongrowing season (fig. 9). Low flow and growing season were the significant explanatory variables that defined conditions when the highest concentrations of TDS occurred at two sites--S.B. Raritan River at High Bridge and N.B. Raritan River at Burnt Mills.

Median concentrations of TDS were significantly lower at Millstone River at Manalapan and Manalapan Brook than at the other sites (fig. A6, table 10). Median concentrations were 69 and 79 mg/ L, respectively. Median concentrations were highest at Matchaponix Brook and Neshanic River, 159 and 157 mg/L, respectively. Results of the Tobit regression indicated that TDS significantly decreased as flow increased at 20 of the 21 sites. The slope of the regression line (-0.32) shows that Matchaponix Brook had the greatest decrease in concentrations as flow increased. Concentrations at Millstone River at Manalapan did not significantly change as flow increased.

Flow is the dominant factor relating to the variability of TDS concentrations in streams in the Raritan River Basin when season, flow, and interaction of both variables are studied together. Concentrations were significantly higher at low flow at 15 of the 21 sites. The interaction of season and flow as an explanatory variable was a significant factor in explaining variability in concentrations only at N.B. Raritan River at Burnt Mills and S.B. Raritan River at High Bridge (table 10). Concentrations were significantly higher at low flow during the growing season at both sites. Samples collected at Raritan River at Manville and Millstone River at Manalapan did not show any significant variation in concentrations with changes in flow and season.

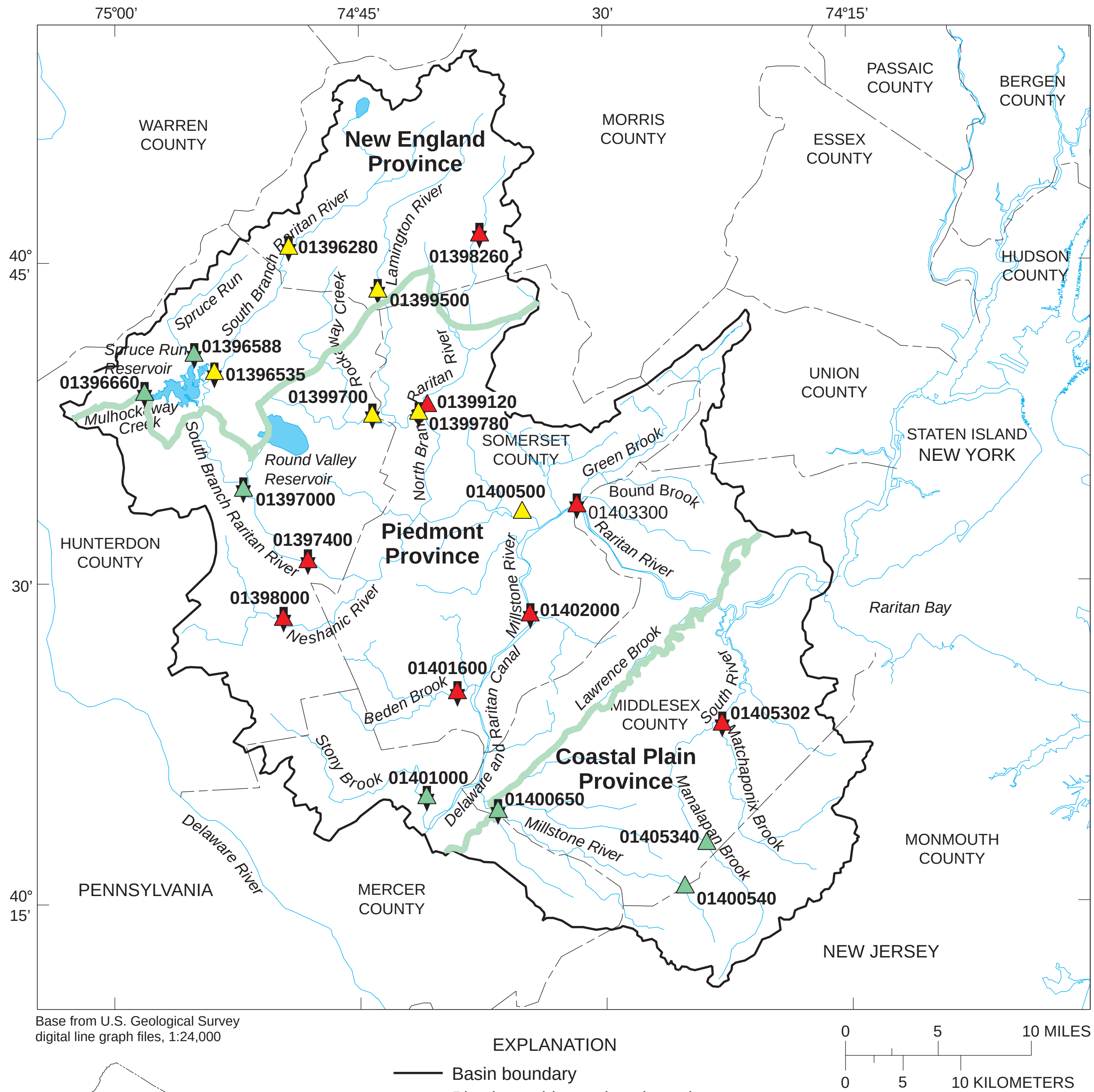
Fecal coliform bacteria.--Season is the dominant factor relating to the variability of fecal coliform counts in streams in the Raritan River Basin. Median fecal coliform counts were highest at all sites during the growing season (table 11, fig. 10). Median counts were significantly higher during the growing season than during the nongrowing season at 17 sites. Median counts were higher at low flows than at high flows at 16 sites. Counts were significantly higher at low-flow conditions at three sites than at high-flow conditions (table 11). Results of the Tobit regression indicated that counts decreased significantly as flow increased at Rockaway Creek and Beden Brook. No other sites had a statistically significant relation of fecal coliform bacteria count to flow.

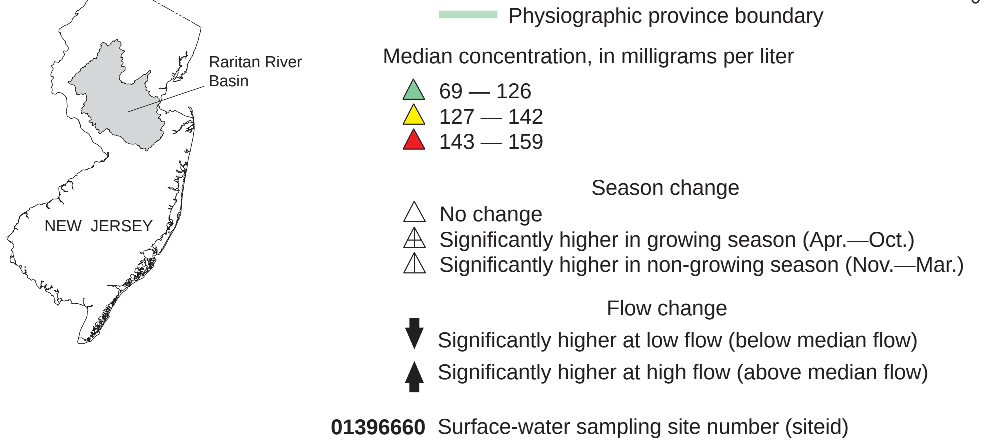
Median fecal coliform counts were highest at Neshanic River (790 colonies/100mL) and N.B. Raritan River at Burnt Mills (310 colonies/100mL) and lowest at the Matchaponix Brook and Manalapan Brook sites (20 colonies/100mL) (fig. A7). A total of eight sites, including the five sites in the Millstone River subbasin, the Lamington River sites at Pottersville and Burnt Mills, and the Neshanic River site, had one sample with counts that exceeded 24,000 colonies per 100 mL. Five of these samples were collected July 22 –24, 1997, during runoff conditions. The samples from the Neshanic River and Millstone River at Grovers Mill were collected at relatively low flows at the beginning of runoff conditions. Neshanic River and

Table 10. Statistical summary of and differences in total dissolved solids concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November- March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

Station number	Stream name	Total dissolved solids										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median Concentration			Median concentration			
		Number of samples	Minimum	Median	Maximum	Growing	Non-growing	Significant seasonal difference	Low flow	High flow	Significant difference with flow	
01396280	S.B. Raritan River	35	93	138	334	139	135	--	154	124	LO	--
01396535	S.B. Raritan River	36	85	136	187	141	136	--	147	125	LO	G@LO
01396588	Spruce Run	36	89	106	123	109	102	--	113	101	LO	--
01396660	Mulhockaway Ck	36	90	119	202	122	119	--	126	110	LO	--
01397000	S.B. Raritan River	31	87	125	150	117	128	--	130	119	LO	--
01397400	S.B. Raritan River	35	89	151	222	148	156	--	172	144	LO	--
01398000	Neshanic River	53	91	157	448	161	151	--	184	139	LO	--
01398260	N.B. Raritan River	35	96	147	204	153	139	--	167	137	LO	--
01399120	N.B. Raritan River	35	104	144	173	141	144	--	146	140	--	G@LO
01399500	Lamington River	35	92	136	171	138	134	--	149	122	LO	--
01399700	Rockaway Creek	34	95	130	187	138	126	--	152	126	LO	--
01399780	Lamington River	35	88	132	210	137	129	--	145	119	LO	--
01400500	Raritan River	35	88	142	205	141	143	--	146	139	--	--
01400540	Millstone River	33	57	69	101	68	69	--	69	68	--	--
01400650	Millstone River	30	60	120	200	114	122	--	139	108	LO	--
01401000	Stony Brook	55	56	126	263	127	126	--	136	111	LO	--
01401600	Beden Brook	36	88	144	259	149	137	--	159	119	LO	--
01402000	Millstone River	31	86	149	274	142	150	--	155	135	LO	--
01403300	Raritan River	53	65	144	203	139	149	--	182	131	LO	--
01405302	Matchaponix Brook	31	74	159	315	160	159	--	200	138	LO	--
01405340	Manalapan Brook	34	61	79	114	74	84	NG	82	79	--	--





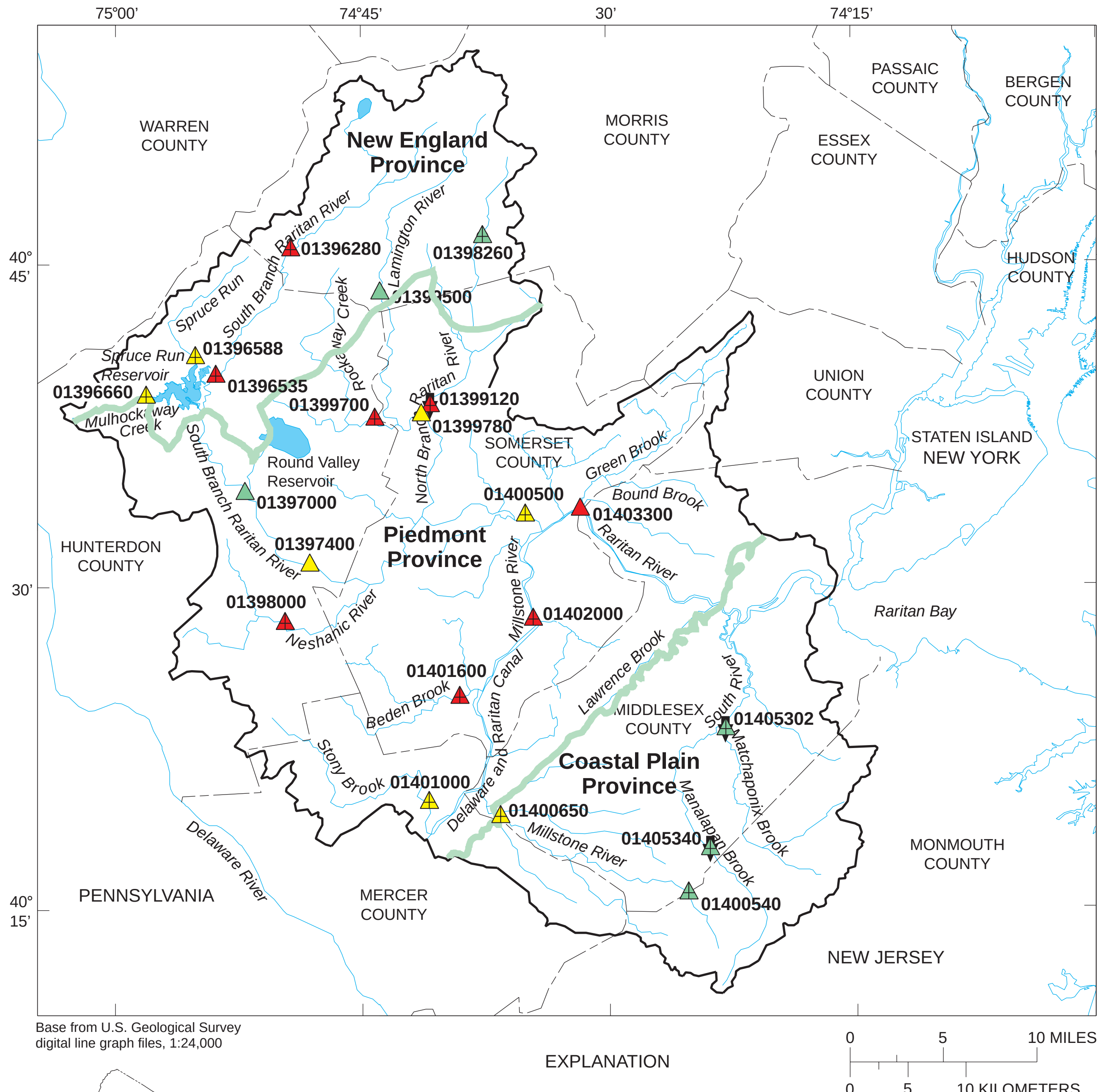
Siteid	Total dissolved solids
01396280	138.0
01396535	136.0
01396588	105.5
01396660	119.0
01397000	125.0
01397400	151.0
01398000	157.5
01398260	147.0
01399120	144.0
01399500	136.0
01399700	130.0
01399780	132.0
01400500	142.0
01400540	69.0
01400650	120.0
01401000	126.0
01401600	143.0
01402000	149.0
01403300	144.0
01405302	159.0
01405340	79.0

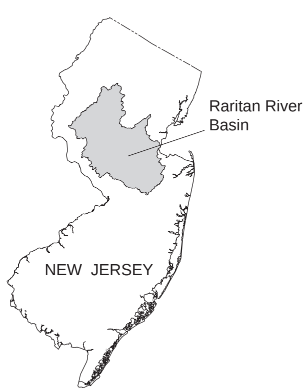
Figure 9. Median total dissolved solids concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 11. Statistical summary of and differences in fecal coliform bacteria counts between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; <, less than the laboratory detection limit; >, greater than the laboratory detection limit; --, indicates the distribution of counts during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest counts occur in the growing season (April- October); LO, significant differences occur between flow conditions and largest counts occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest counts occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Fecal coliform count										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration		Significant seasonal difference	Median concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	35	<20	230	3,500	490	50	G	330	180	--	--
01396535	S.B. Raritan River	35	<20	220	9,200	600	70	G	750	130	--	--
01396588	Spruce Run	35	<20	130	3,500	280	50	G	130	110	--	G@HI
01396660	Mulhockaway Ck	35	<20	170	5,400	330	50	G	170	150	--	--
01397000	S.B. Raritan River	30	<20	100	2,400	170	70	--	50	170	--	--
01397400	S.B. Raritan River	35	<20	170	9,200	330	60	--	330	170	--	--
01398000	Neshanic River	35	20	790	>24,000	1,100	120	G	1,100	640	--	--
01398260	N.B. Raritan River	35	<20	80	5,400	220	40	G	80	85	--	--
01399120	N.B. Raritan River	35	<20	310	3,500	640	150	G	490	170	LO	--
01399500	Lamington River	35	<20	40	>24,000	45	20	--	40	35	--	--
01399700	Rockaway Creek	35	<20	220	9,200	700	60	G	490	220	--	G@HI
01399780	Lamington River	35	<20	170	>24,000	270	80	--	350	310	--	--
01400500	Raritan River	35	<20	170	9,200	230	90	G	155	170	--	G@HI
01400540	Millstone River	35	<20	50	>24,000	330	<20	G	90	20	--	--
01400650	Millstone River	29	<20	110	>24,000	330	35	G	225	80	--	--
01401000	Stony Brook	34	<20	130	>24,000	330	50	G	170	70	--	G@HI
01401600	Beden Brook	35	<20	230	>24,000	600	90	G	280	80	--	--
01402000	Millstone River	31	20.0	230	>24,000	330	80	G	280	140	--	--
01403300	Raritan River	30	<20	280	>24,000	490	50	G	490	130	--	--
01405302	Matchaponix Brook	35	<20	20	5,400	170	<20	G	80	<20	LO	G@HI
01405340	Manalapan Brook	35	<20	20	16,000	130	<20	G	45	20	LO	G@HI





EXPLANATION

Basin boundary

Physiographic province boundary

Median number of colonies per 100 milliters

20 — 100

101 — 190

191 — 790

Season change

No change

Significantly higher in growing season (Apr.—Oct.)

Significantly higher in non-growing season (Nov.—Mar.)

Flow change

Significantly higher at low flow (below median flow)

Significantly higher at high flow (above median flow)

01396660 Surface-water sampling site number (siteid)

Siteid	Fecal
01396280	230
01396535	220
01396588	130
01396660	170
01397000	100
01397400	170
01398000	790
01398260	80
01399120	310
01399500	40
01399700	220
01399780	170
01400500	170
01400540	50
01400650	110
01401000	130
01401600	230
01402000	230
01403300	225
01405302	20
01405340	20

Figure 10. Median fecal coliform bacteria counts and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Millstone River at Blackwells Mills sites are the only sites at which all samples equaled or exceeded 20 colonies per 100mL.

Season was the dominant factor relating to the variability of fecal coliform counts in streams in the Raritan River Basin when season, flow, and interaction of both variables were studied together. The interaction of season and flow was a significant factor in defining the variability in fecal coliform counts at six sites (table 11). Fecal coliform counts were significantly higher at high flow during the growing season at each of the six sites than during the nongrowing season. Samples collected at two sites on the S.B. Raritan River and two sites on the Lamington River did not show any significant variation in fecal coliform counts with changes in flow and season.

Hardness.--The median concentration of hardness was significantly lower at high flow than at low flow at all sites (table 12). Median concentrations were higher at 19 of the 21 sites during the growing season, but significantly higher only during the growing season at 7 sites. Flow as a function of season is a significant explanatory variable in determining variability in concentrations at Stony Brook and S.B. Raritan River at High Bridge. Results of the Tobit regression indicated that hardness concentrations significantly decreased as flow increased at all 21 sites. The slope of the regression line for S.B. Raritan River at Middle Valley indicates that the greatest decrease in concentration occurred as flow increased. The Millstone River at Manalapan site has the smallest slope. Median concentrations were lowest at the sites in the Coastal Plain and in the Millstone River subbasin (fig. 11).

The highest hardness concentrations occurred at Neshanic River site (table 12, fig. A8). Concentrations of more than 200 mg/L were detected in samples collected at low flows in summer. Concentrations varied more at this site than at the others. Concentrations less than 60 mg/L were detected during high flows in winter and spring. The smallest concentrations were measured at Millstone River at Manalapan and Manalapan Brook, two sites in the Coastal Plain without any point sources. Both sites have the least variation in concentrations during the sampling period. Flow is the dominant factor that defines variability in hardness concentrations in the basin.

Flow was the dominant factor relating to the variability of hardness concentrations in streams in the Raritan River Basin when season, flow, and interaction of both variables were studied together. Flow alone was the only significant factor related to variability at 14 sites. Concentrations were significantly higher at low flow at all sites. The interaction of season and flow as an explanatory variable was a significant factor only in explaining variability in concentrations at Stony Brook at Princeton and S.B. Raritan River at High Bridge (table 12). Concentrations were significantly higher at low flow during the growing season. Both season and flow were significant factors at five sites, predicting significantly higher concentrations in the growing season.

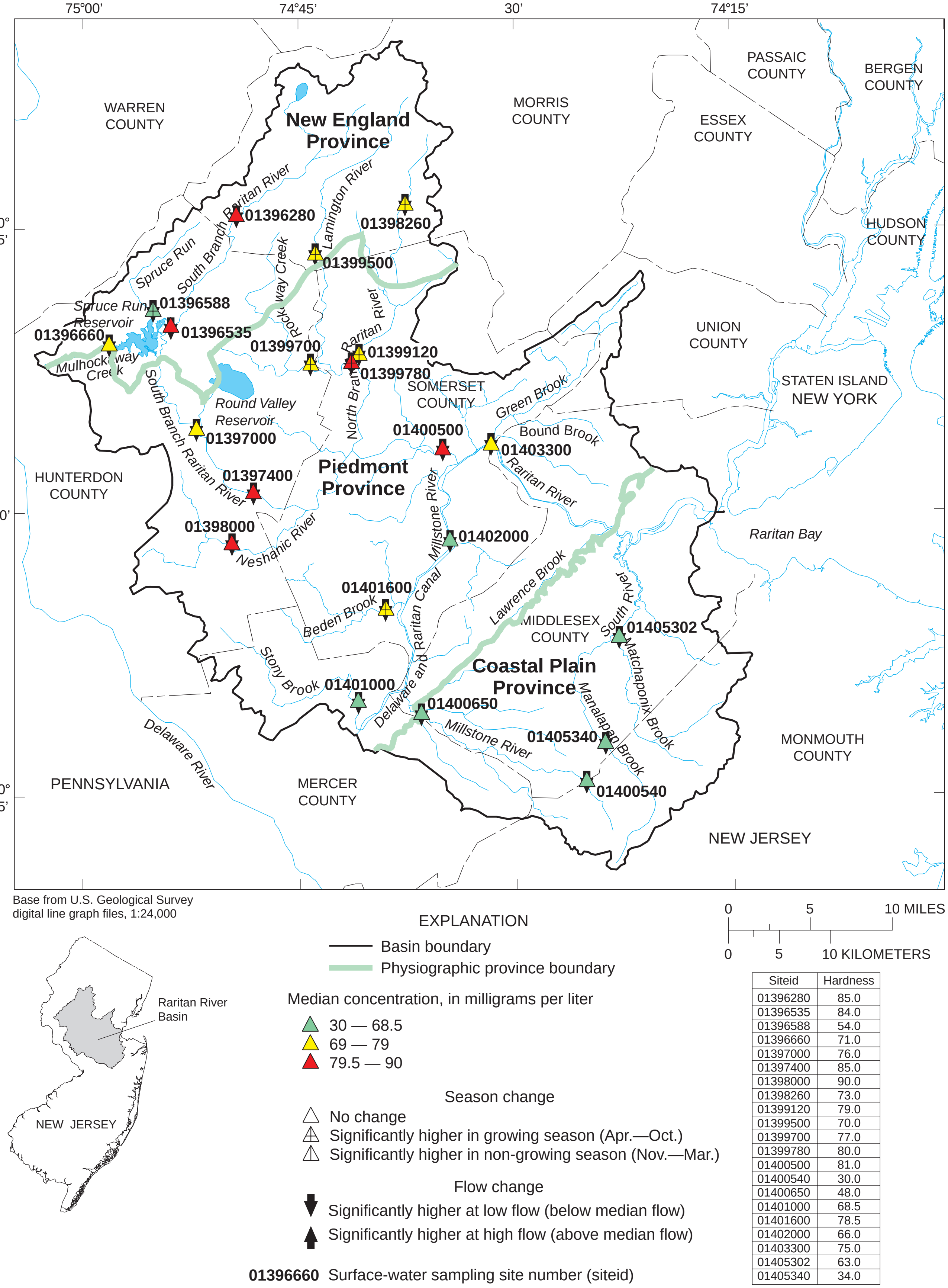
Nitrate plus nitrite.--Concentrations of NO3+NO2 were significantly higher at the Matchaponix Brook site and the Millstone River sites at Grovers Mill and Blackwells Mills than at the other sites (table 13). Concentrations greater than 5 mg/L were measured in samples collected at these sites and at the Rockaway Creek site (fig. A9). Concentrations greater than 5 mg/L were measured in samples from the Millstone River sites and the Matchaponix Brook site at low-flow conditions in summer. At Rockaway Creek, the highest concentration occurred at high flow in spring. Only Neshanic River and Stony Brook sites had concentrations less than 0.10 mg/L at low flows during the growing season. Median concentrations were lowest at Stony Brook and Lamington River at Pottersville sites and highest at the Millstone River sites and Matchaponix Brook site.

Ten sites had significantly higher median concentrations during the nongrowing season than during the growing season (fig. 12). No sites had significantly higher concentrations during the growing season. Eleven sites had significantly higher concentrations at low flow, and three sites had highest concentrations at high flow.

Table 12. Statistical summary of and differences in hardness concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); @, indicates flow as a function of season; NS, not significant]

		Hardness										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration		Significant seasonal difference	Median concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	35	51	85	120	88	75	--	100	69	LO	
01396535	S.B. Raritan River	36	48	84	130	96	81	--	100	74	LO	G@LO
01396588	Spruce Run	36	40	54	68	57	51	G	62	51	LO	--
01396660	Mulhockaway Ck	36	39	71	100	72	71	--	84	64	LO	--
01397000	S.B. Raritan River	31	48	76	100	76	75	--	82	71	LO	--
01397400	S.B. Raritan River	35	46	85	120	88	82	--	96	80	LO	--
01398000	Neshanic River	54	45	90	240	98	80	--	130	76	LO	--
01398260	N.B. Raritan River	35	44	73	110	81	64	G	90	65	LO	--
01399120	N.B. Raritan River	35	55	79	100	84	73	G	88	72	LO	--
01399500	Lamington River	36	43	70	91	75	58	G	78	57	LO	--
01399700	Rockaway Creek	35	50	77	110	85	68	G	96	72	LO	--
01399780	Lamington River	36	43	81	110	82	65	G	85	65	LO	--
01400500	Raritan River	35	42	81	100	87	78	--	88	77	LO	--
01400540	Millstone River	34	23	30	39	30	30	--	31	29	LO	--
01400650	Millstone River	30	26	48	55	48	47	--	49	44	LO	--
01401000	Stony Brook	56	28	68	110	69	67	--	84	64	LO	G@LO
01401600	Beden Brook	36	41	78	140	84	70	G	86	61	LO	--
01402000	Millstone River	31	36	66	94	69	64	--	75	61	LO	--
01403300	Raritan River	53	33	75	110	73	78	--	90	68	LO	--
01405302	Matchaponix Brook	35	31	63	100	74	61	--	83	58	LO	--
01405340	Manalapan Brook	34	25	34	40	33	34	--	35	34	LO	--



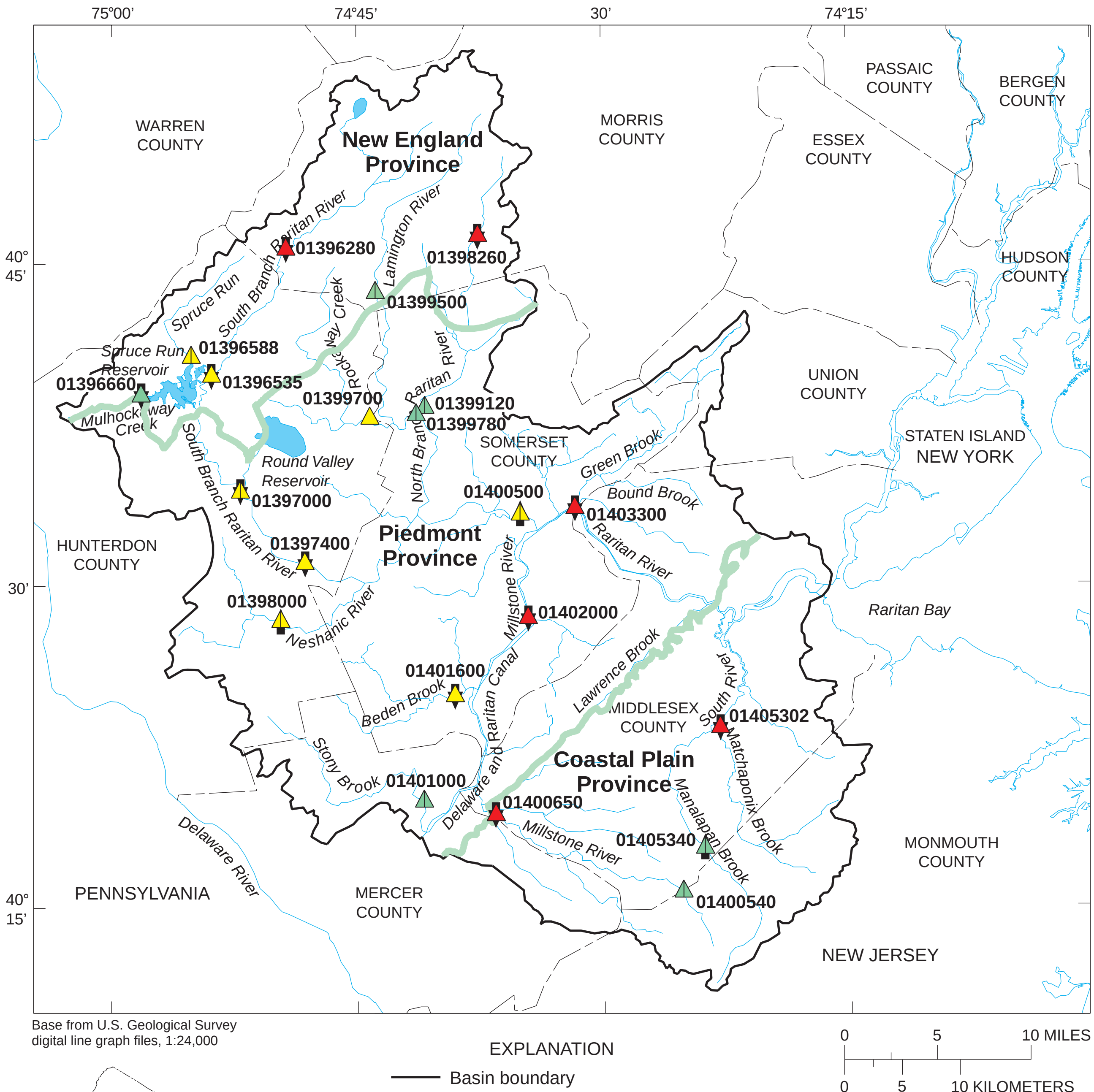
Siteid	Hardness
01396280	85.0
01396535	84.0
01396588	54.0
01396660	71.0
01397000	76.0
01397400	85.0
01398000	90.0
01398260	73.0
01399120	79.0
01399500	70.0
01399700	77.0
01399780	80.0
01400500	81.0
01400540	30.0
01400650	48.0
01401000	68.5
01401600	78.5
01402000	66.0
01403300	75.0
01405302	63.0
01405340	34.0

Figure 11. Median hardness concentration and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Table 13. Statistical summary of and differences in nitrate plus nitrite concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; <, less than the laboratory detection limit; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November-March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Total nitrate plus nitrite as nitrogen										
		Statistical summary of all data				Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
						Median concentration		Significant seasonal difference	Median concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	35	0.91	1.66	2.1	1.7	1.6	--	1.9	1.3	LO	--
01396535	S.B. Raritan River	36	.76	1.38	2.0	1.3	1.4	--	1.6	1.3	LO	--
01396588	Spruce Run	36	.39	1.08	2.0	1.0	1.1	NG	1.1	1.1	--	--
01396660	Mulhockaway Ck	36	.54	.92	1.5	.9	.9	--	1.0	.8	LO	--
01397000	S.B. Raritan River	31	.36	1.20	1.7	1.0	1.2	NG	1.3	1.0	LO	--
01397400	S.B. Raritan River	35	.75	1.53	2.9	1.4	1.6	--	1.6	1.3	LO	--
01398000	Neshanic River	54	<.00	1.60	4.40	1.0	2.1	NG	1.0	1.9	HI	--
01398260	N.B. Raritan River	35	.63	1.90	4.9	2.5	1.6	--	3.3	1.5	LO	--
01399120	N.B. Raritan River	35	.49	.93	1.5	.8	1.0	NG	.8	.9	--	--
01399500	Lamington River	36	.33	.74	3.9	.6	.9	NG	.8	.7	--	--
01399700	Rockaway Creek	35	.73	1.20	5.5	1.2	1.2	--	1.2	1.2	--	--
01399780	Lamington River	36	.22	.88	1.7	.8	.9	NG	.8	1.0	--	--
01400500	Raritan River	35	.34	1.2	2.3	.9	1.5	NG	1.0	1.3	HI	--
01400540	Millstone River	35	.72	1.3	2.3	1.2	1.5	NG	1.2	1.3	--	--
01400650	Millstone River	30	.84	3.7	6.3	3.8	3.6	--	4.1	2.7	LO	--
01401000	Stony Brook	57	.09	.61	1.6	.5	.7	NG	.5	.7	--	--
01401600	Beden Brook	36	.84	1.5	4.1	1.6	1.5	--	1.8	1.2	LO	--
01402000	Millstone River	31	1.19	2.3	6.4	2.4	2.3	--	2.8	2.0	LO	--
01403300	Raritan River	53	.88	1.8	3.3	1.7	1.9	--	2.4	1.5	LO	--
01405302	Matchaponix Brook	34	.90	3.8	10	4.5	3.6	--	6.4	3.1	LO	G@LO
01405340	Manalapan Brook	34	.43	.92	1.6	.7	1.0	NG	.7	1.0	HI	--



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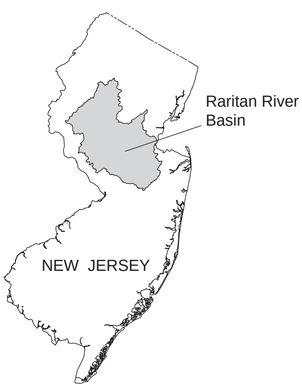


EXPLANATION

Basin boundary

Physiographic province boundary

Median concentration, in milligrams per liter

0.61 — 1.0

1.01 — 1.6

1.61 — 3.83

Season change

No change

Significantly higher in growing season (Apr.—Oct.)

Significantly higher in non-growing season (Nov.—Mar.)

Flow change

Significantly higher at low flow (below median flow)

Significantly higher at high flow (above median flow)

01396660 Surface-water sampling site number (siteid)

Siteid	Nitrogen
01396280	1.660
01396535	1.385
01396588	1.085
01396660	0.915
01397000	1.200
01397400	1.530
01398000	1.600
01398260	1.900
01399120	0.930
01399500	0.735
01399700	1.200
01399780	0.885
01400500	1.200
01400540	1.300
01400650	3.700
01401000	0.610
01401600	1.530
01402000	2.270
01403300	1.800
01405302	3.830
01405340	0.923

Figure 12. Median nitrate plus nitrite as nitrogen concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin, N.J., 1991-97.

Results of the Tobit regression indicated that concentrations changed significantly as flow increased at 11 sites. Neshanic River and Raritan River at Manville were the only sites at which concentrations significantly increased as flow increased. Concentrations at nine other sites decreased significantly as flows increased--S.B. Raritan River sites at Middle Valley, High Bridge, and Three Bridges; N.B. Raritan River at Chester; Millstone River sites at Grovers Mill and Blackwells Mill; Beden Brook; Raritan River at Bound Brook; and Matchaponix Brook.

Season and flow condition were both important variables relating to the variability of NO3+NO2 concentrations in streams in the Raritan River Basin. When season, flow, and the interaction of both variables were studied together, season and flow were significant factors at 19 and 18 sites, respectively. Significantly higher concentrations were present at low flow and (or) during the non-growing season at all sites except Rockaway Creek. Concentrations were significantly higher at high flow at three sites (table 13). Growing season was not a factor at any site. The interaction of season and flow as explanatory variables was a significant factor only in explaining variability in concentrations at the Matchaponix Brook site (table 13). Concentrations were significantly higher at low flow during the growing season than during other season and flow conditions. The Rockaway Creek site was the only site at which concentrations did not vary with season or flow.

Organic carbon, total.--Median concentrations of total organic carbon were highest at Millstone River at Blackwells Mills, Raritan River at Bound Brook, and Stony Brook (table 14). In general, the highest median concentrations were in the Millstone River, Lamington River, and Raritan River mainstem subbasins (fig. 13). The lowest median concentrations were in samples from Spruce Run and Mulhockaway Creek; these concentrations were significantly lower than those at the other sites (fig. A10). The highest concentrations, more than 10 mg/L, were present in samples from Stony Brook, N.B. Raritan River near Chester, and Lamington River at Burnt Mills. Only one sample from S.B. Raritan River at Stanton had a concentration less than 1.0 mg/L, and this sample was collected at low flow in March.

Concentrations were significantly higher during the growing season at seven sites (table 14). No sites had significantly higher concentrations during the nongrowing season. Concentrations at three sites were significantly higher at low flow, and concentrations at two sites were significantly higher at high flow. Concentrations were highest at high flow during the growing season at 13 sites. Concentrations were lowest at low flow during the nongrowing season at 14 sites. Results of the Tobit regression indicated that concentrations increased significantly at four sites (Mulhockaway Creek, Stony Brook, S.B. Raritan (01396280) and Raritan River (01403300)) as flow increased. The other 17 sites did not have significant changes in concentration as flows increased.

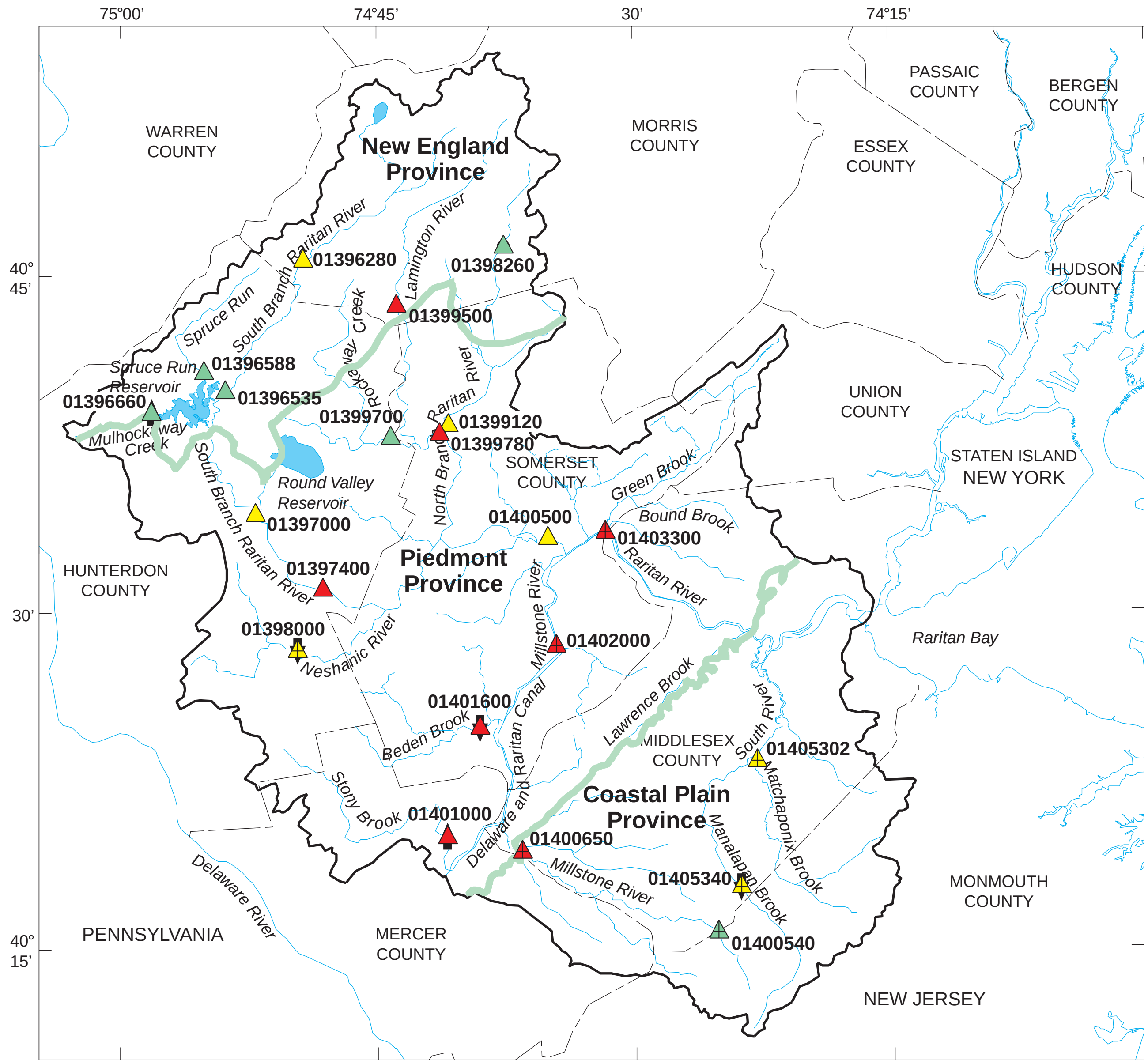
Season was the dominant factor relating to the variability of total organic carbon concentrations in most streams. When season, flow, and interactions of both variables were studied together, season was a significant factor at 15 sites. The interaction of season and flow was the only significant factor that explained the variability of organic carbon concentrations at N.B. Raritan River near Chester (table 14). Concentrations were significantly higher at low flow during the nongrowing season. Flow alone was a factor only at the Mulhockaway Creek site. Mulhockaway Creek had significantly higher concentrations at high flows. Concentrations at 10 sites did not vary with changes in season or flow.

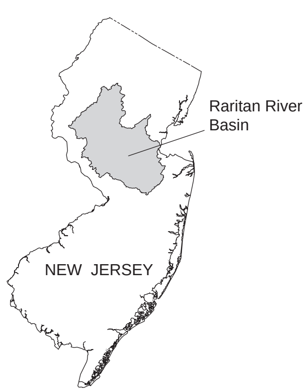
pH.--Median values of pH were highest at low-flow conditions at 20 sites and remained the same regardless of flow condition at Rockaway Creek (table 15). Measurements of pH were significantly higher at low flow than high flow at 12 of these sites. The significant decrease in alkalinity concentrations at high flow at all sites was not great enough to significantly change the pH at nine of the sites. The lowest instantaneous readings at all sites, however, occurred at high-flow conditions. Results of the Tobit regression indicate that pH significantly decreased with increased flow at 17 sites. The slope of the regression lines (-0.01

Table 14. Statistical summary of and differences in total organic carbon concentrations between seasons and flow conditions at 21 surface-water sampling sites in Raritan River Basin, N.J., using all data for 1991-97 water years

[Concentrations are in milligrams per liter; --, indicates the distribution of concentrations during the growing season and nongrowing season or during high-flow and low-flow conditions did not differ at the 0.05 significance level; G, significant differences occur between seasons and largest concentrations occur in the growing season (April-October); NG, significant differences occur between seasons and largest concentrations occur in the nongrowing season (November-March); LO, significant differences occur between flow conditions and largest concentrations occur at low flow (less than median flow); HI, significant differences occur between flow conditions and largest concentrations occur at high flow (greater than median flow); @, indicates flow as a function of season]

		Total organic carbon										
						Seasonal comparison			Flow comparison			Flow and season interaction (highest median)
		Statistical summary of all data				Median concentration		Significant seasonal difference	Median concentration		Significant difference with flow	
Station number	Stream name	Number of samples	Minimum	Median	Maximum	Growing	Non-growing		Low flow	High flow		
01396280	S.B. Raritan River	33	1.5	2.9	8.8	3.0	2.4	--	2.9	2.8	--	--
01396535	S.B. Raritan River	35	1.5	2.8	8.9	2.8	2.5	--	2.8	2.8	--	--
01396588	Spruce Run	33	1.3	1.9	5.3	1.9	1.8	--	2.0	1.8	--	--
01396660	Mulhockaway Ck	36	1.2	1.9	4.2	1.8	2.1	--	1.6	2.4	HI	--
01397000	S.B. Raritan River	29	.8	2.9	8.6	3.2	2.5	--	2.7	3.2	--	--
01397400	S.B. Raritan River	33	2.2	3.4	7.9	3.7	3.2	--	3.5	3.4	--	--
01398000	Neshanic River	54	1.5	3.2	8.2	3.6	2.3	G	3.5	2.6	LO	--
01398260	N.B. Raritan River	35	1.6	2.8	13	2.8	2.8	--	2.9	2.6	--	NG@LO
01399120	N.B. Raritan River	33	1.7	3.0	6.6	3.0	3.0	--	3.2	2.6	--	--
01399500	Lamington River	33	2.6	4.1	9.7	4.0	4.2	--	4.0	4.2	--	--
01399700	Rockaway Creek	31	1.6	2.7	5.4	2.2	2.4	--	2.7	2.7	--	--
01399780	Lamington River	33	2.0	3.4	11	3.0	2.9	--	3.4	3.4	--	--
01400500	Raritan River	33	1.6	3.3	7.2	3.3	2.6	--	3.6	3.2	--	--
01400540	Millstone River	33	1.3	2.7	7.5	3.3	2.2	G	2.7	2.8	--	--
01400650	Millstone River	27	2.5	4.0	7.9	4.2	3.5	G	3.8	4.2	--	--
01401000	Stony Brook	52	1.7	4.3	17	4.3	4.0	--	4.0	5.4	HI	--
01401600	Beden Brook	34	1.5	3.7	7.5	3.8	3.2	--	4.0	3.1	LO	--
01402000	Millstone River	27	2.4	4.9	7.3	5.4	4.2	G	5.0	4.8	--	--
01403300	Raritan River	30	2.2	4.3	8.4	4.5	3.2	G	4.1	4.4	--	--
01405302	Matchaponix Brook	34	2.2	3.0	6.3	3.2	2.6	G	3.0	2.8	--	--
01405340	Manalapan Brook	34	1.4	3.0	6.7	4.1	2.7	G	3.8	2.7	LO	--





Siteid	Total organic carbon
01396280	2.90
01396535	2.80
01396588	1.90
01396660	1.90
01397000	2.90
01397400	3.40
01398000	3.15
01398260	2.80
01399120	3.00
01399500	4.10
01399700	2.70
01399780	3.40
01400500	3.30
01400540	2.70
01400650	4.00
01401000	4.30
01401600	3.70
01402000	4.90
01403300	4.30
01405302	2.95
01405340	3.00

Figure 13. Median total organic carbon concentrations and significant differences, by season and flow condition, at 21 sites in the Raritan River Basin N.J., 1991-97.