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Water Quality and Streamflow in Sasco Brook Watershed, Southwestern Connecticut, 1994–98

Water-Resources Investigations Report 02-4002

Prepared in cooperation with the
Connecticut Department of Environmental Protection

U.S. Department of the Interior
U.S. Geological Survey

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By Jonathan Morrison

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East Hartford, Connecticut
2002

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound (lb)	0.4536	kilogram
pound per year (lb/yr)	0.4536	kilogram per year
pound per square mile per year ($lb/mi^2/yr$)	0.2819	kilogram per square kilometer per year

Temperature in degrees Fahrenheit (°F) may be converted to temperature in degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Sea level, as used in this report, refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L) and micrograms per liter (µg/L).

Concentrations of indicator bacteria are given in colonies per 100 milliliters (mL) of sample.

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ABSTRACT

Water quality was characterized at two sites in Sasco Brook watershed from 1994 to 1998 to monitor the effects of nonpoint-source contamination from activities in the watershed. Routine water samples were collected monthly at Hulls Farms Road and Route 1; analyzed for concentrations of nutrients (nitrogen, phosphorus, and organic carbon), fecal indicator bacteria, trace elements, and major ions; and measured for basic field parameters. Results of the analyses indicate that concentrations of enterococcus bacteria generally exceeded the Connecticut water-quality standard for contact recreation waters from May through October. Concentrations of nitrogen and phosphorus were elevated at both stations, although trace element concentrations did not reach levels of concern at either station. In addition to monthly sampling, samples were collected at the Hulls Farm Road station during seven storms. In general, concentrations of total nitrogen remained fairly constant during each storm, whereas concentrations of its species—dissolved nitrate and nitrite and total Kjeldahl nitrogen—varied throughout the storms.

An average total nitrogen yield of 4,430 pounds per square mile per year was estimated at the U.S. Geological Survey streamflow-gaging station at Hulls Farm Road from 1995 to 1997. The yield of total nitrogen from Sasco Brook watershed was two to three times the yields published for other forested watersheds in Connecticut and throughout the United States. Estimates of total nitrogen inputs into the watershed indicate that substantial loads of nitrogen may be attributed to atmospheric deposition, horse stabling practices in the watershed, and onsite septic systems; other potential inputs of nitrogen in the watershed were not quantified as part of this study.

INTRODUCTION

The western end of Long Island Sound has been identified as an area where loss of dissolved oxygen, a condition known as hypoxia, is a concern (Long Island Sound Study, 1998). Hypoxia results when algal blooms, which are caused by excess nitrogen or other nutrient enrichment from surface-water inflow, settle in bottom waters and consume available oxygen during decomposition. This reduces the amount of oxygen available for fish and other aquatic organisms. To understand and manage hypoxia in Long Island Sound, detailed information is needed on sources and amounts of nitrogen that enter Long Island Sound.

Sasco Brook flows through parts of three towns in southwestern Connecticut—Westport, Southport, and Fairfield—and discharges directly into the western end of Long Island Sound. Nonpoint sources of nutrients and bacteria, primarily from residential development and horse stabling practices, are the principal sources of contamination to the stream. Along its course, Sasco Brook provides water to many ornamental ponds and is used as a source of water for horses. Where Sasco Brook enters Long Island Sound, beaches and recreational shellfish harvesting beds are closed occasionally because of elevated levels of fecal indicator bacteria.

Prior to 1994, water quality in Sasco Brook watershed was not actively monitored, and available water-quality data were limited. The lack of integrated water-quality data from Sasco Brook made it difficult to monitor the effects of nonpoint-source contamination from residential activities in the watershed. In 1994, the U.S. Geological Survey (USGS), in cooperation with the Connecticut Department of Environmental Protection (DEP), began a study to characterize the quality of water in Sasco Brook watershed, as part of DEP's "319" Nonpoint-Source Pollution Program. Results of the study will provide baseline information on concentrations of nutrients, major ions, fecal indicator bacteria, and trace elements, as well as nitrogen and phosphorus loads exported from Sasco Brook watershed. These data can be used to better understand and manage nonpoint-source contamination in Connecticut and to assess the scope and magnitude of contamination problems in Sasco Brook watershed. Data collected during the study also will allow comparison of water-quality conditions before and after future implementation of any land-use management practices.

Purpose and Scope

This report provides information about the quality of water in Sasco Brook in southwestern Connecticut from November 1994 to April 1998. Data are included on concentrations of nutrients, fecal indicator bacteria, trace elements, and major ions; measurements of basic field parameters; and nitrogen and phosphorus loads and yields. Nitrogen and phosphorus yields from Sasco Brook watershed are compared to values from studies in other parts of the United States.

Acknowledgments

Special thanks and appreciation are extended to USGS personnel Michael Colombo and Steven Kiesman for their assistance with storm sampling and to Timothy Frick, James Norris, and James Keith for their assistance with routine data collection. The author also thanks Barbara Korzendorfer for her assistance in the production of this manuscript, and Marcus Waldron and Alison Shipp for their technical reviews.

DESCRIPTION OF THE STUDY AREA

Sasco Brook watershed is one of several watersheds in the southwestern coastal basin area of Connecticut and New York (fig. 1) that collectively encompass 440 mi^2 (Ryder and others, 1970). Sasco Brook drains 10.2 mi^2 of southwestern Connecticut and flows through several ponds and impoundments before discharging directly into Long Island Sound (fig. 2). The outfall of the largest of these ponds, Bulkley Pond, corresponds to the end of the non-tidally affected part of the stream. The study area for this project is confined to the upper 8.7 mi^2 of the watershed that is not tidally affected. Altitudes in the study area range from 10 ft at the outfall of Bulkley Pond to 360 ft above sea level. The remaining 1.5 mi^2 of the watershed is at sea level and is affected by tidal flows.

Two water-quality monitoring stations were established for this study: (1) USGS station 01208950, Sasco Brook at Hulls Farm Road near Southport (referred to as the Hulls Farm Road station), established at the site of an existing streamflow-gaging station, and (2) USGS station 01208960, Sasco Brook at Route 1 at Southport (referred to as the Route 1 station), at the outfall of Bulkley Pond.

Land Use

Sasco Brook watershed is primarily forested, with agricultural land/open space, mixed low-density residential areas, and some urban land (fig. 3; table 1). Many of the approximately 2,500 homes in the watershed (Fairfield County Soil and Water Conservation District, 1995) have large lawns that are adjacent to Sasco Brook. Horse stabling in the watershed also is common, with an estimated 400 horses residing in the watershed (Fairfield County Soil and Water Conservation District, 1995). Forested areas are primarily in the northern part of the watershed; the urban land, which consists mostly of 2- and 4-lane roads with associated commercial developments, is primarily in the southern part of the watershed.

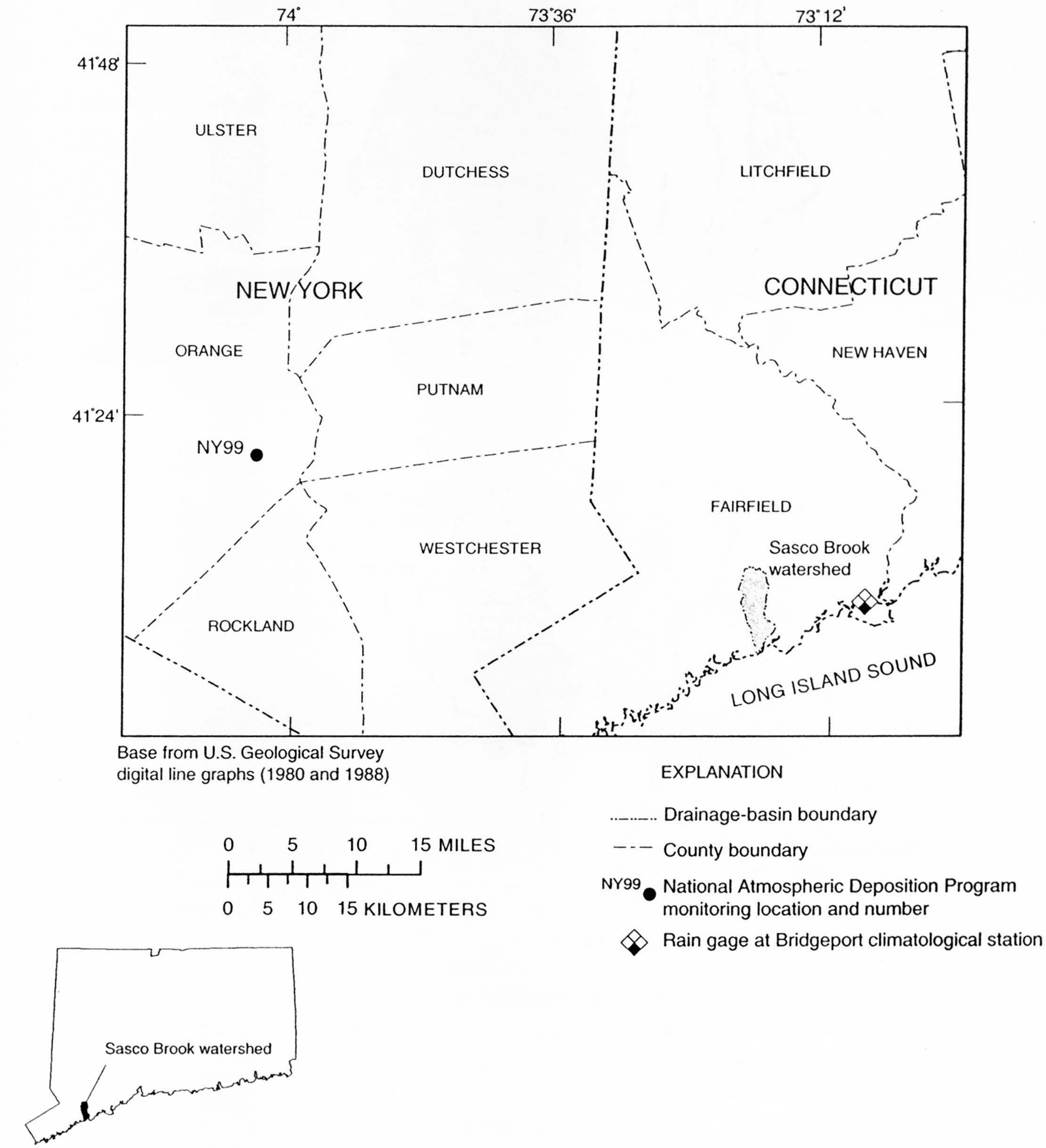


Figure 1. Location of the study area, southwestern Connecticut.

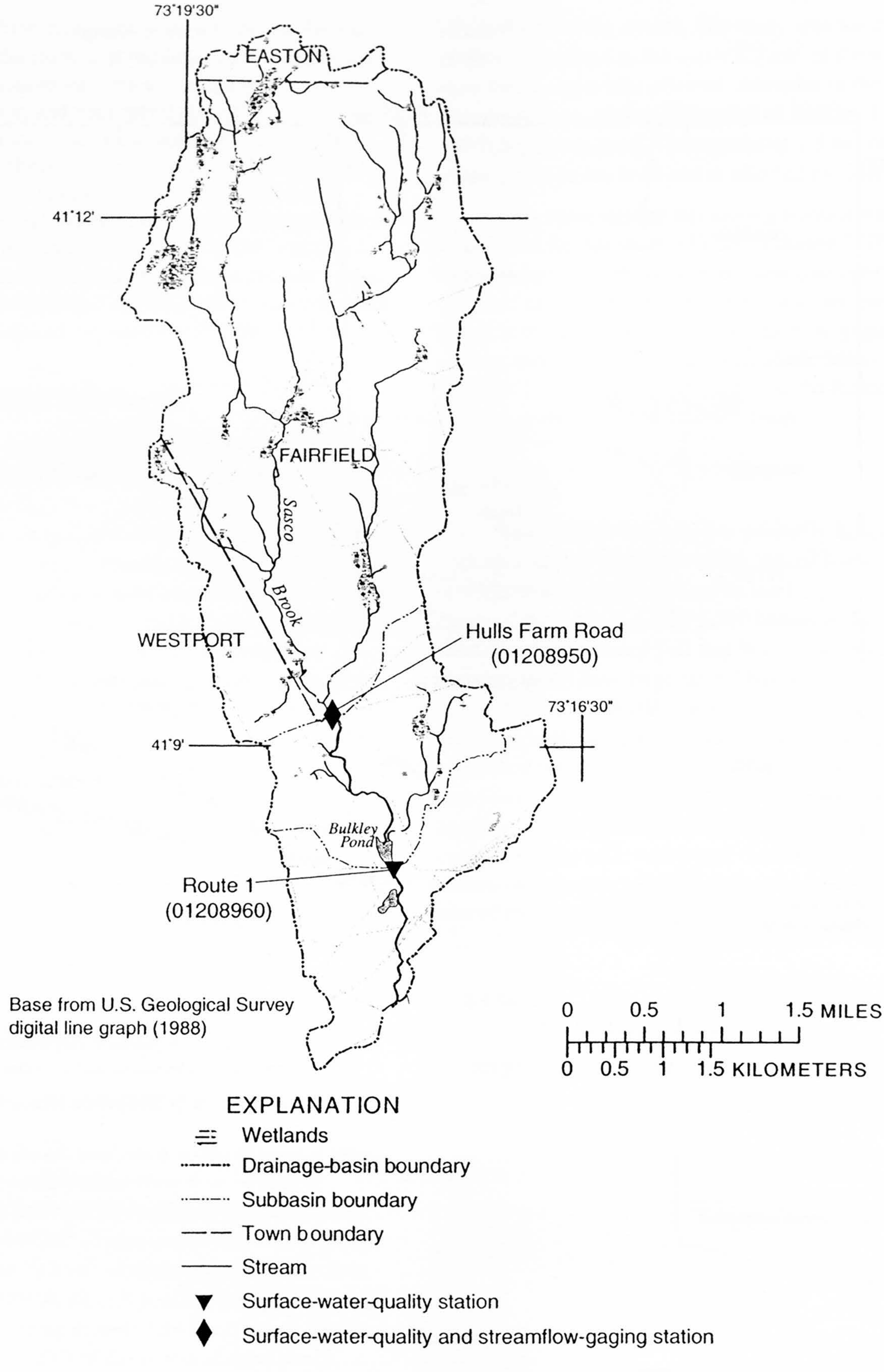


Figure 2. Sasco Brook watershed and data-collection sites.

Figure 3. Land use in Sasco Brook watershed. [Land-use data from Civco and Hurd, 1990.]

Table 1. Land use in Sasco Brook watershed, Connecticut
[Data from Civco and Hurd, 1990]

Location	Drainage area (square miles)	Land use				
		Forested (percent)	Agricultural (percent)	Residential (percent)	Urban (percent)	Total
Watershed above Hulls Farms Road station	7.4	54.6	19.6	16.9	9.0	100
Watershed above Route 1 station	8.7	52.2	19.9	18.4	9.5	100
Total Sasco Brook watershed	10.2	47.5	19.7	20.6	12.7	100

Geology

The surficial materials in the watershed are predominantly till (98 percent) with some deposits of thick till and a small amount of stratified drift (1.9 percent) (Stone and London, 1981). These surficial materials, which are fairly thin and range from less than 1 to more than 35 ft thick, are underlain by interlayered schist and gneiss (Rodgers, 1985).

Climate

The climate in Connecticut is generally temperate and humid (Brumbach, 1965), and precipitation is distributed evenly throughout the year (Hunter and Meade, 1983). The National Oceanic and Atmospheric Administration operates a climatological station near the study area at the Bridgeport Airport in Stratford, Conn. During 1961–90, mean annual precipitation at the Bridgeport station was 41.66 in/yr. During the same period, mean monthly temperatures ranged from 28.9 °F in February to 73.7 °F in July, with a mean of 51.7 °F (unpublished data accessed on 08/31/00 on the World Wide Web at URL http://met-www.cit.cornell/edu/climate/Summary_Ann-99.htm). Average daytime relative humidity at the station is 59 percent and ranges from a minimum of 32 percent in January to a maximum of 61 percent from June to September.

During 1995–97, precipitation at the Bridgeport station averaged 41.73 in/yr, which closely matches the 30-year average of 41.66 in/yr. Although precipitation generally is evenly distributed throughout the year, total annual precipitation can fluctuate by as much as 20 in/yr from the mean (Zimmerman and others, 1996, p. 12). Total annual precipitation during the study period varied substantially from year to year (table 2; fig. 4) and was 8.62 in. below normal in 1995, 13.70 in. above normal in 1996, and 4.86 in. below normal in 1997 (National Oceanic and Atmospheric Data Administration, 1994–98).

Hydrology

Sasco Brook is 5.3 mi long and flows through and is hydraulically connected to many wetlands. Approximately 25 percent of the study area is underlain by wetland soils (U.S. Department of Agriculture, 1996). The mean channel slope of Sasco Brook is 53.3 ft/mi (Weiss, 1983). The brook and its tributaries have a high drainage density of 35 mi/mi^2. (Drainage density is a mathematical representation of the number of miles of stream channel per square mile of drainage area.)

USGS streamflow-gaging station 01208950 Sasco Brook near Southport is on Hulls Farm Road (fig. 2) and has been in operation since October 1964. During water years[1] 1965–98, daily mean streamflow ranged from 0 to 785 ft^3/s, mean annual flow was 13.7 ft^3/s, and long-term average annual runoff was 25.3 in. (Davies and others, 1999, p. 221). The 7-year, 10-day low flow is 0.05 ft^3/s (E.A. Ahearn, U.S. Geological Survey, oral commun., 2001).

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

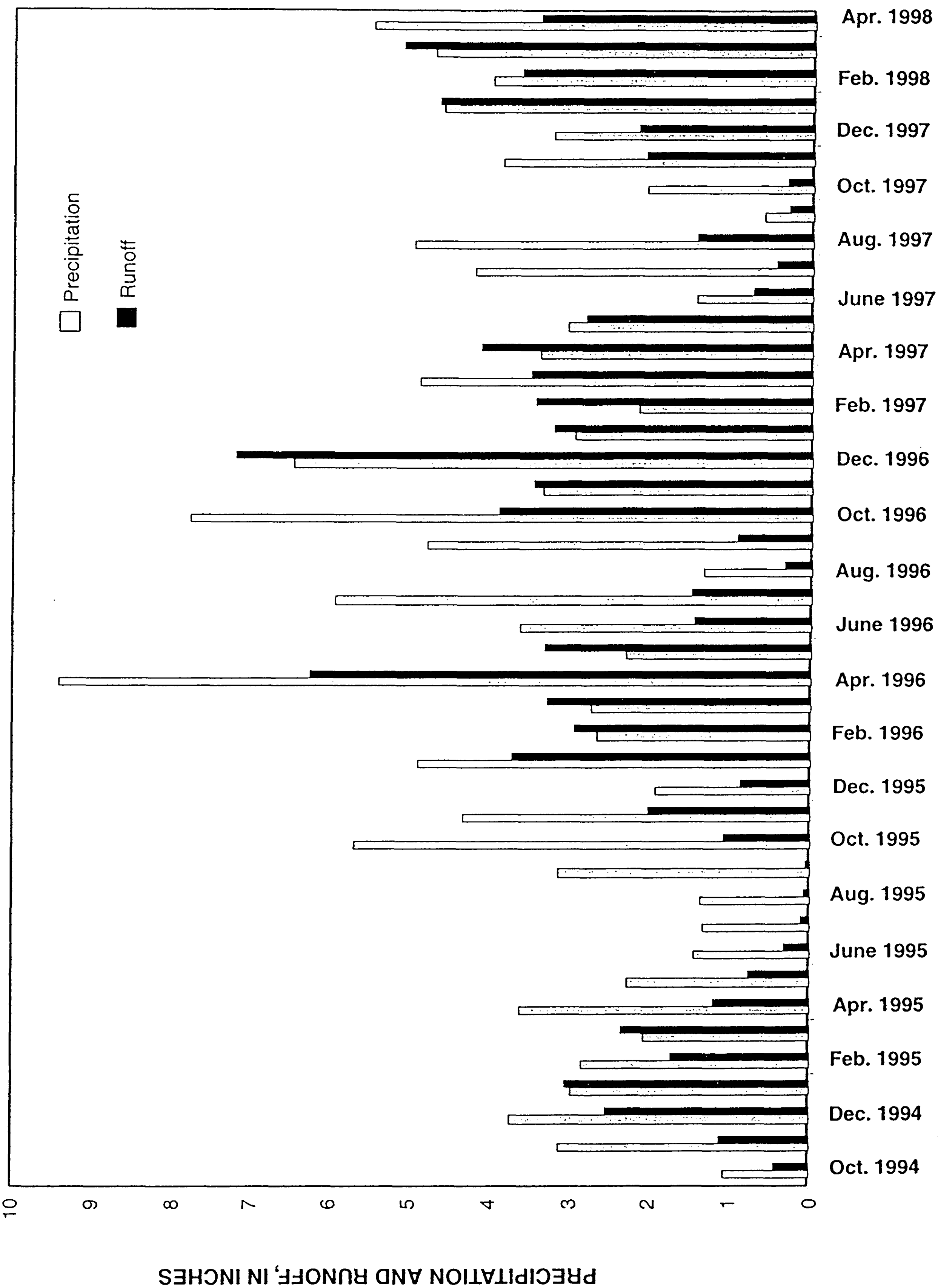


Figure 4. Precipitation and runoff in Sasco Brook watershed, 1994–98.

Table 2. Precipitation and runoff in Sasco Brook watershed, 1995–97

[Precipitation data from National Oceanic and Atmospheric Data Administration, 1994–98; runoff data from Davies and others, 1996–99]

Calendar year	Precipitation at Bridgeport climatological station (inches/year)	Runoff from Sasco Brook (inches/year)
1995	33.04	13.6
1996	55.36	38.4
1997	36.80	24.6
Average (1995–97)	41.73	25.5
Long-term average	41.66 (1961–90)	25.3 (1965–98)

Hydrologic data collected during the study period are representative of the hydrologic conditions of the long-term period of record. During the study, annual runoff from Sasco Brook was variable and ranged from 13.6 to 38.4 in/yr with an average of 25.5 in/yr; this value is approximately equal to the 25.3-in/yr average for water years 1965–98 (table 2). Annual runoff in inches is calculated by dividing annual total mean daily streamflow (in cubic feet per year) by the drainage area (in square miles) and converting the units from cubic feet per square mile to inches. Flow-duration curves, which represent the percentage of time a given streamflow was equalled or exceeded, show that daily mean streamflow in Sasco Brook during the study period matched the distribution of daily mean streamflows for water years 1965–99 (fig. 5). Instantaneous discharges (measured when water-quality samples were collected) plotted on a streamflow hydrograph indicate that samples were collected over the range of flows that took place during the study period (fig. 6).

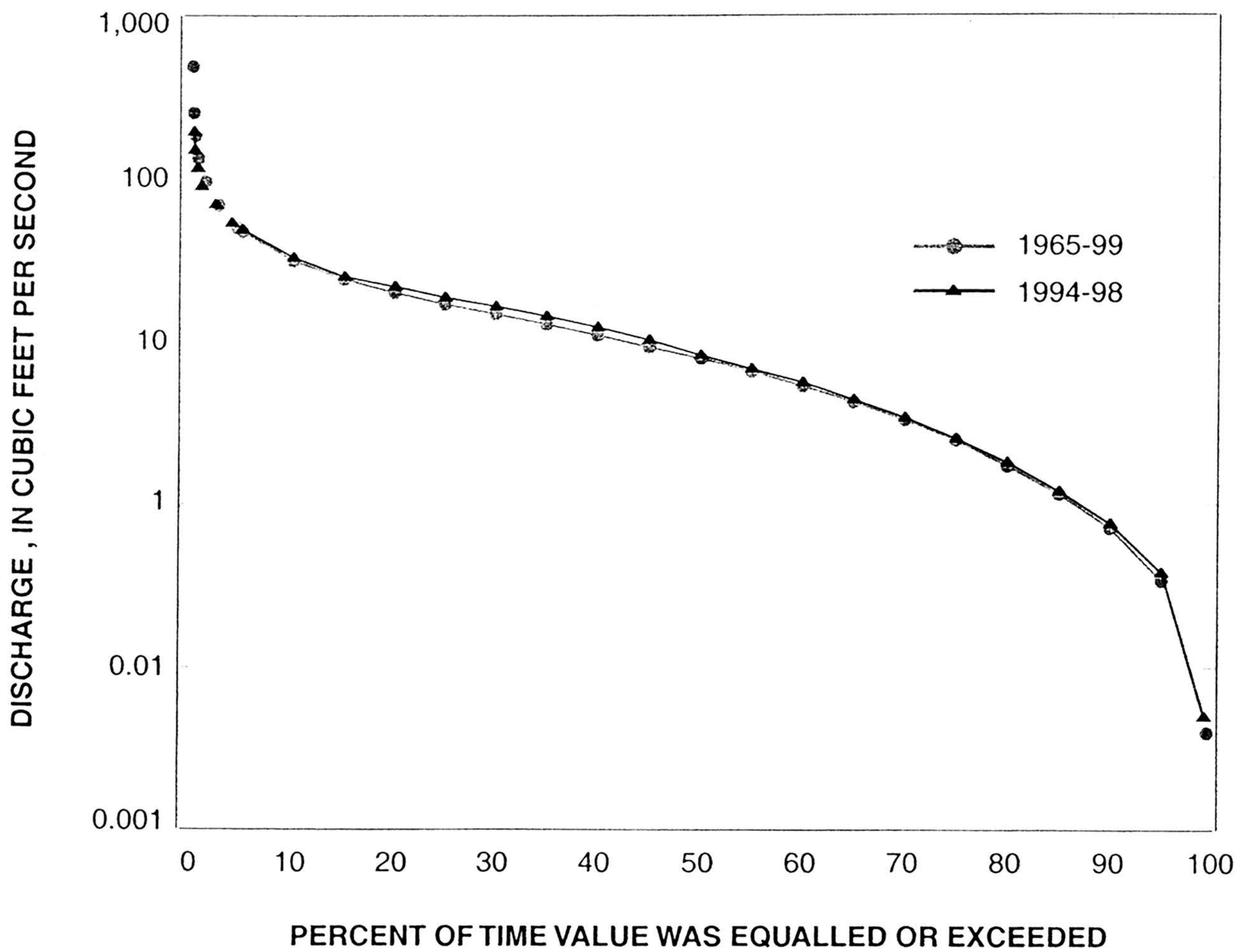


Figure 5. Flow-duration curve showing streamflow in Sasco Brook watershed during the study period (1994–98) and during the long-term period of record (1965–99).

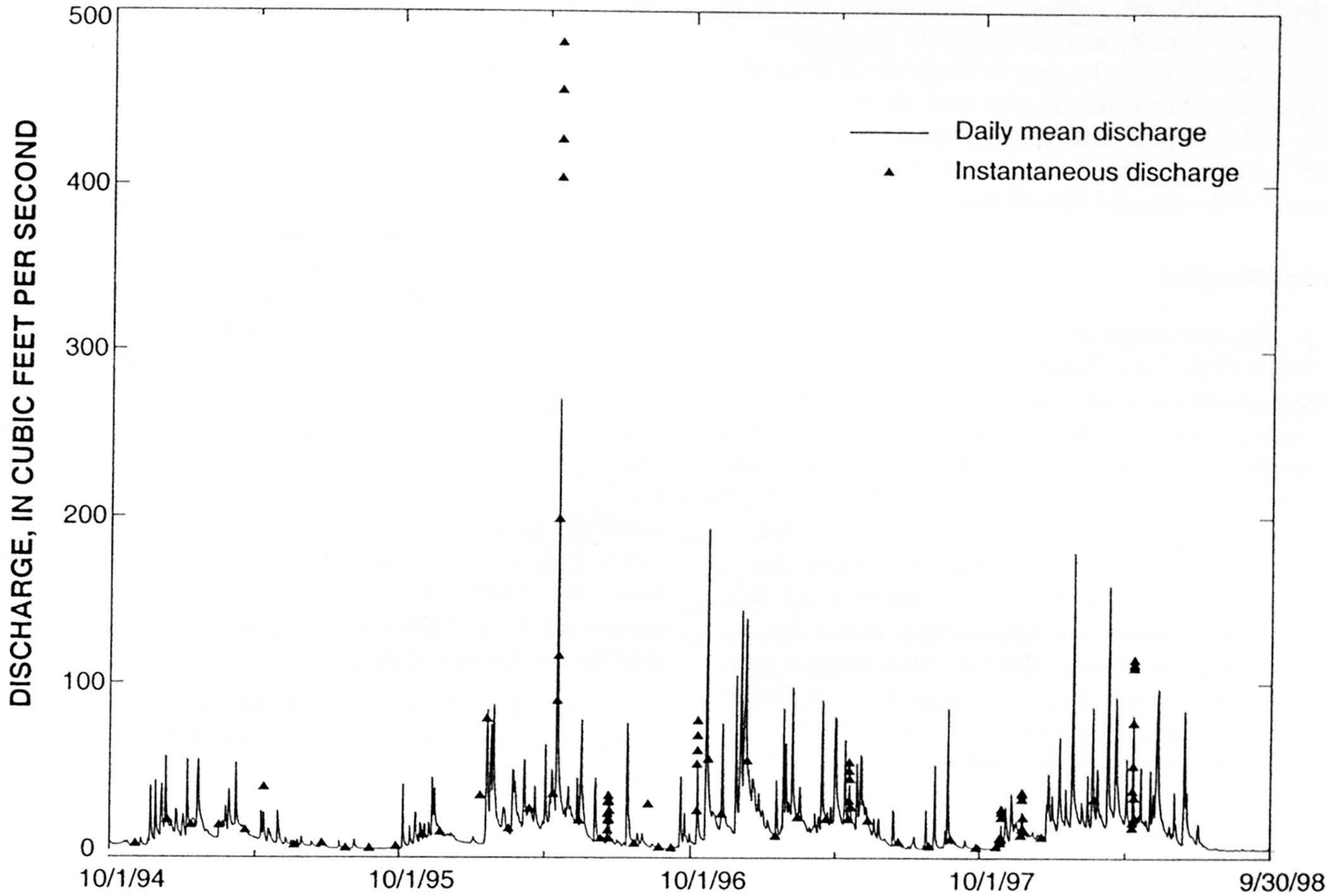


Figure 6. Measurements of streamflow in Sasco Brook, 1994–98.

DATA COLLECTION AND ANALYSIS

Streamflow Measurements

Continuous and instantaneous streamflow measurements were made at the Hulls Farm Road station (USGS streamflow-gaging station 01208950; fig. 2). Collection of streamflow data and computation of streamflow records, including daily values of mean streamflow, were done using procedures described by Rantz (1982). A telemetering device that allowed streamflow to be monitored during storms was installed at the streamflow-gaging station during the project. In addition, instantaneous streamflow was measured at the Route 1 station using the current-meter method and the rating-curve method described by Rantz (1982).

Water-Quality Samples

Water-quality samples were collected monthly (routine samples) and during selected storms (storm samples) in the study period at the two water-quality monitoring stations established for this study—Sasco Brook at Hulls Farm Road near Southport and Sasco Brook at Route 1 at Southport (fig. 2).

Routine Samples

Water samples were collected at the Hulls Farms Road and Route 1 stations each month from November 1994 to December 1997 and analyzed for concentrations of nutrients (nitrogen, phosphorus, and organic carbon), fecal indicator bacteria, trace elements, and major ions, and measurements of basic field parameters. Samples were collected using methods described by Edwards and Glysson (1988). The part-per-billion clean sampling protocols, as described in U.S. Geological Survey Office of Water Quality Technical Memorandum 94.09 (unpub. memorandum dated January 28, 1994, available at the U.S. Geological Survey office in East Hartford, Conn.) also were used. The Route 1 station is at the outfall of Bulkley Pond, a deteriorated 10-ft-high mill dam, and streamflow samples were collected at the base of the dam. Because the Route 1 station is affected by tidal backwater and is sometimes inundated during monthly spring high tides, samples from this station were collected when tidal effects were not present. Salinity and instantaneous streamflow measurements were checked to verify the absence of tidal effects; therefore, samples from the Route 1 station are considered to be representative of streamflow from the outflow of Bulkley Pond and not the lower, tidally affected stream reach.

Storm Samples

Water samples were collected during selected storms at Hulls Farm Road throughout the study period using a combination of manual and automatic sampling methods. When possible, storm samples were collected manually, but because of several factors—the distance from the USGS office to the project area, the size of the brook and its response time during storms, and the timing of storms—automatic sampling devices also were used. An ISCO sampler was connected to a data logger with a telephone telemetering device at the Hulls Farm Road station. The automatic sampler was activated prior to the onset of a storm, and it collected discrete samples at timed intervals. This procedure allowed for sample collection prior to the onset of rain as well as during the early stages of the storm (the rising stage of the hydrograph), when manual samples otherwise might not have been collected. To determine the time interval between samples, the time lag between the middle (center of mass) of the storm and the peak in the streamflow hydrograph for the watershed was calculated, using the following equation:

$$T = 2.51 A_D^{0.38} . \tag{1}$$

This empirical formula can be used to calculate the time lag (T) in hours from the watershed drainage area, in kilometers (A_D), and two constants that represent all remaining watershed characteristics (Dingman, 1994, p. 401). On the basis of this formula, the watershed time lag for Sasco Brook at the Hulls Farm Road station was calculated to be 7.7 hours. The automatic sampler was set to collect one sample per hour, so that the sampler would be activated and would collect a minimum of seven samples during the rising limb of the hydrograph. During a storm, rainfall and runoff were monitored remotely, and sampling teams were dispatched to service the automatic sampler and to collect additional, manual samples. Because of limitations in cleaning the automatic sampler, samples that were collected with it were analyzed only for nutrients.

Load Calculations (including seasonal factors)

Using the USGS program ESTIMATOR (Cohn and others, 1992), monthly and annual loads of total nitrogen, nitrate and nitrite, total Kjeldahl nitrogen, and total phosphorus were calculated using water-quality data from analyses of both the routine monthly and periodic stormwater-quality samples. The ESTIMATOR program is a multivariate log-linear model that relates constituent concentrations to daily mean streamflow and time. The program incorporates a minimum variance unbiased estimator that corrects for bias during model variable retransformation (Cohn and others, 1989; 1992). The ESTIMATOR model also makes use of an adjusted maximum likelihood estimator that allows the program to use data that fall below the minimum reporting level (Cohn and others, 1992). Loads were calculated only for the Hulls Farm Road station because continuous streamflow data, needed for the ESTIMATOR program, are not available for the Route 1 station.

During an investigation of nutrient loads to Chesapeake Bay, Cohn and others (1992) found that a seven-parameter model provided satisfactory and acceptable results in predicting transport of fluvial loads of nutrients and sediment. For this study, this seven-parameter model was used:

$$\ln[C] = \beta_0 + \beta_1 \ln[Q] + \beta_2 \ln[Q]^2 + \beta_3 T + \beta_4 (T^2) + \beta_5 \sin[4\pi T] + \beta_6 \cos[4\pi T] + E, \tag{2}$$

where ln [ ] is the natural logarithm function,
C is constituent concentration,
Q is daily mean discharge,
T is time expressed in years,
β_0 is a constant,
π is a constant (3.14159),
β_1 and β_2 are variability associated with flow dependence,
β_3 and β_4 are variability corresponding to time trends,
β_5 and β_6 and the sine and cosine terms are first-order Fourier series variability associated with seasonality, and
E is random error.

Streamflow and water-quality input data for the ESTIMATOR program were obtained from USGS surface-water and water-quality networks (Davies and others, 1996-99).

Other Statistical Methods

A non-parametric rank sum test (Helsel and Hirsch, 1992) was used to determine whether differences between the Hulls Farm Road and Route 1 stations were statistically significant. The rank sum test has no assumptions about the data distribution and was used because the data were not normally distributed. The rank sum test uses a test statistic called the p-value. When the p-value is less than the chosen confidence level (in this report, 0.05), samples are statistically different. The lower the p-value, the more significant the difference.

Regression analysis (Helsel and Hirsch, 1992) was used to examine the relation between selected variables in the data set. A linear regression model can be constructed to examine the linear relation between an explanatory variable (x) and a response variable (y). The linear regression model has the following form:

$$y = \beta_0 + \beta_1 x + E \ , \quad (3)$$

where x is the explanatory variable,
y is the response variable,
β_0 is the y-intercept term,
β_1 is the slope term for the model line, and
E is random error.

The model also computes the coefficient of determination term (R^2), which represents the variance explained by the regression.

WATER QUALITY IN SASCO BROOK WATERSHED

This section describes the results of the water-quality analysis of routine and storm samples for nutrients, bacteria, and trace elements. Summary statistics for concentrations of major ions and measurements of basic field parameters for the routine monthly samples are presented in appendix 1.

Results from Routine Samples

Nutrients

From November 1994 to December 1997, 78 samples were collected at the Hulls Farm Road and Route 1 water-quality stations (39 samples per station) and were analyzed for total Kjeldahl nitrogen, dissolved nitrate and nitrite, total nitrogen, total phosphorus, and total organic carbon (table 3). Concentrations of total nitrogen ranged from 0.43 to 2.00 mg/L, with a mean concentration of 1.01 mg/L at Hulls Farm Road and 1.13 mg/L at Route 1. Concentrations of total phosphorus ranged from 0.01 to 0.18 mg/L, with a mean concentration of 0.03 mg/L at both stations. Concentrations of total organic carbon ranged from 0.2 mg/L to 14.0 mg/L, with a mean concentration of 5.3 mg/L at both stations

Results of the non-parametric rank sum test, used to analyze for significant statistical differences, showed a significant difference in concentrations of total Kjeldahl nitrogen between the Hulls Farm Road and Route 1 stations. This result indicates that concentrations of total Kjeldahl nitrogen are higher downstream, at the Route 1 station, than they are upstream, at the Hulls Farm Road station. The difference in total nitrogen concentrations between the two stations was not statistically significant, although the mean concentration of total nitrogen was 0.12 mg/L higher at the Route 1 station than at the Hulls Farm Road station. Concentrations of all other nutrient species at the Hulls Farm Road and the Route 1 stations were not found to be significantly different (table 4).

Table 3. Summary statistics of selected nutrient concentrations at water-quality stations in Sasco Brook watershed, 1994–97
[All concentrations are in milligrams per liter]

Water-quality station	Statistic	Total Kjeldahl nitrogen	Dissolved nitrate and nitrite	Total nitrogen	Total phosphorus	Total organic carbon
Hulls Farm Road	Minimum	0.20	0.13	0.43	0.01	0.2
	Maximum	.80	1.70	2.00	.18	14.0
	Mean	.30	.78	1.01	.03	5.3
	Median	.30	.73	1.00	.02	5.0
Route 1	Minimum	.20	.05	.45	.01	.3
	Maximum	1.10	1.50	1.70	.09	12.0
	Mean	.39	.74	1.13	.03	5.3
	Median	.40	.68	1.10	.03	5.3

Table 4. Rank sum test results for water-quality stations in Sasco Brook watershed

Constituent	Statistically significant difference (yes/no)	Rank sum p-value
Total Kjeldahl nitrogen	yes	0.0219
Dissolved nitrate and nitrite	no	.8533
Total nitrogen	no	.4768
Total phosphorus	no	.7101
Total organic carbon	no	.8111
Fecal coliform bacteria	yes	.0031
Enterococcus bacteria	no	.9006

Fecal Indicator Bacteria

From November 1994 to December 1997, 78 samples were collected and analyzed for fecal coliform and enterococcus bacteria (table 5). Concentrations of fecal coliform bacteria ranged from 7 to 21,000 colonies/100 mL of sample, and concentrations of enterococcus bacteria ranged from 1 to 4,900 colonies/100 mL of sample. Concentrations were compared to the State of Connecticut water-quality standards for Class B waters (contact recreation): 400 colonies per 100 mL in an individual sample for fecal coliform bacteria and 61 colonies per 100 mL in an individual sample for enterococcus bacteria (Connecticut Department of Environmental Protection, 1996). Concentrations of fecal coliform bacteria exceeded the standard 20 percent of the time at the Hulls Farm Road station and 43 percent of the time at the Route 1 station. Concentrations of enterococcus bacteria exceeded the standard 59 percent of the time at both stations (figs. 7 and 8).

The non-parametric rank sum test was applied to paired data to evaluate whether concentrations of indicator bacteria at the stations differ significantly (table 4). Results of the statistical tests show that the concentrations of enterococcus bacteria are not different between the Hulls Farm Road and the Route 1 stations; however, concentrations of fecal coliform bacteria are significantly higher at the Route 1 station than at Hulls Farm Road. This may be due to the presence of large populations of birds on Bulkley Pond and under the bridge at Route 1, or from sources between Hulls Farm Road and Route 1.

During the study period, concentrations of indicator bacteria varied substantially both from year to year at each station and between stations in any individual year of the study. This variability indicates that more than one factor probably influences concentrations of indicator bacteria. Indicator bacteria were checked for correlation with flow at the sampling stations, and no correlation was found (figs. 9 and 10). This indicates that bacteria counts do not change predictably with streamflow.

Results of graphical analysis show that concentrations of indicator bacteria differ with season (winter/summer). In general, concentrations of fecal coliform and enterococcus bacteria are higher during the summer season (May to October) than during the winter season (November to April) at both stations. On the basis of the results of the seasonal separation, summer concentrations of fecal coliform bacteria (figs. 11A, B) generally exceeded the State water-quality standard for Class B waters at the Route 1 station. Concentrations of fecal coliforms generally were at or below the standard all year at Hulls Farm Road and during the winter at the Route 1 station. Summer concentrations of enterococcus bacteria (figs. 12A, B) exceeded the State water-quality standard for Class B waters at both stations. Median winter concentrations of enterococcus bacteria were at or below the standard at both stations.

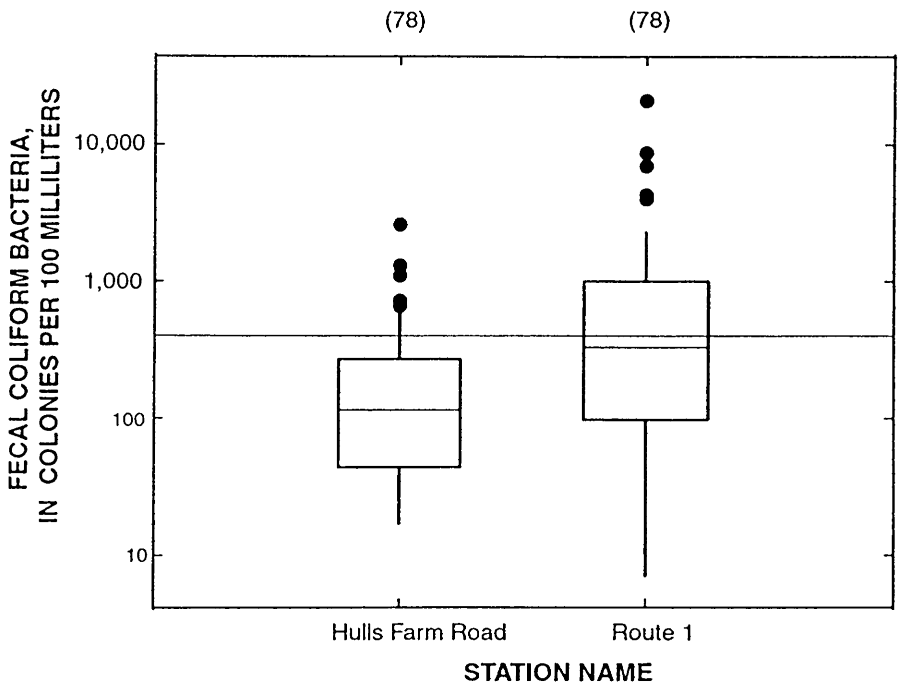
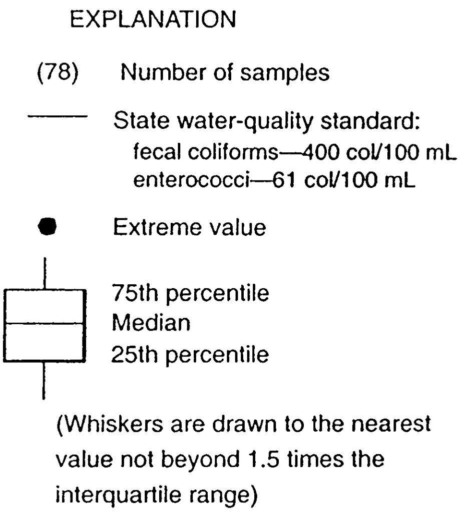


Figure 7. Concentrations of fecal coliform bacteria, Sasco Brook watershed.



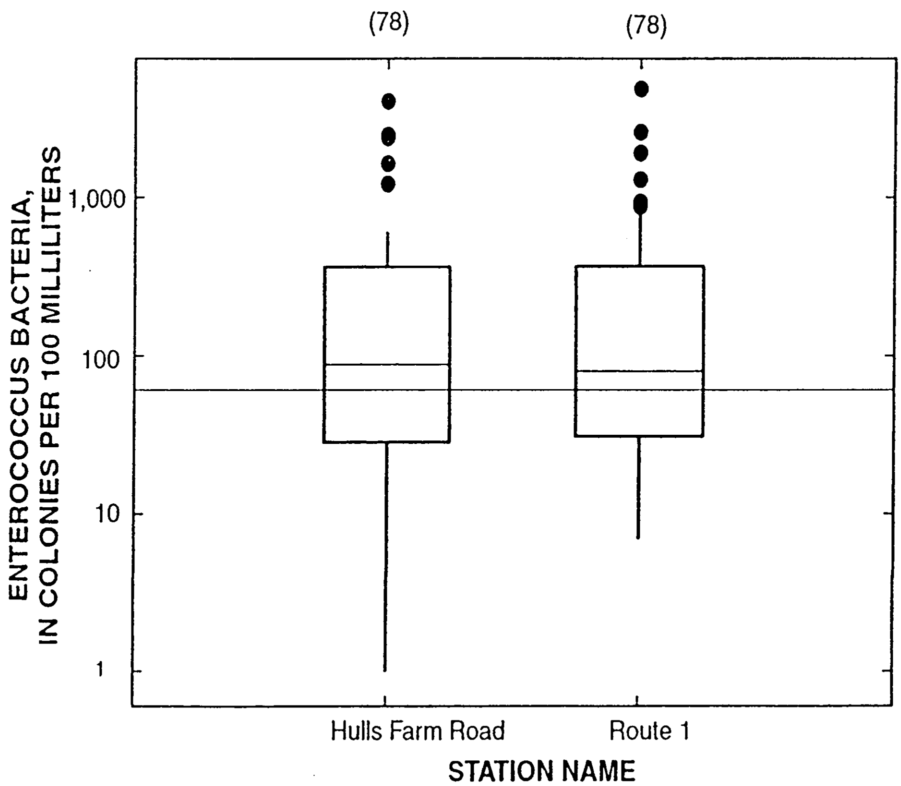
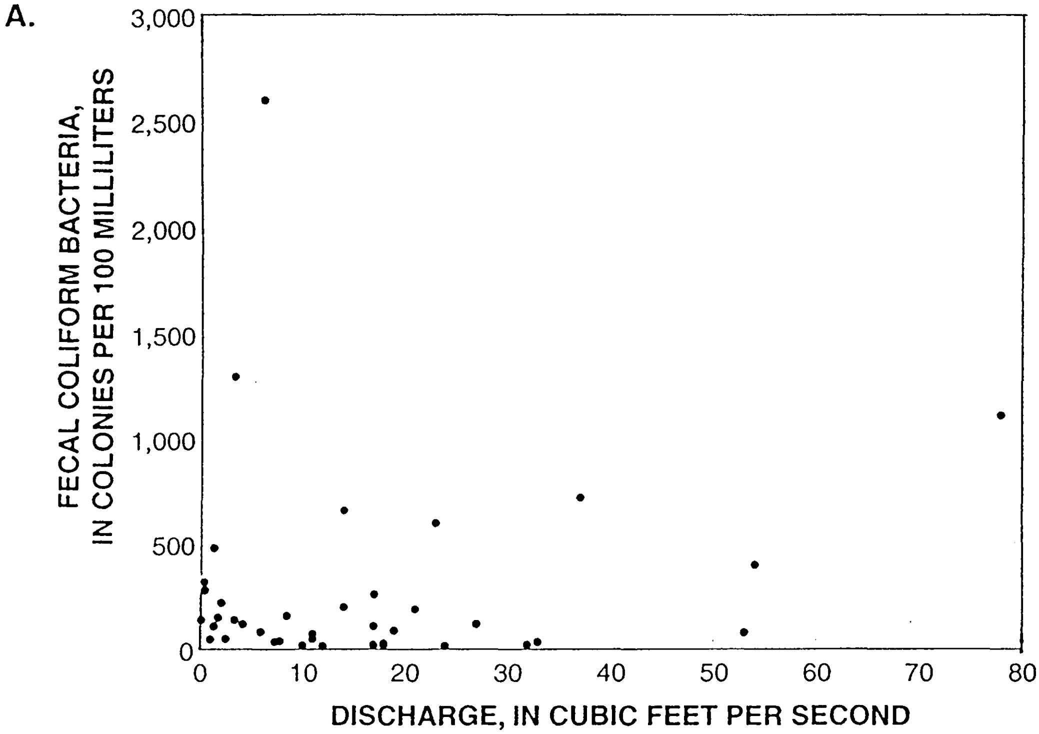


Figure 8. Concentrations of enterococcus bacteria, Sasco Brook watershed.



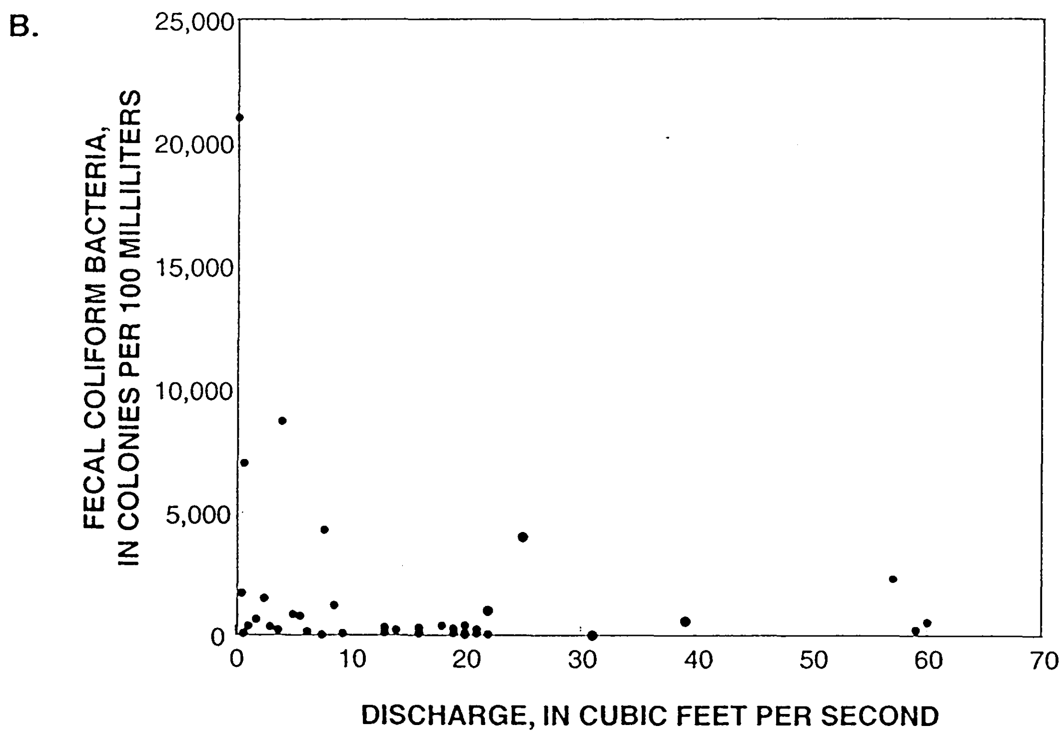


Figure 9. Relation between concentrations of fecal coliform bacteria and streamflow at the
A. Hulls Farm Road station.
B. Route 1 station.

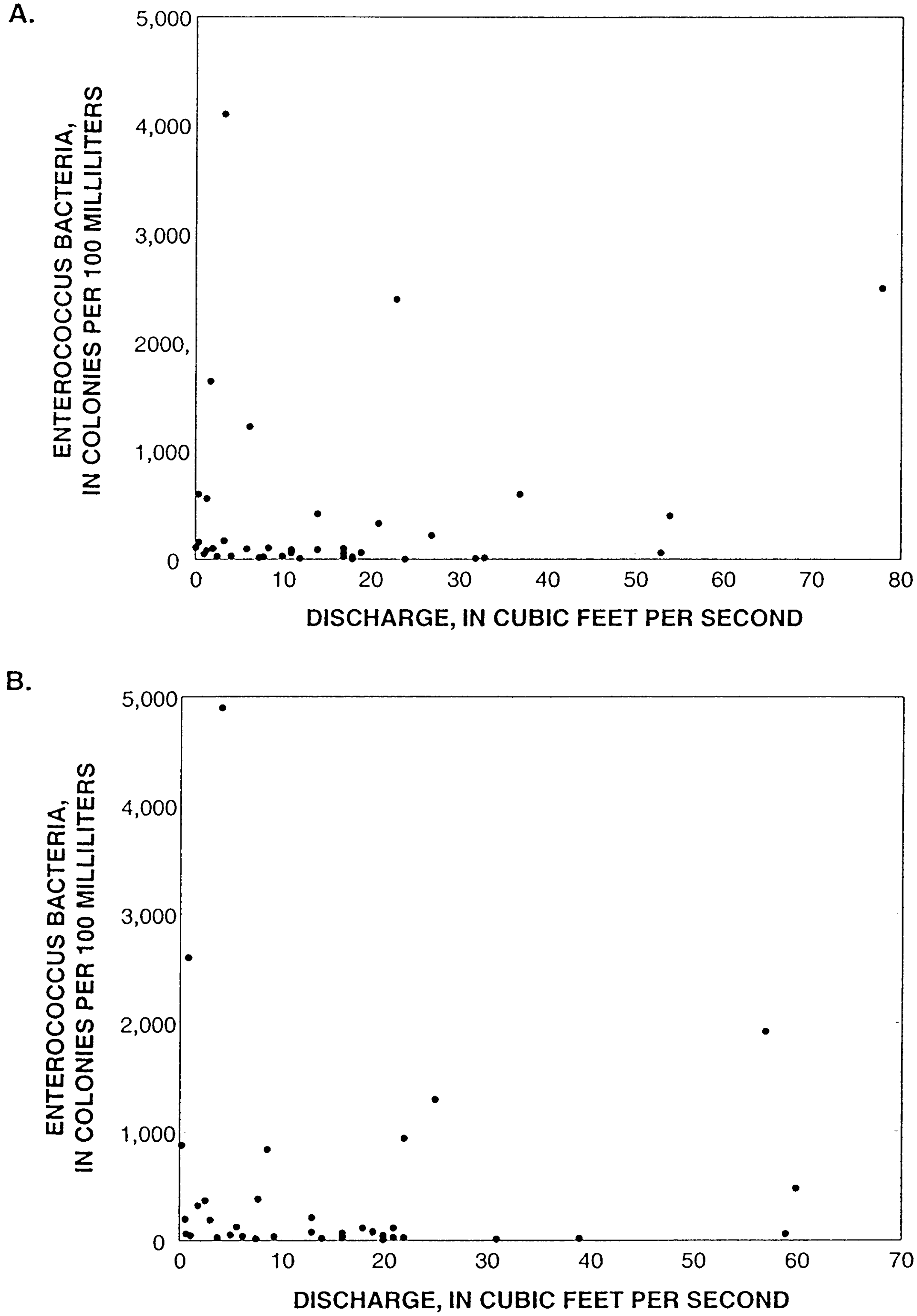


Figure 10. Relation between concentrations of enterococcus bacteria and streamflow at the
A. Hulls Farm Road station.
B. Route 1 station.

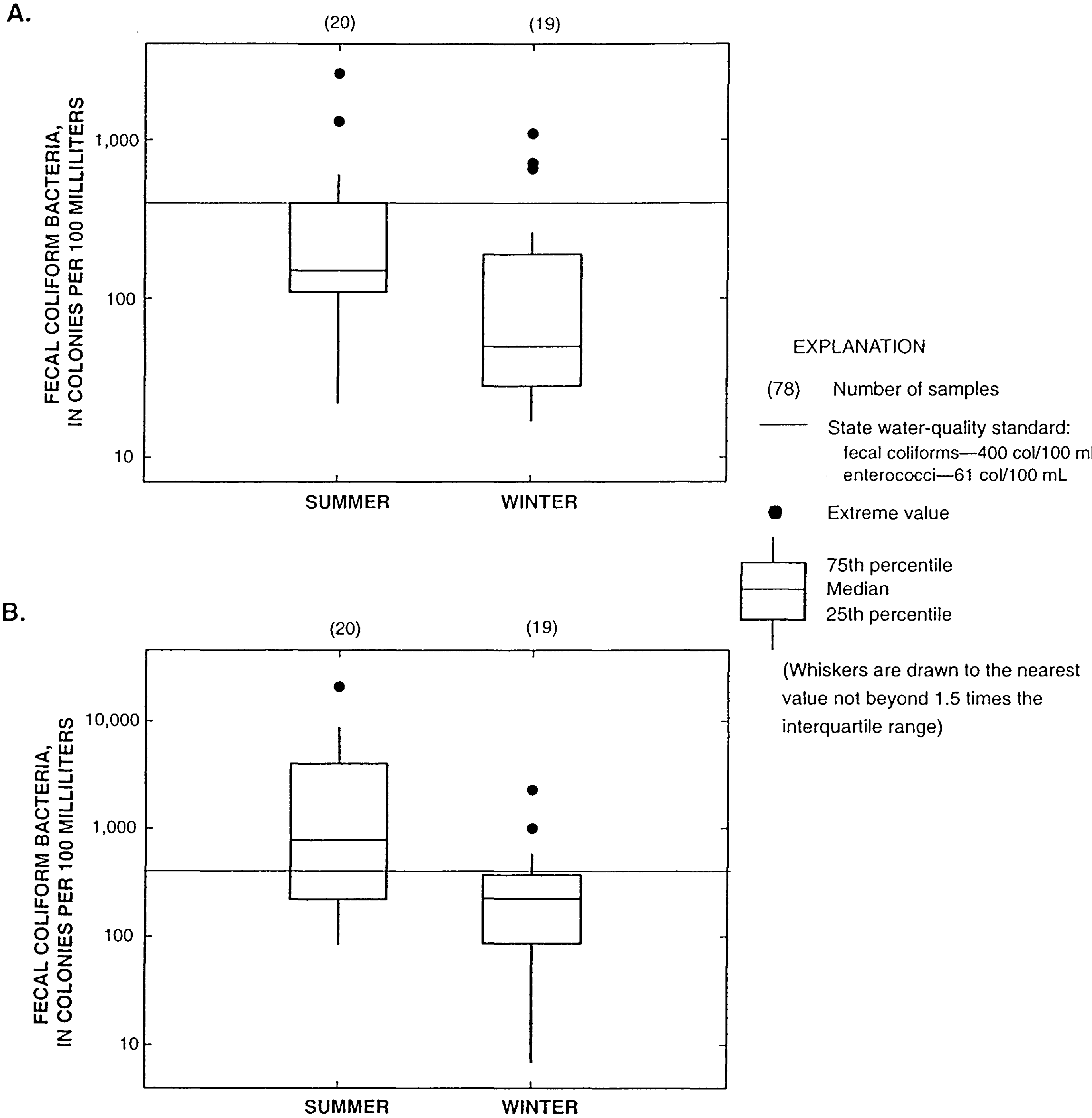


Figure 11. Concentrations of fecal coliform bacteria by season at the
A. Hulls Farm Road station.
B. Route 1 station.

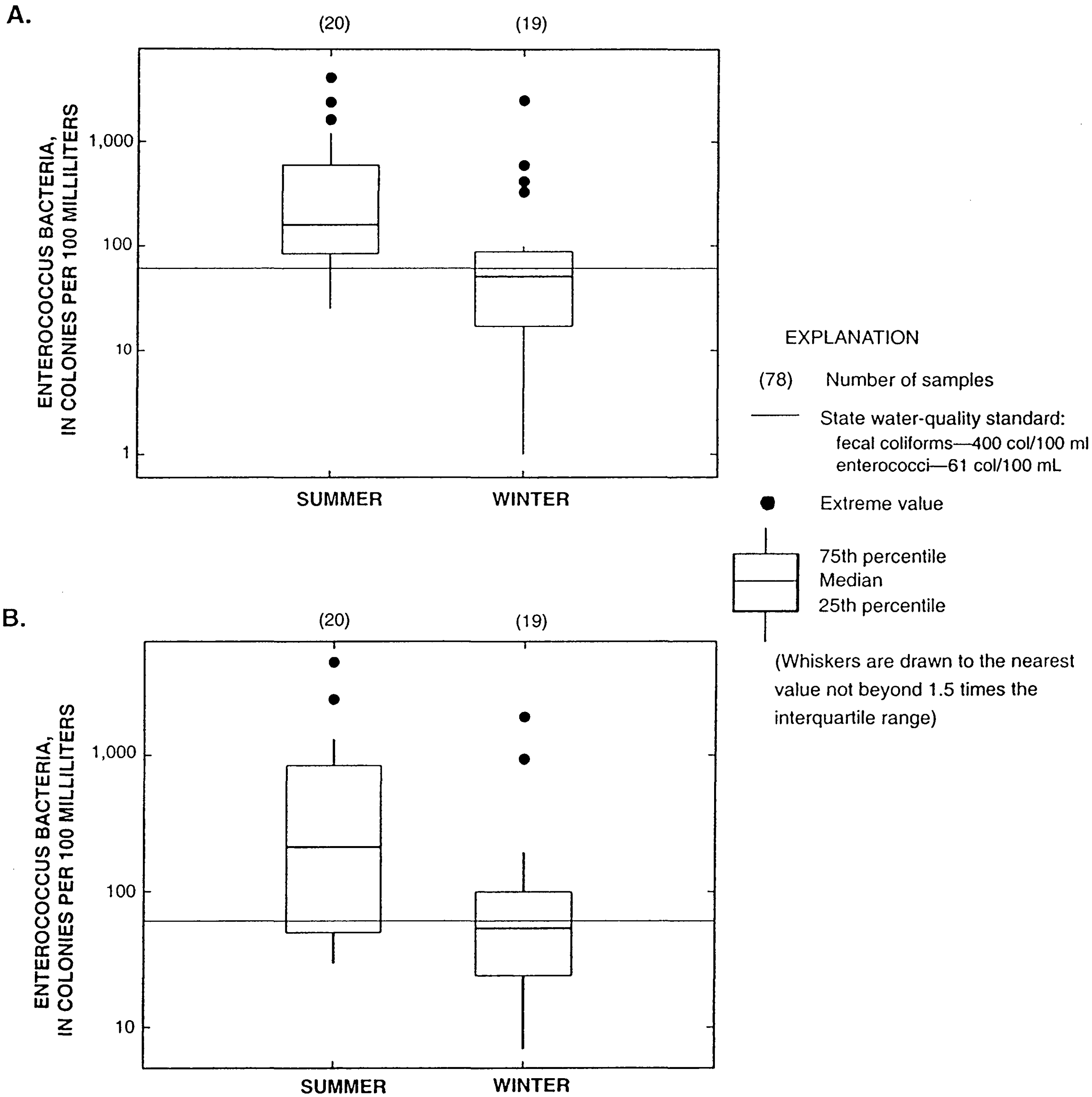


Figure 12. Concentrations of enterococcus bacteria by season at the
A. Hulls Farm Road station.
B. Route 1 station.

Table 5. Summary statistics of fecal indicator bacteria concentrations in Sasco Brook watershed, 1995–97

[Concentrations in colonies per 100 milliliters of sample]

Water-quality station	Calendar year(s)	Fecal coliform bacteria				Enterococcus bacteria			
		Maximum	Minimum	Geometric mean	Median	Maximum	Minimum	Geometric mean	Median
Hulls Farm Road	1995	1,300	20	230		4,100	27	223	
	1996	2,600	17	1,420		2,500	1	105	
	1997	150	22	57		1,640	6	49	
	1995–97				120				88
Route 1	1995	21,000	98	1,514		4,900	26	360	
	1996	4,000	7	353		1,920	15	29	
	1997	1,500	21	143		368	7	21	
	1995–97				330				80

Trace Elements

From November 1994 to July 1997, water samples for analysis of dissolved trace elements were collected 14 times at the Hulls Farms Road station and 11 times at the Route 1 station. In general, analyses of these samples indicate that most trace elements either were not detected or were detected at low concentrations (table 6). Chromium was detected at both stations on January 11 and 19, 1996, at the detection level of 1 μg/L. Concentrations of dissolved copper and dissolved nickel generally were low at both stations and ranged from less than 1 to 3 μg/L. Concentrations of dissolved zinc ranged from 1 to 24 μg/L, with a mean concentration of 8.6 μg/L at Hulls Farm Road and 8.7 μg/L at Route 1. Concentrations of dissolved aluminum ranged from 7 to 78 μg/L, with a mean concentration of 35.7 μg/L at Hulls Farm Road and 32.9 μg/L at Route 1. Beryllium, cadmium, cobalt, lead, molybdenum, silver, and uranium were not detected at either station.

Table 6. Concentrations of trace elements in Sasco Brook watershed, 1994–97

[<, less than]

Water-quality station	Sample date	Concentration of trace elements, in micrograms per liter											
		Aluminum	Beryllium	Cadmium	Chromium	Cobalt	Copper	Lead	Molybdenum	Nickel	Silver	Zinc	Uranium
Hulls Farm Road	11/03/1994	19	<1	<1	<1	<1	<1	<1	<1	1	<1	5	<1
	04/13/1995	78	<1	<1	<1	<1	2	<1	<1	2	<1	6	<1
	08/25/1995	7	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1
	09/27/1995	23	<1	<1	<1	<1	2	<1	<1	2	<1	23	<1
	10/30/1995	58	<1	<1	<1	<1	2	<1	<1	3	<1	12	<1
	11/22/1995	44	<1	<1	<1	<1	2	<1	<1	2	<1	12	<1
	01/11/1996	25	<1	<1	1	<1	2	<1	<1	3	<1	14	<1
	01/19/1996	62	<1	<1	1	<1	3	<1	<1	2	<1	16	<1
	02/16/1996	27	<1	<1	<1	<1	<1	<1	<1	1	<1	11	<1
	04/12/1996	49	<1	<1	<1	<1	<1	<1	<1	1	<1	9	<1
	06/10/1996	23	<1	<1	<1	<1	2	<1	<1	1	<1	3	<1
	06/21/1996	59	<1	<1	<1	<1	2	<1	<1	2	<1	5	<1
	08/08/1996	13	<1	<1	<1	<1	<1	<1	<1	1	<1	2	<1
	07/29/1997	13	<1	<1	<1	<1	<1	<1	<1	1	<1	1	<1
Route 1	11/03/1994	21	<1	<1	<1	<1	<1	<1	<1	<1	<1	4	<1
	09/27/1995	11	<1	<1	<1	<1	2	<1	<1	1	<1	4	<1
	10/30/1995	49	<1	<1	<1	<1	2	<1	<1	2	<1	12	<1
	11/22/1995	38	<1	<1	<1	<1	2	<1	<1	2	<1	11	<1
	01/11/1996	19	<1	<1	1	<1	3	<1	<1	2	<1	20	<1
	01/19/1996	49	<1	<1	1	<1	3	<1	<1	2	<1	24	<1
	04/12/1996	44	<1	<1	<1	<1	1	<1	<1	1	<1	10	<1
	06/10/1996	26	<1	<1	<1	<1	1	<1	<1	2	<1	2	<1
	06/21/1996	53	<1	<1	<1	<1	2	<1	<1	2	<1	5	<1
	08/08/1996	23	<1	<1	<1	<1	<1	<1	<1	1	<1	1	<1
	07/29/1997	29	<1	<1	<1	<1	1	<1	<1	2	<1	3	<1

Results from Storm Samples

Samples were collected during seven storms at the Hulls Farm Road station during the study period. The number of samples collected during each storm ranged from 5 to 11, with an average of 8 samples. Peak instantaneous streamflows during the storms ranged from 24 to 485 ft^3/s. Concentrations of total nitrogen ranged from 0.55 to 1.5 mg/L (table 7). In general, concentrations of total nitrogen remained fairly constant during each storm; whereas the concentrations of its components—dissolved nitrate and nitrite and total Kjeldahl nitrogen—varied throughout the storms (fig. 13). Concentrations of dissolved nitrate and nitrite initially decreased during the rising limb of the hydrograph as a result of dilution of the ground-water base flow (higher in nitrate and nitrite) by surface runoff (lower in nitrate and nitrite). Concentrations of nitrate and nitrite increased after the peak, as contributions from surface runoff decreased and ground water contributed a higher percentage of streamflow. Concentrations of total Kjeldahl nitrogen responded in the opposite way—increasing during the rising limb of the hydrograph as a result of increased surface runoff, and decreasing slowly after the peak, as contributions from surface runoff decreased and ground water contributed a higher percentage of streamflow.

The largest fluctuation in total nitrogen during any storm was 0.5 mg/L—during the April 1996 storm (table 7). The largest fluctuation in total phosphorus during any storm was 0.18 mg/L—also during the April 1996 storm (table 7). During this storm, 5.3 in. of precipitation fell in less than 24 hours, an event with more than a 10-year return interval (Herschfield, 1961). The April 1996 storm was the largest storm sampled and showed the largest changes in streamflow and constituent concentrations. This storm transported the highest nutrient loads during the study period. Because the April 1996 storm was so large, the relative concentrations of nutrients did not follow the pattern that was typical of the other storms (fig. 13).

Table 7. Concentrations of nutrients during selected storms at Hulls Farm Road station, Sasco Brook watershed, 1996–98

[Data from National Oceanic and Atmospheric Administration, 1994–98; mg/L, milligram per liter]

Date	Time	Streamflow, in cubic feet per second	Total Kjeldahl nitrogen, in mg/L	Dissolved nitrate plus nitrite, in mg/L	Total nitrogen, in mg/L	Total phosphorus, in mg/L
			April 1996—total rainfall 5.28 inches			
4/16/1996	0430	89	0.70	0.63	1.3	0.100
4/16/1996	0630	198	.90	.49	1.4	.140
4/16/1996	0930	403	.70	.43	1.1	.180
4/16/1996	1000	426	1.0	.45	1.5	.180
4/16/1996	1230	485	.30	.70	1.0	.010
4/16/1996	1415	456	.60	.42	1.0	.070
4/16/1996	1520	426	.70	.46	1.2	.100
4/17/1996	1000	116	.40	.65	1.0	.030
Mean			.66	.53	1.2	.100
			June 1996—total rainfall 1.46 inches			
6/19/1996	1515	6.2	.60	.64	1.2	.040
6/19/1996	1815	11	.50	.66	1.2	.050
6/19/1996	2115	21	.60	.67	1.3	.060
6/20/1996	0115	21	.50	.64	1.1	.040
6/20/1996	0715	18	.50	.57	1.1	.040
6/20/1996	1130	17	.40	.54	.94	.030
6/20/1996	1530	28	.60	.56	1.2	.040
6/20/1996	1830	32	.60	.52	1.1	.040
6/20/1996	2230	29	.60	.49	1.1	.030
6/21/1996	0915	23	.50	.55	1.0	.050
6/21/1996	1030	23	.60	.51	1.1	.030
Mean			.54	.58	1.1	.040

Table 7. Concentrations of nutrients during selected storms at Hulls Farm Road station, Sasco Brook watershed, 1996–98—Continued

[Data from National Oceanic and Atmospheric Administration, 1994–98; mg/L, milligram per liter]

Date	Time	Streamflow, in cubic feet per second	Total Kjeldahl nitrogen, in mg/L	Dissolved nitrate plus nitrite, in mg/L	Total nitrogen, in mg/L	Total phosphorus, in mg/L
October 1996—total rainfall 1.87 inches						
10/08/1996	1640	23	.40	.57	.97	.040
10/08/1996	2040	51	.70	.55	1.2	.090
10/09/1996	0040	77	.70	.58	1.3	.080
10/09/1996	0540	68	.70	.61	1.3	.080
10/09/1996	0840	59	.60	.59	1.2	.050
Mean			.62	.58	1.1	.070
April 1997—total rainfall 0.5 inches						
4/18/1997	1056	29	0.38	.79	1.2	.035
4/18/1997	1556	47	.45	.75	1.2	.060
4/18/1997	1856	52	.40	.68	1.1	.020
4/19/1997	0956	42	.36	.69	1.0	.026
4/20/1997	0956	25	.31	.76	1.1	.010
Mean			.38	.73	1.1	.030
October 1997—total rainfall 1.76 inches						
10/25/1997	0925	3.6	.27	0.48	0.75	0.015
10/25/1997	1822	6.6	.38	.43	.81	.028
10/26/1997	1622	3.8	.28	.32	.59	<.010
10/26/1997	2325	5.4	.29	.32	.62	.012
10/27/1997	0425	22	.42	.23	.65	.025
10/27/1997	0625	24	.47	.25	.71	.029
10/27/1997	1225	19	.45	.23	.68	.030
10/28/1997	1225	6.2	.43	.12	.55	.031
Mean			.37	.30	.67	.024
November 1997—total rainfall 0.67 inches						
11/21/1997	2300	8.4	.26	.61	.87	.010
11/22/1997	0300	12	.29	.59	.87	<.010
11/22/1997	0900	30	.33	.50	.83	.014
11/22/1997	1300	34	.35	.41	.76	.018
11/22/1997	1500	33	.31	.40	.71	.016
11/23/1997	1500	19	.30	.40	.70	.011
Mean			.31	.48	.79	.014
April 1998—total rainfall 1.56 inches						
4/09/1998	1300	13	.27	.65	.92	.012
4/09/1998	1800	16	.28	.65	.93	.020
4/09/1998	2200	35	.51	.63	1.1	.061
4/10/1998	0400	111	.55	.39	.94	.075
4/10/1998	0500	114	.57	.43	1.0	.067
4/10/1998	0700	109	.40	.41	.81	.039
4/10/1998	1400	76	.38	.59	.97	.047
4/10/1998	2200	50	.39	.54	.93	.033
4/11/1998	0900	31	.33	.62	.95	.028
4/12/1998	1700	19	.33	.78	1.1	.025
Mean			.40	.57	.96	.040

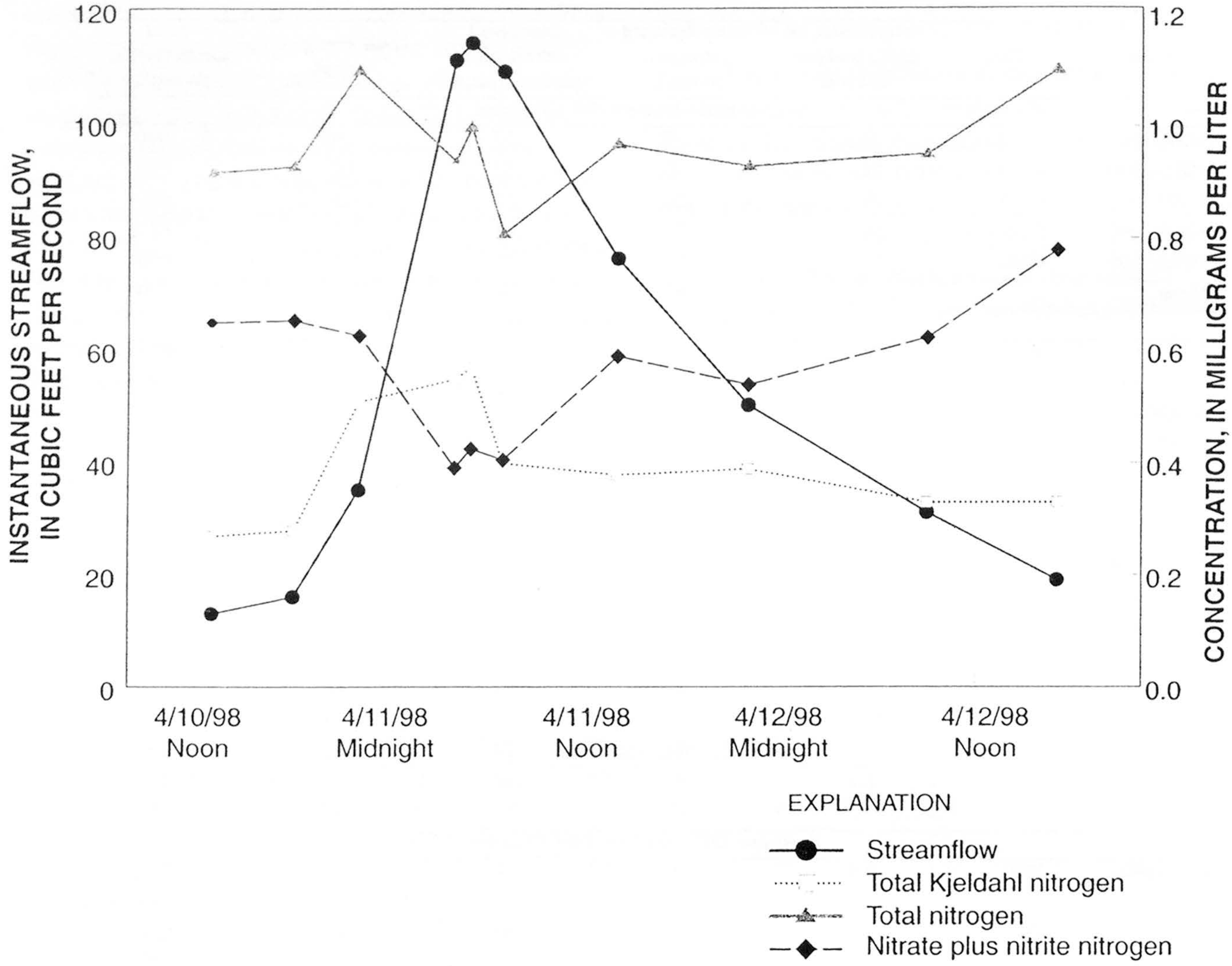


Figure 13. Concentrations of nitrogen species and streamflow during a typical storm, Sasco Brook watershed, April 1998.

Concentrations of total nitrogen in the routine samples collected at the Hulls Farm Road station are positively correlated with concentrations of dissolved nitrate and nitrite. Results of regression analysis of concentrations of total nitrogen on concentrations of dissolved nitrate and nitrite indicate that 89 percent of the variability in total nitrogen concentrations can be explained by variations in dissolved nitrate and nitrite concentrations (fig. 14A). This result indicates that most of the nitrate and nitrite in Sasco Brook streamflow is derived from ground water during base-flow conditions. When regression analysis of concentrations of total nitrogen on concentrations of dissolved nitrate and nitrite is applied to the routine and storm-sample data combined, the regression is still significant; however, there is more spread in the data (fig. 14B). Variations in concentrations of dissolved nitrate and nitrite explain 64 percent of the variability in total nitrogen concentrations in the regression model of the routine and storm-sample data. The additional spread in the total nitrogen data is the result of the increase in the percentage and variability of the total Kjeldahl nitrogen component of total nitrogen during storms.

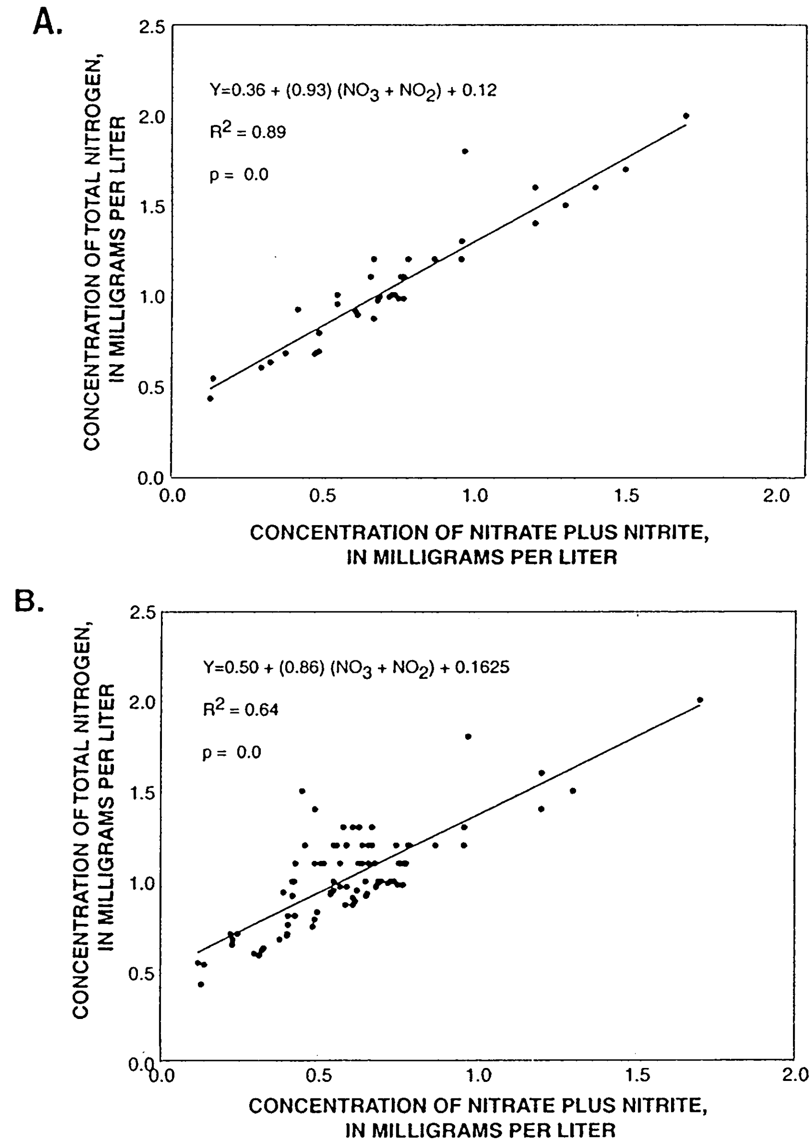


Figure 14. Regression plot showing concentrations of total nitrogen and nitrate plus nitrite at the Hulls Farm Road station for
A. Routine samples.
B. All samples (routine and storm).

NUTRIENT LOADS AND YIELDS IN SASCO BROOK WATERSHED

Water-quality data from routine monthly samples and storm samples from November 1994 through December 1997, as well as results of analyses of additional samples collected during the April 1998 storm, were used in the calibration data set for the ESTIMATOR model. Using the ESTIMATOR program, annual loads of total Kjeldahl nitrogen, dissolved nitrate and nitrite, total nitrogen, and total phosphorus at the Hulls Farm Road station were calculated for the three complete calendar years of the study, 1995–97.

Annual Loads and Yields of Nitrogen and Phosphorus

The annual variability associated with the estimated nutrient loads and the relation of runoff to the estimated nutrient loads can be seen in table 8. Annual loads of total nitrogen from Sasco Brook at the Hulls Farm Road station ranged from 17,100 lb in 1995 to 50,700 lb in 1996. The average annual load of total nitrogen for the study period was 32,700 lb/yr, and the average daily load was 89.6 lb/d. Yields of total nitrogen ranged from 2,320 lb/mi^2/yr in 1995 to 6,870 lb/mi^2/yr in 1996. The average yield of total nitrogen during the study period was 4,430 lb/mi^2/yr. In general, from November 1994 to April 1998, 70 percent of the total nitrogen load from Sasco Brook at Hulls Farm Road was in the form of nitrate and nitrite (fig. 15).

Annual loads of total phosphorus ranged from 352 lb in 1995 to 1,970 lb in 1996. The average annual load of total phosphorus for the study period was 1,040 lb/yr, and the average daily load was 2.8 lb/d. Yields of total phosphorus ranged from 47.7 lb/mi^2/yr in 1995 to 267 lb/mi^2/yr during 1996. The average yield of total phosphorus during the study period was 142 lb/mi^2/yr.

Table 8. Loads and yields of selected nutrients, Sasco Brook at Hulls Farm Road near Southport, Connecticut, 1995–97

Nutrient	Calendar year	Runoff (inches)	Average daily load (pounds per day)	Annual load (pounds per year)	95-percent confidence range (pounds per year)	Yield (pounds per square mile per year)
Total Kjeldahl nitrogen	1995	13.6	13.6	4,980	4,080 - 6,030	675
	1996	38.4	52.8	19,300	17,700 - 21,900	2,620
	1997	24.6	24.9	9,120	7,920 - 10,500	1,240
	Average	25.5	30.4	11,100		1,510
Dissolved nitrate and nitrite	1995	13.6	33.5	12,700	9,320 - 15,700	1,720
	1996	38.4	89.1	32,600	28,300 - 37,300	4,420
	1997	24.6	61.2	23,400	18,400 - 26,900	3,170
	Average	25.5	61.3	22,700		3,100
Total nitrogen	1995	13.6	46.9	17,100	15,000 - 19,400	2,320
	1996	38.4	139	50,700	47,300 - 54,200	6,870
	1997	24.6	82.9	30,300	27,700 - 33,100	4,110
	Average	25.5	89.6	32,700		4,430
Total phosphorus	1995	13.6	0.9	352	218 - 539	47.7
	1996	38.4	5.3	1,970	1,370 - 2,570	267
	1997	24.6	2.2	811	556 - 1,140	110
	Average	25.5	2.8	1,040		142

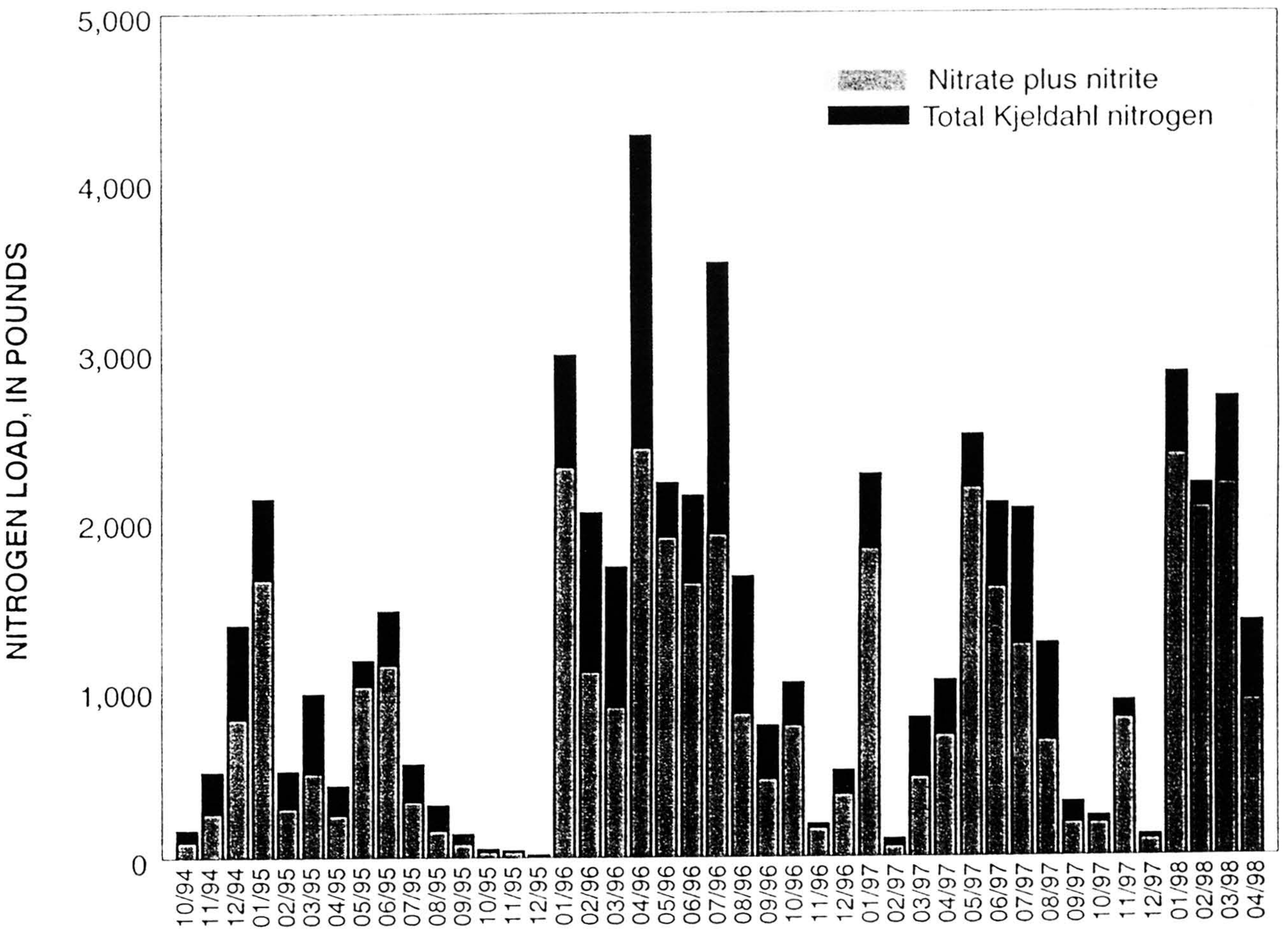


Figure 15. Nitrogen loads in Sasco Brook watershed, 1994–98.

Comparison with Nutrient Loads and Yields in Other Watersheds

Although yields of total nitrogen and total phosphorus can vary substantially from year to year, a comparison with nitrogen and phosphorus yields in other watersheds is useful for examining relative differences among watersheds. Loads and yields of total nitrogen from Sasco Brook were compared to estimates for calendar years 1995–97 (table 9) from the USGS monitoring station on the Saugatuck River near Redding (station 01208990) (J.R. Mullaney, U.S. Geological Survey, written commun., 2000). The Saugatuck River watershed is a 21-mi^2 area and was chosen because its land use and climatic conditions are similar to those of Sasco Brook. From 1995–97, the Sasco Brook watershed had consistently higher loads and yields of total nitrogen than the Saugatuck River watershed, even though Sasco Brook's watershed above Hulls Farm Road is approximately one-third the size of the Saugatuck River watershed. Sasco Brook had an average yield of 4,430 lb/mi^2/yr, which is substantially higher than the average yield of 1,240 lb/mi^2/yr for the Saugatuck River watershed.

Values for Sasco Brook also were compared to those published by Trench (2000) for the Saugatuck, Salmon, and Quinebaug Rivers in Connecticut. (Mullaney's value for average total nitrogen yield in the Saugatuck River—1,240 lb/mi^2/yr—agrees with Trench's value—1,210 lb/mi^2/yr—for 1993–95; see table 10.) The average yield of total nitrogen from Sasco Brook for 1995–97 was two to four times the annual values published by Trench (2000). The average yield of total phosphorus from Sasco Brook (142 lb/mi^2/yr) also was two to three times those published by Trench for the three sites (which ranged from 53 to 80 lb/mi^2/yr). The fact that yields of total nitrogen and total phosphorus from Sasco Brook watershed, which lacks any point sources, are higher than those from the Quinebaug River watershed at Quinebaug, Conn., which has point sources, indicates that Sasco Brook receives large inputs of nitrogen and phosphorus from nonpoint sources.

Table 9. Loads and yields of total nitrogen and runoff from Sasco Brook and Saugatuck River watersheds

[Saugatuck River data from J.R. Mullaney, U.S. Geological Survey, written commun., 2000]

Calendar year	Sasco Brook (7.4 square miles)			Saugatuck River (21.0 square miles)		
	Load (pounds)	Yield (pounds per square mile)	Runoff (inches)	Load (pounds)	Yield (pounds per square mile)	Runoff (inches)
1995	17,100	2,320	13.6	16,100	767	16.4
1996	50,700	6,870	38.4	41,700	1,990	42.5
1997	30,300	4,110	24.6	20,400	971	20.7
Average	32,700	4,430	25.5	26,000	1,240	26.5

Table 10. Annual yields of total nitrogen and total phosphorus for three watersheds in Connecticut, averaged for 1993–95

[Data modified from Trench, 2000, table 15]

U.S. Geological Survey station number	Station name	Total nitrogen yield (pounds per square mile per year)	Total phosphorus yield (pounds per square mile per year)
01124000	Quinebaug River at Quinebaug, Conn.	1,820	80
01193500	Salmon River near East Hampton, Conn.	1,800	63
01208990	Saugatuck River near Redding, Conn.	1,210	53

In a study by Langland (1998), yields of total nitrogen and total phosphorus were estimated for 54 and 75 sites with drainage areas of varying sizes and land uses that drain to Chesapeake Bay. Total nitrogen yields ranged from 960 to 26,000 lb/mi^2/yr. The median total nitrogen yield of 4,480 lb/mi^2/yr from watersheds draining to Chesapeake Bay was slightly higher than the total nitrogen yield from Sasco Brook watershed, and the median total phosphorus yield of 314 lb/mi^2/yr from the Chesapeake Bay study was almost twice the average total phosphorus yield from Sasco Brook watershed. The median nutrient yields from the Chesapeake Bay study reflect a group of watersheds with large percentages of agricultural land (as much as 50 percent); the lowest values are for primarily forested basins with less than 20 percent agricultural land.

Clark and others (2000) reported average total nitrogen yields of 1,430 lb/mi^2/yr from 85 forested or undeveloped watershed sites across the United States. This value indicates that yields of total nitrogen from Sasco Brook are 2.5 times the average yields reported from other forested watersheds. Clark and others (2000, p. 849) also reported that "yields of nitrate tended to be highest in the Northeastern and Mid-Atlantic coastal states and correlated well with areas of high atmospheric nitrogen deposition."

SOURCES OF NITROGEN TO SASCO BROOK WATERSHED

Atmospheric Contributions

Data from the National Atmospheric Deposition Program show that Sasco Brook watershed is in one of the highest deposition zones for atmospheric nitrogen in the United States (table 11). Inputs of total nitrogen vary from year to year, on the basis of climatic conditions, and ranged from 2,720 lb/mi^2/yr during 1995 (dry year) to 4,970 lb/mi^2/yr during 1996 (wet year)—a variation of almost 100 percent. Applying these data to Sasco Brook indicates that atmospheric inputs from 1995–97 ranged from 69 to 117 percent of the total nitrogen load transported past the Hulls Farm Road station.

Other Sources

Nitrogen loads from a combination of sources contribute to the total nitrogen in Sasco Brook that is exported from the watershed above the Hulls Farm Road station. Not all the load from any given source is completely exported from the watershed in Sasco Brook in a given year. This can be seen in the data from 1995, when load from atmospheric sources exceeded 100 percent of the total nitrogen load of Sasco Brook. Some nitrogen is stored in the watershed in the soil, plants, and animals. Nitrogen also can be transformed to the gaseous phase and be released to the atmosphere. These losses of nitrogen from source to exportation in a watershed are called attenuation. Many factors contribute to attenuation; these factors vary greatly from year to year and affect how much source nitrogen is exported from the watershed.

A large source of nitrogen to Sasco Brook watershed may be the estimated 400 horses that are stabled in the watershed. An individual horse contributes an average of 132 lb/yr of nitrogen to a watershed (Valeila and others, 1997, p. 364). This rate, multiplied by the estimated number of horses in the watershed, results in a potential load of 52,800 lb/yr of nitrogen, or 161 percent of the average load of total nitrogen exported per year.

Another large source of nitrogen in the watershed may be the people that live in the watershed above the Hulls Farm Road station. A grid of population density (Price and Clawges, 1999) was used to estimate the population of this area as 5,500. None of the watershed above Hulls Farm Road is sewered, and waste disposal is through private septic systems. An individual person may contribute 10.6 lb/yr of total nitrogen to a watershed from waste (Valeila and others, 1997, p. 364). Therefore, people may contribute as much as 58,300 lb/yr to the watershed. This amount represents 178 percent of the average load of total nitrogen exported per year.

Another source of potentially large inputs of nitrogen to Sasco Brook watershed are chemical lawn fertilizers. Approximately 22 percent of Sasco Brook watershed is covered by urban and recreational grasses (lawn) (Vogelmann and others, 1998). Because of many factors that determine whether or not fertilizer is applied, the concentration of nitrogen used, and the rate of application, loads from this potential source were not quantified as part of this study.

Table 11. Yields and loads of total nitrogen as N (as wet deposition of nitrate and ammonia) from the National Atmospheric Deposition Program, 1995–97

[Unpublished data accessed on 05/17/02 on the World Wide Web at URL http://nadp.sws.uiuc.edu/nadpdata]

National Atmospheric Deposition Program station	Calendar year	Yield of total nitrogen as N (pounds per square mile per year)	Annual load of atmospheric total nitrogen as N to Sasco Brook above Hulls Farm Road (pounds per year)	Annual load of total nitrogen in Sasco Brook above Hulls Farm Road (pounds per year)
NY 99	1995	2,720	20,000	17,100
	1996	4,970	36,700	50,700
	1997	2,850	21,000	30,300
	Average	3,510	25,900	32,700

SUMMARY

Water-quality samples were collected at two stations in Sasco Brook watershed from November 1994 to April 1998 over a range of streamflow conditions that represent long-term streamflow conditions. Results of statistical analyses indicate no difference in the concentrations of nitrogen, phosphorus, total organic carbon, and enterococcus bacteria between the Hulls Farm Road station (upstream) and the Route 1 station (downstream). Concentrations of fecal coliform bacteria were significantly higher at the Route 1 station than at the Hulls Farm Road station. Concentrations of trace elements were very low or below the detection limit.

Total nitrogen loads and yields varied during the study period. Approximately 70 percent of the nitrogen load from Sasco Brook was in the form of nitrate and nitrite. The average nitrogen yield from Sasco Brook (4,430 lb/mi^2/yr) was two to three times the yields reported for the Saugatuck River, the Salmon River, the Quinebaug River, and other forested watersheds throughout the United States. The combined potential sources of nitrogen in Sasco Brook watershed—atmospheric deposition, horse stabling, and residential land use—probably contribute to the high nitrogen yields. The results of this study provide baseline data that can be used to evaluate the effect of future land-use management decisions in the watershed on concentrations of nutrients and fecal indicator bacteria.

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Appendix 1. Summary statistics for concentrations of major ions and measurements of basic field parameters, November 1994 to April 1998

[ft^3/s, cubic foot per second; %, percent; µS/cm, microgram per centimeter, mg/L, milligram per liter]

Water-quality station	Constituent or measurement	Units	Minimum	Maximum	Mean	Median
Hulls Farm Road	Discharge,	ft^3/s	0.07	78.0	15.8	11.0
	Dissolved oxygen	% of saturation	42.0	112	89.2	94.0
	Dissolved oxygen	mg/L	3.5	15.5	10.5	10.2
	pH	standard units	6.7	7.3	7.1	7.2
	Specific conductance	µS/cm	120	255	166	166
	Hardness	mg/L	29	74	42	40
	Calcium	mg/L	7.6	22.0	11.6	11.0
	Magnesium	mg/L	2.4	4.6	3.2	3.1
	Potassium	mg/L	1.6	3.5	2.2	2.1
	Sodium	mg/L	9.1	18.0	11.8	11.0
	Alkalinity	mg/L	12	40	21	18
	Bicarbonate	mg/L	15	49	25	22
	Chloride	mg/L	14.0	33.0	19.7	19.0
	Silica	mg/L	5.9	12.0	9.1	9.4
	Sulfate	mg/L	9.9	47.0	15.8	14.8
	Residue	mg/L	78	133	103	106
Route 1	Discharge	ft^3/s	0.20	60.0	16.1	14.0
	Dissolved oxygen	% of saturation	50.0	110	93.0	96.5
	Dissolved oxygen	mg/L	4.6	14.7	10.7	10.6
	pH	standard units	6.6	7.7	7.2	7.3
	Specific conductance	µS/cm	125	305	178	170
	Hardness	mg/L	31	65	44	43
	Calcium	mg/L	8.2	17.0	12.0	12.0
	Magnesium	mg/L	2.5	5.8	3.4	3.2
	Potassium	mg/L	1.7	3.8	2.4	2.1
	Sodium	mg/L	9.2	26.0	13.1	12.0
	Alkalinity	mg/L	13	41	22	20
	Bicarbonate	mg/L	16.0	50.0	26.7	24.0
	Chloride	mg/L	15.0	47.9	22.9	21.0
	Silica	mg/L	1.6	12.0	8.7	8.7
	Sulfate	mg/L	9.3	34.0	15.9	15.0
	Residue	mg/L	73	159	109	107

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