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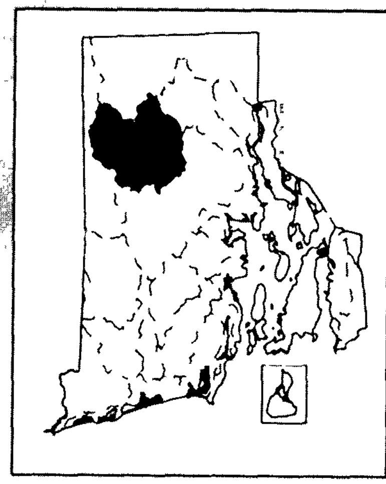
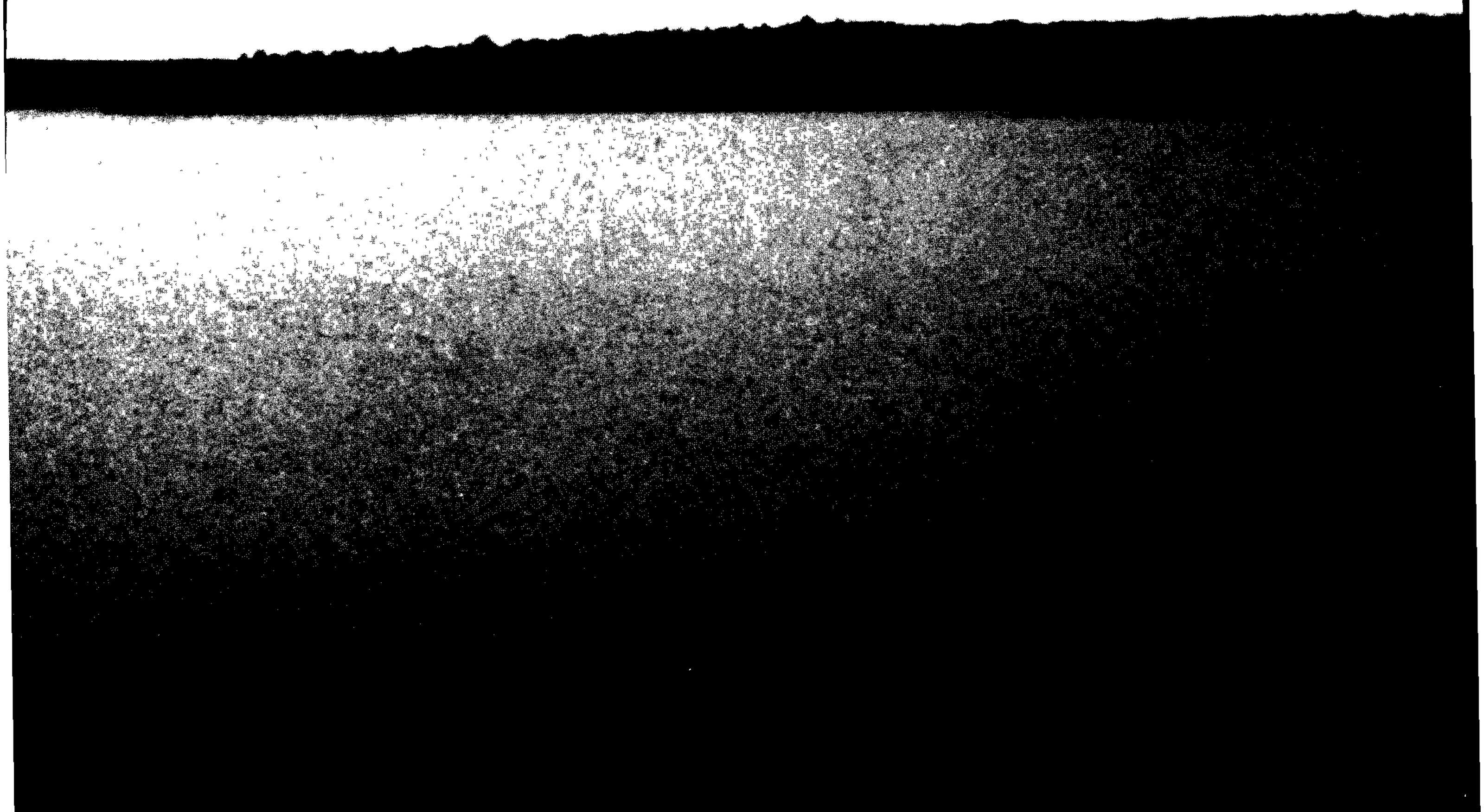
Water-Quality Conditions and Relation to Drainage-Basin Characteristics in the Scituate Reservoir Basin, Rhode Island, 1982–95



Water-Resources Investigations Report 00-4086



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Water-Quality Conditions and Relation to Drainage-Basin Characteristics in the Scituate Reservoir Basin, Rhode Island, 1982–95

By ROBERT F. BREAULT, MARCUS C. WALDRON,
LORA K. BARLOW, and DAVID C. DICKERMAN

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Northborough, Massachusetts
2000

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CONTENTS

FIGURES

TABLE

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

CONVERSION FACTORS

Multiply	By	To obtain
acres	0.00404	square kilometers
billion gallons per day (Bgal/d)	0.00378	billion cubic meters per day
cubic feet per second (ft^3/s)	0.02832	cubic meters per second
feet per day (ft/d)	0.3048	meters per day
gallons per day (gal/d)	0.00378	cubic meters per day
inches	0.3937	meter
miles (mi)	1.609344	kilometers
million gallons per day (Mgal/d)	0.00378	million cubic meters per day
square miles (mi^2)	2.58999	square kilometers
tons per day	1016.05	kilograms per day

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

°F=1.8°C+32

VERTICAL DATUM

Sea level: In this report, "sea level" 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 the United States and Canada, formerly called Sea Level Datum of 1929.

ABBREVIATIONS

CCL	Contaminant candidate list
CFU	Colony forming units
CFU/100 mL	Colony forming units per 100 milliliters
DEMs	Digital elevation models
DOC	Dissolved organic carbon
GIS	Geographical information systems
kg/d	Kilograms per day
MCL	Maximum contaminant level
mg/L	Milligrams per liter
MOVE:1	Maintenance of Variance Extension type 1 method
NTU	Nephelometry turbidity unit
PCU	Platinum cobalt units
PWSB	Providence Water Supply Board
RIDEM	Rhode Island Department of Environmental Management
RIDOT	Rhode Island Department of Transportation
RIGIS	Rhode Island Geographical Information Systems
SMCL	Secondary maximum contaminant level
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey

Water-Quality Conditions and Relation to Drainage-Basin Characteristics in the Scituate Reservoir Basin, Rhode Island, 1982–95

By Robert F. Breault, Marcus C. Waldron, Lora K. Barlow, *and* David C. Dickerman

Abstract

The Scituate Reservoir Basin covers about 94 square miles in north central Rhode Island and supplies more than 60 percent of the State of Rhode Island's drinking water. The basin includes the Scituate Reservoir Basin and six smaller tributary reservoirs with a combined capacity of about 40 billion gallons. Most of the basin is forested and undeveloped. However, because of its proximity to the Providence, Rhode Island, metropolitan area, the basin is subject to increasing development pressure and there is concern that this may lead to the degradation of the water supply.

Selected water-quality constituent concentrations, loads, and trends in the Scituate Reservoir Basin, Rhode Island, were investigated to locate parts of the basin likely responsible for exporting disproportionately large amounts of water-quality constituents to streams, rivers, and tributary reservoirs, and to determine whether water quality in the basin has been changing with time. Water-quality data collected between 1982 and 1995 by the Providence Water Supply Board (PWSB) in 34 subbasins of the Scituate Reservoir Basin were analyzed. Subbasin loads and yields of total coliform bacteria, chloride, nitrate, iron, and manganese, estimated from constituent concentrations and estimated mean daily discharge records for the1995 water year, were used to determine which subbasins contributed disproportionately large amounts of these constituents. Measurements of pH, color, turbidity, and concentrations of total coliform bacteria, sodium, alkalinity, chloride, nitrate, orthophosphate, iron, and manganese made between 1982 and 1995 by the PWSB were evaluated for trends. To determine the potential effects of human-induced changes in drainage-basin characteristics on water quality in the basin, relations between drainage-basin characteristics and concentrations of selected water-quality constituents also were investigated.

Median values for pH, turbidity, total coliform bacteria, sodium, alkalinity, chloride, nitrate, and iron were largest in subbasins with predominately residential land use. Median instantaneous loads reflected drainage-basin size. However, loads normalized by drainage area (median instantaneous yields) also were largest in residential areas where point and non-point sources are likely, and in areas of poorly drained soils.

Significant trends in water-quality constituents from 1982 to 1995 in the Scituate Reservoir Basin indicate that the quality of the water resources in the basin may be slowly changing. Scituate Reservoir subbasins with large amounts of residential land use showed increasing trends in alkalinity and chloride. In contrast, subbasins distributed throughout the drainage

basin showed increasing trends in pH, color, nitrate, and iron concentrations, indicating that these characteristics and constituents may be affected more by atmospheric deposition.

Although changing, water-quality constituent concentrations in the Scituate Reservoir Basin only occasionally exceeded Rhode Island and USEPA water-quality guidelines and standards. Result of correlation analysis between pH, color, turbidity, and concentrations of total coliform bacteria, sodium, alkalinity, chloride, nitrate, orthophosphate, iron, and manganese and land use, geology, wetlands, slope, soil drainability, and roads indicated that the percentage of wetlands, roads, and slope appear to have the greatest effect on water-quality in the Scituate Reservoir Basin. The percentage of urban, residential, and commercial land use also are important, but to a lesser degree than wetlands, roads, and slope. Finally, geology appears to have the least effect on water quality compared to other drainage-basin characteristics investigated.

INTRODUCTION

The Scituate Reservoir, in the towns of Glocester, Foster, and Scituate, R.I. (fig. 1), is the primary source of drinking water for the State. During the mid-1990's, the mean daily demand on the reservoir exceeded 66 Mgal, or about 25 Bgal annually (Providence Water Supply Board, 1995). The Providence Water Supply Board (PWSB) is responsible for the distribution of this water to more than 600,000 customers, including homes and businesses in Providence, North Providence, Johnston, and Cranston, and to a number of additional municipalities. This distribution accounts for about 60 percent of the State's drinking water.

In addition to maintaining an adequate water supply, the PWSB must protect water quality, and for more than 50 years, the PWSB has collected water-quality data at 34 stations on streams tributary to the Scituate Reservoir. Twenty-nine percent of the 94-square-mile Scituate Reservoir Basin is managed and protected by the PWSB; the remaining 71 percent is privately owned. The PWSB is concerned that human-induced changes in the privately owned part of the basin, including changes in agricultural and industrial activities, urbanization, and other land uses, may cause water to be unsuitable for agriculture, commercial uses, or public drinking-water supply.

In 1995, the U.S. Geological Survey (USGS), in cooperation with the PWSB, began an investigation to evaluate water-quality conditions, loads, trends, and relations between drainage-basin characteristics and median concentrations of pH, color, turbidity, total coliform bacteria, sodium, alkalinity, chloride, nitrate, nitrite, orthophosphate, iron, and manganese. These constituents are useful to assess water-quality conditions and are generally detected in smallest concentrations in underdeveloped drainage basins and in largest concentrations in urban drainage basins. Instantaneous loads and yields of water-quality constituents reflect drainage-basin characteristics. Understanding relations between water-quality and drainage-basin characteristics in the Scituate Reservoir Basin will aid the PWSB in deciding how best to protect and manage the water resources of the basin, and add to the understanding of water-supply drainage basins in the Nation.

Purpose and Scope

The purpose of this report is to describe water-quality conditions and relation to drainage-basin characteristics in the Scituate Reservoir drainage basin in Rhode Island between 1982 and 1995. The report presents a series of analyses of water-quality data collected by PWSB at 34 stations representing subbasins of the Scituate Reservoir drainage basin. These analyses include; (1) a summary of water-quality data collected by the PWSB in the Scituate Reservoir Basin from October 1982 to September 1995, (2) instantaneous loads and yields of selected water-quality constituents at water-quality sampling stations for water year 1995[1], (3) trends of selected water-quality constituents in the Scituate Reservoir Basin during water years 1982–95, (4) frequencies of exceedance of water-quality criteria, and (5) relations between water quality and drainage-basin characteristics in the Scituate Reservoir Basin.

[1]The term "Water Year" denotes the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1995 is called "water year 1995."

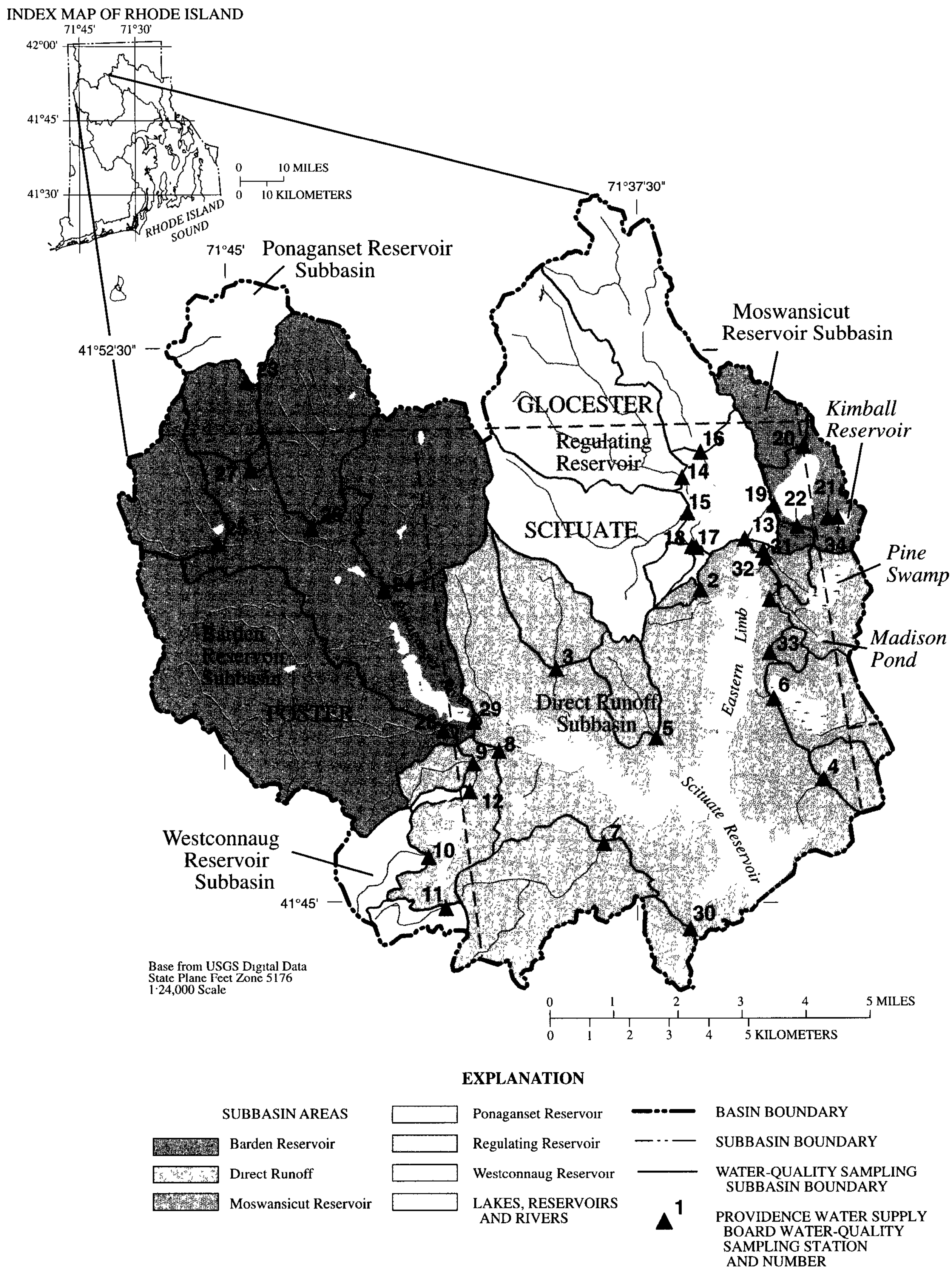


Figure 1. Location of principal rivers, tributaries, and water-quality sampling stations in the Scituate Reservoir Basin, Rhode Island.

Previous Investigations

Various reports are available that address water quality and the PWSB monitoring program in the Scituate Reservoir Basin. Lynk (1982) reviewed the PWSB's stream-sampling program and suggested that monitoring acidity was unnecessary and that monitoring for iron, manganese, and color needed to be reconsidered. Lynk also suggested adding chloride, fecal coliform, and fecal streptococcus to the monitoring program, adding several stations, and establishing a review board to regularly review and update the monitoring program.

A report on the Scituate Reservoir Basin by the Rhode Island Department of Environmental Management (RIDEM) (1983) concluded that increased use of road salt was resulting in increased chloride concentrations at the treatment-plant intake. In addition, the RIDEM did a general assessment of water quality in the basin (Scott, 1987) as part of the Scituate Reservoir Watershed Management Plan (Rhode Island Department of Administration, 1990). Scott (1987) concluded that although the water quality at the treatment-plant intake was acceptable, water quality was being degraded by increased residential development in the watershed. Scott (1987) also suggested that the Scituate Reservoir monitoring program be expanded to include monitoring the reservoir itself, streamflow measurements, and data collection on additional constituents, including nutrients and sediment.

Runge and others (1988) reviewed sodium and chloride data in the watershed and concluded that road salting was the primary source of sodium and chloride in the tributaries to the reservoir. The State suggested that calcium chloride be used instead of sodium chloride on some roads in the drainage basin (Rhode Island Department of Administration, 1990). The State also developed water-quality models of the watershed and collected limited water-quality data on the Scituate Reservoir to calibrate the models. They concluded that the reservoir was oligotrophic, seasonally stratified, and that the concentrations of several contaminants were substantially higher in the eastern limb than in the main body of the reservoir (fig. 1).

Wilbur Smith and Associates (1983; 1984; and 1985) evaluated the potential effect on water quality of upgrading Route 6, the largest highway in the drainage basin. These studies concluded that the general effect would be positive because of improvements in drainage and alignment over the current roadway. CH_2M Hill (1988) evaluated the potential effects of the nearby Central Landfill on the Scituate Reservoir. These studies concluded that seepage from the landfill did not likely pose any threat to the water quality of the Scituate Reservoir.

Kliever (1996) evaluated low streamflows in northern Rhode Island and concluded that the Ponaganset River, Hemlock Brook, and Peeptoad Brook are the largest tributaries to the Scituate Reservoir under low-flow conditions. The Natural Resources Conservation Service (1996) evaluated a runoff model for use in the watershed and determined that Moswansicut Pond is a sediment sink for its subbasin.

DESCRIPTION OF THE STUDY AREA

The Scituate Reservoir Basin consists of the main Scituate Reservoir, six smaller tributary reservoirs (Barden, Kimball, Moswansicut, Ponaganset, Regulating, and Westconnaug) and numerous mill ponds (fig. 1). This series of artificial reservoirs has a combined capacity of more than 40 Bgal and covers a surface area of about 7.2 mi^2. The drainage basin surrounding the Scituate Reservoir covers about 94 mi^2, representing about 9 percent of the total area of Rhode Island (Providence Water Supply Board, 1995). The PWSB owns about 27 mi^2 (29 percent) of the drainage basin. Most of this area (19 mi^2) is forested land that is managed for water-quality protection and timber. The remainder of the drainage basin is privately owned.

Land Use

Although about 70 percent of the Scituate Reservoir Basin is privately owned, more than 97 percent of the land in the basin is undeveloped, including 9.5 percent that is composed of surface-water bodies, wetlands, or barren land. A large part of the basin (87.5

percent) is forested primarily as evergreen or mixed evergreen/deciduous forest. Forest management to establish a diverse forest of native tree species for the purpose of water protection is the principal human activity associated with the forested lands. Only about 3 percent of the drainage basin can be classified as urban (fig. 2), including residential, commercial, industrial, and institutional land uses. Because of its proximity to the Providence metropolitan area, the drainage basin is affected by growing development pressure. For example, the combined populations of the three towns (Glocester, Foster, and Scituate) doubled from 1960 to 1986 (Rhode Island Division of Planning, 1990).

Climate

The climate in the basin is temperate, with a mean annual temperature of 48.3°F based on 19 years of record from the National Weather Service station in North Foster, R.I. (U.S. Department of Commerce, 1995). Mean monthly temperature ranges from 25.4°F in January to 70.4°F in July. A mean of 53.4 in. (87.3 Bgal) of precipitation falls on the Scituate Reservoir Basin annually; of this, 44 percent (38.4 Bgal) is used by vegetation or lost to evaporation (Knox and Nordenson, 1955). Precipitation is distributed fairly evenly throughout the year, averaging 4.4 in/month, however, January and March tend to be the wettest months of the year.

Geology

Two major geologic units underlie the study area--bedrock and surficial materials. The bedrock in the drainage basin is composed primarily of Devonian and late Proterozoic igneous and metamorphic rocks (fig. 3; Hermes and others, 1994), and the reservoir is underlain by granite of the Scituate igneous suite. Granite and gneiss of the Esmond igneous suite underlie the northern and western parts of the drainage basin. These bedrock types can be grouped into three major lithochemical units (Robinson, G.R. U.S. Geological Survey, written commun., 2000) based on mineralogical composition and weathering characteristics: (1) metamorphosed clastic sedimentary rocks, (2) mafic and ultramafic igneous rocks and their metamorphic equivalents, and (3) granitoid plutonic rocks and their metamorphic equivalents (fig. 4).

Glacial deposits of Pleistocene age overlie the bedrock (fig. 5; Richmond and Allen, 1951; Robinson, 1961). Glacial materials consist of ice-laid deposits (till) and meltwater deposits (sand and gravel). Till, locally called hardpan, is a mixture of nonsorted sand, silt, clay, and boulders that is generally compacted and blankets the bedrock surface. The meltwater deposits consist of poor- to well-sorted sand and gravel and are found primarily in low-lying areas, such as stream valleys.

Surface-Water Hydrology

The Scituate Reservoir Basin consists of the Scituate Reservoir and six smaller tributary reservoirs that are fed by many small rivers and streams. Annual mean discharge for the 18 stations where streamflow data were collected in the basin for water year 1995 ranged from 0.1 ft^3/s for the Unnamed Tributary #1 to Regulating Reservoir, to 19 ft^3/s for the Ponaganset River (Socolow and others, 1996). The Ponaganset River is the principal river in the basin, flowing from its source at the Ponaganset Reservoir to its outlet at Barden Reservoir. About 14 mi^2 (about 15 percent) of the basin is drained by the river. Other major tributaries in the basin include Peeptoad, Windsor, Shippee, Westconnaug, and Wilbur Hollow Brooks, which drain about 21 mi^2 (20 percent) of the basin.

Ground-Water Hydrology

The ground-water hydrology of the basin is affected by the glacial meltwater deposits, which generally have horizontal hydraulic conductivity values equal to or exceeding 100 ft/d (Richmond and Allen, 1951; Pollock, 1960; Hahn and Hansen, 1961; Hansen, 1962). These deposits formed aquifers that can store and release significant volumes of water. By contrast, the hydraulic conductivity of till in the drainage basin is typically on the order of 10 ft/d. The bedrock is virtually impervious with a horizontal hydraulic conductivity near 1 ft/d.

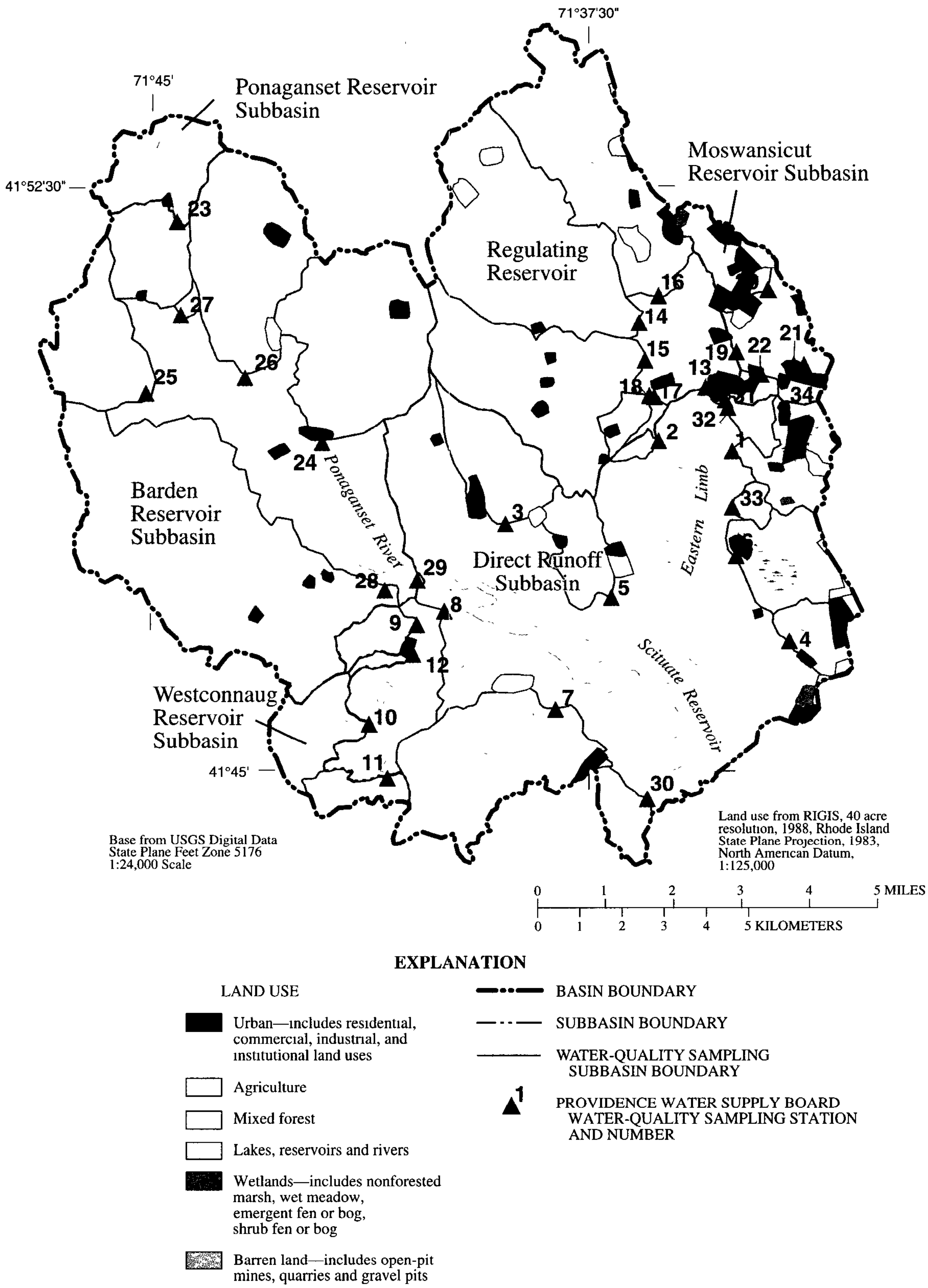


Figure 2. Generalized land use in the Scituate Reservoir Basin, Rhode Island.

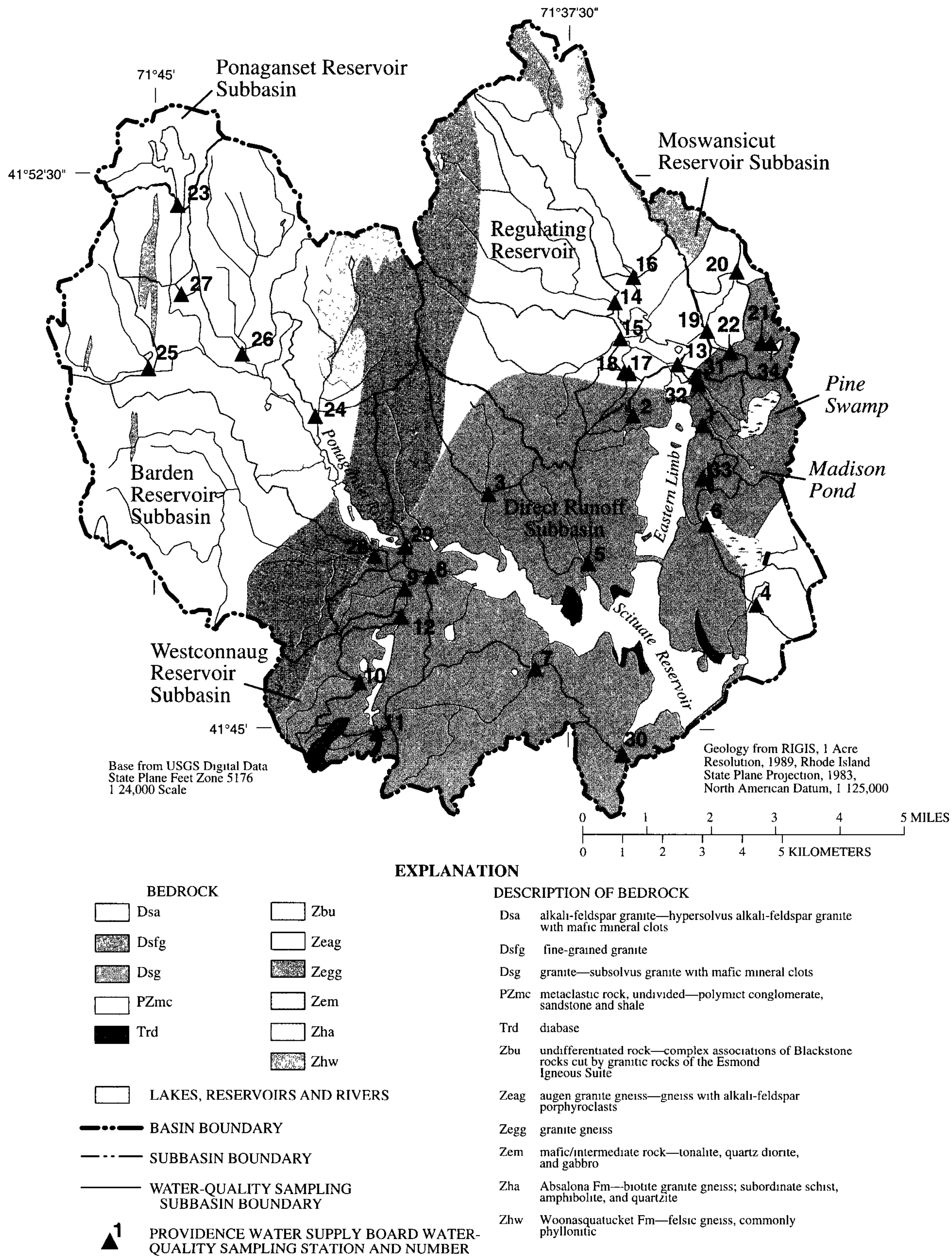


Figure 3. Bedrock geology in the Scituate Reservoir Basin, Rhode Island.

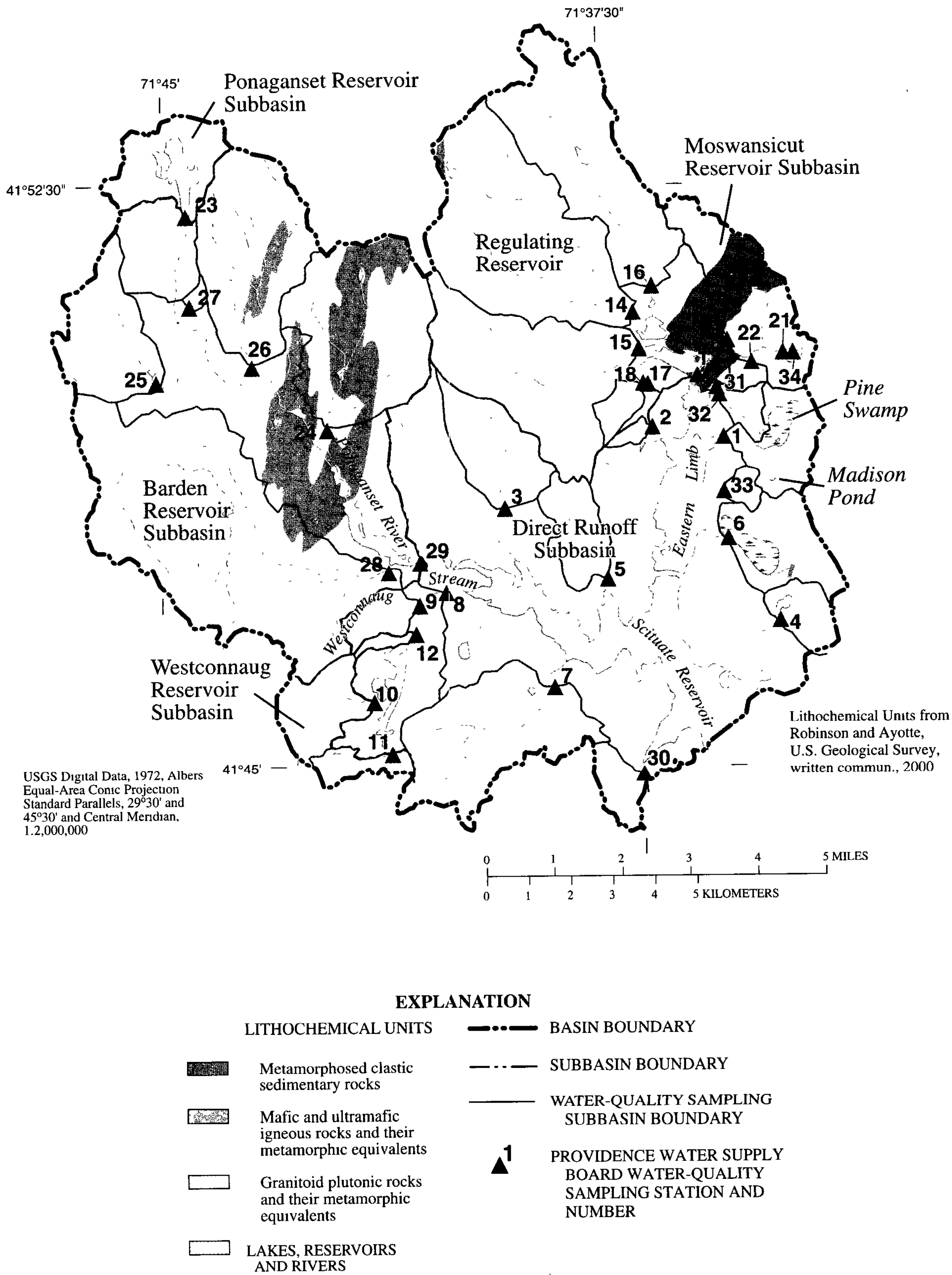
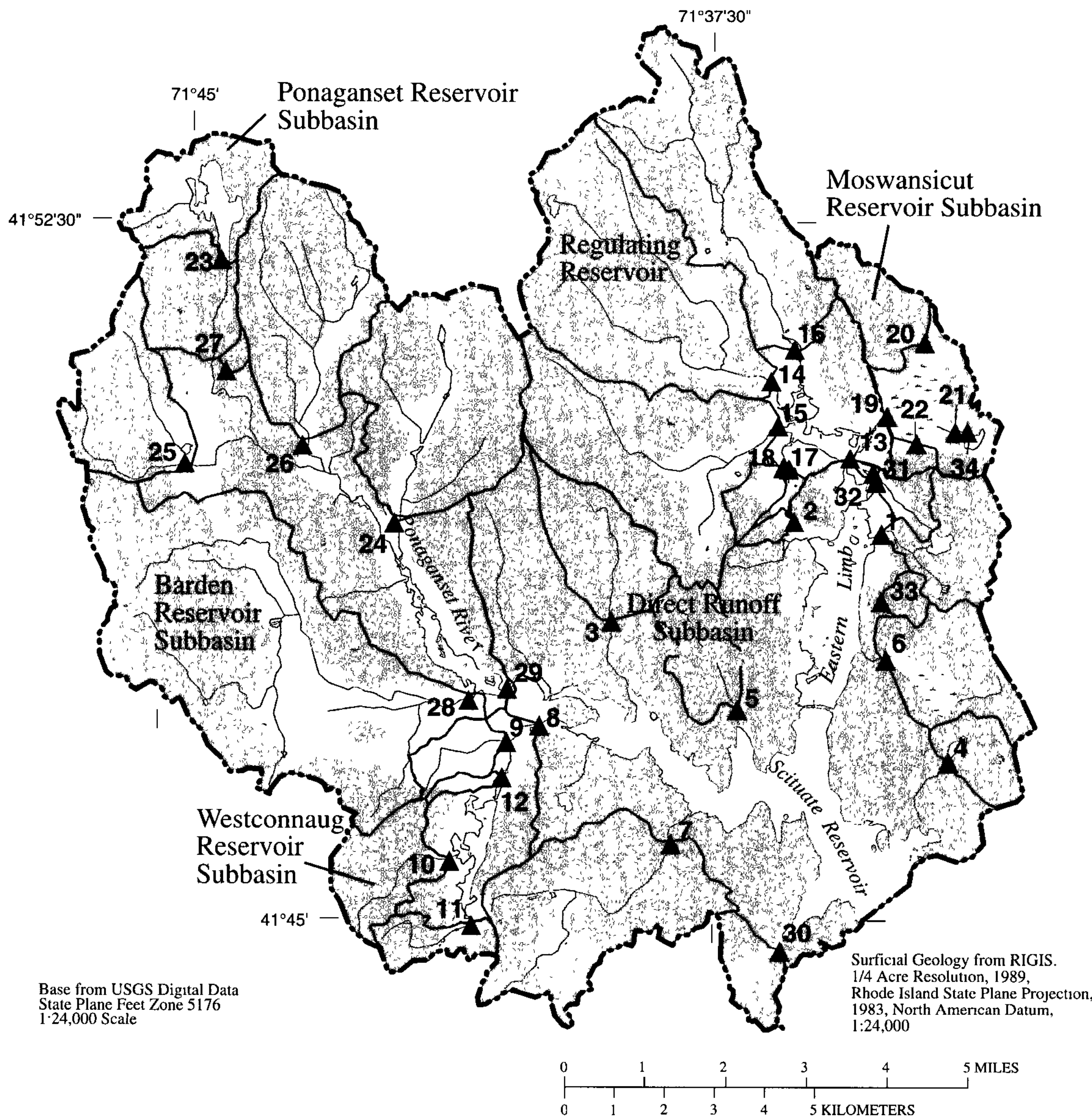


Figure 4. Distribution of lithochemical units in the Scituate Reservoir Basin, Rhode Island.



EXPLANATION

GLACIAL DEPOSITS

- Till and bedrock —includes nonsorted mixture of sand, silt, clay and boulders and bedrock outcrops
- Meltwater deposits—includes poor- to well-sorted sand and gravel
- LAKES, RESERVOIRS AND RIVERS

- BASIN BOUNDARY
- SUBBASIN BOUNDARY
- WATER-QUALITY SAMPLING SUBBASIN BOUNDARY
- ▲1 PROVIDENCE WATER SUPPLY BOARD WATER-QUALITY SAMPLING STATION AND NUMBER

Figure 5. Distribution of surface materials in the Scituate Reservoir Basin, Rhode Island.

DATA COMPILATION AND ANALYSIS

For more than 50 years, the PWSB has collected water-quality data at 34 water-quality sampling stations on streams tributary to the reservoirs in the Scituate Reservoir Basin (fig. 1, table 1). Properties and constituents that are monitored include pH, color, turbidity, total coliform bacteria, sodium, alkalinity, nitrate, nitrite, orthophosphate, iron, and manganese. The periods of record, sampling frequencies, and the constituent lists have varied considerably over the last 50 years. For example, data have been collected on an annual, quarterly, bimonthly, monthly, semi-monthly, or weekly basis depending on the property or constituent, the station, or the monitoring program in place during any given year. Most of these data have been published annually from 1945 to 1995 by the PWSB. Fifteen water-quality sampling stations were monitored monthly in 1945; additional stations were added as follows—7 in 1960, 8 in 1982, 1 in 1983, 2 in 1988, and 1 in 1989, bringing the total number of monitoring stations to 34 in 1995. The first constituents monitored in 1945 were pH, color, turbidity, total coliform bacteria, acidity, alkalinity, iron, and manganese. Additional constituents were added at various times—chloride and nitrate at 30 stations in 1982, nitrate at 31 stations in 1987, sodium at 30–33 stations from 1982 to 1995, and orthophosphorus at 9 stations from 1987 to 1991. Some water-quality data currently are available for 33 of the 34 sampling stations. No water-quality data are available for station 34.

In cooperation with the PWSB and the RIDEM, the USGS began collecting streamflow data at many of the PWSB water-quality sampling stations in 1993 and 1994. By 1995, streamflow data were being collected at 18 PWSB stations. Most of the sampling stations are partial-record stations where streamflow is measured about six times a year, and where a gage height and discharge relation is determined. PWSB station 16 (Peeptoad Brook) is a continuous-record streamflow station where streamflow is computed from automatically recorded gage heights. The USGS published these streamflow data in its annual data report (Socolow and others, 1996).

Limitations of Data Interpretation

During the past 50 years our understanding of how water-quality data are affected by environmental conditions and by the choice of sampling and analytical methods has increased markedly. For example, the value of implementing quality-assurance/quality-control (QA/QC) programs and documenting ancillary data (sampling and analytical methods) to determine if water-quality data are accurate and representative are better understood today. Historically, water-quality data were collected often without appropriate documentation or QA/QC programs, or both, making it difficult to determine if these data are representative and accurate.

Because documentation and QA/QC results do not exist for water-quality data collected by PWSB between 1982 and 1995, sample representativeness and accuracy could not be determined. Thus, the interpretations presented in this report are based on the following assumptions: (1) water-quality samples represent the environmental conditions at the time of sampling; (2) samples represent all environmental conditions (dry and wet weather); (3) sample collection and processing procedures used are not a source of contamination; and (4) accuracy, precision, and bias of laboratory analysis are within acceptable limits.

Instantaneous Load Estimation for Water-Quality Constituents

Instantaneous loads were computed for 5 of the 12 water-quality constituents for water year 1995 at sampling stations with suitable water-quality and streamflow data. Instantaneous loads of water-quality constituents were calculated by multiplying the water-quality constituent concentration on a particular day by the mean daily discharge for the same day. Because stream discharge was not measured each time the PWSB collected a water-quality sample, stream discharge was estimated. Discharge on the day of sampling was estimated using the Maintenance of Variance Extension type 1 method (MOVE.1; Hirsch and others, 1982).

Table 1. Providence Water Supply Board water-quality sampling stations by subbasin in the Scituate Reservoir Basin, Rhode Island

[PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey. Other identifying site name(s) shown in parentheses. PWSB station 34 and the ungaged stations have no water-quality data. No., number; mi^2, square mile]

USGS station No.	PWSB station No.	Site name	Drainage area (mi^2)
		Barden Reservoir Subbasin	
01115190	24	Dolly Cole Brook	5.01
01115200	25	Shippee Brook	2.39
01115185	26	Winsor Brook	4.22
011151845	27	Unnamed Tributary to Ponaganset River, (Unnamed Brook B, Unnamed Brook west of Winsor Brook)	.10
01115270	28	Barden Reservoir, (Hemlock Brook)	10.62
01115187	29	Ponaganset River, (Barden Stream)	[1]33.02
		Ungaged-A	3.69
		Ungaged-B	1.57
		Direct Runoff Subbasin(s)	
01115180	1	Brandy Brook	1.57
01115181	2	Unnamed Tributary #2 to Scituate Reservoir, (Brook, North of Bullhead Brook)	.15
01115280	3	Cork Brook	1.90
01115400	4	Kent Brook, (Betty Pond Stream)	.86
01115184	5	Spruce Brook	1.23
01115183	6	Quonapaug Brook	1.99
01115297	7	Wilbur Hollow Brook, (Wilbur Brook)	4.42
01115276	8	Westconnaug Brook, (Westconnaug Reservoir)	[2]5.10
01115275	9	Bear Tree Brook	.64
01115350	30	Unnamed Tributary #4 to Scituate Reservoir, (Coventry Brook, Knight Brook)	.74
01115177	31	Toad Pond	.04
01115178	32	Unnamed Tributary #1 to Scituate Reservoir, (Pine Swamp Brook)	.40
01115182	33	Unnamed Tributary #3 to Scituate Reservoir, (Hall's Estate Brook)	.27
		Ungaged-C	20.23
		Moswansicut Reservoir Subbasin	
01115170	19	Moswansicut Reservoir, (Moswansicut Stream North, Moswansicut Pond)	[3]3.20
01115160	20	Unnamed Tributary #1 to Moswansicut Reservoir, (Blanchard Brook)	1.21
01115165	21	Unnamed Tributary #2 to Moswansicut Reservoir, (Brook from Kimball Reservoir)	[4].32
01115167	22	Moswansicut Reservoir, (Moswansicut Stream South)	.22
01115164	34	Kimball Reservoir	.27
		Ponaganset Reservoir Subbasin	
011151843	23	Ponaganset Reservoir	1.86
		Regulating Reservoir Subbasin	
01115176	13	Regulating Reservoir	[5]22.17
01115110	14	Huntinghouse Brook	6.24
01115115	15	Regulating Reservoir, (Rush Brook)	4.98
01115098	16	Peeptoad Brook, (Harrisdale Brook)	4.92
01115119	17	Dexter Pond, (Paine Pond)	.13
01115120	18	Unnamed Tributary to Regulating Reservoir, (Unnamed Brook A)	[6].54
		Westconnaug Reservoir Subbasin	
01115274	10	Westconnaug Brook	1.37
01115273	11	Unnamed Tributary to Westconnaug Reservoir, (Unnamed Brook South of Westconnaug Reservoir)	.69
011152745	12	Unnamed Tributary to Westconnaug Brook, (Unnamed Brook north of Westconnaug Reservoir)	.15

[1]No 29 includes stations 23, 24, 25, 26, 27, 28, 29, A, and B.
[2]No. 8 includes stations 11, 8, 9, 10, and 12.
[3]No. 19 includes stations 19, 20, 21, 22, and 34.
[4]No. 21 includes stations 21 and 34.
[5]No. 13 includes stations 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, and 34.
[6]No 18 includes stations 17 and 18.

MOVE.1 correlates daily discharge at a station with limited records to discharge at a partial-record station with more extensive records (for example, USGS long-term streamflow-gaging stations). Once this correlation is determined, the record can be extrapolated to include the time of sampling. It is assumed in the method that the correlation remains constant through time.

Trend Analysis

Trends in concentrations of water-quality constituents can indicate long-term improvement or deterioration in water-quality, caused by various conditions within a stream's drainage basin. Trend tests were performed for nine constituents at 32 sampling stations in the Scituate Reservoir Basin for water years 1982–95. Trend analysis of water-quality-constituent data using the seasonal Kendall test was accomplished with an automated program developed by the USGS (Hirsch and others, 1982; Smith and others, 1982).

Two factors that limit the use of the seasonal Kendall test are (1) more than 10 percent of the measured concentrations are less than the minimum reporting limit for the analytical method used, or (2) streamflow is substantially controlled by human activities. As such, trends in nitrite, manganese, and orthophosphorus, were not calculated using the seasonal Kendall test because only a few concentrations of these constituents were detected. Trends at sampling station 29 were not calculated because discharge at this station is regulated.

Correlation Analysis

The quality of a natural water body often can be associated with different drainage-basin characteristics. To better understand the relative importance of drainage-basin characteristics to the quality of water, the relations between water-quality constituent concentrations and drainage-basin characteristics were investigated using linear correlation coefficients (Pearson's r values). A positive Pearson's r value indicates a direct relation between the characteristic and the constituent; a negative value indicates an inverse relation. Pearson r values greater than 0.71 or less than -0.71 were considered significant and indicates that a particular drainage-basin characteristic explains at least 50 percent of the variability in concentration of the given water-quality constituent.

Sources and Compilation of GIS Data

Drainage-basin characteristics (hydrologic, geologic, and geographic data) were obtained from the USGS and the statewide geographic information system (GIS) maintained by the University of Rhode Island. Thirty-six first-order and second-order drainage basins were delineated from 1:24,000 topographic maps and digitized to create a detailed drainage-basin coverage. Drainage-basin characteristics were either converted to a percentage of the watershed area, or normalized to the watershed area to allow comparability between watersheds of unequal size (table 6, at back of report).

The topographic information used in the analysis was based on Digital Elevation Models (DEMs) at 1:24,000 obtained from the USGS and Rhode Island GIS (RIGIS). The elevation data were converted in GIS to grids containing slope values, using the GRID module of ArcInfo GIS software. Six landscape slope characteristics (0–5, 5–10, 10–15, 15–20, 20–25, and more than 25 percent) were defined for each reservoir subbasin (table 6).

Lithochemical data were obtained from a lithographic analysis (Robinson, G.R., U.S. Geological Survey, written commun., 2000) of geologic units, as mapped from the bedrock geologic map of Rhode Island (Hermes and others, 1994). Lithochemical categories are an aggregation of bedrock types based on mineralogical composition and weathering characteristics. Three lithochemical categories are found in the Scituate Reservoir Basin: (1) metamorphose clastic sedimentary rocks, (2) mafic and ultramafic igneous rocks and their metamorphic equivalents, and (3) granitoid plutonic rocks and their metamorphic equivalents (table 6).

Soil information was based on the 1981 Rhode Island soil survey from the Natural Resource Conservation Service of the U.S. Department of Agriculture (formerly the Soil Conservation Service). The soils data were updated by RIGIS in 1989 using a mylar aerial overlay. The data were obtained in digital format from the RIGIS Web site. Six soil classes based on drainage characteristics were defined by the USGS: (1) excessively drained, (2) moderately well drained, (3) well drained, (4) variable, (5) poorly drained, and (6) very poorly drained (fig. 6; table 6).

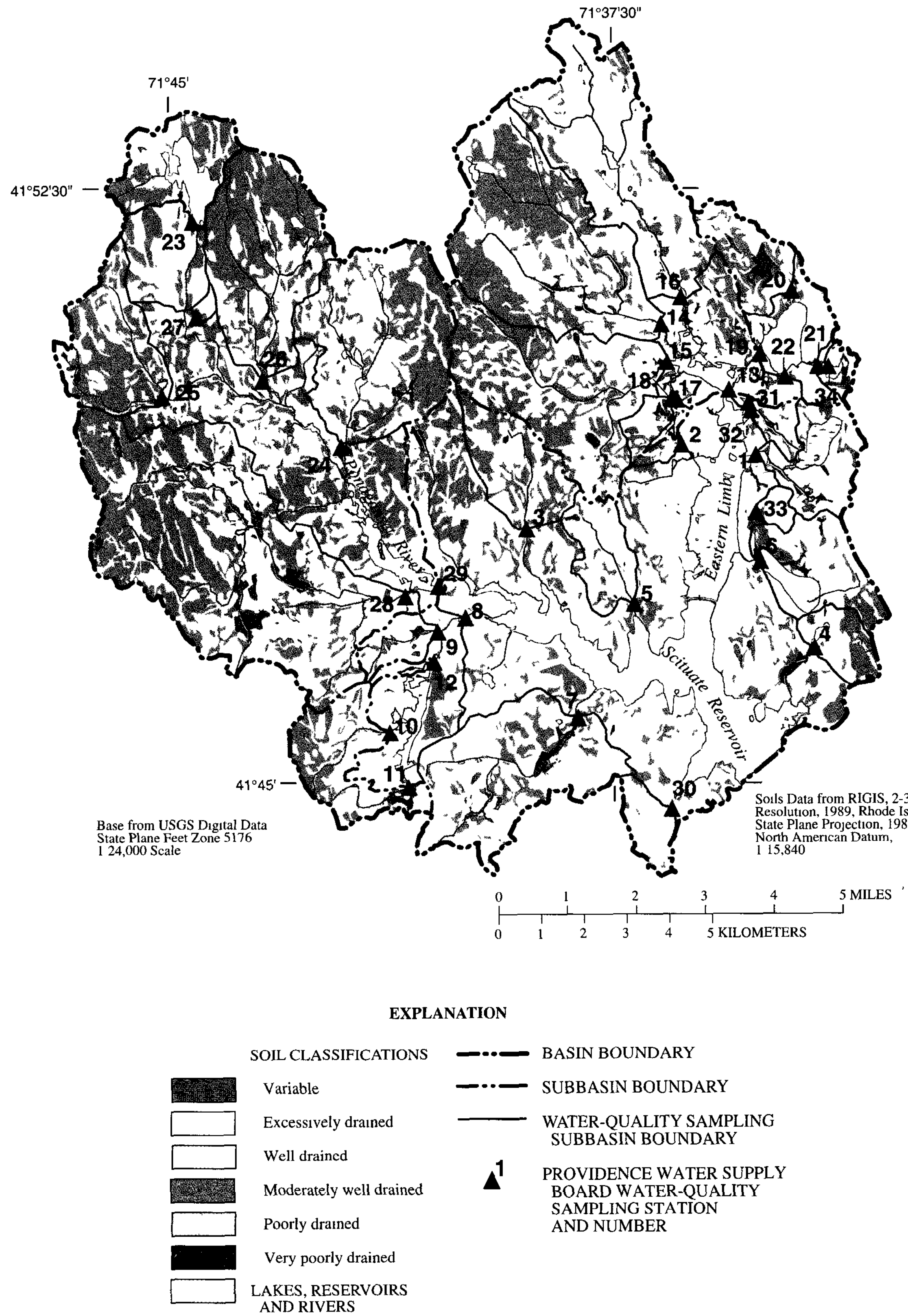
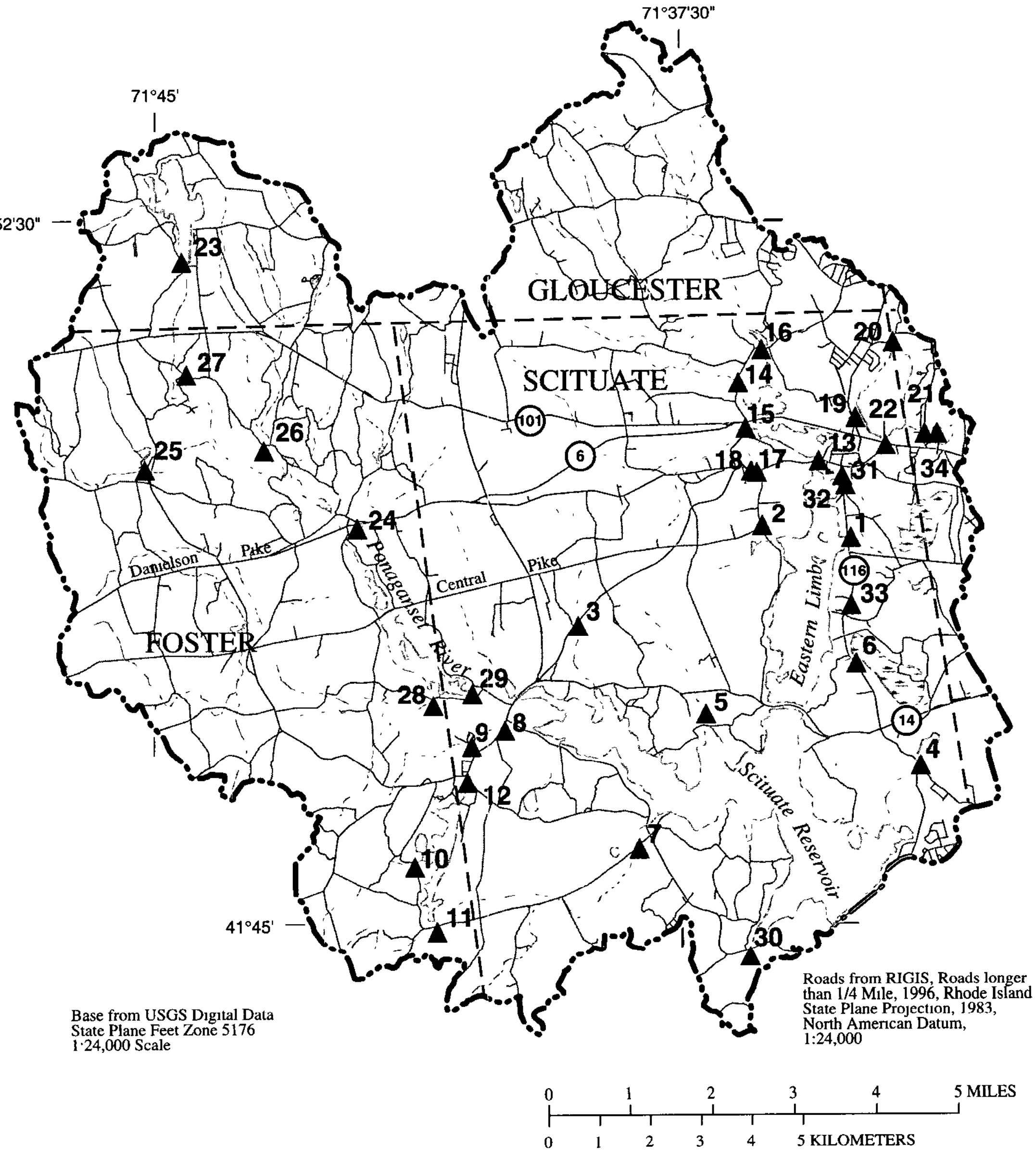


Figure 6. Distribution of soil types in the Scituate Reservoir Basin, Rhode Island.



EXPLANATION

LAKES, RESERVOIRS AND RIVERS

ROADS

Primary, including arterial and collector roads

Secondary, including local roads

BASIN BOUNDARY

PROVIDENCE WATER SUPPLY BOARD WATER-QUALITY SAMPLING STATION AND NUMBER

Figure 7. Distribution of primary and secondary roads in the Scituate Reservoir Basin, Rhode Island.

Land-use data were compiled at 1:250,000 in the 1970's and were updated in 1994 using population data (Hitt, 1994) to indicate new residential land use. The 17 land-use categories in this data layer were grouped into five broad land-use categories (urban, agricultural, mixed-forest land, wetland, and barren) based on Anderson and others (1976). Primary and secondary or local roads were measured from GIS coverages based on USGS 1:24,000 topographic maps and Rhode Island Department of Transportation county maps (fig. 7; table 6).

In addition to wetland data provided by the land-use coverage, wetland data provided by RIGIS were identified from 1:24,000 black and white aerial photographs and then manually transferred onto mylar sheets and digitized by the RIDEM Water Resources Division. Three wetland types in the basin were defined: nonforested (marsh/wet meadow, emergent fen or bog, shrub swamp, shrub fen or bog); forested wetlands (coniferous-forested wetland, deciduous-forested wetland, and wetlands with standing dead trees); and total wetlands.

WATER-QUALITY CONDITIONS IN THE SCITUATE RESERVOIR BASIN

The following discussion of water quality in the Scituate Reservoir Basin is organized by tributary reservoir subbasins. Summary statistics are shown for selected water-quality constituents by sampling station and by tributary subbasin (fig. 8). The constituents include pH, color, turbidity, bacteria, sodium, alkalinity, chloride, nitrate, nitrite, orthophosphate, iron, and manganese. The data (table 2) are reported in standard units, colony forming units per 100 milliliters (CFU/100 mL), platinum cobalt units (PCU), nephelometric turbidity units (NTUs), and milligrams per liter (mg/L).

Concentrations of these water-quality constituents appear to be primarily controlled by the geographic distribution of drainage-basin characteristics, including point and nonpoint contaminant sources, and by complex biological, chemical, and physical processes that take place in the drainage basin. Median concentrations for most constituents generally are similar with the exception of those measured in samples collected from the Moswansicut Reservoir subbasin. Concentrations of pH, turbidity, total coliform bacteria, alkalinity, chloride, nitrate, sodium, and iron generally are larger in samples collected from the Moswansicut Reservoir subbasin, which has the largest percentage of residential land use, compared to the other subbasins. Concentrations were probably high in this largely residential drainage basin because the large number of nonpoint and point sources. Conversely, the other subbasins are predominantly forested and had smaller median concentrations of selected water-quality constituents, as major point and nonpoint sources are not likely to be present.

Instantaneous loads reflect subbasin characteristics and size (fig. 9; table 3). Generally, within lightly developed (less than 1 percent residential land use) and heavily forested (greater than 95 percent mixed forest land use) subbasins, median instantaneous loads are largely a function of drainage area. For example, median instantaneous loads are among the smallest for sampling stations 18, 30, and 33 with the smallest drainage areas (0.54, 0.74 and 0.27 mi^2, respectively), whereas median instantaneous loads are among the largest for sampling stations 7, 8, 14 and 29 that drain the largest (4.4, 5.1, 6.2, and 33 mi^2, respectively) of the lightly developed and heavily forested subbasins.

To compare the results among subbasins of different sizes, it is useful to normalize median instantaneous load values to subbasin area. This produces median instantaneous yields,which allow for comparisons to be made among subbasins (table 3). It appears that yields were generally largest in residential areas where point and non-point sources are likely, and in areas of poorly drained soils.

Barden Reservoir Subbasin

With the exception of manganese (0.02 mg/L), the median values for the water-quality constituents sampled from the Barden Reservoir subbasin were generally among the smallest in the Scituate Reservoir Basin; manganese concentrations were among the largest (table 2). The largest median instantaneous iron (9.9 kg/d) and manganese load (2.3 kg/d) were calculated for station 29 (Ponaganset River). Median instantaneous yields were among the smallest for all of the water-quality constituents for which yields were calculated from the Barden Reservoir subbasin (table 3). These results in combination with the relatively large size of the drainage basin (33 mi^2) indicate that relatively large loads of total coliform bacteria, chloride, iron, and manganese are entering the Barden Reservoir from the subbasin, and perhaps the

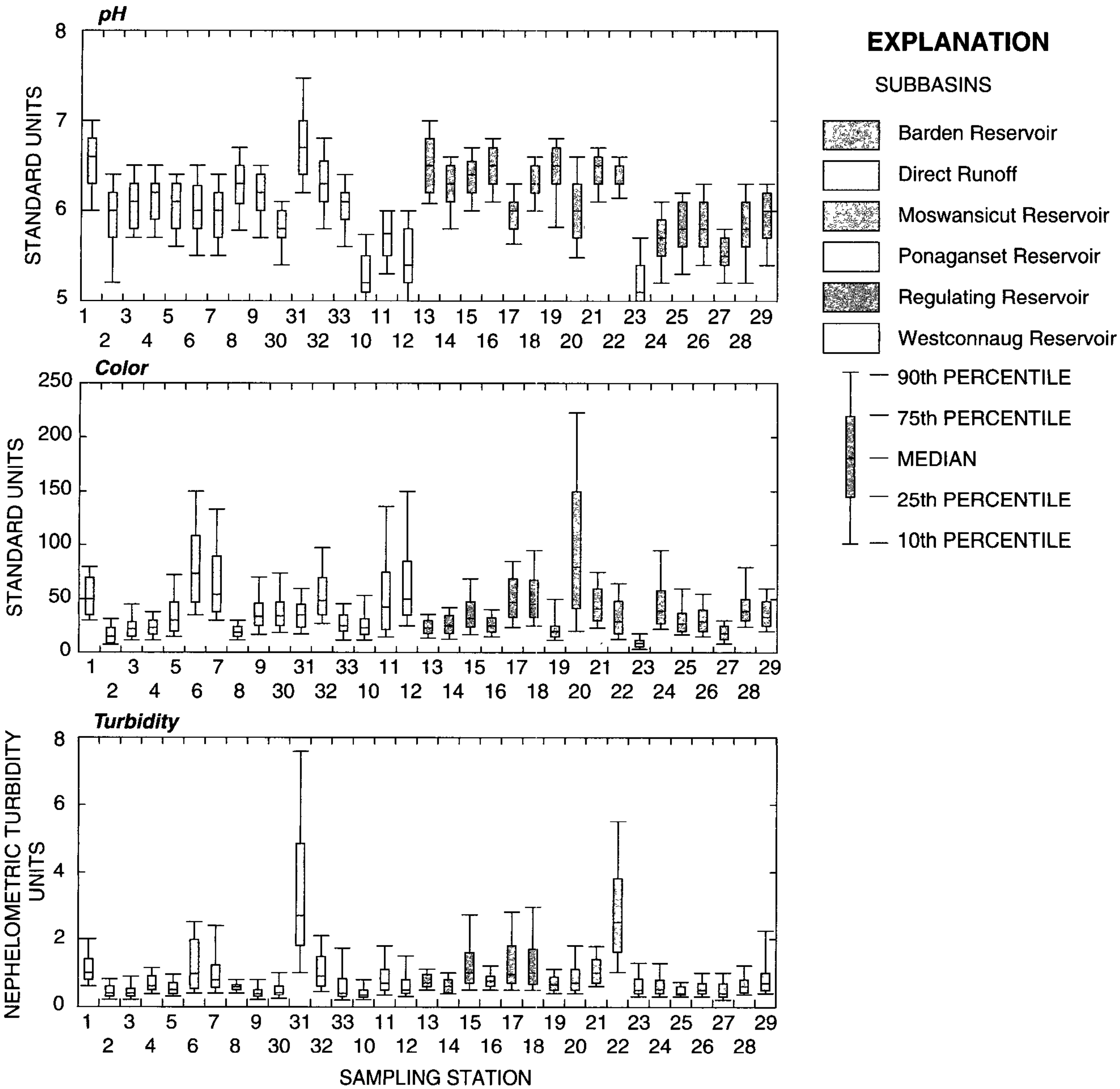


Figure 8. Summary statistics of water-quality constituents by sampling station and by tributary subbasin, Scituate Reservoir Basin, Rhode Island.

Scituate Reservoir, however, these loads are not disproportionately large; that is, they are in keeping with the size of the drainage basin.

Direct Runoff Subbasins

Median concentrations of nitrate (0.1 mg/L as N) are among the largest for samples collected from the Direct Runoff subbasins (table 3) whereas iron (0.14 mg/L) and manganese (0.01 mg/L) were among the smallest. Median values for pH (6.7), turbidity (2.7 NTU), and alkalinity (15 mg/L as $CaCO_3$) at station 31(Toad Pond) were the largest in the study area. Dissolution, precipitation, and the oxidation of solid materials are potential sources of alkalinity, pH, and turbidity to Toad Pond. These solid materials may enter the water through road runoff, erosion, or the breaking up of organic debris. The only surface

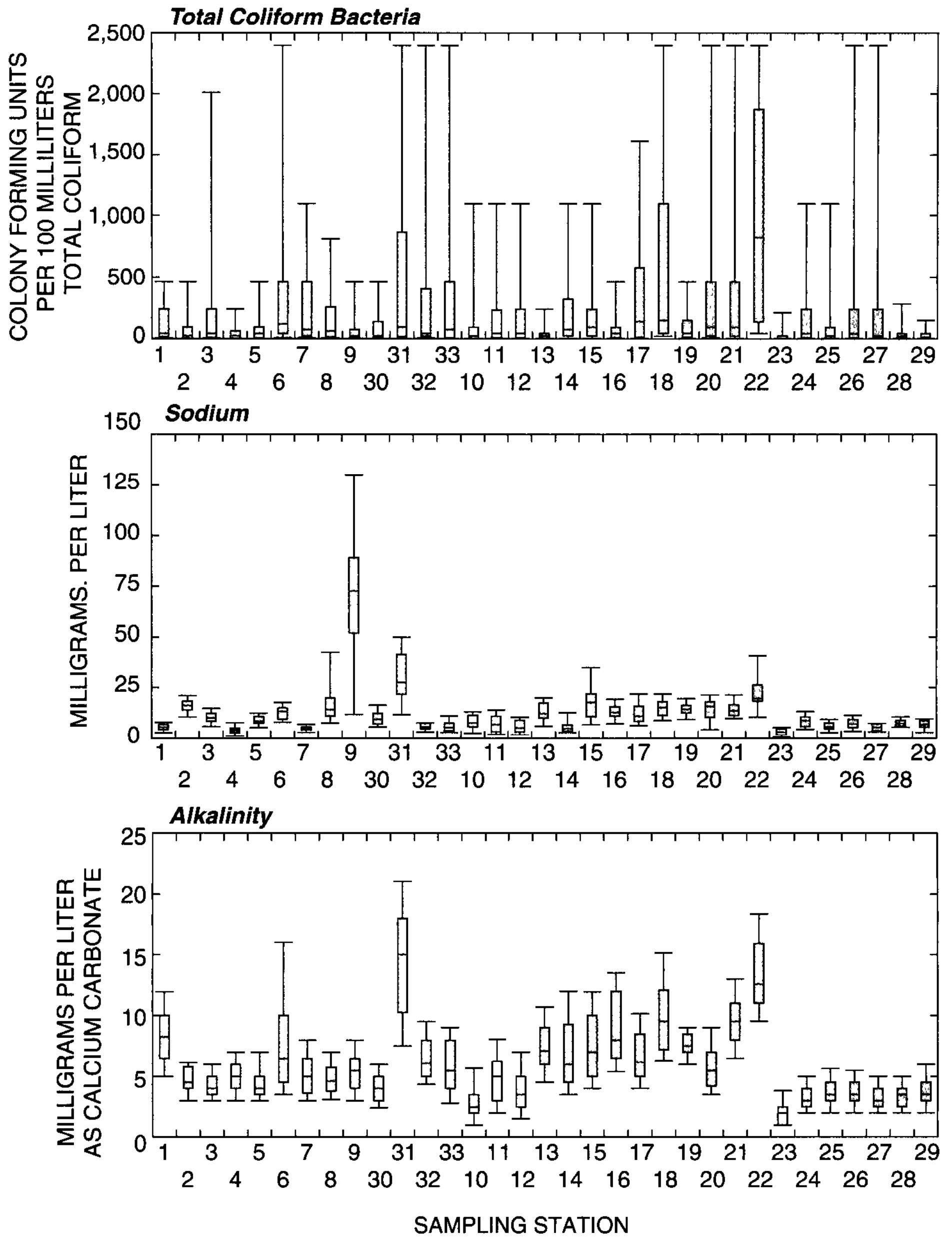


Figure 8. Summary statistics of water-quality constituents by sampling station and by tributary subbasin, Scituate Reservoir Basin, Rhode Island—*Continued.*

inflow to Toad Pond is a storm drain that drains urban runoff. The maximum median concentrations of sodium (73 mg/L) and chloride (110 mg/L) were the largest in the study area at station 9 (Bear Tree Brook), which drains a small subbasin (0.64 mi^2). The most likely source of chloride in this subbasin is ground-water contamination or runoff from the RIDOT's Clayville salt (sodium chloride) storage facility.

The largest median instantaneous total coliform bacteria (7,800 CFU/d) and nitrate (2.0 kg/d) loads were calculated for stations 7 (Wilbur Hollow Brook) and 8 (Westconnaug Brook), respectively. The median instantaneous yields for total coliform bacteria (1,500 CFU/d), chloride (55 kg/d), nitrate (0.42 kg/d), iron (0.9 kg/d), and manganese (0.15 kg/d) sampled from the Direct Runoff subbasins were among the largest in the study area. In particular, the median iron

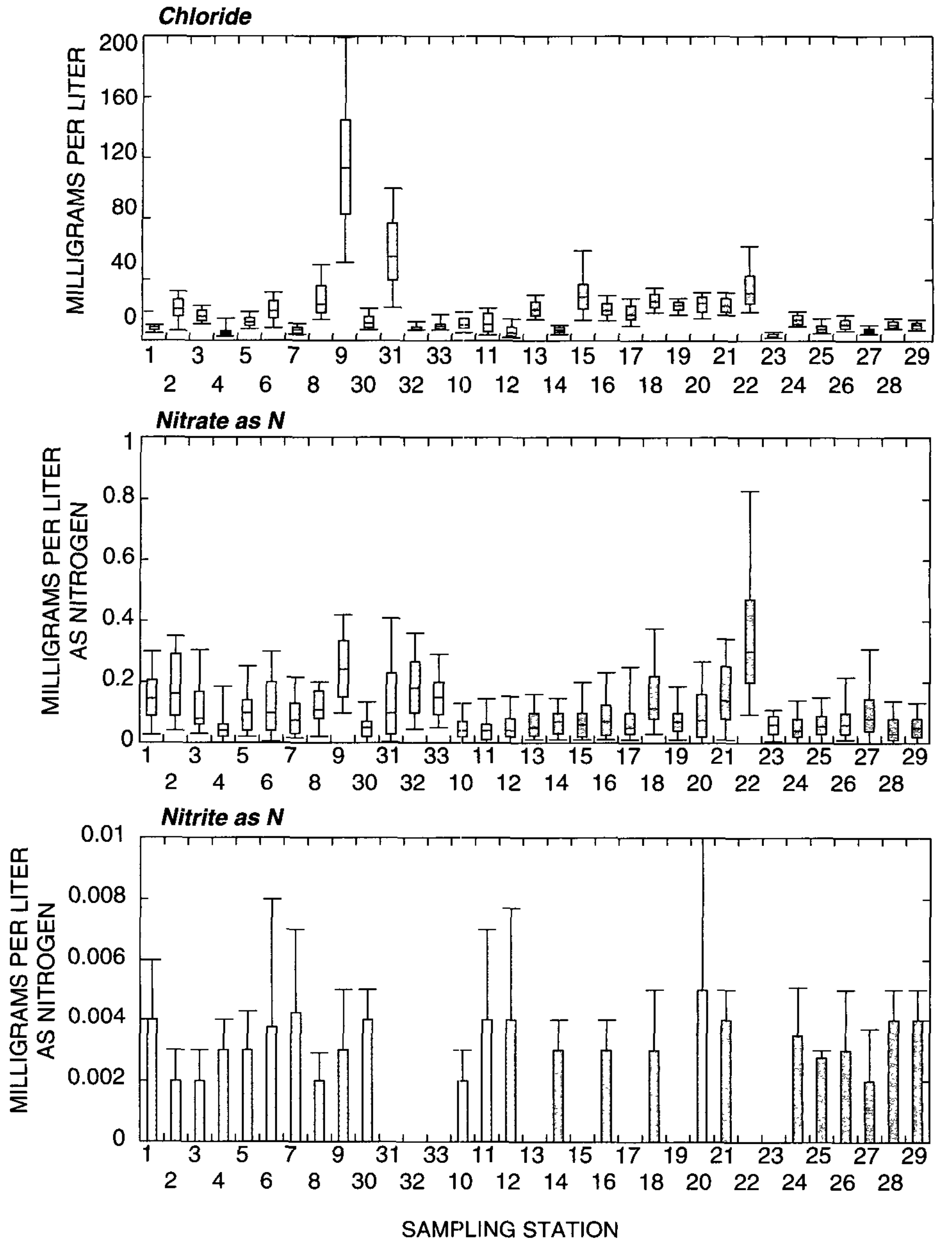


Figure 8. Summary statistics of water-quality constituents by sampling station and by tributary subbasin, Scituate Reservoir Basin, Rhode Island—*Continued.*

(1.4 kg/d/mi^2) and manganese (0.27 kg/d/mi^2) yields were largest at station 5 (Spruce Brook). Median chloride yield (220 kg/d/mi^2) was largest at station 9 (Bear Tree Brook). These results in combination with the relatively large size of the drainage basin (37 mi^2) indicates that relatively large loads of total coliform bacteria, chloride, nitrate, iron, and manganese are entering the Scituate Reservoir, and, these loads are disproportionately large in terms of drainage-basin size.

Moswansicut Reservoir Subbasin

During 1982–95, the median values of pH (6.5), turbidity (0.85 NTU), total coliform bacteria (93 CFU/100mL), sodium (15 mg/l), alkalinity (8.5 mg/L as $CaCO_3$), chloride (24 mg/L), nitrate (0.11 mg/L as N), orthophosphate (0.03 mg/L as P), and iron (0.28 mg/L) were largest in samples collected from the Moswansicut Reservoir subbasin. The median color (35 PCU) value also was relatively large in

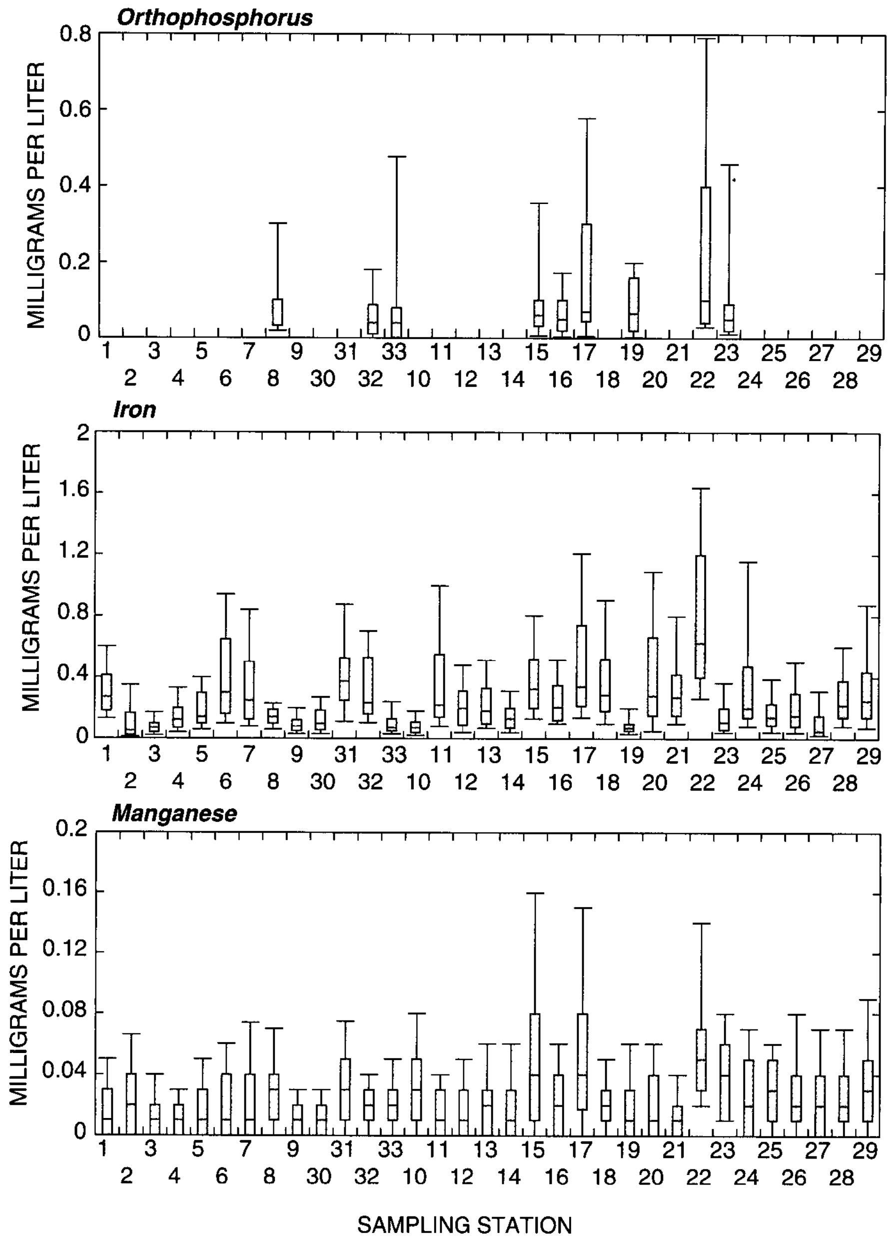


Figure 8. Summary statistics of water-quality constituents by sampling station and by tributary subbasin, Scituate Reservoir Basin, Rhode Island—*Continued.*

samples collected from this subbasin. This indicates that, in general, water-quality at the sampled sites in this subbasin was affected by these selected water-quality constituents more so than in the other subbasins. The median manganese concentration (0.01 mg/L) for Moswansicut Reservoir subbasin was among the smallest. Water-quality sampling station 20 (Unnamed tributary #1 to Blanchard Brook) had the largest median values for color (80 PCU); about 20 percent of the Blanchard Brook subbasin is classified as forested wetlands. In addition, median values for total coliform bacteria (820 CFU/100 mL), nitrate (0.3 mg/L as N), orthophosphorus (0.1 mg/L as P), iron (0.63 mg/L) and manganese (0.05 mg/L) were largest at sampling station 22 (Moswansicut Stream South). A potential source of total coliform bacteria, nitrate, and orthophosphorus to Moswansicut Stream South is the year-round residency of at least a dozen ducks and

Table 2. Median values for water-quality data collected at Providence Water Supply Board sampling stations in the Scituate Reservoir Basin, Rhode Island, October 1982 to June 1995

[PWSB, Providence Water Supply Board; CFU, colony forming units; No., number; NTU, nephelometric turbidity units; PCU, platinum cobalt units, mg/L, milligrams per liter; <, actual value is less than detection value. All median nitrite values are less than detection value (0.01 mg/L).]

PWSB station No.	pH	Color (PCU)	Turbidity (NTU)	Total coliform bacteria (CFU/ 100 mL)	Sodium (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Chloride (mg/L)	Nitrate (mg/L as N)	Ortho-phosphate (mg/L as P)	Iron (mg/L)	Manganese (mg/L)
Barden Reservoir Subbasin											
24	5.7	39	0.50	43	8.8	3	14	0.04	< 0.01	0.20	0.02
25	5.8	27	.40	23	5.7	4	8.0	.1	< .01	.14	.03
26	5.8	29	.50	43	7.1	4	11	.1	< .01	.15	.02
27	5.5	18	.40	23	5.5	3	7.0	.1	< .01	.05	.02
28	5.8	39	.60	21	7.4	4	11	.03	< .01	.22	.02
29	6.0	33	.70	15	6.8	4	11	.1	< .01	.25	.03
Subbasin median	5.8	31	0.51	23	6.9	4	11	.05	< .01	0.18	0.02
Direct Runoff Subbasin(s)											
1	6.6	50	1.0	43	5.4	8	8.0	0.20	< 0.01	0.27	0.01
2	6.0	15	.40	23	16	5	21	.20	< .01	.05	.02
3	6.1	22	.40	43	10	4	16	.10	< .01	.07	.01
4	6.2	23	.60	23	4.0	5	5.0	.04	< .01	.12	.00
5	6.1	30	.50	43	8.3	4	12.0	.10	< .01	.14	.01
6	6.0	75	.95	120	13	7	20	.10	< .01	.30	.01
7	6.0	55	.80	75	4.8	5	7.0	.10	< .01	.25	.01
8	6.3	19	.60	62	14	5	24	.11	.10	.14	.03
9	6.2	34	.40	23	73	6	110	.24	< .01	.08	.01
30	5.8	34	.40	23	9.3	4	12	.10	< .01	.10	.01
31	6.7	35	2.7	93	28	15	55	.10	< .01	.38	.03
32	6.3	49	.90	43	5.6	6	9.0	.20	.04	.24	.02
33	6.1	25	.40	75	5.4	6	10	.20	.04	.07	.02
Subbasin median	6.1	34	0.58	43	9.3	5	12	0.1	<0.01	0.14	0.01

nonresident geese that frequent a small, mill pond that drains into Moswansicut Stream South (Station 22). Additionally, the stream receives water that drains from one of the most densely residential areas (29.1 percent) with a modest percentage of very poorly drained soils (4.4 percent).

Median instantaneous yields for total coliform bacteria (1,800 CFU/d/mi^2), chloride (120 kg/d/mi^2), and iron (0.95 kg/d/mi^2) from the Moswansicut Reservoir subbasin were the largest; nitrate (0.40 kg/d/mi^2) was among the largest. In particular, station 21 had the largest median total coliform bacteria (4,600 CFU/d/mi^2) and nitrate (1.2 kg/d/mi^2) yields of all stations sampled. The relatively small drainage basin size (3.2 mi^2) and high yields calculated for the Moswansicut Reservoir subbasin compared to the other subbasins suggests that the Moswansicut Reservoir subbasin is not contributing a significant amount of the selected water-quality constituents to the Moswansicut Reservoir, and perhaps ultimately to the Scituate Reservoir, but is producing a disproportionate amount of the selected water-quality constituents in terms of drainage-basin size.

Ponaganset Reservoir Subbasin

With the exception of orthophosphorus and manganese median concentrations of the other water-quality constituents were the smallest in samples collected from the Ponaganset Reservoir subbasin; median

Table 2. Median values for water-quality data collected at Providence Water Supply Board sampling stations in the Scituate Reservoir Basin, Rhode Island, October 1982 to June 1995—*Continued*

PWSB station No.	pH	Color (PCU)	Turbidity (NTU)	Total coliform bacteria (CFU/ 100 mL)	Sodium (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Chloride (mg/L)	Nitrate (mg/L as N)	Ortho-phosphate (mg/L as P)	Iron (mg/L)	Manganese (mg/L)
Moswansicut Reservoir Subbasin											
19	6.5	20	0.65	43	14	8	24	0.10	0.07	0.07	0.01
20	6.0	80	.70	93	16	6	25	.08	<.01	.28	.01
21	6.5	41	1.0	93	14	10	23	.14	<.01	.27	.01
22	6.5	29	2.5	820	20	13	32	.30	.10	.63	.05
Subbasin median	6.5	35	0.85	93	15	9	24	0.11	0.03	0.28	0.01
Ponaganset Reservoir Subbasin											
23	5.1	9	0.50	4	3.2	2	4.0	0.10	0.05	0.11	0.04
Subbasin median	5.1	9	0.50	4	3.2	2	4.0	0.10	0.05	0.11	0.04
Regulating Reservoir Subbasin											
13	6.5	23	0.70	23	12	7.	21	0.10	<0.01	0.18	0.02
14	6.3	25	.60	75	5.0	6	7.0	.10	<.01	.13	.01
15	6.4	32	1.00	93	18	7	29	.10	.06	.33	.04
16	6.5	25	.75	43	13	8	20	.10	.05	.21	.02
17	6.0	47	.95	142	11	6	18	.10	.07	.34	.04
18	6.3	45	1.0	150	15	10	26	.12	<.01	.29	.02
Subbasin median	6.4	29	0.86	84	13	7	20	0.07	0.03	0.25	0.02
Westconnaug Reservoir Subbasin											
10	5.2	23	0.30	23	7.7	3	11	0.04	<0.01	0.07	0.03
11	5.8	43	.70	43	7.0	5	11	.04	<.01	.22	.01
12	5.4	50	.50	43	5.2	4	5.0	.04	<.01	.20	.01
Subbasin median	5.4	43	0.50	43	7.0	4	11	0.04	<0.01	0.20	0.02
Scituate Reservoir Basin											
Basin median	6.1	32	0.6	43	8.9	5	12	0.07	<0.01	0.20	0.02

orthophosphorus concentrations (0.05 mg/L as P) and median manganese concentrations (0.04 mg/L) were larger in this subbasin than in all the other subbasins in the study area. Sources of phosphorus and manganese to station 23 may include water released from the Ponaganset Reservoir hypolimnion. "During the summer, the upper water becomes warmer and slightly less dense than the deeper water. As a result, only the water in the warm upper layer (epilimnion) circulates in contact with the atmosphere, whereas greater density keeps the deep, colder layer of water (hypolimnion) away from the surface. In the absence of sufficient light for photosynthesis, oxygen that was present in the hypolimnion when the reservoir became thermally stratified is consumed by the respiratory activity of bacteria and other organisms that degrade organic matter from the upper layer" (Colman, 1998). This elimination of oxygen in the hypolimnion is associated with the release of phosphorus and manganese from iron and manganese complexes. A culvert at the base of

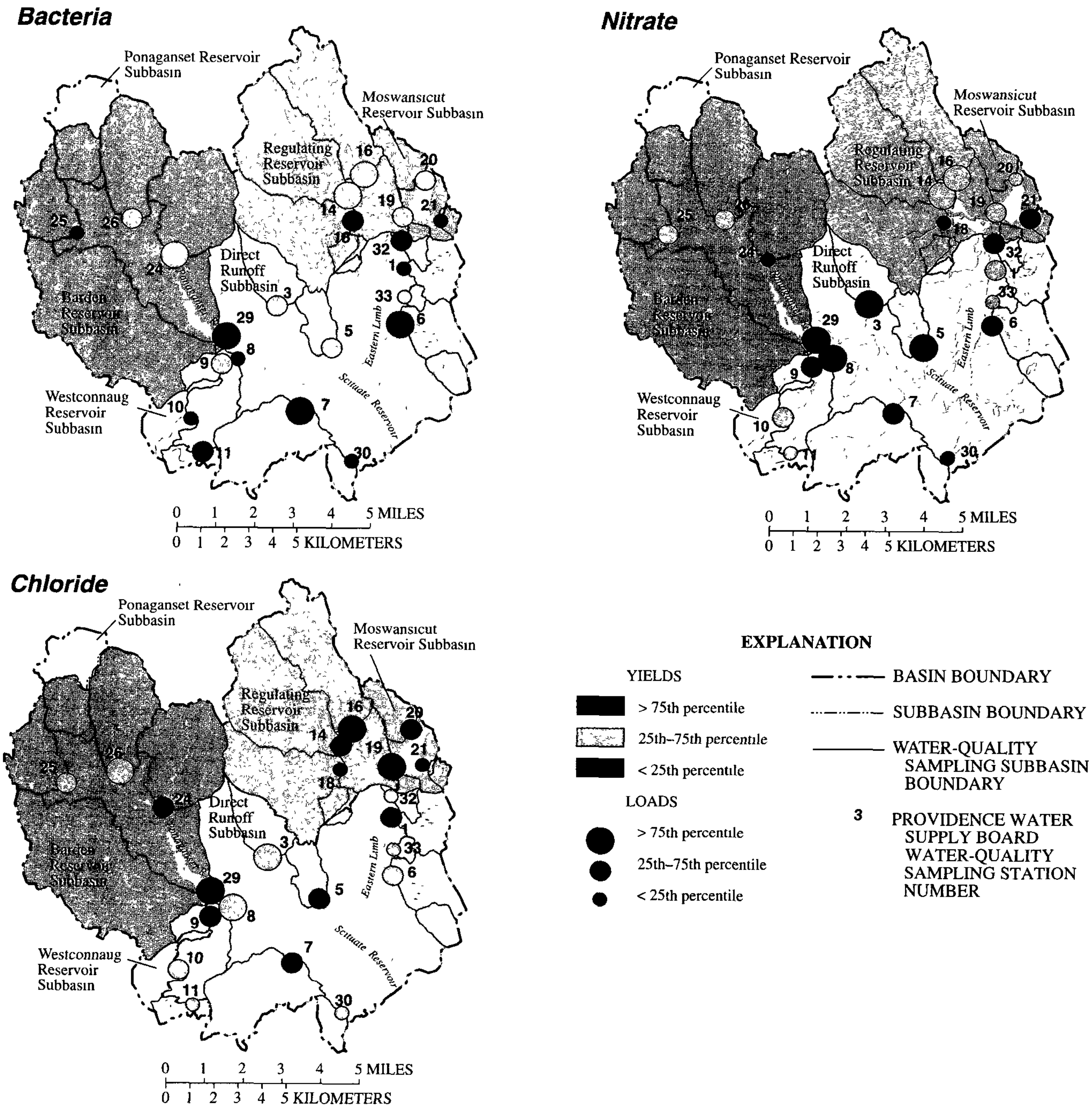


Figure 9. Areal distribution of median instantaneous loads and yields for selected water-quality constituents, October 1994–September 1995, Scituate Reservoir Basin, Rhode Island.

the dam allows this hypolimnetic water, with high concentrations of manganese and phosphorus, to be released directly into the Ponaganset River. Flow data at the sampling station draining the Ponaganset Reservoir (station 23) were not suitable for load and yield analysis for water year 1995.

Regulating Reservoir Subbasin

Median concentrations of pH (6.4), turbidity (0.86 NTU), total coliform bacteria (84 CFU/100 mL), sodium (13 mg/L), alkalinity (7 mg/L as $CaCO_3$), chloride (20 mg/L), iron (0.25 mg/L), and manganese

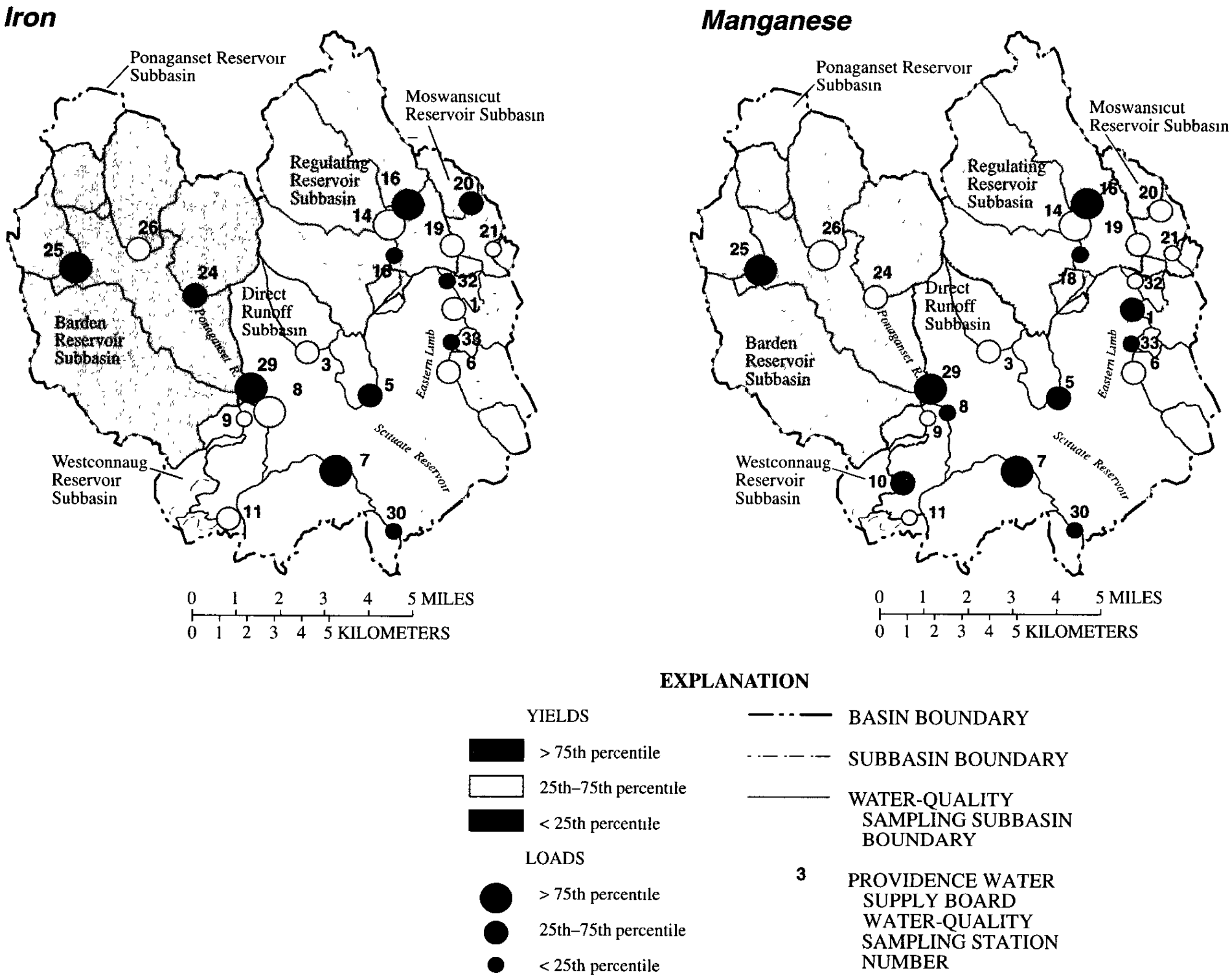


Figure 9. Areal distribution of median instantaneous loads and yields for selected water-quality constituents, October 1994–September 1995, Scituate Reservoir Basin, Rhode Island—*Continued.*

(0.02 mg/L) were among the largest in samples collected from the Regulating Reservoir subbasin. Median concentration of color (28.5) was among the lowest from the subbasin.

Median instantaneous nitrate (2.0 kg/d) and chloride (460 kg/d) loads were largest from samples collected from stations 14 (Huntinghouse Brook) and 16 (Peeptoad Brook), respectively. Median instantaneous yields of all of the water-quality constituents were about average from Regulating Reservoir Subbasin compared to the other tributary reservoir subbasins. These results in combination with the average size of the Regulating Reservoir subbasin (22 mi^2) indicates that loads and yields of the water-quality constitutes entering the Regulating Reservoir and perhaps the Scituate Reservoir are about average and only slightly disproportionately large in terms of drainage-basin size.

Westconnaug Reservoir Subbasin

Median concentrations of pH (5.4), turbidity (0.5 NTU), sodium (7.0 mg/L), alkalinity (4 mg/L as $CaCO_3$), chloride (11 mg/L), and manganese (0.02 mg/L) were among the smallest in samples collected from this subbasin. Median concentration of nitrate (0.04 mg/L as N) and orthophosphorus (less than the detection limit) also were the smallest in this subbasin. In contrast, the median color (43 PCU) value was among the largest.

Table 3. Median and total instantaneous loads and yields, by tributary reservoir subbasin, in the Scituate Reservoir Basin, Rhode Island, October 1, 1994—September 30, 1995

[CFU/d, colony forming units per day; No , number; PWSB, Providence Water Supply Board; Subbasin sum is the sum of the subbasin loads entering directly into the tributary reservoir. CFU/d/mi², colony forming units per day per square mile; ft³/s, cubic foot per second; kg/d, kilogram per day; kg/d/mi², kilogram per day per square mile;--, data not suitable for estimation of instantaneous load and yield]

PWSB station No.	Area (mi²)	Mean daily discharge (ft³/s)	Total coliform bacteria		Chloride		Nitrate as N		Iron		Manganese	
			Load (CFU/d x 10⁶)	Yield (CFU/d/mi² x 10⁶)	Load (kg/d)	Yield (kg/d/mi²)	Load (kg/d)	Yield (kg/d/mi²)	Load (kg/d)	Yield (kg/d/mi²)	Load (kg/d)	Yield (kg/d/mi²)
Barden Reservoir Subbasin												
24	5	2.7	3,600	730	130	26	0.25	0.05	1.8	0.35	0.41	0.08
25	2.4	5.0	500	210	110	46	.38	.16	2.5	1.1	.5	.21
26	4.2	8.8	2,500	590	240	56	.72	.17	2.2	.51	.46	.11
29	33.0	19	3,000	91	450	14	1.8	.05	9.9	.3	2.3	.07
Subbasin total[1]			6,600	570	470	40	1.4	0.12	6.4	0.55	1.4	0.12
Direct Runoff Subbasin(s)												
1	1.6	1.8	720	460	39	25	0.59	0.37	1.3	0.81	0.11	0.07
3	1.9		2,400	1,300	163	86	1.6	.85	1.0	.54	.34	.18
5	1.2	3.7	780	630	110	90	.82	.67	1.8	1.4	.33	.27
6	2.0	2.6	5,700	2,900	113	57	.80	.40	1.3	.67	.24	.12
7	4.4	7.0	7,800	1,800	110	25	.62	.14	5.7	1.3	.8	.17
8	5.1	5.2	580	110	170	33	2.0	.39	2.3	.46	.3	.06
9	.64	.91	750	1,200	140	220	.61	.96	.33	.51	.06	.1
30	.74	1.0	250	330	26	35	.11	.15	.19	.26	.04	.06
32	.4	.52	1,200	2,900	23	57	.26	.66	.17	.42	.07	.16
33	.27	.23	280	1,000	7.2	27	.08	.28	.08	.30	.02	.07
Subbasin total[2]			20,000	1,500	740	56	5.5	0.42	12	0.90	2.0	0.15

Table 3. Median and total instantaneous loads and yields, by tributary reservoir subbasin, in the Scituate Reservoir Basin, Rhode Island, October 1, 1994—September 30, 1995—*Continued*

PWSB station No.	Area (mi^2)	Mean daily discharge (ft^3/s)	Total coliform bacteria Load (CFU/d x 10^6)	Total coliform bacteria Yield (CFU/d/mi^2 x 10^6)	Chloride Load (kg/d)	Chloride Yield (kg/d/mi^2)	Nitrate as N Load (kg/d)	Nitrate as N Yield (kg/d/mi^2)	Iron Load (kg/d)	Iron Yield (kg/d/mi^2)	Manganese Load (kg/d)	Manganese Yield (kg/d/mi^2)
Moswansicut Reservoir Subbasin												
19	3.2	4.7	1,800	560	360	110	0.72	0.22	1.6	0.5	0.40	0.12
20	1.2	1.4	1,300	1,100	150	130	.23	.19	1.2	1.0	.14	.11
21	.32	.47	1,500	4,600	28	88	.39	1.2	.22	.70	.03	.10
Subbasin total[3]			2,800	1,800	180	120	.62	0.4	1.5	0.95	0.17	0.11
Regulating Reservoir Subbasin												
14	6.2	10	6,500	1,000	150	24	2.0	0.31	2.9	0.47	0.53	0.08
16	5.0	6.5	5,100	1,000	460	94	1.8	.37	5.4	1.1	.90	.18
18	.54	.11	1,700	3,100	12	21	.04	.07	.07	.13	.01	.02
Subbasin total[4]			13,000	1,100	619	53	3.8	0.32	8.4	0.72	1.4	0.12
Westconnaug Reservoir Subbasin												
10	1.4	2.5	560	400	76	56	0.32	0.24	--	--	0.25	0.18
11	.69	1.4	1,000	1,500	21	30	.16	.23	0.48	0.70	.07	.09
Subbasin total[5]			1,600	760	97	47	0.5	0.24	0.48	0.24	0.32	0.15

[1] Sum of stations 24, 25, and 26.

[2] Sum of stations 1, 3, 5, 6, 7, 9, 30, 32, and 33.

[3] Sum of stations 20 and 21.

[4] Sum of stations 14, 16, and 18.

[5] Sum of stations 11 and 10.

The median instantaneous loads and yields of many of the selected water-quality constituents sampled from the Westconnaug Reservoir subbasin were among the smallest compared to the other subbasins, except for manganese yield (0.15 kg/d/mi^2) that was among the largest. These results may be due partly to the smaller size of the subbasin and partly to the dominance of forestland cover (99.7 percent). These results indicate that generally the Westconnaug Reservoir subbasin is contributing a small amount of total coliform bacteria, chloride, nitrate, iron, and manganese in terms of both loads and yields to Westconnaug Reservoir, and perhaps ultimately to the Scituate Reservoir, compared to the other tributary subbasins.

TRENDS IN SELECTED WATER-QUALITY CONSTITUENT CONCENTRATIONS

It is important to note that changes in sampling or analytical methods, trends in streamwater discharge, and human uses of land and water resources may have affected the detected trends in water-quality constituents in the Scituate Reservoir Basin. Determining the magnitudes of these factors for specific drainage basins and water-quality constituents is an area for further investigation.

Basinwide trends in concentrations of selected constituents are shown in fig. 10. On each map, a trend is indicated at a sampling station only if a significant trend was found ($p < 0.05$). The following trends in water-quality constituents were detected for water years 1982–95: (1) increasing concentrations of pH, color, turbidity, and alkalinity at most stations, (2) increasing concentrations of chloride at one-third of the stations where a trend was detected, and (3) decreasing concentrations of sodium at all stations where a trend was detected.

pH

Upward trends in pH during 1982 through 1995 indicate less acidic conditions in streams and rivers in the Scituate Basin. Increases in pH may be related to reduced acid deposition (acid rain). Federally mandated improvements (Title VI of the Clean Air Act Amendments of 1990) to reduce acidic deposition in the United States, including phased reductions in sulfur dioxide and nitrogen oxide emissions, have decreased hydrogen-ion concentrations in precipitation in the eastern United States (Lynch and others, 1995). A study of trends in Connecticut (Trench, 1996) also detected geographically widespread increases in pH during a similar time period.

Color

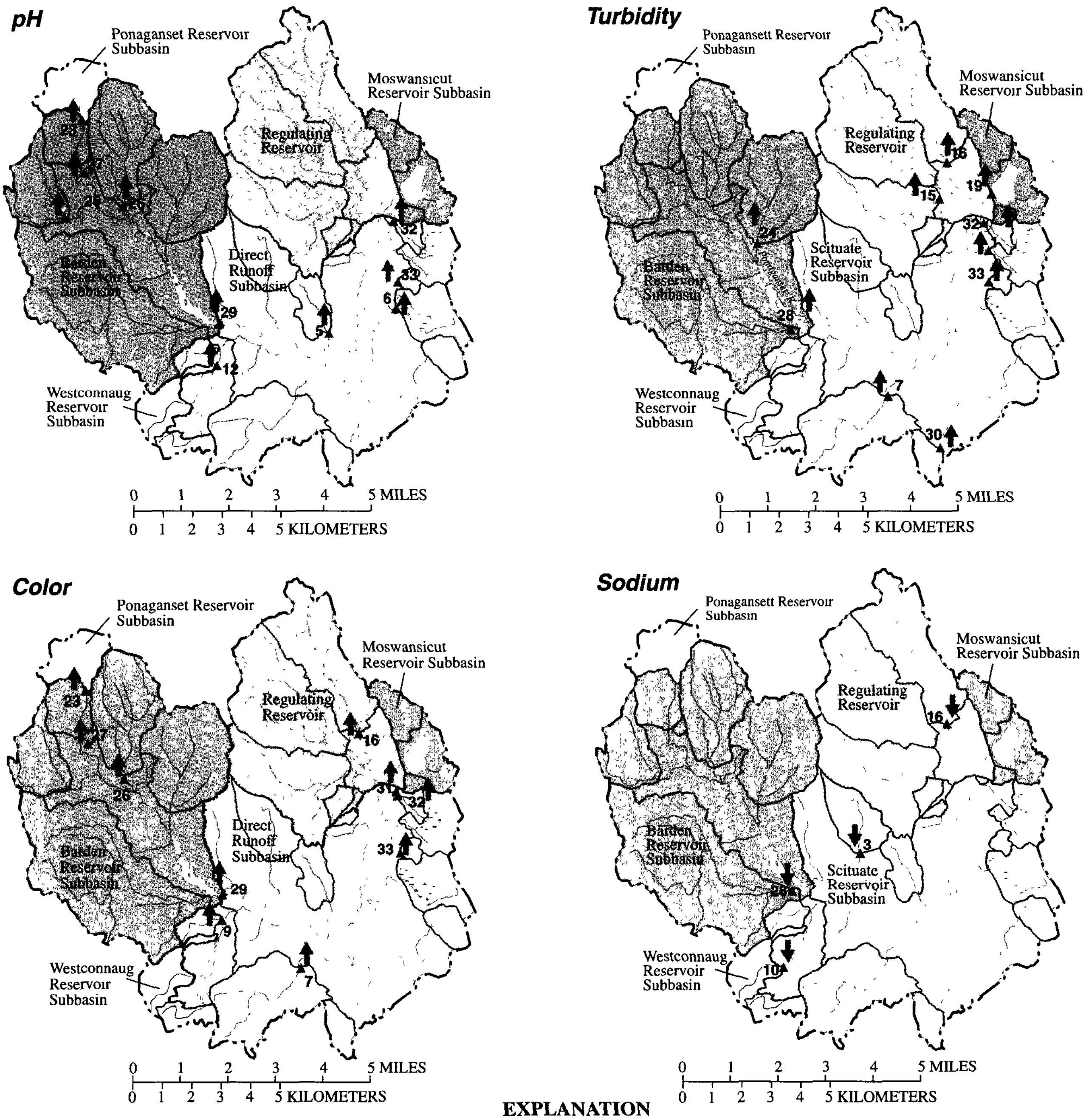
Absorbance of light by naturally occurring dissolved organic carbon (DOC), referred to here as color, is often used as an indicator of DOC, a complex mixture consisting largely of humified plant material that is not easily characterized (Thurman, 1985). A possible reason for the upward trend in color values may be related to increased pH, which would indicate that the surface waters in the Scituate Reservoir Basin are becoming less acidic with time. Less acidic water has a greater capacity to solubilize and dissolve organic carbon than more acidic water (McKnight and Bencala, 1990; Donahue and others, 1998).

Turbidity

Natural or anthropogenic suspended matter is the primary cause of turbidity in surface-waters; components include clay, silt, fine organic and inorganic matter, DOC, and synthetic inorganic and organic contaminants. Increasing volumes of storm runoff from impervious surfaces in expanding residential areas may contribute to the upward trend in turbidity.

Total Coliform Bacteria

Total coliform bacteria is used as an indicator of fecal contamination from humans and other warm-blooded animals, because fecal contamination can introduce disease-causing viruses and bacteria into a stream, river, or reservoir. Total coliform concentrations showed no statistically significant trend at the 32 sampling stations.



EXPLANATION

LESS THAN 1/2 UNIT PER YEAR

GREATER THAN 1/2 UNIT PER YEAR

UPWARD OR DOWNWARD TREND IN CONCENTRATION

BASIN BOUNDARY

SUBBASIN BOUNDARY

WATER-QUALITY SAMPLING SUBBASIN

11 U.S. GEOLOGICAL SURVEY GAGING STATION AND IDENTIFIER

Figure10. Trends of water-quality constituents, October 1982–September 1995, Scituate Reservoir Basin, Rhode Island.

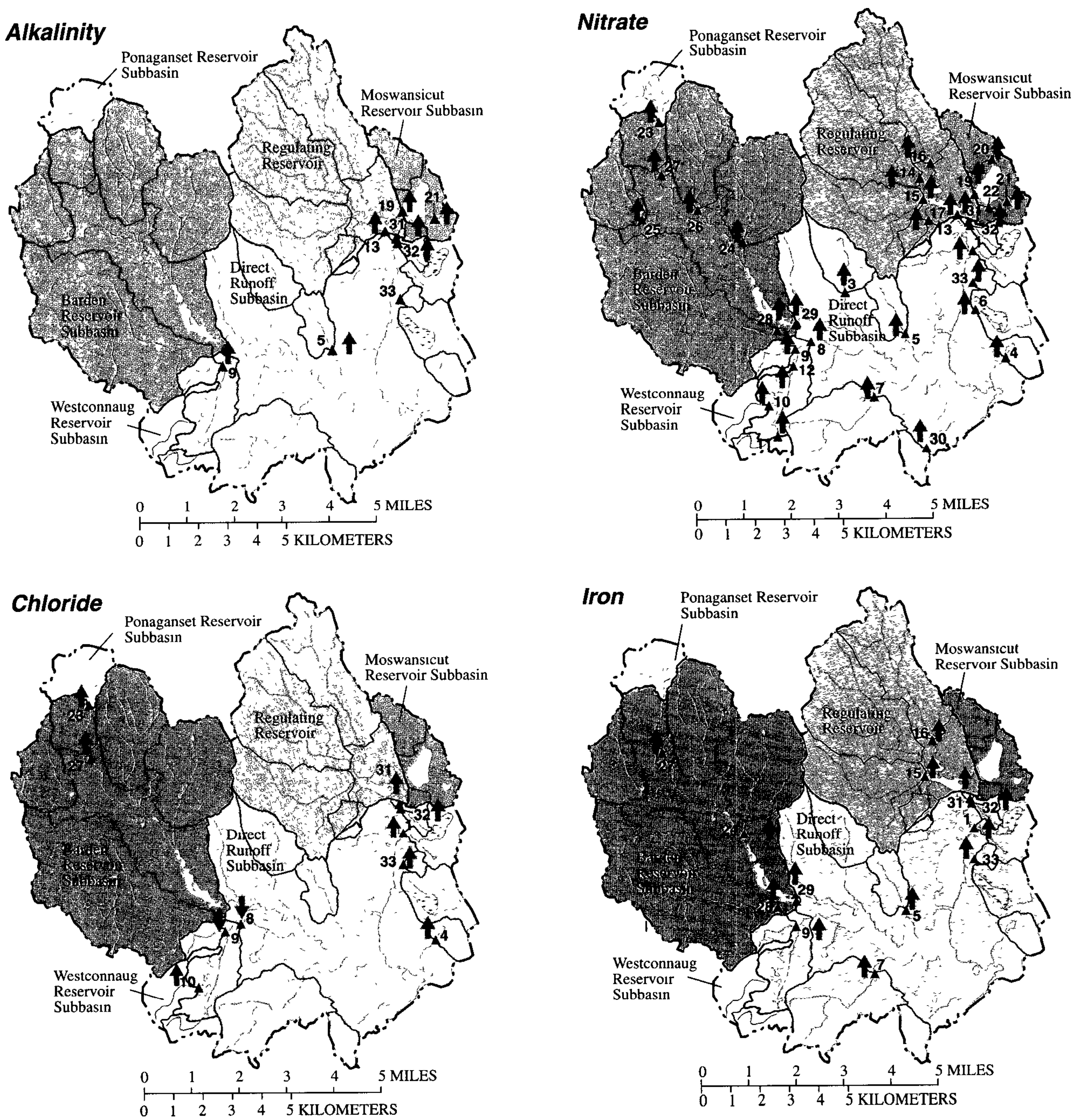


Figure10. Trends of water-quality constituents, October 1982–September 1995, Scituate Reservoir Basin, Rhode Island—*Continued.*

Sodium

The downward trend in sodium concentration at all stations where a trend was detected could have been the result of policy changes in road-deicing practices in the Scituate Reservoir Basin. In the late 1980s, Runge and others (1988) determined that road salt was the largest source of sodium and chloride to the reservoir's drainage basin. Consequently, in 1990, the PWSB and the Rhode Island Department of Transportation (RIDOT) adopted the use of a calcium chloride/sodium chloride premix in place of sodium chloride alone on State roads in the basin. The premix is a 60/40 mixture of $CaCl_2/NaCl$, which is about 12 percent calcium, 26 percent sodium, and 60 percent chloride by weight (Granato and others, 1995).

Alkalinity

Urban and industrial development has increased as a result of population growth in the Scituate Reservoir Basin during 1982 through 1995. Larger quantities of urban runoff and industrial discharge resulting from this development are probable causes of increasing alkalinity. For example, Smith and Lord (1990) showed that highway systems have the capacity to buffer the runoff of acid precipitation by increasing the alkalinity of streams receiving highway runoff.

Chloride

Natural sources of chloride in freshwater streams of the Scituate Reservoir Basin area are limited, and upward trends in chloride are likely caused by a variety of human activities, including nonpoint runoff containing road-deicing salts. Chloride-containing salts are used for many domestic and industrial applications, such as roads, parking areas, and sidewalks, and may be associated with septic system discharge; as the population increases, the quantity of salt increases proportionally. During the winter, salt dissolves and is carried to nearby streams by surface runoff and ground-water discharge. The downward trend in chloride concentrations at sampling stations 9 and 8 may be the result of the 1988 enclosure of the Clayville RIDOT salt-storage facility in the Bear Tree Brook subbasin.

Nitrate

Sources of nitrate in streamwater include the atmosphere, biological activity, and human activities, such as agriculture and onsite sewage disposal (Weiskel and Howes, 1991). For example, many homeowners in the basin have livestock such as horses, cows, pigs, and sheep. Waste from these animals may be a source of nitrate.

Iron

An increase in urban and industrial development has contributed to larger quantities of residential runoff and commercial discharge partly resulting in increased iron concentrations in the Scituate Reservoir Basin. Another possible cause is related to the increased concentrations of dissolved organic carbon or color. Iron in solution can be bound by DOC and stabilized as a dissolved iron-organic carbon complex, allowing for a greater transport of iron (Hem, 1985).

FREQUENCY OF EXCEEDENCE OF WATER-QUALITY CRITERIA AND GUIDELINES

The RIDEM has developed water-quality guidelines that set concentration limits for water-quality constituents, depending on the intended use of the water body. The RIDEM publishes water-quality criteria that are intended to "restore, preserve and enhance the physical, chemical, and biological integrity of the waters and to maintain existing water. These regulations provide for the protection of the surface-waters from pollutants so that the waters shall, where attainable, be fishable and swimmable, be available for all designated uses, taking into consideration their uses and value for public water supplies, propagation of fish and wildlife, and recreational purposes" (State of Rhode Island and Providence Plantations Department of Environmental Protection, 1997). Surface waters in the State are assigned to one of four classes: A, B, B1, and C. The class a surface-water body is assigned to (A, B, B1 or C) is determined by the most sensitive of its intended uses. For example, the water resources in the Scituate Reservoir Basin are assigned to class A, because they are used as a source of public drinking-water supply, although they also are used for primary and secondary contact-recreational activities and for fish and wildlife habitat.

At present, many water-quality constituents monitored by the PWSB are not regulated by the State. The U.S. Environmental Protection Agency (USEPA) publishes water-quality criteria and guidelines for drinking water, not untreated water supply (raw water). These criteria and guidelines include maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), and water contaminant candidates lists (CCLs) and are shown here to represent the degree of treatment and purification needed to meet USEPA criteria for drinking water (table 4). This criteria may be important because some of these constituents are often difficult to remove through present treatment and purification processes.

The following evaluation of the extent and frequency of exceedence of Rhode Island and USEPA water-quality guidelines and standards should be considered an informal screening to distinguish the water-quality constituents and locations that may fail to meet the minimum water-quality necessary to support the designated surface-water use classification (table 4) or require significant treatment and purification to meet USEPA guidelines and standards for drinking water. The frequency of exceedence of water-quality criteria and guidelines is shown in figure 11.

Table 4. Water-quality guidelines and standards for Rhode Island

[RIDEM, Rhode Island Department of Environmental Management (1997); USEPA, U.S. Environmental Protection Agency (1996). MCL, maximum contamination level; SMCL, secondary maximum contamination level; CCL, contaminant candidate list; CFU, colony-forming units; NTU, nephelometry turbidity units; mg/L, milligrams per liter; --, not applicable]

Constituent	RIDEM	USEPA (MCL)	USEPA (SMCL)	USEPA (CCL)
pH	6.5–9.0	--	6.5–8.5	--
Color		--	15	--
Turbidity, in NTU	5 NTU over back-ground	--	--	--
Bacteria, in CFU/100 mL	[1]100	1	--	--
Sodium, in mg/L		--	--	20
Chloride, in mg/L		--	250	--
Nitrate, in mg/L		10	--	--
Nitrite, in mg/L		1	--	--
Iron, in mg/L		--	0.3	--
Manganese, in mg/L		--	0.05	--

[1]Written as a mean for a given site.

pH

The RIDEM has set water-quality standards for untreated water pH of 6.5 to 9.0 (Rhode Island Department of Environmental Management, 1997). At least 80 percent of the samples collected between 1982 and 1995 at 21 of the 33 water-quality sampling stations were less than the RIDEM standard pH of 6.5. This result represents the most geographically widespread failure to meet the minimum water-quality standards necessary to support the applicable drinking-water use classification; however, drinking-water supplies with naturally occurring pH values outside of the RIDEM criteria are presently exempted from this standard.

Color

Color in natural water is usually produced from leaching of organic debris and is used as an indicator of DOC. DOC is important in stream and reservoir chemistry because it complexes many metals and nutrients (Koenings and Hooper, 1976; Jackson and Hecky, 1980), often controls transparency, affects pH and alkalinity (Oliver and others, 1983), and acts as substrate for microbial production (Hessen, 1992). Recently, concern has arisen over the transformation of DOC to various types of chlorinated organic compounds, such as trihalomethanes and haloacetic acids, during the chlorination process (Miller, 1993).

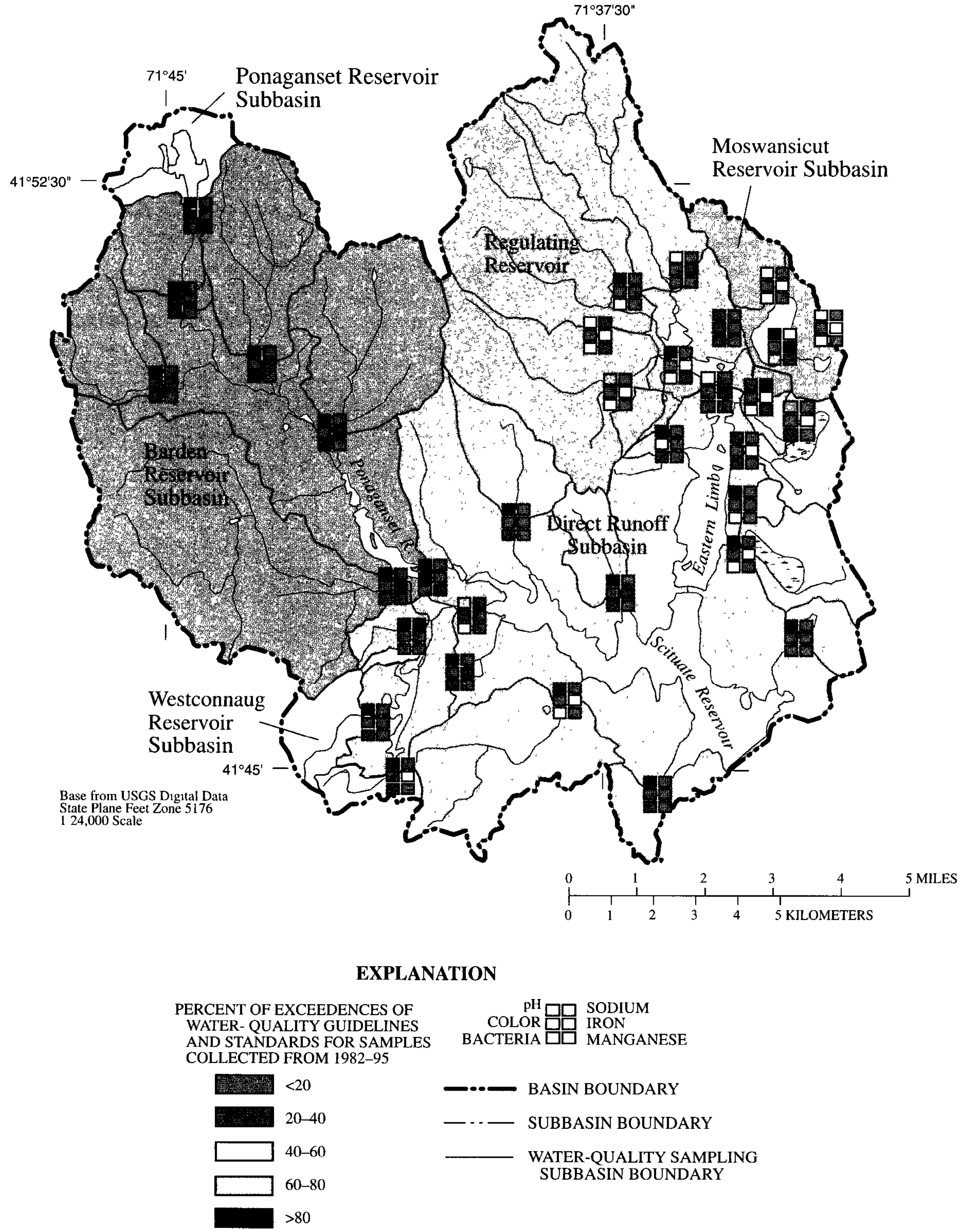


Figure 11. Frequency of exceedences of water-quality standards and guidelines in the Scituate Reservoir Basin, Rhode Island.

Such compounds, known collectively as disinfection by-products, have been identified as possible carcinogens, and the USEPA is presently establishing new limits for by-products in drinking water.

The USEPA has set a SMCL of 15 for color. Generally, color values were less than the SMCL of 15; however, 20 to 60 percent of the samples exceeded the SMCL at four sampling stations. More than 80 percent of the samples collected from station 23 (Ponaganset Reservoir) exceeded the SMCL for color.

Turbidity

The suspended and colloidal material comprising turbidity is important for both aesthetic and health reasons. One heath-related characteristic of turbidity is the association of microorganisms with particulate matter. This association can limit disinfection efficiency and increase production of disinfection by-products. Additionally, suspended solids can be associated with synthetic inorganic and organic contaminants (tire and street surface-wear particles) and also can have negative ecological effects on aquatic life (U.S. Environmental Protection Agency, 1983). The RIDEM has set a maximum water-quality standard of 5 NTU over background for class A waters. Based on the mean-median turbidity value for all water-quality sampling stations as background (5.6 NTU), all of the samples collected for turbidity in the study area had concentrations less than the allowed 5 NTU above background, or 10.6 NTU.

Total Coliform Bacteria

Water in streams and reservoirs commonly contains a wide variety of microorganisms, some of which cause diseases in humans. Many microorganisms occur naturally, and some are introduced into water supplies by human activities, such as sewage disposal. Water suppliers disinfect water from reservoirs to eliminate microbial contamination before drinking water is distributed to consumers. A useful indicator of microbial contamination in water is total coliform bacteria concentrations. Although the total-coliform group does not generally include disease-causing organisms, coliforms indicate the potential presence of other human pathogens including bacteria, protozoans (*Cryptosporidium* and *Giardia*), and enteric viruses.

The RIDEM has established a drinking-water supply standard (Class A waters) for total coliform bacteria of 100 CFU/100 mL (Rhode Island Department of Environmental Management, 1997). The USEPA has established a MCL of 1 CFU/100 mL for treated drinking water (US Environmental Protection Agency, 1996). Untreated water must have total coliform concentrations no greater than 5,000 CFU/100 mL to allow filtration and chlorination to produce treated water with concentrations less than the MCL (James M. Montgomery, Consulting Engineers, 1985).

From 20 to 60 percent of the samples had coliform concentrations greater than the RIDEM standard at 24 of the 33 stations. Total coliform concentrations at sampling station 22, (Moswansicut Reservoir) were greater than the RIDEM standard for at least 60 percent of the samples collected there. Total coliform concentrations for all the Moswansicut Reservoir sampling stations were greater than the RIDEM standard for more than 40 percent of the samples collected in this subbasin; this is the largest percentage of total coliform exceedences observed in the Scituate Basin.

Sodium

Sodium is a common, naturally occurring element found in soil and water. Although necessary for the normal functioning of the human body, sodium can cause problems for some people who have difficulty regulating fluids as a result of various diseases, such as hypertension. Although sodium from drinking water is generally a small part of a person's total sodium intake, monitoring sodium intake in these individuals is important. Additionally, many State and Federal agencies are requiring public water suppliers to report all results that show a detection of sodium to their local board of health. This notification is required so that individuals who are on sodium-restricted diets or who wish to monitor their sodium intake for other reasons will be able to take the amount of sodium in their water into account. The USEPA has set a sodium guideline (defined as a contaminant candidate) of 20 mg/L for drinking water. Generally, sodium concentrations were below the USEPA guideline with the exception of the samples collected at stations 9 and 31 (Bear Tree Brook and Toad Pond); more than 80 percent of the samples collected from these stations exceeded the USEPA sodium guideline.

Chloride

Chloride is present in all natural waters but concentrations are usually low in streams and reservoirs of New England. Although chloride is not considered to be a health hazard, high concentrations can produce corrosion and give water a salty taste. The USEPA has established a SMCL of 250 mg/L for chloride (U.S. Environmental Protection Agency, 1996). Chloride concentrations for all samples analyzed at all stations in the Scituate Reservoir Basin were less than the USEPA SMCL.

Nitrate and Nitrite

Nitrogen can be present in water as nitrite, nitrate, ammonium, and as part of organic solutes (Hem, 1985) Excessive concentrations of nitrate in drinking water can cause methemoglobinemia in small children. As a result, the USEPA has set an MCL of 10 mg/L for nitrate (as nitrogen) in finished drinking-water. Nitrate concentrations for all samples analyzed at all sampling stations in the Scituate Reservoir Basin were less than the USEPA MCL. Nitrite usually occurs in natural waters at much lower concentrations than does nitrate. Currently, the USEPA MCL for nitrite in drinking water is 1 mg/L. The PWSB collects data for nitrite at 33 water-quality sampling stations, but concentrations are generally quite low, commonly less than or near the detection limit, because nitrite is readily oxidized to nitrate under most surface-water conditions.

Iron and Manganese

Iron is a necessary nutrient for human life, but in excess can give an unpleasant taste and odor to water. The USEPA has established a SMCL of 0.3 mg/L for iron (U.S. Environmental Protection Agency, 1996). From 20 to 60 percent of the samples analyzed for iron exceeded the SMCL at 19 sampling stations (56 percent of the stations). More than 80 percent of the samples analyzed for iron from station 22 (Moswansicut Reservoir) exceeded the SMCL for iron. Manganese also is a necessary nutrient for human life, but can give an unpleasant taste to water, cause staining, and foster the growth of microorganisms in water-distribution systems. The USEPA has established a SMCL of 0.05 mg/L for manganese (U.S. Environmental Protection Agency, 1996). More than 85 percent of the samples analyzed for manganese were below the SMCL.

RELATION OF WATER-QUALITY CONDITIONS TO DRAINAGE-BASIN CHARACTERISTICS

The quality of natural waters is affected by a variety of different drainage-basin characteristics; however, the number of water-quality variables, the interspersed nature of drainage-basin characteristics in the Scituate Reservoir Basin, and the fact that water-quality constituents can be affected by more than one drainage-basin characteristic make it difficult to determine the key characteristic(s) responsible for controlling water quality. By clustering water-quality data by tributary subbasin and looking at the effect of drainage-basin characteristics on water-quality at a smaller scale, the likelihood of gaining insights into relations between water-quality variables and drainage-basin characteristics is increased. Subbasin-wide relations between water-quality constituent concentrations and drainage basin characteristics are shown in table 5. In the table, a relation is indicated between each water-quality constituent and drainage-basin characteristic by tributary subbasin only if a significant relation was found ($r > 0.71$).

Table 5. Selected correlation-analysis results (Pearsons *r*-values > 0.71) of median values for water-quality data and selected drainage-basin characteristics by tributary subbasin, Scituate Reservoir Basin, Rhode Island

[No relation between water-quality constituents and commercial, industrial, and institutional land use were found. B; Barden Reservoir subbasin; D, Direct Runoff subbasin; M, Moswansicut Reservoir; R, Regulating Reservoir subbasin; S, Scituate, W, Westconnaug Reservoir subbasin]

Drainage-basin characteristics	pH	Color	Turbidity	Total coliform bacteria	Sodium	Alkalinity	Chloride	Nitrate	Orthophosphate	Iron	Manganese
Land use—Urban											
Urban	M, R	W	D, S	B	B	D, R, S	B				
Residential	M, R				B	R	B				
Land use—Rural											
Agricultural		M		B		S		R			
Mixed Forest		R	M	M, R	M, W	M	M, R, W	M	M	M	M
Water	D, W		D, W			D, M, R, W	B	R			D
Wetlands		M									
Barren Land		M									
Geology—Bedrock											
Felsic	M		R		R	M	R		R	R	R
Igneous				B	B		B				
Non-calcareous		M	D	D		D					
Geology—Surficial											
Outwash	B, M	B, R, W	B	R	D		D			B	
Till	R				W		W	B, R			
Wetlands											
Forested wetlands	W	M	R, W	R		W				R	R
Non-forested wetlands	B	B, R, W	D	W	B	D	B			B, D, W	D
Slope											
Slope 0–5	B		B							B	W
Slope 5–10	W	W	M, W	M, W	M	M, W	M	B, M		M, W	M
Slope 10–15	W	W	W	W	M	W	M			W	
Slope 15–20	W	W	M, W	B, M, W	B, M	M, W	B, M	M	M	M, W	M
Slope 20–25	M	W	D	B, W	B	D	B			W	
Slope >25		R, W	D	B, W	B	D	B			W	
Soil Drainablility											
Excessively drained		W, R	B, M	M, R	D, M	M	D, M	M	M	M	M
Moderately well drained	B	M			W	B					W
Well drained	M, R, W	W	M, W	M, W		R,W		M, R	M	M, W	M
Variable	D, W		D, R, W	B		W,D			R	R, W	
Poorly drained		B, M			R, W		R, W			B	W
Very poorly drained		D,M,R, S,W	B	R, W						B, W	
Roads											
Primary road miles	R	B, D, M	B		B, R		B, R			B	W
Primary road density	R	B	D	B	R	D	B, R			B	
Secondary road miles	R	B, M, D	B		W		W	R		B	W
Secondary road density		M,RW	D	R		D		B			D

Land Use

The significant correlation (Pearsons *r* greater than 0.71) between pH, total coliform, sodium, and chloride and urban land use in some of the tributary reservoir subbasins indicates that these constituents may be partly due to human effects. For example, Weiskel and others (1996) determined that the major sources of total coliform bacteria to stormwater in a largely residential area were most likely the feces of domestic animals. They hypothesized that fecal material accumulates on paved surfaces during dry periods, with surviving bacteria becoming entrained during storm events. Additionally, significant relations among alkalinity, manganese, nitrate, total coliform bacteria, and drainability of soils may indicate a substantial contribution of constituents from onsite septic-tank systems. Because the entire population of the Scituate Reservoir Basin uses septic-tank soil-absorption systems for wastewater disposal, the potential of constituent loads to the Scituate Reservoir Basin is great (Rich Blogget, Providence Water Supply Board, oral commun., 1998).

Geology

The significant correlation (Pearsons *r* greater than 0.71) in some of the subbasins between geology and pH, color, turbidity, total coliform bacteria, chloride, iron, and manganese is likely because sources of some of these water-quality constituents are correlated, such as wetlands and melt water deposits. However, potential sources of manganese and iron may include the weathering of mafic minerals (Robinson, 1997), and mechanical erosion of coatings of manganese and iron oxides that are widely distributed in stream sediments and soils (Hem, 1985).

Wetlands and Soil Drainability

The significant correlation (Pearsons *r* greater than 0.71) between wetlands or soil drainability (table 6) (poorly drained soils may be a more accurate index for wetlands than the available wetland coverages) and pH, color, turbidity, total coliform bacteria, alkalinity, and iron in most of the tributary subbasins indicates that these water-quality constituents are partly controlled by biogeochemical processes in wetlands. Wetland research in recent years has demonstrated that wetlands can act either as a net importer or net exporter of these constituents (Elder, 1987). For example, "when an organic wetland soil is flooded, the oxygen available in the soil and in the water is rapidly depleted through microbial metabolism. Generally, the rate of diffusion of molecular oxygen through water is limited and cannot supply the metabolic demand. When the demand exceeds the supply, dissolved oxygen is depleted, the redox potential in the soil drops rapidly, and ions such as nitrate, manganese, iron, sulfate, and carbon dioxide, are reduced and mobilized" (Mitsch and Gosselink, 1986). Hemond and Benoit (1988) showed the DOC was larger and hydrogen-ion concentrations (pH) were smaller in watersheds that had the greatest percentage of wetland area. Weiskel and others (1996) found that animal bacteria from saturated wetland surfaces is a likely source of total coliform bacteria to streams and has been observed in a wetland-dominated watershed free of residential land-use-related bacterial sources.

Roads and Slope

The significant correlation (Pearsons *r* values greater than 0.71) between roads or slope and pH, color, turbidity, sodium, alkalinity, chloride, and iron in most of the tributary subbasins indicates that these water-quality constituents are partly controlled by stormwater runoff from primary and secondary roads. Increased sodium and chloride concentrations in rivers (Peters and Turk, 1981), ponds (Hutchinson, 1970), and ground water (Hutchinson, 1970), have been attributed to deicing practices. Of particular interest are the results of an investigation done by Runge and others (1988) who reviewed sodium and chloride data in the Scituate Reservoir Basin and concluded that road salting was the primary source of sodium and chloride concentrations in the reservoir and its tributaries. Granato and others (1995) found that concentrations of iron and manganese were larger in ground water down-gradient from a highway, in some cases an order of magnitude larger. Iron and manganese concentrations were highly correlated with chloride concentrations, indicating that mobilization is probably caused by deicing chemical migration. Iron in stormwater also can be derived from the corrosion of cars and other steel (for example, guardrails or stabilizing slag for grade material) and is associated with suspended sediment. Anthropogenic sources of manganese in stormwater include fertilizers and engine parts (Makepeace and others, 1995).

Turbidity can be caused by solids transported in road runoff during rain events. Runoff from paved surfaces transports dissolved, colloidal, and solid constituents in a heterogeneous mixture of metals, organic compounds, and inorganic compounds (Sansalone and Burchberger, 1997). The generation and accumulation of these constituents on highways result from traffic activities, vehicular wear, pavement degradation, maintenance activities, littering, and atmospheric deposition. For example, tire and pavement interaction abrades both materials, generating solids that can be a significant source of turbidity (Muschack, 1990). Pavement has been shown to account for 40 to 50 percent and tires for 20 to 30 percent of solids generated by road runoff (Kobriger and Geinopolos, 1984).

SUMMARY AND CONCLUSIONS

This report discusses the results of a study by the U.S. Geological Survey, in cooperation with the Providence Water Supply Board to provide detailed information about water-quality conditions and relations with drainage-basin characteristics in the Scituate Reservoir Drainage Basin, Rhode Island, between 1982 and 1995. The results of the study reported here indicate that concentrations, loads, and trends of pH, color, turbidity, total coliform bacteria, sodium, alkalinity, chloride, nitrate, orthophosphate, iron, and manganese in streams tributary to the Scituate Reservoir appear to be primarily controlled by the size of the drainage basin and the geographic distribution of drainage-basin characteristics, such as point and nonpoint contaminant sources, wetlands, and external forces such as atmospheric deposition. Median concentrations and yields of these water-quality constituents were larger in residential areas where point and non-point sources are likely, and in areas of poorly drained soils (or wetlands). Median instantaneous loads of the water-quality constituents reflect drainage basin size; that is, loads generally were larger for larger subbasins compared to smaller subbasins. Results of this study indicate that, in general, the Barden and Direct Reservoir subbasins are exporting large loads of most water-quality constituents. In contrast, the Moswansicut and Westconnaug Reservoir subbasins are likely discharging smaller loads of these constituents compared to the other subbasins. The results also indicate that the Direct and Moswansicut Reservoir subbasins are exporting disproportionately large amounts of the water-quality constituents related to other subbasins such as the Barden Regulating, and Westconnaug Reservoir subbasins.

Significant trends in water-quality constituents from 1982 to 1995 in the Scituate Reservoir Basin indicate that the quality of the water resources in the basin may be slowly changing. Scituate Reservoir subbasins with large amounts of residential land use showed increasing trends in alkalinity and chloride. In contrast, subbasins distributed throughout the drainage basin showed increasing trends in pH, color, nitrate, and iron concentrations, indicating that these characteristics and constituents may be controlled more by atmospheric deposition.

Some water-quality constituent concentrations measured between 1982 and 1995 in the Scituate Reservoir Basin occasionally exceeded Rhode Island and USEPA water-quality guidelines and standards for source water. However, at present, most of the selected water-quality constituents monitored by the PWSB are not regulated by the State of Rhode Island or the U.S. Environmental Protection Agency (USEPA) in source water. More accurate assessment of the effects of the presence of elevated concentrations of the selected water-quality constituents would require analysis to be made between intake and finished water.

The percentage of wetlands, roads, and slope appear to have the greatest effect on water-quality in the Scituate Reservoir Basin. The percentage of urban, residential, and commercial land uses also are important, but to a lesser degree than wetlands, roads, and slope. Finally, geology appears to have the least effect on water quality compared to other drainage-basin characteristics investigated.

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Table 6. Drainage-basin characteristics by subbasin in the Scituate Reservoir Basin, Rhode Island

[Values are given as percentages. **Wetlands:** Includes nonforested (marsh/wet meadow, emergent fen or bog, shrub fen or bog) and forested (coniferous forested wetland, deciduous forested wetland and wetlands with standing dead trees). **Barren land:** Includes open-pit mines, quarries, and gravel pits. **Felsic:** Includes granitoid plutonic rocks and their metamorphic equivalents. **Igneous:** Includes mafic and ultramafic igneous rocks and their metamorphic equivalents. **Noncalcareous:** Includes metamorphosed clastic sedimentary rocks. **Meltwater deposits:** Includes noncompacted poor-to-well-sorted sand and gravel. **Till:** Includes nonsorted sand, silt, clay, and boulders. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; Bolded values are the maximum values of the water-quality sampling stations; italics are maximum values of the tributary reservoir subbasins. No., number; mi, mile, mi/mi^2, mile per square mile; mi^2, square mile; >, actual value is greater than value shown]

			Land use									Geology				
			Urban				Rural					Bedrock			Surficial	
USGS station No.	PWSB station No.	Area (mi^2)	Residential	Commercial	Industrial	Institutional	Agricultural	Mixed forest	Water	Wetlands	Barren land	Felsic	Igneous	Noncalcareous	Meltwater deposits	Till
Barden Reservoir Subbasin																
01115190	24	5.01	2.0	0.0	0.0	0.0	0.3	95.8	2.0	0.0	0.0	62.7	**37.3**	0.0	13.8	84.6
01115200	25	2.39	.0	.0	.0	.0	.0	95.4	.0	.0	.0	98.1	.0	.0	13.8	85.6
01115185	26	4.22	.0	2.0	.0	.0	1.4	96.6	.0	.0	.0	91.2	8.8	.0	11.6	88.1
011151845	27	.10	.0	.0	.0	.0	.0	100.0	.0	.0	.0	**100.0**	.0	.0	.0	100.0
01115270	28	10.62	.3	.4	.0	.0	.0	96.7	.0	.0	.0	97.3	1.9	.0	30.5	66.5
01115271	29	**33.02**	.7	.4	.0	.0	.3	94.8	2.5	.0	.0	85.3	14.3	.0	20.6	75.4
01115187	A	3.69	1.8	.0	.0	.0	.3	97.3	.6	.0	.0	81.1	18.9	.0	27.3	71.7
	B	1.57	.3	.0	**.9**	.0	.0	98.0	.4	.0	.0	100.0	.0	.0	**.0**	99.2
Subbasin total...........		31.16	0.7	0.4	0.0	0.0	0.3	95.8	1.5	0.0	0.0	84.4	*15.1*	0.0	21.0	75.9
Direct Runoff Subbasin(s)																
01115180	1	1.57	4.8	0.0	0.0	0.0	5.7	72.8	2.5	**13.2**	1.0	100.0	0.0	0.0	51.3	44.3
01115181	2	.15	.0	.0	.0	.0	.0	**100.0**	.0	.0	.0	100.0	.0	.0	19.4	80.6
01115280	3	1.90	.0	.0	.0	.0	.9	95.2	.0	.0	.0	100.0	.0	.0	.0	99.5
01115400	4	.86	2.9	.0	.0	.0	7.2	78.0	4.4	.0	.0	100.0	.0	.0	.0	95.1
01115184	5	1.23	2.5	.0	.0	.0	2.4	95.0	.0	.0	.0	100.0	.0	.0	.0	95.6
01115183	6	1.99	.0	.0	.0	.0	3.2	88.1	.0	4.0	.0	99.3	.7	.0	26.1	73.9
01115297	7	4.42	.0	.0	.0	.0	1.1	97.0	.0	.0	.2	100.0	.0	.0	10.7	86.6
01115276	8	5.10	.0	.0	.0	.0	.0	95.5	3.6	.0	.0	100.0	.0	.0	34.5	57.2
01115275	9	.64	.0	.0	.0	.0	.0	99.2	.0	.0	.0	100.0	.0	.0	**97.1**	2.8
01115350	30	.74	.1	.0	.0	.0	.1	99.9	.0	.0	.0	100.0	.0	.0	20.0	80.0
01115177	31	.04	.0	.0	.0	**57.4**	.0	17.9	24.7	.0	.0	32.3	.0	**67.7**	93.2	.0
01115178	32	.40	.0	.0	.0	.0	.0	99.8	.2	.0	.0	100.0	.0	.0	36.2	63.8
01115182	33	.27	.0	.0	.0	.0	.0	**100.0**	.0	.0	.0	100.0	.0	.0	4.8	95.0
	C	20.23	1.1	.0	.0	.0	1.1	71.2	**26.3**	.0	.3	99.8	.0	.2	6.8	65.1
Subbasin total...........		*36.97*	1.0	0.0	0.0	*0.5*	1.4	80.3	15.3	0.8	0.2	99.8	0.0	0.2	13.6	69.0

Table 6. Drainage-basin characteristics by subbasin in the Scituate Reservoir Basin, Rhode Island—*Continued*

USGS station No.	PWSB station No.	Area (mi^2)	Land use									Geology				
			Urban				Rural					Bedrock			Surficial	
			Resi-dential	Com-mercial	Indus-trial	Institu-tional	Agri-cultural	Mixed forest	Water	Wet-lands	Barren land	Felsic	Igneous	Noncal-careous	Melt-water deposits	Till
Moswansicut Reservoir Subbasin																
01115170	19	3.20	20.0	0.0	0.0	0.0	5.3	54.5	15.7	3.5	1.1	60.4	0.0	21.3	19.7	65.2
01115160	20	1.21	26.7	.0	.0	.0	**8.8**	52.3	.0	9.2	3.0	53.3	.0	46.7	4.2	95.7
01115165	21	.32	**32.5**	.0	.0	.0	.0	49.8	17.8	.0	.0	**100.0**	.0	.0	37.4	49.0
				.0	.0	.0				.0	.0		.0			
01115167	22	.22	29.1	.0	.0	.0	.0	70.9	.0	.0	.0	95.4	.0	4.6	17.0	82.9
01115164	34	.27	30.4	.0	.0	.0	.0	48.6	21.0	.0	.0	**100.0**	.0	.0	6.8	48.7
Subbasin total..........		3.20	*27.6*	0.0	0.0	0.0	*7.2*	54.5	15.7	*3.5*	*1.1*	60.4	0.0	*21.3*	19.7	65.2
Ponaganset Reservoir Subbasin																
011151843	23	1.86	0.7	0.0	0.0	0.0	0.0	78.0	18.1	0.0	0.0	99.3	0.0	0.0	13.8	67.5
Subbasin total..........		1.86	0.7	0.0	0.0	0.0	0.0	78.0		0.0	0.0	99.3	0.0	0.0	13.8	67.5
Regulating Reservoir Subbasin																
01115176	13	22.17	4.5	0.0	0.0	0.3	2.5	87.6	4.1	0.5	0.2	90.0	0.2	7.1	21.3	74.1
01115110	14	6.24	.3	.0	.0	.0	2.7	96.4	.6	.0	.0	99.2	.8	.0	9.8	88.6
01115115	15	4.98	1.4	.0	.0	.4	.0	98.2	.0	.0	.0	**100.0**	.0	.0	17.6	81.8
01115098	16	4.92	2.2	.0	.0	.4	4.3	92.0	1.1	.0	.0	**100.0**	.0	.0	23.7	75.2
01115119	17	.13	.0	.0	.0	.0	.0	**100.0**	.0	.0	.0	**100.0**	.0	.0	62.2	33.6
01115120	18	.54	.3	**4.9**	.0	.0	.0	94.8	.0	.0	.0	**100.0**	.0	.0	43.8	55.2
Subbasin total..........		18.97	1.9	*0.4*	0.0	0.3	2.0	93.2	2.2	0.0	0.0	95.0	0.3	4.7	*21.1*	75.6
Westconnaug Reservoir Subbasin																
01115274	10	1.37	0.0	0.0	0.0	0.0	0.0	**100.0**	0.0	0.0	0.0	**100.0**	0.0	0.0	3.1	94.6
01115273	11	.69	.0	.0	.0	.0	.0	**100.0**	.0	.0	.0	**100.0**	.0	.0	21.7	77.6
011152745	12	.15	.0	.0	.0	.0	.0	95.2	.0	.0	.0	**100.0**	.0	.0	72.3	26.4
Subbasin total..........		2.20	0.0	0.0	0.0	0.0	0.0	99.7	0.0	0.0	0.0	100.0	0.0	0.0	13.6	*84.7*
Scituate Reservoir Basin																
Basin total		94.10	1.7	0.2	0.0	0.3	1.2	87.6	7.8	0.4	0.1	92.4	5.1	1.8	17.9	72.8

Table 6. Drainage-basin characteristics by subbasin in the Scituate Reservoir Basin, Rhode Island—*Continued*

USGS station No.	PWSB station No.	Wetlands: Forested	Wetlands: Non-forested	Slope: 0–5	Slope: 5–10	Slope: 10–15	Slope: 15–20	Slope: 20–25	Slope: > 25	Soil Drainability: Excessively drained	Soil Drainability: Moderately well drained	Soil Drainability: Well drained	Soil Drainability: Variable	Soil Drainability: Poorly drained	Soil Drainability: Very poorly drained	Roads: Primary miles (mi)	Roads: Primary road density (mi/mi^2)	Roads: Secondary miles (mi)	Roads: Secondary road density (mi/mi^2)
Barden Reservoir Subbasin																			
01115190	24	7.5	3.9	44.3	36.2	13.7	4.3	1.2	0.3	0.3	37.2	39.7	0.8	18.2	1.4	13.55	2.71	37.77	7.54
01115200	25	12.1	2.3	41.1	48.4	10.0	.5	.0	.0	.1	52.5	28.2	.6	15.4	2.6	3.68	1.54	14.20	5.94
01115185	26	9.7	3.1	52.8	32.4	9.5	3.8	1.2	.4	3.7	**54.2**	25.6	2.0	12.4	1.8	8.15	1.93	38.41	9.10
011151845	27	11.3	.0	35.4	**54.6**	10.0	.0	.0	.0	.0	20.3	69.0	.0	10.7	.0	.11	1.02	1.21	11.60
01115270	28	11.1	2.7	57.4	33.8	6.9	1.3	.3	.2	8.6	39.5	26.4	.6	19.1	5.7	18.64	1.76	66.11	6.22
01115271	29	8.9	4.8	48.9	35.9	10.8	3.1	.9	.5	5.1	40.2	32.2	.7	16.1	2.7	58.61	1.76	**244.37**	7.40
01115187	A	7.5	2.3	43.5	41.4	11.5	2.3	.7	.5	7.6	30.5	45.1	.4	14.7	1.0	5.55	1.50	35.31	9.56
	B	11.7	1.5	44.8	26.8	15.6	7.7	2.8	2.3	.0	28.8	50.0	.0	20.5	.5	5.79	3.68	8.0	5.06
Subbasin total..........		9.1	3.8	*49.5*	36.1	10.4	2.8	0.8	0.4	5.2	*40.4*	*32.5*	0.7	16.4	2.8	58.01	1.86	*226.43*	7.27
Direct Runoff Subbasin(s)																			
01115180	1	15.9	7.2	20.8	34.4	26.0	12.5	4.4	1.9	12.4	9.0	53.1	2.3	7.3	11.4	0.031	0.02	19.45	12.36
01115181	2	14.3	.7	13.8	30.9	30.8	17.3	5.6	1.6	7.3	34.3	32.6	.0	23.2	2.6	.0	.0	2.23	14.47
01115280	3	13.7	1.3	**75.8**	23.6	.6	.0	.0	.0	.0	38.7	31.7	.2	**28.7**	.7	6.73	3.54	12.61	6.63
01115400	4	12.5	5.7	22.0	32.2	25.4	15.2	4.4	.9	1.2	33.2	47.0	2.2	11.5	.0	.38	.45	2.69	3.11
01115184	5	9.4	1.7	34.7	40.7	17.2	4.8	1.4	1.2	2.2	8.9	67.9	.1	19.1	1.8	2.08	1.69	3.04	2.47
01115183	6	19.2	1.7	18.4	35.7	26.9	13.0	4.2	1.8	1.0	19.4	58.4	.7	7.4	13.0	7.38	3.72	16.94	8.54
01115297	7	13.9	2.7	42.7	38.8	13.4	3.8	1.0	.4	7.1	15.4	55.3	.4	18.1	3.7	2.93	.66	22.66	5.13
01115276	8	7.2	6.1	42.5	38.4	12.9	4.3	1.4	.5	7.3	17.1	45.5	.5	11.0	2.8	11.69	2.29	33.13	6.5
01115275	9	11.1	1.4	36.2	38.1	16.7	6.5	1.8	.6	**42.7**	7.8	32.6	1.9	9.0	6.0	1.37	2.14	2.22	3.5
01115350	30	7.4	.9	33.6	38.4	18.5	7.6	1.3	.6	.0	3.7	**83.7**	.0	12.2	.4	1.49	2.01	2.43	3.3
01115177	31	.0	9.8	14.2	29.3	21.7	12.8	**8.4**	**3.8**	31.6	.0	.0	6.3	.0	.0	.64	**15.4**	.9	**21.63**
01115178	32	14.3	2.4	13.5	29.4	**31.1**	**18.1**	6.7	1.1	8.2	12.5	62.2	.0	9.1	8.0	.0	.0	2.79	6.91
01115182	33	15.1	1.0	21.5	41.6	27.3	7.7	1.5	.4	.6	8.5	78.7	.0	12.0	.0	.19	.73	2.13	8.05
	C	5.6	**25.9**	46.0	43.7	8.2	.8	.4	.8	4.3	12.6	47.7	.6	8.4	.9	5.03	2.47	92.3	4.56
Subbasin total..........		8.7	16.1	42.4	39.9	12.1	3.6	1.2	0.8	5.9	14.6	50.0	0.6	11.1	2.5	77.61	2.06	201.4	5.49

Table 6. Drainage-basin characteristics by subbasin in the Scituate Reservoir Basin, Rhode Island—*Continued*

USGS station No.	PWSB station No.	Wetlands: Forested	Wetlands: Non-forested	Slope: 0–5	Slope: 5–10	Slope: 10–15	Slope: 15–20	Slope: 20–25	Slope: > 25	Soil Drainability: Excessively drained	Soil Drainability: Moderately well drained	Soil Drainability: Well drained	Soil Drainability: Variable	Soil Drainability: Poorly drained	Soil Drainability: Very poorly drained	Roads: Primary miles (mi)	Roads: Primary road density (mi/mi²)	Roads: Secondary miles (mi)	Roads: Secondary road density (mi/mi²)
Moswansicut Reservoir Subbasin																			
01115170	19	11.2	16.8	28.3	29.2	23.7	12.3	4.3	2.2	6.0	16.0	48.3	1.4	6.3	6.8	19.16	5.99	27.6	8.62
01115160	20	**19.9**	2.5	18.1	36.0	28.4	13.2	3.6	.7	.3	30.7	47.6	.2	8.8	12.4	8.6	7.12	14.49	12.02
01115165	21	11.0	15.1	27.0	26.1	20.3	13.8	7.5	5.4	1.1	1.6	57.5	10.0	6.1	10.1	1.17	3.62	2.59	7.99
01115167	22	7.5	1.8	15.1	34.2	29.0	16.7	4.7	.3	20.5	7.8	62.4	.0	4.9	4.4	1.23	5.62	1.74	7.96
01115164	34	11.0	17.3	28.5	23.6	20.0	13.6	8.1	6.3	1.3	.0	54.9	**11.8**	4.1	11.9	1.72	4.28	2.59	9.44
Subbasin total..........		*11.2*	16.8	28.3	29.2	*23.7*	*12.3*	*4.3*	*2.2*	6.0	16.0	48.3	1.4	63.0	6.8	19.16	*5.99*	27.6	8.62
Ponaganset Reservoir Subbasin																			
011151843	23	5.7	**20.9**	38.5	31.4	18.0	7.8	2.8	1.5	3.0	35.8	26.9	0.0	10.0	0.8	0.6	0.32	17.94	9.63
Subbasin total..........		5.7	*20.9*	38.5	31.4	18.0	7.8	2.8	1.5	3.0	35.8	26.9	0.0	10.0	.8	0.6	0.32	17.94	9.63
Regulating Reservoir Subbasin																			
01115176	13	11.0	6.0	37.1	30.4	18.9	9.3	3.1	1.2	7.8	27.7	41.9	1.4	14.1	2.8	73.69	3.32	143.95	6.49
01115110	14	9.2	1.7	40.3	32.5	17.6	6.9	2.2	.6	1.1	44.6	42.1	.1	9.3	2.3	3.75	0.60	42.30	6.78
01115115	15	15.7	1.4	63.2	26.2	6.7	2.6	1.0	.3	2.7	38.0	29.5	1.6	25.9	2.1	23.0	4.62	26.73	5.37
01115098	16	8.9	3.6	18.5	32.6	27.3	15.1	4.8	1.7	8.4	8.5	61.9	2.1	17.1	.3	13.11	2.66	32.05	6.51
01115119	17	14.0	8.9	14.1	30.1	27.5	15.9	7.8	4.6	37.9	9.1	22.4	2.4	10.6	**13.3**	.0	.0	1.90	14.86
01115120	18	15.6	4.	18.5	34.9	27.7	13.8	3.8	1.2	21.3	14.5	34.4	8.2	12.6	8.0	2.68	4.99	3.37	6.26
Subbasin total..........		11.0	4.2	38.6	30.6	18.1	8.8	2.9	1.1	8.1	29.7	40.8	1.4	15.4	2.1	54.52	2.87	116.36	6.13
Westconnaug Reservoir Subbasin																			
01115274	10	7.9	0.1	50.9	41.3	7.0	0.7	0.1	0.0	5.4	35.8	39.4	0.1	19.3	0.0	5.69	4.14	6.71	4.88
01115273	11	15.1	1.5	30.2	42.9	20.3	5.2	1.2	.3	10.4	9.1	60.1	1.0	9.3	9.6	.21	.30	3.55	5.17
011152745	12	6.7	2.5	34.4	42.2	15.8	5.5	1.6	.5	34.2	1.1	51.5	.0	.0	13.2	2.08	13.86	1.64	1.96
Subbasin total..........		10.0	0.7	43.3	*41.9*	11.7	2..4	0.5	0.1	***8.9***	25.2	46.6	0.4	14.8	3.9	7.98	3.61	11.9	5.38
Scituate Reservoir Basin																			
Basin total		9.3	9.4	43.4	36.3	13.2	4.7	1.5	0.8	6.1	26.9	41.8	0.8	13.6	2.7	215.9	2.29	601.58	6.39