Water-Quality Conditions and Constituent Loads, Water Years 1996–2002, and Water-Quality Trends, Water Years 1983–2002, in the Scituate Reservoir Drainage Area, Rhode Island

By Mark T. Nimiroski, Leslie A. DeSimone, and Marcus C. Waldron

Prepared in cooperation with the
Providence Water Supply Board

Scientific Investigations Report 2008–5060

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

U.S. Department of the Interior
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Suggested citation:
Nimiroski, M.T., DeSimone, L.A., and Waldron, M.C., 2008, Water-quality conditions and constituent loads, water years 1996–2002, and water-quality trends, water years 1983–2002, in the Scituate Reservoir drainage area, Rhode Island: U.S. Geological Survey Scientific Investigations Report 2008–5060, 55 p.

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Conversion Factors and Abbreviations

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square kilometer [$(m^3/s)/km^2$]	91.49	cubic foot per second per square mile [$(ft^3/s)/mi^2$]
liter per second (L/s)	15.85	gallon per minute (gal/min)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

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

Concentrations of bacteria in water are given in colony-forming units (CFU) and in $CFU \times 10^6/d/mi^2$.

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

ABBREVIATIONS

CFU	colony-forming units
DOC	dissolved organic carbon
E. coli	*Escherichia coli*
MCL	maximum contaminant level
MPN	most probable number
NOAA	National Oceanic and Atmospheric Administration
NTU	nephelometric turbidity unit
NWISWeb	National Water Information System Web Site
PCU	platinum-cobalt units
RIDEM	Rhode Island Department of Environmental Management
RIDOH	Rhode Island Department of Environmental Health
SDWR	secondary drinking-water regulation
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WY	water year

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Abstract

The Scituate Reservoir is the primary source of drinking water for more than 60 percent of the population of Rhode Island. Water-quality data and streamflow data collected at 37 surface-water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, from October 1, 1995 through September 30, 2002, (water years (WY) 1996–2002) were analyzed to determine water-quality conditions and constituent loads in the drainage area. Trends in water quality, including physical properties and concentrations of constituents, were investigated for the same period and for a longer period from October 1, 1982 through September 30, 2002 (WY 1983–2002). Water samples were collected and analyzed by Providence Water Supply Board, the agency that manages the Scituate Reservoir. Streamflow data were collected by the U.S. Geological Survey. Median values and other summary statistics were calculated for WY 1996–2002 for all 37 monitoring stations for pH, color, turbidity, alkalinity, chloride, nitrite, nitrate, total coliform bacteria, *Escherichia coli* (*E. coli*) bacteria, orthophosphate, iron, and manganese. Instantaneous loads and yields (loads per unit area) of total coliform and *E. coli* bacteria (indicator bacteria), chloride, nitrite, nitrate, orthophosphate, iron, and manganese were calculated for all sampling dates during WY 1996–2002 for the 23 stations with streamflow data. Values of physical properties and concentrations of constituents were compared to State and Federal water-quality standards and guidelines, and were related to streamflow, land-use characteristics, and road density.

Tributary stream water in the Scituate Reservoir drainage area for WY 1996–2002 was slightly acidic (median pH of all stations equal to 6.1) and contained low concentrations of chloride (median 13 milligrams per liter (mg/L)), nitrate (median 0.04 mg/L as N), and orthophosphate (median 0.04 mg/L as P). Turbidity and alkalinity values also were low with median values of 0.62 nephelometric turbidity units and 4.8 mg/L as calcium carbonate, respectively. Indicator bacteria were detected in samples from all stations, but median concentrations were low, 23 and 9 colony-forming units per 100 mL for total coliform and *E. coli* bacteria, respectively. Median values of several physical properties and median concentrations of several constituents that can be related to human activities correlated positively with the percentages of developed land and correlated negatively with the percentages of forest cover in the drainage areas of the monitoring stations. Median concentrations of chloride also correlated positively with the density of roads in the drainage areas of monitoring stations, likely reflecting the effects of road-salt applications. Median values of color correlated positively with the percentages of wetlands in the drainage areas of monitoring stations, reflecting the natural sources of color in tributary stream waters. Negative correlations of turbidity, indicator bacteria, and chloride with streamflow likely reflect seasonal patterns, in which higher values and concentrations of these properties and constituents occur during low-flow conditions at the ends of water years. Similar seasonal patterns were observed for pH, alkalinity, and color.

Loads and yields of chloride, nitrate, orthophosphate, and bacteria varied among monitoring stations in the Scituate Reservoir drainage area. Loads generally were higher at stations with larger drainage areas and at stations in the eastern, more developed parts of the Scituate Reservoir drainage area. Yields generally were higher at stations in the eastern parts of the drainage area. Upward trends in pH were identified for nearly half the monitoring stations and may reflect regional reductions in acid precipitation. Upward and downward trends were identified in chloride concentrations at various stations; upward trends may reflect the effects of increasing development, whereas strong downward trends at two stations likely result from changes in storage practices at an upgradient road-salt storage facility.

Introduction

The Scituate Reservoir is the primary source of drinking water for more than 60 percent of the population of Rhode Island. The drainage area for the reservoir includes about 94 mi^2 in parts of the towns of Glocester, Foster, Scituate, Cranston, and Johnston, R.I. (fig. 1). During 1995–99, average withdrawals were 71 Mgal/d (110 ft^3/s). Other major water suppliers statewide withdraw 40 Mgal/d (62 ft^3/s) (Emily Wild, U.S. Geological Survey, written commun., 2006). About 60 percent of withdrawals from the reservoir directly supply retail customers and the remainder is used by 10 of the major water suppliers (Wild and Nimiroski, 2007).

Providence Water Supply Board (Providence Water), the agency that manages the reservoir and water-supply system, has collected water-quality data in the area contributing water to the reservoir for more than 50 years as part of its efforts to maintain high-quality source water. Most of the data collection has been done at 37 surface-water monitoring stations on rivers listed as “brooks and streams” in the Providence Water Annual Report (Providence Water Supply Board, 2005). Water-quality physical properties and constituent concentrations measured by Providence Water—pH, alkalinity, turbidity, color, chloride, nutrients, and indicator bacteria—are indicators of overall water-quality conditions. Water-quality data also have been collected by Providence Water at other stations in the drainage area to address site-specific concerns.

Thirty percent of the drainage area is managed and protected by Providence Water; the remaining 70 percent is privately owned (Richard Blodgett, Providence Water Supply Board, written commun., 2005). Human-induced changes in the drainage area, including changes in agricultural and industrial activities, urbanization, and other land-use changes, could cause degradation in the quality of the source water to the reservoir. In 2000, the U.S. Geological Survey (USGS), in cooperation with Providence Water, began an investigation to evaluate water-quality conditions—constituent loads, trends, and factors that affect water quality—by using data collected by Providence Water. A description of water-quality conditions could be used by water-resources managers to develop management plans for the drainage area. Data on instantaneous constituent loads and yields, which depend on both flow and constituent concentrations, contribute to an understanding of the relative importance of various tributary streams to the overall quality of the water in the reservoir. Knowledge of the time trends in the physical properties and constituents could allow water managers to predict future water-quality problems or recognize improvements. In addition, water-quality conditions and trends in the Scituate Reservoir drainage area may be representative of conditions in similar, relatively undeveloped or minimally developed drainage areas and reservoir source areas throughout the northeastern coastal United States.

Purpose and Scope

This report presents analyses of streamflow and water-quality data collected in the Scituate Reservoir drainage area during water years (WY)[1] 1996–2002 (October 1, 1995 through September 30, 2002). Water-quality data were collected by Providence Water personnel at 37 surface-water-monitoring stations distributed throughout the drainage area; streamflow data were collected by USGS personnel at 21 of the 37 stations as part of the present study. Analyses performed on the data included (1) determination of median values and concentrations and other summary statistics for water-quality physical properties and constituents for all monitoring stations; (2) comparison of median values and concentrations with factors potentially affecting water quality, including streamflow, land use, and road density; (3) determination of the frequencies at which water-quality standards or guidelines were exceeded at tributary monitoring stations during the period; (4) estimation of instantaneous loads and yields of selected water-quality constituents at the 19 stations for which streamflow data were available; and (5) identification of trends in values and concentrations of selected water-quality properties and constituents at all monitoring stations.

This report presents the following: median values for water-quality physical properties and constituent concentrations, description of relations between water-quality properties and concentrations and subbasin characteristics, and constituent loads and yields.

Previous Investigations

Water-quality data in the Scituate Reservoir drainage area have been collected by Providence Water since 1945. Most of these data have been published in annual reports by Providence Water (for example, Providence Water Supply Board, 2005). Water-quality data collected by Providence Water from 1982 to 1995 are summarized in Breault and others (2000) and include median values of physical properties and constituent concentrations, trends in selected constituent concentrations, and relations between constituent concentrations and drainage-area characteristics.

The presence of sodium and chloride in the drainage area and reservoir is an important concern of local water-resources managers. A USGS study (Nimiroski and Waldron, 2002) describes the sources of sodium and chloride in the Scituate Reservoir drainage area during WY 2000. In a concurrent USGS study (M.C. Waldron, U.S. Geological Survey, written commun., 2006) sodium and chloride loads in streams tributary to the reservoir were investigated, and a budget of inputs to and outputs from the reservoir system was generated

[1] A water year is defined as the period from October 1 through September 30 of the following year. The water year is designated by the calendar year in which it ends. Thus, the period from October 1, 2007 through September 30, 2008, is called the “2008 water year.”

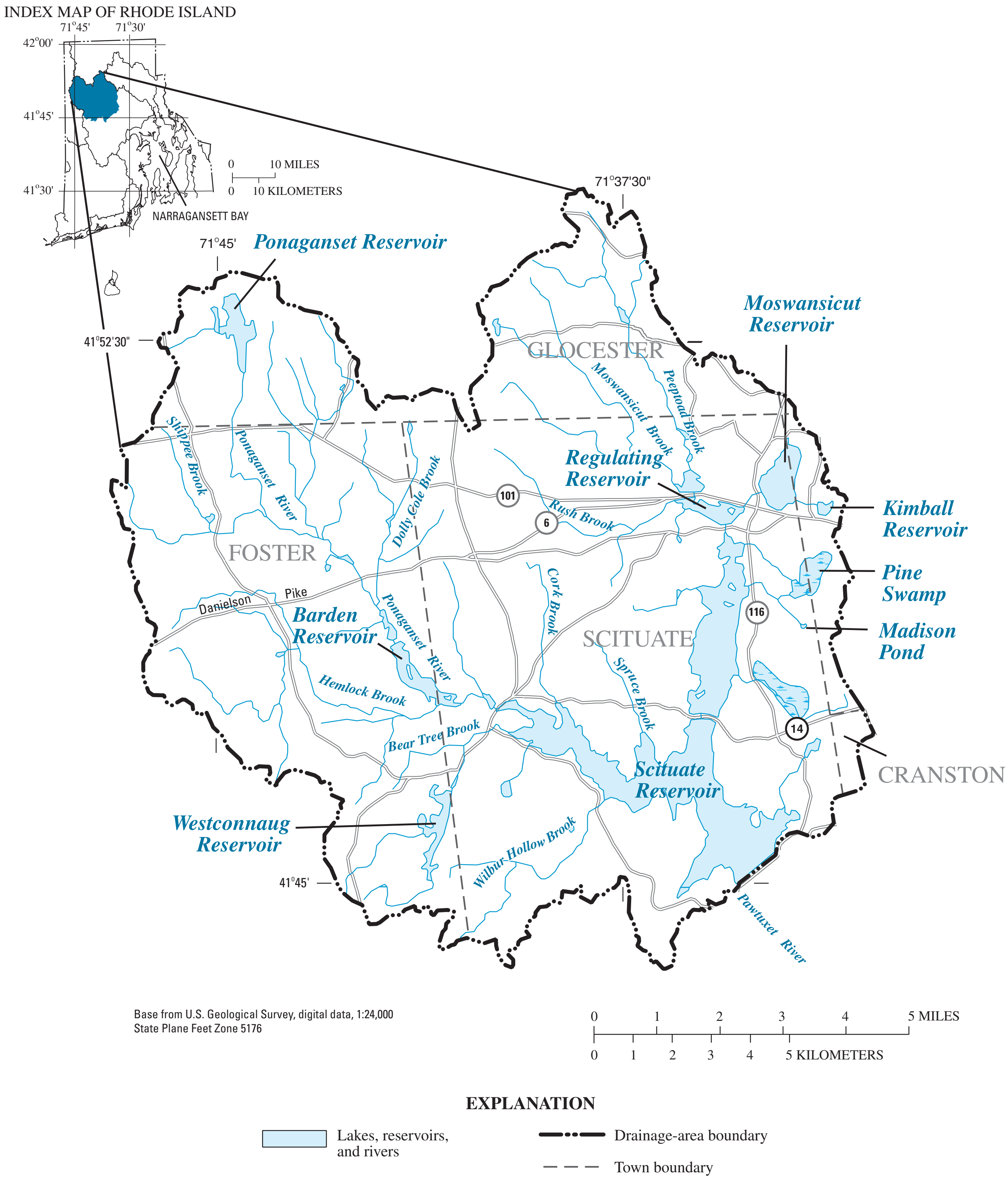


Figure 1. The Scituate Reservoir drainage area, Rhode Island.

for these loads. Equations were developed for estimating the loads of sodium and chloride at ungaged sites.

Streamflow data for the Scituate Reservoir drainage area have been collected by the USGS since 1993 at 21 partial-record streamflow-gaging stations and 2 continuous-record streamflow-gaging stations (fig. 2; table 1). The USGS also continuously monitors temperature and specific conductance at nine stations and collects turbidity data at one site. These data are published in USGS annual reports (for example, Socolow and others, 2003) and are available on the internet through the USGS National Water Information System Web Interface (NWISWeb; U.S. Geological Survey, 2006). As part of a larger study of low-flow characteristics in northern Rhode Island, streamflow data have been collected by the USGS at several additional stations in the Scituate Reservoir drainage area; these data are reported by Kliever (1996) and Gardner Bent (U.S. Geological Survey, written commun., 2005). The 2 continuous streamflow-gaging stations and 11 of the partial-record stations were installed as part of an earlier water-quality study (Breault and others, 2000). Streamflow measurements begun at 13 of these stations by the USGS in 1993 have been continued to the present (2006) in cooperation with Providence Water.

Description of the Study Area

The study area is in north-central Rhode Island and encompasses the Scituate Reservoir, six tributary reservoirs (Barden, Kimball, Moswansicut, Ponaganset, Regulating, and Westconnaug) and numerous mill ponds (fig. 1). This series of reservoirs has a combined capacity of more than 40 billion gallons and covers a surface area of about 7.2 mi^2. The drainage area surrounding the Scituate Reservoir represents about 9 percent of the total land area of Rhode Island. Providence Water owns about 28 mi^2 (30 percent) of the drainage area, and most of this area is forested land that is managed for water-quality protection and timber production (Richard Blodgett, Providence Water Supply Board, written commun., 2005). The remainder of the drainage area is privately owned.

Land Use

Land-use data were obtained from the statewide geographic information system maintained by the University of Rhode Island (Rhode Island Geographic Information, 1995), originally compiled in the 1970s and most recently updated in 2002 by using multispectral IKONOS satellite imagery to indicate changes since 1995 (Richard Blodgett, Providence Water Supply Board, written commun., 2004). Land use and land cover in the Scituate River drainage area, determined on the basis of the updated data, is primarily undeveloped. Forest (65 percent), wetlands (10 percent), and water (8 percent) combined covered about 83 percent of the drainage area in 1995 (fig. 3). Developed areas consisted of residential (11 percent), agricultural (4 percent), nonresidential urban (1.4 percent) and other (0.6 percent) land uses. The distribution of land use in the drainage area in 2002 represents a slight decrease (about 0.7 mi^2 and 0.7 percent) in forested land use and a slight increase (about 0.6 mi^2 and 0.6 percent) in residential land use since 1995 (Rhode Island Geographic Information System, 1995).

Eastern parts of the drainage area are more developed than the rest of the drainage area (fig. 3) and are closest to the city of Providence by way of a State Highway, Route 6. The Moswansicut and Regulating Reservoir subbasins, which are small subbasins in the northeastern part of the drainage area, have the lowest percentages of undeveloped area (62 and 77 percent, respectively, including forest, wetland, and water) and highest percentages of residential land use (26 and 14 percent, respectively) relative to the other four subbasins (table 2). The Moswansicut Reservoir subbasin also has the largest percentage (3.1 percent) of nonresidential urban land use, which includes commercial, industrial, and transportation land uses. Examples of developed land uses in the Moswansicut Reservoir subbasin are shown in figures 4A and B. In contrast, the Barden and Westconnaug Reservoir subbasins in the western part of the drainage area have the highest percentages (86 and 84 percent, respectively) of undeveloped land and relatively low percentages of residential land use (8.7 and 9 percent, respectively).

Climate

Climate in the Scituate Reservoir drainage area is temperate, with a mean annual temperature of 48.6°F, as measured at a National Oceanic and Atmospheric Administration (NOAA) climatological station in operation since 1972, in the Barden Reservoir subbasin in Foster, R.I. (National Oceanic and Atmospheric Administration, 2003). The long-term mean annual precipitation at the NOAA Foster station for the period 1972–2002 was 51.56 in. During WY 1996–2002, precipitation at this station averaged 57.70 in., about 6 in. higher than the long-term mean.

Geology

The bedrock in the drainage area is mostly granite and granitic gneiss; some metasedimentary and mafic igneous rocks also are present (Hermes and others, 1994). Glacial deposits of Pleistocene age overlie the bedrock (Richmond and Allen, 1951; Allen, 1953). Glacial materials consist of ice-laid deposits (till or ground moraine) and meltwater deposits (sand and gravel). Till or ground moraine, locally called "hardpan," is a mixture of nonsorted sand, silt, clay, and boulders that is generally compacted and blankets the bedrock surface. Typically, till was not carried far and thus reflects the character of the underlying bedrock (Robinson, 1961). The meltwater deposits consist of poorly sorted to well sorted sand and gravel and are primarily in stream valleys. As a result, meltwater deposits typically underlie the reservoir water bodies.

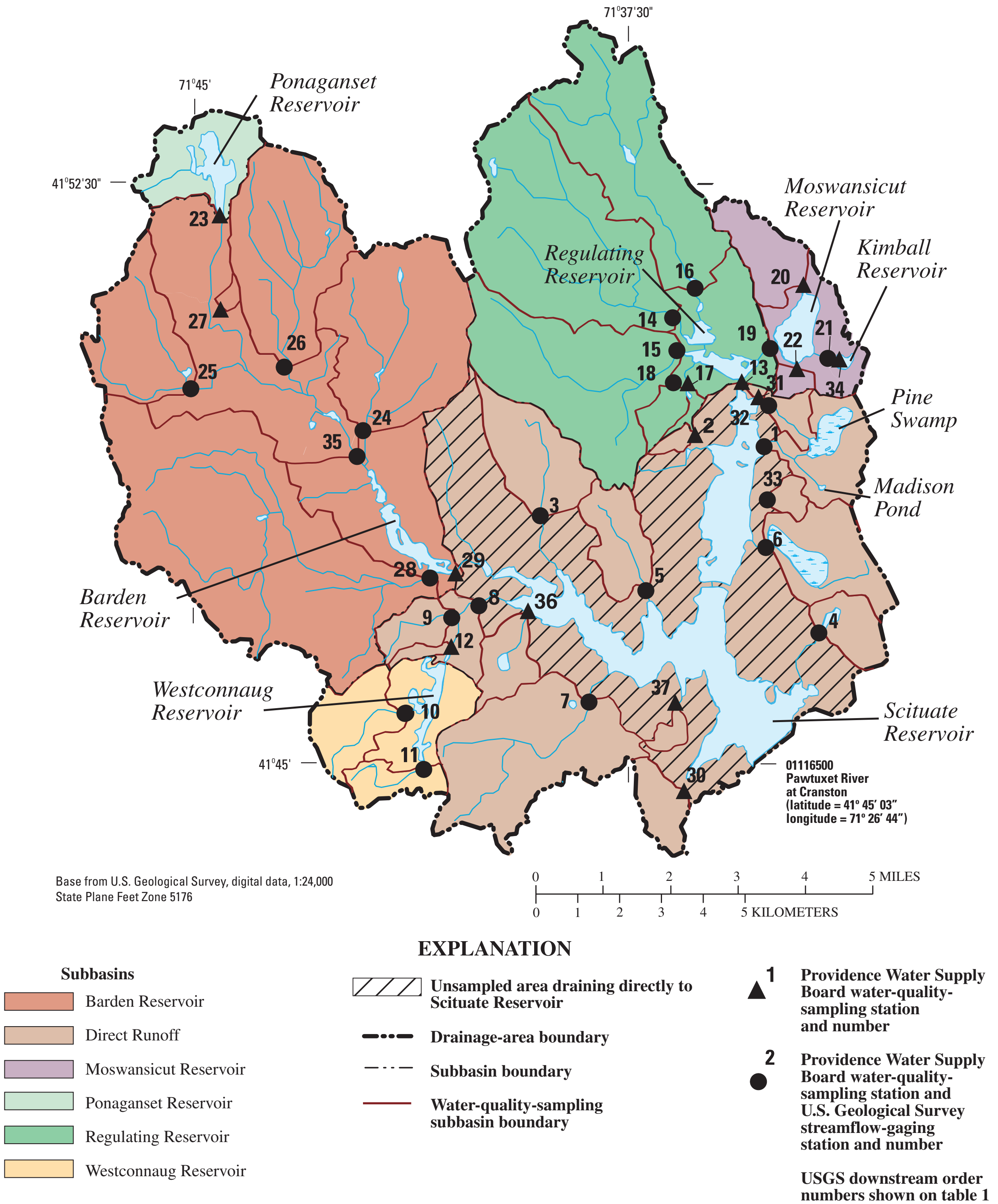


Figure 2. Tributary-reservoir subbasins with Providence Water water-quality sampling stations and U.S. Geological Survey streamflow-monitoring stations in the Scituate Reservoir drainage area, Rhode Island.

Table 1. Providence Water monitoring stations, water-quality samples, and available streamflow data by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island.

[PW, Providence Water; USGS, U.S. Geological Survey; mi^2, square mile; --, not applicable or not determined. **Station name**: Alternate names in parentheses are names that appear in Providence Water annual reports (for example, Providence Water Supply Board, 2005). **Drainage area**: Sums of station drainage areas do not equal subbasin totals because some drainage areas are nested. **Frequency of collection**: M, monthly; Q, quarterly]

PW station number	USGS streamflow-gaging station number	Station name	Drainage area (mi^2)	Water-quality samples, 1996–2002		Available USGS stream-flow data 1993–2002
				Frequency of collection	Number	
		Barden Reservoir subbasin				
24	01115190	Dolly Cole Brook	5.01	M	79	Periodic
25	01115200	Shippee Brook	2.39	Q	33	Periodic
26	01115185	Windsor Brook	4.22	Q	31	Periodic
27	011151845	Unnamed Tributary to Ponaganset River (Unnamed Brook west of Windsor Brook)	.10	Q	17	None
28	01115270	Barden Reservoir (Hemlock Brook)	10.62	M	78	Periodic
29	01115271	Ponaganset River (Barden Stream)	33.02	M	61	None
35	01115187	Ponaganset River	14.40	M	69	Continuous
--	**--**	**Subbasin total**	**31.16**	**--**	**--**	**--**
		Direct Runoff subbasins				
1	01115180	Brandy Brook	1.57	M	80	Periodic
2	01115181	Unnamed Tributary #2 to Scituate Reservoir (Unnamed Brook north of Bullhead Brook)	.15	Q	12	None
3	01115280	Cork Brook	1.90	M	75	Periodic
4	01115400	Kent Brook	.86	M	78	Periodic[1]
5	01115184	Spruce Brook	1.23	Q	28	Periodic
6	01115183	Quonapaug Brook	1.99	M	71	Periodic
7	01115297	Wilbur Hollow Brook	4.42	M	80	Periodic
8	01115276	Westconnaug Brook (Westconnaug Stream)	5.10	M	66	Periodic[1]
9	01115275	Bear Tree Brook	.64	Q	33	Periodic
30	01115350	Unnamed Tributary #4 to Scituate Reservoir (Coventry Brook)	.74	Q	30	None
31	01115177	Toad Pond	.04	Q	10	None
32	01115178	Unnamed Tributary #1 to Scituate Reservoir (Pine Swamp Brook)	.40	Q	27	Periodic
33	01115182	Unnamed Tributary #3 to Scituate Reservoir (Hall's Estate Brook)	.27	Q	24	Periodic
36	--	Outflow from King Pond	.77	Q	21	None
37	--	Fire Tower Stream	.15	Q	21	None
--	**--**	**Subbasin total**	**36.70**	**--**	**--**	**--**
		Moswansicut Reservoir subbasin				
19	01115170	Moswansicut Reservoir	3.20	M	66	Periodic
20	01115160	Unnamed Tributary #1 to Moswansicut Reservoir (Blanchard Brook)	1.21	M	68	None
21	01115165	Unnamed Tributary #2 to Moswansicut Reservoir (Brook from Kimball Reservoir)	.32	Q	23	Periodic
22	01115167	Moswansicut Reservoir (Moswansicut Stream South)	.22	M	70	None
34	01115164	Kimball Stream	.27	Q	14	None
--	**--**	**Subbasin total**	**3.20**	**--**	**--**	**--**

Table 1. Providence Water monitoring stations, water-quality samples, and available streamflow data by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island.—Continued

[PW, Providence Water; USGS, U.S. Geological Survey; mi^2, square mile; --, not applicable or not determined. **Station name**: Alternate names in parentheses are names that appear in Providence Water annual reports (for example, Providence Water Supply Board, 2005). **Drainage area**: Sums of station drainage areas do not equal subbasin totals because some drainage areas are nested. **Frequency of collection**: M, monthly; Q, quarterly]

PW station number	USGS streamflow-gaging station number	Station name	Drainage area (mi^2)	Water-quality samples, 1996–2002		Available USGS streamflow data 1993–2002
				Frequency of collection	Number	
		Ponaganset Reservoir subbasin				
23	011151843	Ponaganset Reservoir	1.86	M	52	None
--	--	**Subbasin total**	**1.86**	--	--	--
		Regulating Reservoir subbasin				
13	01115176	Regulating Reservoir	22.17	M	72	None
14	01115110	Huntinghouse Brook	6.24	M	80	Periodic
15	01115115	Regulating Reservoir (Rush Brook)	4.98	M	72	Periodic
16	01115098	Peeptoad Brook	4.92	M	80	Continuous
17	01115119	Dexter Pond (Paine Pond Brook)	.13	Q	26	None
18	01115120	Unnamed Tributary to Regulating Reservoir (Unnamed Brook A)	.54	Q	20	Periodic
--	--	**Subbasin total**	**18.97**	--	--	--
		Westconnaug Reservoir subbasin				
10	01115274	Westconnaug Brook	1.37	M	64	Periodic
11	01115273	Unnamed Tributary to Westconnaug Reservoir (Unnamed Brook south of Westconnaug Reservoir)	.69	Q	21	Periodic
12	011152745	Unnamed Tributary to Westconnaug Brook (Unnamed Brook north of Westconnaug Reservoir)	.15	Q	22	None
--	--	**Subbasin total**	**2.21**	--	--	--

[1] Streamflow data were collected as part of U.S. Geological Survey low-flow studies.

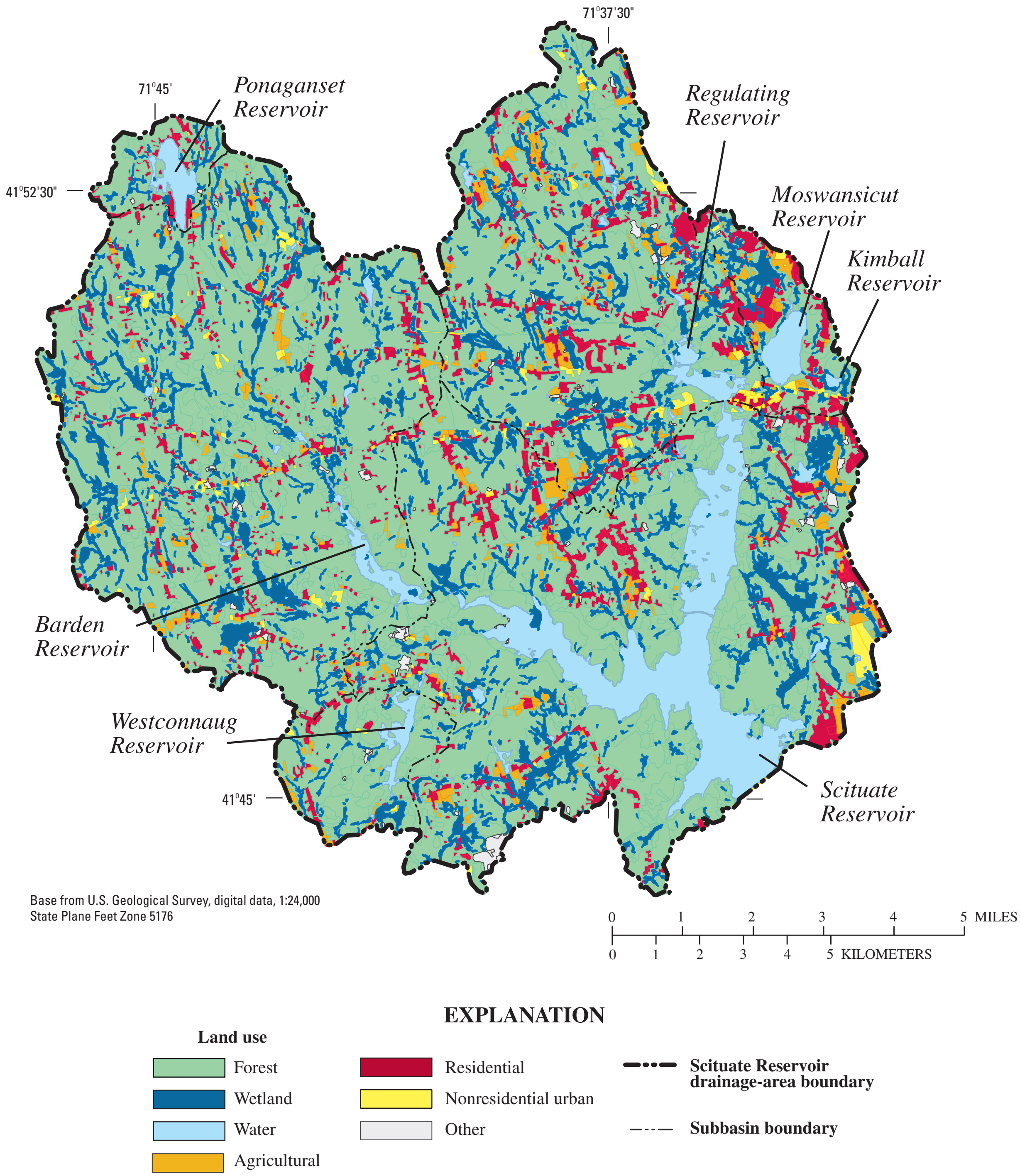


Figure 3. Land use in the Scituate Reservoir drainage area, Rhode Island, 1995.

Table 2. Land use in subbasins of Providence Water monitoring stations by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island.

[PW, Providence Water]

PW station number	Land use (percent of subbasin area)						
	Forest	Water	Wetland	Agricultural	Residential	Nonresidential urban	Other
			Barden Reservoir subbasin				
24	75.6	1.4	9.6	2.0	10.9	0.5	0.0
25	74.0	.7	13.8	1.1	8.8	1.4	.3
26	71.7	.2	12.1	5.7	7.9	2.2	.1
27	69.5	.0	11.3	3.0	14.3	2.0	.0
28	71.8	.4	13.1	3.8	8.9	1.5	.5
29	72.8	2.9	10.6	3.1	9.0	1.3	.3
35	76.8	.8	8.8	3.6	8.8	1.0	.1
Subbasin total	**73.8**	**1.8**	**10.9**	**3.2**	**8.7**	**1.3**	**.3**
			Direct Runoff subbasins				
1	41.8	4.3	18.6	10.2	20.8	0.4	3.9
2	55.0	.6	12.9	4.4	26.6	.0	.5
3	60.0	.1	14.8	6.2	17.4	1.3	.3
4	57.1	4.6	13.5	6.3	2.8	15.7	.0
5	64.4	.1	11.0	4.1	19.8	.0	.7
6	52.9	.1	20.1	6.9	15.7	3.4	.9
7	64.8	1.2	15.3	4.9	10.2	.4	3.2
8	71.8	5.5	7.9	4.4	7.8	.9	1.6
9	58.6	.3	11.8	9.8	7.6	1.9	10.1
30	84.8	.2	8.0	.0	7.0	.0	.0
31	43.4	8.3	.0	.0	17.9	30.4	.0
32	55.9	.0	16.6	2.1	21.2	1.0	3.3
33	59.4	.0	15.9	3.0	21.7	.0	.0
36	73.8	4.1	12.2	4.7	4.6	.7	.0
37	94.0	.0	6.0	.0	.0	.0	.0
Subbasin total	**61.2**	**15.1**	**9.5**	**3.4**	**8.8**	**1.0**	**.9**
			Moswansicut Reservoir subbasin				
19	34.7	14.6	13.0	8.2	26.4	3.1	0.1
20	30.2	.0	21.8	12.4	33.4	2.0	.2
21	51.5	10.3	15.7	1.3	16.7	4.4	.0
22	37.6	.4	8.9	1.5	35.8	15.8	.0
34	50.9	12.0	16.3	1.6	14.0	5.2	.0
Subbasin total	**34.7**	**14.6**	**13.0**	**8.2**	**26.4**	**3.1**	**.1**
			Ponaganset Reservoir subbasin				
23	57.2	20.2	7.0	0.0	14.9	0.3	0.4
Subbasin total	**57.2**	**20.2**	**7.0**	**.0**	**14.9**	**.3**	**.4**
			Regulating Reservoir subbasin				
13	58.7	4.8	11.5	6.5	15.7	2.2	0.6
14	68.8	.5	10.1	6.9	13.1	.4	.2
15	60.2	.3	15.5	6.4	15.6	1.5	.5
16	63.7	1.8	9.7	7.3	13.5	2.2	1.6
17	43.7	3.9	17.7	10.7	18.7	1.9	3.3
18	48.9	15.1	4.2	7.0	14.7	9.3	.8
Subbasin total	**62.8**	**3.1**	**11.3**	**6.3**	**13.9**	**2.0**	**.6**
			Westconnaug Reservoir subbasin				
10	75.2	0.0	8.2	6.0	8.9	0.7	1.0
11	69.5	.3	17.2	5.2	6.5	1.0	.4
12	64.4	.6	8.6	3.8	21.2	1.1	.2
Subbasin total	**72.7**	**.1**	**11.0**	**5.6**	**9.0**	**.8**	**.8**

Figure 4. Potential sources of contamination and tributary stream sites in the Scituate Reservoir drainage area, Rhode Island, include *(A)* waterfowl near a nursery pond in the Moswansicut Reservoir subbasin, *(B)* recreational playing fields and commercial development in the Moswansicut Reservoir subbasin, *(C)* road and Providence Water sampling station 13 in the Regulating Reservoir subbasin, and *(D)* road and Providence Water sampling station 24 in the Barden Reservoir subbasin.

Hydrology

The Scituate Reservoir drainage area encompasses the Scituate Reservoir and six smaller tributary reservoirs that are fed by numerous small rivers and streams (fig. 1). The Ponaganset River, Peeptoad Brook, and Hemlock Brook are the largest tributaries to the Scituate Reservoir. The Pawtuxet River begins at the outlet of the Scituate Reservoir and flows eastward to Narragansett Bay. Mean annual flow in the Pawtuxet River at Cranston, R.I., was 348 ft^3/s (1.74 $ft^3/s/mi^2$) based on a 63-year period of record from 1939–2002 (Socolow and others, 2003). During WY 1996–2002, mean annual streamflow at the streamflow-gaging station Pawtuxet River at Cranston, R.I., was 346 ft^3/s (1.73 $ft^3/s/mi^2$), about equal to the long-term average. This station has a drainage area of about twice that of the Scituate Reservoir. At the two continuous-record streamflow-gaging stations in the Scituate Reservoir drainage area (station 35, Ponaganset River at South Foster and station 16, Peeptoad Brook at Elmdale Road; fig. 2), mean daily flow averaged 33.0 ft^3/s (2.29 $ft^3/s/mi^2$) and 9.78 ft^3/s (1.99 $ft^3/s/mi^2$), respectively, for WY 1996–2002. These two stations have drainage areas of 14.4 mi^2 and 4.92 mi^2, respectively (table 1). The relatively small size of the tributary streams causes them to react fairly quickly to rainfall during periods of both increasing and decreasing stage. Streams of this type are termed “flashy,” and reactions can be observed as sharp peaks in hydrographs.

Surface water and ground water are closely connected in the Scituate River drainage area, as is typical of valley-fill hydrogeologic settings in the northeastern United States. Ground water is recharged from precipitation and generally flows from topographic highs in the uplands toward stream channels and meltwater glacial deposits in the stream valleys (Hahn and Hansen, 1961; Hansen, 1962; Pollock, 1960). Streams typically are gaining, and along with wetlands, are discharge areas for ground water.

Methods of Study

Water-quality data were obtained from Providence Water. The data are based on samples collected and analyzed by Providence Water personnel during WY 1996–2002 and previous years. Streamflow data have been collected by the USGS, in cooperation with Providence Water and the Rhode Island Department of Environmental Management (RIDEM), at many of the Providence Water water-quality-monitoring stations since 1993.

Water-Quality Data

Water-quality data from WY 1996–2002 were obtained electronically from a water-quality database maintained by Providence Water (George Solitro, Providence Water Supply Board, written commun., 2005). Water-quality data for trend analysis were obtained for years prior to 1996 from Providence Water annual reports (for example, Providence Water Supply Board, 2005). During WY 1996–2002, the samples were collected monthly at 19 stations and quarterly at 18 stations in the Scituate Reservoir drainage area (table 1). Sampling frequencies pertaining to data collected prior to WY 1996 varied (Breault and others, 2000). Typically, samples were collected on about the same days of each month. Occasionally, samples could not be collected because streams at the sampling stations were dry or frozen.

Water-quality samples were collected by dipping the sample bottle into the stream at the center of flow (Richard Blodgett, Providence Water Supply Board, written commun., 2005). Samples were transported on ice to the water-quality laboratory of Providence Water at the P.J. Holton Water Purification Plant in Scituate, R.I., for analysis. Samples were not filtered prior to analysis. Sample-collection, analytical, and quality-control procedures are described in a Quality Assurance Program Manual (Providence Water Supply Board Water Quality Laboratory, 2005).

The physical properties and constituent concentrations monitored included pH, color, turbidity, total coliform bacteria, *Escherichia coli (E. coli)* bacteria, alkalinity, chloride, nitrite, nitrate, orthophosphate, iron, and manganese. Analytical methods used for the determination of values or concentrations of pH, color, turbidity, total coliform bacteria, alkalinity, chloride, nitrite, and nitrate are those documented by the American Public Health Association and others (1995). Concentrations of orthophosphate were determined by the Hach PhosVer Method (Hach Method 8048, Hach Company, 2000). Concentrations of iron and manganese were determined by Hach methods (Hach Methods 8008 and 8149) and by atomic absorption spectrophotometry (U.S. Environmental Protection Agency Methods SM 3111B and 200.9, respectively) as described by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1994). Not all analyses were continued throughout the entire 20-year period (WY 1983–2002). Monitoring of nitrate began in 1987. Monitoring of *E. coli* bacteria began in 1992, but data for *E. coli* collected prior to WY 1995 were not included in this investigation. Monitoring of iron and manganese was discontinued in 1996.

The interpretations of water-quality analyses made for this study are limited in some cases by a lack of available information about the historical and current water-quality data. For example, it was not possible to evaluate the accuracy, precision, or bias of laboratory analyses because laboratory quality-control data were not available. Similarly, it was not possible to evaluate the in situ variability of values of physical properties and constituent concentrations or the potential for sample contamination because field quality-control data were not available. Where possible, approaches were used to minimize the limitations that may have resulted from the use of existing data, or to assure that interpretations were based on a well-represented data set. For example, a lack of ancillary information or sample documentation precluded the identification of data values that may have been suspect. The use of nonparametric, rank-based analytical methods reduced the potential effects of these outliers.

The samples analyzed for physical properties and constituents were collected during a wide range of flow conditions. As an example, figure 5 shows the flow duration curve for the Ponaganset River at South Foster (USGS station number 01115187). The flows at this station on days when water-quality samples were collected at a representative station (Dolly Cole Brook) are superimposed on the line. The graphs show that samples were collected at this station during a broad range of flow conditions.

Changes in analytical methods over time could be an unidentified source of variability and trends in the water-quality data. The potential effects of changing analytical detection limits over time were addressed by applying uniform assessment levels, which represent the highest reported detection limit in the data set, to selected constituents. These assessment levels were 3 (lower) and 2,400 (upper) colony-forming units per 100 mL (CFU/100 mL) for total coliform and *E. coli* bacteria, 0.002 mg/L as N for nitrite, 0.01 mg/L as N for nitrate, and 0.02 mg/L as P for orthophosphate.

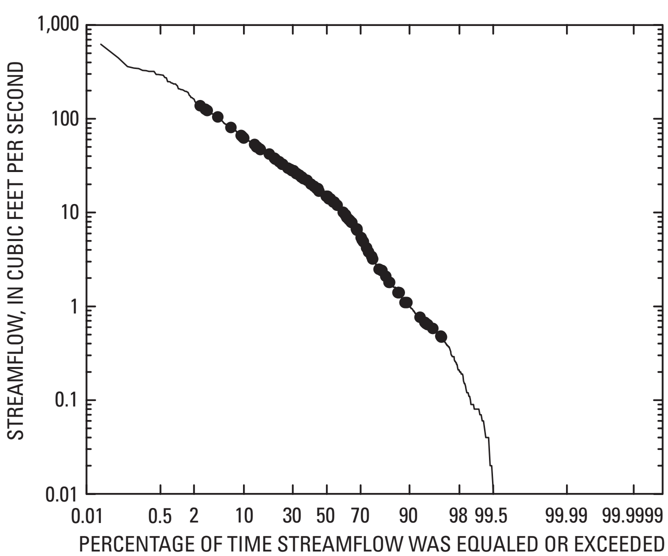


Figure 5. Flow-duration curves for the U.S. Geological Survey continuous-record streamflow-gaging station Ponaganset River at South Foster (station 01115187) and streamflows at the Ponaganset River station (shown as dots) on water-quality-sampling dates at Dolly Cole Brook.

Compilation and Analysis of Streamflow Data

Streamflow data have been collected at 15 of the 37 Providence Water monitoring stations (table 1) since 1995. Streamflow has been monitored continuously at two stations (stations 16 and 35, as described previously) since 1994. Streamflow was measured periodically, about 6 times per year, at 13 measurement stations (partial-record stations) during WY 1996–2002. Six additional stations were measured during WY 1994–95 for a study of low-flow statistics in Rhode Island (Kliever, 1996; Gardner Bent, U.S. Geological Survey, written commun., 2003). Streamflow data for continuous- and partial-record stations were published annually in the USGS Water-Data Reports, together with records of temperature and specific conductance (Socolow and others, 1997, 1998, 1999, 2000, 2001, 2002, 2003); records are available on the USGS NWISWeb site (U.S. Geological Survey, 2006).

Estimation of Instantaneous Loads and Yields

Instantaneous loads and yields (loads per unit area) of water-quality constituents were calculated for all sampling dates during the study period for the 23 stations for which periodic or continuous streamflow data were available (table 1). These loads were calculated by using constituent concentrations in single samples multiplied by the mean daily flow for the date when the sample was collected. These flows, which in most cases were estimated, were assumed to be an accurate representation of the flow at the time of the sample collection. Loads and yields were calculated for total coliform and *E. coli* bacteria, chloride, nitrate, orthophosphate, iron, and manganese. Loads of nitrite were not calculated because measured values typically were near the analytical detection limit. Median values of loads and yields are reported as medians for all water-quality sampling dates during WY 1996–2002. Instantaneous loads for many of these constituents are available for WY 1995 in Breault and others (2000).

For constituents with censored data (nondetections), minimum and maximum loads were calculated, where values less than the assessment level (uniform reporting level) were set equal to 0 for minimum loads and were set equal to the assessment level for maximum loads. Yields were calculated by dividing instantaneous load by drainage area for each sampling station. The calculation of yields allows for direct comparison of loads at stations with different drainage areas. Loads are given in kilograms (or millions of CFUs for bacteria) per day, and yields are given in kilograms (or millions of CFUs for bacteria) per day per square mile.

Mean daily flows at the 21 partial-record stations on the water-quality sampling dates were estimated by using the Maintenance of Variance Extension type 1 method (MOVE.1; Hirsch, 1982). In the MOVE.1 method, a relation is developed between measured instantaneous flow at a partial-record station and mean daily flow at one or more continuous-record streamflow-gaging stations (Ries and Friesz, 2000; DeSimone and others, 2002). Once this relation is developed, streamflow at the ungaged partial-record station can be estimated for any date on which the continuous streamflow records are available. It is assumed that the relation between flow at the partial-record station and flow at the continuous-record station remains constant through time and is consistent over the range of flows in the time period of interest.

Streamflow data from continuous-record streamflow-gaging stations in Rhode Island, southern Massachusetts, and western Connecticut, including the two in the study area (01115098 and 01115187), were used to estimate flow at the partial-record stations (table 3). Drainage areas for the continuous-record stations range from 4.02 to 35.2 mi^2. Data from one to five of the continuous-record stations were used to estimate flow for each partial-record station (table 4). Criteria for use of a particular continuous-record station include the degree of correlation between measured flows at the continuous-record and partial-record stations, as measured by the coefficient of determination (R^2), and the resulting range of calculated flows at the partial-record station, in cubic feet per second per square mile (table 4). Flows at partial-record stations were measured during a wide range of flows at the continuous record stations. As an example, the line on figure 6 is the daily-mean flow-duration curve for Ponaganset River at South Foster (01115187) for water years 1996 through 2002; figure 6 also shows the flows at Ponaganset River when concurrent flows were measured at Dolly Cole Brook. Flows on these days at Ponaganset River span about 95 percent of the flow-duration curve. This indicates that discharge measurements at Dolly Cole Brook represent flow over a wide range of flow conditions. Flows estimated for a partial-record station by using flows from multiple continuous-record stations were combined into a single estimated flow for each sampling date by using a weighting scheme based on the error of the estimate (DeSimone and others, 2002).

Determination of Correlations and Trends

To examine factors affecting water quality in the Scituate Reservoir drainage area, a correlation analysis was performed relating streamflow and subbasin characteristics, such as land use and road density, to median values or concentrations from WY 1996–2002 of pH, color, turbidity, total coliform and *E. coli* bacteria, chloride, nitrate, orthophosphate, iron, and manganese. The analysis was not performed for nitrite because measured values typically were near the analytical detection limit. The nonparametric Spearman correlation test, which is performed on the ranks of the data, was used (Helsel and Hirsch, 2002). Censored data values were set equal to a value less than the uniform assessment level for each constituent; this approach is appropriate for correlation analysis using rank-based, nonparametric methods (Helsel, 2005). A significant correlation was defined as one with a probability of results from chance associations of the data equal to less than 5 percent (p value less than 0.05). Road-density data were obtained by dividing the total length of State- and town-maintained roads in a subbasin by the subbasin area; these data were developed for a concurrent study of sodium and chloride loads in the drainage area (M.C. Waldron, U.S. Geological Survey, written commun., 2006).

Time trends in concentrations of water-quality constituents can indicate long-term changes in stream-water quality. Statistical tests to identify time trends were performed for pH, color, turbidity, total coliform and *E. coli* bacteria, alkalinity, chloride, nitrate, and orthophosphate at all monitoring stations. Trend tests were not performed for nitrite because measured values were typically near the analytical detection limit. Trend tests were performed separately on water-quality physical properties and constituent concentrations for WY 1996–2002 and for the longer period WY 1983–2002.

Table 3. Description of continuous streamflow-gaging stations used to estimate flows at partial-record stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.

[**Period of record**: Limited data may be available for some stations prior to date shown. USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Reference number	Station name	Drainage area (mi^2)	Period of record
01110000	1	Quinsigamond River at North Grafton, Mass.	25.6	1939–present (2002)
01111300	2	Nipmuck River near Harrisville, R.I.	16.0	1964–present[1]
01115187	3	Ponaganset River near South Foster, R.I.	13.7	1994–present
01115098	4	Peeptoad Brook at Elmdale Road near North Scituate, R.I.	4.96	1994–present
01117468	5	Beaver River near Usquepaug, R.I.	8.87	1974–present
01117800	6	Wood River near Arcadia, R.I.	35.2	1964–present[2]
01118300	7	Pendleton Hill Brook near Clarks Falls, Conn.	4.02	1958–present

[1] Period of record omits October 1991 through September 1993.

[2] Period of record omits October 1981 through September 1982.

Table 4. Partial-record stations in the Scituate Reservoir drainage area, Rhode Island, for which records were estimated from records of nearby continuous streamflow-gaging stations.

[Station locations shown on figure 2. **Station name**: Alternate names in parentheses are names that appear in Providence Water annual reports (for example, Providence Water Supply Board, 2005). USGS, U.S. Geological Survey; PW, Providence Water; mi^2, square mile. **Continuous streamflow-gaging stations used in analysis**: Reference numbers are in table 3.]

USGS station number	PW station number	Station name	Drainage area (mi^2)	Reference numbers of continuous streamflow-gaging stations used in analysis	Number of measurements used in analysis	Years of measurements	Correlation coefficients
		Barden Reservoir subbasin					
01115190	24	Dolly Cole Brook	5.01	2,3,4,5	67	1994–2004	0.87–0.92
01115200	25	Shippee Brook	2.39	7	15	1994–95, 2003	.93
01115185	26	Windsor Brook	4.22	2	51	1994–95, 1998–2002	.89
01115270	28	Barden Reservoir (Hemlock Brook)	10.62	2,3,4,6	54	1995–2004	.91–.96
		Direct Runoff subbasins					
01115180	1	Brandy Brook	1.57	3,4,6	64	1994–2004	0.89–0.93
01115280	3	Cork Brook	1.90	2	69	1994–2004	.86–.88
01115400	4	Kent Brook	.86	3	9	1994–95	.90
01115184	5	Spruce Brook	1.23	3,4,5,6	68	1994–2004	.86–.92
01115183	6	Quonapaug Brook	1.99	2	59	1994–2004	.88–.89
01115297	7	Wilbur Hollow Brook	4.42	2,4	66	1994–2004	.86
01115276	8	Westconnaug Brook (Westconnaug Stream)	5.10	5,6	14	1994–95, 2003	.84
01115275	9	Bear Tree Brook	.64	2,3,4,5,6	44	1994–2004	.85–.89
01115178	32	Unnamed Tributary #1 to Scituate Reservoir (Pine Swamp Brook)	.40	3,4	10	1994–95, 2003	.91–.97
01115182	33	Unnamed Tributary #3 to Scituate Reservoir (Hall's Estate Brook)	.27	2	12	1994–95, 2003	.80
		Moswansicut Reservoir subbasin					
01115170	19	Moswansicut Reservoir	3.20	2,3,4	41	1994–95, 2000–04	0.84–0.96
01115165	21	Unnamed Tributary #2 to Moswansicut Reservoir (Brook from Kimball Reservoir)	.32	2,4,7	17	1994–95, 2003	.74
		Regulating Reservoir subbasin					
01115110	14	Huntinghouse Brook	6.24	2,3,4,6	62	1994–2004	0.93–0.96
01115115	15	Regulating Reservoir (Rush Brook)	4.98	2,3,4,6	41	1997–2004	.90–.94
01115120	18	Unnamed Tributary to Regulating Reservoir (Unnamed Brook A)	.54	3,4,6	39	1995–2004	.83–.88
		Westconnaug Reservoir subbasin					
01115274	10	Westconnaug Brook	1.37	2	11	1994–95, 2003	0.84
01115273	11	Unnamed Tributary to Westconnaug Reservoir (Unnamed Brook south of Westconnaug Reservoir)	.15	2	19	1994–95, 2003	.59

Trends for each multiyear period were analyzed by using the seasonal Kendall test (Helsel and Hirsch, 2002). This test accounts for the natural seasonal variation in values of water-quality properties or concentrations of constituents that occur seasonally from changes in streamflow, temperature, biological activity, or other factors. Censored data values were set equal to a value less than the uniform assessment level for each constituent; this approach is appropriate for trend analysis using rank-based, nonparametric methods (Helsel and Hirsch, 2002). The Mann-Kendall test was done separately on subsets of the data grouped by "seasons," for example, months or quarters of the year. In this way, values or concentrations for a given season were compared only to properties or concentrations for the same season during all of the years. A single test result (Kendall's S statistic, Sk) was obtained for all seasons for each physical property or constituent concentration as the sum of the test statistics determined for each season. For this study, seasons were defined as each of the 12 months of the year for the 19 stations where samples were collected monthly and as each of the four quarters of the year for the 18 stations where samples were collected quarterly (table 1). Each season in each year was represented by one sample. A trend was considered significant if the calculated *p* value of the test was less than 0.05, as described previously. For test results that were considered significant, the direction of the trend, upward or downward, was noted.

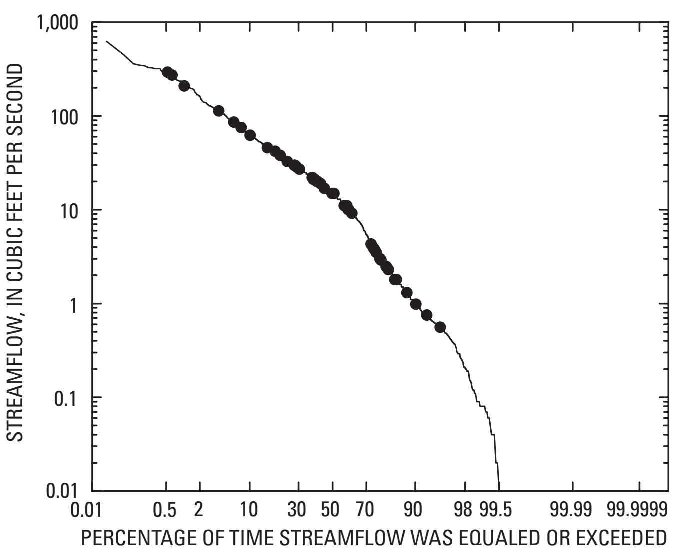


Figure 6. Flow-duration curves for a U.S. Geological Survey continuous-record streamflow-gaging station on the Ponaganset River at South Foster (station 01115187) and streamflows at the Ponaganset River station (shown as dots) on flow-measurement dates at Dolly Cole Brook.

Water-Quality Conditions and Constituent Loads, WY 1996–2002

Water-quality conditions in the Scituate Reservoir drainage area for WY 1996–2002 were described in terms of median values (table 5) and boxplots (fig. 7) of water-quality properties and constituent concentrations in samples from the 37 monitoring stations in the drainage area. Correlations between water-quality properties and constituent concentrations and subbasin characteristics and streamflow also were used to evaluate water-quality patterns in the drainage area (tables 6 and 7). Values of properties and concentrations of constituents were compared to available State and Federal guidelines and standards (tables 8 and 9) to describe water-quality conditions in terms of potential effects on human health and aquatic life.

Water-Quality Properties

Providence Water collected measurements of four water-quality properties—pH, color, turbidity, and alkalinity—for more than 50 years as general indicators of water-quality conditions. The measurements were also used to identify site-specific concerns and were compared with State and Federal guidelines.

pH

pH is a measure of the acidity or alkalinity of water. This property is reported on a scale that commonly ranges from 0 (acidic) to 14 (alkaline) with a value of about 7 being neutral. pH can have a substantial effect on the solubility of metals, such that water with low pH can be corrosive to pipes and plumbing fixtures. Strongly alkaline waters are referred to as basic or caustic and can also be corrosive. pH is an important factor in determining water-treatment procedures. Median pH in tributary streams in the Scituate Reservoir drainage area ranged from 5.3 to 6.7, with a median among all stations of 6.1. Thus, tributary stream water was slightly acidic, reflecting the low pH of precipitation in the northeastern United States (National Atmospheric Deposition Program, 2005) and the relatively nonreactive character of rock types in the drainage area. Samples from the monitoring station at the outlet of the Ponaganset Reservoir subbasin (pH 5.5, station 23) and two monitoring stations in the Westconnaug Reservoir subbasin (pH 5.3 and 5.4, stations 10 and 11) had the lowest pH values (table 5); these subbasins are primarily forested and underlain by granitic bedrock.

Table 5. Median values for water-quality properties and constituent concentrations at Providence Water monitoring stations by tributary reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.

[Station locations shown on figure 2. PW, Providence Water; PCU, platinum-cobalt units; NTU, nephelometric turbidity units; CFU, colony-forming units; mL, milliliter; *E. coli*, *Escherichia coli*; mg/L, milligrams per liter; $CaCo_3$, calcium carbonate; N, nitrogen; P, phosphorus; <, less than; --, no samples]

PW station number	pH	Color (PCU)	Turbidity (NTU)	Total coliform bacteria (CFU/100 mL)	*E. coli* bacteria (CFU/100 mL)	Alkalinity (mg/L as $CaCO_3$)	Chloride (mg/L)	Nitrite (mg/L as N)	Nitrate (mg/L as N)	Orthophosphate (mg/L as P)	Iron (mg/L)	Manganese (mg/L)
Barden Reservoir subbasin												
24	5.9	45	0.68	23	9	3.5	17	0.002	0.02	0.03	0.28	0.05
25	6.0	28	.42	23	9	3.2	8.2	.002	.04	.04	.11	.04
26	5.9	27	.35	15	4	3.1	14	.002	.04	.04	.07	.01
27	5.6	18	.42	9	9	3.2	7.3	<.002	.09	.05	.04	.02
28	5.7	74	.68	23	23	3.5	15	.003	.02	.03	.13	.05
29	6.0	37	.60	4	<3	3.3	11	.002	.03	.02	.20	.06
35	6.1	33	.61	23	23	3.9	12	.030	.03	.03	--	--
Median	**5.9**	**33**	**.60**	**23**	**9**	**3.3**	**12**	**.002**	**.03**	**.03**	**.12**	**.05**
Direct Runoff subbasins												
1	6.6	65	1.5	23	9	9.0	7.7	0.003	0.06	0.04	0.32	0.04
2	6.1	16	.31	9	9	4.4	29	<.002	.15	.04	.02	.03
3	6.2	27	.35	15	9	4.2	19	.002	.10	.05	.04	.01
4	6.3	27	.65	4	<3	6.1	4.2	.002	.03	.02	.08	.02
5	6.0	44	.57	16	4	3.9	12	.060	.06	.07	.16	.03
6	6.1	80	.85	43	23	7.1	16	.004	.06	.04	.07	.02
7	6.1	74	.92	23	23	5.6	7.1	.003	.03	.04	.31	.03
8	6.0	16	.49	<3	<3	3.0	7.5	.002	.04	.02	.14	.04
9	6.3	42	.52	23	4	6.4	41	.003	.18	.06	.14	.02
30	6.0	29	.41	9	4	4.1	13	.002	.03	.05	.06	.01
31	6.4	29	1.3	170	19	17	58	.005	.12	.07	.24	.05
32	6.4	54	.87	23	9	6.1	8.9	.002	.10	.03	.24	.03
33	6.1	25	.36	23	4	5.7	9.8	.002	.07	.06	.22	.01
36	6.4	18	.31	9	4	3.8	1.2	<.002	.02	.03	--	--
37	5.7	17	.23	9	4	3.3	3.6	<.002	.02	.04	--	--
Median	**6.1**	**29**	**.52**	**16**	**4**	**5.6**	**9.8**	**.002**	**.06**	**.04**	**.14**	**.03**
Moswansicut Reservoir subbasin												
19	6.7	22	0.97	23	15	8.9	25	0.003	0.04	0.02	0.08	0.03
20	5.9	120	.73	43	23	5.6	29	.005	.03	.07	.24	.05
21	6.4	45	1.2	43	23	12	23	.003	.10	.03	.28	.02
22	6.4	33	2.1	240	94	14	26	.007	.25	.06	.34	.07
34	6.2	55	.89	23	4	13	26	.003	<.01	.02	--	--
Median	**6.4**	**45**	**.97**	**43**	**23**	**12**	**26**	**.003**	**.04**	**.03**	**.26**	**.04**

Table 5. Median values for water-quality properties and constituent concentrations at Providence Water monitoring stations by tributary reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.—Continued

[Station locations shown on figure 2. PW, Providence Water; PCU, platinum-cobalt units; NTU, nephelometric turbidity units; CFU, colony-forming units; mL, milliliter; *E. coli*, *Escherichia coli*; mg/L, milligrams per liter; $CaCo_3$, calcium carbonate; N, nitrogen; P, phosphorus; <, less than; --, no samples]

PW station number	pH	Color (PCU)	Turbidity (NTU)	Total coliform bacteria (CFU/100 mL)	*E. coli* bacteria (CFU/100 mL)	Alkalinity (mg/L as $CaCO_3$)	Chloride (mg/L)	Nitrite (mg/L as N)	Nitrate (mg/L as N)	Orthophosphate (mg/L as P)	Iron (mg/L)	Manganese (mg/L)
Ponaganset Reservoir subbasin												
23	5.5	8	0.49	<3	<3	2.0	5.5	0.002	0.05	0.02	0.07	0.06
Median	**5.5**	**8**	**.49**	**<3**	**<3**	**2.0**	**5.5**	**.002**	**.05**	**.02**	**.07**	**.06**
Regulating Reservoir subbasin												
13	6.5	24	0.72	4	<3	8.1	22	0.002	0.03	0.02	0.11	0.03
14	6.3	27	.62	23	23	6.9	6.7	.002	.03	.04	.11	.03
15	6.4	38	.86	23	21	8.7	25	.002	.04	.04	.19	.05
16	6.5	27	.84	23	8	10	24	.002	.05	.02	.22	.06
17	5.8	46	.67	<3	<3	4.8	17	.003	.02	.02	.23	.09
18	6.1	44	.71	26	20	8.1	30	.003	.05	.04	.16	.02
Median	**6.4**	**33**	**.71**	**23**	**14**	**8.1**	**23**	**.002**	**.04**	**.03**	**.18**	**.04**
Westconnaug Reservoir subbasin												
10	5.3	23	0.26	4	4	2.2	13	<0.002	0.02	0.04	0.05	0.03
11	5.4	80	.52	23	4	3.6	1.1	.003	.03	.03	.14	.02
12	5.8	38	.57	23	9	4.8	8.0	.003	.03	.04	.22	.03
Median	**5.4**	**38**	**.52**	**23**	**4**	**3.6**	**8.0**	**.003**	**.03**	**.04**	**.14**	**.03**
Scituate Reservoir drainage area												
Median	**6.1**	**33**	**0.62**	**23**	**9**	**4.8**	**13**	**0.002**	**0.04**	**0.04**	**0.14**	**0.03**

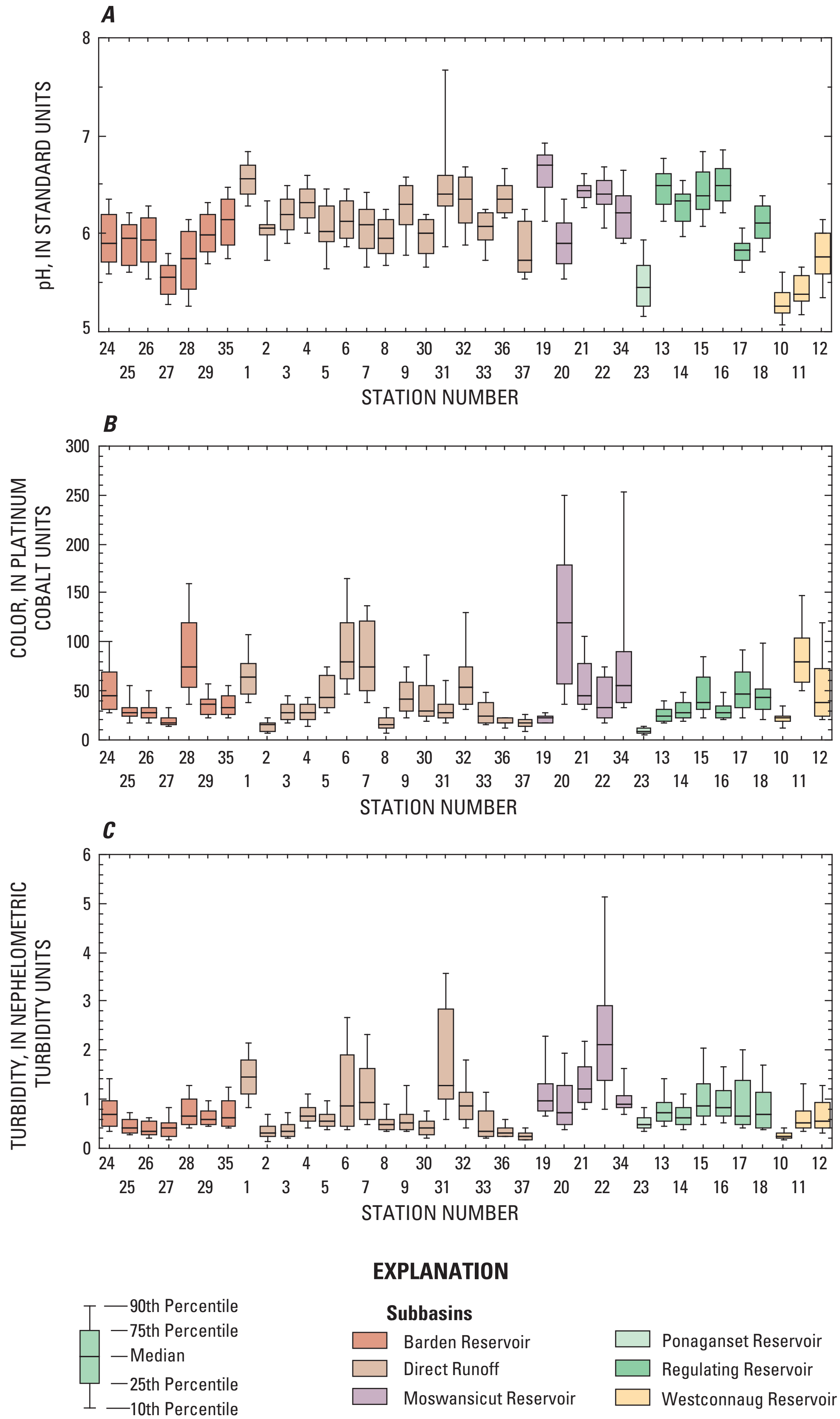


Figure 7. *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, and concentrations of *(E)* chloride, *(F)* nitrite, *(G)* nitrate, *(H)* orthophosphate, *(I)* total coliform bacteria, *(J) E. coli (Escherichia coli)* bacteria, *(K)* iron, and *(L)* manganese in samples collected at Providence Water monitoring stations by tributary-reservoir subbasin in the Scituate Reservoir drainage area, water years 1996–2002.

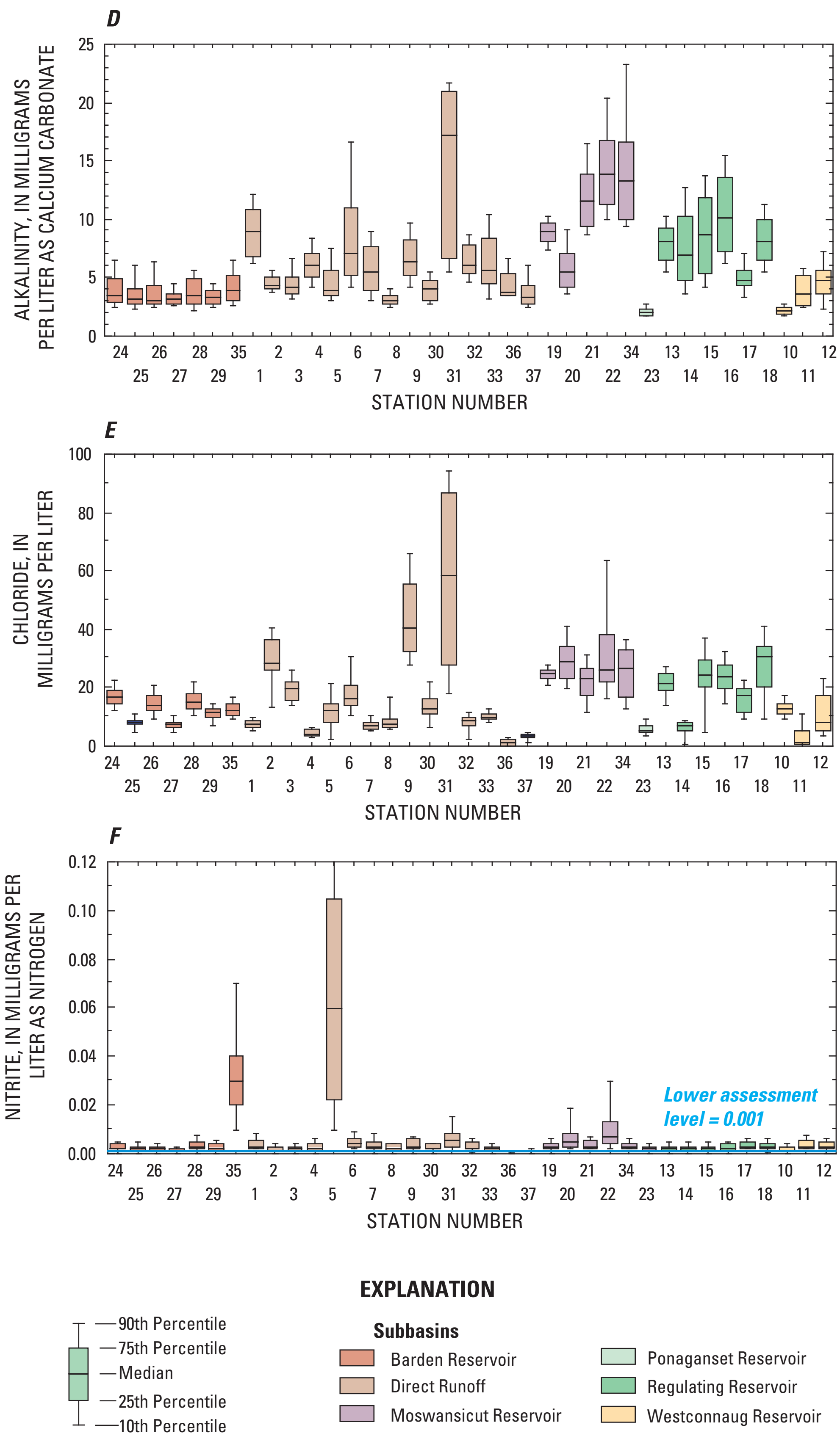
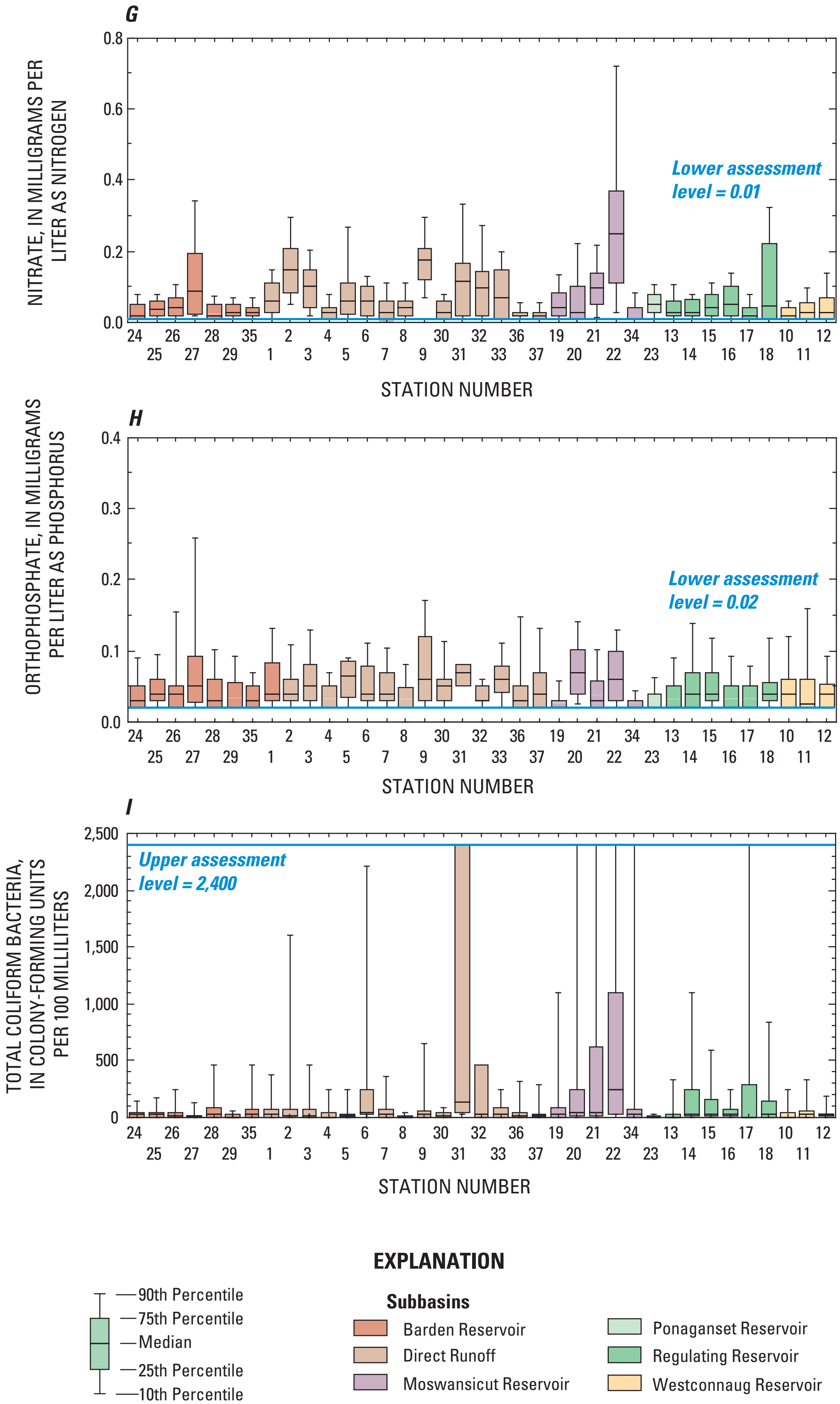


Figure 7. *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, and concentrations of *(E)* chloride, *(F)* nitrite, *(G)* nitrate, *(H)* orthophosphate, *(I)* total coliform bacteria, *(J) E. coli (Escherichia coli)* bacteria, *(K)* iron, and *(L)* manganese in samples collected at Providence Water monitoring stations by tributary-reservoir subbasin in the Scituate Reservoir drainage area, water years 1996–2002.—Continued



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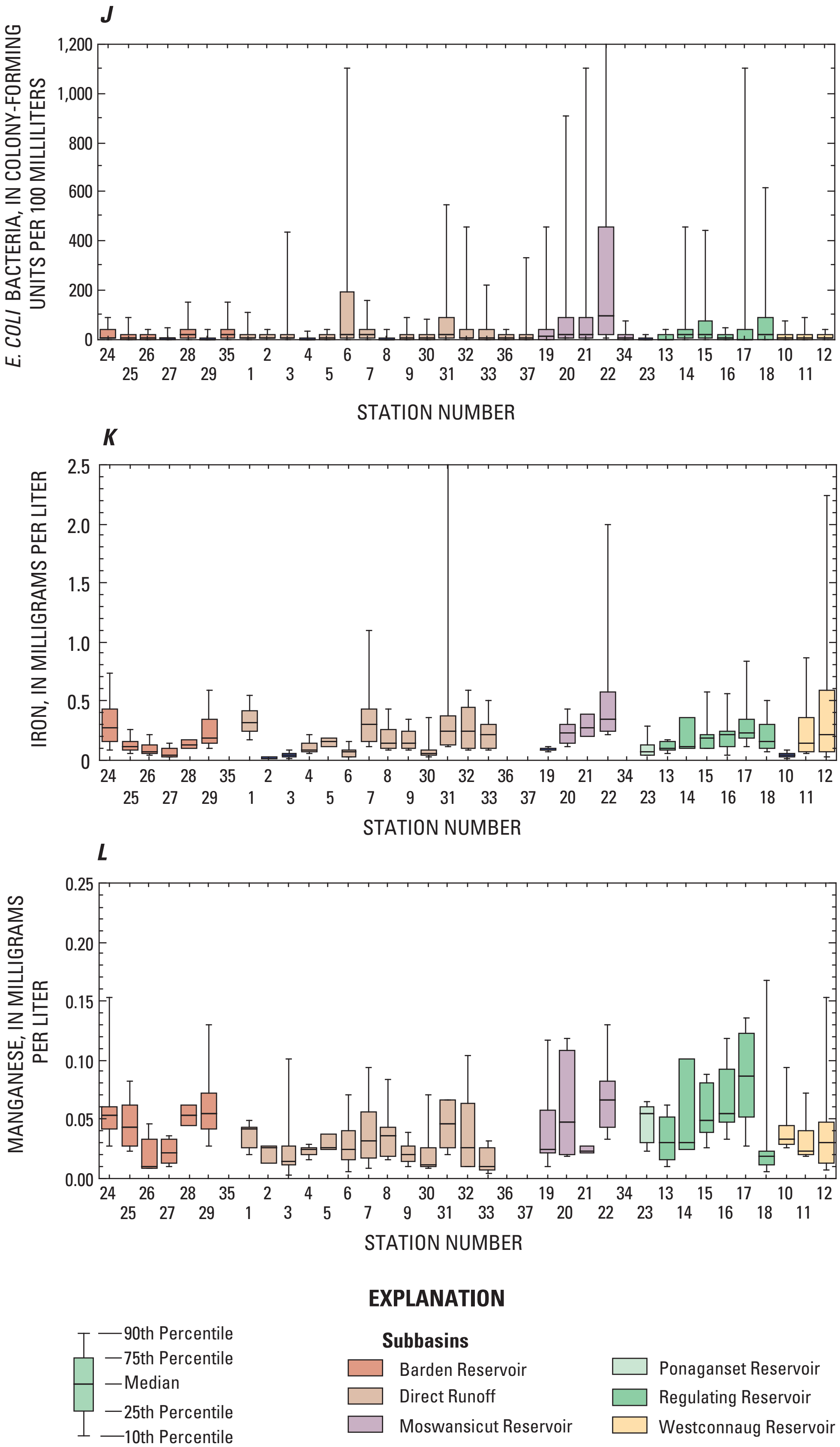


Figure 7. *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, and concentrations of *(E)* chloride, *(F)* nitrite, *(G)* nitrate, *(H)* orthophosphate, *(I)* total coliform bacteria, *(J) E. coli (Escherichia coli)* bacteria, *(K)* iron, and *(L)* manganese in samples collected at Providence Water monitoring stations by tributary-reservoir subbasin in the Scituate Reservoir drainage area, water years 1996–2002.—Continued

Table 6. Significance levels (*p* values) for rank correlations between subbasin characteristics and median values of water-quality properties and constituent concentrations at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.

[*E. coli*, *Escherichia coli*; *p* values for trends considered significant are shown in **bold**; (+), variables are positively correlated; (-), variables are inversely correlated]

Subbasin characteristic	pH	Color	Turbidity	Total coliform bacteria	*E. coli* bacteria	Alkalinity	Chloride	Nitrate	Orthophosphate	Iron	Manganese
Land use											
Forest	**0.003** (-)	0.11	**0.0001** (-)	**0.012** (-)	0.13	**<0.0001** (-)	**0.0003** (-)	**0.006** (-)	0.58	**0.02** (-)	0.62
Water	.071	.08	.11	.38	.14	.09	.90	.48	**.001** (-)	.70	.18
Wetlands	.12	**.001** (+)	**.02** (+)	.052	.28	**.02** (+)	.49	.54	.97	.14	.64
Agricultural	.20	.37	.42	.91	.91	.10	.19	.66	.71	.57	.38
Residential	.13	.54	**.02** (+)	**.03** (+)	**.03** (+)	**.002** (+)	**.007** (+)	**.008** (+)	.06	.07	.15
Nonresidential urban	.08	.74	**.03** (+)	**.03** (+)	.45	**.006** (+)	**.001** (+)	.12	.55	.74	.34
Other	.68	.27	.53	.32	**.08** (-)	.37	.79	.51	.93	.13	.17
Road density											
Locally maintained roads	0.52	0.90	0.33	0.18	0.22	0.09	**<0.0001** (+)	0.91	0.34	0.53	0.45
State-maintained roads	.52	.91	.31	.20	.20	.09	**<.0001** (+)	.92	.43	.66	.35
All roads	.55	.90	.32	.19	.19	.09	**<.0001** (+)	.96	.41	.61	.37

Table 7. Significance levels (*p* values) for rank correlations between mean daily streamflow and selected physical properties and constituent concentrations at Providence Water monitoring stations by tributary reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.

[Station locations shown on figure 2. PW, Providence Water; *E. coli*, *Escherichia coli*; *p* values for correlations considered significant are shown in **bold**; (-), negative correlation; (+), positive correlation]

PW station number	Turbidity	Total coliform bacteria	*E. coli* bacteria	Chloride	Nitrate	Orthophosphate
Barden Reservoir subbasin						
24	**<0.0001 (-)**	**0.008 (-)**	**0.0002 (-)**	**0.004 (-)**	0.124	0.811
25	**.010 (-)**	.351	.098	.326	.435	.247
26	.258	.238	.379	.316	**.024 (+)**	.761
28	**.0002 (-)**	**.011 (-)**	**.013 (-)**	**<.0001 (-)**	.666	.676
35	**.0003 (-)**	**<.0001 (-)**	**.0004 (-)**	**<.0001 (-)**	.071	.621
Direct Runoff subbasins						
1	0.567	**0.002 (-)**	**0.0009 (-)**	**<0.0001 (-)**	0.361	0.604
3	.414	.470	.357	**.029 (-)**	.678	.178
4	.233	**.002 (-)**	**.004 (-)**	**.019 (-)**	**.017 (+)**	.103
5	**.029 (-)**	.077	.126	.243	.113	.096
6	**<.0001 (-)**	**<.0001 (-)**	**<.0001 (-)**	**<.0001 (-)**	.093	.602
7	**<.0001 (-)**	.063	.082	**.0003 (-)**	.187	.309
8	**.048 (+)**	.457	.169	.085	**.006 (+)**	.345
9	.134	.105	.136	**<.0001 (-)**	.525	.061
32	.067	.074	.195	.055	**.025 (+)**	.829
33	**.001 (-)**	**.044 (-)**	.238	**.0009 (-)**	**.271 (+)**	.487
Moswansicut Reservoir subbasin						
19	**0.002 (-)**	0.078	**0.039 (-)**	0.109	0.248	0.829
21	.077	.336	.274	.362	**.006 (+)**	.232
Regulating Reservoir subbasin						
14	0.059	**0.031 (-)**	**<0.0001 (-)**	0.301	0.555	0.857
15	.172	.234	.218	**.043 (-)**	.052	.445
16	.247	.420	.050	.128	**<.0001 (+)**	.088
18	.953	.694	.765	.429	.343	.177
Westconnaug Reservoir subbasin						
10	0.195	**0.009 (-)**	**0.002 (-)**	0.993	0.113	0.506
11	**.0008 (-)**	.427	.156	.304	.176	.540
Scituate Reservoir drainage area						
All samples	**<0.0001 (-)**	**<0.0001 (-)**	**<0.0001 (-)**	0.210	0.073	0.343

Color

Color in stream water, typically pale yellow to dark brown, is usually caused by dissolved organic material, such as humic and fulvic acids, that result from natural sources (Hem, 1985). Inorganic materials, such as metals, also can be common sources of color. As an indicator of the amount of dissolved organic carbon (DOC), highly colored water may be of concern in source waters because DOC can be transformed into chlorinated organic compounds such as trihalomethanes during water chlorination (Miller, 1993; Breault and others, 2000). Color intensity is measured in standard units (platinum-cobalt units or PCU) based on dilutions of a chemical solution that closely matches the color of natural stream water. Median values of color ranged from 8 to 120 PCU, with the highest values at a monitoring station in the Moswansicut subbasin (table 5).

Turbidity

Turbidity in stream water results from the presence of suspended particles, such as silt, clay, organic matter, and microorganisms, and dissolved colored material. It is measured in standard units that quantify the ability of the water to transmit light. Turbidity is considered an overall indicator of environmental health and an early indicator of ecosystem change caused by excessive productivity (U.S. Environmental Protection Agency, 2000). High turbidity also can interfere with water-disinfection processes (World Health Organization, 2004). The turbidity of tributary stream water in the drainage area generally was low; median values at most stations were less than 1 nephelometric turbidity unit (NTU) (table 5). Median values at all but one station were below the proposed USEPA reference value of 1.68 NTU for what the agency describes as “minimally impacted conditions” for streams in the Northeastern Coastal Zone ecoregion (U.S. Environmental Protection Agency, 2000, table 3A). The low values indicate that water quality in tributary streams in the Scituate Reservoir drainage area was minimally affected relative to stream water in this region of the United States. Monitoring stations with the highest values of turbidity were in the Direct Runoff (1.5 NTU, station 1) and Moswansicut Reservoir (2.1 NTU, station 22) subbasins (table 5). One of the lowest median values of turbidity was for the monitoring station at the outlet of the Ponaganset Reservoir subbasin (0.49 NTU, station 23; fig. 7C); transport of tributary stream water through a reservoir can result in low concentrations of particulate matter that can contribute to turbidity.

Alkalinity

Alkalinity is a measure of the ability of water to neutralize acid and primarily results from the concentrations of dissolved carbon dioxide species in most natural waters (Hem, 1985). Like pH, alkalinity can affect the corrosivity of water and is an important factor in water treatment. Alkalinity of stream water can result from weathering of carbonate rocks, natural organic activity, and human activities such as waste disposal or fertilizer application that add organic or inorganic carbon to the environment. Median alkalinity in samples from tributary streams was low, ranging from 2.0 to 17 mg/L as calcium carbonate ($CaCO_3$). Among all stations in the drainage area, median alkalinity was 4.8 mg/L as $CaCO_3$ (table 5). Alkalinity was consistently low at monitoring stations in the western part of the drainage area—in the Barden, Ponaganset, and Westconnaug Reservoir subbasins—and was highest at monitoring stations in the Direct Runoff, Moswansicut, and Regulating Reservoir subbasins (fig. 7D).

Constituent Concentrations

Concentrations of four categories of constituents—chloride, nutrients, bacteria, and iron and manganese—were also measured by Providence Water. Like measurements of physical properties, concentrations of constituents were used as a measure of overall water quality and of compliance with Federal and State guidelines.

Chloride

Chloride (Cl) is a nonreactive ion that originates in stream water from precipitation and weathering. Cl is added to the environment through human activities such as waste disposal and road deicing. The median chloride concentration for all stations in the drainage area was low, 13 mg/L, which is typical of natural stream water in coastal New England. Chloride concentrations were highest at stations in the Moswansicut (26 mg/L) and Regulating Reservoir (23 mg/L) subbasins and at some stations in the Direct Runoff subbasins. The highest median chloride concentrations were measured at the Bear Tree Brook (station 9; 41 mg/L) and Toad Pond (station 31; 58 mg/L) monitoring stations in the Direct Runoff subbasins (fig. 7E). A formerly uncovered salt-storage facility in the Bear Tree Brook subbasin likely contributed to the high chloride concentrations at that monitoring station. At the monitoring station on Toad Pond, water flows from a small pond in a developed area. The values for turbidity and other physical properties and constituents at this station, which were high compared with those for other stations, also indicated degraded water quality.

Nutrients

Nutrients, including chemical species of nitrogen and phosphorus, are essential elements for plant and animal life. Nutrient enrichment, however, can lead to excessive productivity and plant growth with consequent low concentrations of dissolved oxygen and degradation of aquatic life (U.S. Environmental Protection Agency, 2000). In tributary streams in the Scituate Reservoir drainage area, concentrations of the nutrient species nitrite, nitrate, and orthophosphate were low and, in many cases, were near the reporting limits (table 5, and figs. 7F, G, and H). Median concentrations of nitrate were less than 0.1 mg/L as N at most monitoring stations. Median nitrate concentrations at all stations were below the proposed USEPA reference concentration of 0.31 mg/L as N for minimally impacted conditions for streams in the Northeastern Coastal Zone ecosystem (U.S. Environmental Protection Agency, 2000, table 3A). Potential sources of nitrate to tributary stream water include atmospheric deposition, leaching of naturally occurring organic material, discharge of ground water that is enriched in nitrate from septic-system leachate, and runoff contaminated with fertilizer or animal waste (for example, figs. 4A and B). Relatively high concentrations of nitrate at some monitoring stations, such as Moswansicut Reservoir (station 22, 0.25 mg/L as N) in the Moswansicut Reservoir subbasin, may be affected by nitrogen-enriched runoff or ground water. Median concentrations of nitrite were less than 0.01 mg/L as N at all but two monitoring stations (stations 5 and 35). Median concentrations of orthophosphate were all less than or equal to 0.07 mg/L as P and did not vary much among monitoring stations or reservoir subbasins. Median orthophosphate concentrations at most monitoring stations were greater than the USEPA-proposed reference concentration of 0.024 mg/L as P for minimally impacted conditions for streams in the Northeastern Coastal Zone ecosystem at most monitoring stations (U.S. Environmental Protection Agency, 2000, table 3A); however, this reference concentration may not be representative of local or subregional conditions. Phosphorus typically is considered the limiting nutrient in inland aquatic systems (Schlesinger, 1991); therefore, orthophosphate concentrations elevated above background concentrations could be of concern.

Bacteria

Water in streams and reservoirs commonly contains a variety of microorganisms, some of which can cause disease in humans. Many microorganisms occur naturally, and some are introduced into water supplies by sewage disposal, either directly to surface waters or through septic-system failure. It is estimated that 94 percent of the population in the Scituate Reservoir drainage area during 1995–99 used septic or other individual sewage-disposal systems (Wild and Nimiroski, 2007). Other sources of bacteria to surface waters include waterfowl and runoff from impervious area that is affected by animal waste (Weiskel and others, 1996). Water suppliers disinfect water from reservoirs to eliminate microbial contamination before drinking water is distributed to consumers. Total coliform and *E. coli* bacteria are indicators that are used to identify bacterial growth and the presence of sewage contamination. Although these bacteria groups generally do not include disease-causing organisms, they may indicate the presence of human pathogens, including bacteria, protozoans (*Cryptosporidium* and *Giardia*), and enteric viruses. Total coliform bacteria include types that can grow in the environment (for example, in soils and on vegetation) and in human and animal intestines, whereas *E. coli* bacteria are specifically intestinal bacteria and thus are a more definitive indicator of fecal contamination (World Health Organization, 2004; Francy and others, 2000).

Median concentrations of total coliform and *E. coli* bacteria were greater than the detection limit (3 CFU/100 mL) at nearly all stations (table 5, figs. 7I and J). Total coliform bacteria concentrations were in all cases equal to or greater than *E. coli* concentrations (as expected because the former group is more inclusive) with median concentrations for all stations in the drainage area equal to 23 CFU/100 mL for total coliform bacteria and 9 CFU/100 mL for *E. coli* bacteria. Concentrations of total coliform and *E. coli* bacteria also correlated with one another in individual samples (p value less than 0.001, Spearman correlation). Among stations, concentrations of total coliform and *E. coli* bacteria were greatest at specific stations in the Direct Runoff and Moswansicut Reservoir subbasins; these include the station at Toad Pond (31), which likely is affected by parking-lot runoff as stated previously, and the Moswansicut Reservoir station (22). High concentrations of indicator bacteria at these and other stations could result from fecal contamination directly from wildlife, such as geese or other waterfowl; from runoff contaminated with animal waste (for example, fig. 4A); or from failing septic systems. Low values of indicator bacteria in some cases were measured at monitoring stations immediately downstream from subbasin reservoirs, such as station 23 at the outlet of the Ponaganset Reservoir and station 29 at the outlet of the Barden Reservoir; the transport of tributary-stream water through a reservoir can result in lower concentrations of indicator bacteria caused by settling and die-off.

Iron and Manganese

Iron and manganese are common in soils, unconsolidated glacial materials, and igneous and metasedimentary bedrock like that in the study area (Hem, 1985). The solubility of these metals in stream water, however, depends on geochemical conditions including pH, dissolved oxygen concentrations, and the availability of DOC with which to form complexes (McKnight and Bencala, 1990). Thus, concentrations of iron and manganese may be greater in areas such as wetlands, where large amounts of organic matter and low stream velocities contribute to anaerobic conditions. Iron and manganese concentrations also may be high in areas where anoxic, iron- or manganese-rich ground water discharges to streams. Measurements of iron and manganese in samples from the tributary streams in the Scituate Reservoir drainage area were suspended after 1996, so conditions described for these constituents are based on one year of data only. Median iron concentrations at monitoring stations ranged from 0.02 to 0.34 mg/L, and median manganese concentrations ranged from 0.01 to 0.09 mg/L (table 5, figs. 7K and L).

Factors Affecting Water-Quality Properties and Constituent Concentrations

Values of water-quality properties and constituents are affected by many factors, including land-use, road density and streamflow. Comparison of median values of water-quality properties and constituent concentrations with land-use-area percentages and road density can assist water-resources managers with drainage-area-protection strategies, such as purchasing land and restricting certain land uses. Many water-quality properties and concentrations vary with streamflow, either directly through the association of high flows with increased runoff of constituents, or inversely through the dilution of contaminants derived from base flow.

Subbasin Characteristics

Land use and road density in the subbasins are factors that affect constituent concentrations, especially of anthropogenic contaminants, in tributary streams. Percentages of residential and nonresidential urban land use in subbasins of monitoring stations correlated significantly (p value less than 0.05) with median values or concentrations of several water-quality properties and concentrations that can be indicative of human activities, including turbidity, alkalinity, and concentrations of total coliform bacteria, *E. coli* bacteria, chloride, and nitrate (table 6). Most of these values also correlated negatively with the percentage of forest cover in subbasins of monitoring stations (table 6). Chloride concentrations showed a strong positive correlation with the density of roads in subbasin areas. Sampling stations on tributary streams and reservoirs are near roads in most cases (figs. 4C and D), and road salt has been determined to be the largest source of chloride and sodium in the drainage area (Nimiroski and Waldron, 2002). Median values of color correlated positively with the percentage of wetlands in the monitoring station subbasins; this correlation suggests that naturally occurring organic material and possibly iron and manganese were likely sources of color in tributary stream water. A statistically significant correlation between median water-quality values at monitoring stations and measures of a subbasin characteristic indicates that water-quality values tend to be higher in subbasins with higher values of the subbasin characteristic. Graphs showing relations between the two types of variables (fig. 8), however, illustrate that median water-quality values can exhibit considerable variability that is not accounted for by particular subbasin characteristics.

Streamflow

In addition to increased runoff or dilution, values of water-quality properties and constituent concentrations may vary with flow because of seasonal effects. For example, as a result of biological activity, concentrations of some constituents are higher or lower during low-flow periods of the year. Correlations of median values of selected water-quality properties and constituent concentrations with estimated or measured mean daily streamflows indicate that values of several properties and concentrations were greater at low streamflows than at high streamflows (table 7). Turbidity, total coliform bacteria, and *E. coli* bacteria were negatively correlated with flow when all samples from all 37 stations were considered (p value less than 0.0001). Chloride correlated negatively with flow at multiple stations in each of the Barden, Direct Runoff, and Regulating Reservoir subbasins. The strong inverse correlation of chloride with flow could reflect the dilution of high chloride concentrations in base flow by storms producing high and moderate flows. The strong inverse correlation could also reflect seasonal patterns.

Median concentrations of nitrate correlated positively with flow at one or more stations in each of the Barden Reservoir, Direct Runoff, Moswansicut Reservoir, and Regulating Reservoir subbasins (table 7). At these stations, larger nitrate concentrations tended to occur at higher flows. Nitrogen-enriched runoff in streamflow during storms could be a factor in these relations. Median concentrations of orthophosphate were not related to flow at any monitoring station (table 7). The low values and minimal variation in orthophosphate concentration make any relations with flow difficult to identify.

Comparison of Water-Quality Properties and Constituent Concentrations with Water-Quality Standards and Guidelines

Values of water-quality properties and concentrations of constituents can be compared to several types of standards and guidelines. RIDEM sets water-quality standards for surface water based on the intended uses of the water. Some inland surface-water bodies that are sources of drinking water and streams tributary to those water bodies are designated "Class A" (Rhode Island Department of Environmental Management, 2000). Standards for Class A waters include standards for pH, turbidity, and maximum allowable concentrations of indicator bacteria and phosphorus (table 8). The USEPA has established water-quality standards and guidelines for finished drinking water (U.S. Environmental Protection Agency, 2004). These include maximum contaminant levels (MCLs), secondary drinking-water regulations (SDWRs), and health guidelines (table 8). MCLs and health guidelines are intended to protect human health; SDWRs are guidelines for aesthetics and other considerations. The Rhode Island Department of Health (RIDOH) also has established MCLs for drinking water (table 8; Rhode Island Department of Health, 2005). USEPA and RIDOH standards and guidelines for drinking water are not applicable to tributary stream water or source water in a regulatory sense but are useful benchmarks against which to compare constituent concentrations in tributary stream and source water.

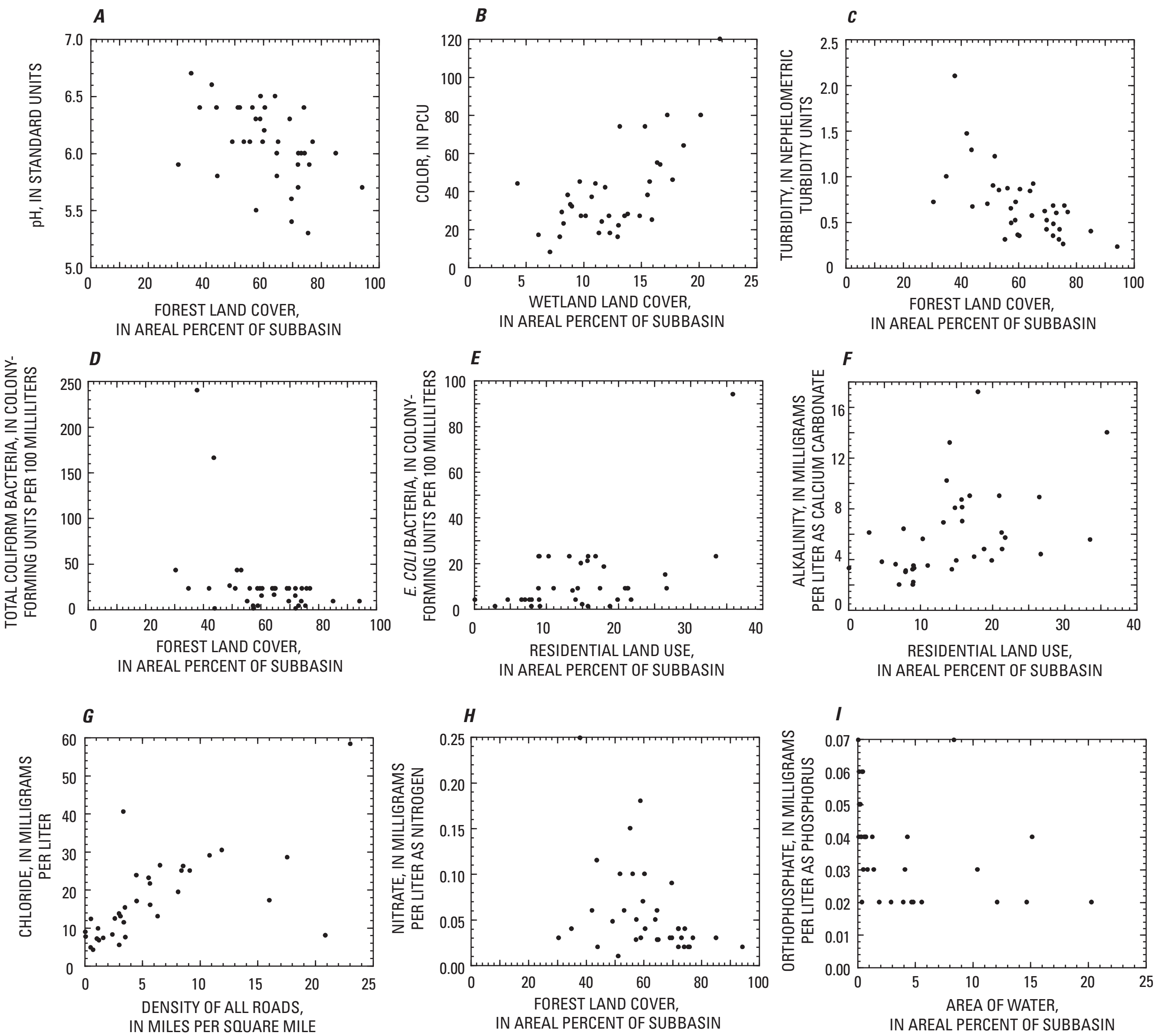


Figure 8. Relations between median values of *(A)* pH, *(B)* color, and *(C)* turbidity, and median concentrations of *(D)* total coliform bacteria, *(E) E. coli* bacteria, *(F)* alkalinity, *(G)* chloride, *(H)* nitrite, and *(I)* orthophosphate at Providence Water monitoring stations in relation to subbasin characteristics in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002. PCU, platinum-cobalt units; *E. coli*, *Escherichia coli*.

Table 8. Selected Federal and State water-quality standards and guidelines.

[Sources of standards and guidelines: Rhode Island Department of Environmental Management (RIDEM), 2000; U.S. Environmental Protection Agency (USEPA), 2004; Rhode Island Department of Health (RIDOH), 2005. Class A waters are waters used for drinking-water supply or tributary streamwater to drinking-water sources in Rhode Island. Maximum contamination levels (MCLs), secondary drinking-water regulations (SDWRs), and lifetime health advisories apply to finished drinking water, not to source water or tributary stream water. NTU, nephelometric turbidity units; CFU/100 mL, colony-forming units per 100 milliliters; *E. coli*, *Escherichia coli*; mg/L, milligrams per liter; <, less than; ≤, less than or equal to; >, greater than; --, none; N, nitrogen; P, phosphorus]

Constituent	RIDEM water-quality standards for Class A waters	USEPA and RIDOH MCLs for public-water supplies	USEPA SDWRs for public-water supplies	USEPA lifetime health advisories for drinking water
pH	[1]6.5–9.0	--	6.5–8.5	--
Color	--	--	15	--
Turbidity, in NTU	5 above background	[2]5	[2]5	--
Total coliform bacteria, in CFU/100 mL	Geometric mean <100; ≤10 percent of samples >500	[3]Detection	--	--
E. coli bacteria, in CFU/100 mL	--	[4]Detection	--	--
Chloride, in mg/L	--	--	250	--
Nitrate, in mg/L as N	--	10	--	--
Total phosphorus, in mg/L as P	.025	--	--	--
Iron, in mg/L	--	--	.3	--
Manganese, in mg/L	--	--	.05	0.3

[1] or as occurs naturally.

[2] USEPA MCL requires that treatment techniques result in turbidity not exceeding 5 NTU. RIDOH standards require that average turbidity for any two consecutive days be below 5 NTU.

[3] Compliance with USEPA and RIDOH MCL for a water-supply system with one or more samples in which total coliform bacteria are detected depends on the number of samples collected. Any sample in which total coliform bacteria are detected requires further testing.

[4] RIDOH MCL only; *E. coli* or fecal coliform bacteria tests are required for any sample in which total coliform bacteria are detected; presence of *E. coli* bacteria requires notification of the Director of RIDOH.

Water-Quality Properties

RIDEM water-quality standards for Class A waters establish an allowable range for pH of 6.5 to 9.0, or as occurs naturally; the recommended range for drinking water by USEPA is 6.5 to 8.5 (table 8). The pH was less than 6.5 in more than 80 percent of all samples collected during WY 1996–2002 at most sites (26 of 37 stations, table 9) in the Scituate Reservoir drainage area. Low pH values are common in New England streams and result primarily from the low pH of precipitation (National Atmospheric Deposition Program, 2005).

Water-quality guidelines for color consist only of a USEPA SDWR for public drinking-water supplies (table 8). Color in source water, however, is an important indicator of DOC, which can affect concentrations of trihalomethanes in finished water and therefore is a factor in water treatment. Most samples at most stations exceeded the SDWR for color of 15 PCU (table 8) during WY 1996–2002.

Turbidity values in tributary streams in the drainage area rarely exceeded 5 NTU (table 9), the maximum allowable value (on average) for drinking-water supplies and the maximum allowable value above background for RIDEM Class A waters (table 8). Similarly, the turbidity value of 1.68 NTU, the USEPA proposed reference concentration for minimally impacted conditions in the region (U.S. Environmental Protection Agency, 2000, table 3A), was exceeded more than 10 percent of the time at only eight stations. These results suggest that the water quality of tributary streams in the Scituate Reservoir drainage area is minimally affected by suspended particles relative to stream water in the northeastern coastal region of the United States, as noted previously.

Table 9. Percentage of samples at Providence Water monitoring stations with concentrations or values greater than water-quality standards and guidelines by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.

[Station locations shown on figure 2. Water-quality standards and guidelines are given in table 8. **pH**: Percentage shown is that of samples with values less than the lower limit (6.5) specified by water-quality criteria. **Iron** and **manganese**: Percentage shown is for samples collected between October 1, 1995 and June 30, 1996. PW, Providence Water; CFU/100 mL, colony-forming units per 100 milliliters; *E. coli*, *Escherichia coli*; --, no samples. All values in percent.]

PW station number	pH	Color	Turbidity	Chloride	Total coliform bacteria			*E. coli* bacteria	Nitrite	Nitrate	Orthophos-phate	Iron	Manganese	
					Detec-tion	Greater than 100 CFU/100 mL	Greater than 500 CFU/100 mL						Greater than 0.05 mg/L	Greater than 0.3 mg/L
Barden Reservoir subbasin														
24	96	99	0	0	78	11	1.3	77	0	0	58	44	67	0
25	97	94	0	0	82	12	0	70	0	0	83	0	44	0
26	100	97	0	0	78	13	3.1	63	0	0	70	0	0	0
27	100	79	0	0	78	11	0	61	0	0	77	0	0	0
28	100	99	1.3	0	84	22	9.1	77	0	0	72	0	73	0
29	100	95	0	0	51	3.3	1.6	39	0	0	46	38	63	0
35	93	100	0	0	85	16	8.8	84	0	0	57	--	--	--
Average	**98**	**95**	**.2**	**0**	**77**	**13**	**3.4**	**67**	**0**	**0**	**66**	**8**	**41**	**0**
Direct Runoff subbasins														
1	35	98	1.3	0	87	23	3.8	81	0	0	78	71	0	0
2	92	55	0	0	100	18	9.1	91	0	0	89	0	0	0
3	89	92	1.3	0	81	22	8.1	76	0	0	81	0	14	0
4	81	88	0	0	52	13	3.9	39	0	0	45	0	0	0
5	96	100	0	0	57	18	3.6	57	0	0	83	0	0	0
6	94	100	0	0	90	34	19	89	0	0	78	0	13	0
7	93	96	1.3	0	80	19	6.3	79	0	0	79	56	22	0
8	98	50	1.5	0	41	6.3	3.1	34	0	0	49	11	11	0
9	79	100	0	0	75	19	9.4	59	0	0	83	22	0	0
30	97	93	0	0	66	6.9	3.5	55	0	0	81	11	11	0
31	60	100	0	0	100	50	30	90	0	0	100	33	50	0
32	63	96	0	0	77	35	19	77	0	0	86	50	33	0
33	100	92	0	0	71	17	0	54	0	0	87	25	0	0
36	71	76	0	0	68	11	5.3	62	0	0	67	--	--	--
37	95	71	0	0	63	11	5.3	53	0	0	71	--	--	--
Average	**83**	**87**	**.4**	**0**	**74**	**20**	**8.6**	**66**	**0**	**0**	**77**	**22**	**12**	**0**

Table 9. Percentage of samples at Providence Water monitoring stations with concentrations or values greater than water-quality standards and guidelines by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.—Continued

[Station locations shown on figure 2. Water-quality standards and guidelines are given in table 8. **pH**: Percentage shown is that of samples with values less than the lower limit (6.5) specified by water-quality criteria. **Iron** and **manganese**: Percentage shown is for samples collected between October 1, 1995 and June 30, 1996. PW, Providence Water; CFU/100 mL, colony-forming units per 100 milliliters; *E. coli*, *Escherichia coli*; --, no samples. All values in percent.]

PW station number	pH	Color	Turbidity	Chloride	Total coliform bacteria			*E. coli* bacteria	Nitrite	Nitrate	Orthophos-phate	Iron	Manganese	
					Detec-tion	Greater than 100 CFU/100 mL	Greater than 500 CFU/100 mL						Greater than 0.05 mg/L	Greater than 0.3 mg/L
Moswansicut Reservoir subbasin														
19	29	91	4.6	0	74	22	11	69	0	0	35	0	29	0
20	94	97	1.5	0	98	29	18	92	0	0	90	33	50	0
21	61	100	0	0	90	43	24	86	0	0	58	25	0	0
22	59	93	8.7	0	97	57	29	97	0	0	84	56	67	0
34	86	100	0	0	80	13	13	73	0	0	43	--	--	0
Average	**66**	**96**	**2.9**	**0**	**88**	**33**	**19**	**83**	**0**	**0**	**62**	**28**	**36**	**0**
Ponganset Reservoir subbasin														
23	100	4	1.9	0	36	6.0	4.0	30	0	0	36	13	63	0
Average	**100**	**4**	**1.9**	**0**	**36**	**6.0**	**4.0**	**30**	**0**	**0**	**36**	**13**	**63**	**0**
Regulating Reservoir subbasin														
13	46	92	1.4	0	59	11	5.6	44	0	0	47	0	33	0
14	82	99	0	0	89	30	13	86	0	0	71	33	33	0
15	61	99	0	0	89	27	9.6	86	0	0	79	17	50	0
16	50	100	1.3	0	86	16	3.8	73	0	0	49	14	71	0
17	100	96	0	0	48	28	16	44	0	0	41	44	78	0
18	100	90	0	0	67	28	11	67	0	0	92	38	13	0
Average	**73**	**96**	**.4**	**0**	**73**	**23**	**9.8**	**67**	**0**	**0**	**63**	**24**	**46**	**0**
Westconnaug Reservoir subbasin														
10	100	88	3.1	0	63	13	4.8	60	0	0	73	0	14	0
11	100	100	4.8	0	67	19	4.8	57	0	0	50	29	14	0
12	100	100	0	0	86	14	4.8	76	0	0	62	33	22	0
Average	**100**	**96**	**2.6**	**0**	**72**	**15**	**4.8**	**65**	**0**	**0**	**62**	**21**	**17**	**0**
Scituate Reservoir drainage area														
Average	**84**	**90**	**0.9**	**0**	**75**	**20**	**8.8**	**68**	**0**	**0**	**68**	**21**	**28**	**0**

Constituent Concentrations

RIDEM water-quality standards for Class A waters establish maximum concentrations for total phosphorus and total coliform bacteria. Orthophosphate (one component and a variable fraction of the total phosphorus) in stream water was the only phosphorus species measured in this study; concentrations of orthophosphate were greater than the RIDEM standard for total phosphorus in 35 to 100 percent of samples collected from all stations (table 9). At most stations, however, median concentrations were within a factor of two of the standard (table 5). Phosphorus concentrations that exceed the standard could be of concern because phosphorus can contribute to excessive plant growth. The RIDOH and USEPA MCL for nitrate in source water is 10 mg/L as N, and was not exceeded at any of the stations (table 9).

RIDEM's total coliform bacteria standard for Class A waters is based on a multiple-tube method and expresses results as a most probable number (MPN) of total coliform bacteria per 100 mL. The standard requires that total coliform bacteria not exceed a geometric mean of 100 MPN/100 mL and that no more than 10 percent of the samples exceed a value of 500 MPN/100 mL (Rhode Island Department of Environmental Management, 2000). Providence Water routinely measures total coliform bacteria by a membrane filtration method in which results are expressed as colony forming units (CFU) per 100 mL. Although the two methods use different approaches for quantifying total coliform populations, their results should be comparable if the methods are performed correctly (American Public Health Association and others, 1995). If all samples collected during WY 1996–2002 in the Scituate Reservoir drainage area are considered together to represent one monitoring period for each station, the criterion that requires that 10 percent or fewer of all samples exceed 500 CFU/100 mL was met at about two-thirds of stations (table 9).

Standards and guidelines for other constituents consist of MCLs, SDWRs, and lifetime health advisories for drinking water. SDWRs for iron and manganese in drinking water were exceeded most frequently (table 9). In contrast, the USEPA lifetime health advisory for manganese of 0.3 mg/L and the USEPA SDWR for chloride of 250 mg/L were not exceeded in any sample at any station during WY 1996–2002.

Loads and Yields of Selected Constituents, WY 1996–2002

The potential adverse effects of a constituent on reservoir water could depend on the total amount of the constituent added as well as on the concentrations of the constituent in tributary waters. This mass flux of a constituent, or constituent load, can be calculated on an annual, daily, or instantaneous basis from streamflow and concentration data. In this study, instantaneous loads were calculated for selected constituents for all sampling dates during WY 1996–2002. Instantaneous yields, or loads per unit of subbasin drainage area, also were calculated to allow for direct comparison of loads among sampling stations with drainage areas of different sizes. The median instantaneous loads and yields for the 23 monitoring stations for which sufficient data were available are given in table 10. Median values of instantaneous yields for reservoir subbasins and for the entire Scituate Reservoir drainage area were calculated as the medians of the median values for the individual stations (table 10). The spatial distributions of loads and yields are shown in figure 9.

The instantaneous loads and yields represent point measurements of a continuous mass flux that varies seasonally with hydrologic conditions and, in some cases, with other factors (for example, for chloride, with road-salt application); daily with biologic activity; and, in some cases, daily, hourly, or even more frequently with precipitation and runoff. Sampling dates also differed among stations. Thus, differences in median values of loads and yields among monitoring stations incorporate variability resulting from these factors as well as differences in constituent sources and transport characteristics.

Chloride

Chloride loads and yields differed among monitoring stations in the drainage area (fig. 9A), but median yields at most stations were within a factor of 2 of the overall drainage-area median of 30 kg/d/mi^2. The largest median chloride loads were determined for stations 16, 28, and 35 in the Regulating and Barden Reservoir subbasins. A relatively large load at station 28 is a result of the large drainage areas to this station (greater than 10 mi^2; table 10); yields are comparable to the median drainage-area yield. The largest median chloride yields were determined for one station in the Direct Runoff subbasins (9; 192 kg/d/mi^2), one station in the Regulating Reservoir subbasin (18; 67.0 kg/d/mi^2), and two stations in the Moswansicut Reservoir subbasin (19 and 21; 85.9 and 144 kg/d/mi^2, respectively). Relatively high yields at these stations likely reflect the greater percentages of developed land uses in their subbasin drainage areas (table 2), the location of a salt-storage facility, and perhaps the proximity of the stations to major roads. The application of road salt to major roads was estimated to be the largest source of chloride in the Scituate Reservoir drainage area in water year 2000 (Nimiroski and Waldron, 2002).

Nutrients

Loads of nitrate and orthophosphate were largest at several stations with large drainage areas in the Barden Reservoir subbasin; at stations with moderately large drainage areas (5–6 mi^2) in the Regulating Reservoir subbasin; and at stations in the eastern, more developed part of the Scituate Reservoir drainage area (figs. 9B and C). Yields ranged from 0.02 to 0.72 kg/d/mi^2 for nitrate as N, and from 0.02 to 0.22 kg/d/mi^2 for orthophosphate as P; medians for the Scituate Reservoir drainage area were about 0.13 kg/d/mi^2 as N, and 0.07 kg/d/mi^2 as P, respectively (table 10). The yields

Table 10. Median instantaneous loads and yields of selected constituents in samples from Providence Water monitoring stations by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.

[Station locations shown on figure 2. Ranges of loads and yields are based on significant numbers of nondetections; the lower number is the median based on a lower concentration limit of zero, whereas the higher number is the median based on the detection limit. See text for more information. Loads and yields of iron and manganese are based on data from water year 1996 only. PW, Providence Water; no., number; mi^2, square mile; ft^3/s, cubic foot per second; *E. coli*, *Escherichia coli*; CFU×10^6/d, million colony-forming units per day; kg/d, kilogram per day; N, nitrogen; P, phosphorus; --, not applicable or not determined]

PW station no.	Area (mi^2)	Mean daily discharge (ft^3/s)	Total coliform bacteria		*E. coli* bacteria		Chloride		Nitrate		Orthophosphate		Iron		Manganese	
			Load (CFU×10^6/d)	Yield (CFU×10^6/d/mi^2)	Load (CFU×10^6/d)	Yield (CFU×10^6/d/mi^2)	Load (kg/d)	Yield (kg/d/mi^2)	Load (kg/d as N)	Yield (kg/d/mi^2 as N)	Load (kg/d as P)	Yield (kg/d/mi^2 as P)	Load (kg/d)	Yield (kg/d/mi^2)	Load (kg/d)	Yield (kg/d/mi^2)
Barden Reservoir subbasin																
24	5.0	9.74	814–1,100	163–221	479–871	96–174	155	31.0	0.16–0.17	0.03	0.22–0.28	0.04–0.06	4.44	0.89	0.63	0.13
25	2.39	4.36	640	268	292–335	122–140	27.8	11.6	.09	.04	.08–.10	.03–.04	.83	.35	.20	.08
26	4.2	9.04	653	156	288–639	68.6–152	98.6	23.5	.29–.32	.07–.08	.11–.27	.03–.06	.88	.21	.17	.04
28	10.62	18.6	3,420	322	2,240–2,410	211–227	319	30	.21–.32	.02–.03	.56–.65	.05–.06	12.1	1.14	4.51	.42
35	14.4	27.4	4,070–4,730	283–328	2,540–3,080	177–214	299	20.7	.69	.05	.60–.98	.04–.07	--	--	--	--
Median	--	--	**814–1,100**	**268**	**479–871**	**122–140**	**155**	**23.5**	**.21–.32**	**.04**	**.22–.28**	**.04–.06**	**2.66**	**.62**	**.42**	**.10**
Direct Runoff subbasins																
1	1.6	2.79	1,340	836	676	423	48.7	30.4	0.36	0.22	0.24	0.15	2.61	1.63	0.27	0.17
3	1.9	3.98	471–490	248–258	394–444	207–234	63.9	33.6	.27	.14	.09–.12	.05–.06	.68	.36	.16	.08
4	.86	2.0	.40–124	.5–145	0–89	0–104	7.67	8.92	.03–.04	.03–.05	.02–.04	.02–.05	.60	.70	.23	.27
5	1.2	3.33	80–368	66–306	34–326	28–272	35.1	29.2	.26	.22	.19	.16	1.32	1.1	.28	.23
6	2.0	4.41	3,260	1,630	1,860	928	129	64.5	.31	.16	.31	.16	2.26	1.13	.22	.11
7	4.4	9.58	1,700–1,910	388–435	1,300–1,428	296–325	84.2	19.1	.18–.32	.04–.07	.45–.50	.10–.11	8.07	1.83	.69	.16
8	5.1	8.31	0–765	0–150	0–755	0–148	138	27.1	.66	.13	.39–.58	.8–.11	4.08	.8	.86	.17
9	.64	1.28	401	627	164–184	257–288	123	192	.40	.62	.14	.22	.78	1.22	.08	.12
32	.4	.55	360	900	148	371	12.1	30.2	.1	.25	.04	.1	.38	.95	.04	.1
33	.27	.53	76–85	280–316	10–48	38–179	5.2	19.3	.03	.11	.01	.04	.07	.26	.01	.04
Median	--	--	**380–446**	**334–374**	**156–385**	**232–280**	**56.3**	**29.8**	**.26–.29**	**.15**	**.16**	**.10–.11**	**1.05**	**1.02**	**.22**	**.14**
Moswansicut Reservoir subbasin																
19	3.2	6.9	1,960	614	1,260–1,660	393–518	275	85.9	0.48	0.15	0.05–0.28	0.02–0.09	1.25	0.39	0.69	0.22
21	.32	.67	865	2,700	342	1,070	46.2	144	.23	.72	.04	.12	.59	1.4	.06	.19
Median	--	--	**1,410**	**1,660**	**801–1,000**	**731–794**	**161**	**115**	**.36**	**.43**	**.04–.16**	**.07–.11**	**.92**	**1.12**	**.38**	**.20**
Regulating Reservoir subbasin																
14	6.2	13.2	2,700–2,740	435–441	896–1,220	145–196	70.7	11.4	0.32	0.05	0.43	0.07	1.71	0.28	0.48	0.08
15	5.0	10.4	2,660	532	1,065	213	232	46.4	.38	.08	.44–.47	.09	3.97	.79	.99	.20
16	5.0	10.2	2,630–2,740	527–549	754–1,070	151–215	307	61.4	.80	.16	.17–.38	.03–.08	5.01	1	1.06	.21
18	.54	.41	363	673	15.7	29.1	36.2	67.0	.08	.15	.04	.07	.23	.43	.03	.06
Median	--	--	**2,640–2,700**	**529–540**	**825–1,170**	**148–205**	**151**	**53.9**	**.35**	**.11**	**.3–.4**	**.07–.08**	**2.84**	**.61**	**.74**	**.14**
Westconnaug Reservoir subbasin																
10	1.37	2.79	176–324	129–237	96.2–248	70.2–181	61.2	44.7	0.10	0.07	0.16–0.18	0.12–0.13	0.23	0.17	0.24	0.18
11	.69	2.46	368–427	533–619	86.4–291	125–422	22.1	32.0	.05–.08	.08–.11	.03–.04	.04–.06	.84	1.22	.14	.20
Median	--	--	**272–376**	**331–428**	**91.3–270**	**97.7–270**	**41.6**	**38.4**	**.10–.11**	**.11**	**.10–.11**	**.08–.09**	**.54**	**.69**	**.19**	**.19**
Scituate Reservoir drainage area																
Median	--	--	**653–765**	**386–434**	**342–639**	**151–227**	**70.7**	**30.4**	**0.31**	**0.13**	**0.16–0.24**	**0.06–0.08**	**1.06**	**0.84**	**0.24**	**0.16**

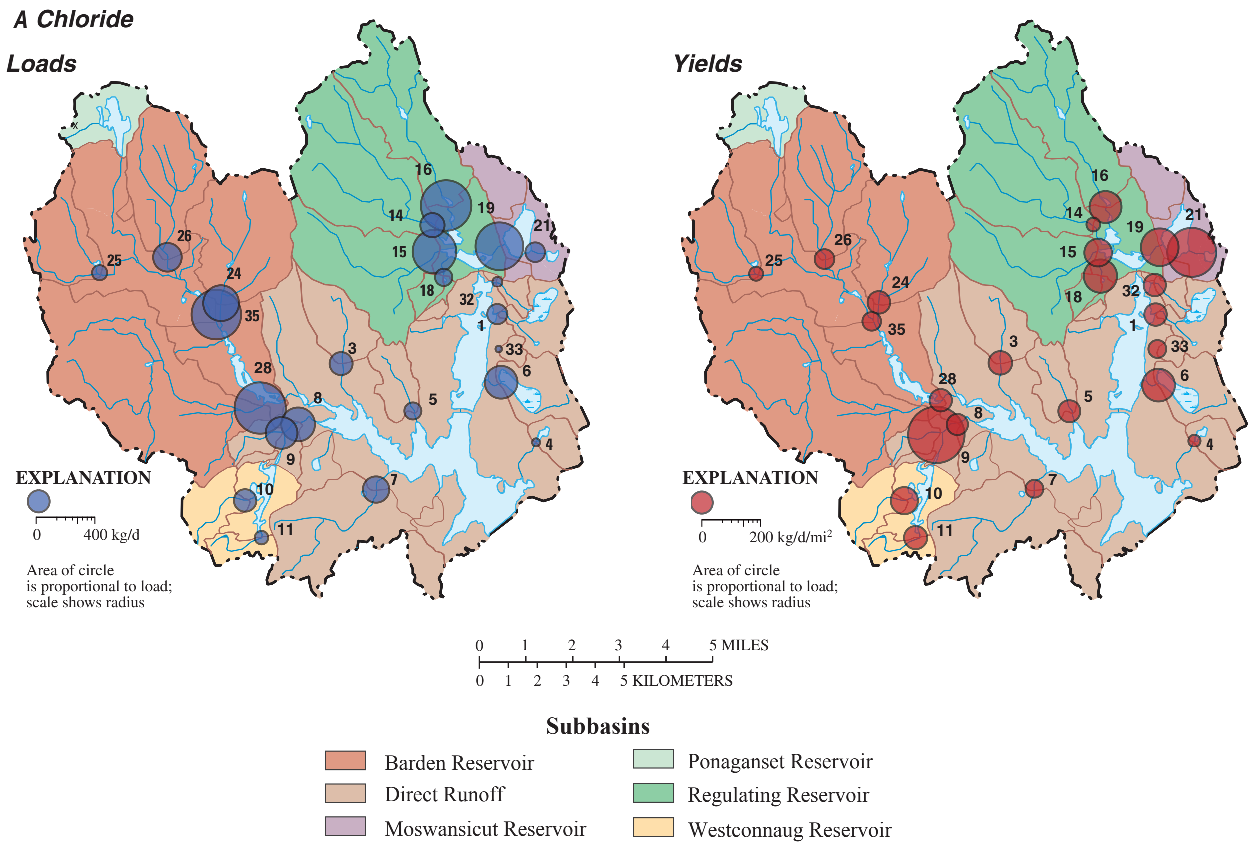


Figure 9. Loads and yields of *(A)* chloride, *(B)* nitrate, *(C)* orthophosphate, *(D)* total coliform bacteria, and *(E) Escherichia coli* bacteria at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002. For constituents with ranges of loads or yields reported in table 11, the symbol size in this figure represents the maximum value of the range.

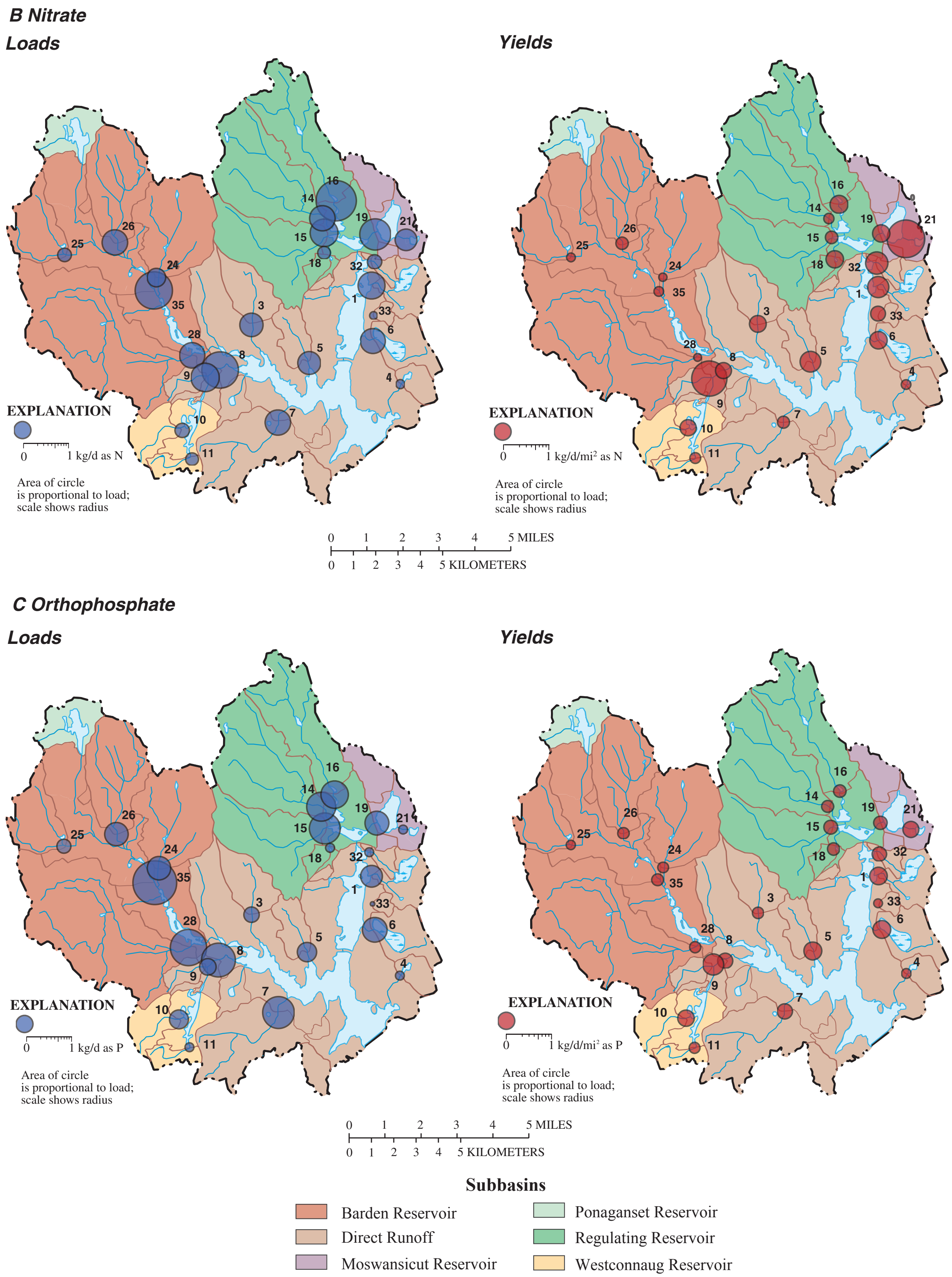
of nitrate and orthophosphate at all stations in the Barden Reservoir subbasin were small, reflecting the relatively undeveloped land in this subbasin. As with chloride, yields were greatest at stations in the Moswansicut Reservoir and Direct Runoff subbasins. The median yield of nitrate was greatest at station 21 in the eastern part of the Moswansicut Reservoir subbasin (fig. 9B).

Bacteria

Loads and yields of total coliform and *E. coli* bacteria varied by more than three orders of magnitude but showed spatial patterns that were similar to those of chloride, nitrate, and orthophosphate (figs. 9D and E; table 10). Relatively high median yields of total coliform and *E. coli* bacteria were similarly clustered in the eastern part of the drainage area, with the highest median yields determined for station 21 in the Moswansicut Reservoir subbasin and at stations 1, 6, and 32 in the Direct Runoff subbasins (table 10). High median yields of bacteria for these stations could result from the effects of waterfowl, runoff from impervious areas, and animal waste. Although relatively high for monitoring stations in the Scituate Reservoir basin, median bacteria yields for these stations were low overall compared to median yields of bacteria for sewage-contaminated stream water or stream water affected by stormwater runoff in an urban environment (Breault and others, 2002).

Iron and Manganese

Median loads of iron (12.1 kg/d) and manganese (4.51 kg/d) were highest at the outflow of the Barden Reservoir subbasin, probably owing to the predominance of forest cover and the large area of this subbasin. The highest yield of manganese (0.42 kg/d/mi²) was also calculated for samples from this station, but the highest yield of iron (1.63 kg/d/mi²) was calculated for the outflow from a tributary subbasin dominated by wetlands. Loads and yields were calculated only for WY 1996 because it was the only year during which concentration data were collected by Providence Water for these constituents.



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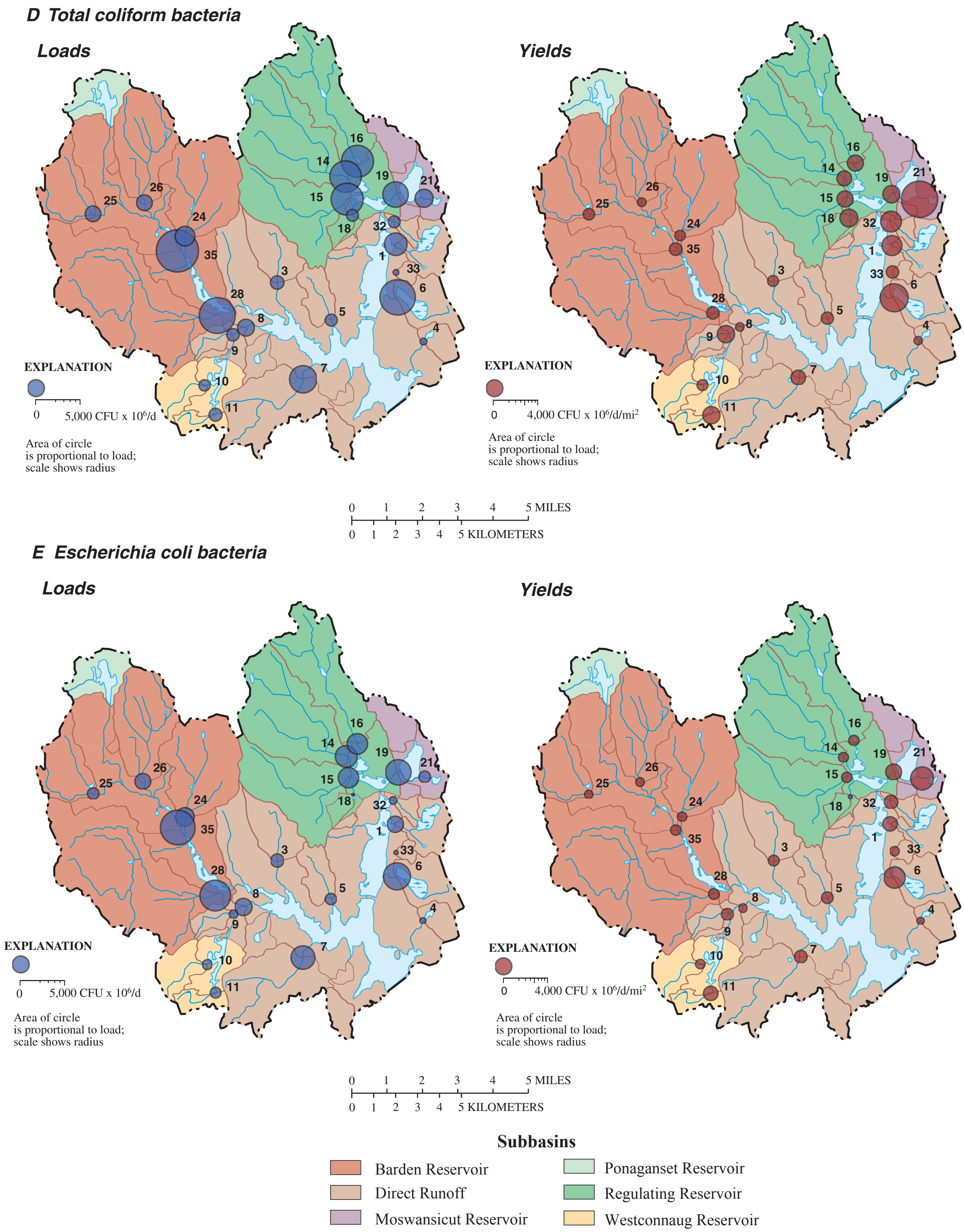


Figure 9. Loads and yields of *(A)* chloride, *(B)* nitrate, *(C)* orthophosphate, *(D)* total coliform bacteria, and *(E) Escherichia coli* bacteria at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002. For constituents with ranges of loads or yields reported in table 11, the symbol size in this figure represents the maximum value of the range.—Continued

Trends in Water-Quality Properties and Constituent Concentrations

Time trends in water-quality properties and constituents were investigated for the shorter 7-year study period of WY 1996–2002 and for the longer 20-year period WY 1983–2002. Trends during the shorter period may be considered current trends in water-quality properties and constituent concentrations, whereas trends during the longer period may reflect ongoing or past changes. Differences in time trends for the two time periods, however, also could result from the fact that time trends are more readily detected in larger and longer data sets. Time trends during the shorter period also could differ from trends during the longer period because the shorter, more recent data set could embody less variability, for example, as a result of changes in sampling and analytical procedures over time. The results of statistical tests for time trends in water-quality properties and concentrations at monitoring stations are shown in tables 11 and 12; the geographic distribution of trends that are considered statistically significant (p values less than 0.05) is shown in figure 10.

Water-Quality Properties

Upward trends in pH were identified at more stations for the longer period WY 1983–2002 than for the period WY 1996–2002. Upward trends in the pH of tributaries may be associated with reductions in acid precipitation in North America since the 1980s (Lynch and others, 2000). Samples collected at the Ponaganset Reservoir station (23) had the most statistically significant upward trend in pH for WY 1983–2002 (p value less than 0.0001) (table 12). The drainage area of this station is one of the least developed in the Scituate Reservoir drainage area, and stream water at this station is characterized by low turbidity values and low chloride concentrations (table 5). Downward trends in pH are apparent in the data for only two stations (8 and 31 in the Direct Runoff subbasins) for WY 1983–2002; no downward trends in pH were identified for the shorter period (fig. 10A).

Time trends in color also were nearly all upward at stations where trends were identified for WY 1996–2002 and WY 1983–2002. Because color is likely to have a natural source, such as dissolved organic material or perhaps suspended or colloidal iron or manganese, upward trends in color are difficult to interpret. Trends in color could be related to changes in the geochemical conditions that favor the mobility of dissolved organic material or other color sources. A downward trend in color was apparent for one station (8) in the Direct Runoff subbasins for WY 1996–2002 (fig. 10B).

Few time trends were identified for turbidity. Six stations in the Barden Reservoir, Direct Runoff, Moswansicut Reservoir, and Regulating Reservoir subbasins showed upward trends in turbidity for WY 1983–2002; no upward trends were identified for WY 1996–2002. A downward trend was apparent in the data for one station (10) in the Westconnaug Reservoir subbasin for WY 1983–2002 and one station (8) in the Direct Runoff subbasins for WY 1996–2002 (fig. 10C).

Time trends in alkalinity, like trends in pH, were primarily upward for WY 1996–2002 and WY 1983–2002 and similarly could be related to changes in precipitation chemistry. For WY 1983–2002, upward trends in alkalinity were identified at several stations in the Regulating Reservoir subbasin, whereas no upward pH trends were identified for any stations in this subbasin. Downward trends in alkalinity were apparent at one station (8) in the Direct Runoff subbasins and one station (17) in the Regulating Reservoir subbasin for WY 1983–2002 (fig. 10D).

Constituent Concentrations

Time trends in chloride concentrations for WY 1983–2002 were upward at four stations (24, 26, and 28 in the Barden Reservoir subbasin, and 20 in the Moswansicut Reservoir subbasin) and downward at two stations (8 and 9) in the Direct Runoff subbasins and at two stations (11 and 12) in the Westconnaug Reservoir subbasin (fig. 10E). For WY 1996–2002, trends were identified for only three stations—upward for stations 3 and 10, and downward for station 4. Upward trends in chloride concentrations could indicate the effects of land-use changes over time or changes in road-salt applications. Downward trends at stations 8 and 9 are likely the result of changes in storage practices at a salt-storage facility in the drainage area of station 9 on Bear Tree Brook, a tributary to Westconnaug Brook (station 8). The salt-storage facility previously contained uncovered piles of road salt and sand, but these materials were enclosed in 1988 (Nimiroski and Waldron, 2002; fig. 11).

Time trends in nitrate concentrations were primarily downward for WY 1983–2002 and WY 1996–2002. Downward trends in nitrate concentrations for WY 1983–2002 could be the result of higher concentrations at the beginning of the measurement period for nitrate, which began in 1987. Trends in nitrate concentrations in tributary stream water could be affected by changes in atmospheric deposition of nitrogen, but these changes have been variable in the eastern United States since the 1980s (Lynch and others, 2000). Trends in nitrate concentrations also could be affected by changes in land use, watershed processes, or nitrate concentrations in base flow. Nitrate concentrations at many stations, however, are low and close to reporting limits; apparent time trends could be affected by factors other than environmental sources, such as changes in analytical procedures (fig. 10F). Orthophosphate concentration data were not available for the longer period, and few trends were identified for WY 1996–2002. Orthophosphate concentrations also were low and near the reporting level at most stations.

Table 11. Significance levels (*p* values) of seasonal Kendall tests for time trends in water-quality properties and constituent concentrations at Providence Water monitoring stations by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002.

[Stations locations shown on figure 2. *p* values for trends considered significant are shown in **bold**; PW, Providence Water; *E. coli*, *Escherichia coli*; (+), variables are positively correlated; (-), variables are inversely correlated]

PW station number	pH	Color	Turbidity	Total coliform bacteria	*E. coli* bacteria	Alkalinity	Chloride	Nitrate	Phosphate
Barden Reservoir subbasin									
24	**0.038** (+)	0.083	0.212	0.156	0.856	**0.040** (+)	0.708	**0.014** (-)	**0.050** (-)
25	.282	.474	1.000	.135	.317	**.050** (+)	.949	**.050** (-)	.078
26	**.040** (+)	.197	.254	.225	.794	.229	.156	**.015** (-)	.563
27	.057	.243	.078	.383	.307	.130	.838	.091	.364
28	.691	.068	.657	1.000	.164	.199	.072	**.031** (+)	.241
29	.305	.162	.153	.077	.120	.158	.298	.054	.241
35	.159	.874	.394	.197	.386	.443	.144	**.020** (-)	.108
Direct Runoff subbasins									
1	0.083	0.294	0.893	0.149	0.060	0.114	0.966	**0.021** (-)	0.107
2	1.000	.866	.704	.358	.773	.556	.391	.080	.320
3	.080	.617	.057	.265	.955	**.023** (+)	**.045** (+)	.203	.227
4	.221	**.043** (+)	.409	.145	**.024** (+)	**.014** (+)	**.049** (-)	**.045** (+)	.196
5	.905	.195	.338	.517	.508	.236	.532	.060	.458
6	.410	.149	.476	.289	.159	.070	.590	**.012** (-)	.052
7	**.039** (+)	**.039** (+)	.797	.218	.167	**.015** (+)	.463	**.017** (-)	.138
8	.402	**.025** (-)	**.034** (-)	.150	.098	.922	.641	**.008** (-)	.843
9	.119	.052	.058	.363	.051	.119	.068	.333	.276
30	.389	1.000	.923	.240	1.000	**.016** (+)	.263	.055	.767
31	.806	1.000	.806	1.000	.806	.221	.086	.130	**.037** (+)
32	.203	.806	.382	.754	.494	.206	1.000	.134	.215
33	.124	.869	.516	.794	.766	.203	1.000	.235	.157
36	.298	.169	.857	.279	.660	.522	.106	.520	1.0
37	.635	1.0	1.0	1.0	.180	.888	.437	.320	.427
Moswansicut Reservoir subbasin									
19	**0.014** (+)	1.000	0.483	0.827	1.000	**0.037** (+)	0.719	**0.030** (+)	1.000
20	.051	.113	.185	.362	.220	.304	.648	**.024** (+)	.175
21	.291	**.013** (+)	.511	1.000	.235	.104	.769	.089	.757
22	.078	.065	.454	.438	.463	.071	.569	**.047** (-)	**.028** (-)
34	.766	.295	1.000	.230	.816	1.000	.535	.176	1.000
Ponganset Reservoir subbasin									
23	0.814	0.167	0.295	1.000	0.568	0.215	0.112	0.042	0.142
Regulating Reservoir subbasin									
13	0.056	0.902	0.960	**0.014** (-)	0.096	**0.034** (+)	0.511	**0.008** (-)	0.144
14	.836	.181	.670	.608	.531	.383	.967	**.023** (-)	.718
15	**.029** (+)	.058	.775	.063	.458	**.009** (+)	.686	**.012** (-)	.188
16	**.015** (+)	.436	.341	.428	.455	.058	.467	**.009** (-)	.063
17	1.000	.206	1.000	.441	.345	**.045** (+)	.238	**.017** (-)	1.000
18	**.010** (+)	.133	.141	1.000	.596	.217	.804	.131	.350
Westconnaug Reservoir subbasin									
10	0.172	0.563	0.726	0.721	**0.049** (+)	0.149	**0.017** (+)	**0.009** (-)	0.853
11	.243	.060	.809	.499	.099	.209	.598	.134	.241
12	.206	.807	.507	.069	1.000	.817	.507	.109	.139

Table 12. Significance levels (*p* values) of seasonal Kendall tests for time trends in water-quality properties and constituent concentrations at Providence Water monitoring stations by tributary-reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, October 1, 1982 through September 30, 2002.

[Station locations shown on figure 2. PW, Providence Water; *p* values for trends considered significant are shown in **bold**; (+), variables are positively correlated; (-), variables are inversely correlated]

PW station number	pH	Color	Turbidity	Total coliform bacteria	Alkalinity	Chloride	Nitrate
				Barden Reservoir subbasin			
24	**0.027** (+)	**0.023** (+)	**0.003** (+)	**0.003** (-)	**0.048** (+)	**0.031** (+)	0.083
25	**.003** (+)	.502	.179	**.003** (-)	.793	.526	.127
26	**.009** (+)	.581	.275	**.020** (-)	.906	**.017** (+)	**.035** (-)
27	.078	**.012** (+)	.204	.112	.962	.075	.096
28	.896	**.0002** (+)	**.007** (+)	.509	.343	**.011** (+)	**.032** (-)
29	**.009** (+)	.051	.681	**.002** (-)	.638	.222	.104
35	.069	.874	.417	.286	.315	.144	**.012** (-)
				Direct Runoff subbasins			
1	0.511	**0.012** (+)	**0.0009** (+)	**0.0006** (-)	0.314	0.682	**0.001** (-)
2	**.022** (+)	.301	.856	.234	.162	.417	.499
3	**.036** (+)	**.030** (+)	.374	**.0005** (-)	**.042** (+)	.186	.403
4	**.012** (+)	.250	.329	**.002** (-)	**.005** (+)	.885	.054
5	.087	**.024** (+)	**.006** (+)	**.005** (-)	.175	.574	.524
6	**.001** (+)	.257	.604	**.007** (-)	**.004** (+)	.178	**.008** (-)
7	**.045** (+)	**<.0001** (+)	.070	**.0003** (-)	**.047** (+)	.152	**.001** (-)
8	**.007** (-)	.220	.052	**<.0001** (-)	**.016** (-)	**.0005** (-)	**.011** (-)
9	.080	**.022** (+)	.052	**.026** (-)	**.021** (+)	**.0006** (-)	**.023** (-)
30	**.005** (+)	.499	.131	**.003** (-)	.320	.538	.635
31	**.008** (-)	.130	.401	.935	.136	.837	.730
32	.273	**.013** (+)	.720	.695	.820	.697	**.025** (-)
33	.964	.582	.701	.844	.985	.234	**.002** (-)
36	.233	.170	.857	1.000	.522	.106	.401
37	.090	1.000	1.000	1.000	.888	.437	.353
				Moswansicut Reservoir subbasin			
19	0.050	0.223	**<0.0001** (+)	**0.0008** (-)	**<0.0001** (+)	0.169	0.087
20	.959	**.007** (+)	.350	**.002** (-)	.646	**.002** (+)	**.033** (-)
21	.779	**.013** (+)	.077	.030	**<.0001** (+)	.369	.314
22	.924	.195	.119	**.001** (-)	**.031** (+)	.310	.061
34	.766	.294	.159	.383	1.000	.535	.070
				Ponganset Reservoir subbasin			
23	**<0.0001** (+)	0.068	0.610	**0.007** (-)	0.234	0.215	0.933
				Regulating Reservoir subbasin			
13	0.605	0.347	0.470	**0.002** (-)	**0.015** (+)	0.676	0.113
14	.993	**.005** (+)	.204	.052	.453	.547	.055
15	.178	**.001** (+)	.128	**.032** (-)	**.005** (+)	.854	.055
16	.350	**.033** (+)	**.031** (+)	**.005** (-)	**.016** (+)	.160	.120
17	.086	.848	.234	**.0003** (-)	**.024** (-)	.900	**.012** (-)
18	.256	.166	.158	**.001** (-)	.258	.859	**.003** (-)
				Westconnaug Reservoir subbasin			
10	0.132	0.270	**0.011** (-)	**0.003** (-)	0.734	0.313	0.101
11	.070	**.0009** (+)	1.000	**.001** (-)	.148	**.004** (-)	.698
12	**.003** (+)	.481	.147	**.006** (-)	**.009** (+)	**.006** (-)	.837

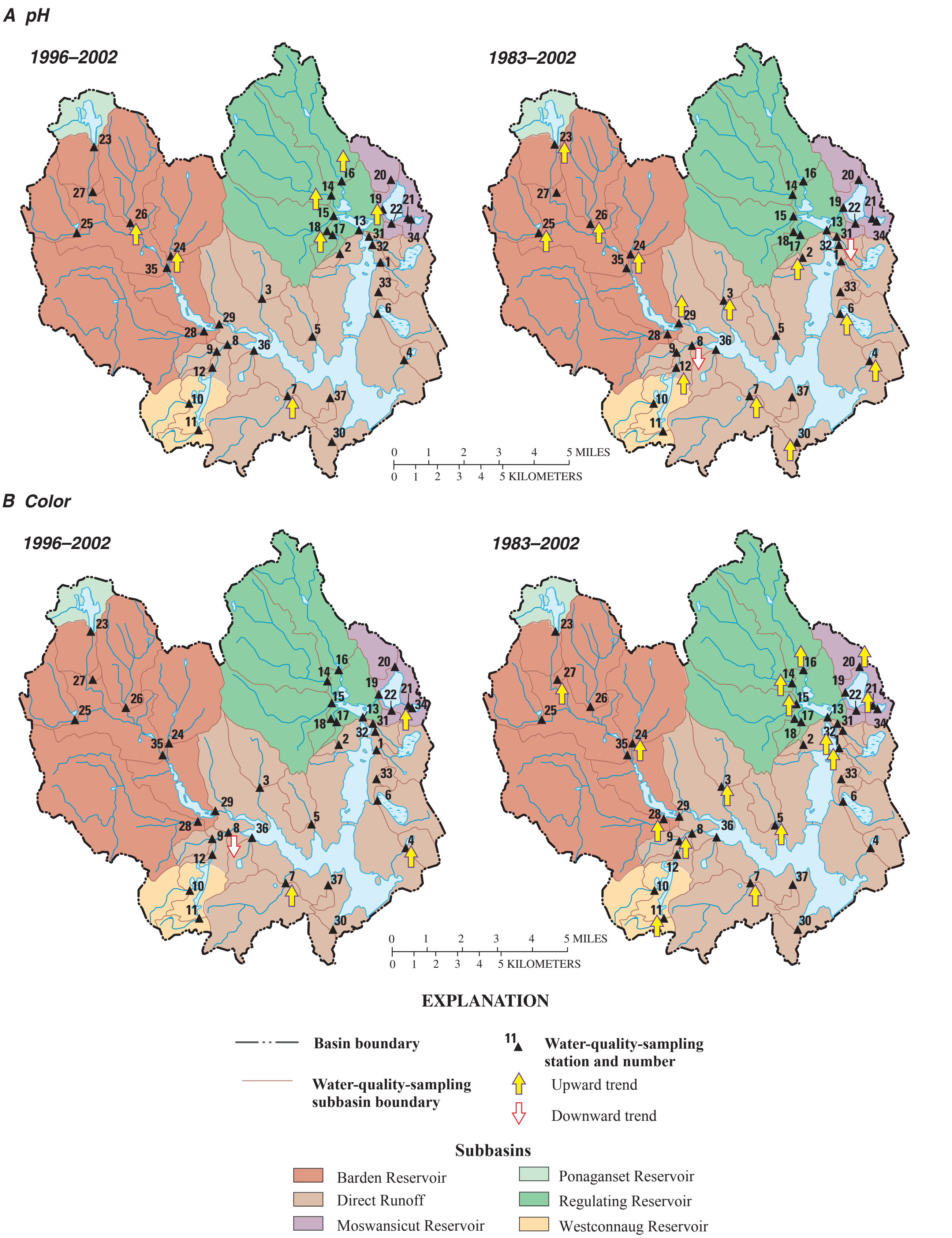


Figure 10. Time trends for *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, *(E)* chloride, *(F)* nitrate, *(G)* total coliform bacteria, and *(H) Escherichia coli* bacteria, at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002, and October 1, 1982 through September 30, 2002.

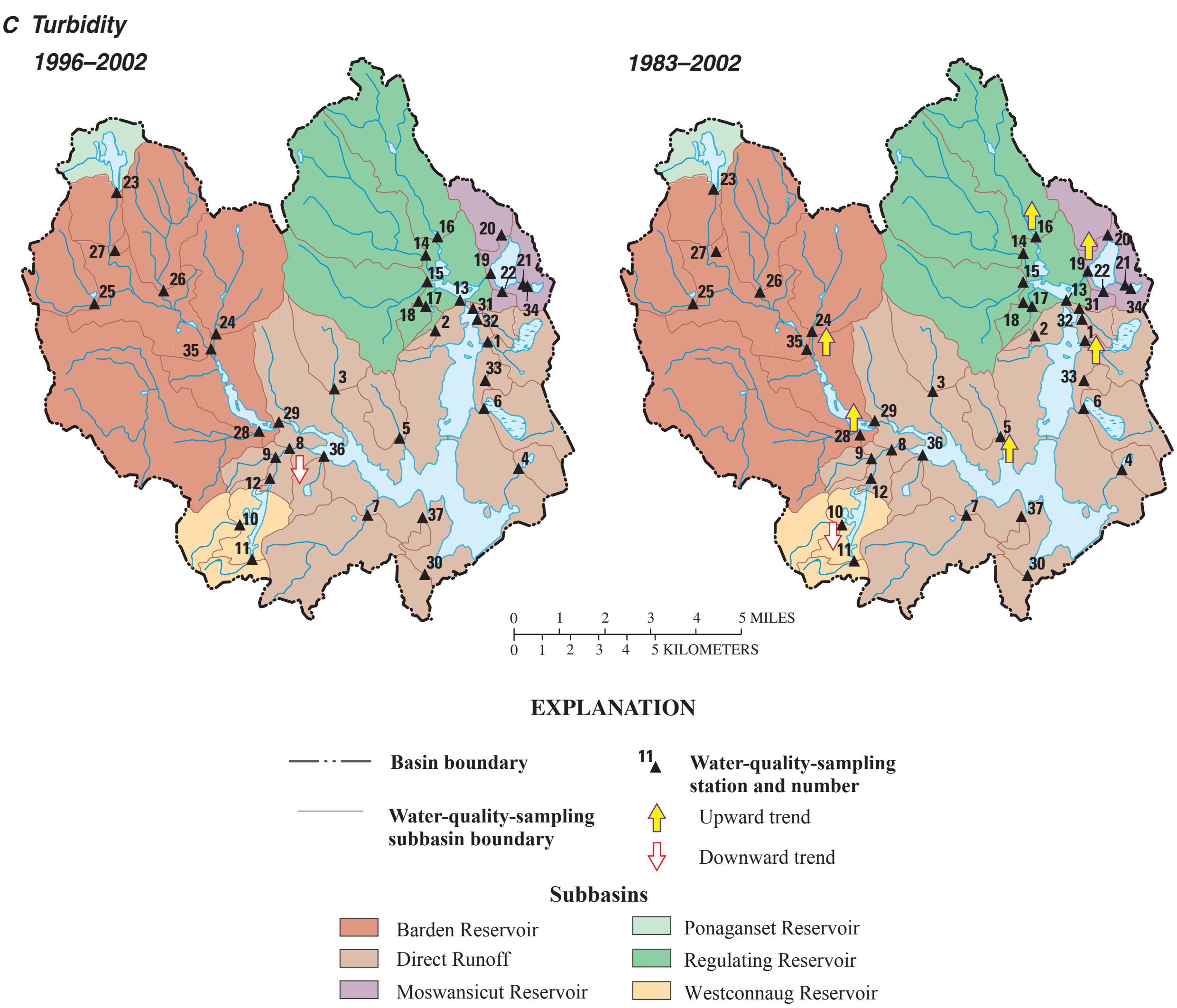


Figure 10. Time trends for *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, *(E)* chloride, *(F)* nitrate, *(G)* total coliform bacteria, and *(H) Escherichia coli* bacteria, at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002, and October 1, 1982 through September 30, 2002.—Continued

Downward time trends in concentrations of total coliform bacteria were apparent at about two-thirds of stations for WY 1983–2002. For WY 1996–2002, no trends in total coliform or *E. coli* bacteria concentrations were identified for 34 of the 37 stations (figs. 10G and H; table 11). Bacteria concentrations in stream water are extremely variable and are strongly affected by contributions from base flow and stormwater runoff. Thus, time trends in bacteria concentrations can be difficult to interpret. Changes in sampling or analytical methods or procedures for handling censored data might have affected the results of tests for time trends in concentrations of total coliform bacteria. Environmental sources that produce downward trends in concentrations of total coliform bacteria include changes in the routing and disposal of stormwater runoff, changes in waterfowl abundance, and improvements to on-site sewage-disposal systems.

Because sampling and analysis for iron and manganese were suspended in 1996, insufficient data were available for the determination of time trends. Trends analyses for these two constituents for WY 1983–1995 are available in Breault and others (2000).

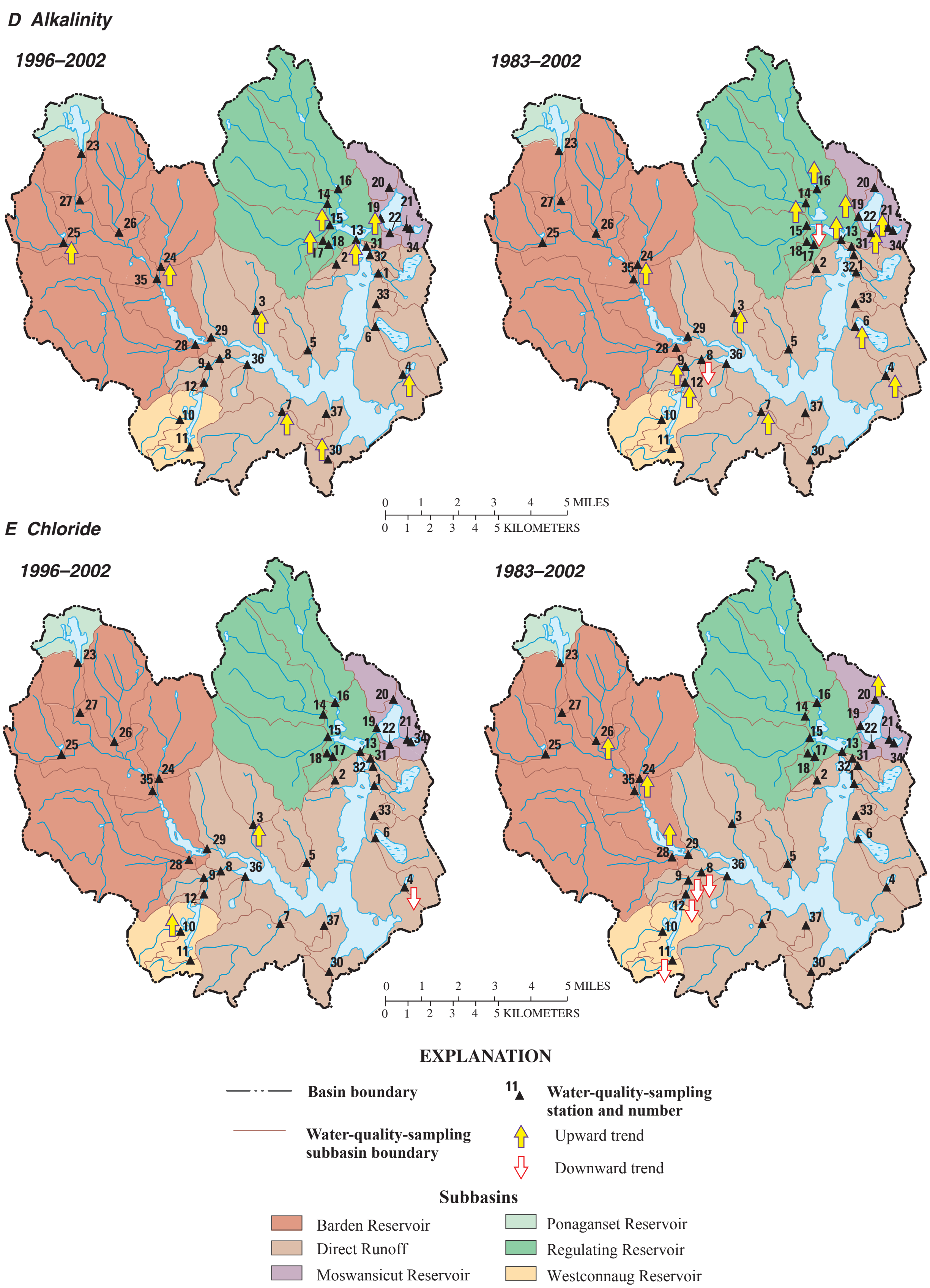


Figure 10. Time trends for *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, *(E)* chloride, *(F)* nitrate, *(G)* total coliform bacteria, and *(H) Escherichia coli* bacteria, at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002, and October 1, 1982 through September 30, 2002.—Continued

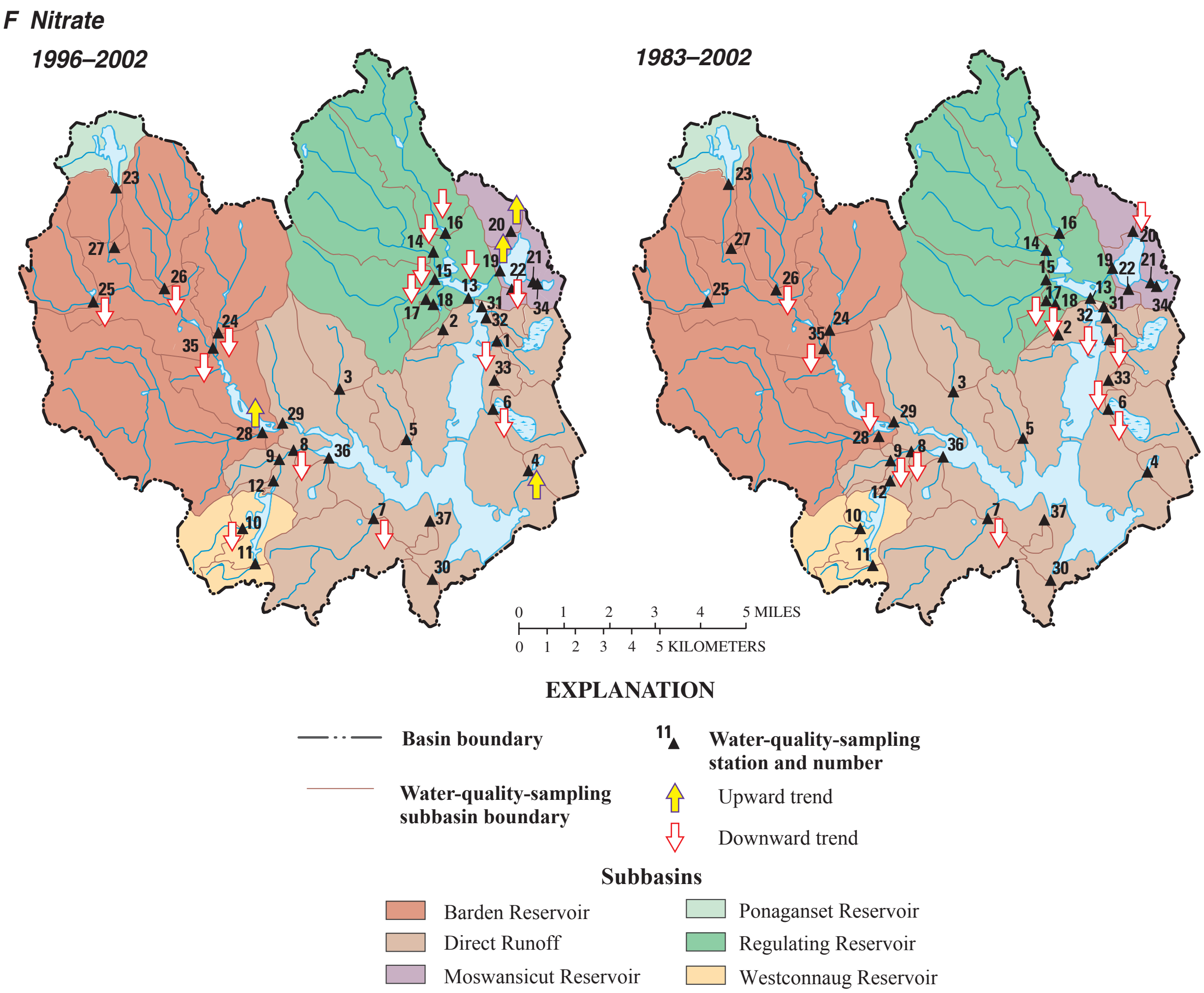
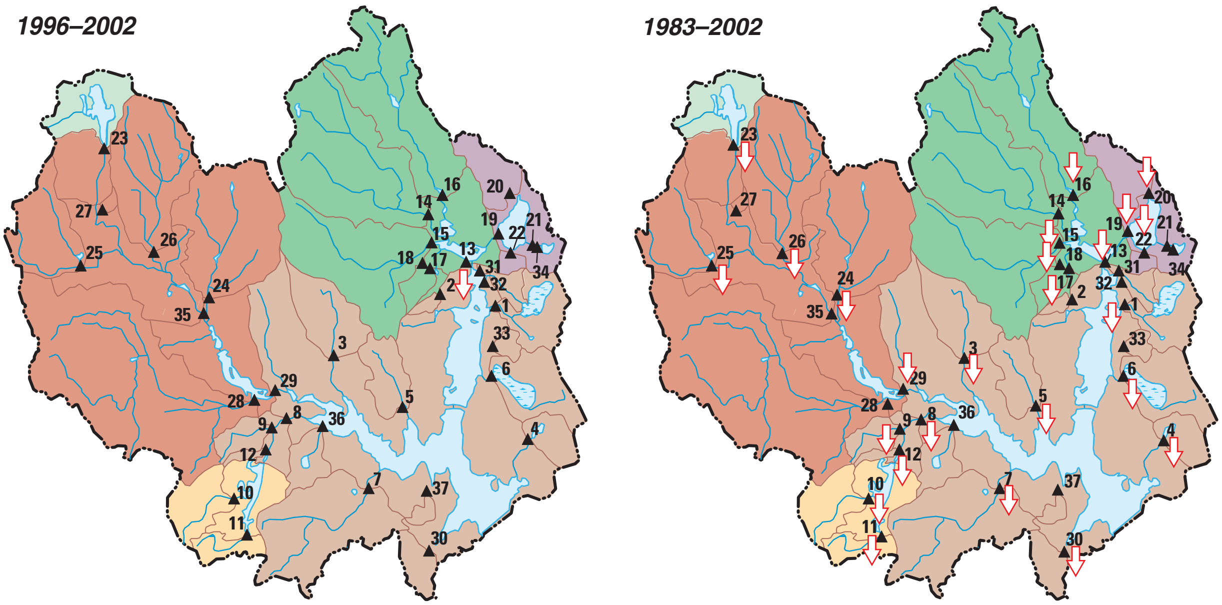


Figure 10. Time trends for *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, *(E)* chloride, *(F)* nitrate, *(G)* total coliform bacteria, and *(H) Escherichia coli* bacteria, at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002, and October 1, 1982 through September 30, 2002.—Continued

G Total coliform bacteria



H Escherichia coli bacteria

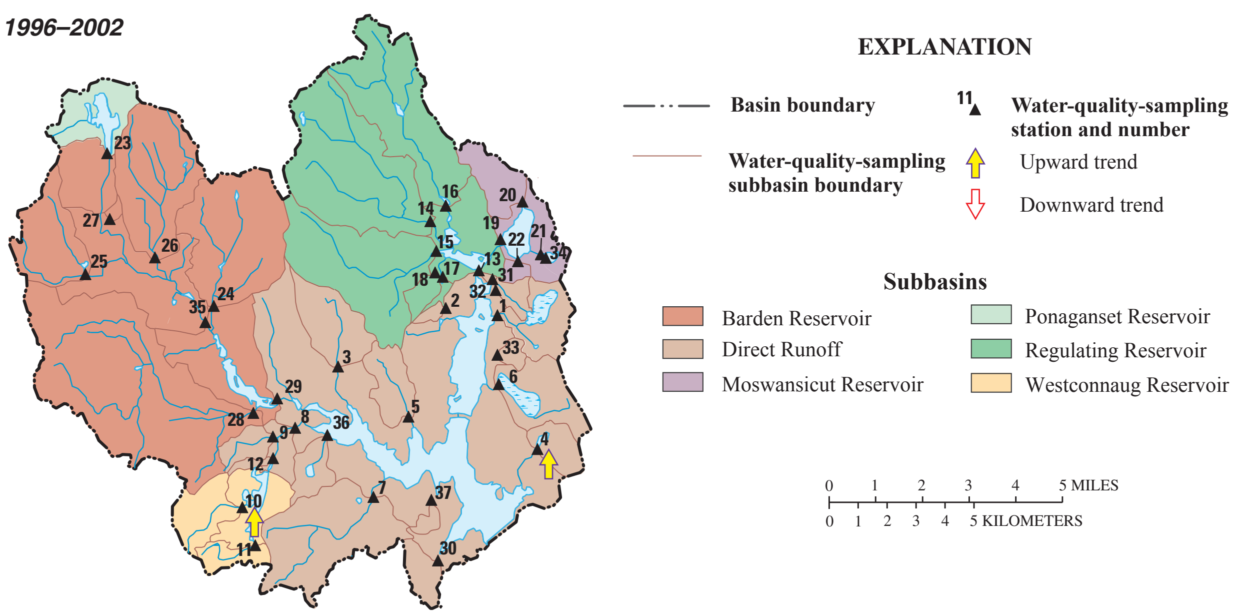


Figure 10. Time trends for *(A)* pH, *(B)* color, *(C)* turbidity, *(D)* alkalinity, *(E)* chloride, *(F)* nitrate, *(G)* total coliform bacteria, and *(H) Escherichia coli* bacteria, at Providence Water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, October 1, 1995 through September 30, 2002, and October 1, 1982 through September 30, 2002.—Continued

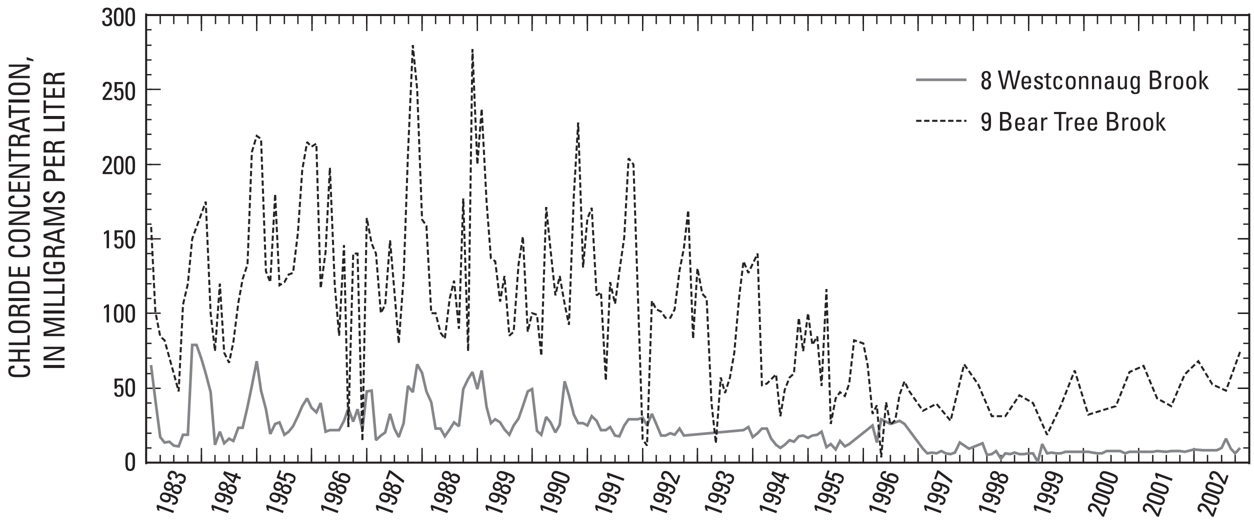


Figure 11. Concentrations of chloride measured in samples collected at station 8, Westconnaug Brook, and station 9, Bear Tree Brook, in the Scituate Reservoir drainage area, Rhode Island, from October 1, 1982 through September 30, 2002.

Summary

Water-quality and streamflow data collected at 37 surface-water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, from October 1, 1995 through September 30, 2002 (WY 1996–2002), were analyzed to determine water-quality conditions and constituent loads and yields in the drainage area. Trends in selected water-quality properties and constituent concentrations also were investigated for WY 1996–2002 and for a longer period, WY 1983–2002, by using historical data. Water-quality samples were collected and analyzed by personnel of Providence Water, the agency that manages the reservoir. Streamflow data were collected by USGS personnel. Median values and other summary statistics were calculated for all water samples collected at 37 monitoring stations during WY 1996–2002 for pH, color, turbidity, alkalinity, chloride, nitrite, nitrate, total coliform and *E. coli* bacteria, orthophosphate, iron, and manganese. Instantaneous loads and subbasin yields of chloride, nitrate, orthophosphate, total coliform and *E. coli* bacteria, iron, and manganese were calculated for all sampling dates during WY 1996–2002 for the 23 stations for which sufficient flow data were available. Values of physical properties and concentrations of constituents were compared to State and Federal water-quality standards and guidelines and were related to streamflow, land-use characteristics, and road density.

The interpretations of the results of water-quality analyses presented in this report are limited in some cases by a lack of quality-control information on the data. Because laboratory or field quality-control data were not available, it was not possible to evaluate the accuracy, precision, or bias of laboratory analyses, the in situ variability of water-quality properties and constituents, or the potential for sample contamination. Wherever possible, however, approaches were used to minimize the limitations that may have resulted from the use of existing data.

Tributary stream water in the Scituate Reservoir drainage area during WY 1996–2002 was slightly acidic, with a median pH for all stations of 6.1. The pH of most samples from most stations was less than 6.5, which has been established as the lower limit by the RIDEM for Class A waters (waters that are used for drinking water or are tributary streams to drinking-water sources, unless low pH values occur naturally). The low pH values in tributary streams in the Scituate Reservoir drainage area likely reflect the low pH of precipitation and the relatively nonreactive rock types in the drainage area.

The median values of turbidity were low in samples from most or all monitoring stations; the median value for the entire Scituate Reservoir drainage area was 0.62 NTU. Median turbidity values measured in samples from all 37 stations were less than the maximum allowable value above background established by the RIDEM for Class A waters (5 NTU) and less than the maximum allowable value established by the

USEPA for drinking-water supplies (5 NTU). Median turbidity values measured in samples from all but one station were below the USEPA's proposed reference concentration for minimally impacted conditions in the region (1.68 NTU). These results suggest that tributary streams in the Scituate Reservoir drainage area are minimally affected by suspended particles, organic matter, and dissolved colored material relative to stream water elsewhere in the region.

Median alkalinity values measured in samples from tributary streams ranged from around 2 to 17 mg/L as $CaCO_3$, and the median value for all sampling stations for the entire Scituate Reservoir drainage area was 4.8 mg/L as $CaCO_3$. Alkalinity was consistently low in the Barden Reservoir, Ponaganset Reservoir, and Westconnaug Reservoir subbasins in the western part of the study area; and was highest in the Moswansicut, Regulating, and Direct Reservoir subbasins in the eastern part of the study area.

Median chloride concentrations were highest in samples collected from stations in the Moswansicut (23 to 29 mg/L), Regulating (6.7 to 30 mg/L), and Direct Runoff (1.2 to 58 mg/L) subbasins. The median chloride concentration for the entire study area was 13 mg/L, a low value typical for natural stream water in coastal New England.

Concentrations of the nutrient species nitrate, nitrite, and orthophosphate were low. Median concentrations of nitrate were less than or equal to 0.1 mg/L as N at 33 of the 37 stations, and median concentrations of orthophosphate were less than or equal to 0.07 mg/L as P at all stations. Median nitrate concentrations at all stations were less than the USEPA's proposed reference concentration of 0.31 mg/L as N for the region. Median concentrations of orthophosphate were greater than the RIDEM's standard for total phosphorus in Class A waters (0.025 mg/L as P) and the USEPA's proposed reference concentration of 0.024 mg/L as P for the region at 28 of the 37 stations. Because biological productivity typically is limited by phosphorus concentrations in inland waters, elevated concentrations of phosphorus may be of concern.

Indicator bacteria were detected in samples from all stations, but median concentrations for the study area were low—23 and 9 colony-forming units per 100 mL for total coliform and *E. coli* bacteria, respectively. Class A or drinking-water standards for indicator bacteria generally differ depending on the number of samples analyzed. However, if all samples in the Scituate Reservoir drainage area collected during WY 1996–2002 are considered together to represent one monitoring period for each station, the class A criterion for total coliform bacteria—that concentrations in fewer than 10 percent of samples exceed 500 CFU/100 mL—was met at about two-thirds of the stations.

Median values of some water-quality properties and constituent concentrations that are affected by human activities correlated positively with the percentages of developed land and negatively with the percentage of forest cover. Median concentrations of chloride correlated positively (p less than 0.0001) with road density, possibly owing to the application of road salt. The significant positive correlation (p less than 0.001) between median values of color and the percentages of wetlands in the drainage areas suggests that some sources of color in tributary stream waters may be natural. Negative correlations of turbidity, indicator bacteria, and chloride with streamflow likely reflect seasonal patterns in which values of water-quality properties and concentrations are higher during low-flow conditions in summer and fall at the end of the water years. The strong inverse correlation of chloride concentrations with streamflow at 10 stations in the Barden and Direct Runoff subbasins might reflect the dilution of chloride in base flow by stormwater during periods of high and moderate streamflow as well as seasonal patterns within the water year. Median concentrations of nitrate correlated positively with streamflow at seven stations, possibly owing to the effects of runoff contaminated by animal waste or fertilizer.

Loads generally were greater at stations with larger drainage areas and at stations in the eastern, more developed part of the Scituate Reservoir drainage area than in other parts of the drainage area. Yields generally were higher at stations in the eastern part of the drainage area. The instantaneous loads and yields reported in this study represent point measurements of continuous mass fluxes that vary seasonally, daily, and in some cases more frequently. Thus, differences in median values of loads and yields among stations incorporate variability that results from differences in sampling schedules as well as differences in the sources and transport characteristics of constituents.

The highest median chloride load (319 kg/d) was measured at the station at the outflow of the Barden Reservoir subbasin; this high value may be related to the large area of this subbasin. The highest median yields were measured at a station in the Direct Runoff subbasins (192 kg/d/mi^2) and a station in the Moswansicut (144 kg/d/mi^2) subbasin. These yields may be high because they were calculated for stream water from drainage areas with nearby salt-storage facilities, roads, or development. Median nutrient loads were highest at a station in the Barden Reservoir subbasin (0.60 to 0.98 kg/d as P for orthophosphate) and at a station in the Regulating Reservoir subbasin (0.80 kg/d as N for nitrate), probably because the drainage areas to the stations are large; median nutrient yields were lowest in the Barden Reservoir subbasin (about 0.04 kg/d/mi^2 as N or as P for both nitrate and orthophosphate), in which land use is relatively undeveloped. Median yields of both total coliform (2,700 CFU×10^6/d/mi^2) and *E. coli* (1,070 CFU×10^6/d/mi^2) bacteria were highest at stations in the Moswansicut Reservoir subbasin in the eastern, more developed part of the study area. Median loads of iron (12.1 kg/d) and manganese (4.51 kg/d) were highest at the outflow of the Barden Reservoir subbasin, probably owing to the predominance of forest cover and the large area of this subbasin. Loads and yields of iron and manganese were calculated only for WY 1996 because it was the only year during which data for these constituents were collected by Providence Water.

Significant upward and downward time trends were identified in water-quality properties and concentrations of several constituents for WY 1996–2002 and WY 1983–2002. Significant (*p* less than 0.05) upward trends in pH were identified at nearly one-third of the monitoring stations for WY 1983–2002 and may reflect regional reductions in acid precipitation. Significant downward trends in pH were observed for WY 1983–2002 at only 2 stations, both of them in the Direct Runoff subbasins. Significant trends in color were upward in samples from 15 of the 37 stations for WY 1983–2002, and few significant trends in either direction were observed for WY 1996–2002. Only one significant downward trend was observed for color, and this was for a station in the Direct Runoff subbasins for WY 1996–2002. Significant upward trends in turbidity were observed for 6 of the 37 stations for WY 1983–2002. Downward trends in turbidity were significant for only 2 stations. Significant trends in alkalinity were generally similar to those for pH—upward over both time intervals—and are likely related to the same set of changes in precipitation chemistry. Downward trends in alkalinity were observed at only 2 stations, one in the Direct Runoff subbasins and one in the Regulating Reservoir subbasin for WY 1983–2002.

Few significant trends were observed for chloride. Upward trends in chloride concentrations for WY 1983–2002 at 4 stations may reflect the effects of increased development, whereas strong downward trends at 2 stations in the Direct Runoff subbasins for the same period likely are the result of changes in storage practices at an upgradient road-salt storage facility. Significant trends in nitrate concentrations were primarily downward at 13 of the 37 stations for WY 1983–2002 and at 15 stations for WY 1996–2002. Concentrations of both nitrate and orthophosphate, however, were low and close to reporting limits; as a result, trends could be affected by factors like changes in analytical procedures in addition to changes in environmental sources. Downward trends in concentrations of total coliform bacteria were identified at 25 of the 37 stations for WY 1983–2002, but these could have been affected by changes in analytical or other procedures. A significant trend in *E. coli* was observed at only 1 station, and this was for WY 1996–2002 in the Direct Runoff subbasins.

In conclusion, water-quality conditions for WY 1996–2002 reflect the generally high quality of tributary stream water in the Scituate Reservoir drainage area. Changes in the monitored water-quality properties and constituent concentrations generally appear to have been small, except for the specific case of downward chloride concentrations related to activities at a road-salt storage facility. The relations of concentrations and values of several water-quality constituents and properties to land-use and road-density characteristics in monitoring-station drainage areas, however, point to the effects of human activities on tributary stream-water quality.

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