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Water-Quality Trends in the Scituate Reservoir Drainage Area, Rhode Island, 1983–2012

Scientific Investigations Report 2015–5058

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

Cover. Photograph of the Scituate Reservoir from Route 12, taken by Kimberly Campo.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

International System of Units to Inch/Pound

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)
	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]
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as
°C = (°F – 32) / 1.8.

Supplemental Information

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

Chemical concentration is given in units of milligrams per liter (mg/L) or milliequivalents per liter (meq/L). Milliequivalents per liter are units expressing the number of electron-moles of a solute per unit volume (liter). A mole is the mass in grams numerically equal to the atomic mass of a given element.

Abbreviations

CFU	colony-forming unit
DOC	dissolved organic carbon
E. coli	*Escherichia coli*
NWIS	National Water Information System
NTU	nephelometric turbidity unit
PCU	platinum-cobalt unit
RIDEM	Rhode Island Department of Environmental Management
RIGIS	Rhode Island Geographic Information System
SDWR	secondary drinking-water regulations
USGS	U.S. Geological Survey
WY	water year

Water-Quality Trends in the Scituate Reservoir Drainage Area, Rhode Island, 1983–2012

By Kirk P. Smith

Abstract

The Scituate Reservoir is the primary source of drinking water for more than 60 percent of the population of Rhode Island. Water-quality and streamflow data collected at 37 surface-water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, from October 2001 through September 2012, water years (WYs) 2002–12, 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 1982 through September 2012 (WYs 1983–2012). Water samples were collected and analyzed by the 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 for pH, color, turbidity, alkalinity, chloride, nitrite, nitrate, total coliform bacteria, *Escherichia coli* (*E. coli*), and orthophosphate were calculated for WYs 2003–12 for all 37 monitoring stations. Instantaneous loads and yields (loads per unit area) of total coliform bacteria and *E. coli*, chloride, nitrite, nitrate, and orthophosphate were calculated for all sampling dates during WYs 2003–12 for 23 monitoring stations with streamflow data. Values of physical properties and concentrations of constituents were compared with State and Federal water-quality standards and guidelines and were related to streamflow, land-use characteristics, varying classes of timber operations, and impervious surface areas.

Tributaries in the Scituate Reservoir drainage area for WYs 2003–12 were slightly acidic (median pH of all stations equal to 6.1) and contained low median concentrations of chloride (22 milligrams per liter [mg/L]), nitrate (0.01 mg/L as nitrogen), nitrite (0.001 mg/L as nitrogen), and orthophosphate (0.02 milligrams per liter as phosphorus [mg/L as P]). Turbidity and alkalinity values also were low with medians of 0.57 nephelometric turbidity units and 5.1 mg/L as calcium carbonate, respectively. Total coliform bacteria and *E. coli* were detected in most samples from all stations, but median concentrations were generally low—43 colony-forming units per 100 milliliters (mL) and 15 colony-forming units per 100 milliliters, respectively.

Median values of several physical properties and median concentrations of several constituents correlated positively with the percentages of developed land and negatively with the percentages of forest cover in the drainage areas above the monitoring stations. Median concentrations of chloride correlated positively with the percentages of impervious land use in the subbasins of monitoring stations, likely reflecting the effects of deicing compounds applied to roadways during winter maintenance. Median concentrations of alkalinity also correlated positively with the percentage of impervious land use, which may be related to the deterioration of fabricated structures containing calcium carbonate. Median values of color correlated positively with the percentage of wetland area in the subbasins of monitoring stations, reflecting the natural sources of color in tributaries. Streamflows were negatively correlated with turbidity and concentrations of total coliform bacteria and *E. coli*, possibly reflecting seasonal patterns in which relatively high values of these properties and constituents occur during warmer low-flow conditions late in the water year. Similar seasonal patterns were observed for pH, alkalinity, and color. Negative correlations between concentrations of chloride and streamflow also were significant, indicating that deicing salts from roadways and other impervious surfaces that lack direct connection to the tributaries are likely infiltrating to the groundwater and discharging to some of the tributaries late in the water year. While salt-laden runoff directly enters some of the tributaries at roadway crossings, most of the roadway runoff infiltrates into the adjacent berms throughout the drainage area. Statistically significant correlations were not identified between various degrees of tree-canopy reduction caused by timber operations in the subbasins and median values or concentrations of water-quality properties.

Loads and yields of chloride, nitrate, nitrite, orthophosphate, and bacteria varied at monitoring stations in the Scituate Reservoir drainage area in WYs 2003–12. Loads generally were greater at stations in the Barden Reservoir and the Regulating Reservoir Subbasins that have larger drainage areas than in subbasins with smaller drainage areas. Subbasin yields of fecal-indicator bacteria and orthophosphate generally were largest in the Westconnaug Reservoir Subbasin, and subbasin yields for chloride, nitrate, and nitrite were largest in the Moswansicut Reservoir Subbasin in the northeastern part of the drainage area.

Upward trends in pH were identified for nearly half of the monitoring stations for WYs 1983–2012 and may reflect regional reductions in acid precipitation. Many upward trends in alkalinity also were identified for both the WYs 1983–2012 and for WYs 2003–12 periods and are likely related to the natural weathering of structures containing concrete or, in some cases, the application of lime or fertilizers on agriculture lands. Significant trends in chloride concentrations at most stations during WYs 1983–2012 were upward; however, results for WYs 2003–12 substantiate few significant upward trends and, in a few cases, downward trends were identified in several tributary drainage areas.

Introduction

Scituate Reservoir, the primary source of drinking water for more than 60 percent of the population of Rhode Island, covers about 94 square miles (mi^2) in parts of the towns of Cranston, Foster, Glocester, Johnston, and Scituate, R.I. (fig. 1). The Providence Water Supply Board (Providence Water) manages the Scituate Reservoir and water-supply system from the Scituate Reservoir. The average demand for treated water is approximately 67 million gallons per day, of which 59 percent is for the cities of Cranston, Providence, and North Providence and for the town of Johnston R.I.; the remainder is sold to nine surrounding communities (Providence Water Supply Board, 2014).

Providence Water owns about one-third of the Scituate Reservoir drainage area and manages the area for water-quality protection and timber production (Richard Blodgett, Providence Water Supply Board, written commun., 2005); the remaining area is privately owned (Providence Water Supply Board, 2014). Human-induced changes in the drainage area, including changes in agricultural and industrial activities, urbanization, and other land-use changes, can cause degradation in the quality of the source water to the reservoir.

Providence Water 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 have been collected at 37 surface-water monitoring stations on tributaries to the Scituate Reservoir. 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.

Purpose and Scope

In 2008, the U.S. Geological Survey (USGS), in cooperation with Providence Water, began an investigation to evaluate water-quality conditions, including constituent loads, trends, and factors that affect water quality. Water-resources managers can use descriptions of water-quality conditions to develop management plans for the drainage area. Data on constituent loads and yields, which depend on both flow and constituent concentrations, contribute to an understanding of tributary water quality and the overall quality of the water in the reservoir. Knowledge of the time trends in the physical properties and constituents can enable water managers to predict future water-quality problems, assess the effectiveness of management actions, and identify improvements in water quality. Water-quality conditions and trends in the Scituate Reservoir drainage area may represent conditions in similar, relatively undeveloped or minimally developed drainage areas and reservoir source-water areas throughout the Northeastern United States.

This report presents analyses of streamflow and water-quality data collected in the Scituate Reservoir drainage area during water years[1] (WYs) 1983–2012 (October 1, 1982 through September 30, 2012). Water-quality data were collected by Providence Water at 37 surface-water-monitoring stations distributed throughout the drainage area, streamflow data were collected by the USGS at 23 of the 37 stations, and specific conductance data were collected by USGS personnel at 14 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 at all monitoring stations; (2) comparison of median values and concentrations with factors potentially affecting water quality, including streamflow, land use, and impervious area; (3) determination of the frequencies at which water-quality standards or guidelines were exceeded at tributary monitoring stations during the period; (4) estimation of loads and yields of selected water-quality constituents at the 23 stations for which streamflow data were available; (5) estimation of loads and yields of chloride and sodium at 14 stations for which streamflow and specific conductance data were available; and (6) identification of trends in values and concentrations of selected water-quality properties and constituents at all stations. Trends in water-quality properties and constituents were investigated for the 10-year study period of WYs 2003–12, representing a new period of analysis, and also were investigated for a longer 29-year period of WYs 1983–2012 which was inclusive of all available data (Nimiroski and others 2008). 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.

Previous Investigations

Providence Water has collected water-quality data in the Scituate Reservoir drainage area since 1945. Breault and others (2000) and Nimiroski and others (2008) summarized water-quality data collected by Providence Water before the present study and include median values of physical properties

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

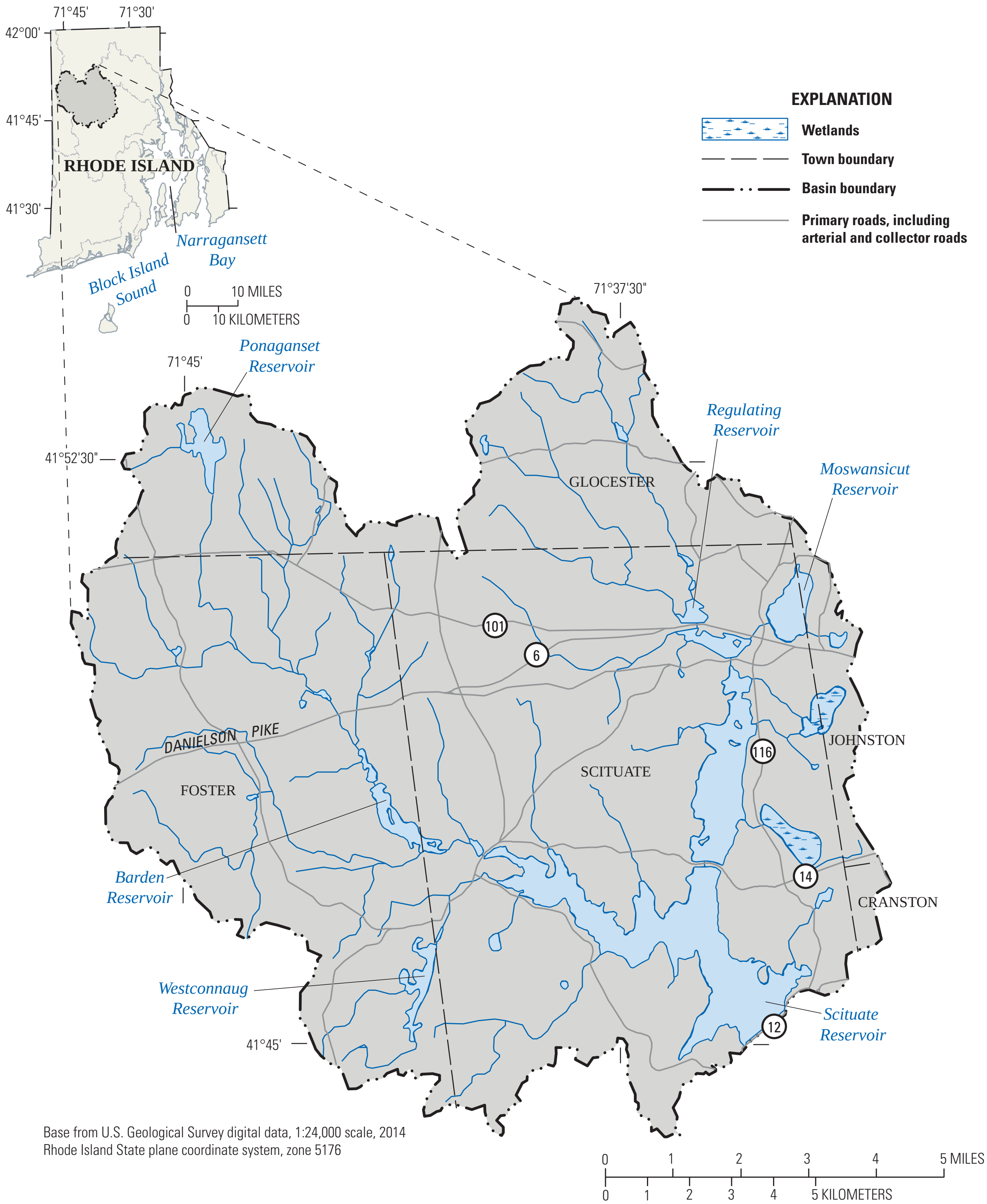

Figure 1. The Scituate Reservoir drainage area, Rhode Island, 2012.

and constituent concentrations, trends in selected constituent concentrations, and relations between constituent concentrations and drainage-area characteristics. Since 2002, interim reports on water-quality data (WYs 2002–12) were published by USGS.

Since 1993, the USGS has cooperated with Providence Water and the Rhode Island Department of Environmental Management (RIDEM) to measure streamflow and specific conductance in selected tributaries to the Scituate Reservoir. Specific conductance serves as a surrogate for chloride and sodium, which are important concerns to local water-resources managers because they are difficult to remove from source water and can affect the quality of finished drinking water. Nimiroski and Waldron (2002) described potential sources of chloride and sodium in the Scituate Reservoir drainage area. Since 2009, streamflow and specific conductance have been continuously measured at 14 stations in the drainage area, and measurements of streamflow have been made periodically at 9 additional stations in the drainage area (fig. 2; table 1). These data are published in USGS annual reports (for example, Socolow and others, 2003) and are available through the National Water Information System (NWIS; U.S. Geological Survey, 2001). As part of a study of low-flow characteristics in northern Rhode Island, the USGS has collected streamflow data at several additional stations in the Scituate Reservoir drainage area (Kliever, 1995; Bent and others, 2014).

Description of the Study Area

The study area is in north-central Rhode Island and encompasses the Scituate Reservoir, five tributary reservoirs (Barden, Moswansicut, Ponaganset, Regulating, and Westconnaug) and numerous millponds (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.

Land Use

Land use in the Scituate Reservoir drainage area is primarily undeveloped with an impervious area of about 3.8 percent (Rhode Island Geographic Information, 2013). Forest (66 percent), wetlands (10 percent), and water (8 percent) accounted for about 84 percent of the drainage area's land use in 1995 (fig. 3; table 2). Developed areas consisted of residential (10 percent), agricultural (4 percent), commercial/industrial (1.1 percent), and other urban (0.6 percent) land uses boundaries (Rhode Island Geographic Information, 2005). The eastern part of the drainage area is more developed than the rest of the drainage area (fig. 3) and is close to Providence. The Moswansicut Reservoir and Regulating Reservoir Subbasins, small subbasins in the northeastern part of the drainage area, have the smallest percentages of undeveloped area (60 and 78 percent, respectively, including forest, wetland, and water) and largest percentages of residential land use (27 and 14 percent, respectively) relative to the other four subbasins (table 2). The Moswansicut Reservoir Subbasin also has the largest percentages (3.7 percent) of commercial/industrial land use and impervious area (10.5 percent) of the five major subbasins in the Scituate Reservoir drainage area. In contrast, the Barden Reservoir and Westconnaug Reservoir Subbasins in the western part of the drainage area has the greatest percentages (86 and 85 percent, respectively) of undeveloped land, relatively low percentages of residential land use (about 8 and 9 percent, respectively), and of impervious area (about 3 percent).

Providence Water manages its land within the Scituate Reservoir drainage area by implementing a strategic forest-stewardship plan (Providence Water Supply Board, 2011). Timber harvesting is an important part of the plan because the age and species of trees in the forests can affect both the hydrology and quality of water in the tributary-reservoir subbasins (Binkley and others, 2004; Dawson, 1996). Timber-management activity in this report is expressed as percentage of area timbered and by the relative amount of open tree canopy remaining after the completion of logging activities (table 2). These data reflect all available reports of timbering from 1993 through 2013. The direct runoff subbasin, the area adjacent to the Scituate Reservoir, comprised the greatest amount of overall timbering activity (about 30 percent) among the reservoir subbasins. Overall timbering activity in the other five subbasins ranged from about 1 percent (Ponaganset Reservoir Subbasin) to about 15 percent (Moswansicut Reservoir and Westconnaug Reservoir Subbasins).

Climate

Climate in the Scituate Reservoir drainage area is temperate, with a mean annual temperature of 38.9 degrees Fahrenheit (WYs 1975–2012) at a National Oceanic and Atmospheric Administration climatological station in the Barden Reservoir Subbasin in Foster, R.I. (National Oceanic and Atmospheric Administration, 2014). The long-term mean annual precipitation and mean annual snowfall at the Foster station for WYs 1975–2012 were 53.69 inches (in.) and 57.1 in., respectively. During WYs 2003–12, mean annual precipitation and snowfall at this station were greater than the long-term mean annual values at 57.16 and 63.0 in., respectively.

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

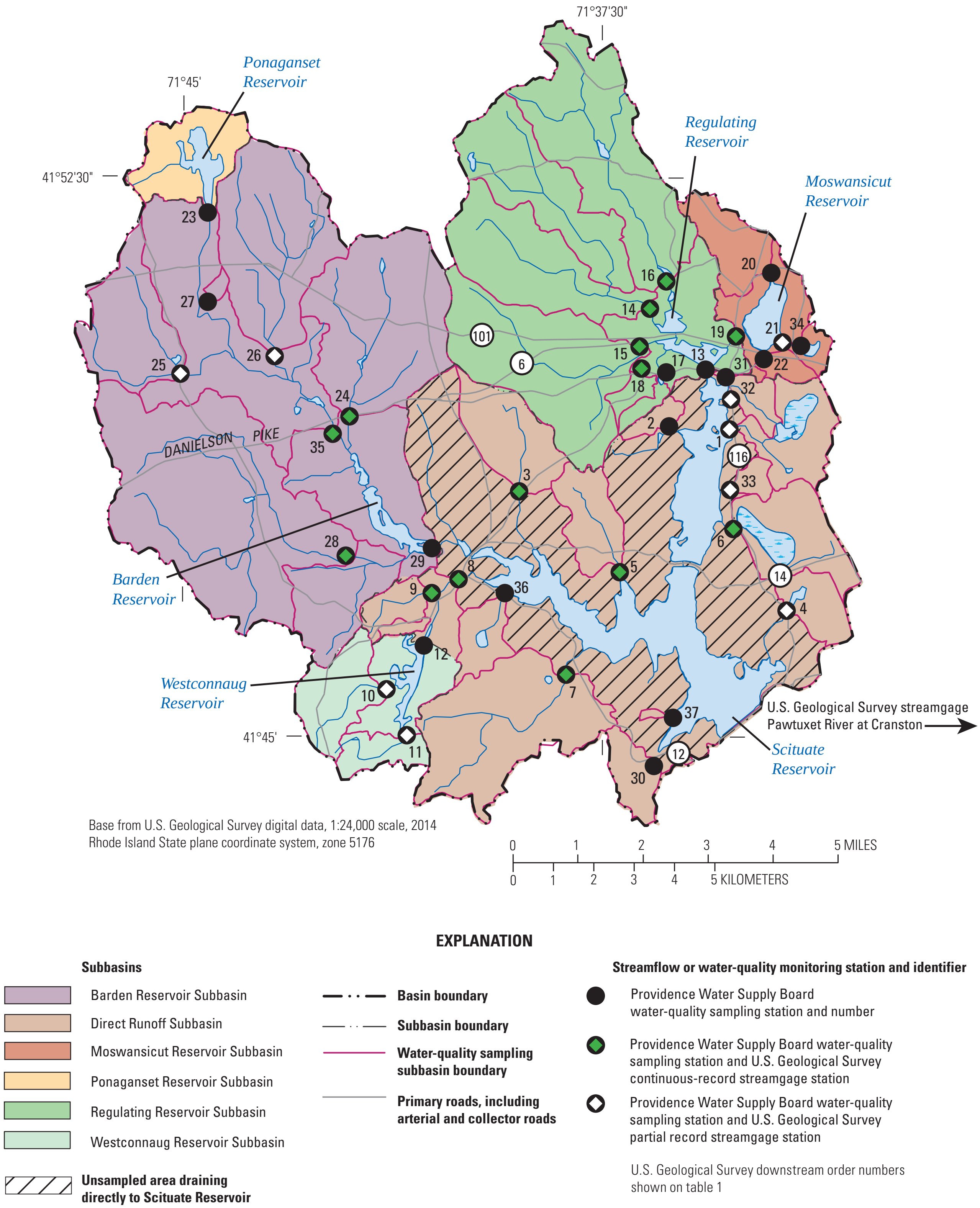

Figure 2. Locations of tributary reservoir subbasins and stations in the Scituate Reservoir drainage area, Rhode Island, 2012.

Table 1. Providence Water Supply Board water-quality-monitoring stations, water-quality sample collection frequency, and available streamflow and specific conductance data by tributary-reservoir subbasins in the Scituate Reservoir drainage area, Rhode Island.

[Alternate station names given in parenthesis for stations where different historical names were used for the same sampling location by the Providence Water Supply Board (PWSB). Sums of drainage areas do not equal subbasin totals because some drainage areas are nested. USGS, U.S. Geological Survey; mi^2, square miles; M, monthly; Q, quarterly]

PWSB	USGS station number	Station name	Drainage area (mi^2)	Water-quality samples for water years 2003–12		Available USGS streamflow data 2003–12 (water years)	Available USGS specific conductance data 2009–12 (water years)
				Frequency of collection	Number[1]		
Barden Reservoir Subbasin							
24	01115190	Dolly Cole Brook	4.90	M	109	Periodic, continuous[2]	Continuous
25	01115200	Shippee Brook	2.35	Q	33	Periodic	None
26	01115185	Windsor Brook	4.32	Q	36	Periodic	None
27	011151845	Unnamed Tributary to Ponaganset River (Unnamed Brook B, Unnamed Brook West of Windsor Brook)	0.10	Q	23	None	None
28	01115265	Barden Reservoir (Hemlock Brook)	8.72	M	116	Periodic, continuous[2]	Continuous
29	01115271	Ponaganset River (Barden Stream)	33.0	M	95	None	None
35	01115187	Ponaganset River	14.0	M	107	Continuous	Continuous
Direct Runoff Subbasin							
1	01115180	Brandy Brook	1.57	M	116	Periodic	None
2	01115181	Unnamed Tributary 2 to Scituate Reservoir (Unnamed Brook North of Bullhead Brook)	0.29	Q	19	None	None
3	01115280	Cork Brook	1.79	M	104	Periodic, continuous[2]	Continuous
4	01115400	Kent Brook (Betty Pond Stream)	0.85	M	114	Periodic	None
5	01115184	Spruce Brook	1.22	Q	34	Periodic, continuous[2]	Continuous
6	01115183	Quonapaug Brook	1.96	M	101	Periodic, continuous[2]	Continuous
7	01115297	Wilbur Hollow Brook	4.32	M	116	Periodic, continuous[2]	Continuous
8	01115276	Westconnaug Brook (Westconnaug Reservoir)	5.18	M	79	Periodic, continuous[2]	Continuous
9	01115275	Bear Tree Brook	0.62	Q	38	Periodic, continuous[2]	Continuous
30	01115350	Unnamed Tributary 4 to Scituate Reservoir (Coventry Brook, Knight Brook)	0.78	Q	36	None	None
31	01115177	Toad Pond	0.04	Q	12	None	None
32	01115178	Unnamed Tributary 1 to Scituate Reservoir (Pine Swamp Brook)	0.45	Q	34	Periodic	None
33	01115182	Unnamed Tributary 3 to Scituate Reservoir (Hall's Estate Brook)	0.28	Q	32	Periodic	None
36	--	Outflow from King Pond	0.77	Q	32	None	None
37	--	Fire Tower Stream	0.05	Q	32	None	None

Table 1. Providence Water Supply Board water-quality-monitoring stations, water-quality sample collection frequency, and available streamflow and specific conductance data by tributary-reservoir subbasins in the Scituate Reservoir drainage area, Rhode Island. —Continued

[Alternate station names given in parenthesis for stations where different historical names were used for the same sampling location by the Providence Water Supply Board (PWSB). Sums of drainage areas do not equal subbasin totals because some drainage areas are nested. USGS, U.S. Geological Survey; mi^2, square miles; M, monthly; Q, quarterly]

PWSB	USGS station number	Station name	Drainage area (mi^2)	Water-quality samples for water years 2003–12		Available USGS streamflow data 2003–12 (water years)	Available USGS specific conductance data 2009–12 (water years)
				Frequency of collection	Number[1]		
Moswansicut Reservoir Subbasin							
19	01115170	Moswansicut Reservoir (Moswansicut Stream North, Moswansicut Pond)	3.25	M	96	Periodic, continuous[2]	Continuous
20	01115160	Unnamed Tributary 1 to Moswansicut Reservoir (Blanchard Brook)	1.18	M	97	None	None
21	01115165	Unnamed Tributary 2 to Moswansicut Reservoir (Brook from Kimball Reservoir)	0.29	Q	28	Periodic	None
22	01115167	Moswansicut Reservoir (Moswansicut Stream South)	0.30	M	99	None	None
34	01115164	Kimball Stream	0.27	Q	24	None	None
Ponaganset Reservoir Subbasin							
23	011151843	Ponaganset Reservoir	1.92	M	103	None	None
Regulating Reservoir Subbasin							
13	01115176	Regulating Reservoir	22.1	M	112	None	None
14	01115110	Huntinghouse Brook	6.23	M	105	Periodic, continuous[2]	Continuous
15	01115114	Rush Brook	4.70	M	109	Periodic, continuous[2]	Continuous
16	01115098	Peeptoad Brook (Harrisdale Brook)	4.96	M	115	Continuous	Continuous
17	01115119	Dexter Pond (Paine Pond)	0.22	Q	25	None	None
18	01115120	Unnamed Tributary to Regulating Reservoir (Unnamed Brook A)	0.28	Q	19	Periodic, continuous[2]	Continuous
Westconnaug Reservoir Subbasin							
10	01115274	Westconnaug Brook	1.48	M	102	Periodic	None
11	01115273	Unnamed Tributary to Westconnaug Reservoir (Unnamed Brook south of Westconnaug Reservoir)	0.72	Q	28	Periodic	None
12	011152745	Unnamed Tributary to Westconnaug Brook (Unnamed Brook north of Westconnaug reservoir)	0.16	Q	22	None	None

[1]Not all samples were analyzed for all water-quality properties or constituents.

[2]Continuous streamflow data available for water year 2009–12.

Figure 3. Land use and locations of stations in the Scituate Reservoir drainage area, Rhode Island, 2012.

Table 2. Percentages of impervious area, land use, and canopy closure in the Scituate Reservoir drainage area, Rhode Island, 2012.

[Land-use data from Rhode Island Geographic Information System (2005); impervious area data from Rhode Island Geographic Information System (2013). Timber operation calculated from data collected during water years 1992–2012. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; <, less than; --, information not available]

PWSB station number	USGS station number	Impervious area (percent)	Land use (percent)							Percentage of area timbered				
			Forest	Water	Wetland	Agricultural	Residential	Commercial/ industrial	Other urban	0–100	80–100	50–79	20–49	<20
										Remaining canopy closure (percent) after logging				
Barden Reservior Subbasin														
24	01115190	3.5	75.5	1.4	9.6	1.8	10.5	0.3	0.8	3.6	3.6	0.0	0.0	0.0
25	01115200	2.8	75.8	0.7	14.0	1.4	7.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0
26	01115185	3.5	72.2	0.2	12.1	5.6	7.6	1.4	0.8	0.0	0.0	0.0	0.0	0.0
27	011151845	4.9	68.0	0.0	11.7	3.4	15.7	1.2	0.0	0.3	0.3	0.0	0.0	0.0
28	01115265	3.1	69.9	0.5	14.1	4.2	8.9	2.1	0.3	0.0	0.0	0.0	0.0	0.0
29	01115271	3.2	73.4	2.9	10.6	3.1	8.5	1.1	0.4	6.5	5.0	0.9	0.4	0.2
35	01115187	3.5	72.3	3.1	10.9	3.3	8.6	1.2	0.6	1.5	1.5	0.0	0.0	0.0
Subbasin	--	3.3	72.5	1.4	12.0	3.5	8.8	1.3	0.5	1.7	1.5	0.1	0.0	0.0
Direct Runoff Subbasin														
1	01115180	6.1	44.2	4.3	18.5	9.9	20.7	2.3	0.1	24.4	18.8	4.5	1.0	0.1
2	01115181	8.0	56.1	3.6	8.7	3.0	28.5	0.0	0.0	44.6	28.7	15.9	0.0	0.0
3	01115280	6.0	59.9	0.1	15.6	6.3	16.5	1.3	0.3	3.0	3.0	0.0	0.0	0.0
4	01115400	2.5	55.5	4.7	13.7	6.5	3.1	1.3	15.2	36.3	19.4	16.3	0.6	0.0
5	01115184	5.3	66.8	0.1	10.9	4.2	17.4	0.0	0.6	9.2	8.9	0.2	0.0	0.0
6	01115183	6.2	53.6	0.1	20.4	7.0	13.8	1.2	4.0	68.3	41.9	18.9	7.4	0.0
7	01115297	3.2	69.0	1.2	15.5	5.0	8.8	0.1	0.4	16.9	14.7	1.7	0.1	0.4
8	01115276	2.9	73.7	5.5	7.9	4.5	6.0	1.9	0.5	30.1	23.3	5.8	1.1	0.0
9	01115275	5.1	57.7	0.3	12.4	9.3	8.0	12.2	0.1	2.9	2.9	0.0	0.0	0.0
30	01115350	2.7	85.2	0.2	7.8	0.0	5.9	0.0	1.0	97.4	24.0	58.4	14.1	0.9
31	01115177	18.7	36.9	10.9	0.0	0.0	18.0	18.3	16.0	43.3	22.8	15.3	0.0	5.2
32	01115178	5.6	56.6	0.0	16.1	1.9	20.7	4.7	0.0	46.3	7.0	33.6	4.5	1.1
33	01115182	5.5	60.0	0.0	17.1	1.9	21.0	0.0	0.0	30.6	28.7	0.0	1.8	0.0
36	--	1.9	74.0	4.2	12.6	4.5	4.1	0.7	0.0	38.0	33.2	3.1	0.6	1.1
37	--	1.9	99.6	0.0	0.4	0.0	0.0	0.0	0.0	53.5	23.8	21.1	4.6	4.0
Subbasin	--	4.4	63.7	1.9	14.2	5.5	11.7	1.4	1.5	29.7	19.0	8.5	1.9	0.3

Table 2. Percentages of impervious area, land use, and canopy closure in the Scituate Reservoir drainage area, Rhode Island, 2012.—Continued

[Land-use data from Rhode Island Geographic Information System (2005); impervious area data from Rhode Island Geographic Information System (2013). Timber operation calculated from data collected during water years 1992–2012. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; <, less than; --, information not available]

PWSB station number	USGS station number	Impervious area (percent)	Land use (percent)							Percentage of area timbered				
			Forest	Water	Wetland	Agricultural	Residential	Commercial/ industrial	Other urban	0–100	80–100	50–79	20–49	<20
										Remaining canopy closure (percent) after logging				
Moswansicut Reservoir Subbasin														
19	01115170	9.2	36.0	14.4	13.4	8.2	25.2	2.9	0.1	21.1	18.0	2.9	0.2	0.0
20	01115160	10.3	30.3	0.0	22.2	12.4	33.1	1.9	0.2	0.9	0.9	0.0	0.0	0.0
21	01115165	8.9	51.9	11.4	17.2	1.4	14.0	4.1	0.0	55.8	50.1	5.6	0.0	0.0
22	01115167	19.1	44.6	0.0	4.9	5.6	30.9	13.9	0.0	0.4	0.2	0.2	0.0	0.0
34	01115164	8.7	52.7	12.3	16.6	1.6	12.4	4.4	0.0	59.4	53.3	6.0	0.0	0.0
Subbasin	--	10.5	36.2	7.6	16.1	8.9	27.4	3.7	0.1	15.3	13.3	1.9	0.1	0.0
Ponaganset Reservoir Subbasin														
23	011151843	5.1	59.1	19.7	7.0	0.0	13.7	0.3	0.2	0.9	0.9	0.0	0.0	0.0
Regulating Reservoir Subbasin														
13	01115176	7.2	59.7	4.4	11.9	6.5	14.9	1.8	0.8	10.9	6.8	2.9	1.0	0.3
14	01115110	3.4	70.1	0.5	10.1	6.8	12.2	0.1	0.2	1.7	1.0	0.4	0.2	0.1
15	01115114	6.6	60.1	0.3	15.9	6.8	15.0	1.1	0.8	2.6	1.7	0.1	0.1	0.7
16	01115098	4.9	64.4	1.8	9.6	7.1	13.2	2.4	1.5	0.5	0.4	0.1	0.0	0.0
17	01115119	5.4	56.8	2.2	19.4	8.2	10.4	2.3	0.7	0.0	0.0	0.0	0.0	0.0
18	01115120	12.5	47.2	0.0	19.0	4.5	14.9	6.3	8.1	0.1	0.1	0.0	0.0	0.0
Subbasin	--	5.2	64.3	1.3	11.9	6.8	13.6	1.3	0.9	2.8	1.8	0.6	0.2	0.2
Westconnaug Reservoir Subbasin														
10	01115274	2.9	76.0	0.0	8.2	5.9	9.0	0.4	0.6	19.2	19.1	0.0	0.1	0.0
11	01115273	1.4	73.2	0.3	16.2	5.6	3.4	1.3	0.0	2.3	0.2	2.1	0.0	0.0
12	011152745	10.4	61.4	0.7	9.8	4.7	19.1	1.8	2.3	28.0	16.2	8.9	2.8	0.0
Subbasin	--	2.9	74.3	0.1	10.6	5.7	7.9	0.8	0.5	14.7	13.4	1.1	0.2	0.0
Scituate Reservoir Drainage Area														
--	--	3.8	65.8	8.0	10.5	4.1	9.9	1.1	0.6	--	--	--	--	--

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, which are primarily in stream valleys, consist of poorly sorted to well sorted sand and gravel. As a result, meltwater deposits typically underlie the reservoir water bodies.

Hydrology

The Scituate Reservoir drainage area encompasses the Scituate Reservoir and five smaller tributary reservoirs that receive water from numerous small rivers and streams (fig. 1). The Ponaganset River, Peeptoad Brook, and Hemlock Brook are the largest tributaries to the Scituate Reservoir (fig. 2; table 1). The Pawtuxet River begins at the outlet of the Scituate Reservoir and flows eastward to Narragansett Bay (not shown on figs. 2 and 3). The mean annual flow and water yield in the Pawtuxet River at Cranston, R.I., (USGS station 01116500) were 356 cubic feet per second (ft^3/s) and 1.78 cubic feet per second per square mile ($ft^3/s/mi^2$), respectively, for the 72-year period of record from 1940 through 2012 (http://waterdata.usgs.gov/nwis/). During WYs 2003–12, mean annual streamflow and water yield at the Pawtuxet River at Cranston, R.I., station, were 410 ft^3/s and 2.05 $ft^3/s/mi^2$, respectively, about 15 percent greater than the long-term mean annual streamflow. Mean annual streamflows and water yields at the USGS stations on the Ponaganset River (Providence Water station 35, USGS station 0111578) and Peeptoad Brook (Providence Water station 16, USGS station 01115098; fig. 2) in the Scituate Reservoir drainage area averaged about 32 ft^3/s and 2.20 $ft^3/s/mi^2$ and 12 ft^3/s and 2.37 $ft^3/s/mi^2$, respectively, for WYs 2003–12. The latter two stations have drainage areas of 14.4 and 4.92 mi^2, respectively (table 1), whereas the drainage area above the USGS station on the Pawtuxet River at Cranston is 200 mi^2.

Surface water and groundwater are closely connected in the Scituate River drainage area, as is typical of valley-fill hydrogeologic settings in the Northeastern United States. Groundwater 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, along with wetlands, typically are discharge areas for groundwater.

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 WYs 2003–12 and previous years. The USGS, in cooperation with Providence Water and the RIDEM, has collected streamflow data at many of the Providence Water monitoring stations since 1993.

Water-Quality Data

Water-quality data from WYs 2003–12 were obtained annually from a water-quality database maintained by Providence Water (appendix 1; Richard Blodgett, Providence Water Supply Board, written commun., 2005–12). Water-quality datasets for trend analysis for years before 2003 were obtained periodically from Providence Water. During WYs 2003–12, the water-quality samples were collected monthly at 19 stations and quarterly at 18 stations in the Scituate Reservoir drainage area (table 1). Sampling frequencies for data collected before WY 1996 varied (Breault and others, 2000). Typically, samples were collected at approximately the same day 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. Complete sample-collection, analytical, and laboratory quality-control procedures are described in a Providence Water quality assurance program manual (Providence Water Supply Board Water Quality Laboratory, 2005, 2012). Field quality-control samples were not collected.

Physical properties and constituent concentrations measured in the water samples included pH, color, turbidity, total coliform bacteria, *Escherichia coli* (*E. coli*), alkalinity, chloride, nitrite, nitrate, and orthophosphate. Analytical methods used for the determination of values or concentrations of pH, color, turbidity, bacteria, alkalinity, chloride, and nitrite are those documented by the American Public Health Association and others (2012). Concentrations of nitrate were determined by the Hach Nitrate LR Method (Hach Method 8192; Hach Company, 2000). Concentrations of orthophosphate were determined by the Hach PhosVer Method (Hach Method 8048; Hach Company, 2000). In July 2012, the analytical method for bacteria was changed to the Standard Methods 9222 method, which has a higher upper reporting limit than the previously used Standard Methods 9221 (multiple tube fermentation method that limited values to 2,400 colony-forming units per 100 milliliters (CFU/100 mL; American Public Health Association and others, 2012). Not all the analyses were done throughout the entire 29-year period, (WYs 1983–2012), and some of the data are missing. Monitoring of nitrate began in WY 1988, monitoring of nitrite began in WY 1985, and monitoring of orthophosphate began in WY 1997. Monitoring of *E. coli* began in 1992, but data for *E. coli* collected before WY 1995 were not available.

The interpretations of water-quality analyses made for this study were 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, statistical 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 dataset. 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 generally were collected during a wide range of flow conditions. As an example, the daily mean flow-duration curve for the Peeptoad Brook at North Scituate station (USGS station number 01115098) for WY 2012 represents the percentage of time that each flow was exceeded at this station (fig. 4). The flows at this station are represented by the points plotted on the curve for the days when water-quality samples were collected. In this example, samples were collected at flow durations ranging from the 20th percentile to the 98th percentile.

Changes in analytical methods or lab personnel could be unidentified sources of variability and trends in the water-quality data. The potential effects of changing analytical detection limits and the upper method performance levels

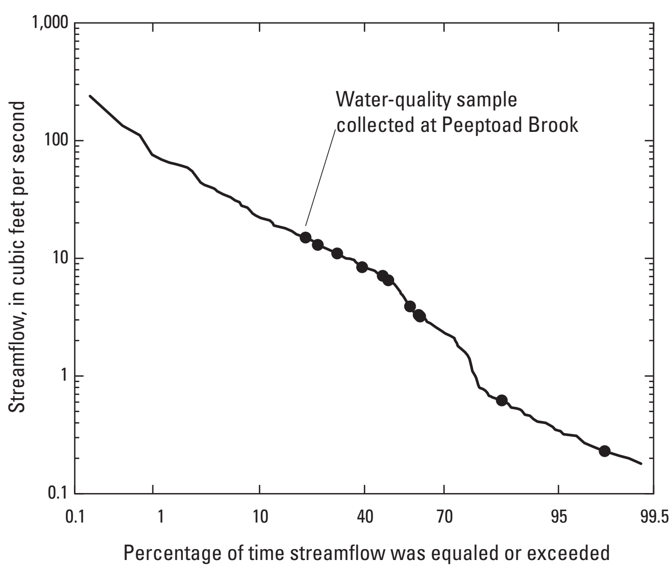

Figure 4. Flow-duration curve and streamflow values on the dates (represented by points) when water-quality samples were collected for the U.S. Geological Survey station on Peeptoad Brook at North Scituate (station 01115098), Rhode Island, for water year 2012.

over time were addressed by applying uniform assessment levels, which represent the reported detection limits in the dataset, to selected constituents. These assessment levels were 0.001 milligrams per liter as nitrogen (mg/L as N) for nitrite, 0.01 mg/L as N for nitrate, 0.003 milligrams per liter as phosphorus (mg/L as P) for orthophosphate, and 3 CFU/100 mL (lower) and 2,400 CFU/100 mL (upper) for total coliform bacteria and *E. coli*, respectively.

Compilation and Analysis of Streamflow and Continuous Water-Quality Data

Streamflow data have been collected at 23 of the 37 Providence Water monitoring stations (table 1) since 1994. Streamflow has been monitored continuously at 2 stations (Providence Water stations 16 and 35) since 1994 and at 12 additional stations since WY 2009 (table 1). Streamflow was measured intermittently at 9 other stations (partial-record stations) during WYs 1994–2012. Specific conductance and water temperature has been monitored concurrently with streamflow at 14 stations since WY 2009 (table 1). Streamflow, specific conductance, and water temperature data for continuous- and partial-record stations are available through NWIS (U.S. Geological Survey, 2001).

Estimation of Loads and Yields

Loads are the quantity of a constituent transported by a stream during a specific time interval and are determined by multiplying the concentration of a constituent by the streamflow. Yields are loads normalized by dividing the load by the drainage area of each subbasin. Daily loads and yields of total coliform bacteria, *E. coli*, alkalinity, chloride, nitrite, nitrate, and orthophosphate were estimated from analyte concentrations in samples collected by Providence Water. Daily loads and yields were only estimated for stations which streamflow data were available. Loads and yields of chloride and sodium were estimated from continuous records of streamflow and specific conductance, and estimated dissolved concentrations of chloride and sodium derived from correlations with specific conductance for all monitoring stations with these data records.

Estimation of Daily Loads and Yields

Daily loads and yields of water-quality constituents were calculated for all dates during the study period when Providence Water collected water-quality samples at the 23 stations for which periodic or continuous streamflow data were available (table 1). These loads were calculated by multiplying the constituent concentrations in single samples by the mean daily flow for the date when the sample was collected. These flows, which in most cases were estimated (before WY 2008, in particular), were assumed to reasonably represent the flow at the time of the sample collection. Daily loads and yields were calculated for total coliform bacteria, *E. coli*, chloride, nitrate, nitrite, and orthophosphate. Median values of loads and yields are reported for all water-quality sampling dates during WYs 2003–12.

For constituents with censored data (concentrations reported as less than the minimum method detection level or greater than the upper method performance level), minimum loads were calculated by multiplying the mean daily flow by half of the method detection level as the concentration of each constituent and where values were greater than the upper method performance level, maximum loads were estimated by multiplying the mean daily flow by the upper assessment level (2,400 CFU for bacteria). The calculation of yields allows for direct comparison of loads at stations with different drainage areas. Yields were calculated by dividing load by the drainage area for each station. Loads are given in kilograms per day (kg/d) or millions of colony-forming units per day (MCFU/d) for bacteria, and yields are given in kilograms per day per square mile or millions of colony-forming units per day per square mile for bacteria.

Mean daily flows at the partial-record stations on the water-quality sampling dates were estimated with the Maintenance of Variance Extension type 1 method (MOVE.1), as described by Ries and Friesz (2000); data needed to estimate streamflows at partial-record sites were retrieved from NWIS (http://waterdata.usgs.gov/nwis/). In the MOVE.1 method, an equation (equation 1) is developed to relate measured instantaneous flow at a partial-record station and flow at one or more continuous-record streamgaging stations. When 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.

$$Q = \left(q^{m}\right) \times b, \quad (1)$$

where

- Q is the mean daily flow at the station of interest, in cubic feet per second;
- q is the mean daily flow at the reference station, in cubic feet per second;
- m is the slope from the MOVE.1 analysis (table 3); and
- b is the intercept from the MOVE.1 analysis (table 3).

Data from the station on the Ponaganset River (Providence Water station 35; USGS station 01115187) were used primarily to estimate flow at the partial-record stations (table 3). Although flow data from other stations outside the Scituate Reservoir drainage area were available for analyses, inclusion of these data did not reduce the difference between predicted and observed streamflow values as indicated by the resultant average standard error of the estimate[2] of the relation with data from Ponagaset River alone. For several stations, flows after WY 2008 were estimated with separate equations developed from the continuous-record streamflow-gaging station on Quonapaug Brook (Providence Water station 6; USGS station 01115183). In general, data from Quonapaug Brook are more hydrologically similar to many of the partial record stations than they are to Ponaganset River. As a result, the average standard error of the estimate for regression equations developed from continuous records of flow from Quonapaug Brook after 2008 are smaller than the average standard error of the estimate for regression equations used before WY 2008 (table 3).

Estimation of Continuous Loads and Yields of Chloride and Sodium

Specific conductance measurements are commonly used to estimate concentrations of dissolved major ions (Hem, 1982, 1985; Miller and others, 1988; Church and others, 1996; Granato and Smith, 1999; Smith and Granato, 2010; Smith, 2013). In this study, the measurements were used to estimate concentrations and loads of dissolved chloride and sodium in 14 subbasins in the Scituate Reservoir drainage area in WYs 2009–12. Concentrations of dissolved chloride and sodium were not only measured in water-quality samples primarily collected during WYs 2009–12 at the 14 continuous-record stations (table 1; http://waterdata.usgs.gov/nwis/), but also were estimated from the more frequent, in situ measurements of specific conductance. These continuous specific conductance data were available for nearly every day of the study and represent a variety of hydrologic conditions (base flow, rain, mixed precipitation, and snowmelt runoff events).

Instantaneous concentrations of chloride and sodium were estimated from continuous measurements of specific conductance by using equations developed to relate specific conductance to concentrations of the respective ions (equation 2). These regression equations were developed with the MOVE.1 technique based on concurrent measurements of log-transformed values of specific conductance and concentrations of chloride and sodium in tributary water samples. The data set includes 185 concentrations for these constituents, where specific conductance values ranged from 44 to 351 microsiemens per centimeter at 25 degrees Celsius (U.S. Geological Survey, 2001). The MOVE.1 technique was chosen for regression analysis because it minimizes errors in both the x and y directions, producing a unique equation that can be used to predict either variable from the other (Helsel and Hirsch, 2002).

[2]Average standard error of the estimate is a measure of the average variation between regression estimates and observed values. About two-thirds of the regression estimates have errors less than the average standard error of estimate and about one-third of the estimates have errors larger than the average standard error of estimate.

Table 3. Stations in the Scituate Reservoir drainage area, Rhode Island, for which streamflow data were estimated, water years 2002–12, and U.S. Geological Survey index stations, period of streamflow measurements, and maintenance of variance extension type 1 method regression coefficients.

[Values in parentheses are applicable for estimated streamflow data during water years 2009–12. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey]

PWSB station number	USGS station number	Number of USGS station used in analysis	Number of streamflow measurements used in analysis	Years of streamflow measurements	Slope	Intercept	Standard error of regressions (percent)	Period of estimated streamflow (water years)
				Barden Reservoir Subbasin				
24	01115190	01115187	114	1994–2007, 2009–13	1.211	0.155	81.7	2003–08
25	01115200	01115187, (01115183)	31 (11)	1994–95, 2003, 2009–13	1.560 (1.372)	0.031 (0.0758)	97.3 (89.6)	2003–12
26	01115185	01115187, (01115183)	79 (11)	1994–2007, 2009–13	1.358 (1.392)	0.0692 (1.034)	116 (103)	2003–12
28	01115265	01115187	94	1996–2007, 2009–13	1.091	0.467	45.1	2003–08
				Direct Runoff Subbasin				
1	01115180	01115187, (01115183)	89 (12)	1994–2007, 2009–13	0.7177 (0.7263)	0.3094 (1.004)	49.1 (37.1)	2003–12
3	01115280	01115187	111	1994–2007, 2009–13	1.1512	0.0650	67.3	2003–08
4	01115400	01115187	20	1994–2007, 2009–13	1.3674	0.0139	123	2003–12
5	01115184	01115187	112	1994–2007, 2009–13	1.0189	0.0973	70.4	2003–08
6	01115183	01115187	105	1994–2007, 2009–13	1.1194	0.1055	75.1	2003–08
7	01115297	01115187	112	1994–2007, 2009–13	1.0057	0.3288	59.1	2003–08
8	01115276	01115187	48	1994–95, 2003, 2009–13	0.4352	2.3202	42.3	2003–08
9	01115275	01115187	93	1994–95, 2000–07, 2009–13	0.5334	0.3024	48.1	2003–08
32	01115178	01115187, (01115183)	22 (11)	1994–95, 2003, 2009–13	0.8375 (0.8206)	0.0472 (0.2165)	52.5 (44.3)	2003–12
33	01115182	01115187	23	1994–95, 2003, 2009–13	1.0596	0.0125	69.5	2003–12
				Moswansicut Reservoir Subbasin				
19	01115170	01115187	91	1994–95, 2000–07, 2009–13	0.9341	0.3034	85.9	2003–08
21	01115165	01115187, (01115183)	28 (11)	1994–95, 2003, 2009–13	0.7346 (0.8708)	0.0643 (0.2134)	95.3 (51.4)	2003–12
				Regulating Reservoir Subbasin				
14	01115110	01115187	106	1994–2007, 2009–13	1.3161	0.1276	57.2	2003–08
15	01115114	01115187	81	1997–2007, 2009–13	1.3014	0.0948	62.6	2003–08
18	01115120	01115187	73	1994–2007, 2009–13	1.6816	0.0009	109	2003–08
				Westconnaug Reservoir Subbasin				
10	01115274	01115187, (01115183)	28 (11)	1994–95, 2003, 2009–13	1.793 (1.064)	0.0130 (0.5206)	136 (36.3)	2003–12
11	01115273	01115187, (01115183)	28 (7)	1994–95, 2003, 2009–13	0.9838 (0.8601)	0.0740 (0.4255)	49.4 (33.1)	2003–12

$$C = \left(Spc^{m}\right) \times b\ , \qquad (2)$$

where

C is the concentration of the ion of interest, in milligrams per liter

Spc is the specific conductance, in microsiemens per centimeter at 25 degrees Celsius;

m is the slope from the MOVE.1 analysis (table 4); and

b is the intercept from the MOVE.1 analysis (table 4).

With the exception of chloride and sodium, concentrations of other major ions did not vary substantially as specific conductance increased from sample to sample and from station to station (fig. 5). Only minimal increases in the concentrations of calcium and sulfate, trace constituents of road salt (Smith and Granato, 2010), occurred over the range of specific conductance. As a result, concentrations of chloride and sodium, the primary constituents of road salt, governed the relation with specific conductance and in many cases, the same equation coefficients produced satisfactory estimates for concentrations of chloride and sodium at multiple stations. At some stations, however, separate coefficients were developed to improve the average standard error of the estimate of the relations between measurements of specific conductance to concentrations of chloride and sodium. The average standard error of the estimate ranged from about 5 to 9 percent for chloride and from about 7 to 11 percent for sodium for all 14 stations. These equations provide reasonable estimates for dissolved concentrations of chloride and sodium on the basis of specific conductance measurements (fig. 6).

Loads were calculated by multiplying estimated flow-weighted concentrations of chloride and sodium, in milligrams per liter, for each day by the daily-mean flow, in liters per day, and summed for each water year. The average daily load, yield, and concentration of chloride and sodium were estimated for WYs 2009–12 at each of the 14 stations.

Determination of Correlations and Trends

To examine factors affecting water quality in the Scituate Reservoir drainage area, correlation analyses were performed relating streamflow and subbasin characteristics, such as land use, and impervious area, to median values or concentrations of pH, color, turbidity, total coliform bacteria and *E. coli*, chloride, nitrite, nitrate, and orthophosphate from WYs 2003–12. Correlation analyses also were performed relating

Table 4. Regression equation coefficients used to estimate concentrations of chloride and sodium from values of specific conductance at U.S. Geological Survey stations in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

[PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey]

PWSB station number	USGS station number	Chloride			Sodium		
		Slope	Intercept	Standard error of regressions (percent)	Slope	Intercept	Standard error of regressions (percent)
24	01115190	1.0995	0.1368	5.2	1.0522	0.1043	7.1
28	01115265	1.0995	0.1368	5.2	1.0522	0.1043	7.1
35	01115187	1.0995	0.1368	5.2	1.0522	0.1043	7.1
3	01115280	1.0995	0.1368	5.2	1.0522	0.1043	7.1
5	01115184	1.1901	0.0772	8.5	1.0808	0.0760	10.6
6	01115183	1.1561	0.0942	5.1	0.9534	0.1577	7.0
7	01115297	1.1901	0.0772	8.5	1.0808	0.0760	10.6
8	01115276	1.0995	0.1368	5.2	1.0522	0.1043	7.1
9	01115275	1.0995	0.1368	5.2	1.0522	0.1043	7.1
19	01115170	1.0995	0.1368	5.2	1.0522	0.1043	7.1
14	01115110	1.1901	0.0772	8.5	1.0808	0.0760	10.6
15	01115114	1.0995	0.1368	5.2	1.0522	0.1043	7.1
16	01115098	1.1561	0.0942	5.1	0.9534	0.1577	7.0
18	01115120	1.0995	0.1368	5.2	1.0522	0.1043	7.1

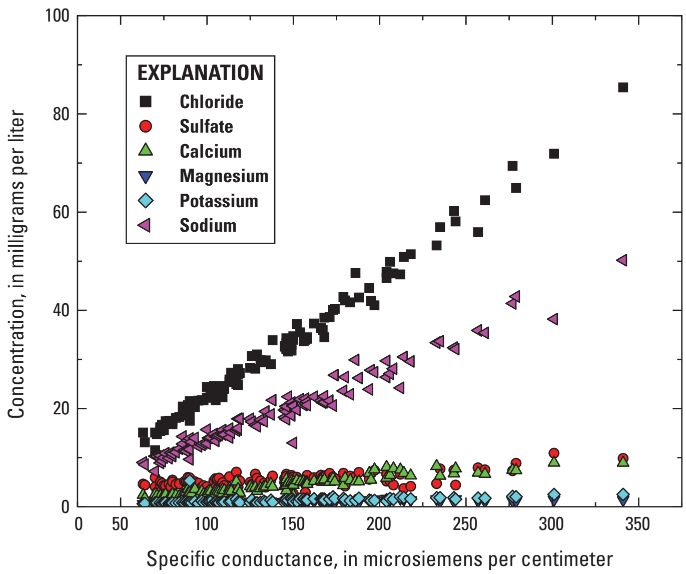

Figure 5. Relations between specific conductance and concentrations of selected major ions in water-quality samples collected from tributaries at 14 U.S. Geological Survey stations in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

the density of timber activity expressed as varying degrees of tree-canopy reduction in each subbasin to median values or concentrations of pH, color, turbidity, total coliform bacteria and *E. coli*, chloride, nitrite, nitrate, and orthophosphate from WYs 1992–2012. 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 based on 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).

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 bacteria, *E. coli*, alkalinity, chloride, nitrite, nitrate, and orthophosphate at all monitoring stations. Trend tests were performed separately on water-quality physical properties and constituent concentrations for WYs 2003–12 and for WYs 1983–2012.

Trends for each multiyear period were analyzed by 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 caused by changes in streamflow, temperature, biological activity, or other factors. A trend was considered significant if the calculated p value of the test was less than 0.05, as described previously. Significant trends were identified as either upward or downward.

Water-Quality Conditions and Constituent Loads, WYs 2003–12

Water-quality conditions in the Scituate Reservoir drainage area for WYs 2003–12 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 among water-quality properties and constituent concentrations (table 6), and correlations between water-quality properties and subbasin characteristics and streamflow and between constituent concentrations and subbasin characteristics and streamflow also were used to evaluate water-quality patterns in the drainage area (tables 7 and 8). Values of properties and concentrations of constituents were compared to available State and Federal guidelines and standards (tables 9 and 10) to describe water-quality conditions in terms of potential effects on human health and aquatic life.

Water-Quality Properties

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

pH

Measurements of pH represent the negative base-10 logarithm of the hydrogen-ion concentration or activity. pH values near 7 are considered neutral, below 7 are acidic, and above 7 are alkaline or basic. The pH of river water generally ranges from about 6.5 to 8.5 (Hem, 1985). The pH of water affects the solubility and biological availability of chemical constituents such as nutrients and metals. The pH of the stream and reservoir waters also affects water-treatment procedures. Median pH in the tributaries in the Scituate Reservoir drainage area ranged from 5.4 to 6.7 with a median for all stations of 6.1. Thus, tributaries were slightly acidic, reflecting the low pH of precipitation in the Northeastern United States (mean annual precipitation-weighted pH was 4.7 for WYs 2003–12; National Atmospheric Deposition Program, 2014) and the relatively nonreactive character of rock types in the drainage area. Water samples collected at two monitoring stations in the Westconnaug Reservoir Subbasin, Providence Water stations 10 and 11, had the lowest median pH values (5.4 and 5.6, respectively; table 5); water samples collected in several tributary subbasins had median pH values less than 6.0. The highest median pH value, 6.7, was determined for Moswansicut Stream (Providence Water station 19) and Brandy Brook (Providence Water station 1)—in areas that are less forested and more developed than those in the Westconnaug Reservoir Subbasin (table 2).

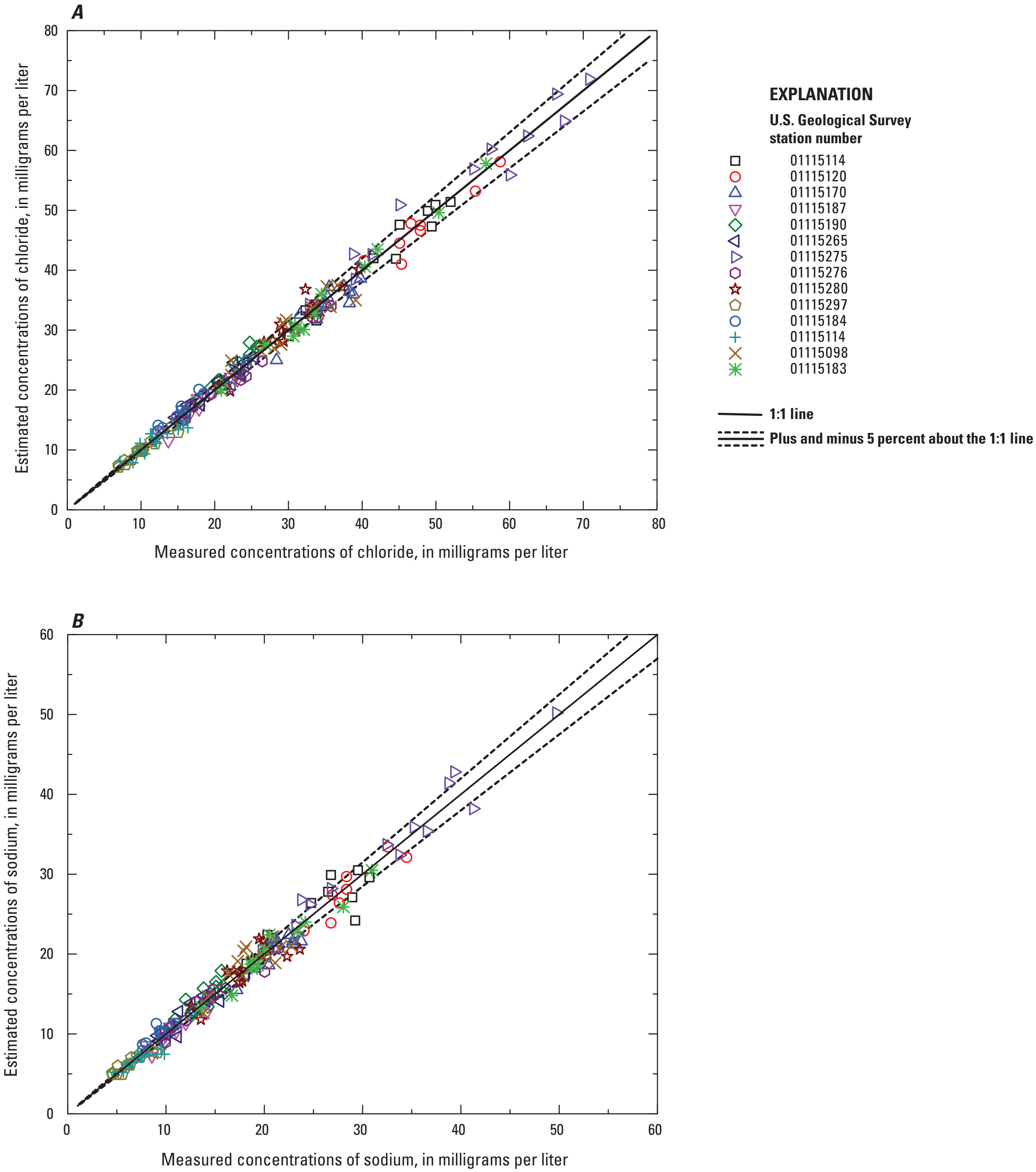

Figure 6. Relations between measured and estimated concentrations of *A,* chloride and *B,* sodium at 14 U.S. Geological Survey stations in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

Table 5. Median values for water-quality data collected at Providence Water Supply Board stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB). Not all samples were analyzed for all water-quality properties or constituents. USGS, U.S. Geological Survey; PCU, platinum cobalt units; NTU, nephelometric turbidity units; CFU/100mL, colony-forming units per 100 milliliters; *E. coli*, *Escherichia coli*; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; <, less than; --, no USGS station number assigned]

PWSB station number	USGS station number	Properties			Constituents						
		pH (units)	Color (PCU)	Turbidity (NTU)	Total coliform bacteria (CFU/100mL)	*E. coli* (CFU/100mL)	Alkalinity (mg/L as $CaCO_3$)	Chloride (mg/L)	Nitrite (mg/L as N)	Nitrate (mg/L as N)	Orthophosphate (mg/L as P)
Barden Reservoir Subbasin											
24	01115190	5.9	54	0.59	43	10	3.8	25	0.002	0.01	0.02
25	01115200	5.9	36	0.37	23	9	3.5	11	0.001	0.01	0.02
26	01115185	6.2	35	0.33	23	8	3.9	20	0.001	0.01	0.03
27	011151845	5.7	25	0.26	23	9	3.9	9.9	0.001	0.02	0.03
28	01115265	5.8	80	0.51	43	23	3.5	22	0.002	0.01	0.03
29	01115271	6.0	45	0.60	9	4	3.6	19	0.001	0.01	0.02
35	01115187	6.1	49	0.60	23	12	3.5	18	0.001	0.01	0.02
Direct Runoff Subbasin											
1	01115180	6.7	72	1.4	75	23	9.0	11	0.002	0.01	0.03
2	01115181	6.1	18	0.28	93	23	3.7	53	0.001	0.03	0.02
3	01115280	6.3	34	0.32	43	9	4.7	31	0.001	0.02	0.03
4	01115400	6.3	30	0.57	23	4	6.4	4.5	0.001	0.01	0.02
5	01115184	6.1	52	0.42	43	9	4.1	17	0.001	0.03	0.03
6	01115183	6.3	98	1.0	150	43	8.2	34	0.002	0.01	0.03
7	01115297	6.1	82	0.78	43	23	5.5	10	0.002	0.01	0.02
8	01115276	5.9	20	0.42	4	<3	2.9	12	0.001	0.01	0.02
9	01115275	6.3	36	0.32	43	9	6.5	60	0.001	0.11	0.02
30	01115350	6.1	48	0.38	43	23	3.9	20	0.001	0.02	0.02
31	01115177	6.4	35	0.93	350	59	14	87	0.003	0.13	0.04
32	01115178	6.4	63	0.70	59	23	5.9	12	0.002	0.02	0.03
33	01115182	6.1	32	0.36	23	20	4.7	13	0.001	0.02	0.02
36	--	6.4	25	0.31	23	4	3.9	3.8	0.001	0.01	0.02
37	--	5.8	24	0.26	23	4	3.1	4.2	0.001	0.01	0.02

Table 5. Median values for water-quality data collected at Providence Water Supply Board stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.—Continued

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB). Not all samples were analyzed for all water-quality properties or constituents. USGS, U.S. Geological Survey; PCU, platinum cobalt units; NTU, nephelometric turbidity units; CFU/100mL, colony-forming units per 100 milliliters; *E. coli*, *Escherichia coli*; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; <, less than; --, no USGS station number assigned]

PWSB station number	USGS station number	Properties			Constituents						
		pH (units)	Color (PCU)	Turbidity (NTU)	Total coliform bacteria (CFU/100mL)	*E. coli* (CFU/100mL)	Alkalinity (mg/L as $CaCO_3$)	Chloride (mg/L)	Nitrite (mg/L as N)	Nitrate (mg/L as N)	Orthophosphate (mg/L as P)
Moswansicut Reservoir Subbasin											
19	01115170	6.7	25	0.93	23	5	8.4	36	0.002	0.01	0.01
20	01115160	6.0	135	0.64	240	43	6.1	45	0.003	0.01	0.03
21	01115165	6.6	55	0.89	43	11	10	32	0.002	0.03	0.02
22	01115167	6.5	35	1.5	460	75	14	39	0.005	0.14	0.03
34	01115164	6.3	50	0.76	23	4	10	33	0.002	0.01	0.03
Ponaganset Reservoir Subbasin											
23	011151843	5.7	12	0.43	9	2	2.3	12	0.001	0.01	0.01
Regulating Reservoir Subbasin											
13	01115176	6.6	32	0.71	9	4	7.9	31	0.001	0.01	0.02
14	01115110	6.4	36	0.56	84	41	6.6	10	0.001	0.01	0.03
15	01115115	6.6	51	0.76	150	23	8.4	42	0.002	0.01	0.03
16	01115098	6.5	36	0.76	75	23	9.6	34	0.002	0.01	0.02
17	01115119	5.8	56	0.53	23	4	5.2	31	0.002	0.01	0.02
18	01115120	6.4	66	0.75	75	23	8.9	45	0.001	0.02	0.03
Westconnaug Reservoir Subbasin											
10	01115274	5.4	26	0.22	43	17.5	2.3	24	0.001	0.01	0.03
11	01115273	5.6	120	0.56	210	23	3.9	6.1	0.003	0.01	0.02
12	011152745	5.9	72	0.94	43	23	5.1	43	0.002	0.02	0.02
Scituate Reservoir Drainage Area											
Minimum		5.4	12	0.22	4	<3	2.3	3.8	0.001	0.01	0.01
Median		6.1	36	0.57	43	15	5.1	22.0	0.001	0.01	0.02
Maximum		6.7	135	1.5	460	75	14.0	87.0	0.005	0.14	0.04

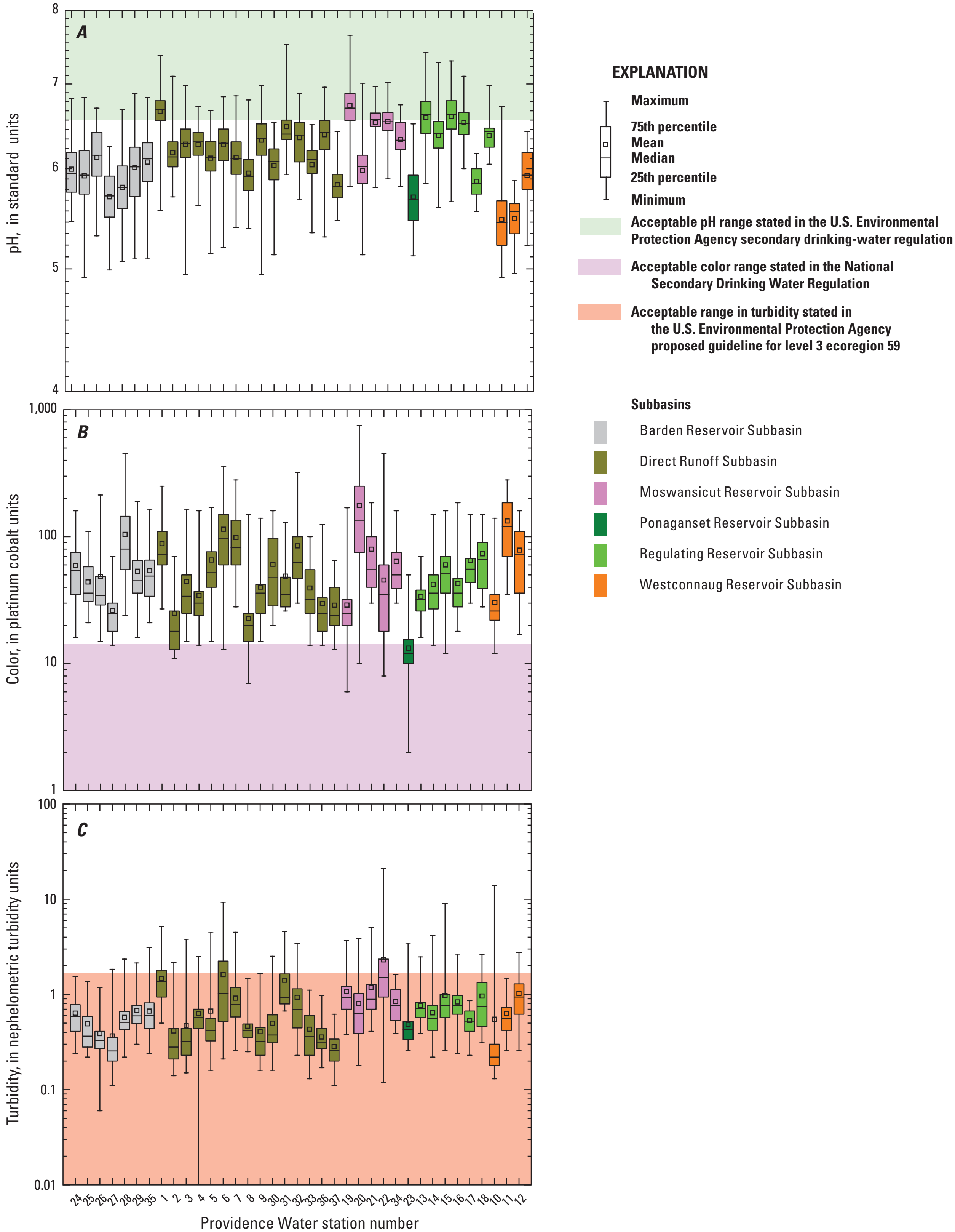

Figure 7. Distributions of measurements of *A,* pH, *B,* color, and *C,* turbidity and concentrations of *D,* alkalinity, *E,* chloride, *F,* nitrite, *G,* nitrate, *H,* nitrate plus nitrite, *I,* orthophosphate, *J,* total coliform bacteria, and *K, Escherichia coli (E. coli)* in samples collected at Providence Water Supply Board (Providence Water) water-quality-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.

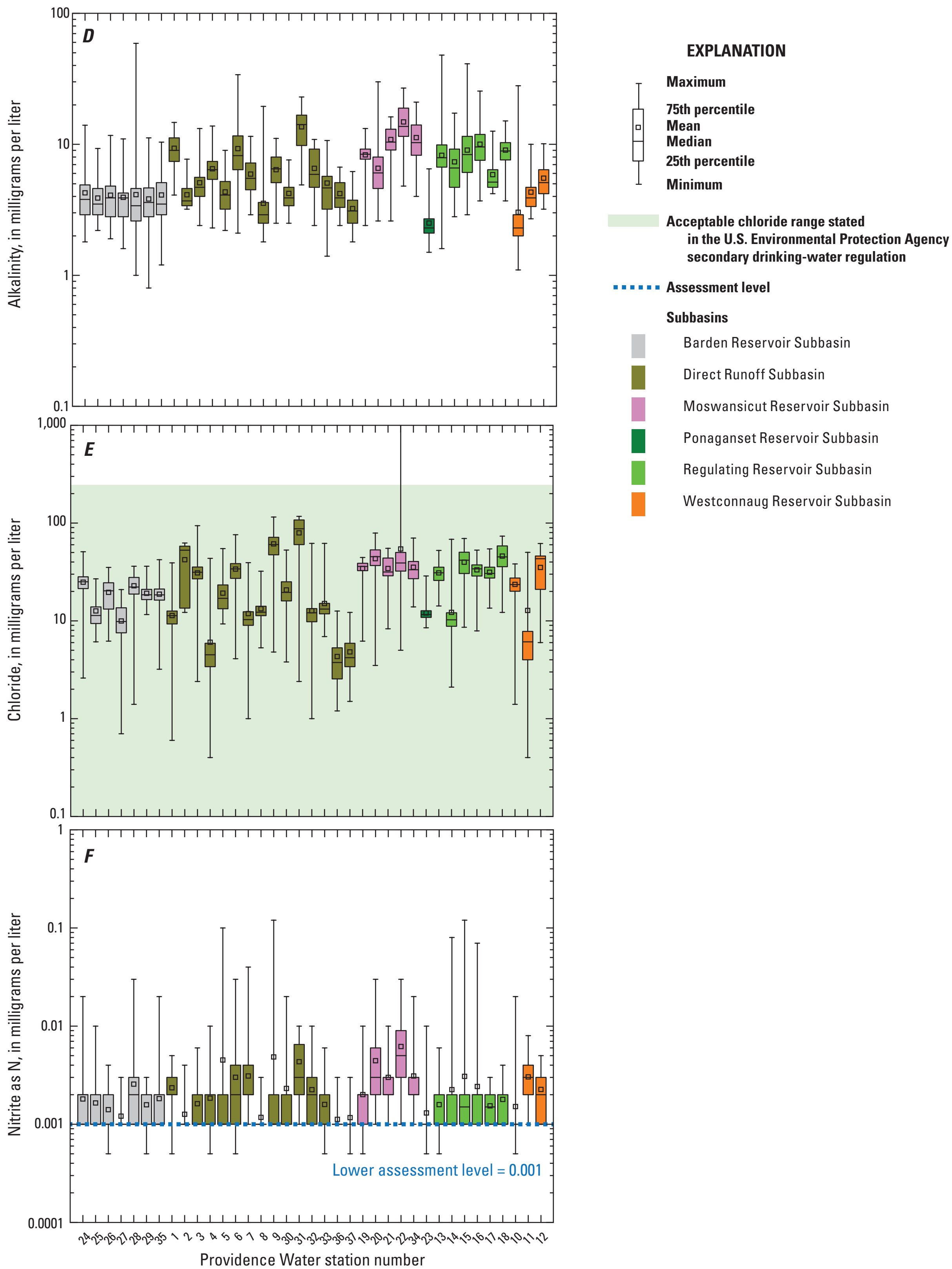

Figure 7. Distributions of measurements of *A,* pH, *B,* color, and *C,* turbidity and concentrations of *D,* alkalinity, *E,* chloride, *F,* nitrite, *G,* nitrate, *H,* nitrate plus nitrite, *I,* orthophosphate, *J,* total coliform bacteria, and *K, Escherichia coli (E. coli)* in samples collected at Providence Water Supply Board (Providence Water) water-quality-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.—Continued

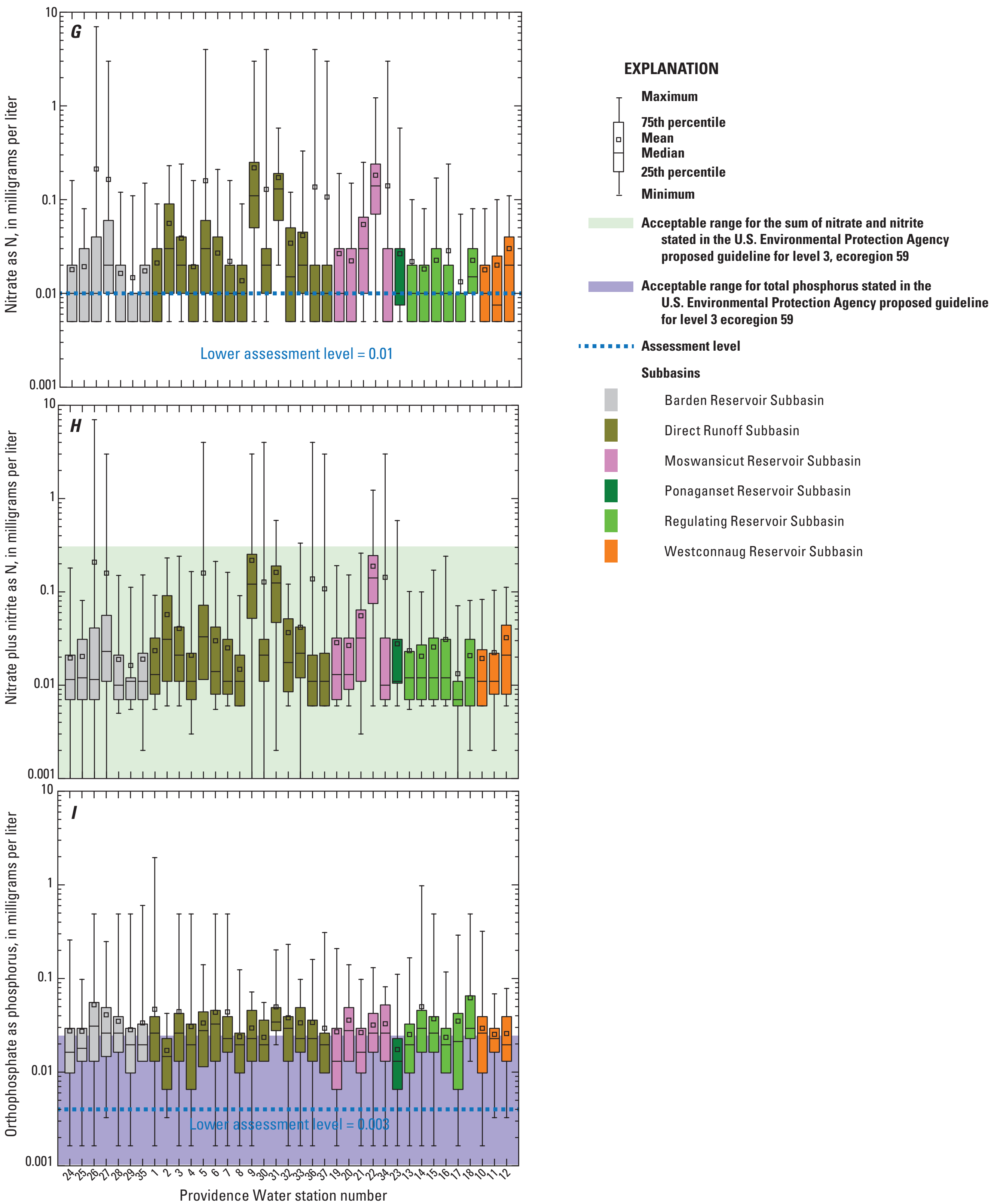

Figure 7. Distributions of measurements of *A,* pH, *B,* color, and *C,* turbidity and concentrations of *D,* alkalinity, *E,* chloride, *F,* nitrite, *G,* nitrate, *H,* nitrate plus nitrite, *I,* orthophosphate, *J,* total coliform bacteria, and *K, Escherichia coli (E. coli)* in samples collected at Providence Water Supply Board (Providence Water) water-quality-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.—Continued

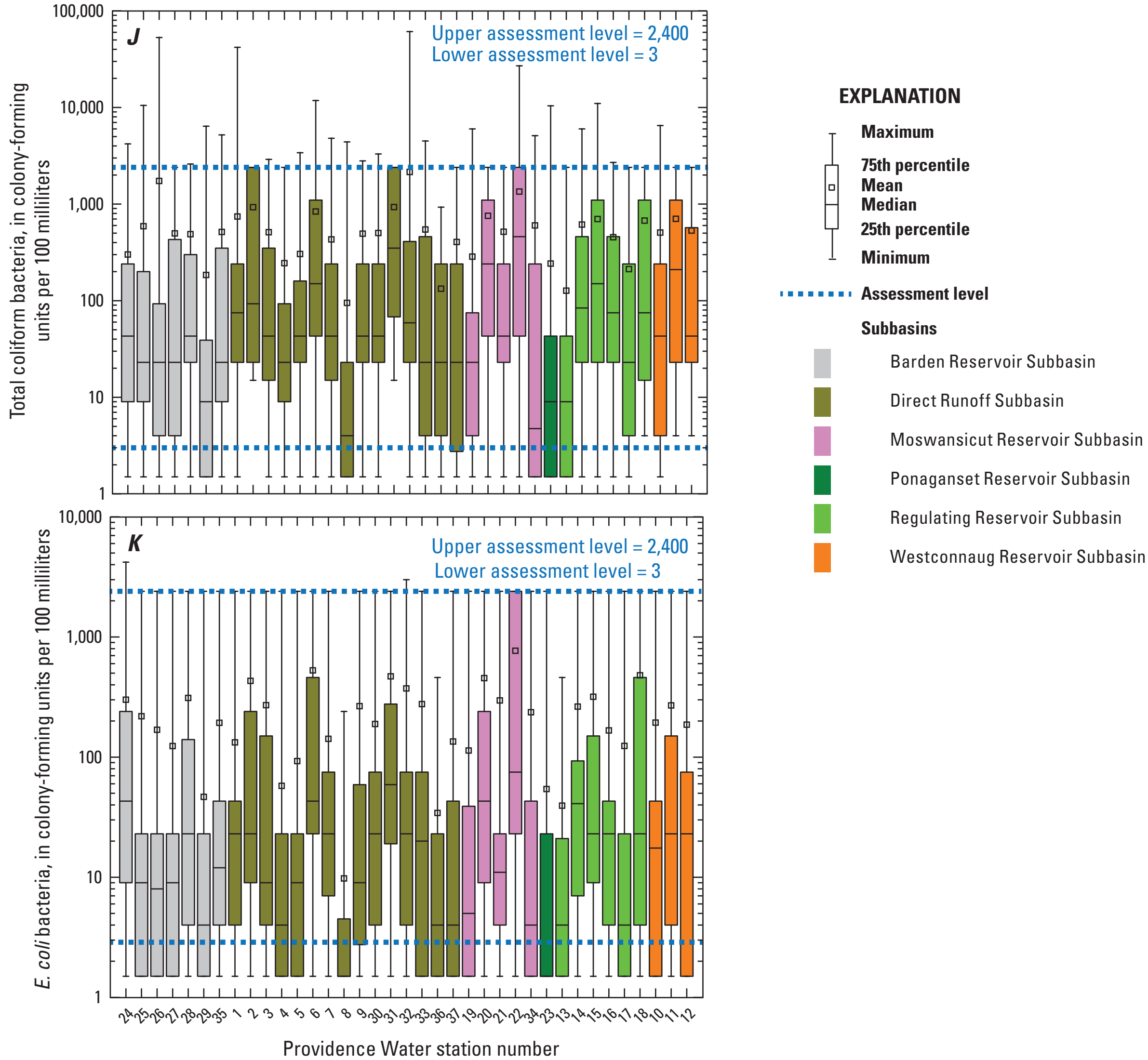

Figure 7. Distributions of measurements of *A,* pH, *B,* color, and *C,* turbidity and concentrations of *D,* alkalinity, *E,* chloride, *F,* nitrite, *G,* nitrate, *H,* nitrate plus nitrite, *I,* orthophosphate, *J,* total coliform bacteria, and *K, Escherichia coli (E. coli)* in samples collected at Providence Water Supply Board (Providence Water) water-quality-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.—Continued

Table 6. Significance levels (*p* values) for rank correlations between selected physical properties and constituent concentrations at Providence Water Supply Board water-quality-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.

[All significant correlations are positive; *p* values for correlations considered significant are shown in **bold**. *E. coli*, *Escherichia coli*; <, less than value shown]

Property or constituent	pH	Color	Turbidity	Alkalinity	Total coliform bacteria	*E. coli* bacteria	Chloride	Nitrite	Nitrate
Color	0.958								
Turbidity	**0.001**	**0.001**							
Alkalinity	**<0.001**	0.068	**<0.001**						
Total coliform bacteria	0.072	**0.002**	**0.025**	**0.002**					
E. coli bacteria	0.193	**0.001**	**0.008**	**0.010**	**<0.001**				
Chloride	0.059	0.294	**0.019**	**0.005**	**0.009**	**0.033**			
Nitrite	0.237	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.001**	**0.021**		
Nitrate	0.219	0.656	0.963	0.085	**0.031**	0.054	**0.012**	1.000	
Orthophosphate	0.390	**0.027**	0.718	**0.044**	**0.002**	**0.004**	0.504	0.236	0.352

Color

Color in stream water, typically pale yellow to dark brown, is usually caused by dissolved organic material, such as humic and fulvic acids, derived from natural sources (Hem, 1985). Inorganic materials, such as metals, also can be common sources of color. Dark-colored water, indicating a substantial concentration of dissolved organic carbon (DOC), may be of concern in source waters because some forms of 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), based on dilutions of a chemical solution that closely matches the color of natural stream water. Median values of color ranged from 12 to 135 platinum-cobalt units (PCU), with the highest value determined at the monitoring station in the Moswansicut Reservoir Subbasin (Providence Water station 20; table 5). The majority of discrete measurements of color at most monitoring stations were less than 100 PCU (fig. 7B).

Turbidity

Turbidity in stream water is caused by the presence of suspended particles, such as silt, clay, organic matter, and microorganisms, and dissolved colored material. Turbidity is measured in standard units that quantify the ability of the water to transmit light and is considered an indicator of environmental health and early stages of ecosystem change caused by excessive productivity (U.S. Environmental Protection Agency, 2000). High levels of turbidity also can interfere with water-disinfection processes (World Health Organization, 2004). The turbidity of tributaries in the drainage area generally was low; no median values exceeded 1.5 nephelometric turbidity unit (NTU) (fig. 7C; table 5) and all were less than the proposed U.S. Environmental Protection Agency (EPA) 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). The median turbidity was 0.57 NTU (table 5) among all stations in the drainage area. About 25 percent or more of the discrete turbidity measurements at Providence Water stations 1, 6, and 31 in the Direct Runoff Subbasin and station 22 in the Moswansicut Reservoir Subbasin were greater than 1.5 NTU (fig. 7C).

Alkalinity

Alkalinity is a measure of the ability of water to neutralize acid primarily as a result of the concentrations of dissolved carbon dioxide species in most natural waters (Hem, 1985). Similar in effect to 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 applications that add organic or inorganic carbon to the environment. Median alkalinity in samples from tributaries was low, ranging from 2.3 to 14 milligrams per liter as calcium carbonate (mg/L as $CaCO_3$). Among all stations in the drainage area, median alkalinity was 5.1 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 Reservoir, Ponaganset Reservoir, and Westconnaug Reservoir Subbasin—and was highest at monitoring stations in the Direct Runoff, Moswansicut Reservoir, and Regulating Reservoir Subbasin (fig. 7D).

Table 7. Significance levels (*p* values) for rank correlations between subbasin characteristics and median values of selected physical properties and constituent concentrations at Providence Water Supply Board water-quality-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, 2002–12.

[*p* values for trends considered significant are shown in **bold**. Median values of physical properties and constituent concentrations for timber operation calculated from data collected during water years 1992–2012. *E. coli*, *Escherichia coli*; (+), variables are positively correlated; (-), variables are negatively correlated]

Subbasin characteristic	pH	Color	Turbidity	Total coliform bacteria	*E. coli* bacteria	Alkalinity	Chloride	Nitrite	Nitrate	Orthophosphate
Agricultural	0.105	0.118	0.138	0.187	0.552	**0.029 (+)**	0.227	0.309	0.734	0.303
Commercial and industrial	**0.016 (+)**	0.138	**<0.001 (+)**	0.141	0.327	**<0.001 (+)**	**0.001 (+)**	**0.045 (+)**	0.121	0.486
Forest	**<0.001 (-)**	0.173	**<0.001 (-)**	**0.012 (-)**	0.091	**<0.001 (-)**	**0.001 (-)**	**0.007 (-)**	**0.014 (-)**	0.131
Other urban	0.841	0.432	0.094	0.877	1.000	0.595	0.099	0.465	0.308	0.978
Residential	**0.032 (+)**	0.564	**0.006 (+)**	**0.023 (+)**	**0.008 (+)**	**0.002 (+)**	**0.001 (+)**	0.078	**0.001 (+)**	0.054
Water	0.058	0.246	0.056	0.125	**0.045 (-)**	0.350	0.673	0.809	0.107	**<0.001 (-)**
Wetlands	0.269	**<0.001 (+)**	0.069	0.074	0.328	**0.043 (+)**	0.618	**0.027 (+)**	0.694	0.061
Imperviousness	**0.003 (+)**	0.260	**<0.001 (+)**	**0.021 (+)**	**0.026 (+)**	**<0.001 (+)**	**<0.001 (+)**	**0.039 (+)**	**0.004 (+)**	0.095
Timber operations										
Sum of all areas	0.971	0.520	0.708	0.486	0.986	0.803	0.301	0.468	0.756	0.503
80–100 percent canopy closure	0.830	0.224	0.605	0.377	0.601	0.775	0.475	0.382	0.412	0.550
50–79 percent canopy closure	0.639	0.885	0.321	0.985	0.500	0.691	0.264	0.895	0.740	0.194
20–49 percent canopy closure	0.601	0.794	0.538	0.467	0.547	0.135	**0.005 (-)**	0.074	0.142	0.405
Less than 20 percent canopy closure	0.119	0.903	0.571	0.509	0.639	0.716	0.189	0.355	0.126	0.984

Table 8. Significance levels (*p* values) for rank correlations between mean daily streamflow and selected physical properties or constituent concentrations at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1994–2012.

[Station locations shown on figure 2. *p* values for correlations considered significant are shown in **bold**. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; *E. coli*, *Escherichia coli*; (-), negative correlation; (+), positive correlation; <, less than value shown]

PWSB station number	USGS station number	Turbidity	Total coliform bacteria	*E. coli* bacteria	Chloride	Nitrate	Nitrite	Orthophosphate
Barden Reservoir Subbasin								
24	01115190	**<0.001 (-)**	**0.001 (-)**	**<0.001 (-)**	0.749	0.711	**<0.001 (-)**	0.740
25	01115200	**0.002 (-)**	**0.003 (-)**	**0.001 (-)**	0.181	0.262	0.276	0.546
26	01115185	0.802	0.109	**0.026 (-)**	**0.026 (-)**	0.872	0.121	0.864
28	01115265	**<0.001 (-)**	**0.004 (-)**	**0.002 (-)**	**<0.001 (-)**	0.447	**0.004 (-)**	0.686
35	01115187	**<0.001 (-)**	**<0.001 (-)**	**<0.001 (-)**	**0.031 (-)**	0.806	0.050	0.259
Direct Runoff Subbasin								
1	01115180	**<0.002 (-)**	**0.001 (-)**	**0.045 (-)**	**0.012 (-)**	0.096	0.067	0.067
3	01115280	**0.013 (+)**	0.268	0.325	0.255	0.300	0.256	0.253
4	01115400	**0.015 (-)**	**<0.001 (-)**	**<0.001 (-)**	0.131	0.064	0.374	0.295
5	01115184	**0.003 (-)**	**0.008 (+)**	**0.010 (+)**	**0.015 (-)**	0.085	0.989	0.444
6	01115183	**<0.001 (-)**	**<0.001 (-)**	**<0.001 (-)**	**<0.001 (-)**	0.501	**<0.001 (-)**	0.224
7	01115297	**<0.001 (-)**	**0.008 (-)**	0.162	**0.003 (-)**	0.265	**0.001 (-)**	0.923
8	01115276	0.217	**<0.001 (-)**	0.095	0.984	0.820	0.647	0.211
9	01115275	0.083	**<0.001 (-)**	**0.010 (-)**	**<0.001 (-)**	0.165	**0.025 (+)**	0.427
32	01115178	**0.001 (-)**	**0.015 (-)**	**0.024 (-)**	0.619	**0.011 (+)**	0.870	0.563
33	01115182	**<0.001 (-)**	**<0.001 (-)**	**0.001 (-)**	0.086	0.159	0.431	0.285
Moswansicut Reservoir Subbasin								
19	01115170	**0.003 (-)**	**0.024 (-)**	0.205	0.428	0.248	**0.022 (+)**	0.225
21	01115165	0.076	**0.017 (-)**	0.129	0.136	**0.001 (+)**	0.668	0.658
Regulating Reservoir Subbasin								
14	01115110	**0.002 (-)**	**0.001 (-)**	0.134	0.733	0.844	0.523	0.761
15	01115114	**0.040 (-)**	0.068	0.608	**<0.001 (-)**	0.148	**0.010 (+)**	0.531
16	01115098	0.817	0.308	**0.036 (+)**	0.387	**<0.001 (+)**	**0.035 (+)**	0.076
18	01115120	0.965	0.689	0.519	0.188	0.643	0.865	0.423
Westconnaug Reservoir Subbasin								
10	01115274	0.980	**<0.001 (-)**	**<0.001 (-)**	0.234	**<0.001 (+)**	**0.663**	0.663
11	01115273	**<0.001 (-)**	0.174	0.262	0.683	0.078	**0.003 (-)**	0.287

Table 9. Selected relevant Federal and Rhode Island State water-quality standards and guidelines.

[Sources of standards and guidelines include Rhode Island Department of Environmental Management (RIDEM; 2010) and U.S. Environmental Protection Agency (EPA; 2009). Class AA waters are waters used for drinking-water supply or tributary stream water to drinking-water sources in Rhode Island. NTU, nephelometric turbidity units; CFU/100 mL, colony-forming units per 100 milliliters; mg/L, milligrams per liter; <, less than; >, greater than; --, none; P, phosphorus]

Parameter or constituent	RIDEM water-quality standards for Class AA waters	USEPA National Secondary Drinking Water Regulations
pH, in standard units	6.5–9.0[1]	6.5–8.5
Color, platinum cobalt units	--	15
Turbidity, in NTU	<5 above background	--
Total coliform bacteria, in CFU/100 mL	Geometric mean 20; <10 percent of samples >200	--
Chloride, in mg/L	--	250
Total phosphorus, mg/L as P	0.025	--

[1]Or as occurs naturally.

Constituent Concentrations

Providence Water also monitors concentrations of three categories of constituents—chloride, nutrients, and bacteria. Similar to values of physical properties, constituent concentrations are used as an indicator of overall water quality and of compliance with Federal and State guidelines.

Chloride

Chloride, a nonreactive ion commonly found in stream water, is found in precipitation, minerals and soils in the environment (Hem, 1985), septic effluent, industrial wastes, and wastewater (Mullaney and others, 2009). The mean annual precipitation-weighted chloride was less than 0.5 milligrams per liter (mg/L) during WYs 2002–12 west of the study area near Abington, Connecticut (National Atmospheric Deposition Program, 2014). Chloride is a major constituent of road salt and other deicing compounds. The median chloride concentration for discrete samples collected by Providence Water for all stations in the drainage area was low, 22 mg/L (table 5), which is typical of natural stream water in coastal New England (Robinson and others, 2003). Median values for individual stations ranged from 3.8 to 87 mg/L. Discrete chloride concentrations were greatest at a few stations in the Direct Runoff Subbasin (fig. 7E). The greatest median chloride concentrations, 87 and 60 mg/L, were measured at Toad Pond (Providence Water station 31) and Bear Tree Brook (Providence Water station 9), respectively. A formerly uncovered salt-storage facility in the Bear Tree Brook Subbasin likely contributed to the chloride concentrations at that monitoring station (Nimiroski and Waldron, 2002). Toad Pond receives flows from a developed area with relatively large percentage of impervious area (about 19 percent) in comparison with the other monitoring stations in the Scituate Reservoir drainage area.

Nutrients

Nutrients, including chemical species[3] 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 to degradation of aquatic life (U.S. Environmental Protection Agency, 2000). Sources of nitrogen in the tributaries include atmospheric deposition, leaching of naturally occurring organic material, discharge of groundwater that is enriched in nitrate from septic-system leachate, and runoff contaminated with fertilizer or animal waste. In tributaries in the Scituate Reservoir drainage area, concentrations of nutrient species nitrite, nitrate, and orthophosphate were low (table 5) and, in many cases, were not detected at the reporting limits; (figs. 7F, G, and I). Other forms of nitrogen, such as dissolved and particulate ammonia, were not measured as part of this study.

Median concentrations of nitrate were less than 0.1 mg/L as N at most monitoring stations. High median concentrations of nitrate at some monitoring stations, such as Moswansicut Reservoir (Providence Water station 22; 0.14 mg/L as N) in the Moswansicut Reservoir Subbasin and Toad Pond (Providence Water station 31; 0.13 mg/L as N) in the Direct Runoff Subbasin, may be caused by nitrogen-enriched runoff or groundwater. Median concentrations of nitrite at all monitoring stations were less than 0.006 mg/L as N (table 5). Median concentrations of nitrite at all monitoring stations in the Moswansicut Reservoir Subbasin were greater than the median Scituate Reservoir drainage area value of 0.001 mg/L as N. The median values for the sum of nitrite and nitrate concentrations at all stations were less than the proposed EPA reference concentration for the sum of nitrite and nitrate concentrations (0.31 mg/L as N) for minimally impacted

[3]A chemical species of an element may be an atom, molecule, or ion containing that element.

Table 10. Percentages of samples, collected at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12, with values or concentrations not meeting water-quality standards and guidelines.

[PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; PCU, platinum-cobalt units; NTU, nephelometric turbidity units; mg/L, milligrams per liter; <, less than; >, greater than; --, none; P, phosphorus]

PWSB station number	USGS station number	Properties			Constituents	
		pH	Color	Turbidity	Chloride	Orthophosphate
		<6.5	>15 PCU	>5 NTU	>250 mg/L	>0.025 mg/L as P
Barden Reservoir Subbasin						
24	01115190	93	100	0	0	32
25	01115200	97	100	0	0	27
26	01115185	92	97	0	0	56
27	011151845	100	86	0	0	52
28	01115265	97	100	0	0	53
29	01115271	89	100	0	0	37
35	01115187	92	100	0	0	40
Average		94	98	0	0	42
Direct Runoff Subbasin						
1	01115180	17	100	1	0	55
2	01115181	95	65	0	0	26
3	01115280	78	97	0	0	53
4	01115400	89	97	0	0	37
5	01115184	91	97	0	0	53
6	01115183	82	99	5	0	65
7	01115297	91	100	0	0	49
8	01115276	91	72	0	0	33
9	01115275	76	97	0	0	45
30	01115350	97	100	0	0	29
31	01115177	58	100	0	0	85
32	01115178	74	100	0	0	53
33	01115182	100	93	0	0	44
36	--	63	97	0	0	47
37	--	100	90	0	0	26
Average		80	94	0	0	47
Moswansicut Reservoir Subbasin						
19	01115170	18	96	0	0	32
20	01115160	97	99	0	0	56
21	01115165	29	100	4	0	29
22	01115167	38	85	8	1	54
34	01115164	71	100	0	0	50
Average		50	96	2	0	44
Ponaganset Reservoir Subbasin						
23	011151843	99	25	0	0	24

Table 10. Percentages of samples, collected at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12, with values or concentrations not meeting water-quality standards and guidelines.—Continued

[PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; PCU, platinum-cobalt units; NTU, nephelometric turbidity units; mg/L, milligrams per liter; <, less than; >, greater than; --, none; P, phosphorus]

PWSB station number	USGS station number	Properties			Constituents	
		pH	Color	Turbidity	Chloride	Orthophosphate
		<6.5	>15 PCU	>5 NTU	>250 mg/L	>0.025 mg/L as P
Regulating Reservoir Subbasin						
13	01115176	36	100	0	0	40
14	01115110	66	99	0	0	57
15	01115115	32	99	2	0	56
16	01115098	43	100	0	0	35
17	01115119	100	100	0	0	48
18	01115120	84	100	0	0	58
Average		60	100	0	0	49
Westconnaug Reservoir Subbasin						
10	01115274	98	97	2	0	50
11	01115273	100	100	0	0	46
12	011152745	100	100	0	0	41
Average		99	99	1	0	46
Scituate Reservoir Drainage Area						
Minimum		17	25	0	0	24
Median		91	99	0	0	47
Maximum		100	100	8	1	85

conditions in streams in the Northeastern Coastal Zone ecoregion (U.S. Environmental Protection Agency, 2000).

Orthophosphate is generally considered the most biologically available form of phosphorus (Reddy and others, 1999), which is considered the limiting nutrient in inland aquatic systems; therefore, orthophosphate often is used as an indicator of potential water-quality problems, such as algae blooms or excessive aquatic plant growth (Schlesinger, 1991). The median of the median orthophosphate concentrations for the 37 monitoring stations was 0.02 mg/L as P and median values ranged from 0.01 to 0.04 mg/L as P. Median orthophosphate concentrations, as well as much of the discrete sample data (fig. 7I) at many of the monitoring stations, were greater than the EPA-proposed total phosphorus reference concentration of 0.024 mg/L for minimally impacted conditions for streams in the Northeastern Coastal Zone ecoregion (U.S. Environmental Protection Agency, 2000).

Bacteria

Streams and reservoirs commonly contain a variety of microorganisms, some of which can cause disease in humans. Some microorganisms are introduced into water supplies by sewage disposal, either directly to surface waters or through septic-system failure. Septic or other individual sewage-disposal systems are predominantly used throughout the Scituate Reservoir drainage area (Richard Blodgett, Providence Water Supply Board, written commun., 2014). Other sources of bacteria to surface waters include waterfowl and runoff from impervious areas that are affected by animal waste (Weiskel and others, 1996). Total coliform bacteria and *E. coli* are indicators 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* are specifically intestinal bacteria and thus are a more definitive indicator of fecal contamination (Francy and others, 2000; World Health Organization, 2004).

Median concentrations of total coliform bacteria and *E. coli* were greater than the detection limit (3 CFU/100 mL) at nearly all stations (table 5; figs. 7J and K). Median concentrations of *E. coli* were typically less than the associated median concentrations of total coliform bacteria. The median concentrations of total coliform and *E. coli* bacteria for all stations in the drainage area were 43 and 15 CFU/100 mL, respectively. A substantial number of discrete concentrations of total coliform bacteria and *E. coli* were greater at specific stations in the Direct Runoff (Providence Water stations 2, 6, and 31) and Moswansicut Reservoir Subbasins (Providence Water station 22; figs. 7J and K) than at other stations in the Scituate Reservoir drainage area. Drainage conveyance structures often direct stormwater runoff, one source of bacteria, to streams and ponds; thus, the relatively high percentage of impervious surfaces (table 2) in the drainage areas of stations 31 (Toad Pond) and 22 (Moswansicut Stream South) may contribute to the bacteria concentrations in water-quality samples. Some low concentrations of indicator bacteria were determined from samples collected at monitoring stations immediately downstream from subbasin reservoirs, such as Providence Water station 23 (at the outlet of the Ponaganset Reservoir), station 13 (at the outlet of Regulating Reservoir), and station 29 (at the outlet of the Barden Reservoir). Low concentrations at such stations may be the result of settling and dieoff of indicator bacteria during the passage of water through the impoundments.

Correlations Between Water-Quality Properties and Constituent Concentrations

Relations between water-quality properties and constituent concentrations may be useful to identify potential sources of constituents or natural processes occurring in the tributary drainage areas. Correlations between discrete measurements of turbidity and pH, color, and alkalinity were significant (table 6); as a result, tributary subbasins with high values of pH, color, and alkalinity tended to have high turbidity values. Correlations also were significant between discrete measurements of turbidity and concentrations of bacteria, chloride, and nitrite constituents that are often associated with stormwater runoff from impervious area. No significant correlations were found between nitrite, nitrate, and orthophosphate; however, positive relations between orthophosphate and color, alkalinity, and bacteria were significant (table 6). Concentrations of chloride were significantly correlated with concentrations of nitrite, nitrate, and most physical properties in the drainage area.

Factors Affecting Water-Quality Properties and Constituent Concentrations

Values of water-quality properties and constituents are affected by many factors, including land use, impervious area, and streamflow. Comparison of median values of water-quality properties and constituent concentrations with percentages of land-use area, impervious area, and timber activity 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 that entrain additional constituents with surface runoff or through the dilution or addition of contaminants derived from base flow dominated by groundwater.

Subbasin Characteristics

Land use, impervious surface areas, and timber activity in the subbasins are factors that can affect constituent concentrations in the tributaries. Percentages of residential land use and of impervious area in tributary subbasins correlated significantly with median values or concentrations of several water-quality properties that can indicate human activities, including pH, turbidity, alkalinity, and concentrations of total coliform bacteria, *E. coli*, chloride, nitrite, and nitrate (fig. 8; table 7). Correlations with commercial and industrial land use also were significant for many of the same properties and constituents, except for correlations with concentrations of total coliform bacteria, *E. coli*, and nitrate. Median values of pH, turbidity, alkalinity, and concentrations of total coliform bacteria, chloride, nitrite, and nitrate correlated negatively with the percentage of forest in subbasins of the monitoring stations. The correlations between chloride concentrations and various land uses related to impervious area are likely a direct result of the application of deicing compounds during winter maintenance activities throughout the drainage area. Road salt was previously determined to be the largest source of chloride in the drainage area (Nimiroski and Waldron, 2002). Median values of color correlated positively with the percentage of wetlands in the tributary subbasins; this correlation suggests that naturally occurring organic material and possibly dissolved iron and manganese were likely sources of color in tributary stream water (Nimroski and others, 2008).

Median values of alkalinity correlated positively with the percentage of agriculture in the tributary subbasins; positive correlations with pH were only significant at a lower probability level (*p* value of about 10-percent). This relation may be associated with the application of lime to the poorly buffered croplands in the subbasins (Shearin and others, 1943) or as a result of nitrification following applications of fertilizer that promotes soil acidification and consequently accelerates chemical weathering of the soil materials (Kaushal and others, 2013). The application or remnants of animal manure on agricultural land may also increase the alkalinity in runoff entering the tributaries (Hansen and others, 1976). Median values of alkalinity also correlated positively with the percentage of imperviousness and other land use related to development. The relation between the level of alkalinity in the tributaries and these subbasin characteristics may be related to the weathering of anthropogenic structures containing concrete (sidewalks, buildings, drainage convenience structures, and so forth) through contact with relatively low-pH precipitation common to this region of the country (Prestegaard and others, 2005).

Providence Water manages the forests around the reservoirs through a selective timber management program

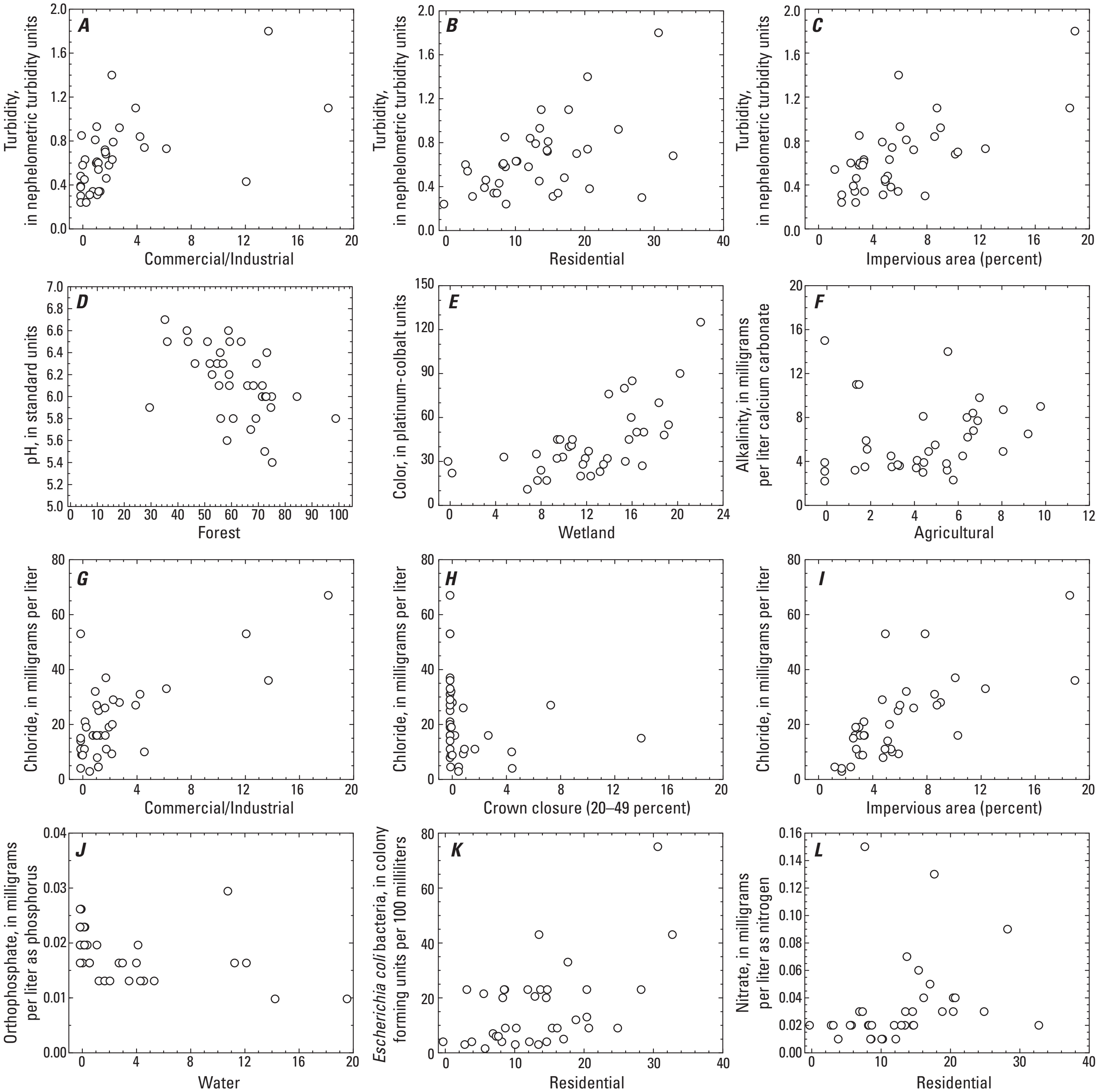

Figure 8. Relations between *A*, median values of turbidity and percent commercial and industrial land use; *B,* turbidity and percent residential land use; *C,* turbidity and percent impervious area; *D,* pH and forested land use; *E*, color and percent wetland area; *F*, alkalinity and percent agricultural land use; *G*, chloride and percent commercial and industrial land use; H, chloride and 20- to 49-percent canopy closure; I, chloride and percent impervious area; *J,* median concentrations of orthophosphate and percent water land cover; *K*, median numbers of *Escherichia coli* colony-forming units per 100 milliliters and percent residential land use; and *L*, nitrate and percent residential land use at Providence Water Supply Board water-quality monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.

(Providence Water Supply Board, 2011). Some amount of timbering was performed in nearly all tributary drainage areas during WYs 1992–2012; however, most of the operations were focused in the Direct Runoff Subbasin. With only one exception (concentrations of chloride), no statistically significant correlations were determined among percentages of various degrees of tree-canopy reduction in drainage area of monitoring stations and median values or concentrations of water-quality properties (table 7). While the reduction of a forest canopy can affect water quality, increases in chloride concentrations are not normally documented as a result (Martin and others, 1986).

Streamflow

Values of water-quality properties and constituent concentrations may vary with flow because of seasonal changes in precipitation or stormwater runoff. For example, concentrations of some constituents vary during warm low-flow periods of the year because of biological activity. Several water-quality properties and constituent concentrations are negatively correlated with streamflow (table 8). In general, turbidity, concentrations of total coliform bacteria, and *E. coli* often are negatively correlated with flow at most stations. Concentrations of chloride also correlated negatively with streamflow. The strong relation between streamflow and chloride, estimated from continuous measurements of specific conductance, is illustrated for Quonapaug Brook (Providence Water station 6; fig. 9). At some stations in the Barden Reservoir, Direct Runoff, and Regulating Reservoir Subbasins, concentrations of chloride tends to increase during the summer when streamflow is low and decrease during higher base-flow conditions and stormflows. The seasonal relation between daily mean streamflow and daily mean specific conductance, a surrogate for chloride, is illustrated for Dolly Cole Brook, Quonapaug Brook, and Rush Brook (Providence Water stations 24, 6, and 15) in figure 10. This observation indicates that chloride in runoff containing deicing compounds, which in many cases infiltrates along the roadways and parking lots, is entering the groundwater and discharging to the tributaries later in the year

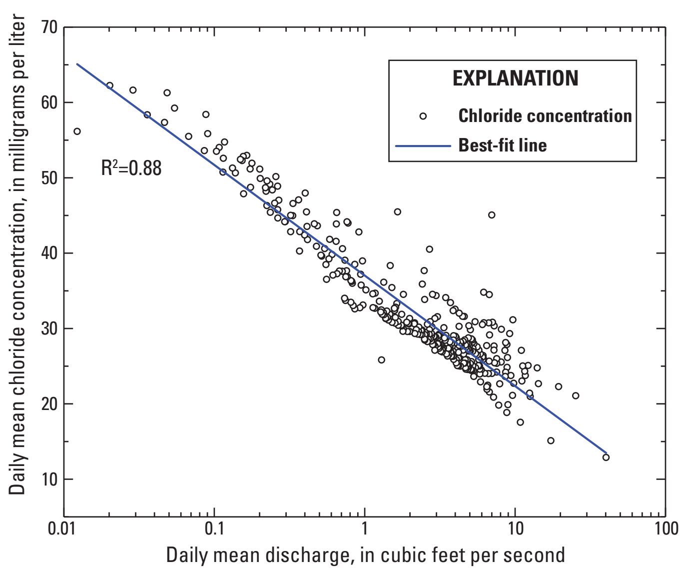

Figure 9. Relations between daily mean streamflow and daily mean concentrations of chloride estimated from continuous measurements of specific conductance for Quonapaug Brook in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

Median concentrations of nitrate correlated positively with flow at only a few stations found in the Direct Runoff, Moswansicut Reservoir, Regulating Reservoir, and Westconnaug Reservoir Subbasins (table 8). Nitrogen-enriched runoff in streamflow during storms could be a factor in these relations. Correlations between median concentrations of nitrite and flow were significant at about one-third of the stations; however, the direction of the trends was inconsistent. Correlations between median concentrations of orthophosphate and flow were only significant at *p*-values of about 0.07 at Brandy Brook and Peeptoad Brook (Providence Water stations 1 and 16, respectively; table 8).

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 their tributaries are designated class AA (Rhode Island Department of Environmental Management, 2010). Class AA waters have standards for pH, turbidity, and maximum allowable concentrations of total phosphorus (table 9). The EPA has established secondary drinking-water regulations (SDWRs) for measurements of pH and color and concentrations of chloride (table 9). SDWRs are nonmandatory water-quality guidelines established by the EPA and are designed to assist public water suppliers in managing aesthetic aspects of water, such as taste, odor, color, foaming, corrosivity, staining, scaling, and sedimentation; the regulations are not related to risk to human health (U.S. Environmental Protection Agency, 2009). Although these guidelines typically are applied to finished water, the presence of these constituents at concentrations exceeding SDWRs can result in damage to equipment and reduce the effectiveness of treatment for other constituents. Some constituents, such as chloride and nitrates, are not effectively removed by many water treatment systems (Smith, 2007).

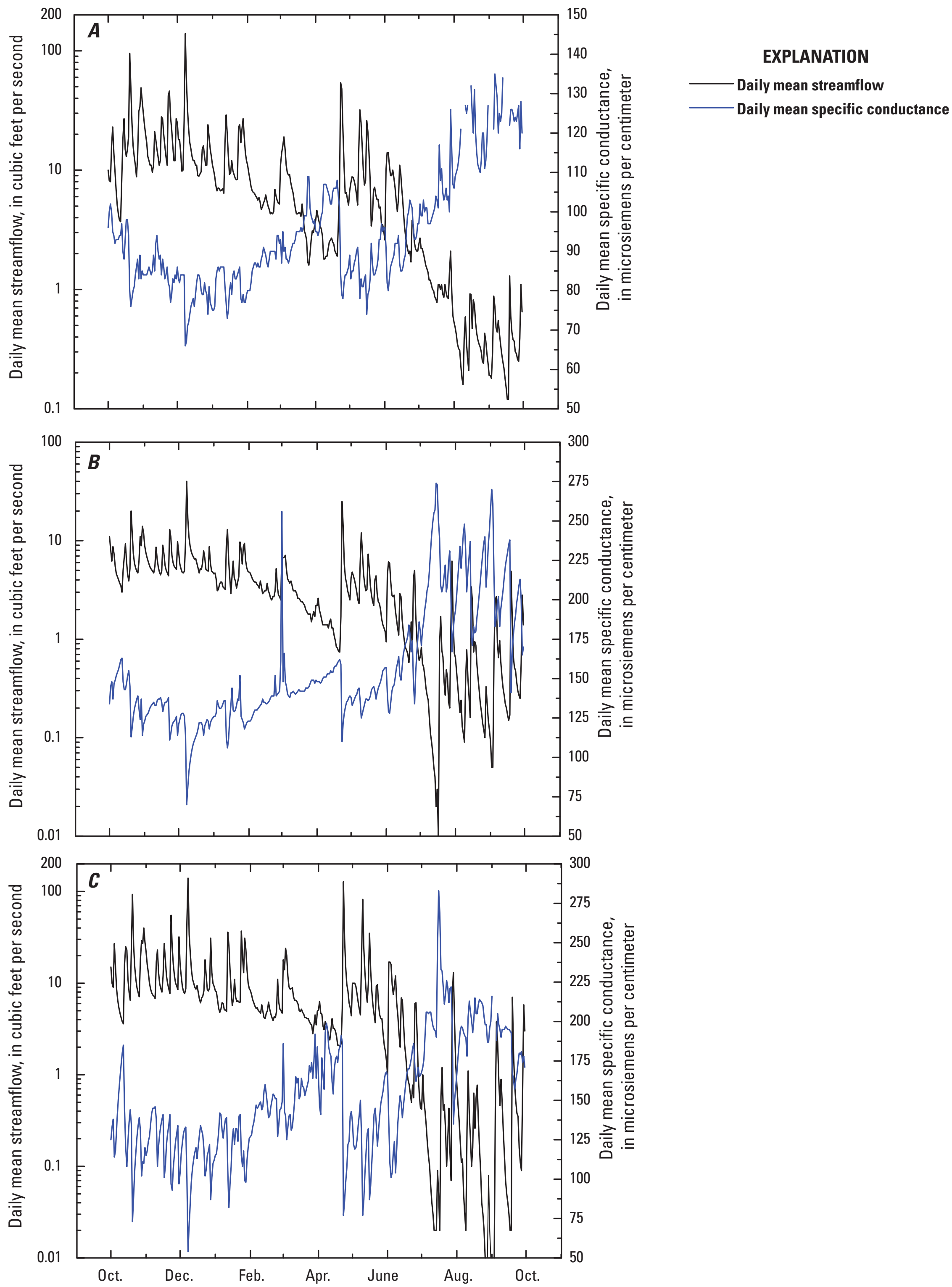

Figure 10. Relations between daily mean streamflow and daily mean values of specific conductance at *A*, Dolly Cole Brook in the Barden Reservoir Subbasin, *B*, Quonapaug Brook in the Direct Runoff Subbasin, and *C*, Rush Brook in the Regulating Reservoir Subbasin, Scituate Reservoir drainage area, Rhode Island, water year 2012.

Water-Quality Properties

RIDEM water-quality standards for class AA waters establish an allowable range for pH of 6.5 to 9.0 or, as occurs naturally; the EPA's recommended pH range of drinking water is 6.5 to 8.5 (table 9). The pH of water samples collected during WYs 2003–12 by Providence Water did not exceed 8.5; however, the pH was less than 6.5 in 17 to 100 percent of samples at stations (table 10) 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, 2014); the low buffering capacity of the soil material in the Scituate Reservoir drainage area contributes to the low pH values observed there.

Water-quality guidelines for color consist only of the EPA SDWR for public drinking-water supplies (table 9). Color in source water, however, is an important indicator of DOC, which can contribute to the formation of trihalomethanes when chlorine is added to finished drinking water; thus, DOC is a factor in water treatment. Most water samples at most stations exceeded the SDWR for color of 15 PCU during WYs 2003–2012 (fig. 7B).

Turbidity values in tributaries in the drainage area rarely exceeded the background level by 5 NTU or more (table 10), the maximum allowable for RIDEM class AA waters (table 9). Similarly, the turbidity value of 1.68 NTU, the EPA proposed reference concentration for minimally affected conditions in the region (U.S. Environmental Protection Agency, 2000), was rarely exceeded at most of the monitoring stations (fig. 7C). These results suggest that the water quality of tributaries in the Scituate Reservoir drainage area is minimally affected by suspended particles relative to stream water in the Northeastern Coastal Zone ecoregion of the United States, as noted previously.

Constituent Concentrations

RIDEM water-quality standards for class AA waters establish maximum concentrations for total phosphorus. Orthophosphate (a component and 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 24 to 85 percent of samples collected from all stations (table 10). At 16 of the 37 stations, the median orthophosphate concentration (table 5) was two or more times greater than the standard value of 0.025 mg/L. Phosphorus concentrations that exceed the standard could be of concern because phosphorus can contribute to excessive plant and algae growth.

The EPA SDWR for chloride (250 mg/L) was only exceeded once—in a single sample collected at Moswansicut Reservoir (Providence Water station 22)—during WYs 2003–12; however, instantaneous chloride concentrations estimated from continuous records of specific conductance (representing all base flow and runoff conditions) from Quonapaug Brook for water years 2009–12 (Providence Water station 6) exceeded the SDWR in WYs 2011 and 2012 during winter runoff events (fig. 11). Although elevated concentrations of chloride commonly occur during winter runoff events in many of the tributaries in the drainage area, estimated concentrations of chloride did not exceed the SDWR at the other 13 stations (table 1) equipped to continuously monitor specific conductance during WYs 2009–12.

Loads and Yields of Selected Constituents, WYs 2003–12

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, the constituent load, can be calculated on an annual, daily, or instantaneous basis from streamflow and concentration data. In this study, daily loads were calculated for selected constituents for all sampling dates during WYs 2003–12. Daily yields, or loads per unit of subbasin drainage area, also were calculated to allow for direct comparisons of loads among sampling stations with drainage areas of different sizes. The median daily loads and yields were calculated for the 23 monitoring stations for which sufficient data were available (table 11).

Discrete loads and yields represent point measurements of continuous mass flux that may vary seasonally (for example, in association with hydrologic conditions or road-salt application) and daily (for example, in association with

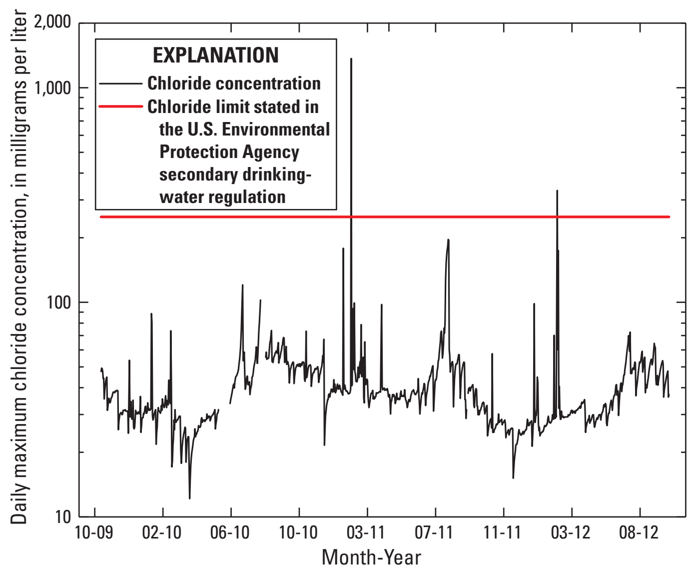

Figure 11. Daily maximum concentrations of chloride estimated from continuous records of specific conductance for Quonapaug Brook in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

Table 11. Median daily loads and yields of chloride, nitrite, nitrate, orthophosphate, and bacteria, in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.

[Water-quality data are from samples collected and analyzed by the Providence Water Supply Board (PWSB). USGS, U.S. Geological Survey; CFU×10⁶/d, millions of colony forming units per day; *E. coli*, *Escherichia coli*; N, nitrogen; P, phosphorus; kg/d, kilograms per day; kg/d/mi², kilograms per day per square mile; g/d, grams per day; g/d/mi², grams per day per square mile]

PWSB station number	USGS station number	Chloride		Nitrite (as N)		Nitrate (as N)		Orthophosphate (as P)		Total coliform bacteria		*E. coli*	
		(kg/d)	(kg/d/mi²)	(g/d)	(g/d/mi²)	(g/d)	(g/d/mi²)	(g/d)	(g/d/mi²)	(CFU×10⁶/d)	(CFU×10⁶/mi²)	(CFU×10⁶/d)	(CFU×10⁶/mi²)
Barden Reservoir Subbasin													
24	01115190	450	92	27	5.5	170	34	300	60	6,900	1,400	1,600	330
25	01115200	90	38	10	4.3	100	44	130	54	1,400	600	460	200
26	01115185	160	37	10	2.2	160	37	170	39	1,200	280	530	120
28	01115265	530	61	50	5.7	190	21	510	58	14,000	1,600	5,700	650
35	01115187	1,100	79	83	5.9	560	40	1,200	86	17,000	1,200	5,300	380
Direct Runoff Subbasin													
1	01115180	70	45	15	9.2	70	44	130	85	2,800	1,800	580	370
3	01115280	130	73	5.5	3.1	80	45	120	65	1,700	950	500	280
4	01115400	12	14	2.9	3.4	25	29	34	40	480	560	95	110
5	01115184	80	66	7.3	6.0	120	94	85	70	1,500	1,200	210	170
6	01115183	300	150	17	8.7	110	56	240	120	11,000	5,600	4,000	2,000
7	01115297	190	43	36	8.2	180	41	410	94	6,600	1,500	2,500	570
8	01115276	300	58	24	4.6	240	46	360	69	750	140	440	85
9	01115275	180	290	3.7	6.0	300	480	57	92	1,400	2,200	230	370
32	01115178	19	41	2.2	4.9	23	50	32	71	610	1,400	300	670
33	01115182	13	46	1.1	3.9	21	75	20	70	230	800	89	320
Moswansicut Reservoir Subbasin													
19	01115170	420	130	27	8.2	200	62	210	65	2,600	780	570	170
21	01115165	57	190	3.6	12	44	150	25	87	520	1,800	100	340
Regulating Reservoir Subbasin													
14	01115110	200	32	22	3.5	190	30	490	79	21,000	3,400	5,000	800
15	01115114	460	98	18	3.8	130	28	330	70	15,000	3,200	3,000	640
16	01115098	590	120	27	5.4	180	36	280	57	12,000	2,400	2,300	460
18	01115120	34	120	1.3	4.6	11	39	22	79	360	1,300	61	220
Westconnaug Reservoir Subbasin													
10	01115274	130	88	5.1	3.4	57	38	130	85	2,100	1,400	520	350
11	01115273	29	40	9.6	13	37	51	95	130	6,200	8,500	1,100	1,500
Scituate Reservoir Drainage Area													
Minimum		12	14	1.1	2.2	11	21	20	39	230	140	61	85
Median		160	66	10	5.4	120	44	130	70	2,100	1,400	530	350
Maximum		1,100	290	83	13	560	480	1,200	130	21,000	8,500	5,700	2,000

biologic activity and, even more frequently in association 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 the above factors, as well as from differences in constituent sources and transport characteristics.

Chloride

Chloride loads and yields differed among monitoring stations in the drainage area (table 11). Median daily loads of chloride estimated on the basis of Providence Water sample data ranged from 12 to 1,100 kg/d. The largest median chloride loads were determined for Providence Water stations 16, 18, 19, 6, 21, and 9 in the Direct Runoff, Moswansicut Reservoir, and Regulating Reservoir Subbasins.

The relatively large median load (1,100 kg/d) at Providence Water station 35 (Ponaganset River) is a result of this station's large drainage area (14 mi^2; table 11); the yield was 79 kilograms per day per square mile (kg/d/mi^2), which is comparable to the median drainage area yield (66 kg/d/mi^2). Median daily yields ranged from 14 to 290 kg/d/mi^2. The largest median chloride yield was determined for Bear Tree Brook (Providence Water station 9) and was caused in part by the location of a formerly uncovered salt-storage facility within the subbasin drainage area. Relatively high chloride yields ranging from 120 to 190 kg/d/mi^2 in several subbasins likely reflect the greater percentages of developed land uses and imperviousness in their drainage areas (table 2).

Nutrients

Loads of nitrite, nitrate, and orthophosphate were greatest in the subbasins 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 part of the Scituate Reservoir drainage area that are more developed than other parts of the drainage area (fig. 2; table 11). Yields ranged from 2.2 to 13 grams per day per square mile as nitrogen (g/d/mi^2 as N) for nitrite, 21 to 480 g/d/mi^2 as N for nitrate, and 39 to 130 grams per day per square mile as phosphorus (g/d/mi^2 as P) for orthophosphate. The median yields for the Scituate Reservoir drainage area were 5.4 g/d/mi^2 as N for nitrite, 44 g/d/mi^2 as N for nitrate, and 70 kilograms per day per square mile as phosphorus (kg/d/mi^2 as P) for orthophosphate, respectively. Nutrient yields varied from station to station; however, subbasin yields estimated from available data (sum of subbasin loads divided by subbasin area) indicate that yields for nitrite and nitrate were greatest in the Moswansicut Reservoir Subbasin (8.6 and 69 g/d/mi^2 as N, respectively) and subbasin yields for orthophosphate were greatest in the Westconnaug Reservoir Subbasin (100 kg/d/mi^2 as P). Yields of nitrite and orthophosphate were greatest at Providence Water station 11 in the Westconnaug Reservoir Subbasin (fig. 2; table 11). The greatest median yield of nitrate (480 kg/d/mi^2 as N) was determined for Providence Water station 9 (Bear Tree Brook) in the Direct Runoff Subbasin and was about 10 times greater than the median yield for the Scituate Reservoir drainage area.

Bacteria

Loads and yields of total coliform bacteria and *E. coli* varied among stations by more than two orders of magnitude (table 11). Median loads of total coliform and *E. coli* bacteria were 2,100 and 530 MCFU/d, respectively. The greatest median load of total coliform bacteria (21,000 million CFU/d) and *E. coli* (5,700 million CFU/d) were found at the stations on Hunting House Brook (Providence Water station 14) and at Hemlock Brook (Providence Water station 14), respectively. Median yields of total coliform and *E. coli* bacteria were 1,400 million colony-forming units per square mile (MCFU/d/mi^2) and 350 MCFU/d/mi^2, respectively. The greatest median yields of total coliform bacteria (5,600–8,500 MCFU/d/mi^2) and *E. coli* (800–2,000 MCFU/d/mi^2) were found at the station on Quonapaug Brook (Providence Water station 6), an unnamed tributary to the Westconnaug Reservoir (Providence Water station 11), and at Hunting House Brook (Providence Water station 14). As previous discussed, concentrations of bacteria tended to vary with concentrations of chloride and nutrients and, as a result, stations with high chloride and nutrient yields tend to have high yields for bacteria. High median yields of fecal indicator bacteria (greater than 2,000 MCFU/d/mi^2) for these stations could result from runoff from impervious areas, waterfowl defecation, and other animal waste. Although relatively high for monitoring stations in the Scituate Reservoir drainage area, median bacteria yields for these stations were low overall compared to yields of bacteria for sewage-contaminated stream water or stream water affected by stormwater runoff in an urban environment which could be more than 1 trillion colony-forming units per square mile (Breault and others, 2002).

Loads and Yields of Chloride and Sodium, WYs 2009–12

Average daily loads and yields of chloride and sodium were estimated based on streamflow and estimated concentration data collected at 14 stations for WYs 2009–12 (table 12). Similar data were not available at these 14 stations before WYs 2009. Concentrations of chloride and sodium were estimated using the correlations between concentration data and values of specific conductance. The average daily load for each station was calculated by dividing the sum of the daily loads for WYs 2009–12 by the number of days in that period; the average daily yield for each station was calculated by dividing the average daily load by the drainage area of each station. Average daily loads (herein referred to as USGS daily

Table 12. Average chloride and sodium concentrations, loads, and yields estimated on the basis of streamflow and estimated concentration data collected at 14 Providence Water Supply Board stations in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

[Mean annual concentrations were calculated by dividing the annual load for each year by the total discharge for that year. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; mg/L, milligrams per liter; kg/d, kilograms per day; kg/mi²/d, kilograms per square mile per day; Cl, chloride; Na, sodium]

PWSB station number	USGS station number	Concentration		Load		Yield	
		Cl (mg/L)	Na (mg/L)	Cl (kg/d)	Na (kg/d)	Cl (kg/mi²/d)	Na (kg/mi²/d)
Barden Reservoir Subbasin							
24	01115190	21.2	13.0	550	340	110	69
28	01115265	15.6	9.68	800	490	91	57
35	01115187	15.8	9.81	1,300	780	90	56
Direct Runoff Subbasin							
3	01115280	26.5	16.1	250	150	140	85
5	01115184	13.5	8.22	89	54	73	45
6	01115183	30.4	18.4	330	200	170	100
7	01115297	8.64	5.50	200	130	46	29
8	01115276	19.9	12.2	380	230	74	45
9	01115275	47.4	28.0	170	100	280	160
Moswansicut Reservoir Subbasin							
19	01115170	35.8	21.5	640	380	200	120
Regulating Reservoir Subbasin							
14	01115110	8.6	5.47	280	180	46	29
15	01115114	29.3	17.7	680	410	140	87
16	01115098	26.8	16.6	800	490	160	100
18	01115120	36.9	22.1	52	31	190	110
Scituate Reservoir Drainage Area							
		Average		Total		Average	
		24	15	6,500	4,000	100	64

loads) and yields, estimated using continuous records of specific conductance and flow, were expected to be more accurate than average daily loads estimated on the basis of intermittent sample data collected by Providence Water (herein referred to as Providence Water daily loads) because the continuous-record-estimated loads and yields represented a broader range of hydrologic conditions than the daily mean streamflow data associated with individual samples and contained information from all runoff events, including snowmelts.

The USGS daily loads of chloride and sodium ranged from 52 to 1,300 kg/d and 31 to 780 kg/d (table 12), respectively, where the magnitude of the loads generally correlated with the size of the drainage area of each subbasin. Ponaganset River (Providence Water station 35) had the largest USGS daily loads for chloride and sodium loads (1,300 and 780 kg/d, respectively), which represented 20 percent of the total load for the 14 stations. Bear Tree Brook (Providence Water station 9) had the highest average chloride and sodium daily yields at 280 and 160 kg/d/mi², respectively. The average daily yields of chloride and sodium for the drainage areas above the 14 USGS stations, which represent nearly 66 percent of the Scituate Reservoir drainage area, were 100 and 64 kg/d/mi², respectively (table 12). These yields represent low to moderate values in comparison to other areas in the northeast region of the country. For example, yields of chloride in surface water in the glaciated Northern United States were estimated to range from 16 kg/d/mi² in forested areas to 220 kg/d/mi² in urbanized areas (Mullaney and others, 2009). Yields of chloride and sodium in the drinking-water supply area for Cambridge, Massachusetts, ranged from 170 and 96 kg/d/mi², respectively, in a low-density residential area to 1,700 to 810 kg/d/mi², respectively, in an area dominated by commercial land use and large percentages of imperviousness (Smith, 2013). With the exception of the drainage area for Bear Tree Brook, estimated average daily yields for chloride and sodium at the 14 USGS stations in the Scituate Reservoir drainage area tended to be greatest in the northeastern part of the drainage area (for sodium, see fig. 12) that contains greater percentages of developed land uses and impervious surfaces.

The spatial distributions of yields for chloride were similar to the distributions of yields for sodium; however, the yields for chloride were about 1.6 times higher than the yields for sodium. The difference in magnitude between the yields is primarily explained by the difference in the molecular mass of the two elements since the relation for sodium to chloride in water samples was nearly 1:1.

The USGS daily loads of chloride for WYs 2009–12 were compared to the Providence Water daily loads of chloride (arithmetic average of intermittent daily loads for WYs 2009–12; fig. 13). The Providence Water daily loads of chloride differed from the USGS daily loads of chloride by 0.2 to 83 percent. At five stations (Providence Water stations 24, 28, 35, 3, and 6), the Providence Water daily chloride loads differed from the USGS daily chloride loads by less than 5 percent and were within the 95 percent confidence interval about the USGS daily chloride loads. These data indicate that the collection of periodic (monthly at these stations) samples by Providence Water was sufficient to characterize the average daily chloride load at these five stations. At 9 of the 14 stations, the difference between the Providence Water daily chloride loads and the USGS daily chloride loads was 10 percent or greater. The difference between the Providence Water daily chloride loads and the USGS daily chloride loads was greater than 45 percent for Wilbur Hollow Brook, Hunting House Brook, Peeptoad Brook, and Unnamed Tributary to Scituate Reservoir (Providence Water stations 7, 14, 16, and 18). For these four stations in particular, the limited number of daily chloride load values estimated based on periodic samples collected by Providence Water and daily mean streamflow were not sufficient to characterize the average daily chloride load for WYs 2009–12. The Providence Water daily chloride loads at these stations likely were greater than the USGS daily chloride loads because periodic daily load estimates often were not available during the summer months when loads of chloride generally were small. With the exception of periods of stormflow, the tributaries at these four stations during the summer often were dry or streamflow was too low to collect samples during scheduled visits by Providence Water. In the absence of these low load estimates, the Providence Water daily chloride loads likely were overestimated at these four stations for WYs 2009–12. The dissimilarities between load estimates were not necessarily surprising considering the difference in the magnitude of data used to estimate the loads in both methods—the collection of tens of thousands of discrete measurements of specific conductance values at each station used to estimate concentrations of chloride compared with the collection and analysis of monthly or quarterly grab samples.

Trends in Water-Quality Properties and Constituent Concentrations

Trends in water-quality properties and constituents were investigated for the 10-year study period of WYs 2003–12 (table 13) and for the 29-year period WYs 1983–2012 (table 14). Trends during the WYs 2003–12 shorter period may be considered current trends in water-quality properties and constituent concentrations, whereas trends during the WYs 1983–2012 longer period may reflect ongoing or past changes. Differences between the two trends could result from the relative ease in detecting trends in larger and longer duration datasets than in smaller and shorter duration datasets. Other sources of differences in the trends could be caused by less variability in the shorter dataset than the longer one, as well as by changes in sampling and analytical procedures.

Water-Quality Properties

Significant trends of upward pH were identified for samples collected at 19 stations for the shorter period and at 11 stations during the longer period (tables 13 and 14). Upward trends in the pH of samples collected from tributaries may be associated with reductions in acid precipitation in North America since the 1980s (Lynch and others, 2000). Downward pH trends were statistically significant in samples collected from Providence Water stations 8, 31, 17 and 11 during the longer period (table 14; fig. 14A); no significant downward trends in pH were identified for the shorter period (fig. 14A). The low *p* values for nine stations (*p* value less than 0.001; table 14) indicate that the statistically significant trends in pH for the longer period are strong.

Significant upward trends in color were identified for samples from 25 of 37 stations during the longer period. Significant trends in color were identified in samples from only five stations during the shorter period. Because color is likely to have a natural source, such as dissolved organic material or 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. Samples collected at Providence Water station 20 in the Moswansicut Reservoir Subbasin had the only significant downward trend in color during the WYs 2003–12 trend-analysis period (fig. 14B).

Significant trends in turbidity were identified for samples from 10 of 37 stations for WYs 2003–12 and for samples from 9 of 37 stations for WYs 1983–2012 (fig. 14C; tables 13 and 14). Six significant trends identified during the longer period were not identified as significant during the shorter period. Upward trends in turbidity were identified at nine stations for the shorter period; seven of these trends were not significant for WYs 1983–2012. Westconnaug Brook (Providence Water station 10) and Ponaganset Reservoir (Providence Water

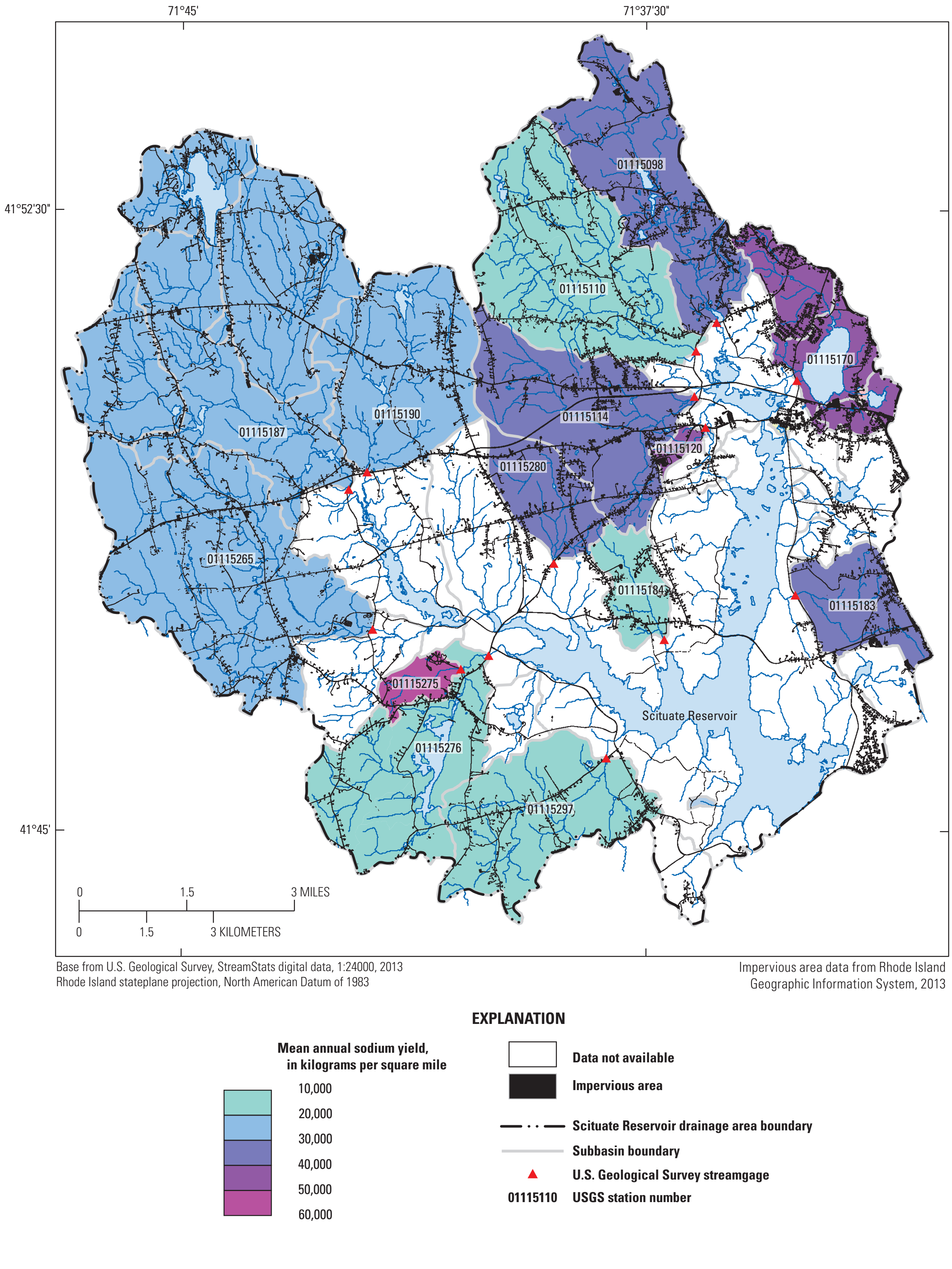

Figure 12. Spatial distribution of sodium yields for 14 subbasins in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

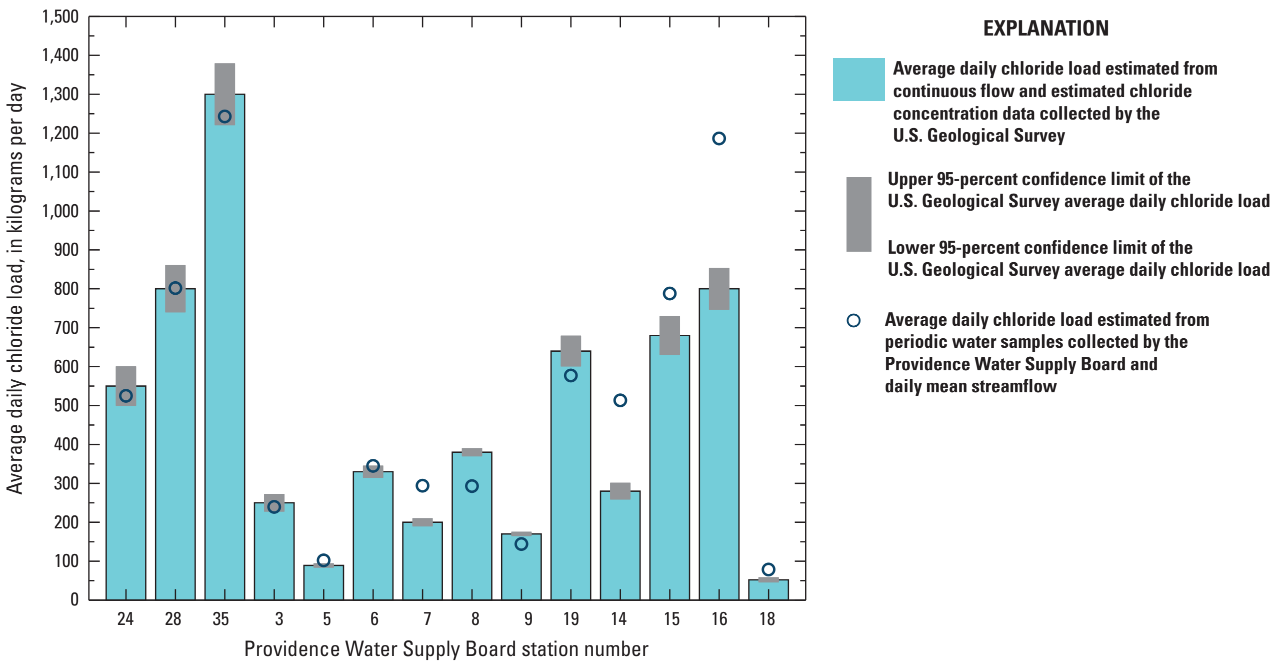

Figure 13. Average daily chloride loads estimated from continuous measurements of flow and estimated concentration data and average daily chloride loads estimated from water-quality samples and daily mean streamflow at 14 Providence Water Supply Board stations in the Scituate Reservoir drainage area, Rhode Island, water years 2009–12.

station 23) were the only stations with a significant upward trend in turbidity for the shorter period within the significant downward trend of their longer period. Although turbidity values were low throughout the Scituate Reservoir drainage area, data collected at these nine stations indicated that turbidity values were increasing during the shorter period. Toad Pond (Providence Water station 31) in the Direct Runoff Subbasin was the only tributary with a significant downward trend during both periods.

Significant trends in alkalinity, like trends in pH, were primarily upwards during WYs 2003–12 and WYs 1983–2012 (fig. 14D) and may be related in part to the relatively low pH of precipitation in this region of the country. Upward trends in alkalinity are common in the Northeastern United States (Kaushal and others, 2013). As previously discussed, low pH precipitation can increase alkalinity in tributaries through chemical weathering of bedrock and overlying soils, and through chemical weathering of structures containing concrete. All significant trends in alkalinity identified during the shorter period were upward, including trends at six new stations (Providence Water stations 27, 28, 35, 20, 10, and 11; fig. 14D) differing significantly from the values determined for the longer period. Changes in the applications of lime and fertilizer in agricultural areas, which occupy as much as 12 percent of the subbasin area (table 2), may explain the differences between trends in alkalinity for some tributaries during the two periods.

Chemical-Constituent Concentrations

Twenty-seven significant trends in chloride concentrations were upward during WYs 1983–2012; two, at Providence Water stations 8 and 9 in the Direct Runoff Subbasin, were identified as downward trends (fig. 14E). Only nine trends were significant for WYs 2003–12. Trends for the shorter period indicate fewer statistically significant upward trends than during the longer period; several downward trends were statistically significant in the shorter period: at Providence Water station 28 in the Barden Reservoir Subbasin and at stations 13, 15, and 18 in the Regulating Reservoir Subbasin. Stations with significant upward chloride trends in the shorter period include stations 27, 1, 33, 20, 4, and 23 (fig. 14E). The smaller number of statistical significant trends in chloride concentrations during the shorter period indicate that the chloride concentrations in many subbasins were neither increasing nor decreasing during WYs 2003–12. These results may reflect minimal development in the subbasins (U.S. Census Bureau, 2014) or a somewhat consistent use of road salt during the relatively short period. Conversely, significant downward trends identified at several stations, particularly in subbasins that are more developed and contain higher percentages of State-maintained roadways than others, may reflect in part the effects of changes in winter maintenance methods used by the Rhode Island Department of

Transportation (RIDOT; 2014). Although the RIDOT still uses sodium chloride for winter maintenance activities throughout the State, the use of vehicles equipped with new spreader systems and real-time measurements of roadway temperature have resulted in reported decreases in the amount of material, including sodium chloride, applied to the roadways during 2005–12 (Rhode Island Department of Administration, 2014). The amount of reduction in the amount of deicing materials applied to the State-maintained roads within the Scituate Reservoir drainage area is not known, and the new winter maintenance methods used by the RIDOT have been offered as one potential explanation for declining trends in chloride concentrations in some subbasins.

Trends in nitrate concentrations were downward and significant at nearly every station for WYs 1988–2012 (fig. 14F). Significant trends were primarily downward for WYs 2003–12 as well; however, fewer significant trends were identified, and trends were upward at Providence Water station 33 in the Direct Runoff Subbasin and at station 18 in the Regulating Reservoir Subbasin. Significant downward trends for nitrite concentrations were identified at nine of the stations during the longer period (fig. 14G). Fewer significant trends in concentrations of nitrite were identified during WYs 2003–12 than during WYs 1985–2012; however, four significant upward nitrite concentration trends were identified at Providence Water stations 25, 7, 18, and 12. Trends in nitrate and nitrite concentrations in tributary 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 and nitrite concentrations also could be affected by changes in land use, drainage area processes, or their concentrations in base flow. Nitrate and nitrite concentrations at many stations, however, are low and sometimes less than reporting limits. Concentration data that are near the method detection limit also tend to be variable, and results often can be improperly interpreted (for example, false-positive detections). As a result, factors other than environmental sources could affect the identification of statistically significant trends.

Orthophosphate concentration data were not available until WYs 1997. Eleven upward trends were identified as significant during WYs 1997–2012 (fig. 14H; table 14); however, neither upward nor downward trends were identified as significant during WYs 2003–12 (fig. 14H; table 13). Trends identified as upward during the WYs 1997–2012 period might reflect environmental changes or be affected by the relatively small difference in the duration of the datasets or by changes in analytical methods.

Nine significant downward and three significant upward trends in concentrations of total coliform bacteria were identified for WYs 1983–2012 in the Scituate Reservoir drainage area (fig. 14I; table 14). For the WYs 2003–12, a single significant upward trend was identified at Providence Water station 10 in the Westconnaug Reservoir Subbasin (fig. 14I). For WYs 1995–2012, downward trends in *E. coli* concentrations at Providence Water stations 35, 8, and 19 also were significant (table 14). Significant upward *E. coli* concentration trends were identified for Providence Water station 6 in the Direct Runoff Subbasin and for station 14 in the Regulating Reservoir Subbasin for the longer period. Only a single significant trend in *E. coli* concentrations (upward) was identified for the Scituate Reservoir drainage area during WYs 2003–12 (Providence Water station 26). Bacteria concentrations in the tributaries were extremely variable and were strongly affected by flow and land use (table 7), particularly subbasin areas containing high percentages of residential and impervious areas (table 2). Thus, trends in bacteria concentrations can be difficult to interpret. Changes in sampling or analytical methods or procedures for handling censored data also could affect the results of tests for trends in concentrations of bacteria. Downward trends in concentrations of total coliform and *E. coli* bacteria may have resulted from changes in the routing or disposal of stormwater runoff, changes in waterfowl abundance, and improvements to onsite sewage-disposal systems.

Table 13. Significance levels (*p* values) of seasonal Kendall tests for time trends in water-quality properties and constituent concentrations at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.

[Stations locations shown on figure 2. *p* values for trends considered significant are shown in **bold**. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; *E. coli*, *Escherichia coli*; (+), variables are positively correlated; (-), variables are negatively correlated; --, not available]

PWSB station number	USGS station number	Properties			Constituents						
		pH	Color	Turbidity	Total coliform bacteria	*E. coli*	Alkalinity	Chloride	Nitrate	Nitrite	Orthophosphate
Barden Reservoir Subbasin											
24	01115190	0.018	0.032	0.119	0.355	0.303	**0.006 (+)**	0.794	0.109	0.385	0.216
25	01115200	0.472	0.777	0.052	0.318	0.644	0.347	1.000	0.457	**0.048 (+)**	0.900
26	01115185	0.107	0.331	0.062	0.157	**0.013 (+)**	0.297	0.274	0.119	0.714	0.353
27	011151845	0.082	0.636	0.177	0.114	0.328	**0.024 (+)**	**0.005 (+)**	**0.027 (-)**	1.000	1.000
28	01115265	**0.047 (+)**	0.325	**0.032 (+)**	0.083	0.106	**0.033 (+)**	**0.041 (-)**	**0.029 (-)**	1.000	0.591
29	01115271	0.675	0.473	0.416	0.063	0.232	0.135	1.000	**0.032 (-)**	0.915	0.277
35	01115187	**0.046 (+)**	0.068	**0.042 (+)**	0.659	0.16	**0.040 (+)**	0.365	0.285	0.301	0.154
Direct Runoff Subbasin											
1	01115180	0.583	0.596	0.533	0.933	0.919	**0.015 (+)**	**0.010 (+)**	**0.022 (-)**	0.308	0.269
2	01115181	0.075	0.826	0.461	0.840	0.387	0.141	0.089	**0.034 (-)**	0.518	0.687
3	01115280	0.134	**0.043 (+)**	0.243	0.440	0.254	**0.023 (+)**	0.076	**0.026 (-)**	0.210	0.059
4	01115400	0.572	0.210	**0.034 (+)**	0.669	0.418	0.191	**0.008 (+)**	0.113	0.123	0.466
5	01115184	0.486	0.325	0.594	0.249	0.340	0.179	0.911	0.071	0.687	0.378
6	01115183	**0.003 (+)**	0.521	0.139	0.295	0.238	**0.008 (+)**	0.176	**0.030 (-)**	0.679	0.473
7	01115297	**0.018 (+)**	0.263	0.29	0.081	0.218	1.000	0.181	0.297	**0.006 (+)**	0.524
8	01115276	0.065	0.786	0.116	0.964	0.467	0.124	0.771	**0.005 (-)**	0.309	0.678
9	01115275	0.088	0.225	0.095	0.610	0.453	0.352	0.260	0.074	0.713	0.467
30	01115350	0.227	0.867	0.065	0.256	0.695	0.066	0.060	0.053	0.840	0.158
31	01115177	0.135	0.875	**0.046 (-)**	0.900	0.213	0.902	0.108	0.764	0.379	0.060
32	01115178	0.189	0.803	0.068	0.324	0.571	0.832	0.154	0.052	0.771	0.349
33	01115182	**0.007 (+)**	0.324	0.120	0.884	0.284	0.685	**0.043 (+)**	**0.039 (+)**	0.808	0.949
36	--	0.497	0.237	0.096	0.065	0.379	0.466	0.149	**0.040 (-)**	0.454	0.935
37	--	**0.042 (+)**	0.073	**0.022 (+)**	0.161	0.345	0.125	0.054	**0.015 (-)**	0.836	0.248

Table 13. Significance levels (*p* values) of seasonal Kendall tests for time trends in water-quality properties and constituent concentrations at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12.—Continued

[Stations locations shown on figure 2. *p* values for trends considered significant are shown in **bold**. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; *E. coli*, *Escherichia coli*; (+), variables are positively correlated; (-), variables are negatively correlated; --, not available]

PWSB station number	USGS station number	Properties			Constituents						
		pH	Color	Turbidity	Total coliform bacteria	*E. coli*	Alkalinity	Chloride	Nitrate	Nitrite	Orthophosphate
Moswansicut Reservoir Subbasin											
19	01115170	0.297	0.293	0.303	0.666	0.295	0.485	0.071	**0.013 (-)**	**0.039 (-)**	0.811
20	01115160	**0.004 (+)**	**0.046 (-)**	**0.031 (+)**	0.826	0.886	**0.015 (+)**	0.973	**0.005 (-)**	0.974	0.656
21	01115165	0.333	0.57	**0.017 (+)**	0.162	0.066	0.746	0.244	**0.048 (-)**	0.790	0.44
22	01115167	0.051	0.620	0.869	0.262	0.402	0.889	0.061	**0.003 (-)**	**0.014 (-)**	0.822
34	01115164	0.335	0.908	0.256	1.000	0.350	0.697	0.301	0.677	1.000	0.221
Ponaganset Reservoir Subbasin											
23	011151843	**0.008 (+)**	**0.041 (+)**	**0.020 (+)**	0.159	0.408	**0.020 (+)**	**0.022 (+)**	**0.008 (-)**	0.300	0.179
Regulating Reservoir Subbasin											
13	01115176	0.121	**0.044 (+)**	**0.026 (+)**	0.613	0.388	**0.044 (+)**	**0.043 (-)**	**0.009 (-)**	0.548	0.716
14	01115110	0.413	0.218	0.072	0.796	0.483	0.057	0.109	**0.006 (-)**	0.412	0.305
15	01115114	0.095	0.171	0.180	0.496	0.683	**0.027 (+)**	**0.004 (-)**	**0.018 (-)**	0.648	0.768
16	01115098	0.860	0.187	0.152	0.812	0.830	0.513	0.459	**0.008 (-)**	0.403	0.199
17	01115119	0.451	0.625	0.636	0.065	0.245	0.268	1.000	0.259	0.315	0.345
18	01115120	0.481	0.073	0.505	0.306	0.720	0.848	**0.013 (-)**	**0.036 (+)**	**0.039 (+)**	0.705
Westconnaug Reservoir Subbasin											
10	01115274	**0.002 (+)**	**0.004 (+)**	**0.047 (+)**	**0.021 (+)**	0.641	**0.002 (+)**	0.062	**0.006 (-)**	0.038	0.616
11	01115273	**0.010 (+)**	1.000	0.550	0.245	0.323	**0.038 (+)**	0.028	0.603	0.080	0.417
12	011152745	**0.002 (+)**	0.124	0.496	0.235	0.177	0.810	0.222	0.940	**0.006 (+)**	0.913

Table 14. Significance levels (*p* values) of seasonal Kendall tests for time trends in water-quality properties and constituent concentrations at Providence Water Supply Board water-quality monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2012.

[Station locations shown on figure 2. *p* values for trends considered significant are shown in **bold**. *Escherichia coli* (*E. coli*) data not available until after 1995; nitrate data not available until after 1987; nitrite data not available until 1985; and orthophosphate data not available until 1997. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; (+), variables are positively correlated; (-), variables are negatively correlated; --, not available]

PWSB station number	USGS station number	Properties			Constituents						
		pH	Color	Turbidity	Total coliform bacteria	*E. coli*	Alkalinity	Chloride	Nitrate	Nitrite	Orthophosphate
Barden Reservoir Subbasin											
24	01115190	**<0.001** (+)	**0.001** (+)	0.308	0.256	0.385	**0.006** (+)	**<0.001** (+)	**0.001** (-)	0.901	0.265
25	01115200	**0.008** (+)	0.053	0.102	0.094	0.968	0.968	**0.028** (+)	**0.001** (-)	0.267	0.612
26	01115185	**<0.001** (+)	**0.029** (+)	0.092	**0.019** (-)	0.427	1.000	**<0.001** (+)	**<0.001** (-)	0.448	**0.032** (+)
27	011151845	**<0.001** (+)	**0.003** (+)	0.184	0.417	0.363	0.157	**<0.001** (+)	0.056	0.314	0.456
28	01115265	0.663	**<0.001** (+)	0.733	**0.004** (+)	0.296	0.324	**<0.001** (+)	**<0.001** (-)	0.874	**0.030** (+)
29	01115271	**0.013** (+)	**<0.001** (+)	0.292	**0.019** (-)	0.869	0.428	**<0.001** (+)	**<0.001** (-)	0.991	**0.032** (+)
35	01115187	0.276	**0.002** (+)	0.188	0.419	**0.043** (-)	0.723	**<0.001** (+)	**0.001** (-)	**<0.001** (-)	0.081
Direct Runoff Subbasin											
1	01115180	0.261	**<0.001** (+)	**0.002** (+)	0.328	0.322	**0.005** (+)	**<0.001** (+)	**<0.001** (-)	0.490	0.261
2	01115181	**0.020** (+)	0.220	0.051	0.588	0.157	0.858	0.089	**0.004** (-)	0.477	0.957
3	01115280	**0.001** (+)	**<0.001** (+)	0.142	0.102	0.255	**0.001** (+)	**0.001** (+)	**<0.001** (-)	0.713	0.220
4	01115400	**0.006** (+)	**0.001** (+)	0.204	0.782	0.684	**<0.001** (+)	0.877	**<0.001** (-)	0.436	0.047
5	01115184	0.059	**0.016** (+)	0.822	0.140	0.258	0.149	**0.016** (+)	0.074	0.249	0.137
6	01115183	**<0.001** (+)	**0.015** (+)	0.194	0.883	**0.006** (+)	**<0.001** (+)	**0.001** (+)	**<0.001** (-)	0.968	**0.022** (+)
7	01115297	**<0.001** (+)	**<0.001** (+)	0.571	**0.001** (-)	0.669	**0.045** (+)	**<0.001** (+)	**<0.001** (-)	0.554	0.079
8	01115276	**0.002** (-)	0.419	**0.001** (-)	**<0.001** (-)	**0.004** (-)	**<0.001** (-)	**0.001** (-)	**<0.001** (-)	0.610	**0.032** (+)
9	01115275	**0.026** (+)	0.392	0.674	0.562	0.363	**0.034** (+)	**0.001** (-)	**0.002** (-)	0.418	0.274
30	01115350	**<0.001** (+)	0.139	0.345	0.546	0.403	0.406	**0.012** (+)	**0.006** (-)	0.444	0.292
31	01115177	**0.003** (-)	0.610	**0.023** (-)	0.516	0.853	0.426	0.598	0.298	0.546	0.780
32	01115178	0.877	**0.002** (+)	0.503	0.529	0.772	0.255	**0.002** (+)	**<0.001** (-)	**0.016** (-)	0.123
33	01115182	0.825	0.069	0.162	0.783	0.527	0.182	**0.002** (+)	**<0.001** (-)	**0.014** (-)	0.391
36	--	0.521	**0.008** (+)	0.302	**0.024** (+)	0.290	0.844	**0.008** (+)	**0.009** (-)	0.396	0.056
37	--	0.125	**0.011** (+)	0.262	**0.009** (+)	0.181	0.974	**0.014** (+)	**0.021** (-)	0.689	0.302

Table 14. Significance levels (*p* values) of seasonal Kendall tests for time trends in water-quality properties and constituent concentrations at Providence Water Supply Board water-quality monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2012.—Continued

[Station locations shown on figure 2. *p* values for trends considered significant are shown in **bold**. *Escherichia coli* (*E. coli*) data not available until after 1995; nitrate data not available until after 1987; nitrite data not available until 1985; and orthophosphate data not available until 1997. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; (+), variables are positively correlated; (-), variables are negatively correlated; --, not available]

PWSB station number	USGS station number	Properties			Constituents						
		pH	Color	Turbidity	Total coliform bacteria	*E. coli*	Alkalinity	Chloride	Nitrate	Nitrite	Orthophosphate
					Moswansicut Reservoir Subbasin						
19	01115170	**0.002 (+)**	**0.001 (+)**	**<0.001 (+)**	**<0.001 (-)**	**0.025 (-)**	**0.001 (+)**	**<0.001 (+)**	**<0.001 (-)**	**0.003 (-)**	**0.019 (+)**
20	01115160	0.377	**0.003 (+)**	0.272	0.777	0.506	0.208	**<0.001 (+)**	**<0.001 (-)**	0.724	0.072
21	01115165	0.106	**0.007 (+)**	0.918	0.050	0.759	**0.001 (+)**	0.182	**0.007 (-)**	0.277	0.221
22	01115167	**0.016 (+)**	0.638	**<0.001 (-)**	**0.003 (-)**	0.448	**0.033 (+)**	0.206	**<0.001 (-)**	**0.001 (-)**	0.268
34	01115164	0.574	0.726	0.307	0.746	0.331	0.131	0.273	0.189	0.798	**0.009 (+)**
					Ponaganset Reservoir Subbasin						
23	011151843	**<0.001 (+)**	**<0.001 (+)**	**0.017 (-)**	0.249	0.303	**0.001 (+)**	**<0.001 (+)**	**0.001 (-)**	**0.017 (-)**	0.268
					Regulating Reservoir Subbasin						
13	01115176	0.082	**<0.001 (+)**	0.858	**0.013 (-)**	0.276	**<0.001 (+)**	**0.001 (+)**	**<0.001 (-)**	**0.012 (-)**	**0.040 (+)**
14	01115110	**0.036 (+)**	**<0.001 (+)**	0.919	0.378	**0.032 (+)**	0.199	**<0.001 (+)**	**<0.001 (-)**	0.647	**0.008 (+)**
15	01115115	**<0.001 (+)**	**<0.001 (+)**	0.228	0.417	0.208	**0.001 (+)**	**0.024 (+)**	**<0.001 (-)**	**0.022 (-)**	0.073
16	01115098	0.450	**<0.001 (+)**	0.080	0.345	0.165	**0.032 (+)**	**<0.001 (+)**	**<0.001 (-)**	0.910	**0.019 (+)**
17	01115119	**0.017 (-)**	0.663	**0.014 (-)**	**0.001 (-)**	1.000	**0.021 (-)**	**0.007 (+)**	**0.001 (-)**	**0.006 (-)**	0.058
18	01115120	0.205	0.199	0.864	**0.004 (-)**	0.839	**0.005 (-)**	0.143	**0.001 (-)**	0.336	**0.026 (+)**
					Westconnaug Reservoir Subbasin						
10	01115274	**0.002 (+)**	**0.004 (+)**	**<0.002 (-)**	0.757	0.683	0.306	**<0.001 (+)**	**<0.001 (-)**	0.809	0.208
11	01115273	**0.015 (-)**	**<0.001 (+)**	0.284	0.409	0.473	0.298	0.056	**0.020 (-)**	0.283	0.393
12	011152745	**<0.001 (+)**	0.390	**0.007 (+)**	0.140	0.194	**0.001 (+)**	**<0.001 (+)**	0.441	0.139	0.418

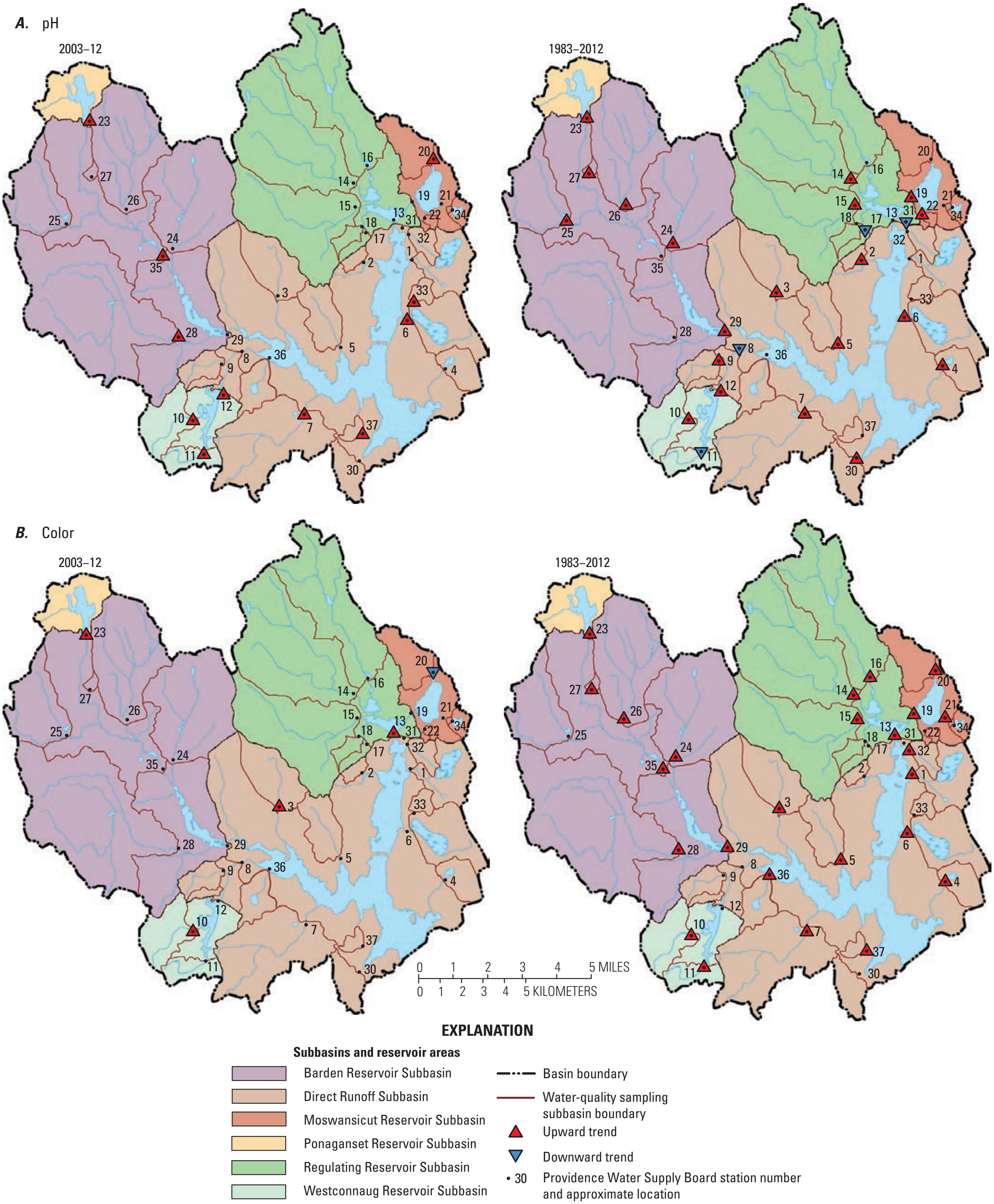

Figure 14. Time trends of *A*, pH, *B*, color, *C*, turbidity, *D*, alkalinity, *E*, chloride, *F*, nitrate, *G*, nitrite, *H*, orthophosphate, *I*, total coliform bacteria, and *J*, *Escherichia coli* at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12 and water years 1983–2012.

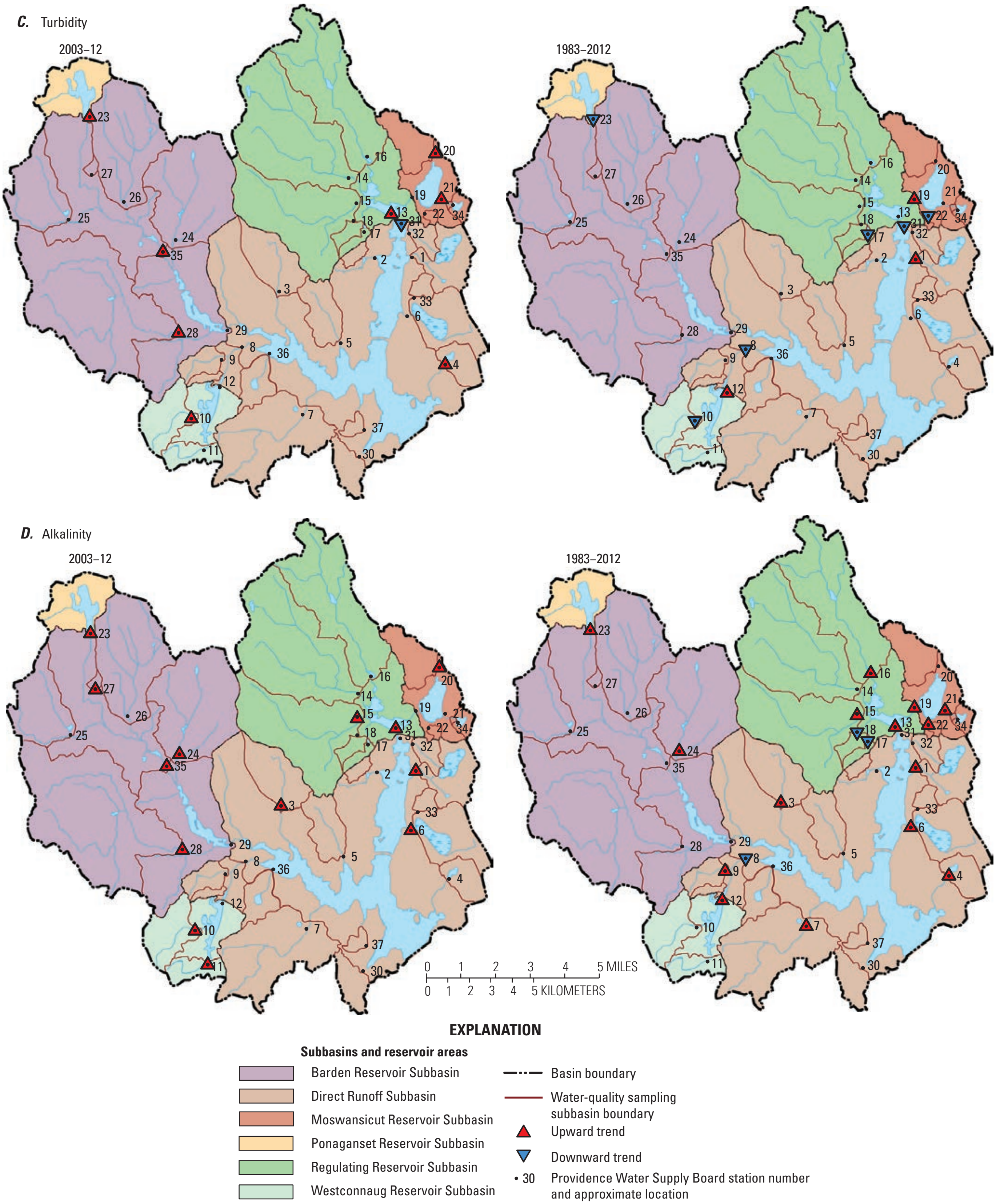

Figure 14. Time trends of *A*, pH, *B*, color, *C*, turbidity, *D*, alkalinity, *E*, chloride, *F*, nitrate, *G*, nitrite, *H*, orthophosphate, *I*, total coliform bacteria, and *J*, *Escherichia coli* at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12 and water years 1983–2012.—Continued

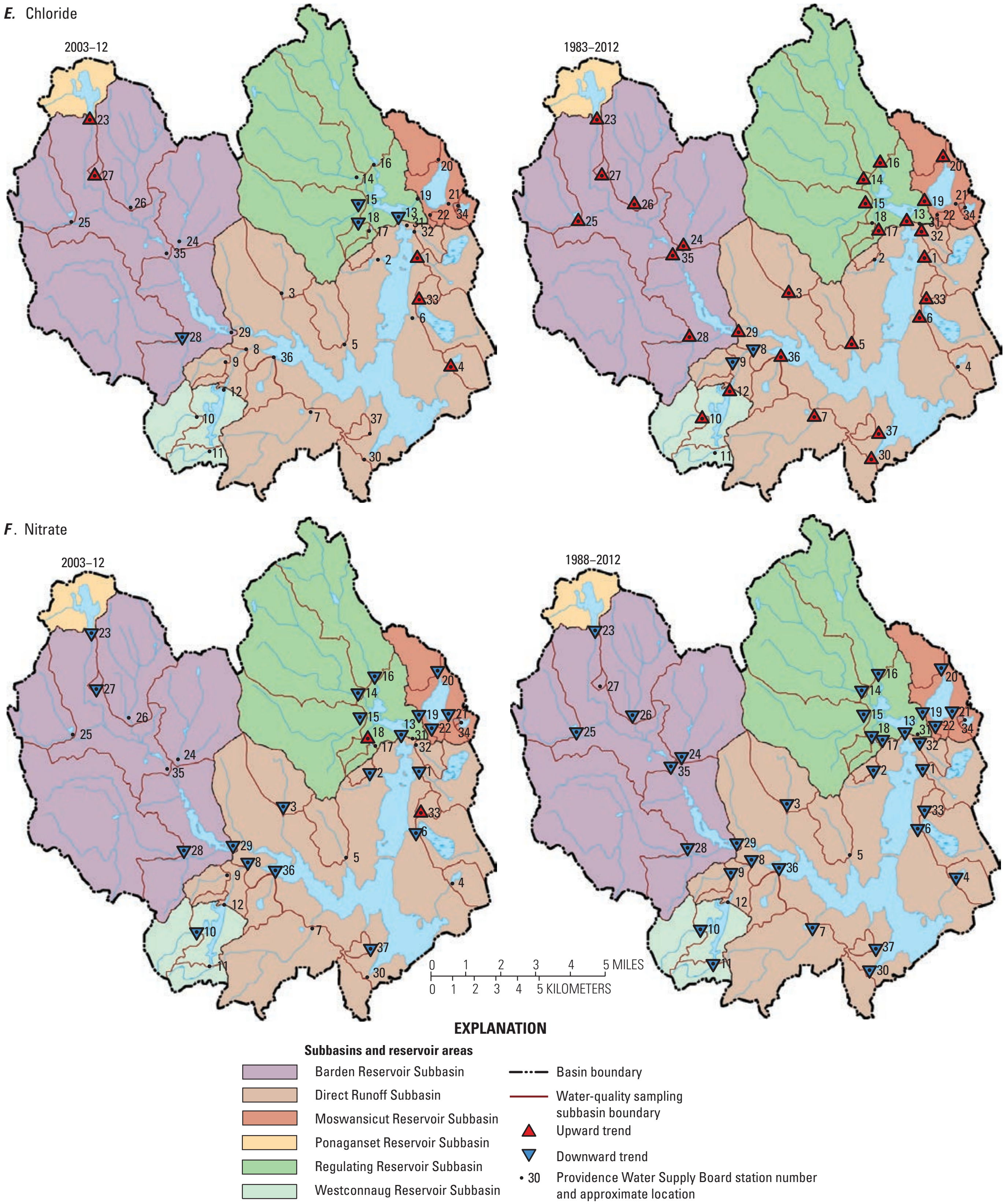

Figure 14. Time trends of *A*, pH, *B,* color, *C,* turbidity, *D,* alkalinity, *E,* chloride, *F,* nitrate, *G,* nitrite, *H,* orthophosphate, *I,* total coliform bacteria, and *J, Escherichia coli* at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12 and water years 1983–2012.—Continued

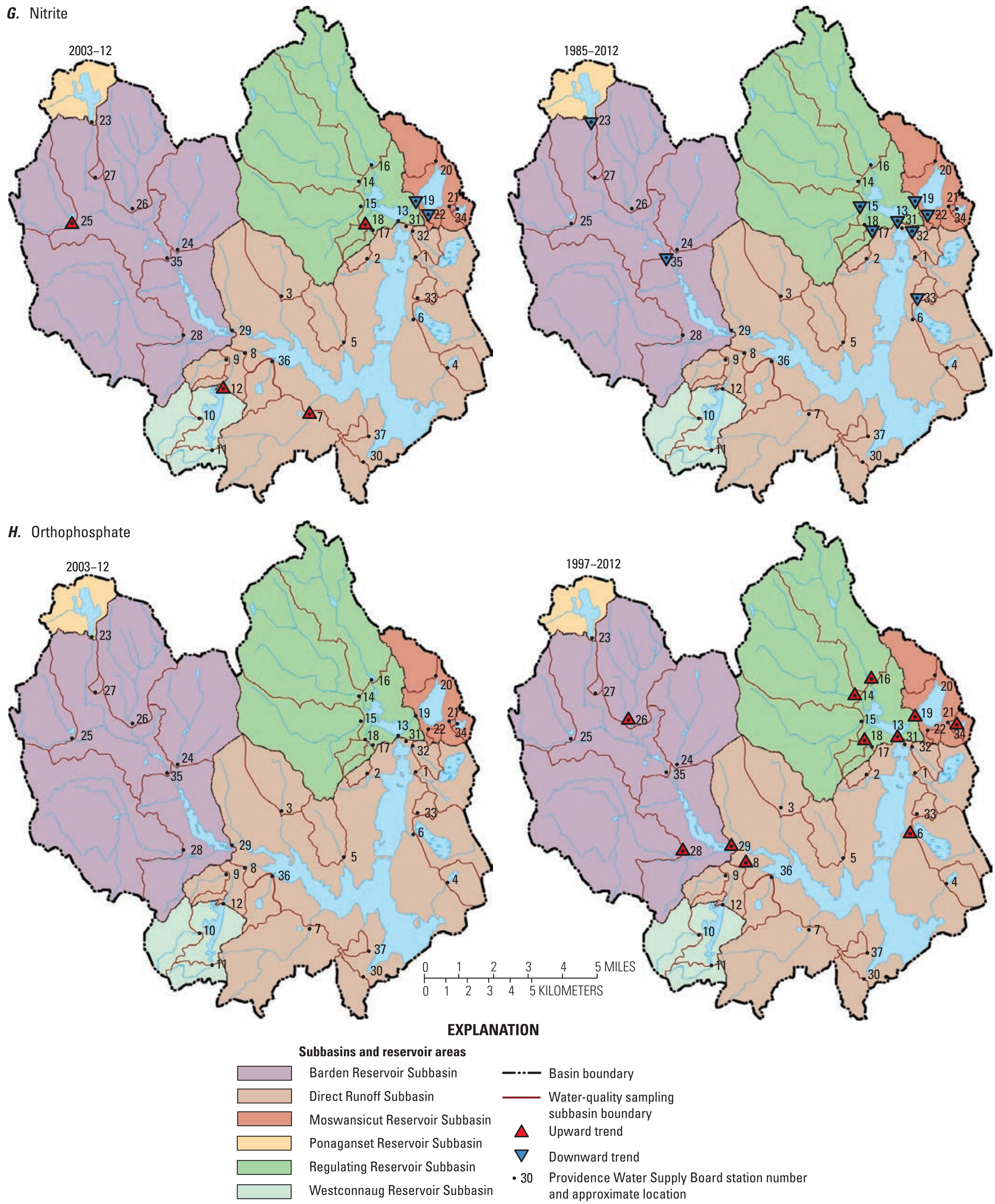

Figure 14. Time trends of *A*, pH, *B,* color, *C,* turbidity, *D,* alkalinity, *E,* chloride, *F,* nitrate, *G,* nitrite, *H,* orthophosphate, *I,* total coliform bacteria, and *J, Escherichia coli* at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12 and water years 1983–2012.—Continued

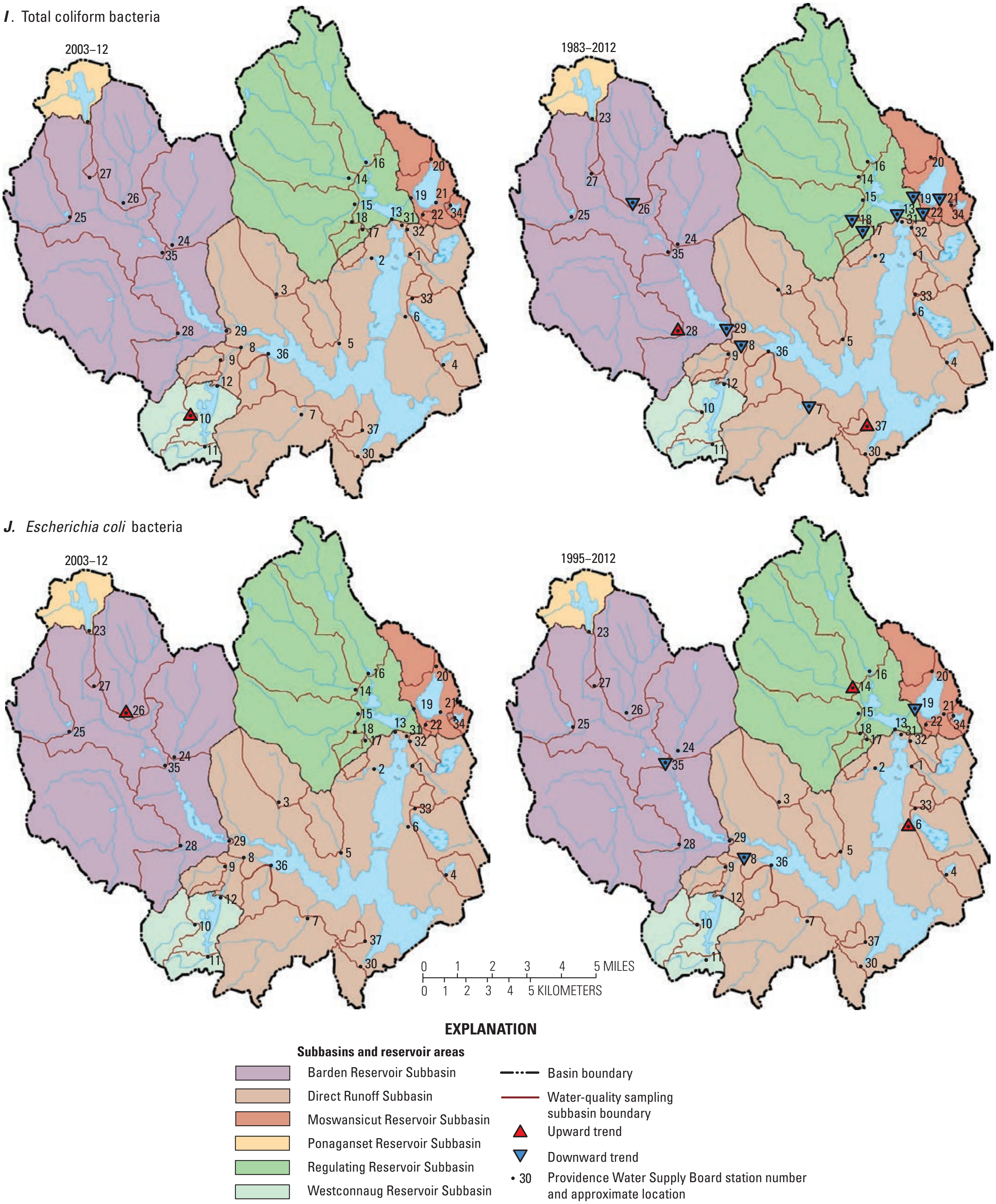

Figure 14. Time trends of *A*, pH, *B,* color, *C,* turbidity, *D,* alkalinity, *E,* chloride, *F,* nitrate, *G,* nitrite, *H,* orthophosphate, *I,* total coliform bacteria, and *J, Escherichia coli* at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2003–12 and water years 1983–2012.—Continued

Summary

Water-quality and streamflow data were collected at 37 surface-water monitoring stations in the Scituate Reservoir drainage area, Rhode Island, from October 1, 2002, through September 30, 2012 (water years [WYs] 2003–12). These data 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 WYs 2003–12 and for WYs 1983–2012, by using historical data. Water-quality samples were collected and analyzed by personnel of Providence Water Supply Board (Providence Water), the agency that manages the reservoir. Streamflow and specific conductance data were collected by U.S. Geological Survey (USGS) personnel. Median values and other summary statistics were calculated for all water samples collected at 37 monitoring stations during WYs 2003–12 for pH, color, turbidity, alkalinity, chloride, nitrate, nitrite, orthophosphate, and total coliform bacteria and *E. coli*. Daily loads and subbasin yields of chloride, nitrate, nitrite, orthophosphate, and total coliform bacteria and *E. coli* were calculated for all sampling dates during WYs 2003–12 for the 23 stations for which sufficient flow data were available. Values of physical properties and concentrations of constituents were compared with State and Federal water-quality standards and guidelines and were related to streamflow, land-use characteristics, timber operations, and imperviousness.

The interpretations of the results of water-quality analyses presented in this report were limited because of the absence of quality-control data. Without laboratory and field quality-control data, 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, statistical approaches were used to minimize the limitations that may have resulted from the use of existing data.

Tributary water in the Scituate Reservoir drainage area during WYs 2003–12 was slightly acidic, with a median pH for all stations of 6.1. The pH was less than 6.5, the lower pH limit established by the Rhode Island Department of Environmental Management (RIDEM) for class AA waters, in 17 to 100 percent of samples collected at stations in the Scituate Reservoir drainage area. The low pH values in tributaries likely reflect the low pH of precipitation and the relatively nonreactive rock types in the drainage area.

Median values of color ranged from 12 to 135 platinum-cobalt units (PCU) and as a result, most median values and the majority of discrete measurements of color at most monitoring stations exceeded the U.S. Environmental Protection Agency (EPA) secondary drinking-water regulation (SDWR) value of 15 PCU during WYs 2003–2012.

Turbidity values in tributaries in the drainage area were typically low and rarely exceeded 5 NTU, the maximum allowable value above background for RIDEM class AA waters. The median turbidity values at all 37 stations were less than 1.68 nephelometric turbidity units (NTU), the proposed EPA reference value for streams in the Northeastern Coastal Zone ecoregion. These results indicate that the water quality of tributaries in the Scituate Reservoir drainage area was minimally affected by suspended particles relative to stream water in the Northeastern Coastal Zone ecoregion. Correlations between turbidity and pH, color, and alkalinity were significant.

Median alkalinity values measured in samples from tributaries ranged from 2.3 to 14 milligrams per liter calcium carbonate (mg/L as $CaCO_3$), and the median value for all sampling stations for the entire Scituate Reservoir drainage area was 5.1 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 Direct Runoff, Moswansicut Reservoir, and Regulating Reservoir Subbasins in the eastern part of the study area.

The median chloride concentration for the entire study area was 22 milligrams per liter (mg/L), a low value typical of natural stream water in coastal New England. Median values for individual stations ranged from 3.8 to 87 mg/L. Median chloride concentrations were highest in samples collected from Toad Pond and Bear Tree Brook. A formerly uncovered salt-storage facility in the Bear Tree Brook Subbasin likely contributed to the high chloride concentrations at that monitoring station. With the exception of one sample collected from Moswansicut Stream South (Providence Water station 22), concentrations of chloride in water samples did not exceed the 250-mg/L EPA SDWR for chloride during WYs 2003–12. Concentrations of chloride estimated from continuous records of specific conductance, which represent a broad concentration range during base-flow, runoff, and snowmelt conditions, also did not exceed the EPA SDWR for chloride during WYs 2009–12 except at Quonapaug Brook (Providence Water station 6) in WY 2011 and WY 2012 during winter runoff events.

Concentrations of the nutrient species nitrate, nitrite, and orthophosphate were low. Median concentrations of nitrate did not exceed 0.14 milligrams per liter as nitrogen (mg/L as N) throughout the drainage area, although concentration at most stations were about 0.01 mg/L as N. Median nitrite concentrations at all 37 stations were less than or equal to 0.005 mg/L as N. The median values for the sum of nitrite and nitrate concentrations at all stations were less than the proposed EPA reference concentration for the sum of nitrite and nitrate concentrations that represent minimally affected conditions for streams in the Northeastern Coastal Zone ecoregion. Median concentrations of orthophosphate ranged from 0.01 to 0.04 milligrams per liter as phosphorus (mg/L as P). Concentrations of orthophosphate in water samples from the tributaries often were greater than the RIDEM standard of 0.025-mg/L as P for total phosphorus, and at 16 of the 37 stations, the median orthophosphate concentration was two or more times greater than the RIDEM standard. Phosphorus concentrations that exceed the standard could be of concern

because phosphorus can contribute to excessive plant and algae growth.

The median concentrations of total coliform bacteria and *E. coli* for the 37 stations in the drainage area were 43 colony-forming units per 100 milliliters (CFU/100 mL) and 15 CFU/100 mL, respectively. Concentrations of total coliform bacteria and *E. coli* in many water samples were high at stations on the Unnamed Brook North of Bullhead Brook, Quonapaug Brook, Toad Pond, and Moswansicut Stream South in the Moswansicut Reservoir Subbasin. The relatively high percentage of impervious area in the drainage areas of stations on Toad Pond and Moswansicut Stream South, which can convey surface-water runoff to these tributaries, may contribute to the bacteria concentrations measured in water-quality samples.

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. In general, statistically significant correlations (p value less than 0.05) were not identified between median values or concentrations of water-quality properties and constituents and various degrees of tree-canopy reduction resulting from timber operations in the subbasins. Significant positive correlations were identified between median concentrations of chloride and impervious area and developed area. These relations are likely associated with the application of road salt and other deicing compounds during winter maintenance activities. The significant positive correlation between median values of color and the percentages of wetlands in the drainage areas indicates that some sources of color in tributary waters are likely natural. Negative correlations of turbidity and indicator bacteria with streamflow at many stations likely reflect seasonal patterns in which these values are higher during low-flow conditions in summer and fall at the end of the water year. The negative correlation between chloride concentrations and streamflow at stations primarily in the Barden Reservoir and Direct Runoff Subbasins indicates that road salt is likely infiltrating to the groundwater and discharging as base flow. Median concentrations of nitrate correlated positively with streamflow at four stations. Correlations between concentrations of nitrite and streamflow were numerous.

The highest median chloride load (1,100 kilograms/day [kg/d]) was measured at the station on the Ponaganset River above the Barden Reservoir; this high value may be related in part to the large area of this subbasin. The largest median chloride yield (290 kilograms per day per square mile [kg/d/mi^2]) was determined for Bear Tree Brook that has historically been affected by the location of a salt-storage facility within the subbasin drainage area. Relatively high chloride yields ranging from 120 to 190 kg/d/mi^2 likely reflect the greater percentages of developed land uses and imperviousness in several subbasins. Average daily loads and yields of chloride and sodium also were calculated for 14 continuous-monitoring stations in the Scituate Reservoir drainage area for WYs 2009–12. These USGS data were estimated based on continuous records of flow and specific conductance and relations between specific conductance values and concentrations of chloride and sodium. The USGS daily loads of chloride and sodium ranged from 52 to 1,300 kg/d and 31 to 780 kg/d, respectively. The largest USGS daily loads for chloride and sodium (1,300 and 780 kg/d, respectively) were calculated for Ponaganset River and represent 20 percent of the total load for the 14 stations. The USGS daily yields of chloride and sodium for the drainage areas above the 14 stations, which represent nearly 66 percent of the Scituate Reservoir drainage area, were 100 and 64 kg/d/mi^2, respectively.

Median nutrient loads (nitrate, nitrite, and orthophosphate) tended to be larger in tributary subbasins with large drainage areas and in the eastern part of the Scituate Reservoir drainage area, which is more developed than the other parts. The median nutrient yields for the Scituate Reservoir drainage area were 5.4 grams per day per square mile as nitrogen (g/d/mi^2 as N) for nitrite, 44 g/d/mi^2 as N for nitrate, and 70 kilograms per day per square mile as phosphorus (kg/d/mi^2 as P) for orthophosphate. Mean subbasin yields for nitrite and nitrate were largest in the Moswansicut Reservoir Subbasin (8.6 and 69 g/d/mi^2 as N, respectively), and the mean yield for orthophosphate was largest in the Westconnaug Reservoir Subbasin (100 kg/d/mi^2 as P). The largest median yield of nitrate (480 kilograms per day per square mile as nitrogen) was determined for Bear Tree Brook in the Direct Runoff Subbasin and was about 10 times larger than the median yield for the Scituate Reservoir drainage area.

Loads and yields of total coliform bacteria and *E. coli* varied by nearly two orders of magnitude among the stations in the Scituate Reservoir drainage area. Median loads of total coliform and *E. coli* bacteria were 2,100 million colony-forming units per day (MCFU/d) and 530 MCFU/d, respectively. The greatest median load of total coliform bacteria (21,000 MCFU/d) and *E. coli* (5,700 MCFU/d) were found at the stations on Hunting House Brook (Providence Water station 14) and at Hemlock Brook (Providence Water station 14), respectively. Median yields of total coliform and *E. coli* bacteria were 1,400 million colony-forming units per day per square mile (MCFU/d/mi^2) and 350 MCFU/d/mi^2, respectively. The largest median yields of total coliform and *E. coli* bacteria were at Quonapaug Brook and several other monitoring stations in the Westconnaug Reservoir and Regulating Reservoir Subbasins.

Significant upward and downward time trends (p values less than 0.05) were identified in water-quality properties and concentrations for several constituents for WYs 2003–12 and WYs 1983–2012. Significant upward trends in pH were identified at nearly half of the monitoring stations for WYs 1983–2012 and might reflect regional reductions in acid precipitation in the Northeast. All significant trends in color were upward in samples from 25 of the 37 stations for WYs 1983–2012, but few significant trends were observed for WYs 2003–12. Significant upward trends in turbidity were identified at about one-quarter of the stations for both trend periods. Trends for WYs 2003–12 indicated that turbidity values for nine statins, including Westconnaug Brook and Ponaganset Reservoir, were increasing. A consistent downward trend in turbidity was identified at a single monitoring station during both test periods—Toad Pond in the Direct Runoff Subbasin.

Significant trends in alkalinity were upward during both trend periods and were likely related either to the natural weathering of structures containing concrete or to the application of lime or fertilizers that can increase alkalinity in the poorly buffered soils in the drainage area. Thirteen significant upward trends in alkalinity were identified during WYs 2003–12, many of which were not identified for WYs 1983–2012.

Trends in chloride concentrations (primarily upward) for WYs 1983–2002 were identified at 29 of the 37 stations in the Scituate Reservoir drainage area; however, only nine significant trends were identified for WYs 2003–12. Significant downward trends for WYs 2003–12 were identified for monitoring stations in the Barden Reservoir and Regulating Reservoir Subbasins. The reduction in the number of significant trends for the recent period indicates that chloride concentrations are neither increasing nor decreasing. Decreasing trends at some stations, particular those with large percentages of roadways, may indicate the effects of either changes in the quantity of the deicing compounds applied during the study period or changes in winter maintenance procedures by the Rhode Island Department of Transportation and other local agencies responsible for road maintenance.

Significant trends in nitrate concentrations were downward at 32 of the 37 stations for WYs 1988–2012 and at 20 stations for WYs 2003–12. Nine significant downward trends for nitrite were identified for WYs 1985–2012; only two significant upward trends were identified for the shorter period. Four upward trends in nitrite concentrations also were identified for WYs 2003–12. Concentrations of both nitrate and nitrite typically were low and close to reporting limits; as a result, trends could be affected by factors like changes in environmental sources and changes in analytical procedures or sampling irregularities not identified because of the absence of field quality-control data. Eleven significant increasing trends were identified for concentrations of orthophosphate during WYs 1997–2002; no trends were significant during WYs 2003–12.

Nine significant downward and three significant upward time trends in concentrations of total coliform bacteria were identified for WYs 1983–2012 in the Scituate Reservoir drainage area; a single significant upward trend was identified in the Westconnaug Reservoir Subbasin for the shorter period. Three downward and two upward trends in *E. coli* concentrations for WYs 1995–2012 were significant, but only a single significant upward trend in *E. coli* concentrations was identified for a station in the Barden Reservoir Subbasin during WYs 2003–12. Bacteria concentrations in the tributaries were extremely variable with discrete concentrations often ranging by nearly two orders of magnitude at a single monitoring station.

In conclusion, water-quality conditions for WYs 2003–12 continue to reflect the generally high-quality, drinking-water-source tributaries in the Scituate Reservoir drainage area. Monitored water-quality properties and constituent concentrations for the current study were similar to historical values at most stations. Fewer significant trends for most parameters and constituents were identified for WYs 2003–12 than were identified for WYs 1983–2012. The differences in trends for WYs 2003–12, in general, did not contradict the trend results for WYs 1983–2012, with the exception of trends in chloride concentrations, which indicated that concentrations were decreasing at several monitoring stations. The relations of concentrations and values of several water-quality constituents and properties to land use and impervious area in the drainage areas of the monitoring stations point to the effects of human activities on tributary water quality.

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Appendix 1. Water-Quality Data Collected by the Providence Water Supply Board at 37 Monitoring Stations in the Scituate Reservoir Drainage Area, Water Years 1983–2012

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