Prepared in cooperation with the Providence Water Supply Board

Water-Quality Conditions and Constituent Loads, Water Years 2013–19, and Water-Quality Trends, Water Years 1983–2019, in the Scituate Reservoir Drainage Area, Rhode Island

Scientific Investigations Report 2022–5043

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

Cover. The horseshoe dam at the outlet of the Regulating Reservoir in Scituate, Rhode Island; view facing northwest from Danielson Pike. Photograph by Phillip Woodford, U.S. Geological Survey.

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By Alana B. Spaetzel and Kirk P. Smith

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Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile ($[ft^3/s]/mi^2$)	0.01093	cubic meter per second per square kilometer ($[m^3/s]/km^2$)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile ($[Mgal/d]/mi^2$)	1,461	cubic meter per day per square kilometer ($[m^3/d]/km^2$)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Density	
mile per square mile (mi/mi^2)	0.6215	kilometer per square kilometer
	Application rate	
pound per year (lb/yr)	0.4536	kilogram per year (kg/yr)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
pound per year per square mile ($lb/yr/mi^2$)	0.4536	kilogram per year per square mile ($kg/yr/mi^2$)

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

°C = (°F – 32) / 1.8.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

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

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

A water year (WY) is the period between October 1 and September 30 and is designated by the year in which it ends.

Abbreviations

AICc	corrected Akaike Information Criterion
Ca	calcium
$CaCO_3$	calcium carbonate
CCC	criterion continuous concentration
CFU	colony-forming unit
Cl	chloride
CMC	criterion maximum concentration
DN	dissolved nitrogen
DOC	dissolved organic carbon
DP	dissolved phosphorus
E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
Fps	F-pseudosigma
K	potassium
KM	Kaplan-Meier
Mg	magnesium
MOVE.1	Maintenance of Variance Extension Type 1
MPV	most probable value
N	nitrogen
Na	sodium
NADA	Nondetects and Data Analysis
NTU	nephelometric turbidity unit
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
P	phosphorus
PCU	platinum-cobalt unit
PN	particulate nitrogen
PO_4	orthophosphate
PPCC	probability plot correlation coefficient
PWSB	Providence Water Supply Board
QA	quality assurance
QC	quality control
QSB	U.S. Geological Survey Quality Systems Branch
RIDEM	Rhode Island Department of Environmental Management

RIGIS	Rhode Island Geographic Information System
RMSE	root mean square error
RPD	absolute relative percent difference
RSD	relative standard deviation
SDWR	secondary drinking-water regulations
SEP	standard error of prediction
SO_4	sulfate
SRS	standard reference sample
SSC	suspended-sediment concentration
TN	total nitrogen
TP	total phosphorus
USGS	U.S. Geological Survey

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By Alana B. Spaetzel and 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. From October 1, 1982, to September 30, 2019, water years (WYs) 1983–2019 (a water year is the period between October 1 and September 30 and is designated by the year in which it ends), the Providence Water Supply Board maintained a fixed-frequency sampling program at 37 stations to monitor water quality in tributaries to the Scituate Reservoir. The U.S. Geological Survey (USGS), in cooperation with the Providence Water Supply Board, has measured streamflow at selected streamgages in the Scituate Reservoir drainage area since WY 1994, monitored water quality at selected stations since WY 2009, and conducted targeted base-flow and stormflow sampling at five stations in WYs 2016–19. Daily loads and yields of constituents (chloride, nitrite, nitrate, total coliform bacteria, *Escherichia coli*, and orthophosphate) were determined for sampled days during WYs 2013–19, and trends were examined for the entire period of record, predominantly WYs 1983–2019. USGS water-quality data were used to determine annual loads and yields of chloride and sodium for WYs 2013–19 at 14 stations, and nutrients and suspended sediment for WYs 2016–19 at 5 stations.

Tributaries in the Scituate Reservoir drainage area for WYs 2013–19 were slightly acidic (pH values less than 7.0 standard units) and often below the recommended pH range of 6.5 to 8.5 standard units, as described by the U.S. Environmental Protection Agency (EPA) in the secondary drinking-water regulations. Most measurements of water color in the tributaries were greater than the EPA secondary drinking-water regulation of 15 platinum-cobalt units. Chloride concentrations in Providence Water Supply Board samples rarely exceeded the EPA secondary drinking-water regulation for chloride (250 milligrams per liter); however, chloride concentrations estimated from continuous measurements of specific conductance exceeded the EPA criterion continuous concentration recommended for freshwater (230 milligrams per liter) for short periods ranging from 10 minutes to 26 hours at two streamgages.

Positive trends in pH, color, alkalinity, and chloride at more than half of the monitoring stations were identified for WYs 1983–2019. Fewer than half of the stations had significant trends in turbidity values, and significant trends varied in direction (positive or negative trends). Trend tests were not performed on total coliform bacteria, *Escherichia coli*, and nitrate concentrations because of analytical method changes that coincide with abrupt shifts in the magnitude and distribution of concentration data.

The median of daily loads and yields of chloride, nitrite, nitrate, orthophosphate, and bacteria determined for each Providence Water Supply Board sample in WYs 2013–19 varied across the 37 monitoring stations, but yields were generally greater at stations in the Moswansicut and Regulating Reservoir subbasins. Average daily yields of chloride and sodium estimated from continuous records of specific-conductance and streamflow data at 14 stations ranged from 42 to 310 kilograms per square mile per day and 28 to 180 kilograms per square mile per day, respectively. The mean annual yields of total phosphorus, total nitrogen, and suspended sediment determined for five stations ranged from 16 to 78 kilograms per square mile, from 370 to 2,100 kilograms per square mile, and from 5,000 to 13,000 kilograms per square mile, respectively. More than half of the nutrient and suspended sediment loads occurred during stormflow.

Introduction

Scituate Reservoir, the primary source of drinking water for more than 60 percent of the population of Rhode Island, is in parts of the towns of Cranston, Foster, Glocester, Johnston, and Scituate, R.I. (fig. 1). The reservoir and its drainage area cover about 94 square miles (mi^2), about 9 percent of the total area of Rhode Island. The Providence Water Supply Board (PWSB) manages the Scituate Reservoir and the water-supply system from the Scituate Reservoir. The average demand for treated water is approximately 61 million gallons per day (daily average from July 1, 2019, to June 30, 2020), of which 61 percent is for the cities of Cranston, Providence, and North Providence and for the Rhode Island towns of Johnston and part of Smithfield; the remainder is sold to seven wholesale customers (Richard Blodgett, Providence Water Supply Board, written commun., 2021).

The PWSB protects nearly 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, 2021); the remaining area is privately owned (Providence Water Supply Board, 2019). Although the majority of the drainage area is forested (RIGIS, 2015), future development may cause degradation in the quality of the source water to the reservoir.

The PWSB has collected water-quality data throughout the Scituate Reservoir drainage area 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 (fig. 1; table 1). Water-quality physical properties and constituent concentrations measured by PWSB—pH, alkalinity, turbidity, and color and chloride, nutrients, and bacteria, respectively—are indicators of overall water-quality conditions.

In 2008, the U.S. Geological Survey (USGS), in cooperation with PWSB, 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 Scituate Reservoir drainage area. Data on constituent loads and yields, which are determined based on both flow and constituent concentrations, contribute to an understanding of tributary and reservoir water quality. Knowledge of the time trends in the physical properties and constituents can enable water managers to anticipate and consider 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, minimally developed drainage areas and reservoir source-water areas throughout the northeastern United States.

Purpose and Scope

This report presents analyses of streamflow and water-quality data collected in the Scituate Reservoir drainage area to characterize water-quality conditions and loads and yields of selected constituents from October 1, 2012, to September 30, 2019 (water years[1] [WYs] 2013–19) and to assess water-quality trends for the entire monitoring period (WYs 1983–2019). Water-quality data were collected by PWSB, and additional water-quality and streamflow data were collected by USGS as part of various cooperative monitoring initiatives. Fixed-frequency water-quality sample collection at 37 surface-water-monitoring stations distributed throughout the drainage area (fig. 1) has been maintained by PWSB. USGS collected streamflow data (either continuously or by discrete measurements) at 23 of the 37 stations, continuous specific-conductance data at 14 of the 37 stations, and base-flow and flow-proportional composite stormflow samples at 5 of the 37 stations. Analyses performed on the data included (1) determination of median values 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, impervious area, and road density; (3) determination of the frequencies at which water-quality standards or guidelines were exceeded at tributary monitoring stations; (4) identification of trends in values and concentrations of selected water-quality properties and constituents at all monitoring stations; (5) identification of trends in estimated concentrations and loads of chloride (Cl) and sodium (Na) at 14 stations; (6) estimation of daily loads and yields of chloride, nutrients, and bacteria at the 23 stations for which streamflow data were available; (7) estimation of annual loads and yields of Cl and Na at 14 stations for which continuous streamflow and specific-conductance data were available; (8) estimation of loads and yields of nutrients and suspended sediment for five stations at which base-flow and composite stormflow samples were collected. The water-quality data used in each of these analyses are summarized in table 2.

Previous Investigations

PWSB has maintained a fixed-frequency sampling program at 37 stations to monitor water quality in the tributaries to the Scituate Reservoir since WY 1983; data collected by PWSB prior to WY 1983 have not been analyzed in USGS studies. Breault and others (2000), Nimiroski and others (2008), and Smith (2015b) summarized water-quality data collected by PWSB before the present study and included median values of physical properties and constituent concentrations, trends in selected constituent concentrations, and relations between constituent concentrations and drainage-area characteristics. Smith (2015b) also included estimation of continuous

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

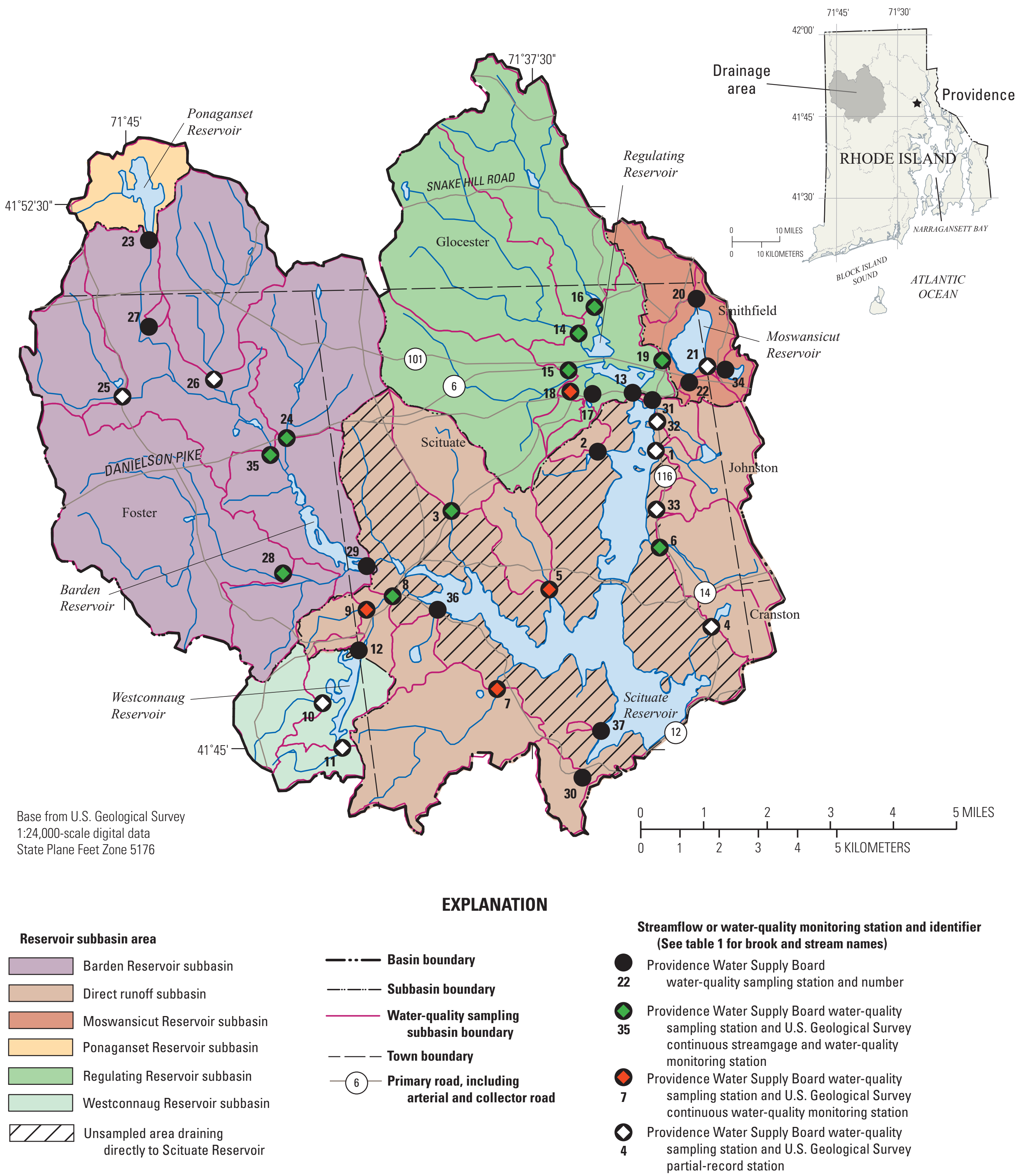


Figure 1. Locations of tributary reservoir subbasins and stations in the Scituate Reservoir drainage area, Rhode Island.

Table 1. Providence Water Supply Board water-quality monitoring stations, water-quality sample collection frequency and type, and available streamflow and specific-conductance data by tributary reservoir subbasins in the Scituate Reservoir drainage area, Rhode Island, October 1, 2012, to September 30, 2019.

[Alternate station names given in parentheses for stations where different historical names were used for the same sampling location by Providence Water Supply Board (PWSB). All stations for which chloride (Cl) and sodium (Na) loads were estimated have continuous specific-conductance records. Locations of stations are shown in figure 1. USGS, U.S. Geological Survey; mi², square mile; QW, water quality; WY, water year; M, monthly; Y, yes; Q, quarterly; N, no; --, not applicable]

PWSB station number (fig. 1)	USGS station number	Station name	Drainage area (mi²)	Frequency of QW sample collection	Number of samples collected by Providence Water[1]	Daily estimated Cl and Na loads	Estimated nutrient and sediment loads WYs 16–19	Streamflow availability
Barden Reservoir subbasin								
24	01115190	Dolly Cole Brook	4.90	M	77	Y	N	Continuous
25	01115200	Shippee Brook	2.37	Q	19	N	N	Estimated
26	01115185	Windsor Brook	4.33	Q	22	N	N	Estimated
27	011151845	Unnamed Tributary to Ponaganset River (Unnamed Brook B, Unnamed Brook West of Windsor Brook)	0.11	Q	15	N	N	None
28	01115265	Barden Reservoir (Hemlock Brook)	8.72	M	75	Y	N	Continuous
29	01115271	Ponaganset River (Barden Stream)	33.0	M	72	N	N	None
35	01115187	Ponaganset River	14.0	M	70	Y	N	Continuous
Direct runoff subbasin								
1	01115180	Brandy Brook	1.57	M	72	N	N	Estimated
2	01115181	Unnamed Tributary 2 to Scituate Reservoir (Unnamed Brook North of Bullhead Brook)	0.22	Q	12	N	N	None
3	01115280	Cork Brook	1.87	M	67	Y	N	Continuous
4	01115400	Kent Brook (Betty Pond Stream)	0.85	M	59	N	N	Estimated
5	01115184	Spruce Brook	1.26	Q	24	Y	N	Continuous,[2] estimated
6	01115183	Quonapaug Brook	1.96	M	70	Y	Y	Continuous
7	01115297	Wilbur Hollow Brook	4.33	M	73	Y	N	Continuous,[2] estimated
8	01115276	Westconnaug Brook (Westconnaug Reservoir)	5.18	M	70	Y	N	Continuous
9	01115275	Bear Tree Brook	0.62	Q	19	Y	N	Continuous,[2] estimated
30	01115350	Unnamed Tributary 4 to Scituate Reservoir (Coventry Brook, Knight Brook)	0.79	Q	15	N	N	None
31	01115177	Toad Pond	0.03	Q	2	N	N	None
32	01115178	Unnamed Tributary 1 to Scituate Reservoir (Pine Swamp Brook)	0.45	Q	17	N	N	Estimated
33	01115182	Unnamed Tributary 3 to Scituate Reservoir (Halls Estate Brook)	0.28	Q	18	N	N	Estimated
36	--	Outflow from King Pond	0.76	Q	20	N	N	None
37	--	Fire Tower Stream	0.03	Q	18	N	N	None

Table 1. Providence Water Supply Board water-quality monitoring stations, water-quality sample collection frequency and type, and available streamflow and specific-conductance data by tributary reservoir subbasins in the Scituate Reservoir drainage area, Rhode Island, October 1, 2012, to September 30, 2019.—Continued

[Alternate station names given in parentheses for stations where different historical names were used for the same sampling location by Providence Water Supply Board (PWSB). All stations for which chloride (Cl) and sodium (Na) loads were estimated have continuous specific-conductance records. Locations of stations are shown in figure 1. USGS, U.S. Geological Survey; mi², square mile; QW, water quality; WY, water year; M, monthly; Y, yes; Q, quarterly; N, no; --, not applicable]

PWSB station number (fig. 1)	USGS station number	Station name	Drainage area (mi²)	Frequency of QW sample collection	Number of samples collected by Providence Water[1]	Daily estimated Cl and Na loads	Estimated nutrient and sediment loads WYs 16–19	Streamflow availability
		Moswansicut Reservoir subbasin						
19	01115170	Moswansicut Reservoir (Moswansicut Stream North, Moswansicut Pond)	3.25	M	75	Y	Y	Continuous
20	01115160	Unnamed Tributary 1 to Moswansicut Reservoir (Blanchard Brook)	1.18	M	61	N	N	None
21	01115165	Unnamed Tributary 2 to Moswansicut Reservoir (Brook from Kimball Reservoir)	0.30	Q	13	N	N	Estimated
22	01115167	Moswansicut Reservoir (Moswansicut Stream South)	0.10	M	59	N	N	None
34	01115164	Kimball Stream	0.27	Q	18	N	N	None
		Ponaganset Reservoir subbasin						
23	011151843	Ponaganset Reservoir	1.92	M	61	N	N	None
		Regulating Reservoir subbasin						
13	01115176	Regulating Reservoir	22.1	M	68	N	N	None
14	01115110	Huntinghouse Brook	6.29	M	58	Y	Y	Continuous
15	01115114	Rush Brook	4.70	M	65	Y	Y	Continuous
16	01115098	Peeptoad Brook (Harrisdale Brook)	4.97	M	72	Y	Y	Continuous
17	01115119	Dexter Pond (Paine Pond)	0.22	Q	12	N	N	None
18	01115120	Unnamed Tributary to Regulating Reservoir (Unnamed Brook A)	0.28	Q	12	Y	N	Continuous,[2] estimated
		Westconnaug Reservoir subbasin						
10	01115274	Westconnaug Brook	1.48	M	63	N	N	Estimated
11	01115273	Unnamed Tributary to Westconnaug Reservoir (Unnamed Brook south of Westconnaug Reservoir)	0.72	Q	18	N	N	Estimated
12	011152745	Unnamed Tributary to Westconnaug Brook (Unnamed Brook north of Westconnaug Reservoir)	0.16	Q	15	N	N	None

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

[2]Continuous streamflow monitoring discontinued at the end of water year 2014.

Table 2. Summary of water-quality data used to characterize water-quality conditions, analyze trends, and estimate loads and yields of selected properties and constituents in the Scituate Reservoir drainage area, Rhode Island.

[Water years listed for trends reflect earliest year of data collection. Streamflow data availability is provided for each site in table 1. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; NWIS, National Water Information System.]

Purpose and scope analysis number	Analysis	Period(s), water years	Collecting agency	Type of water-quality data	Number of stations	Properties and constituents	Data publication(s)
1	Summary of water-quality conditions	2013–19	PWSB	Fixed-frequency discrete water-quality samples	37	pH, color, turbidity, alkalinity, chloride, nitrite, nitrate, total coliform bacteria, *Escherichia coli*, and orthophosphate	Smith, 2015a, 2016, 2018c, d, 2019b, 2021
2	Comparison of water-quality properties and constituent concentrations with streamflow and basin properties	2013–19; 1994–2019 (streamflow)	PWSB	Fixed-frequency discrete water-quality samples	37; 23	pH, alkalinity, turbidity, color, chloride, nitrite, nitrate, total coliform bacteria, *Escherichia coli*, and orthophosphate	Smith, 2015a, 2016, 2018c, d, 2019b, 2021
3	Comparison of water-quality properties and constituent concentrations to relevant standards or guidelines	2013–19	PWSB and USGS	Fixed-frequency discrete water-quality samples	37	pH, color, turbidity, chloride (PWSB); total phosphorus and chloride (USGS)	Smith, 2015a, 2016, 2018c, d, 2019b, 2021
4	Trends in selected properties and constituents with respect to time	1983–2019, 2002–19	PWSB	Fixed-frequency discrete water-quality samples	37	pH, color, turbidity, chloride, nitrite, and orthophosphate	Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021
5	Trends in chloride and sodium concentrations and loads	2009–19	USGS	Discrete water-quality samples collected to cover the range of observed specific-conductance values and continuous (10- or 15-minute frequency) measurements of specific conductance	14	Chloride and sodium	NWIS, U.S. Geological Survey, 2020b
6	Estimation of daily loads and yields	2013–19	PWSB	Fixed-frequency discrete water-quality samples	23	Chloride, nitrite, nitrate, orthophosphate, total coliform bacteria, *Escherichia coli*	Smith, 2015a, 2016, 2018c, d, 2019b, 2021
7	Estimation of daily and annual loads and yields of chloride and sodium	2013–19	USGS	Discrete water-quality samples collected to cover the range of observed specific-conductance values and continuous (10- or 15-minute frequency) measurements of specific conductance	14	Chloride, sodium, and specific conductance	NWIS, U.S. Geological Survey, 2020b
8	Estimation of annual loads and yields	2016–19	USGS	Discrete base-flow samples and time-composited stormflow samples	5	Dissolved phosphorus, total phosphorus, dissolved nitrogen, total nitrogen, suspended-sediment concentration	NWIS, U.S. Geological Survey, 2020b, and Spaetzel and Smith, 2022

concentrations, loads, and yields of Cl and Na at 14 stations for which continuous streamflow and continuous specific-conductance data were available over WYs 2009–12 (fig. 1; table 1). Specific conductance serves as a surrogate for estimating Cl and Na concentrations, which are critical concerns to local water-resources managers because these constituents are difficult to remove from source water and can affect the quality of finished drinking water. Nimiroski and Waldron (2002) described potential sources of Cl and Na in the Scituate Reservoir drainage area. The USGS published annual water-year summary reports of streamflow, water-quality conditions, and chloride, nutrient, and bacteria loads and yields for WYs 2002–19 (Breault, 2010; Breault and Campbell, 2010a, b, c, d; Breault and Smith, 2010; Smith and Breault, 2011; Smith, 2013, 2014, 2015a, 2016, 2018a, b, 2019a, 2022a, b), and more comprehensive summaries for WYs 1996–2002 and 2002–19 are presented in Nimiroski and others (2008) and Smith (2015b), respectively.

Since 1993, the USGS has cooperated with PWSB and the Rhode Island Department of Environmental Management (RIDEM) to measure streamflow at Ponaganset River (USGS streamgage 01115187; PWSB station 35) and Peeptoad Brook (USGS streamgage 01115098; PWSB station 16) (fig. 1). Additional streamgages were added in October 2008 in cooperation with PWSB. As part of studies of low-flow characteristics in northern Rhode Island, the USGS has collected streamflow measurements at nine partial-record stations in the Scituate Reservoir drainage area (fig. 1; Kliever, 1995; Bent and others, 2014).

Description of the Study Area

The study area is located in north-central Rhode Island and encompasses the Scituate Reservoir, five tributary reservoirs (Barden, Moswansicut, Ponaganset, Regulating, and Westconnaug) and numerous millponds with a total area of 94 mi^2 (fig. 1). The 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 is 86.8 mi^2.

Land Use

Land use in the Scituate Reservoir drainage area is primarily undeveloped with an impervious area of about 4.1 percent (Rhode Island Geographic Information System [RIGIS], 2013, 2015). Forest (78 percent), wetlands (0.6 percent), and water (8.4 percent) accounted for about 87 percent of the land use within the entire drainage area in 2011 (RIGIS, 2013, 2015; fig. 2; table 3). Developed areas consisted of residential (8.4 percent), agricultural (3.1 percent), commercial/industrial (0.8 percent), and other urban (0.8 percent) classifications (RIGIS, 2013, 2015). The basin includes approximately 276 centerline road miles, of which 76 percent are local roads, which are generally paved streets with single lanes of traffic in each direction (U.S. Geological Survey, 2020a). The total road density in miles per square mile (mi/mi^2) is 2.9. The eastern part of the drainage area is more developed than the rest of the drainage area (fig. 2) and is close to the city of Providence. Moswansicut Reservoir subbasin, in the northeastern corner of the Scituate Reservoir drainage area, has the smallest area of undeveloped land (70 percent, including forest, wetland, and water), the greatest percentage of impervious cover (9.9 percent), and the highest road density (5.7 mi/mi^2) relative to the other reservoir subbasins (table 3). The Moswansicut Reservoir subbasin also has the largest percentages of commercial/industrial land use (2.3 percent) and residential land use (21 percent) of the five major subbasins within the drainage area.

The percentage of wetland area in the Scituate Reservoir drainage area, as reported in this study, is lower than the percentage of wetland area reported by Nimiroski and others (2008) and Smith (2015b). These studies used RIGIS land-use datasets published in 1995 and 2005, respectively, which were developed based on a different designation for forested wetlands. In the RIGIS 2011 land-use data, forested wetlands are grouped with forested areas (RIGIS, 2015). For most data-collection sites within the Scituate Reservoir drainage area, the percentage of forested area in the 2011 data (RIGIS, 2015) is higher by approximately the percentage of wetland coverage as identified in previous land-use data versions. This change in the land-use data, and its relevance to this study, is discussed in more detail in a later section.

Climate

Climate in the Scituate Reservoir drainage area is temperate with a mean annual temperature of 48.8 degrees Fahrenheit (WYs 1975–2019), recorded at a National Oceanic and Atmospheric Administration climatological station in the Barden Reservoir subbasin in Foster, R.I. (National Oceanic and Atmospheric Administration, 2020). The long-term mean annual precipitation and mean annual snowfall at the Foster station for WYs 1975–2019 were 53.5 inches (in.) and 59.0 in., respectively. During WYs 2013–19, mean annual precipitation was slightly less than the long-term mean annual value at 52.7 in. However, during this period, which included the winter of 2015 when 111 in. of snowfall was recorded at the climatological station, mean annual snowfall (72.3 in.) was greater than the long-term mean (59.0 in.).

Geology

The bedrock in the drainage area is mostly granite and granitic gneiss; some metasedimentary and mafic igneous rocks also are present (Hermes and others, 1994). Glacial deposits of Pleistocene age overlie the bedrock (Richmond and Allen, 1951; Allen, 1953). Glacial materials consist of ice-laid deposits (till or ground moraine) and meltwater deposits (sand and gravel). Till or ground moraine, locally called hardpan, is

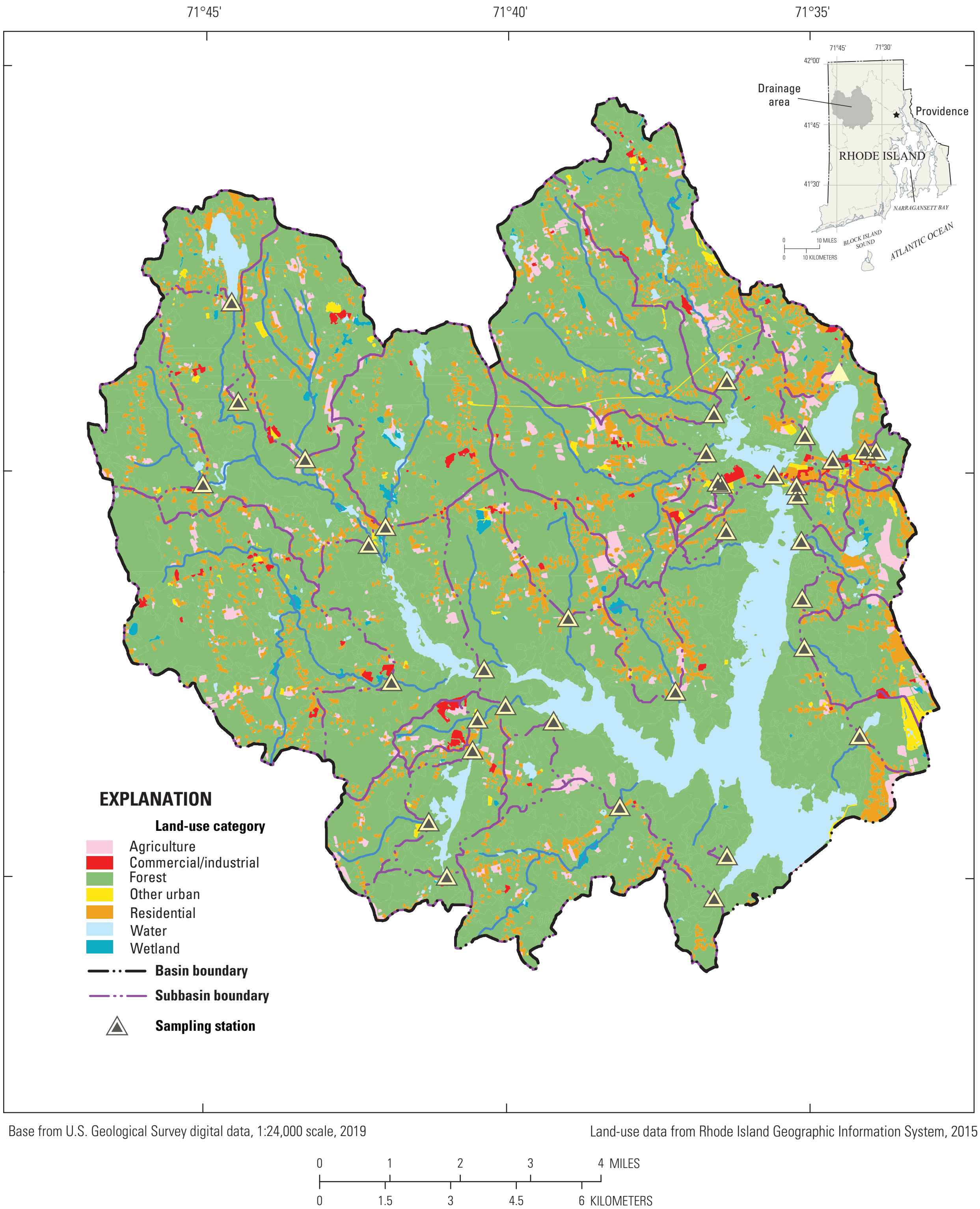


Figure 2. Land use and locations of stations in the Scituate Reservoir drainage area, Rhode Island.

Table 3. Percentages of land use, percent impervious area, and road density in the Scituate Reservoir drainage area, Rhode Island.

[Land-use data from Rhode Island Geographic Information System (RIGIS) (2015) based on orthophotography captured in spring 2011; impervious area data from RIGIS, 2013. Note that wetlands designation has changed from previous versions. Road density is length of road in miles per square mile computed in StreamStats from U.S. Geological Survey (USGS) National Transportation Dataset (USGS, 2020a). Direct runoff subbasin includes gaged and ungaged area. PWSB, Providence Water Supply Board; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Land use (percent)							Impervious area (percent)	Road density (miles per square mile)
		Residential	Commercial/ industrial	Other urban	Agricultural	Forest	Water	Wetlands		
Barden Reservoir subbasin										
24	01115190	7.8	0.9	0.3	1.3	85.2	2.9	1.6	3.7	2.5
25	01115200	7.4	0.0	0.2	1.7	90.0	0.7	0.0	2.9	2.2
26	01115185	7.9	1.2	1.5	3.9	83.7	0.3	1.5	3.9	3.2
27	011151845	11.5	0.1	0.0	5.8	82.6	0.0	0.0	5.0	3.4
28	01115265	8.3	1.3	0.4	3.0	85.2	0.7	1.1	3.4	3.0
29	01115271	7.3	0.4	0.4	1.8	83.0	6.7	0.5	3.4	2.8
35	01115187	8.5	0.6	0.7	2.5	83.6	3.4	0.7	3.8	2.9
Subbasin	--	7.3	0.8	0.5	2.4	85.7	2.3	0.9	3.3	2.8
Direct runoff subbasin										
1	01115180	17.7	0.1	1.3	11.6	63.2	4.6	1.4	6.6	4.0
2	01115181	19.8	0.0	0.0	0.0	79.9	0.3	0.0	6.9	4.0
3	01115280	13.5	0.6	0.0	5.7	79.6	0.1	0.5	6.0	3.4
4	01115400	3.4	1.4	13.9	3.6	72.1	5.4	0.3	2.3	0.7
5	01115184	13.1	0.0	0.1	3.3	80.7	0.1	2.6	5.3	2.7
6	01115183	14.0	1.0	3.0	4.6	76.6	0.1	0.5	6.1	3.8
7	01115297	9.1	0.1	0.0	2.9	85.8	0.7	1.3	3.5	2.4
8	01115276	6.0	2.1	0.7	3.4	81.8	5.6	0.4	3.0	2.8
9	01115275	5.8	13.7	0.2	10.9	67.1	0.4	1.4	4.6	2.1
30	01115350	6.7	0.0	0.0	0.0	92.8	0.2	0.3	2.9	2.3
31	01115177	21.2	31.8	0.0	0.0	47.0	0.0	0.0	37.9	--
32	01115178	15.6	0.9	2.5	1.0	79.2	0.2	0.5	6.3	3.5
33	01115182	15.7	0.0	0.0	0.1	84.1	0.1	0.0	6.2	4.4
36	--	4.5	0.5	0.2	5.0	85.5	4.2	0.3	1.8	2.1
37	--	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.8	2.5
Subbasin	--	7.3	0.6	0.7	2.8	72.2	15.8	0.6	3.5	2.6

Table 3. Percentages of land use, percent impervious area, and road density in the Scituate Reservoir drainage area, Rhode Island.—Continued

[Land-use data from Rhode Island Geographic Information System (RIGIS) (2015) based on orthophotography captured in spring 2011; impervious area data from RIGIS, 2013. Note that wetlands designation has changed from previous versions. Road density is length of road in miles per square mile computed in StreamStats from U.S. Geological Survey (USGS) National Transportation Dataset (USGS, 2020a). Direct runoff subbasin includes gaged and ungaged area. PWSB, Providence Water Supply Board; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Land use (percent)							Impervious area (percent)	Road density (miles per square mile)
		Residential	Commercial/ industrial	Other urban	Agricultural	Forest	Water	Wetlands		
Moswansicut Reservoir subbasin										
19	01115170	20.7	2.3	1.2	5.5	54.6	15.2	0.5	9.9	5.7
20	01115160	25.9	1.6	0.6	7.8	62.8	0.1	1.0	11.1	7.5
21	01115165	14.3	3.7	0.0	0.0	67.8	13.6	0.7	9.3	4.1
22	01115167	17.6	15.7	12.6	1.1	52.5	0.5	0.0	21.4	11
34	01115164	11.2	4.0	0.0	0.0	69.4	14.7	0.7	9.0	4.2
Subbasin	--	20.7	2.3	1.2	5.5	54.6	15.2	0.5	9.9	5.7
Ponaganset Reservoir subbasin										
23	011151843	13.9	0.0	0.6	0.1	65.6	19.3	0.5	5.4	3.6
Regulating Reservoir subbasin										
13	01115176	10.3	1.1	1.4	4.7	79.2	2.9	0.4	6.2	3.7
14	01115110	8.7	0.2	0.7	4.6	84.7	0.6	0.4	3.7	2.7
15	01115114	12.4	0.6	1.2	5.3	79.9	0.4	0.1	7.0	3.6
16	01115098	10.2	1.1	1.7	5.6	78.3	2.1	0.9	5.4	3.2
17	01115119	12.9	0.3	1.7	10.4	71.5	3.2	0.0	5.6	2.2
18	01115120	11.7	8.4	9.2	4.9	65.8	0.0	0.0	14.2	5.3
Subbasin	--	10.3	1.1	1.4	4.7	79.2	2.9	0.4	5.6	3.3
Westconnaug Reservoir subbasin										
10	01115274	7.5	0.0	1.2	4.0	87.3	0.0	0.0	3.1	2.9
11	01115273	4.0	0.9	0.0	3.0	90.7	0.8	0.6	1.7	1.3
12	011152745	15.9	0.7	0.0	2.6	79.1	0.4	1.1	8.8	7.5
Subbasin	--	5.6	0.2	0.7	2.3	84.0	6.9	0.3	2.5	2.6
Scituate drainage area										
--	--	8.4	0.8	0.8	3.1	77.8	8.4	0.6	4.1	2.9

a mixture of nonsorted sand, silt, clay, cobbles, 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 waterbodies.

Hydrology

The Scituate Reservoir drainage area encompasses the Scituate Reservoir and five smaller tributary reservoirs that receive water from numerous small rivers, streams, and brooks. The Ponaganset River is the largest tributary to the Scituate Reservoir; at the location of the streamgage (USGS streamgage 01115187; PWSB station 35) it drains 14.0 mi^2, and at the outlet of the Barden Reservoir (USGS station 01115271; PWSB station 29) it drains 33.0 mi^2 (fig. 1; table 1). The Pawtuxet River begins at the outlet of the Scituate Reservoir and flows eastward to Narragansett Bay (not shown on fig. 1). The mean annual flow and water yield in the Pawtuxet River at Cranston, R.I. (USGS streamgage 01116500), were 355 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 79-year period of record, WYs 1941–2019 (U.S. Geological Survey, 2020b). During WYs 2013–19, mean annual streamflow and water yield in the Pawtuxet River at Cranston, R.I., station were 345 ft^3/s and 1.73 $ft^3/s/mi^2$, respectively, about 3 percent less than the long-term mean annual streamflow. The Pawtuxet River streamgage drains 200 mi^2, which is approximately twice the size of the Scituate Reservoir drainage area (94 mi^2). Mean annual streamflows and water yields at the USGS stations on the Ponaganset River (USGS streamgage 01115187; PWSB station 35) and Peeptoad Brook (USGS streamgage 01115098; PWSB station 16; fig. 1) in the Scituate Reservoir drainage area averaged about 28.2 ft^3/s and 1.96 $ft^3/s/mi^2$ and 9.58 ft^3/s and 1.93 $ft^3/s/mi^2$, respectively, for WYs 2013–19. The latter two stations have drainage areas of 14.4 mi^2 and 4.96 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 drainage divides closely correspond in the Scituate Reservoir drainage area, as is typical of valley-fill hydrogeologic settings in the northeastern United States (Hahn and Hansen, 1961; Hansen, 1962; Pollock, 1960). 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. Streams, along with wetlands, typically are discharge areas for groundwater.

Data-Collection Methods

Data described in this report were collected by the USGS and PWSB. Data collected by the PWSB consisted of water-quality data from discrete (representing a single point in time) samples collected at 37 monitoring stations and analyzed by the PWSB for pH, color, turbidity, alkalinity, chloride, nitrite, nitrate, total coliform bacteria, *Escherichia coli* (*E. coli*), and orthophosphate. Data collected by USGS included flow data at 23 stations, continuous specific conductance, and discrete water-quality samples at 14 stations. Since WY 2016, discrete base-flow samples and composite stormflow samples (flow-proportionally collected samples representing the duration of a storm-runoff event) were collected at five monitoring stations for analysis of phosphorus, nitrogen, and suspended-sediment concentrations.

Data Collected by the U.S. Geological Survey

Water-Quality Sampling

The USGS collected water samples at 14 stations in the Scituate Reservoir drainage area during WYs 2009–19 to characterize loads and yields of chloride and sodium (tables 1 and 4). These samples were analyzed for dissolved major ions, including calcium (Ca), chloride (Cl), magnesium (Mg), potassium (K), sodium (Na), and sulfate (SO_4). These discrete base-flow samples were typically collected from the centroid of the stream in 2-liter (L) polyethylene bottles a minimum of three times per WY. USGS also collected water samples at five stations during WYs 2016–19 to characterize loads and yields of total phosphorus (TP), dissolved phosphorus (DP), total nitrogen (TN), dissolved nitrogen (DN), and suspended sediment (suspended-sediment concentration [SSC]; tables 1 and 4). The base-flow samples collected at these five stations also were analyzed for additional nutrient constituents that were not used to compute loads—orthophosphate, dissolved ammonia, nitrate plus nitrite, and nitrate (table 4).

Base-flow and composite stormflow samples were collected 4 to 10 times each WY at USGS streamgages on Peeptoad Brook (USGS streamgage 01115098; PWSB station 16), Huntinghouse Brook (USGS streamgage 01115110; PWSB station 14), Rush Brook (USGS streamgage 01115114; PWSB station 15), Quonapaug Brook (USGS streamgage 01115183; PWSB station 6), and below the outlet of Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19). A target of collecting an equal number of base-flow and stormflow samples (ideally 10 each) per station per WY was planned for this study; however, in some cases, this sampling plan was disrupted by dry summer conditions or freezing winter conditions. Base-flow samples were collected on days preceded by a minimum of 48 hours without any precipitation. The streamflow and depths at these five USGS stations are too low during base-flow conditions for isokinetic water-sampling techniques (U.S. Geological Survey, 2006); therefore, similarly to the samples analyzed for major ions,

Table 4. Parameter codes, laboratory detection limits, concentration units, and sampling period for water-quality constituents measured in samples collected by U.S. Geological Survey in the Scituate Reservoir drainage area, Rhode Island, water years 2009–19.

[Detection limits changed during period of sample collection; the most recent detection limit applicable to the sampling period is reported in this table. USGS, U.S. Geological Survey; mg/L, milligram per liter; P, phosphorus; N, nitrogen; --, not applicable]

Constituent	Constituent abbreviation	USGS parameter code	Method detection limit	Unit	Begin date (mm/dd/yyyy)	End date (mm/dd/yyyy)	Composite storm sampling
Calcium	Ca	00915	0.022	mg/L	1/22/2009	8/27/2019	No
Chloride	Cl	00940	0.02	mg/L	1/22/2009	8/27/2019	No
Magnesium	Mg	00925	0.011	mg/L	1/22/2009	8/27/2019	No
Potassium	K	00935	0.3	mg/L	1/22/2009	8/27/2019	No
Sodium	Na	00930	0.4	mg/L	1/22/2009	8/27/2019	No
Sulfate	SO_4	00945	0.02	mg/L	1/22/2009	8/27/2019	No
Dissolved phosphorus	DP	00666	0.004	mg/L as P	10/1/2015	9/26/2019	Yes
Orhophosphate	PO_4	00671	0.004	mg/L as P	10/1/2015	9/26/2019	No
Total phosphorus	TP	00665	0.004	mg/L as P	10/1/2015	9/26/2019	Yes
Total dissolved nitrogen[1]	DN	62854	0.05	mg/L as N	10/1/2015	9/26/2019	Yes
Total nitrogen	--	62855	0.05	mg/L as N	10/1/2015	9/26/2019	Yes
Particulate nitrogen	PN	49570	0.06	mg/L as N	10/1/2015	9/26/2019	Yes
Total nitrogen, sum of DN and PN	TN	--	--	mg/L as N	10/1/2015	9/26/2019	Yes
Dissolved ammonia	NH_3	00608	0.01	mg/L as N	10/1/2015	9/26/2019	No
Nitrate plus nitrite, filtered	$NO_2 + NO_3$	00631	0.01	mg/L as N	10/1/2015	9/26/2019	No
Nitrite, filtered	NO_2	00613	0.001	mg/L as N	10/1/2015	9/26/2019	No
Suspended- sediment concentration	SSC	80154	0.5	mg/L	10/1/2015	9/26/2019	Yes

[1]0.65-micrometer pore size disc filter used to filter for dissolved nitrogen instead of customary 0.45-micrometer filter.

base-flow samples were collected in the centroid of each stream in 2-L polyethylene bottles. Stormflow samples were collected year round, and the storms selected reflect both the seasonal variation in the length of antecedent dry conditions between stormflow events (fig. 3*A*) and the variation in precipitation totals (fig. 3*B*). During some stormflow events, noncomposited stormflow samples, which represent a single point in time, also were collected with the automatic sampler in response to incremental changes in measured levels of specific conductance, enabling the capture of the high and low ends of specific-conductance ranges. Occasionally, isokinetic equal-width increment samples also were manually collected during storm events for quality-assurance purposes (fig. 4).

Composite stormflow samples were collected with automatic samplers during stormflow conditions using methods that are similar to those documented by Smith (2017). Automatic samplers were controlled by a datalogger to collect flow-proportional composite stormflow samples for targeted storm events. A flow-proportional sample consists of numerous subsamples of equal volume collected at equal intervals of flow volume throughout the storm event (fig. 5). The flow intervals were estimated based on the prestorm base-flow volume, the estimated duration of the event at which base-flow volume was considered constant, and the amount of runoff anticipated from the storm. Continuous gage-height measurements were converted to continuous flow values by programming the dataloggers with the relation between gage height and flow for each USGS station. For flow-proportional composite samples, the first aliquot was collected when a determined threshold, which was marginally greater than pre-storm base flow, was exceeded, with subsequent aliquots collected at flow-proportional intervals (fig. 5). Collection of sample aliquots continued throughout the flow recession following the peak flow until either the computed length of the recession period was reached or the rate of streamflow returned to prestorm levels. The lengths of the recession periods were calculated based on the size of each drainage area at the location of the USGS station using the following equation:

$$T = (A)^{0.2}, \tag{1}$$

where

T is the time value, in days, for the length of the recession period;

A is the area of the drainage basin, in square miles, upstream from the sampling station; and

0.2 is a constant (Bedient and Huber, 2002).

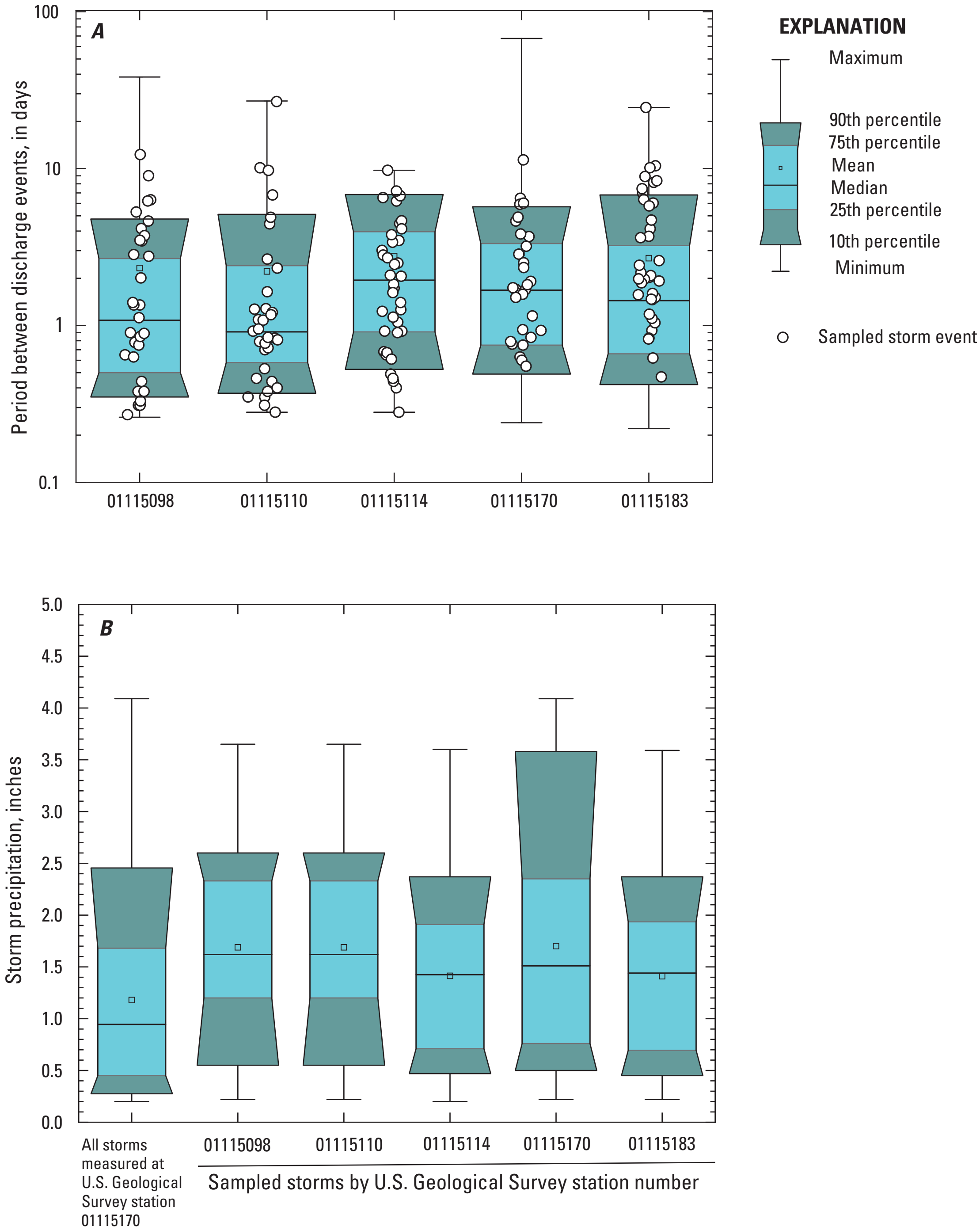


Figure 3. *A*, Distribution of antecedent dry periods between discharge events at U.S. Geological Survey (USGS) monitoring stations in the Scituate Reservoir drainage area during water years 2016–19, and the antecedent periods between discharge events for storms during which flow-proportional composite stormflow samples were collected. *B*, Distribution of all storm precipitation totals greater than or equal to 0.2 inch recorded at USGS station 01115170 (Providence Water Supply Board station 19) during water years 2016–19, and precipitation totals for storms during which stormflow composite samples were collected. Station names and Providence Water Supply Board station numbers are given in table 1; locations are shown in figure 1.

Figure 4. U.S. Geological Survey (USGS) technician collecting an isokinetic equal-width increment sample at Rush Brook at Elmdale Road near North Scituate, Rhode Island (USGS streamgage 01115114; Providence Water Supply Board station 15); view looking downstream. Station location shown on figure 1. Photograph by Meghan Santos, U.S. Geological Survey.

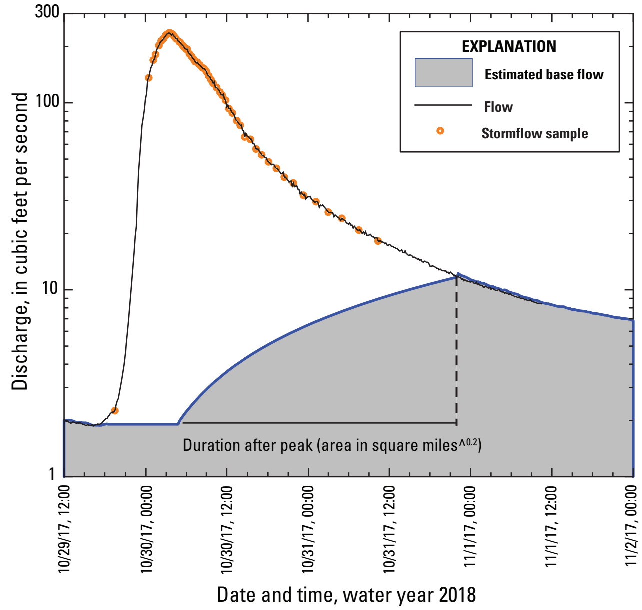


Figure 5. Example of automated flow-proportional collection of stormflow subsamples at Rush Brook near Elmdale Road near North Scituate, Rhode Island (U.S. Geological Survey streamgage 01115114; Providence Water Supply Board station 15), water year 2018. Location of station shown in figure 1. Duration after peak is estimated based on equation 1.

To collect stormflow composite samples, each automatic sampler was configured to hold four 3.5-L polyethylene bottles and fitted with a precleaned half-inch, inner-diameter polyethylene intake and a short piece of silicon pump-head tube. Sample bottles were cleaned with phosphate-free, laboratory-grade soap and tap water; then immersed in a 5-percent solution of hydrochloric acid for at least 6 hours; and finally rinsed with deionized water until the specific conductance of the waste rinse water was less than 1 microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C). Automatic sampler lines and pump-head tubing were cleaned after each sampling event using only phosphate-free, laboratory-grade soap and then thoroughly rinsed with deionized water. For a storm composite sample, two sequential aliquots (200 milliliters [mL] each) were collected for each flow-proportional interval. One aliquot was dispensed into a modified bottle containing a funnel connected to a peristaltic pump controlled by the datalogger. This aliquot was subsequently pumped through a 600-square-centimeter (cm^2) capsule filter with 0.45-micrometer (µm)-sized pores into a preacidified bottle affixed to the wall of the gage structure (fig. 6); the second aliquot was collected into the unfiltered (whole-water) sample bottle, which was also preacidified with 2 mL of dilute sulfuric acid. Field crews added a fixed amount of acid to the bottles prior to sample collection to maintain low pH in the samples and to prevent DP from partitioning to the bottle walls. The third bottle was used for unfiltered samples if the storm runoff volume exceeded estimates; any samples collected in this bottle would then be combined in a churn with the other unfiltered sample aliquots during sample processing. The fourth bottle was not preacidified; this bottle was reserved for occasional noncomposited stormflow samples intended to capture the high and low ends of specific-conductance ranges.

Physical properties, including specific conductance and turbidity, were measured in base-flow samples during sample processing. Water samples were processed in the USGS laboratory in Northborough, Massachusetts, after each storm or scheduled base-flow sample collection. Composite stormflow samples were picked up from the monitoring station within 24 hours of the end of the sampling period. The pH of the samples was determined with a pH meter prior to processing. Nutrient analyses require that sample pH be between 1.60 and 1.95 standard units, so additional sulfuric acid was added if the sample pH was above this range. Composite samples were left overnight after pH adjustment and prior to processing to leach any phosphorus that may have partitioned to the bottle wall. Subsamples were split directly from the unfiltered bottle or from a 14-L polyethylene churn whenever two unfiltered sample bottles were combined. One subsample was filtered with a vacuum-filtration apparatus equipped with a 25-millimeter diameter, 0.65-µm pore size disc filter. The filter

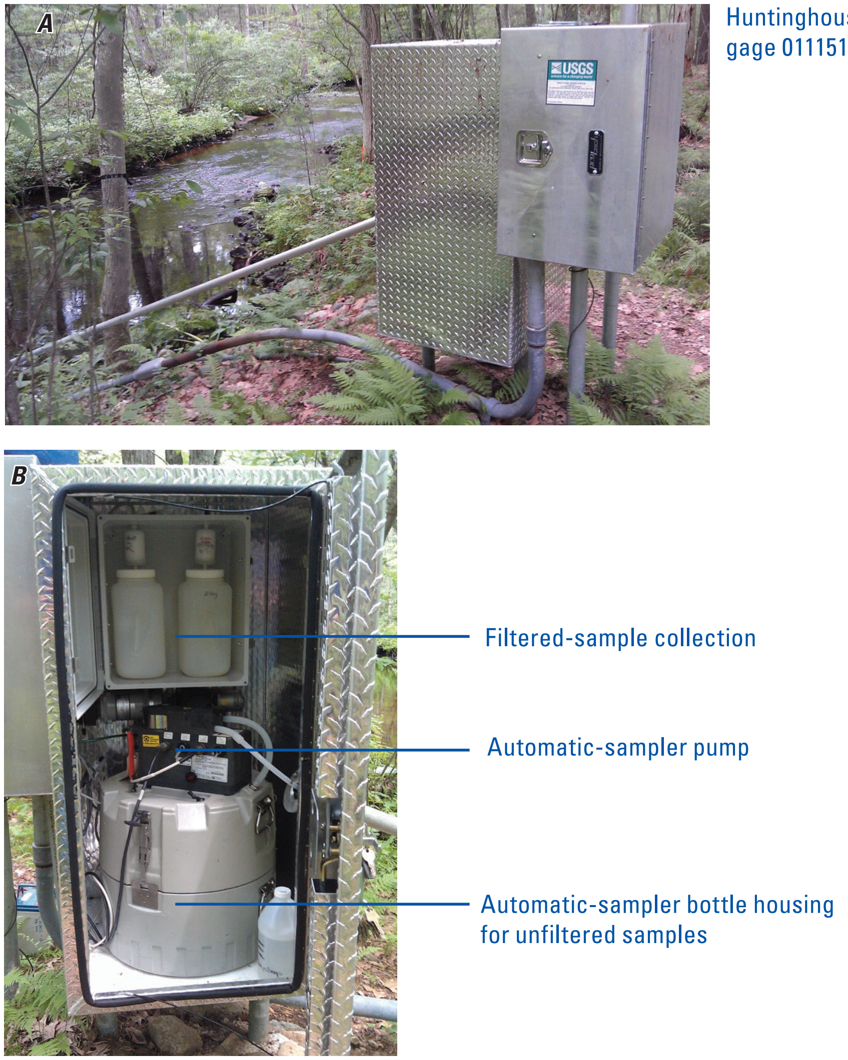


Figure 6. *A*, U.S. Geological Survey streamgage 01115110 (Providence Water Supply Board station 14) Huntinghouse Brook at Elmdale Road near North Scituate, Rhode Island, looking downstream, and *B*, the sampling system used to collect flow-proportional filtered and unfiltered composite samples of stormflow at this streamgage. Station location shown on figure 1. Photographs by the U.S. Geological Survey.

was submitted to the laboratory for particulate nitrogen (PN) analysis, whereas the filtrate was submitted for DN analysis. The deviation from the customary 0.45-µm pore size filter for DN analysis was necessary to avoid contamination issues associated with the capsule filter inline filtration. Composite samples of stormwater were not analyzed for major ions. After the processing, the samples were packed in ice and shipped overnight to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, where samples were analyzed for major ions or nutrients. Suspended-sediment concentrations were analyzed at the USGS Kentucky Sediment Laboratory in Louisville, Kentucky.

Streamflow, Specific Conductance, and Precipitation

The USGS collected and analyzed continuous-record specific-conductance data and streamflow at 14 streamgages in WYs 2009–19 (fig. 1; table 1). Streamflow measurement was discontinued at four stations in WY 2014, but specific-conductance monitoring continued. Streamflow at each station was computed with a relation between gage height and discharge, which was developed and maintained based on periodic streamflow measurements (Rantz and others, 1982). Concurrent specific-conductance measurements were recorded automatically at 10- or 15-minute intervals at each streamgage. Measurements were made using an instream probe and standard USGS methods for continuous water-quality monitoring in streams (Wagner and others, 2006). Streamflow and specific-conductance data are available through the NWIS web interface (U.S. Geological Survey, 2020b).

A meteorological station was operated at Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19; fig. 1). Precipitation data at Moswansicut Reservoir were collected using a weighing-bucket gage (beginning WY 2018) and an unheated tipping-bucket rain gage (beginning WY 2015; fig. 7). Snowfall and air temperature were also recorded at Moswansicut Reservoir. The Moswansicut

Figure 7. Meteorological equipment located near U.S. Geological Survey streamgage 01115170 (Providence Water Supply Board station 19), Moswansicut stream near North Scituate, Rhode Island. Location of station shown on figure 1. Photograph by Phillip Woodford, U.S. Geological Survey.

precipitation record was used to define antecedent conditions for the five stations where storm samples were collected. The meteorological data are available in NWIS (U.S. Geological Survey, 2020b).

Data Collected by the Providence Water Supply Board

Water-quality data from WYs 2013–19 were obtained annually from a water-quality database maintained by PWSB and are published in USGS annual reports and data releases (Richard Blodgett, Providence Water Supply Board, written commun., 2005–19; Smith, 2015a, 2016, 2018a, b, c, d, 2019a, b, 2021, 2022a, b). During WYs 1996–2019, 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 and generally reflect a range of streamflow conditions with respect to time (Nimiroski and others, 2008; Smith, 2015b). Occasionally, samples could not be collected because streams were dry or frozen.

Water-quality samples were collected by PWSB by dipping the sample bottle into the stream at the center of flow (Richard Blodgett, PWSB, written commun., 2005). Samples were transported in ice to the water-quality laboratory of PWSB at the P.J. Holton Water Purification Plant in Scituate, R.I., for analysis. Samples were not filtered prior to analysis. Sample-collection, analytical, and laboratory quality assurance/quality-control procedures are described in a PWSB quality-assurance program manual that has been periodically revised to reflect changes in protocol (Providence Water Supply Board Water Quality Laboratory, 2005, 2012, 2018).

Physical properties and constituent concentrations measured by PWSB in the water samples included pH, color, turbidity, total coliform bacteria, *Escherichia coli* (*E. coli*), alkalinity, Cl, nitrite, nitrate, and orthophosphate (table 5). The PWSB Water Quality Laboratory used analytical methods documented by the American Public Health Association (2018e) to measure pH, color, turbidity, alkalinity and concentrations of bacteria, Cl, and nitrite. Nitrate concentrations were determined by Standard Method 4500-NO_3-part F (American Public Health Association, 2018a) at a contracted laboratory during WYs 2015–19 with a reporting limit of 0.05 mg/L as nitrogen (N); prior to WY 2015, nitrate analyses were performed at the PWSB Water Quality Laboratory using the Hach Nitrate LR Method with a reporting limit of 0.01 mg/L as N (Hach Method 8192; Hach Company, 2000). Orthophosphate concentrations were determined with the Hach PhosVer Method. This method has a lower reporting limit of 0.0065 mg/L as P (Hach Method 8048; Hach Company, 2000). Orthophosphate concentration results were reported as less than (<) 0.003 mg/L and <0.0065 mg/L as P in the data furnished by PWSB. The PWSB laboratory changed the analytical method for measuring bacteria concentrations twice since data collection began. Bacteria was initially measured using Standard Method 9221 (multiple tube fermentation), which has an analytical range of 3 to 2,400 colony-forming units per 100 milliliters (CFU/100 mL) (American Public Health Association, 2018b). Between July 2012 and August 2016, the analytical method for bacteria was Standard Method 9222 (American Public Health Association, 2018c). Bacteria results between these dates are censored below 10 CFU/100 mL. In September 2016, the analytical method for bacteria was changed to Standard Method 9223 B, Colilert media, and the detection limit was lowered to 1 CFU/100 mL (American Public Health Association, 2018d); however, left-censored results are present at 10 CFU/100 mL for total coliform and at 1, 2, 5, 10 and 20 CFU/100 mL for *E. coli*. Detection limits have changed because of the changes in analytical methods, and the presence of multiple reporting limits in the dataset are because of variations in sample preparation (dilutions). For example, bacteria concentrations were commonly censored below 10 CFU/100 mL during WYs 2017–19, when the method detection limit was 1 CFU/100 mL, because

Table 5. Water-quality constituents, analytical methods, reporting limits, and sampling periods for samples collected by the Providence Water Supply Board in the Scituate Reservoir drainage area, Providence, Rhode Island, water years 1983–2019.

[Standard Methods from American Public Health Association (2018a, b, c, d, e). Methods and reporting limits separated by semicolons represent different periods of collection. NTU, nephelometric turbidity unit; PCU, platinum-cobalt unit; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; H^+, hydrogen; N, nitrogen; NO_2, nitrite; NO_3, nitrate; CFU, colony-forming unit; mL, milliliter; P, phosphorus; Cl, chloride; PO_4, orthophosphate; --, not applicable]

Constituent name	Units	Method	Method detection limit(s)	Period of collection
Turbidity	NTU	Standard Method 2130 part B, Nephelometric Method	--	1983–2019
Color	PCU	Standard Method 2120 part B, Visual Comparison Method	0.001	1983–2019
Alkalinity	mg/L as $CaCO_3$	Standard Method 2320 part B, Titration Method	--	1983–2019
pH	Standard units	Standard Method 4500-H^+ part B, Electrometric Method	--	1983–2019
Nitrite	mg/L as N	Standard Method 4500-NO_2 part B, Colorimetric Method	0.001	1985–2019
Nitrate	mg/L a N	Hach Nitrate LR Method, Hach Method 8192; Contract Laboratory, Standard Method 4500-NO_3 part F;	0.01; 0.05	1987– September 2014; October 2015–2019
Total coliform bacteria	CFU/100 mL	Standard Method 9221 (multiple tube fermentation); Standard Method 9223 part B; Standard Method 9222 (Colilert media)	3–2,400; 1; 1	1983–June 2012; July 2012–August 2016; September 2016–2019
Escherichia coli	CFU/100 mL	Standard Method 9221 (multiple tube fermentation); Standard Method 9223 part B; Standard Method 9222 (Colilert media)	3–2,400; 1; 1	1997–June 2012; July 2012–August 2016; September 2016–2019
Orthophosphate	mg/L as P[1]	Hach PhosVer Method, Hach Method 8048	0.0065	1997–2019
Chloride	mg/L	Standard Method 4500-Cl part B, Argentometric Method	0.01	1983–2019

[1]The Providence Water Supply Board Water Quality Laboratory reports orthophosphate in units of mg/L as PO_4, but data are converted to mg/L as P for consistency in reporting. Method detection limit is 0.02 mg/L as PO_4.

a 10-times dilution was applied to samples prior to analysis (Nicole Mucci, PWSB, written commun., 2020). Sampling conditions resulted in occasional gaps in the data, and not all constituents were analyzed throughout the entire 36-year period, WYs 1983–2019 (table 5).

Data-Quality Assessment

Quality-control (QC) samples were collected to determine bias and variability associated with sample data. As part of the USGS water-quality data collection in WYs 2009–19, field replicates and field blank samples were collected in accordance with USGS guidelines (Mueller and others, 2015). PWSB did not collect QC samples, but the PWSB laboratory processed replicate samples collected by USGS personnel and participated informally in the USGS Quality Systems Branch (QSB) standard reference sample (SRS) interlaboratory comparison study from spring 2015 to fall 2017, and formally from spring 2018 to fall 2019 (U.S. Geological Survey, 2021). Insufficient QC data are available to characterize the quality of PWSB data for the complete sampling period of WYs 1984–2019.

U.S. Geological Survey Quality-Control Data

Blank samples are used to assess bias caused by contamination introduced in sample collection and processing methods (Mueller and others, 2015). Thirty-three field blank samples were prepared in WYs 2009–19 at 12 USGS monitoring stations (number of analytes varied per sample) in association with samples collected by USGS; field blank results are published in the companion data release to this report and summarized in table 6 (Spaetzel and Smith, 2022). Field blanks collected from the autosamplers (at three stations) only include total nutrients and SSC, whereas manual field blanks (at nine stations) also include nutrient species and major ions. The latter constituents were not collected during storm events, except for discrete samples collected during occurrences of extreme low or high specific conductance or for other quality-control tests. Nutrient and sediment data are associated with samples collected in WYs 2015–19, as part of the nutrient and sediment loading study performed at five stations.

Constituent concentrations in most blank samples were below the detection limits and indicate that the equipment cleaning, sample collection, processing, and analytical steps were satisfactory to prevent contamination of the water-quality sample. Detection limits for major ions, Ca, Cl, Mg, K, Na, and SO_4, changed during WYs 2009–19, by varying magnitudes. Blank detections are compared to the detection limit at the time the sample was analyzed. The only major ion

Table 6. Summary of field blank sample detections in quality-control data collected by U.S. Geological Survey in the Scituate Reservoir drainage area, Rhode Island, water years 2009–19.

[Quality-control data available in Spaetzel and Smith (2022). Field blanks collected with an autosampler and manually collected field blanks are reported together. mg/L, milligram per liter; E, estimated laboratory concentration; <, less than; --, not applicable]

Constituent	Number of samples	Number of samples with concentrations greater than the reporting limit	Maximum detected blank water concentration (mg/L)	Minimum environmental concentration (mg/L)
Calcium	14	1	E 0.01	1.68
Chloride	14	0	--	9.5
Magnesium	14	0	--	0.429
Potassium	14	0	--	0.68
Sodium	14	0	--	6
Sulfate	14	0	--	2.13
Dissolved phosphorus	19	2	0.006	0.004
Orthophosphate	17	0	--	<0.004
Total phosphorus	19	2	0.011	0.004
Total dissolved nitrogen	19	2	0.23	0.11
Total nitrogen[1]	21	0	--	0.15
Particulate nitrogen	16	1	0.047	<0.030
Dissolved ammonia	15	1	0.01	<0.01
Nitrate plus nitrite	17	0	--	0.01
Nitrite	17	1	E 0.001	<0.001
Suspended sediment concentration	13	4	1	1

[1]U.S. Geological Survey parameter code 62855.

with a single detection was Ca, and the blank concentration (0.01 mg/L) was estimated below the laboratory detection limit, which is also an order of magnitude lower than the minimum environmental concentration (minimum concentration measured in samples that represent environmental conditions) (table 6). Ammonia and nitrite each had a single blank concentration at their respective detection limits. Concentrations of DP in two field blanks were measured just above the detection limit at 0.0065 mg/L, with one sample not having an accompanying TP value; however, the second sample had a similar TP concentration (0.007 mg/L). A separate sample had a TP detection (0.011 mg/L) without an accompanying DN detection (table 6). One DP field blank result and one TP field blank result were affected by contaminated acid preservative and are not reported in the accompanying data release or table 6. Environmental samples affected by the contaminated acid preservative were not used in analyses herein and are not publicly available in NWIS. Total dissolved nitrogen was measured in two blank samples; the first contaminated sample with a DN concentration equal to 0.23 mg/L was identified early in the project and linked to organic ammonia leaching from the inline filtration system at each station (table 6). Inline filtration for DN was discontinued, and the filtrate from the PN filtration process was submitted for DN analysis for stormwater samples, as described above. DN concentrations measured in samples collected through the inline filtration process are not included in the analyses or published in NWIS. A second contaminated blank sample resulted after the change in filtration method, but the detected concentration was equal to the detection limit (0.05 mg/L).

Concurrent replicate samples are samples that are collected from the same location at approximately the same time using the same methods; these samples are compared to assess the variability introduced by sample collection, processing (splitting and [or] filtering), and laboratory analysis (Mueller and others, 2015). Irreplicate samples, samples collected at the same time and location but with different methods, are used to assess comparability of different collection methods or processing techniques (Mueller and others, 2015); these samples also encompass the variability introduced by laboratory analysis. Irreplicate samples were used in this study to assess whether samples collected at a single point in the stream channel with an automated sampler were representative of the stream cross section. Samples collected with an automated sampler were compared to samples collected concurrently using the isokinetic, equal-width increment technique (U.S. Geological Survey, 2006). Replicate grab samples were manually collected during base-flow conditions by dipping a 2-L polyethylene bottle into the centroid of flow, similarly to how the environmental base-flow samples were collected. On average, 56 percent of the sample pairs for each constituent were irreplicates and 44 percent were replicate pairs;

however, some exceptions resulted because not all nutrient species were measured in each sample set. Replicate and irreplicate pairs were compared by determining the absolute value of the relative percent difference (absolute relative percent difference; RPD) of paired concentrations. Irreplicate sample pairs generally had similar ranges of RPDs and are combined in the summary of quality-control data to reflect overall variability across the range of observed environmental conditions (table 7). RPD cannot be determined when one or both of the paired results are censored, so the number of sample pairs with at least one censored result are reported, as well as the number of sample pairs with matching censored results. The overall low RPDs of these samples indicate low variability, which means that samples collected with automated sampling techniques are good representations of the stream cross section and that the variability, introduced by sample collection, processing, and analysis, is minimal.

The observed RPD values were compared with laboratory-performance data that reflect analytical variability. The USGS QSB reports performance data for the USGS NWQL collected by repeated measurements of blind quality-assurance samples over time as part of the inorganic blind sample project (U.S. Geological Survey, undated). Observed RPDs similar to or less than the QSB average relative standard deviation (RSD) indicate that sample collection and processing do not introduce more variability than is expected because of laboratory analysis alone. The RSD values reported in table 7 reflect analytical quality-assurance results for most constituents during WYs 2007–20. The RSD is the ratio of the standard deviation of many replicate concentrations to the mean of those concentrations and is written as a percentage. Ideally, the collection and processing of samples will not introduce variability; however, in practice, the RPDs of environmental replicates can be large for samples with low-level concentrations (near the respective detection limits) and small arithmetic differences between measured replicate concentrations and for constituents associated with sediment that can be difficult to split in a completely representative manner.

Concentration data for dissolved major ions were precise, and the average RPD values for each ion, which ranged from 0.55 to 2.7 percent, were less than the QSB average RSDs (table 7). Nutrient results tended to have larger ranges in RPDs, and seven constituents had sample pairs with at least one censored result. Most censored sample pairs agreed for orthophosphate, ammonia, nitrate plus nitrite, and nitrite. The average RPD values for DN and total nitrogen (U.S. Geological Survey parameter code 62855) were similar to the QSB average RSDs at 4.1 percent and 5.8 percent, respectively (table 7). The average RPD values for DP and TP were 11 percent and 12 percent, respectively; however, some

Table 7. Summary of replicate quality-control samples collected by U.S. Geological Survey in the Scituate Reservoir drainage area, Rhode Island, water years 2009–19.

[Quality-control data available in Spaetzel and Smith (2022). A matching censored sample pair is a replicate pair where both results are left censored (less than reporting limit). RPD, absolute relative percent difference; QSB, U.S. Geological Survey Quality Systems Branch; RSD, relative standard deviation in percent; --, not applicable]

Constituent	Number of sample pairs	Minimum RPD	Median RPD	Average RPD	Maximum RPD	QSB average RSD	Number of sample pairs with at least one censored result	Matching censored sample pairs
Calcium	25	0.0	1.2	2.3	8.5	3.0	--	--
Chloride	25	0.0	0.20	0.55	4.0	1.6	--	--
Magnesium	25	0.0	0.97	1.9	6.7	2.9	--	--
Potassium	25	0.0	1.8	2.7	11	4.3	--	--
Sodium	25	0.0	1.7	2.0	7.8	4.0	--	--
Sulfate	25	0.0	0.19	0.67	5.4	2.3	--	--
Dissolved phosphorus	27	0.0	8.3	11	55	2.6	5	1
Orthophosphate	20	0.0	2.2	5.7	18	3.2	16	15
Total phosphorus	28	0.0	7.2	12	61	3.0	--	--
Total dissolved nitrogen	31	0.0	3.3	4.1	21	4.5	--	--
Total nitrogen[1]	36	0.0	3.6	5.8	21	5.3	--	--
Particulate nitrogen	29	1.1	25	26	73	--	16	10
Dissolved ammonia	18	0.0	0.0	9.7	67	3.2	7	6
Nitrate plus nitrite	21	0.0	1.9	6.5	46	4.0	5	5
Nitrite	21	0.0	0.0	1.1	5.7	--	16	13
Suspended- sediment concentration	27	0.0	40	47	182	--	2	0

[1]U.S. Geological Survey parameter code 62855.

replicate samples differed by as much as 61 percent. The average RPD for SSC was high at 47 percent. However, the environmental concentrations tended to be low and, under these conditions, the differences between the replicates are exaggerated because the results are reported in whole numbers—that is, a sample pair consisting of a concentration of 1 and 2 mg/L results in an RPD of 67 percent. Whereas the quality of replicate data results for nutrients and sediment varied, consistent significant bias was not identified.

Providence Water Supply Board Quality-Control Data

The PWSB Water Quality Laboratory processed environmental replicate samples collected by USGS periodically between WYs 2015 and 2019. The samples were collected sequentially in 2-L bottles in the center of the stream. One sample was processed by USGS and sent to the NWQL for analysis, and the second sample was submitted to the PWSB laboratory for pH, color, turbidity, alkalinity, Cl, nitrate, and orthophosphate analyses to characterize the comparability of analytical results from the two laboratories (each using different methods and processing). The USGS did not process samples for bacteria; instead, replicate samples of streamwater were collected by the USGS in sterile bottles and submitted to the PWSB laboratory for total coliform bacteria and *E. coli* analyses; these replicates reflect the variability introduced by sample collection, processing, and laboratory analysis (Mueller and others, 2015). RPDs were computed for samples with paired uncensored results. RPD cannot be determined when one or both of the paired results are censored, so the number of sample pairs with at least one censored result is reported, as well as the number of sample pairs with matching censored results. It is important to note that USGS samples were filtered for all analyses except turbidity, whereas PWSB samples were not filtered for any analysis. Therefore, these sample comparisons may reflect, in part, the effect of the processing differences between the two laboratories. Orthophosphate results measured by PWSB were always higher than those measured by USGS because the analysis of unfiltered sample water for orthophosphate included both dissolved and suspended orthophosphate. Nitrate results (n=10 uncensored pairs) and orthophosphate results (n=6 uncensored pairs) consistently had the highest magnitude RPDs between the two laboratories, whereas pH had the highest agreement between laboratories, with RPDs ranging from 0 to 7 percent for sample pairs (table 8). Measurements of turbidity, color, and pH, as well as concentrations of Cl, were consistently higher in USGS results than PWSB results, whereas nitrate and orthophosphate results were consistently lower as measured by USGS. *E. coli* and total coliform

Table 8. Summary of quality control data replicate comparisons and standard reference sample comparisons collected at Providence Water Supply Board stations in the Scituate Reservoir drainage area, Rhode Island, calendar years 2015–19.

[Providence Water Supply Board (PWSB) quality-control data published by Smith (2018c, d; 2019b; 2021). A matching censored sample pair is a replicate pair where both results are left censored (less than reporting limit). Acceptable range is defined as within 2 F-pseudosigma of the most probable value (MPV). Absolute relative percent differences (RPDs) computed with uncensored samples pairs. USGS, U.S. Geological Survey; --, not applicable]

Constituent	Replicate							Standard reference samples	
	Number of uncensored sample pairs	Minimum RPD	Median RPD	Average RPD	Maximum RPD	Number of sample pairs with at least one censored result	Matching censored sample pairs	Number of samples	Number of samples within acceptable range of MPV
PWSB and USGS laboratories[1]									
Turbidity	12	6.6	17	35	132	--	--	--	--
Color	11	0.0	22	26	87	--	--	--	--
Alkalinity	4	1.3	20	31	82	--	--	3	3
pH	10	0.0	1.4	2.4	7	--	--	8	6
Chloride	12	1.7	5.5	7.0	25	--	--	8	3
Nitrate	10	17	40	60	132	2	0	7	5
Nitrite	2	--	--	--	--	10	0	--	--
Orthophosphate	6	15	69	74	131	4	1	12	9
PWSB laboratory									
Escherichia coli bacteria	3	13	33	45	89	3	2	--	--
Total coliform bacteria	6	13	23	25	39	--	--	--	--

[1]Samples analyzed by PWSB were not filtered. Samples analyzed by USGS were filtered for all analyses, except turbidity.

bacteria replicates were analyzed by PWSB exclusively; results were variable and samples sizes were small (*n*= 3 and 6, respectively).

The PWSB laboratory processed USGS QSB standard reference samples (SRSs) approximately twice per year during WYs 2015–19 for pH, alkalinity, Cl, nitrate, and orthophosphate. SRS results are assessed by the USGS QSB using nonparametric statistics described by Hoaglin and others (1983). SRSs analyzed by PWSB are characterized with respect to the SRS most probable value (MPV) to determine if the results are within an acceptable range. QSB defines the acceptable range as a value within two F-pseudosigmas (Fps) of the MPV, where one Fps is comparable to one standard deviation in traditional statistics (Hoaglin and others, 1983; Woodworth and Connor, 2003). Most or all of the SRSs analyzed by PWSB were within the acceptable range of the MPV except for Cl results (table 8). Of eight SRSs analyzed for Cl, only three were within an acceptable statistical range. Those results, which fell outside of the acceptable range, were typically less than the MPV and ranged from 4.8 Fps to 21 Fps away from the MPV. For other constituents, SRS results did not exceed 10 Fps from the MPV and were not consistently higher or lower than the MPV.

The interpretations of water-quality analyses for this study were limited in some cases by a lack of available information about the historical and current (2019) water-quality data collected by PWSB. For example, it was not possible to evaluate the accuracy, precision, or bias of laboratory analyses because laboratory QC data were not available for the entire period of record (1983–2019). More attention has been given to quality-assurance/quality-control (QA/QC) measures since 2015; however, a more robust QA/QC plan would improve future data-quality assessments. It was not possible to evaluate the in situ variability of values of physical properties and constituent concentrations nor the potential for sample contamination because field QC data were not available. Whenever possible, statistical approaches were used to minimize the limitations that may have resulted from the use of available data or to ensure 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 and considered outliers. The use of nonparametric, rank-based analytical methods reduced the potential effects of these outliers.

Changes in analytical methods or laboratory personnel could be sources of variability and may affect trends in the water-quality data, but such changes and their effect on the data are difficult to quantify. The effect of analytical method changes cannot be quantitatively determined because replicate samples measured with both methods are not available. The data indicate that changes in analytical methods for nitrate and bacteria have substantially affected concentrations; therefore, the results of trend tests are not reported for these constituents. The presence of multiple reporting limits in the data complicates routine statistical analyses. Whenever possible, statistical tests were used that accommodate multiple reporting limits. Less than half of 1 percent of orthophosphate concentrations were left censored at values of 0.98 mg/L as P or 3.3 mg/L as P. Because these values are left censored, exceed the analytical method detection upper limit (0.82 mg/L as P), and are a small fraction of the dataset, these values were excluded from subsequent analyses. Because of limited ancillary data, the values cannot be verified but are considered as suspected errors.

Data-Analysis Methods

Water-quality data collected by PWSB and USGS were analyzed to characterize conditions in tributary subbasins, test for correlations and trends, and estimate constituent loads and yields. Nonparametric statistical tests and statistical tests designed to analyze censored data were used to determine the presence of censored data and nonnormal distributions. Daily loads were computed using PWSB concentration data and daily mean flow for those stations with estimated or measured flow data. Daily Cl and Na loads were estimated from continuous measurements of specific conductance. Annual loads of nutrients and suspended sediment were estimated using two methods (stratified and regression) for WYs 2016–19. These methods are discussed in detail later in the report.

Characterization of Water-Quality Conditions

Water-quality properties and constituent concentrations measured during WYs 2013–19 by PWSB at 37 stations were summarized from median values determined using the nonparametric Kaplan-Meier method (KM; Kaplan and Meier, 1958; Helsel, 2011). Median values are reasonable for summarizing samples collected using a fixed-frequency sampling approach, such as used by PWSB, because the samples are collected regardless of streamflow conditions. PWSB samples reflect a random sampling of flow conditions as a function of time. Median values were not determined for Toad Pond (USGS station 01115177; PWSB station 31; fig. 1) because only two samples were collected during WYs 2013–19. For this station, the individual sample results were reported and were not considered when determining the minimum, median, or maximum of median values at all stations. For constituents with greater than or equal to 50 percent censored observations, the median was reported as less than the censored value. For constituents with a single reporting limit and less than 50 percent censored results, the median determined by KM will equal the median determined after substituting half the reporting limit for censored observations; therefore, median concentrations in this study are generally comparable to previous investigations in the drainage area (Smith, 2015b). Percentages of censored results were generally between 0 and 10 percent for total coliform bacteria and orthophosphate but greater than 10 percent for *E. coli* and nitrate concentrations. The percentages of censored *E. coli* or nitrate concentrations exceeded 50 percent at some stations. KM was selected for constituents with censored data to avoid recensoring the data at the highest reporting limit or substituting half the reporting limit for variably censored data; substituting half the reporting limit for these variably censored data can introduce inaccurate ranking of observations (Helsel, 2011).

Compilation and Analysis of Streamflow and Continuous Water-Quality Data

Streamflow data have been collected at 23 of the 37 PWSB monitoring stations (table 1) since 1994. Streamflow has been monitored continuously at Ponaganset River (USGS streamgage 01115187; PWSB station 35; fig. 1) and Peeptoad Brook (USGS streamgage 01115098; PWSB station 16; fig. 1) since 1994 and at 12 additional stations since WY 2009; 4 of these stations were discontinued at the end of WY 2014 (short-term stations; table 1). Continuous records predominantly consist of streamflow measurements recorded every 10 minutes, but changes in recording may have resulted because of stream conditions or temporary equipment malfunction. Streamflow was measured intermittently at nine other stations (partial-record stations) during WYs 1994–2019. Specific conductance and water temperature have also been monitored concurrently (every 10 minutes) with streamflow at 14 stations since WY 2009 (table 1). Streamflow, specific-conductance, and water-temperature data are available through NWIS (U.S. Geological Survey, 2020b).

Daily mean flow records at the 4 short-term continuous-record stations (WYs 2009–14) and 9 partial-record stations (intermittently measured during WYs 1994–19) were extended from October 1, 2012, to September 30, 2019. Complete daily flow records are necessary to compute loads with the PWSB concentration data. Records were estimated using the Maintenance of Variance Extension Type 1 method (MOVE.1), as described by Ries and Friesz (2000) and implemented in the Streamflow Record Extension Facilitator program (SREF Version 1.0; Granato, 2009). The SREF program is used to retrieve flow measurements and continuous-record data from NWIS (U.S. Geological Survey, 2020b) and simulates the flow relation in log (base 10) space. In the MOVE.1 method, an equation is developed to relate either measured instantaneous streamflow (at a partial-record station) or daily mean streamflow (at a short-term station) to corresponding daily flow values from a continuous-record streamgage. This equation is given as

$$Q = q^{m} \times b, \qquad (2)$$

where

Q is the daily mean flow at the station of interest, in cubic feet per second;

q is the daily mean flow at the reference station, in cubic feet per second;

m is the slope from the MOVE.1 analysis (table 9); and

b is the y-intercept from the MOVE.1 analysis (table 9).

When the regression equation described above (eq. 2) is developed, streamflow at the ungaged partial-record station or short-term station can be estimated for any date on which the continuous-streamflow records are available at the selected reference station. It is assumed that the relation between flow at the partial-record station or short-term station and flow at the continuous-record index station remains constant through time and is consistent over the range of flows in the period of interest.

Ten continuously monitored streamgages within the Scituate Reservoir drainage area and one nearby streamgage on the Pawtuxet River at Cranston, R.I. (USGS streamgage 01116500), were considered as potential reference stations for the 9 partial-record and 4 short-term stations of interest. The reference station that produced the best linear relation for each station of interest was selected to extend the record. For the short-term continuous stations of interest, the best fit was selected based on root mean square error (RMSE) and visual inspection of linearity. For partial-record stations of interest, the number of paired flow values was also considered in order to capture a wider range of flow conditions in the partial-record data. For example, the relation between partial-record station Brandy Brook (USGS station 01115180; PWSB station 1; fig. 1) and potential reference station Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19; fig. 1) had a RMSE equal to 0.170 but was characterized by 18 pairs of instantaneous flow and daily mean flow values, whereas the RMSE for the regression between Brandy Brook and Ponaganset River (USGS streamgage 01115187; PWSB station 35) was 0.198 but was characterized by 95 data pairs (table 9). The Ponaganset River station was selected as the reference station for Brandy Brook and four other partial-record stations (table 9). Average standard error of the regressions is a measure of the average variation between regression estimates and observed values; the median of the errors was 52.5 percent (range, from 38.3 to 110 percent; table 9). Regressions were developed using the best available streamflow data but, in some cases, were limited by number of available flow measurements. The drainage area of some stations for which streamflow was estimated was small compared to the available reference stations, which typically results in weaker relations; for example, the Unnamed Tributary to Regulating Reservoir (USGS station 01115120; PWSB station 18) has the largest error and the smallest drainage area (0.28 mi^2).

Hydrograph separation (using the fixed-base method) (Chow and others, 1988; Smith, 2017) was performed on continuous flow records at five stations for which nutrient and sediment loads were estimated for WYs 2016–19 (table 1; fig. 5). Precipitation and air-temperature data from the meteorological station located near Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19) were used to distinguish between storm runoff and isolated snowmelt events. Hydrograph separation was performed on instantaneous measurements (10- or 15-minute frequency)

Table 9. Stations in the Scituate Reservoir drainage area, Rhode Island, for which streamflow data were estimated, water years 2013–19, and U.S. Geological Survey index stations, period of measurements, and Maintenance of Variance Extension Type 1 method regression coefficients.

[Values used in analysis are either discrete measurements at partial-record stations or daily mean streamflows from continuous records at streamgages that were discontinued at the end of water year 2014. Data available in the National Water Information System (U.S. Geological Survey, 2020b). PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey]

PWSB station number (fig. 1)	USGS station number (table 1)	Number of USGS station used in analysis	Number values used in analysis	Years of streamflow measurements	Slope	Intercept	Standard error of regressions (percent)	Period of estimated streamflow (water years)
Barden Reservoir subbasin								
25	01115200	01115187	37	1994–95, 2003, 2009–14, 2018–19	1.5079	0.0332	82.0	2013–19
26	01115185	01115187	88	1994–95, 2003, 2009–14, 2018–19	1.4315	0.0617	52.5	2013–19
Direct runoff subbasin								
1	01115180	01115187	95	1994–95, 2003, 2009–14, 2018–19	0.7157	0.3060	48.1	2013–19
4	01115400	01115276	17	2009–14, 2018–19	2.358	0.0075	84.0	2013–19
5	01115184	01115265	2,225	2008–14	0.8041	0.2686	52.1	2015–19
7	01115297	01115183	2,178	2008–14	0.9210	2.3967	46.1	2015–19
9	01115275	01115276	1,840	2009–14	1.0172	0.1691	38.3	2015–19
32	01115178	01115183	17	2009–14, 2018–19	0.8087	0.2401	39.6	2013–19
33	01115182	01115170	17	2009–14, 2018–19	1.1604	0.0412	54.5	2013–19
Moswansicut Reservoir subbasin								
21	01115165	01115183	17	2009–14, 2018–19	0.6917	0.2655	48.9	2013–19
Regulating Reservoir subbasin								
18	01115120	01115110	1,486	2008–14	1.5719	0.0074	110	2015–19
Westconnaug Reservoir subbasin								
10	01115274	01115187	31	1994–95, 2003, 2009–14, 2018	1.2041	0.0542	57.0	2013–19
11	01115273	01115187	29	1994–95, 2003, 2009–14, 2018	1.0728	0.0533	64.8	2013–19

and averaged over a daily time step to produce records of daily mean flow, daily mean base flow, and daily mean runoff in cubic feet per second. These records are published in the companion data release (Spaetzel and Smith, 2022). The hydrograph-separation method and the method for determining storm-sampling duration for composite stormflow-sample collection are the same; therefore, sampled storm durations are representative of storm durations determined through hydrograph separation. These hydrograph-separation-based records were used to estimate annual loads of phosphorus, nitrogen, and suspended sediment.

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, impervious area, and road density, to median values or concentrations of pH, color, turbidity, total coliform bacteria and *E. coli*, Cl, nitrate, and orthophosphate from WYs 2013–19. Correlation analyses also were performed relating daily mean streamflow to discrete values or concentrations of pH, color, turbidity, total coliform bacteria and *E. coli*, Cl, nitrate, and orthophosphate from WYs 1985–2019. The nonparametric Kendall tau correlation test, a rank-based test that considers and is resistant to outlier results, was used to identify significant correlations (Helsel and others, 2020). For left-censored median concentrations, Kendall's tau was computed using the R package Nondetects and Data Analysis (NADA; Lee, 2020). The NADA package implements a modified form of Kendall's tau that can account for ties resulting from censored data (Helsel, 2011). The null hypothesis that no correlation is present between two variables was rejected at a critical alpha (α) value of 0.05, indicated by a *p* value less than 0.05. At this α-value, there is a 5-percent chance that the null hypothesis will be rejected erroneously. Spearman's rho, which was used in previous studies (Nimiroski and others, 2008; Smith, 2015b), and Kendall's tau correlation tests yield similar *p* values. Kendall's tau was chosen for this study because of the presence of data censored at multiple reporting limits.

Time trends in concentrations of water-quality constituents can indicate long-term changes (usually years) in streamwater quality. Statistical tests to identify trends in the PWSB data were performed for pH, color, turbidity, alkalinity, Cl, nitrite, and orthophosphate at all monitoring stations. Orthophosphate results were uniformly censored at the maximum reporting limit, which was 0.0065 mg/L as P. Trends in water-quality physical properties and constituents were investigated for the 18-year period of WYs 2002–19 and were investigated for a longer 37-year period of WYs 1983–2019, which was inclusive of all available data (Nimiroski and others 2008; Smith, 2015b). Trends during the shorter period considered here reflect more recent trends in water-quality properties and constituent concentrations, whereas trends during the longer period may reflect ongoing or past changes in water quality. Trend tests were also performed for average monthly Cl and Na concentrations derived from continuous specific-conductance records for WYs 2009–19.

Trends for each multiyear period were analyzed with the nonparametric seasonal Kendall test and Theil-Sen slope estimate (Hirsch and others, 1982; Helsel and others, 2020; Helsel, 2011) using the R package EnvStats (Millard and Kowarik, 2020). The seasonal Kendall test accounts for the natural seasonal variation of water-quality properties or constituent concentrations caused by changes in streamflow, temperature, biological activity, or other factors by comparing water-quality results within the same season (month or multiple months). The number of seasons in each test was determined by the minimum sampling frequency. Sites sampled monthly had 12 seasons (months), whereas sites sampled quarterly had 4 seasons. Trend slopes and 95-percent confidence intervals were computed based on the Theil-Sen slope estimator (Hirsch and others, 1982; Millard and Kowarik, 2020) to indicate the magnitude and direction of trends. A trend was considered significant if the calculated *p* value of the test was less than 0.05 (as described previously) and the 95-percent confidence interval about the slope did not include zero. The number of samples, censored results, and sampling period for each station and water-quality property (or constituent) analyzed in the tests for trend are provided to support statistical trend results. Maps of summarized trend results are provided for pH, color, turbidity, alkalinity, chloride, and orthophosphate.

Trend tests were not performed on total coliform bacteria, *E. coli*, and nitrate concentrations because of analytical method changes that coincided with abrupt shifts in the magnitude and distribution of constituent concentration data. The effect of analytical method changes cannot be quantitatively determined because replicate samples measured with both methods during each transition are not available; see table 5 for a description of methods. Because the effect of the analytical changes cannot be quantified, there is no way to determine whether changes in concentrations through time and across different methods are attributable to environmental changes or analytical changes. In the absence of trend tests for total coliform bacteria, *E. coli*, and nitrate, the concentration data for these constituents were characterized in context of the analytical method changes. Changes in analytical methods also resulted in changes in reporting limits (table 5); therefore, to compare across the methodological changes, uniform limits for all properties and constituents were used. For bacteria concentrations, the percentage of samples greater than or equal to 2,400 CFU/100 mL and percentage of samples less than or equal to 10 CFU/10 mL were used to compare the distribution of sample concentrations along with boxplots and KM median concentrations. For nitrate concentrations, which do not have an upper analytical limit, the uniform lower limit of 0.05 mg/L as N was used to compare between the two analytical methods in addition to boxplots and KM median concentrations. These analyses were conducted for the combined datasets from all stations; however, plots of concentrations through time are also provided for six stations to illustrate the observed changes in constituent concentrations at the station subbasin scale.

Estimation of Constituent 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 load by drainage area; computing yields allows for direct comparison of loads among subbasins with varying sizes. Loads and yields of Cl and Na were estimated from continuous records of streamflow and specific conductance, and estimated dissolved concentrations of Cl and Na were derived from correlations with specific conductance for all monitoring stations with these data records (14 stations). Daily loads and yields of Cl, nitrite, nitrate, total coliform bacteria, *E. coli*, and orthophosphate were estimated for stations with available streamflow data (23 stations) using concentration data collected by PWSB. Annual loads and yields of nutrients and sediment were estimated from streamflow and mean constituent concentration. For constituents with a sufficient statistical relation between streamflow and constituent concentration (defined as a concentration-model-adjusted R^2 greater than or equal to 0.20; Aulenbach and others, 2022), regression models were also utilized to estimate loads and yields.

Estimation of Continuous Concentrations, 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, 2015b). In this study, the measurements were used to estimate concentrations and loads of dissolved Cl and Na in 14 subbasins in the Scituate Reservoir drainage area in WYs 2013–19. Concentrations of dissolved Cl and Na were measured in water samples collected during WYs 2009–19 at the 14 continuous-record stations, including the 4 stations where streamflow monitoring was discontinued at the end of WY 2014 (table 1; U.S. Geological Survey, 2020b). Cl and Na concentrations also were estimated from the more frequent, in situ measurements of specific conductance by developing a regression equation to relate specific conductance to the ion concentrations measured in water samples. Continuous specific-conductance data recorded in 10-minute increments were available at 14 stations for nearly every day of the study period and represent a variety of hydrologic conditions (base flow, rain, mixed precipitation, and snowmelt runoff events).

Cl and Na concentrations were estimated from continuous measurements of specific conductance based on equations developed to relate specific conductance to concentrations of the respective ions (see eq. 3 below). These regression equations were developed with the MOVE.1 technique based on concurrent measurements of log-transformed values of specific conductance and log-transformed concentrations of Cl and Na in tributary water samples. Smith (2015b) estimated Cl and Na loads and yields for WYs 2009–12. MOVE.1 regressions developed by Smith (2015b) were updated using all available data for WYs 2009–20. The complete dataset includes 488 discrete samples measured for Cl and Na concentrations. The MOVE.1 technique was chosen for regression analysis because it minimizes errors in both the x and y directions. MOVE.1 generates a unique equation, which can then be used to estimate either variable from the other; the estimations reflect the variance of the measured concentrations (Helsel and others, 2020). The MOVE.1 equation is given as

$$C = (Spc^{m}) \times b, \quad (3)$$

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 10); and
- b is the y-intercept from the MOVE.1 analysis (table 10).

Concentrations of other major ions (SO_4, Ca, Mg, and K) did not vary substantially as specific conductance increased at any station; therefore, specific conductance is a poor surrogate for the concentrations of these ions (fig. 8*A*). Only minimal increases in the concentrations of Ca and SO_4, trace constituents of road salt (Smith and Granato, 2010), resulted over the range of specific conductance. As a result, Cl and Na concentrations, the primary constituents of road salt, governed the relation with specific conductance. Ratios of Na to Cl concentrations in water samples collected throughout the drainage area since WY 2009 varied slightly throughout the period of record but often were similar to the molar ratio of sodium chloride (NaCl; 0.65) (figs. 8*B*, *C*, *D*). Ratios of Na to Cl were highest in the relatively low specific-conductance samples collected at Wilbur Hollow Brook (USGS station 01115297; PWSB station 7; fig. 1), ranging from 0.56 to 0.80. Ratios of Na to Cl concentration higher than 0.65 indicate that the water matrix contains higher Na concentrations from sources other than NaCl, such as sodium carbonate, sodium nitrate, or sodium sulfate. The relatively consistent ratio for Na to Cl concentrations in the water samples over time indicates that the source of these elements remains relatively constant (figs. 8*B*–*D*).

The specific conductance of dilute electrolytic solutions is affected by the matrix of available anions and cations in the sample and the equivalent ionic conductance for each element (Granato and Smith, 1999). The presence and concentration of

Table 10. Data and regression equation coefficients used to estimate concentrations of chloride and sodium from values of specific conductance for each U.S. Geological Survey streamgage in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

[Constituent concentrations and continuous specific conductance available in National Water Information System (U.S. Geological Survey, 2020b). Locations of stations are shown in figure 1. U.S. Geological Survey (USGS) parameter codes: specific conductance, 90095; chloride, 00940; sodium, 00930. PWSB, Providence Water Supply Board]

PWSB station number (fig. 1)	USGS station number (table 1)	Samples used in analyses		Chloride			Sodium		
		Sample data range (month/day/year)	Sample count	Slope	Intercept	Standard error of regressions (percent)	Slope	Intercept	Standard error of regressions (percent)
24	01115190	03/08/2000; 03/29/2005; 01/22/2009 to 01/29/2020	33	1.2568	0.06927	2.3	1.2341	0.04747	4.6
28	01115265	03/28/2001; 03/30/2005; 01/22/2009 to 01/29/2020	34	1.2272	0.07969	3.4	1.1145	0.08224	5.7
35	01115187	03/28/2001; 03/29/2005; 01/22/2009 to 01/14/2020	33	1.0644	0.16539	4.3	1.1690	0.06355	5.4
3	01115280	03/08/2000; 03/30/2005; 01/22/2009 to 01/14/2020	33	1.2248	0.07611	3.0	1.1018	0.08370	5.0
5	01115184	03/05/2009 to 01/29/2020	30	1.2604	0.06112	4.0	1.0811	0.08487	4.4
6	01115183	03/08/2000; 03/30/2005; 01/22/2009 to 01/28/2020	43	1.1794	0.08455	4.2	1.2057	0.04413	5.9
7	01115297	03/28/2001; 03/30/2005; 01/22/2009 to 01/14/2020	33	1.0728	0.12410	4.1	0.88661	0.17736	5.8
8	01115276	01/22/2009 to 01/29/2020	30	1.0995	0.13738	2.9	1.0392	0.11477	3.8
9	01115275	03/08/2000; 03/30/2005; 01/22/2009 to 01/29/2020	32	1.0585	0.17773	2.5	1.0720	0.09770	3.4
19	01115170	03/08/2000; 03/29/2005; 01/22/2009 to 01/14/2020	39	1.2116	0.07599	2.6	1.2080	0.04599	2.8
14	01115110	03/28/2001; 03/29/2005; 01/22/2009 to 01/14/2020	41	1.1225	0.10393	7.1	1.0317	0.09412	7.7
15	01115114	01/22/2009 to 01/28/2020	47	1.1441	0.11191	2.9	1.0839	0.09260	5.2
16	01115098	03/28/2001; 03/29/2005; 01/22/2009 to 01/14/2020	34	1.2598	0.05894	4.3	1.0895	0.08335	6.3
18	01115120	01/22/2009 to 01/14/2020	26	1.1633	0.09758	2.8	1.1463	0.06160	3.4

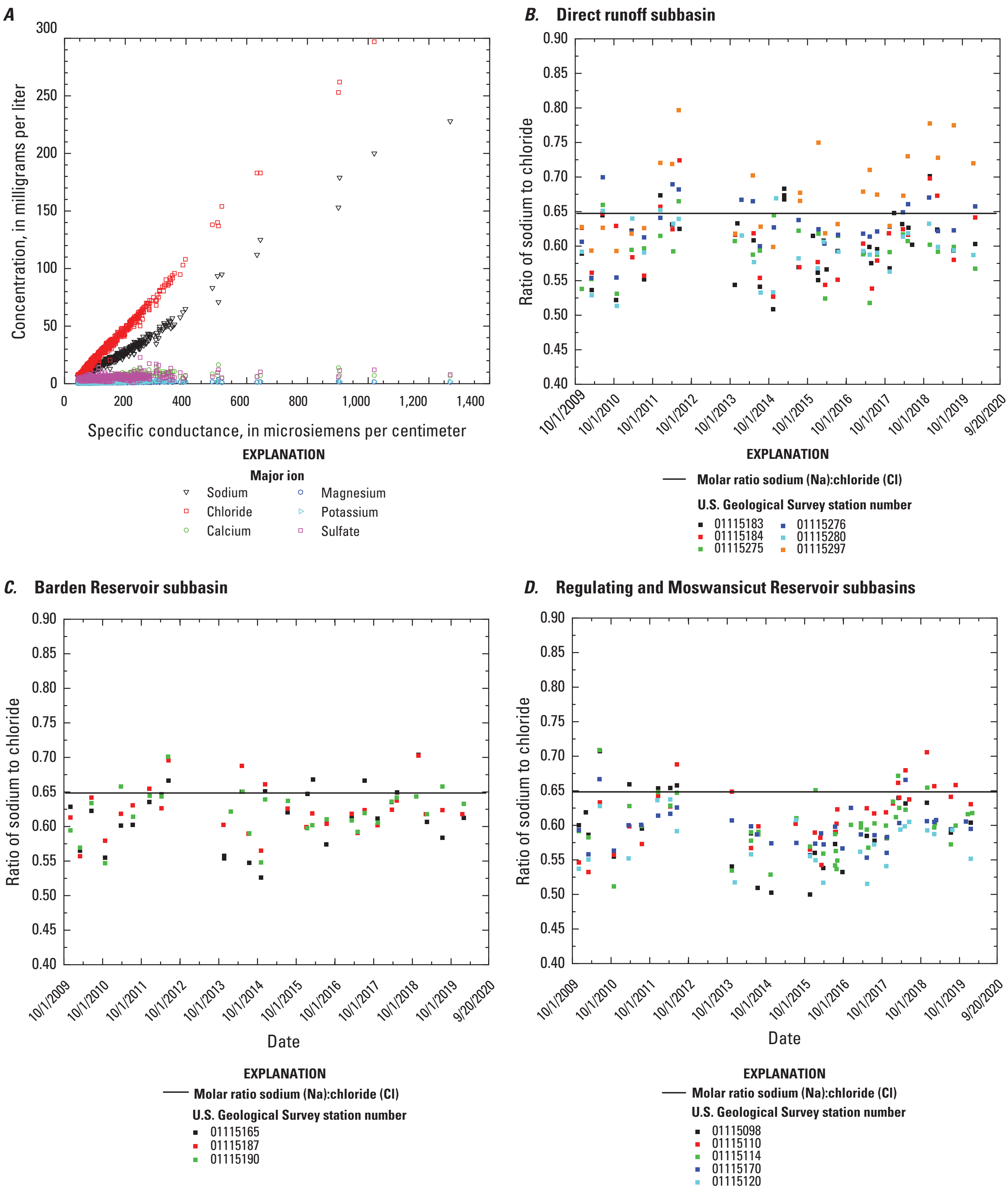


Figure 8. *A*, Relation between specific conductance and concentrations of selected major ions in water samples collected from tributaries at 14 U.S. Geological Survey continuous-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2009–19, and *B*–*D*, the ratios of sodium to chloride in water samples collected in the Direct runoff subbasin (*B*), Barden subbasin (*C*), and Regulating and Moswansicut Reservoir subbasins (*D*). Station names and Providence Water Supply Board station numbers are given in table 1; locations are shown in figure 1.

dissolved organic carbon, which is naturally present, also can attenuate the measured specific conductance. Although there were no substantial differences in the major ion sample matrix between most sites, separate coefficients were developed to improve the average standard error of estimates between the relations of measured specific conductance to measured concentrations of Cl and Na for each site. The average standard error of regressions ranged from about 2.3 to 7.1 percent for Cl equations and from about 2.8 to 7.7 percent for Na equations for all 14 stations (table 10). These equations provide reasonable estimates for dissolved concentrations of Cl and Na based on specific-conductance measurements (fig. 9).

Continuous records (10- or 15-minute frequency) of estimated Cl and Na concentrations and streamflow measurements were used to compute daily concentrations and loads. Daily flow-weighted concentrations of Cl and Na were calculated by summing the product of instantaneous flows and concurrent concentrations of Cl and Na for each 10- or 15-minute period and dividing that sum by the total flow for that day. Instantaneous streamflow was unavailable during WYs 2015–19 at the four short-term continuous-record stations; therefore, daily mean concentrations of Cl and Na were calculated from the daily mean value of specific conductance and the estimated daily mean flow. The latter method described above may result in less accurate concentrations because instantaneous specific-conductance measurements may change (decrease or increase) with surface-water runoff. However, the variability of instantaneous specific-conductance measurements at the four short-term streamgages was generally small, and daily mean values did not differ substantially from daily flow-weighted values. These daily values had been estimated during prior water years when instantaneous flow data were available. Daily loads of Cl and Na were estimated by multiplying daily concentrations of Cl and Na (in milligrams per liter) by daily discharge (in liters per day), and daily loads were summed to estimate annual loads for WYs 2013–19.

Estimation of Providence Water Supply Board Daily Loads and Yields

Daily loads and yields of Cl, nitrite, nitrate, total coliform bacteria, *E. coli*, and orthophosphate were calculated for all dates during WYs 2013–19 when PWSB collected water-quality samples at the 23 stations for which periodic or continuous streamflow data were available (table 1). Each daily load was calculated by multiplying the constituent concentration in a single sample by the daily mean flow for the date when the sample was collected. These daily flows, which were estimated for 13 stations (WYs 2013–19; table 9), were assumed to reasonably represent the flow at the time of the sample collection. 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 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 reflect variability resulting from the above factors, as well as from differences in constituent sources and transport characteristics. Median values of daily loads are given in kilograms per day (kg/d), grams per day (g/d), or millions of colony-forming units per day (CFU × 10^6/d) for bacteria; and yields are given in kilograms per day per square mile (kg/d/mi^2), grams per day per square mile (g/d/mi^2), or millions of colony-forming units per day per square mile (CFU × 10^6/d/mi^2) for bacteria.

For constituents with left-censored data (concentrations reported as less than the minimum reporting limit), minimum loads were calculated by multiplying the daily mean flow by the lower concentration limit of zero, and maximum loads were calculated by multiplying the daily mean flow by the reporting limit. Because right-censored concentrations (values reported as greater than an upper reporting limit) do not have a known concentration interval, loads for right-censored concentrations were computed by multiplying the daily mean flow by the upper reporting limit. Median loads of constituents with left-censored results were determined for the minimum and maximum loads, and the ranges in median loads are reported.

Estimation of Annual Loads and Yields of Nutrients and Sediment

Annual loads and yields of total phosphorus (TP), dissolved phosphorus (DP), total nitrogen (TN, see below), dissolved nitrogen (DN), and suspended sediment (SSC) were estimated for WYs 2016–19 at five stations where USGS collected base-flow water samples and composite stormflow samples. Total nitrogen was computed as the sum of DN (USGS parameter code 62854) and PN (USGS parameter code 49570) (table 4). Although this method is less precise than the analytical results of alkaline-persulfate digestion of unfiltered sample water (USGS parameter code 62855), the method chosen for this study is not subject to the well-documented bias introduced by the digestion step (Rus and others, 2013). Annual-load estimates in this study are estimated with calculated total nitrogen concentrations, herein referred to as total nitrogen or TN.

Loads were estimated using two methods; a regression-model method was used to estimate loads and yields for constituents with a sufficiently strong concentration-flow relation (defined as a concentration-model adjusted R^2 greater than or equal to 0.20; Aulenbach and others, 2022). A second method, referred to herein as the stratified method, is based on streamflow data that have been stratified into base-flow and stormflow volumes and the corresponding mean concentration of either base-flow or stormflow composite samples. Annual loads and yields are reported in kilograms per year (kg/yr) and kilograms per year per square mile (kg/yr/mi^2), respectively.

Regression models using continuous daily flow records and discrete water-quality sample data are commonly implemented to estimate annual loads (Ferguson, 1986; Cohn and others, 1989; Crawford, 1991; Lathrop and others, 2019;

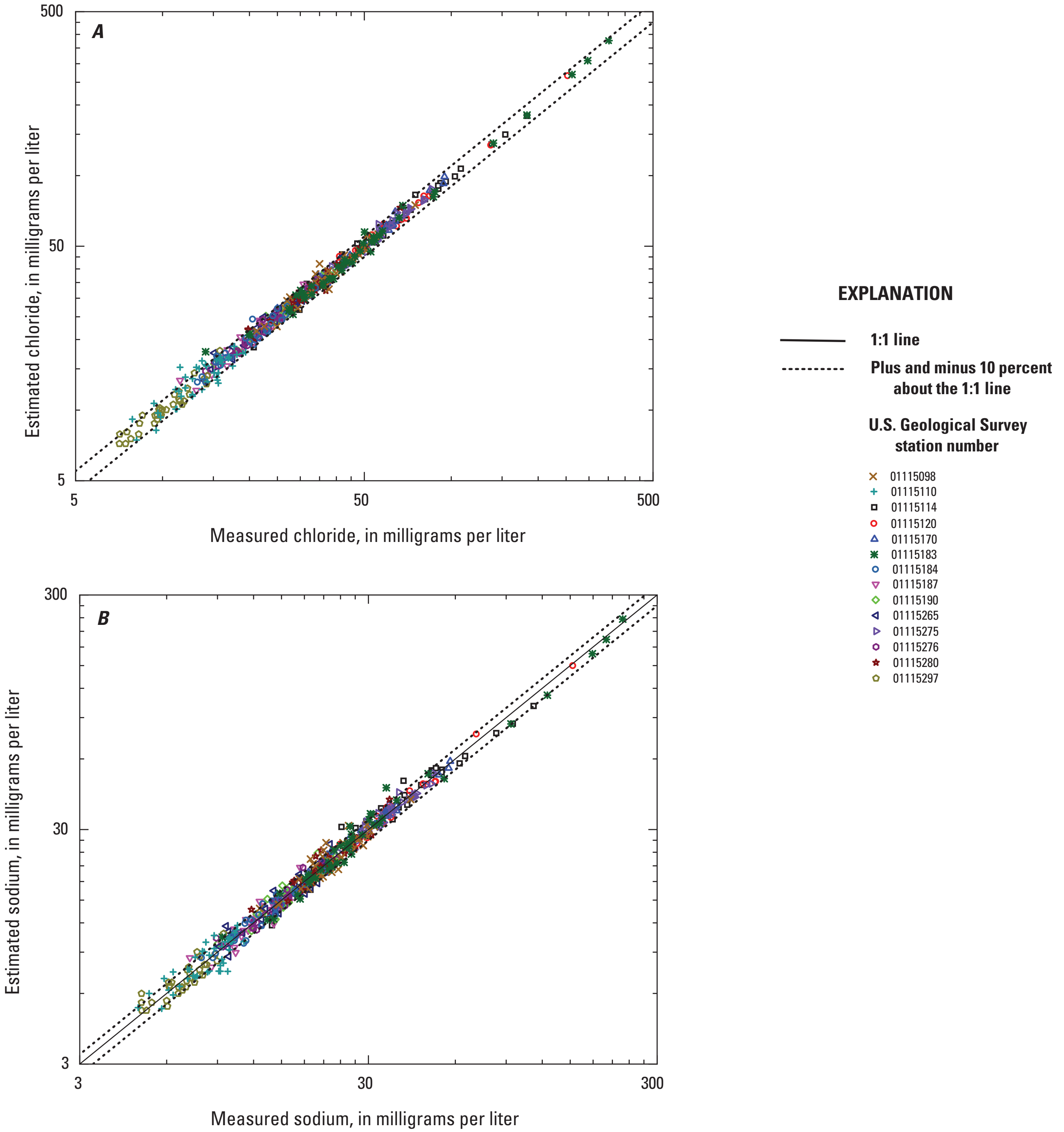


Figure 9. Relation between measured concentrations of *A,* chloride and estimated concentrations of chloride and *B*, measured concentrations of sodium and estimated concentrations of sodium at 14 U.S. Geological Survey continuous-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2009–19. Station names and Providence Water Supply Board station numbers are given in table 1; locations are shown in figure 1.

Aulenbach and others, 2022). A relation between infrequent measurements of concentration and continuous-streamflow record is used to determine constituent concentration for unsampled days. Estimating concentrations at a daily time step of streamflow is appropriate when sample concentrations are reasonably representative of daily flows. For sample populations that consist primarily of base-flow samples, this requirement is typically met. However, when flow-proportional composite stormflow samples and base-flow samples are used to develop a regression model, the time-step over which concentrations (or loads) are estimated should represent the average streamflow of stormflow samples (Landers and others, 2007). In addition to evaluating the appropriate time step for a regression model of mixed sample types, the relation between concentration and paired streamflow in each sample population should be assessed. Whereas stormflow composite sampling is useful to document event mean concentrations associated with storm events and capture potentially high-load events, the resulting samples may represent a statistically unique population from base-flow samples. This unique population complicates the application of the load-regression method. A regression method was developed by Landers and others (2007), Joiner and others (2014), Aulenbach and others (2017), and refined by Aulenbach and others (2022) to estimate loads at a site-specific time step with combined datasets of discrete base-flow samples and composite stormflow samples that may have unique statistical distributions. Aulenbach and others (2022) used a custom regression equation to model the storm-composite concentration-flow relation and the base-flow discrete concentration-flow relation simultaneously.

Aulenbach and others (2022) developed a nine-parameter regression model with the flexibility to fit two distinct concentration distributions. Equation 4 is a modified seven-parameter model used in this study; two model parameters pertaining to turbidity are excluded because continuous turbidity records are not available in the Scituate Reservoir drainage area:

$$\ln(L) = a_0 + a_1 S + a_2 \ln Q + a_3(1-S)\ln Q + a_4 \ln Q_b + a_5 \sin\theta + a_6 \cos\theta \quad (4)$$

where

- L is load, mass of a constituent per time;
- a_x are fitted term coefficients;
- S is a flow condition indicator, 0 for base-flow conditions and 1 for stormflow conditions;
- Q is flow, in cubic feet per second;
- Q_b is daily mean base flow, in cubic feet per second; and
- θ is 2 times pi times day of year divided by 365.25.

The indicator variable, S, gives the model form flexibility to fit the unique distributions of base-flow and stormflow samples by use of an intercept adjustment (a_1S) and (or) slope adjustment [$a_3(1-S)\ln Q$]. Load model terms were selected based on the corrected Akaike Information Criterion (AICc; Akaike, 1974; Burnham and Anderson, 2002) determined for a subset of all possible concentration-flow regressions with the R package MuMIn (Bartoń, 2020). All possible regressions were subset with the following criteria in order to meet load model requirements: the flow term (ln$Q$) was always required, and the two seasonal terms (cosθ and sinθ) had to be present together (either both present or both absent). This model-selection approach allowed the evaluation of candidate models based on quantitative criteria (AICc) and environmental knowledge. In the case of DP and DN, specific-conductance terms (lnSpc and SlnSpc) were also considered as explanatory variables. Load models were developed for constituents with an adjusted R^2 value, from a concentration-flow regression model, equal to or greater than 0.2 (Aulenbach and others, 2022).

Implementing the custom regression model over a site-specific computational time step is intended to better represent the average streamflow sampled during stormflow events (Landers and others, 2007; Aulenbach and others, 2022). Storm durations were evaluated in this study to determine if a custom time step less than 24 hours would better represent stormflow samples. Storm durations of sampled events in this study ranged from 4 hours to 3 days, with a normal distribution of approximately 36 to 48 hours in average duration; therefore, a time step less than 24 hours was not implemented (table 11). Hydrograph separation and the autosampler programs were based on the same governing principles, discussed in previous sections, so that the duration of sampled events is also representative of unsampled events.

The USGS program LOADEST (Runkel and others, 2004; Runkel, 2013) is frequently used to implement the regression-model approach because LOADEST includes methods to address issues associated with load estimation, such as retransformation bias (because of modeling in log space) and data censoring. Adjusted maximum likelihood estimation (AMLE) is used in LOADEST to estimate loads, which is appropriate for censored data and is equivalent to maximum likelihood estimation (MLE) for uncensored datasets (Runkel and others, 2004). Additionally, LOADEST is programmed to implement user-defined models, which were required to accommodate combined base-flow and stormflow datasets. The original LOADEST FORTRAN (Formula Translation) program was updated in the R programming language (R Core Team, 2018), which enables a streamlined approach to accessing sample data and developing regression models completely within the R environment. Rloadest version 0.4.5 (Runkel and DeCicco, 2017) is available at USGS-R Github (https://github.com/USGS-R/rloadest).

Regression-model input data were prepared in two parts for each station: first, the calibration dataset consists of the sample concentrations, streamflow, base flow, indicator (S), and seasonal terms (sinθ and cosθ); and second, the estimation dataset is the record over which daily loads are estimated, consisting of daily mean flow, base flow, indicator, and seasonal terms. The calibration dataset was used to determine the explanatory variables and define the load-regression model. Only discrete samples collected during base-flow and flow-proportional composite stormflow samples were included in

Table 11. Duration of storm events, in hours, during which composite samples were collected in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19.

[Storm event durations determined by hydrograph separation (Spaetzel and Smith, 2022). PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey]

PWSB station number (fig. 1)	USGS station number (table 1)	Minimum (hours)	25th Percentile (hours)	Median (hours)	Mean (hours)	75th Percentile (hours)	Maximum (hours)	Number of events
16	01115098	4	41	46	48	54	74	31
14	01115110	12	34	39	40	46	79	34
15	01115114	15	32	40	41	51	65	38
19	01115170	12	30	36	36	42	62	30
6	01115183	18	27	38	36	44	65	38

the calibration datasets. Sample criteria were checked by both inspection of the sample database coding and comparison with the separated instantaneous flow record. In a few cases, samples collected on the falling limb of a storm-event hydrograph were labeled as base-flow samples. Snowmelt samples and discrete stormflow samples were also excluded. To minimize serial correlation, the sample data were modified to include samples with a minimum spacing of 3 days. If two base-flow samples were collected within 3 days, the sample with fewer missing results was kept. If a base-flow sample was collected within the 3 days prior to a stormflow sample, the stormflow sample was retained if the ratio of runoff flow to total flow during the event was greater than or equal to 0.6. In these cases, it is assumed that the composite stormflow concentration is determined by runoff quality and is not affected by preceding base-flow conditions. Selected samples were paired with potential explanatory variables. Base-flow sample data were paired with the nearest instantaneous flow value (Q) and the daily base flow determined by hydrograph separation (Q_b). Stormflow samples were paired with average event flow (Q) and daily base flow determined by hydrograph separation (Q_b).

Outliers in constituent concentration data were considered carefully to ensure regression models were not affected by rare environmental conditions or erroneous results. Outliers in the sample data were identified by visual inspection of data plots. Correlated constituents such as DP and TP, DN and TN, and SSC and TP were examined. Concentrations were plotted against flow, and sample distributions were examined in boxplot figures. In total, seven outlier concentrations were removed, the majority of which were from base-flow samples. Base-flow sample concentrations ranges varied less than stormflow concentrations, and outliers were readily observed in the dataset. Censored values were not removed or modified for load estimation using Rloadest. Removed outliers and the final calibration datasets are reported in the companion data release (Spaetzel and Smith, 2022).

The estimation dataset is the daily record consisting of mean flow, base flow, indicator, and seasonal terms and is the input dataset for the load-regression model. The flow values in the estimation dataset were derived from hydrograph separation. Storm-event intervals were used to assign the indicator variable S to each unit-value time step and then averaged over a 24-hour period to assign the S variable to each day in the estimation dataset. Daily S values range from 0 to 1 and represent the proportion of stormflow values in that day. The estimation datasets are published in the companion data release (Spaetzel and Smith, 2022).

The LOADEST software was also used to calculate annual load uncertainties and regression model statistics. The upper and lower 95-percent confidence intervals are based on the standard error of prediction (SEP), which captures the uncertainty of model parameters and the random error about the model (Runkel and others, 2004). These errors are not symmetrical about the estimate because loads were simulated in logarithmic space (Aulenbach and others, 2022).

The stratified method was implemented by Smith (2017) to make simple estimations of load by using the combined datasets of base-flow and flow-proportional composite stormflow samples, each representing two different sample populations and streamflow conditions. By computing storm loads and base-flow loads separately, the portion of annual load delivered in stormflow can be assessed. Sample data were investigated by visual inspection of data plots and a statistical test to determine if stormflow and base-flow concentrations were significantly different. The Mann-Whitney test (two-sided Wilcoxon rank-sum test) was used to determine whether base-flow concentrations and stormflow concentrations were statistically different at the 95-percent confidence level (p value less than 0.05; table 12). The Mann-Whitney test is a nonparametric statistical test to compare two independent groups of data of any given distributional shape; specifically, it determines if there is evidence that the groups are from the same population (Helsel and others, 2020). For those constituents with statistically different results, the sample and flow data were stratified (categorized) into two classes (base flow and stormflow). The annual load for each class was determined by multiplying mean annual flow by the mean concentration; the loads for each class were summed by water year to determine the overall annual loads. Flow separation was performed using the fixed-base method described in an earlier section. The annual stormflow volume was determined by summing the individual storm-event flow volumes over each water year. The annual base-flow volume was determined by subtracting the stormflow volume from the annual total

Table 12. Mann-Whitney test *p* values (dimensionless) to identify statistically significant difference between base-flow sample concentrations and stormflow sample concentrations at five stations in Scituate Reservoir drainage area, Rhode Island, water years 2016–19.

[Water-quality data available in Spaetzel and Smith (2022). PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; *p* values less than (<) 0.05 considered significant at 95-percent confidence level]

PWSB station number (fig. 1)	USGS station number (table 1)	Dissolved phosphorus	Total phosphorus	Total nitrogen	Dissolved nitrogen	Suspended-sediment concentration
16	01115098	0.139	0.047	<0.001	0.232	0.003
14	01115110	0.382	<0.001	<0.001	0.043	<0.001
15	01115114	0.001	<0.001	<0.001	0.003	<0.001
19	01115170	0.686	0.236	<0.001	0.022	0.202
6	01115183	0.342	0.056	0.002	0.230	0.001

streamflow volume. The 95-percent confidence intervals about the mean concentrations were used to estimate the 95-percent confidence intervals about the annual load estimates. The stratified method was implemented using the sample data selected during the development of regression models. Keeping the sample data consistent between both methods addresses one potential source of variability when comparing the estimates derived from each method.

Water-Quality Conditions

Water-quality conditions in the Scituate Reservoir drainage area for WYs 2013–19 were described in terms of median values (table 13) and boxplots (fig. 10) of water-quality properties and constituent concentrations in samples collected and analyzed by PWSB from the 37 monitoring stations in the drainage area. Correlations among water-quality properties and constituent concentrations (table 14) together with correlations of water-quality properties and constituent concentrations with subbasin characteristics and streamflow also were used to evaluate water-quality patterns in the drainage area (fig. 11; tables 15 and 16). Values of properties and concentrations of constituents were compared to available State and Federal guidelines and standards (tables 17 and 18) to characterize water-quality conditions in terms of potential effects on human health and aquatic life.

Water-Quality Properties

The PWSB measured four water-quality properties—pH, color, turbidity, and alkalinity—as general indicators of water-quality conditions in the Scituate Reservoir drainage area. The measurements were used to identify site-specific conditions and were compared with State and Federal guidelines over the period from October 1, 2012, to September 30, 2019.

pH

Measurements of pH represent the negative base-10 logarithm of the hydrogen-ion concentration or activity. pH values near 7 standard units 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 (fig.10; 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 5.7 to 6.9 with a median for all stations of 6.3 standard units (table 13). The observed pH range and median pH of tributaries in the drainage area indicated that water from the tributaries was slightly acidic, reflecting the low pH of precipitation in the northeastern United States (mean annual precipitation-weighted pH was 5.1 for WYs 2013–18; National Atmospheric Deposition Program, 2021); the relatively nonreactive character of rock types in the drainage area was also a contributing factor to the observed pH. Water samples collected at two monitoring stations in the Westconnaug Reservoir subbasin, Westconnaug Brook (USGS station 01115274; PWSB station 10) and Unnamed Tributary to Westconnaug Brook (USGS station 01115273; PWSB station 11), had the lowest median pH value at 5.7 (table 13). Two other stations had median pH values less than 6.0, Fire Tower Stream (PWSB station 37; fig. 1) and Unnamed Tributary to Ponaganset (USGS station 011151845; PWSB station 27). The highest median pH value, 6.9, was determined for Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19; fig. 1) and Brandy Brook (USGS station 01115180; PWSB station 1)—in areas that are less forested and more developed than those in the Westconnaug Reservoir subbasin (table 3).

Color

Color in streamwater, typically pale yellow to dark brown, is usually caused by dissolved-organic material, such as humic and fulvic acids, derived from natural sources

Table 13. Median values computed with Kaplan-Meier method for water-quality data collected at Providence Water Supply Board stations, by tributary reservoir subbasin, in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB) (Smith, 2015a, 2016, 2018c, d, 2019b, 2021). Station 31 had two samples during water years 2013–19, so both discrete values are shown; all other stations had between 12 and 77 samples. Less than symbol (<) indicates that greater than 50 percent of data were censored; median is equal to maximum reporting limit. USGS, U.S. Geological Survey; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; CFU/100mL, colony-forming unit per 100 milliliters; *E.coli.*, *Escherichia coli*; mg/L, milligram per liter ; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Properties			Constituents						
		pH (Standard 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	6.3	40	0.59	1,400	20	4.4	29	0.002	0.05	0.01
25	01115200	6.2	52	0.53	580	10	3.8	14	0.001	0.05	0.02
26	01115185	6.4	35	0.36	780	10	3.9	25	0.001	0.02	0.03
27	011151845	5.8	20	0.27	740	10	3.4	15	0.001	0.07	0.02
28	01115265	6.1	100	0.60	550	20	4.0	27	0.002	0.02	0.02
29	01115271	6.3	45	0.66	230	<20	4.0	22	0.002	<0.05	0.02
35	01115187	6.3	40	0.58	710	10	4.0	24	0.002	0.05	0.02
Direct runoff subbasin											
1	01115180	6.9	70	1.34	890	20	10	13	0.002	0.13	0.02
2	01115181	6.2	13	0.30	300	10	4.7	77	0.001	0.15	0.01
3	01115280	6.4	37	0.34	760	10	5.0	37	0.001	0.10	0.02
4	01115400	6.5	25	0.62	360	5	6.8	6	0.001	<0.05	0.01
5	01115184	6.3	45	0.54	1,300	<10	4.7	20	0.002	0.20	0.02
6	01115183	6.4	100	1.07	850	70	10	38	0.003	0.18	0.02
7	01115297	6.3	70	0.75	1,140	40	5.9	9.8	0.002	0.01	0.02
8	01115276	6.3	18	0.46	150	<20	3.6	13	0.001	<0.05	0.01
9	01115275	6.5	38	0.59	1,020	20	6.9	56	0.002	0.40	0.02
30	01115350	6.1	55	0.43	1,460	20	4.0	27	0.001	0.05	0.02
31	01115177	6.6, 6.5	39, 40	0.75, 0.60	480, 130	<10, 30	17, 20	94, 174	0.004, 0.003	0.01, 0.08	0.02, 0.01
32	01115178	6.5	49	0.76	550	16	6.4	14	0.002	0.31	0.03
33	01115182	6.2	36	0.37	520	20	5.5	11	0.001	0.09	0.02
36	--	6.5	25	0.33	610	10	4.0	4.0	0.001	0.01	0.01
37	--	5.8	20	0.21	400	2	3.0	5.7	0.001	<0.05	0.03

Table 13. Median values computed with Kaplan-Meier method for water-quality data collected at Providence Water Supply Board stations, by tributary reservoir subbasin, in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.—Continued

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB) (Smith, 2015a, 2016, 2018c, d, 2019b, 2021). Station 31 had two samples during water years 2013–19, so both discrete values are shown; all other stations had between 12 and 77 samples. Less than symbol (<) indicates that greater than 50 percent of data were censored; median is equal to maximum reporting limit. USGS, U.S. Geological Survey; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; CFU/100mL, colony-forming unit per 100 milliliters; *E.coli.*, *Escherichia coli*; mg/L, milligram per liter ; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Properties			Constituents						
		pH (Standard 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	6.9	19	0.96	200	<20	9.6	54	0.002	0.05	0.01
20	01115160	6.2	110	0.71	810	30	6.7	71	0.004	0.08	0.04
21	01115165	6.7	40	0.87	1,000	20	11	38	0.003	0.42	0.03
22	01115167	6.7	26	1.54	1,300	62	15	64	0.008	0.47	0.03
34	01115164	6.4	50	0.85	620	10	11	36	0.003	0.04	0.02
Ponaganset Reservoir subbasin											
23	011151843	6.2	15	0.53	180	<10	3.1	20	0.001	0.02	0.01
Regulating Reservoir subbasin											
13	01115176	6.7	33	0.82	210	5	8.5	39	0.002	0.01	0.01
14	01115110	6.6	35	0.57	860	40	7.2	15	0.002	0.05	0.02
15	01115114	6.7	55	0.73	760	37	8.3	56	0.002	0.05	0.02
16	01115098	6.6	36	0.82	500	10	10	44	0.002	0.05	0.02
17	01115119	6.1	70	0.73	820	10	7.5	34	0.002	<0.05	0.01
18	01115120	6.4	55	0.63	420	20	9.8	56	0.002	0.15	0.03
Westconnaug Reservoir subbasin											
10	01115274	5.7	26	0.29	850	10	2.7	25	0.001	<0.05	0.02
11	01115273	5.7	64	0.60	970	10	4.0	5.8	0.002	<0.05	0.02
12	011152745	6.1	31	0.60	510	10	4.9	17	0.001	0.04	0.01
Scituate Reservoir drainage area											
Minimum	--	5.7	13	0.21	150	2	2.7	4.0	0.001	0.01	0.01
Median	--	6.3	39	0.60	725	13	5.3	25	0.002	0.05	0.02
Maximum	--	6.9	110	1.5	1,460	70	15	77	0.008	0.47	0.04

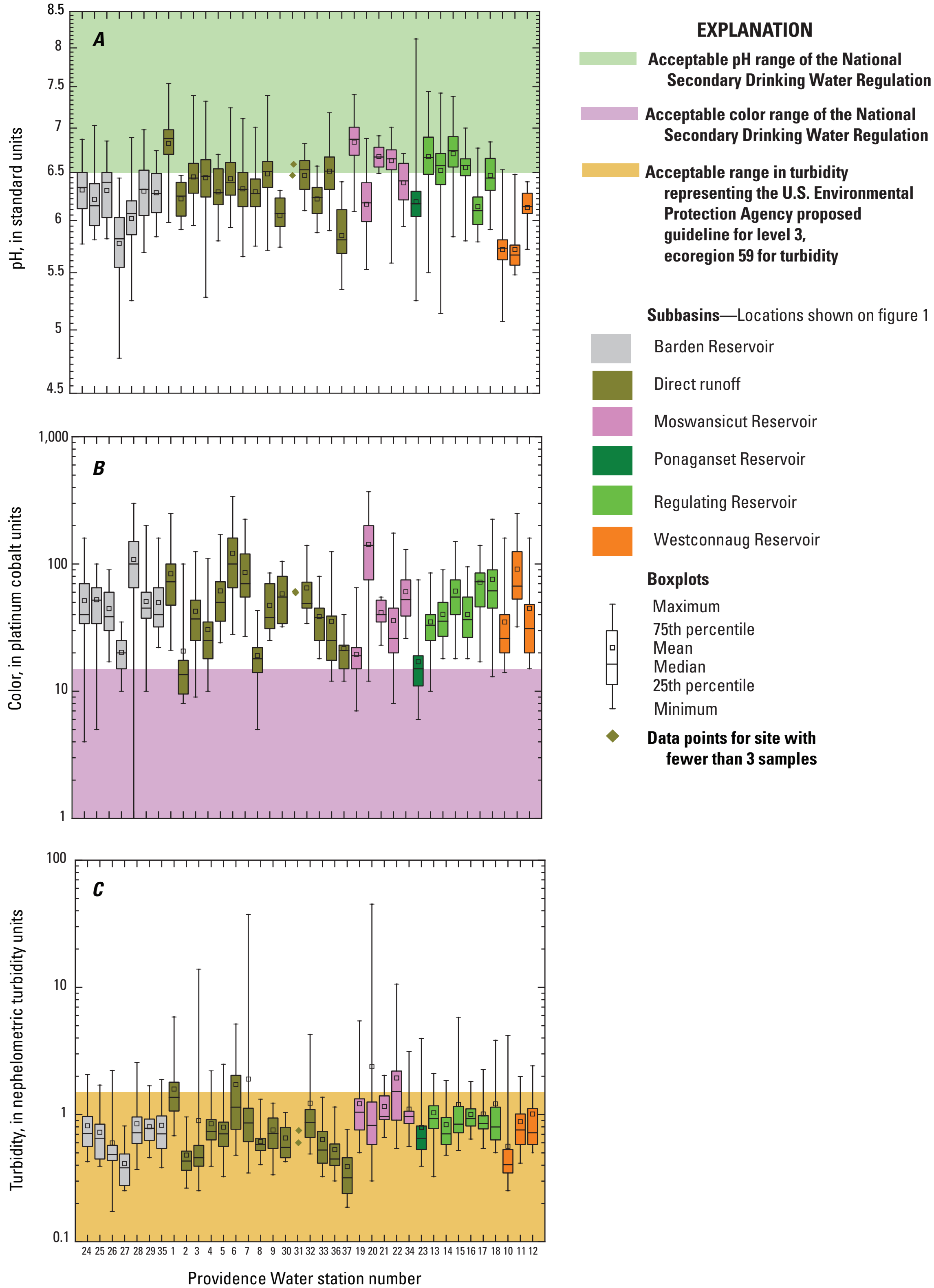


Figure 10. Distributions of measurements of *A*, pH, *B*, color, and *C*, turbidity and concentrations of *D*, alkalinity, *E*, chloride, *F*, nitrite, *G*, nitrate, *H*, orthophosphate, *I*, total coliform bacteria, and *J*, *Escherichia coli (E. coli)* in samples collected at Providence Water Supply Board water-quality-monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19. Locations of reservoir subbasins and monitoring stations are shown in figure 1. The uniform reporting limit is the maximum value at which results were censored during the study period, water years 2013–19. [Censored data are reported as half the uniform reporting limit for the purpose of graphing.]

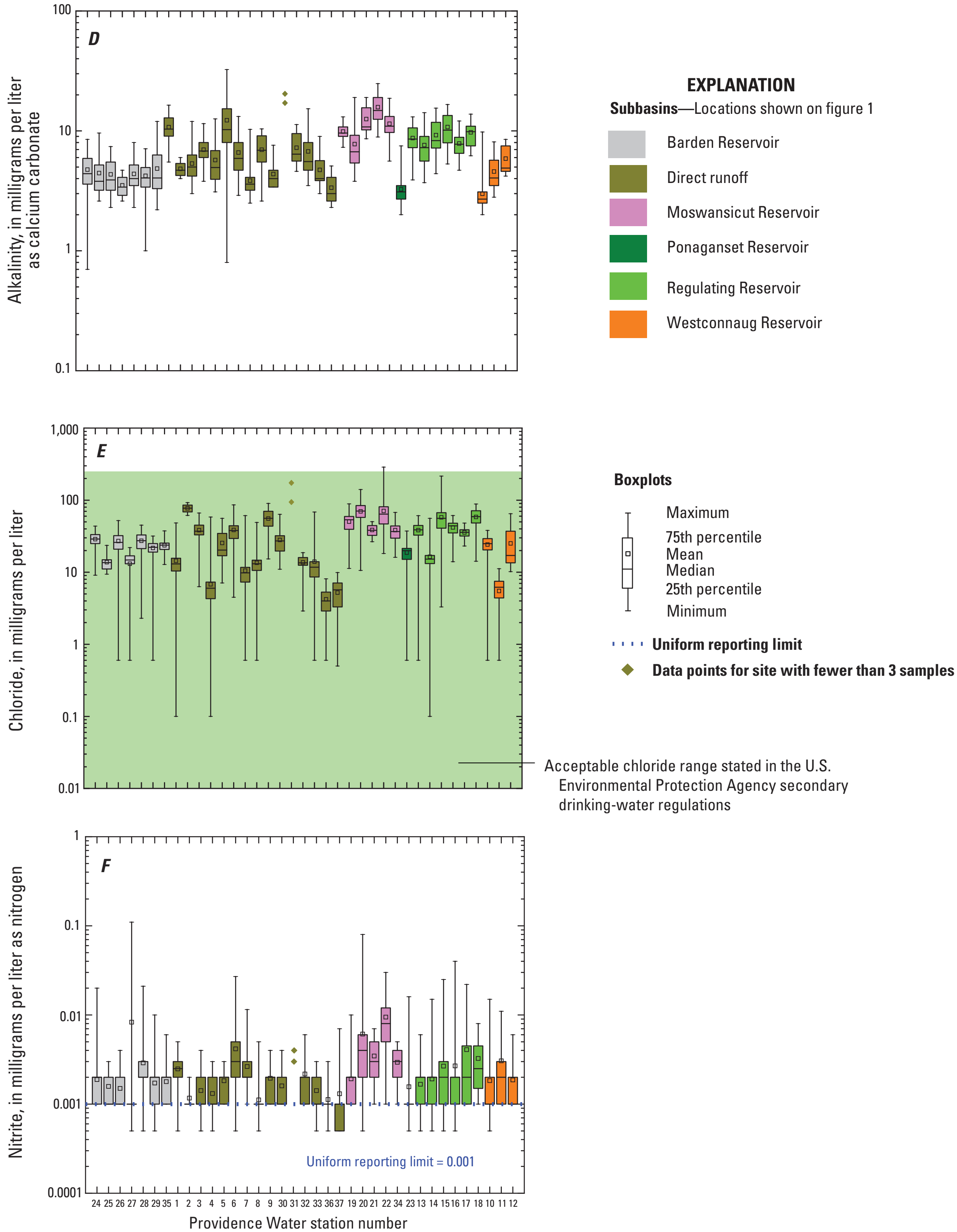


Figure 10.—Continued

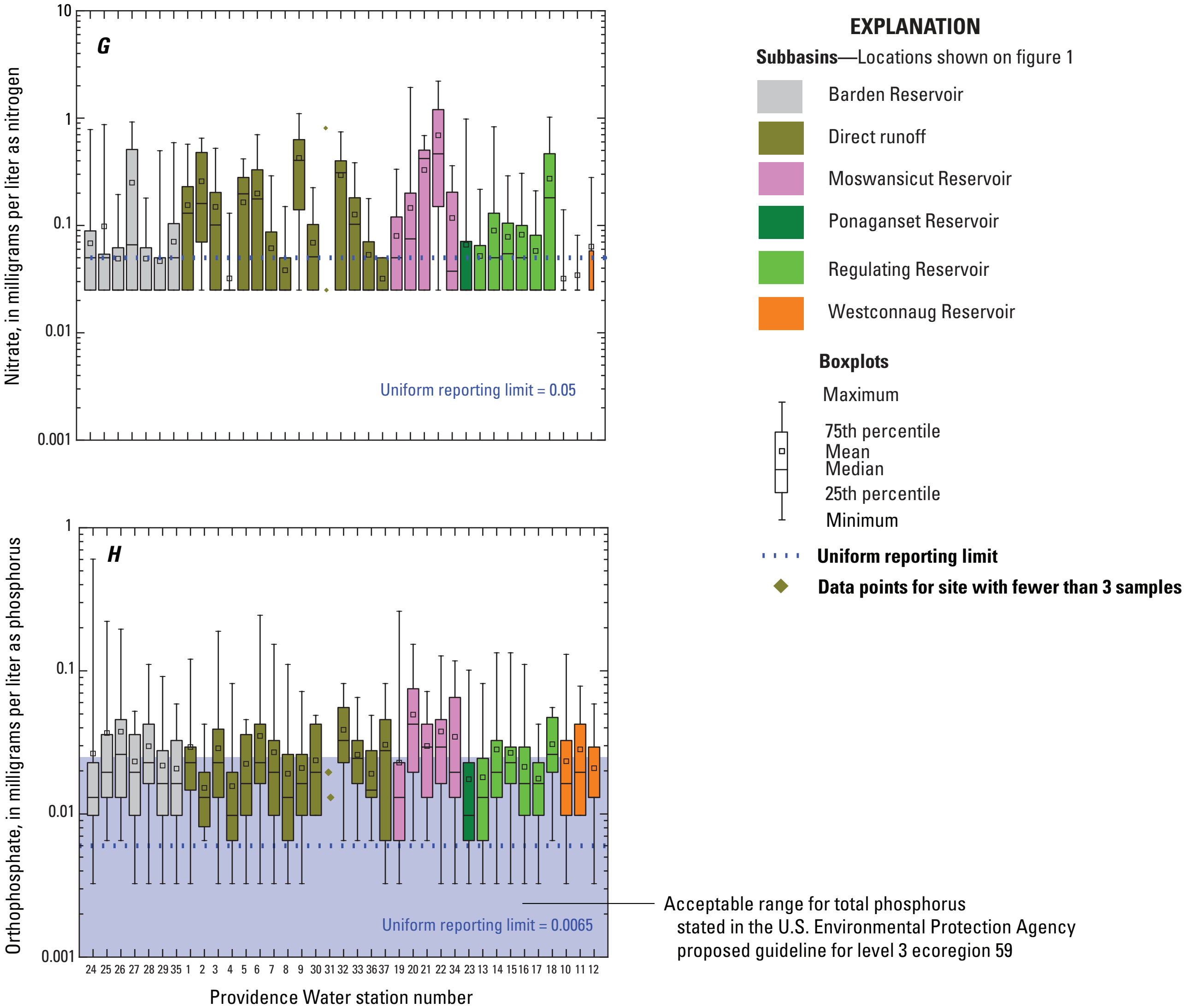


Figure 10.—Continued

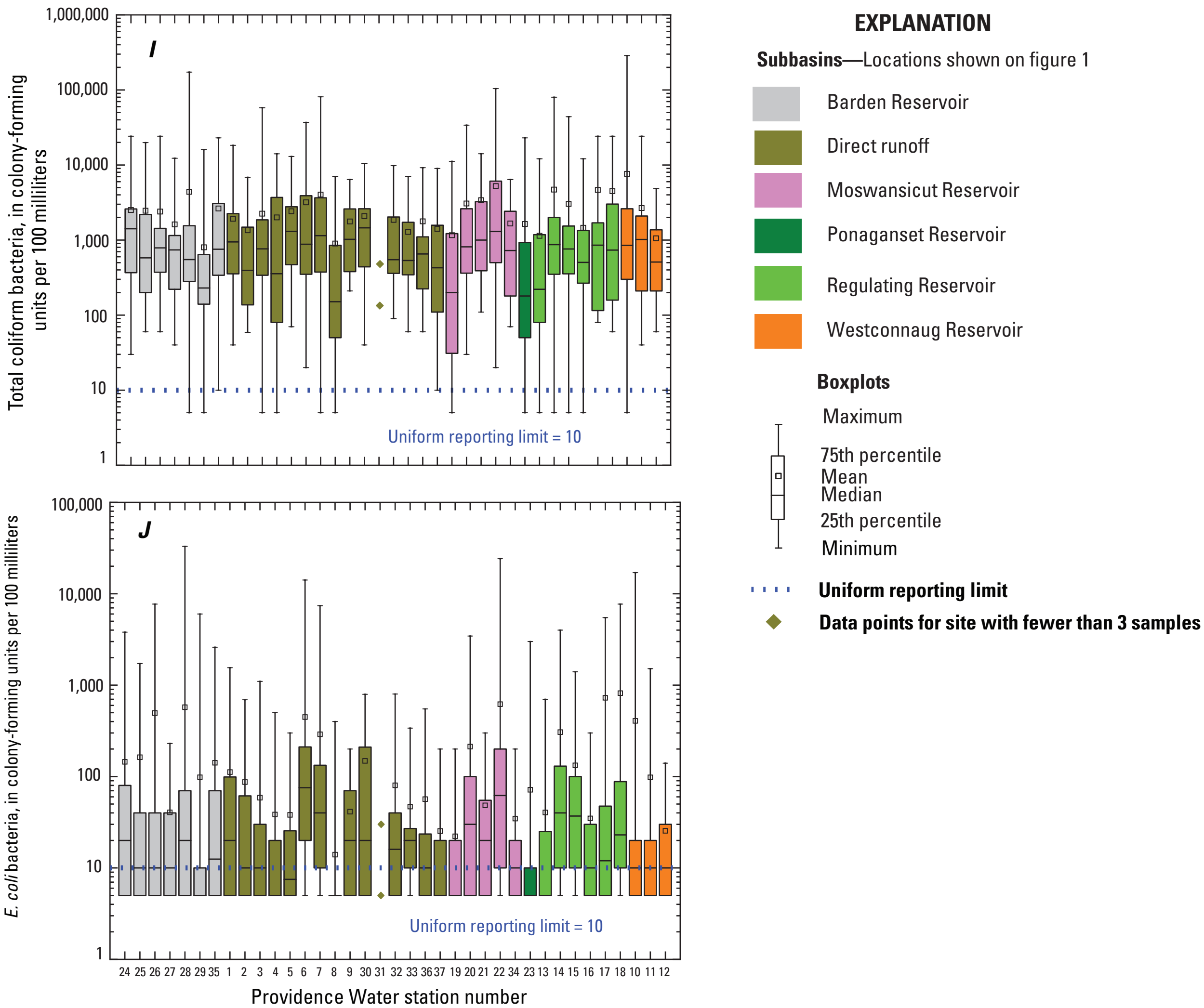


Figure 10.—Continued

Table 14. Significance levels (*p* values) (dimensionless) for Kendall's rank correlation tests between selected median physical properties and constituent concentrations measured by Providence Water Supply Board at 37 stations in the Scituate Reservoir drainage basin, Rhode Island, water years 2013–19.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB) (Smith, 2015a, 2016, 2018c, d, 2019b, 2021). *p* values less than or equal to 0.05 are denoted with the sign of the correlation, where (+) indicates that variables are positively correlated. *E. coli*, *Escherichia coli*; —, results not listed for duplicative combinations; <, less than value shown]

Property or constituent	pH	Color	Turbidity	Alkalinity	Total coliform bacteria	*E. coli*	Chloride	Nitrite	Nitrate
Color	0.634	—	—	—	—	—	—	—	—
Turbidity	<0.001 (+)	0.006 (+)	—	—	—	—	—	—	—
Alkalinity	<0.001 (+)	0.090	<0.001 (+)	—	—	—	—	—	—
Total coliform bacteria	0.782	0.004 (+)	0.628	0.529	—	—	—	—	—
E. coli	0.175	0.002 (+)	0.026 (+)	0.007 (+)	0.001 (+)	—	—	—	—
Chloride	0.037 (+)	0.529	0.022 (+)	0.001 (+)	0.875	0.084	—	—	—
Nitrite	0.007 (+)	0.001 (+)	<0.001 (+)	<0.001 (+)	0.082	0.003 (+)	0.001 (+)	—	—
Nitrate	0.038 (+)	0.389	0.217	0.006 (+)	0.035 (+)	0.050 (+)	0.009 (+)	0.030 (+)	—
Orthophosphate	0.737	0.022 (+)	0.468	0.390	0.036 (+)	0.017 (+)	0.375	0.024 (+)	0.009 (+)

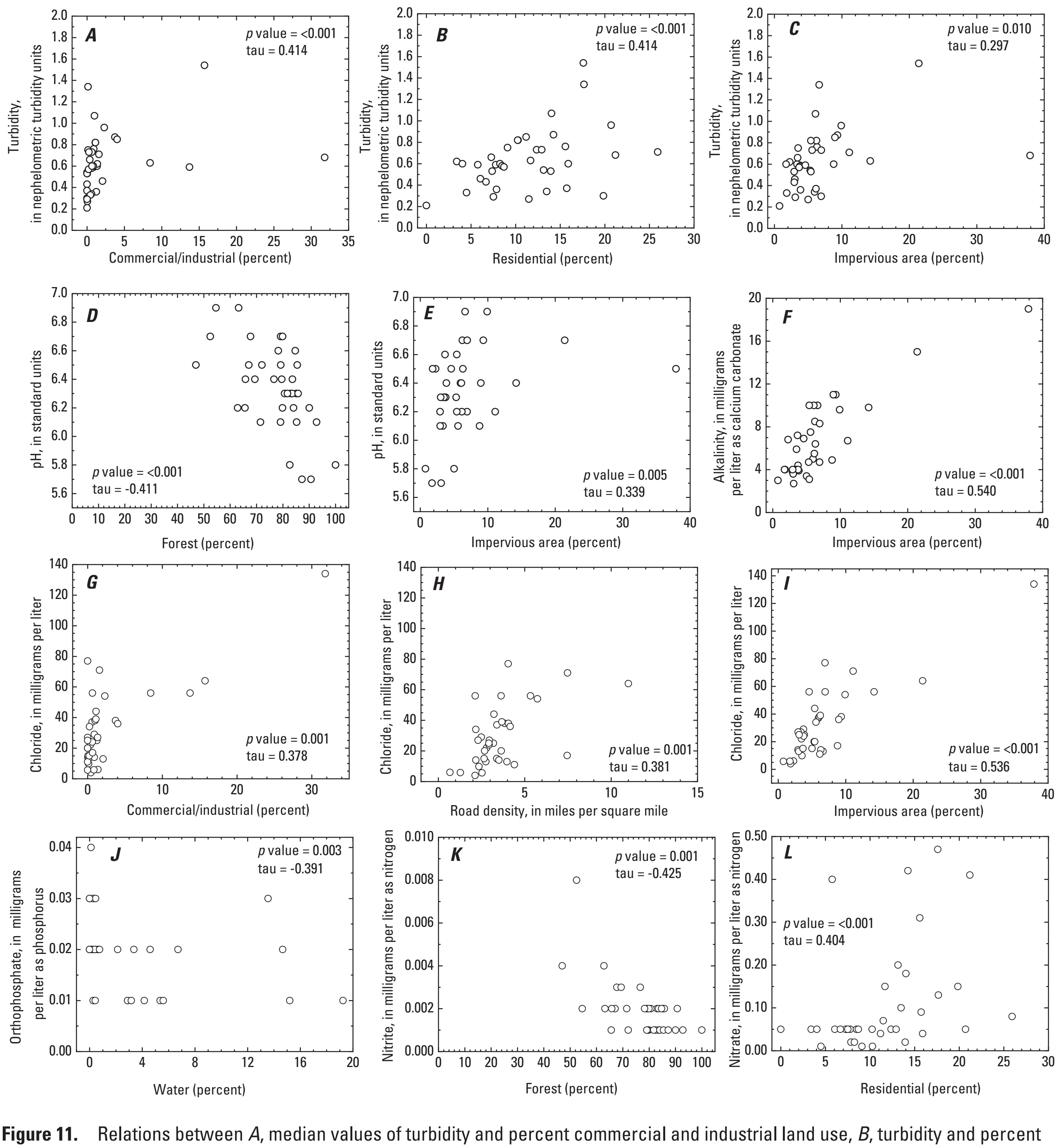


Figure 11. Relations between *A*, median values of turbidity and percent commercial and industrial land use, *B*, turbidity and percent residential land use, and *C*, turbidity and percent impervious area; *D*, median values of pH and forested land use and *E*, pH and percent impervious area; *F*, median values of alkalinity and percent impervious area; *G*, median concentrations of chloride and percent commercial and industrial land use, *H*, chloride and road density, and *I*, chloride and impervious area; *J*, median concentrations of orthophosphate and percent water land cover; *K*, median nitrite concentrations and percent forested land use; and *L*, median concentrations of nitrate and residential land use. Water-quality data collected by Providence Water Supply Board at 37 stations in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19. Significance levels (*p* values) and Kendall's tau reported for the rank correlation test for each relation, where < is less than.

Table 15. Significance levels (*p* values) for Kendall rank correlations between subbasin characteristics and median values of selected physical properties and constituent concentrations measured at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB) (Smith, 2015a, 2016, 2018c, d, 2019b, 2021). Median values of physical properties and constituent concentrations calculated from data collected during water years 2013–19 by PWSB. Land-use statistics reported in table 3. *p* values less than 0.05 are denoted with the sign of the correlation: (+), variables are positively correlated; (−), variables are inversely correlated. *E. coli*, *Escherichia coli*; <, less than value shown]

Subbasin characteristic	pH	Color	Turbidity	Total coliform bacteria	*E. coli*	Alkalinity	Chloride	Nitrite	Nitrate	Ortho-phosphate
Agricultural	0.104	0.386	0.439	0.691	0.447	0.311	0.512	0.808	0.894	0.561
Commercial and industrial	0.002 (+)	0.502	<0.001 (+)	0.139	0.581	<0.001 (+)	0.001 (+)	<0.001 (+)	0.210	0.344
Forest	<0.001 (−)	1.00	<0.001 (−)	0.533	0.255	<0.001 (−)	<0.001 (−)	0.001 (−)	0.004 (−)	0.988
Other urban	0.01 (+)	0.515	0.006 (+)	0.398	0.671	0.089	0.265	0.137	0.968	0.802
Residential	0.077	0.656	0.01 (+)	0.106	0.744	0.001 (+)	0.002 (+)	0.012 (+)	<0.001 (+)	0.495
Water	0.049 (+)	0.520	0.017 (+)	0.187	0.265	0.572	0.277	0.521	0.024 (−)	0.003 (−)
Wetlands	0.330	0.062	0.104	0.578	0.044 (+)	0.596	0.853	0.098	0.946	0.747
Imperviousness	0.005 (+)	0.618	0.001 (+)	0.070	0.592	<0.001 (+)	<0.001 (+)	<0.001 (+)	<0.001 (+)	0.276
Road density	0.094	0.774	0.027 (+)	0.165	0.225	0.008 (+)	0.001 (+)	0.043 (+)	0.012 (+)	0.149

Table 16. Significance levels (p values) for Kendall rank correlations between mean daily streamflow and selected physical properties and constituent concentrations at Providence Water Supply Board monitoring stations by tributary reservoir subbasin in the Scituate Reservoir drainage area, Rhode Island, water years 1994–2019.

[Water-quality data collected by Providence Water Supply Board (PWSB) (Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Streamflow data are available in the National Water Information System (NWIS; U.S. Geological Survey, 2020b). Station locations shown on figure 1. p values less than 0.05 are denoted with the sign of the correlation: (+), variables are positively correlated; (−), variables are inversely correlated. USGS, U.S. Geological Survey; *E. coli, Escherichia coli*; <, less than value shown]

PWSB station number (fig. 1)	USGS station number (table 1)	Turbidity	Total coliform bacteria	*E. coli* bacteria	Chloride	Nitrate	Nitrite	Ortho-phosphate
Barden Reservoir subbasin								
24	01115190	<0.001 (−)	<0.001 (−)	<0.001 (−)	0.042 (−)	0.392	<0.001 (−)	0.260
25	01115200	0.001 (−)	0.048 (−)	0.005 (−)	0.295	0.932	0.554	0.609
26	01115185	0.485	0.246	0.109	0.147	0.743	0.422	0.983
28	01115265	<0.001 (−)	0.002 (−)	0.050 (−)	<0.001 (−)	0.592	<0.001 (−)	0.811
35	01115187	<0.001 (−)	<0.001 (−)	<0.001 (−)	0.006 (−)	0.721	0.006 (−)	0.968
Direct runoff subbasin								
1	01115180	0.006 (−)	0.004 (−)	0.060	0.012 (−)	0.236	0.041 (+)	0.039 (−)
3	01115280	<0.001 (+)	0.106	0.295	0.290	0.182	0.024 (+)	0.961
4	01115400	0.048 (−)	0.005 (−)	<0.001 (−)	0.196	0.306	0.101	0.654
5	01115184	0.011 (−)	0.024 (−)	0.053	0.003 (−)	0.030 (+)	0.603	0.133
6	01115183	<0.001 (−)	<0.001 (−)	<0.001 (−)	<0.001 (−)	0.748	<0.001 (−)	0.034 (−)
7	01115297	<0.001 (−)	<0.001 (−)	0.004 (−)	0.001 (−)	0.022 (+)	<0.001 (−)	0.537
8	01115276	0.298	0.008 (−)	0.096	0.681	0.670	0.993	0.156
9	01115275	0.013 (+)	0.004 (−)	0.031 (−)	<0.001 (−)	0.149	0.21	0.189
32	01115178	<0.001 (−)	0.035 (−)	0.011 (−)	0.112	0.025 (+)	0.328	0.167
33	01115182	<0.001 (−)	<0.001 (−)	0.006 (−)	0.014 (−)	0.055	0.081	0.794
Moswansicut Reservoir subbasin								
19	01115170	<0.001 (−)	<0.001 (−)	0.119	0.117	0.020 (+)	0.052	0.291
21	01115165	0.012 (−)	0.078	0.194	0.298	<0.001 (−)	0.378	0.390
Regulating Reservoir subbasin								
14	01115110	<0.001 (−)	<0.001 (−)	0.061	0.733	0.813	0.27	0.451
15	01115114	<0.001 (−)	0.008 (−)	0.24	<0.001 (−)	0.154	0.026 (+)	0.243
16	01115098	0.425	0.027 (−)	0.011 (+)	0.456	<0.001 (−)	0.031 (+)	0.076
18	01115120	0.883	0.586	0.181	0.794	0.226	0.375	0.658
Westconnaug Reservoir subbasin								
10	01115274	0.723	<0.001 (−)	<0.001 (−)	0.451	0.004 (+)	0.168	0.362
11	01115273	<0.001 (−)	0.115	0.031 (−)	0.305	0.036 (+)	<0.001 (−)	0.485

Table 17. Selected Federal and State water-quality standards and guidelines.

[Sources: Rhode Island Department of Environmental Management (RIDEM), 2006; U.S. Environmental Protection Agency (EPA), 1988, 2000, 2021. Class AA waters are waters used for drinking-water supply or tributary streamwater to drinking-water sources in Rhode Island. NTU, nephelometric turbidity unit; mg/L, milligram per liter; P, phosphorus; <, less than; --, not applicable]

Parameter or constituent	RIDEM water-quality standards for Class AA waters.	EPA		
		Secondary drinking-water regulations	Ambient aquatic life criteria	Reference value for minimally affected conditions
pH, in standard units	[1]6.5–9.0	6.5–8.5	--	--
Color, platinum-cobalt units	--	15	--	--
Turbidity, in NTU	<5 above background	--	--	1.68
Chloride, in mg/L	--	250	Continuous: 230, acute: 860	--
Total phosphorus, mg/L as P	0.025	--	--	--

[1]Or as occurring naturally.

Table 18. Percentage of samples collected at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19, with values or concentrations not meeting selected water-quality standards and guidelines.

[Water-quality data collected by Providence Water Supply Board (PWSB) (Smith, 2015a, 2016, 2018c, d, 2019b, 2021). See table 17 for descriptions of standards, guidelines, and turbidity reference condition. Totals given for subbasin and drainage area represent the percentage of all samples collected in the subbasin or entire drainage area that do not meet the water-quality standard or guideline. USGS, U.S. Geological Survey; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; mg/L, milligram per liter; P, phosphorus; <, less than; >, greater than; --, not applicable.]

PWSB station number (fig. 1)	USGS station number (table 1)	Properties			Constituents	
		pH <6.5 pH standard units (percent)	Color >15 PCU (percent)	Turbidity >1.68 NTU (percent)	Chloride >250 mg/L (percent)	Orthophosphate >0.025 mg/L as P (percent)
Barden Reservoir subbasin						
24	01115190	74	99	4	0	23
25	01115200	89	95	5	0	33
26	01115185	73	100	5	0	57
27	011151845	100	67	0	0	40
28	01115265	97	99	4	0	45
29	01115271	71	99	1	0	26
35	01115187	79	100	4	0	36
Subbasin total		81	97	3	0	34
Direct runoff subbasin						
1	01115180	10	100	31	0	46
2	01115181	100	25	0	0	8
3	01115280	58	97	3	0	42
4	01115400	51	81	5	0	19
5	01115184	71	100	4	0	39
6	01115183	57	100	39	0	43
7	01115297	74	100	7	0	41
8	01115276	83	63	0	0	26
9	01115275	42	100	0	0	32
30	01115350	100	100	0	0	40
31	01115177	50	100	0	0	0
32	01115178	47	100	12	0	71

Table 18. Percentage of samples collected at Providence Water Supply Board monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19, with values or concentrations not meeting selected water-quality standards and guidelines.— Continued

[Water-quality data collected by Providence Water Supply Board (PWSB) (Smith, 2015a, 2016, 2018c, d, 2019b, 2021). See table 17 for descriptions of standards, guidelines, and turbidity reference condition. Totals given for subbasin and drainage area represent the percentage of all samples collected in the subbasin or entire drainage area that do not meet the water-quality standard or guideline. USGS, U.S. Geological Survey; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; mg/L, milligram per liter; P, phosphorus; <, less than; >, greater than; --, not applicable.]

PWSB station number (fig. 1)	USGS station number (table 1)	Properties			Constituents	
		pH <6.5 pH standard units (percent)	Color >15 PCU (percent)	Turbidity >1.68 NTU (percent)	Chloride >250 mg/L (percent)	Orthophosphate >0.025 mg/L as P (percent)
Direct runoff subbasin—Continued						
33	01115182	89	100	0	0	50
36	--	45	80	0	0	25
37	--	100	67	0	0	56
Subbasin total		60	90	11	0	37
Moswansicut Reservoir subbasin						
19	01115170	7	72	12	0	24
20	01115160	89	98	10	0	66
21	01115165	8	100	8	0	54
22	01115167	14	81	44	2	59
34	01115164	56	100	6	0	33
Subbasin total		35	85	19	0.4	47
Ponaganset Reservoir subbasin						
23	011151843	93	41	3	0	20
Regulating Reservoir subbasin						
13	01115176	25	94	7	0	25
14	01115110	43	100	5	0	41
15	01115114	15	100	14	0	42
16	01115098	32	100	3	0	32
17	01115119	92	100	8	0	17
18	01115120	58	92	17	0	58
Subbasin total		32	98	8	0	35
Westconnaug Reservoir subbasin						
10	01115274	98	94	2	0	32
11	01115273	100	100	6	0	33
12	011152745	100	93	13	0	33
Subbasin total		99	95	4	0	32
Scituate Reservoir drainage area						
Minimum	--	7	25	0	0	0
Median	--	71	99	5	0	36
Drainage area total	--	60	91	9	0.06	37

(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 streamwater. Median values of color for the tributaries in the Scituate Reservoir drainage area ranged from 13 to 110 platinum-cobalt units (PCU), with the highest value observed at Unnamed Tributary 1 to Moswansicut Reservoir (USGS station 01115160; PWSB station 20; fig. 1: table 13). Most discrete measurements of color at most monitoring stations were less than 100 PCU (fig. 10*B*), and 75 percent of all color measurements were less than 70 PCU.

Turbidity

Turbidity in streamwater is caused by the presence of suspended particles, such as silt, clay, organic matter, microorganisms, and dissolved colored material. Turbidity is measured in standard units that quantify the capacity 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 Scituate Reservoir drainage area generally was low; no median values exceeded 1.54 nephelometric turbidity unit (NTU) (fig. 10*C*; table 13), and all medians were less than the proposed U.S. Environmental Protection Agency (EPA) reference value of 1.68 NTU for what the agency considers as “minimally impacted conditions” for streams in the Northeastern Coastal Zone ecoregion (U.S. Environmental Protection Agency, 2000). The median turbidity was 0.60 NTU among all stations in the drainage area (table 13). However, turbidity measurements above the 1.68 NTU EPA reference value were observed in the sample data. More than 30 percent of discrete turbidity measurements at Brandy Brook (USGS station 01115180; PWSB station 1; fig.1), Quonapaug Brook (USGS streamgage 01115183; PWSB station 6), and Moswansicut Stream South (USGS station 01115167; PWSB station 22) exceeded 1.68 NTU in WYs 2013–19 (fig. 10*C*).

Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acid, most commonly caused by 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 streamwater 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 alkalinities in samples from tributaries were low, ranging from 2.7 to 15 mg/L as calcium carbonate (mg/L as $CaCO_3$). Among all stations in the drainage area, median alkalinity was 5.3 mg/L as $CaCO_3$ (table 13). Toad Pond (USGS station 01115177; PWSB station 31; fig. 1) was characterized by two measurements during WYs 2013–19; therefore, a median alkalinity was not determined for this station, but both measurements exceeded the medians at all other stations (fig. 10*D*; table 13). Alkalinity was consistently low at monitoring stations in the western part of the drainage area—in the Barden Reservoir, Ponaganset Reservoir, and Westconnaug Reservoir subbasins—and was highest at monitoring stations in the Direct runoff, Moswansicut Reservoir, and Regulating Reservoir subbasins (fig. 10*D*).

Constituent Concentrations

Chloride

Chloride, a nonreactive ion commonly found in streamwater, is found in precipitation, environmental minerals and soils (Hem, 1985), septic effluent, industrial wastes, and wastewater (Mullaney and others, 2009). The mean annual volume-weighted Cl concentration in precipitation was 0.32 milligram per liter (mg/L) during WYs 2013–18 west of the study area near Abington, Connecticut (National Atmospheric Deposition Program, 2021). Cl is also a major constituent of road salt and other deicing compounds. The median Cl concentration for discrete samples collected by PWSB for all stations in the drainage area was 25 mg/L (table 13), which reflects an increase compared to median concentrations from the previous study period (Nimiroski and others, 2008; Smith, 2015b). Median values for individual stations ranged from 4.0 to 77 mg/L. Unnamed Tributary 2 to Scituate Reservoir (USGS station 01115181; PWSB station 2) had the highest median Cl concentration at 78 mg/L. Toad Pond (USGS station 01115177; PWSB station 31) was characterized by two measurements during WYs 2013–19, so a median concentration was not determined for this station, but both measurements exceeded the medians at all other stations (fig. 10*E*; table 13). The Toad Pond station (USGS station 01115177; PWSB station 31) drains a small area that includes a parking lot (impervious area is 38 percent) making it more impervious than any other area containing a monitoring station in the Scituate Reservoir drainage area (in which impervious area is generally less than 10 percent).

Nutrients

Nutrients, including chemical species[2] of nitrogen and phosphorus, are essential elements for plant and animal life. Nutrient enrichment, however, can lead to excessive

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

productivity and plant growth, with consequent low concentrations of dissolved oxygen, and degradation of aquatic life (U.S. Environmental Protection Agency, 2000). Sources of nitrogen in tributaries include atmospheric deposition, leaching of naturally occurring organic material, discharge to groundwater that is enriched in nitrate from septic-system leachate, and runoff contaminated with fertilizer or animal waste. Within tributaries in the Scituate Reservoir drainage area, concentrations of the nutrient species nitrite, nitrate, and orthophosphate were generally near their respective detection limits (table 13). Other forms of nitrogen, such as dissolved and particulate ammonia, were not measured by PWSB.

The median concentration of nitrite at all monitoring stations was 0.002 mg/L as N, and median concentrations of nitrite varied minimally throughout the basin (table 13). Nitrite is not typically present at concentrations greater than 0.1 mg/L in streamwater because it is an intermediate product of processes like nitrification and denitrification; elevated concentrations (greater than background concentrations) may indicate the presence of wastewater-effluent contamination (Hem, 1985; Brandt and others, 2017). Median nitrate concentrations were less than 0.1 mg/L as N at all monitoring stations. The mean annual volume-weighted nitrate concentration in precipitation was 0.53 mg/L during WYs 2013–18 approximately 25 miles (mi) west of the study area near Abington, Connecticut (National Atmospheric Deposition Program, 2021). In many cases, nitrate was not detected at the reporting limit of 0.05 mg/L in samples (fig. 10*G*). Low nitrate concentrations in streamwater as compared with precipitation may reflect the effect of biological uptake in decreasing nitrate in streamwater. Higher median concentrations of nitrate (greater than 0.40 mg/L) at two stations in the Moswansicut Reservoir subbasin and at Bear Tree Brook (USGS station 01115275; PWSB station 9; fig. 1) in the Direct runoff subbasin may be caused by nitrogen-enriched runoff or groundwater. 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 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 P (Reddy and others, 1999) and the limiting nutrient in inland aquatic systems; therefore, orthophosphate is often used as an indicator of potential water-quality problems, such as algae blooms or excessive aquatic plant growth (Schlesinger, 1991). The median orthophosphate concentration 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. Some median orthophosphate concentrations, as well as much of the discrete sample data (fig. 10*H*), were greater than the EPA-proposed TP 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 groundwater contaminated by septic-system failure. Septic or other individual sewage-disposal systems are used predominantly throughout the Scituate Reservoir drainage area (Richard Blodgett, Providence Water Supply Board, written commun., 2014). Other sources of bacteria in surface waters include waterfowl and runoff from impervious areas that are affected by animal waste (Weiskel and others, 1996). Total coliform and *E. coli* bacteria are indicator bacteria used to identify bacterial growth and the presence of sewage contamination. Although these bacteria groups are not exclusively composed of disease-causing organisms, these organisms may indicate the presence of human pathogens, including bacteria, protozoans (*Cryptosporidium* and *Giardia*), and enteric viruses (viruses primarily transmitted by the fecal-oral route, either by person-to-person contact or by ingestion of contaminated food or water). 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 a subset of total coliform bacteria, specifically intestinal bacteria of warm-blooded animals, and, thus, are a more definitive indicator of fecal contamination (Francy and others, 2000; World Health Organization, 2004).

Median concentrations of total coliform bacteria ranged by an order of magnitude from 150 CFU/100 mL to 1,460 CFU/100 mL, whereas *E. coli* concentrations ranged from 2 to 70 CFU/100 mL. Total coliform medians were greater than 10 CFU/100 mL at all stations considered in this study (table 13; figs. 10*I* and *J*). Two percent of total coliform discrete measurements were censored below 10 CFU/100 mL, and 32 percent of *E. coli* concentrations were censored below 20 CFU/100 mL (reporting limits equal to 1, 2, 5, 10, and 20 CFU/100 mL).

Correlations Between Water-Quality Properties and Constituent Concentrations

Identifying commonalities in relations among water-quality properties and constituent concentrations by conducting tests for correlations may indicate the presence of constituent sources and natural processes within the tributary drainage areas. Correlations between median measurements of turbidity and pH, color, and alkalinity were significant (table 14); 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 *E. coli* bacteria, Cl, and nitrite. Median concentrations of Cl were significantly correlated with concentrations of nitrite, nitrate, and most physical properties in the drainage area (table 14).

Factors Affecting Water-Quality Properties and Constituent Concentrations

Water-quality property values and constituent concentrations 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 road density can assist water-resources managers with drainage-area-protection strategies, such as purchasing land and restricting certain land uses. Many water-quality properties and constituent concentrations vary with streamflow, either directly through the association of high flows that entrain additional constituents with surface runoff, or through the dilution of contaminants derived from base flow.

Subbasin Characteristics

Land use and impervious surface areas, including roads, are factors that can affect constituent concentrations in the tributaries. Percentages of impervious area in tributary subbasins correlated significantly with median values or concentrations of various water-quality properties or constituents that can indicate human activities, including pH, turbidity, alkalinity, and Cl, nitrite, and nitrate concentrations. Some of the significant relations between water-quality properties and land uses are shown on figure 11. Percentages of residential area and density of roads correlated with the same constituents and properties except for pH. Turbidity was significantly correlated with imperviousness, road density, and all land-use categories except agricultural and wetlands (table 15). Median values of pH, turbidity, alkalinity, and Cl, nitrite, and nitrate concentrations correlated negatively with the percentage of forest in subbasins of the monitoring stations. The correlations between Cl 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, based on findings from previous investigations (Nimiroski and others, 2008). Road salt was previously determined to be the largest source of Cl in the drainage area, and strong correlations between median Cl concentrations and State road density were detected (Nimiroski and Waldron, 2002; Nimiroski and others, 2008). In previous studies, median values of color correlated positively with the percentage of wetlands in the tributary subbasins; this correlation indicated that naturally occurring organic material and possibly dissolved iron and manganese were likely sources of color in tributary streamwater (Nimiroski and others, 2008). In this study, color was not correlated with wetlands area, which is likely the result of differences in how wetlands were categorized in the land-use datasets as opposed to being affected by environmental changes.

Streamflow

Water-quality properties and constituent concentrations may vary with streamflow because of seasonal changes in precipitation, evaporation, or stormwater runoff. The relation between the concentration of a constituent and streamflow also may reflect washoff and dilution processes, in which washoff refers to the mobilization of constituents from the contributing area and streambed during stormflow conditions. Various water-quality properties and constituent concentrations are negatively correlated with streamflow, which reflects dilution of these constituents at higher flows (table 16). In general, turbidity, concentrations of total coliform bacteria, and *E. coli* were negatively correlated with streamflow at more than half of the stations (23 stations had streamflow data and PWSB sample data). Cl concentrations also correlated negatively with streamflow at 10 stations. At some stations in the Barden Reservoir, Direct runoff, and Regulating Reservoir subbasins, Cl concentrations tended to be higher during the summer when streamflow was low, lower during higher base-flow conditions, and decrease during stormflow conditions (based on estimates of Cl concentrations from continuous records of specific conductance). This relation may differ during winter runoff events when road salt has been applied. The average monthly Cl concentrations, estimated from specific-conductance records, and mean monthly flows for WYs 2013–19 at Barden Reservoir (USGS streamgage 01115265; PWSB station 28; fig. 1), Quonapaug Brook (USGS streamgage 01115183; PWSB station 6), and Rush Brook (USGS streamgage 01115114; PWSB station 15) indicate that higher concentrations (greater than 30, 50, and 60 mg/L at these three stations, respectively) are more frequent in June through September when streamflows are also low (fig. 12). This pattern was observed at 10 of the 14 stations for which Cl concentrations were estimated and may indicate that Cl 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. The transit times and groundwater flowpaths contributing to the Scituate Reservoir drainage area are unknown, and elevated Cl concentrations (above background concentrations) may persist over longer periods (months to years). The presence of elevated concentrations at Bear Tree Brook (USGS station 01115275; PWSB station 9; fig. 1), which drains an area where a road salt storage facility had been left uncovered up until the late-1980s, indicates that long-term retention of Cl and Na in the environment may occur, but more information is required to determine this possible retention.

Median concentrations of nitrate were correlated positively with flow at six stations found in the Direct runoff, Moswansicut Reservoir, Regulating Reservoir, and Westconnaug Reservoir subbasins (table 16). Nitrogen-enriched runoff in streamflow during storm events could be a factor in these relations. Correlations between median concentrations of nitrite and daily streamflow were significant at about one-third of the stations; however, the direction of the

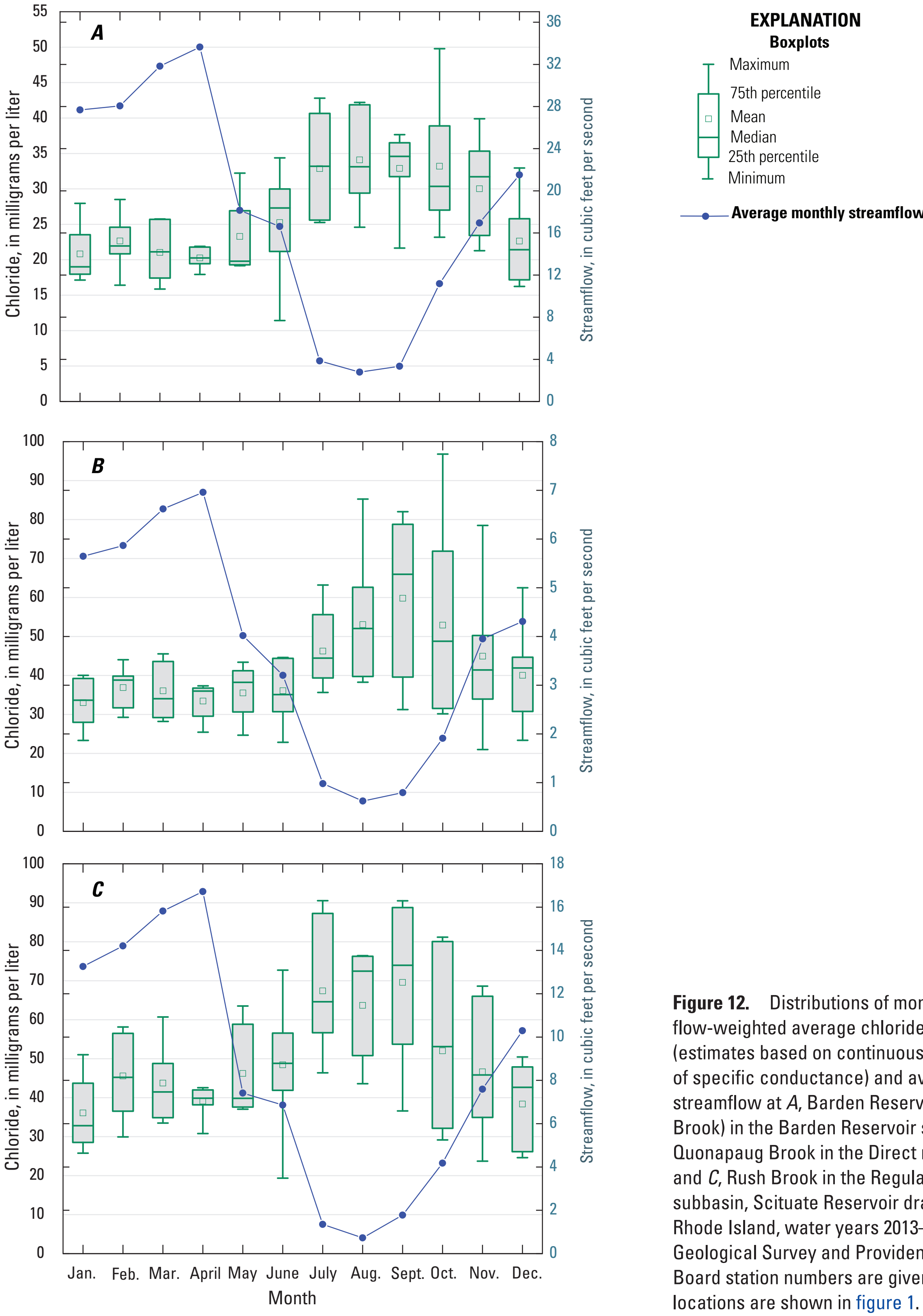


Figure 12. Distributions of monthly flow-weighted average chloride concentrations (estimates based on continuous measurements of specific conductance) and average monthly streamflow at *A*, Barden Reservoir (Hemlock Brook) in the Barden Reservoir subbasin, *B*, Quonapaug Brook in the Direct runoff subbasin, and *C*, Rush Brook in the Regulating Reservoir subbasin, Scituate Reservoir drainage area, Rhode Island, water years 2013–19. U.S. Geological Survey and Providence Water Supply Board station numbers are given in table 1; locations are shown in figure 1.

relations was inconsistent. Correlations between median concentrations of orthophosphate and flow were significant only at Brandy Brook (USGS station 01115180; PWSB station 1) and Quonapaug Brook (USGS streamgage 01115183; PWSB station 6; fig. 1) and had inverse relations (table 16).

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

Values of water-quality properties and constituent concentrations can be compared to various types of standards and guidelines. The RIDEM assigns water-use classifications and sets water-quality standards for surface water based on the intended uses of the water. Class AA is assigned to sources of public drinking water and tributaries within a drinking-water supply watershed, such as the Scituate Reservoir and its tributaries (Rhode Island Department of Environmental Management, 2006). Class AA numeric criteria for pH and TP were compared to available PWSB data for WYs 2013–19 (table 17). The RIDEM criteria for turbidity of class AA waters mandates that turbidity values do not exceed background conditions by more than 5 NTU, in which "background" is described as the water quality at a sampling location unaffected by point and nonpoint contamination sources. Because of the scarcity of such background data, turbidity values determined in PWSB samples were compared to the ecoregion-specific (level III) EPA proposed turbidity for minimally affected conditions (table 17; U.S. Environmental Protection Agency, 2000).

EPA has established various water-quality guidelines, including the criterion continuous concentration (CCC), also referred to as a chronic concentration, and the criterion maximum concentration (CMC) for freshwater aquatic life, in addition to secondary drinking-water regulations (U.S. Environmental Protection Agency, 1988; 2021). The EPA CCC is an estimate of the highest concentration of a constituent to which an aquatic community can be exposed indefinitely without adverse effects; an average period of 4 days is generally applied for the CCC (Stephen and others, 1985). In contrast, the EPA CMC is an estimate of the highest concentration of a constituent to which an aquatic community can be exposed briefly without adverse effects; an average period of 1 hour is generally applied for the CMC (Stephen and others, 1985). The EPA CCC and CMC for Cl are 230 and 860 mg/L, respectively (table 17). Secondary drinking-water regulations (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, 2021). 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 (Smith, 2017). The EPA SDWRs and guidelines for drinking water are useful benchmarks to compare against the levels of constituent concentrations measured in the drinking-water source area.

Water-Quality Properties

RIDEM water-quality standards for class AA waters establish an allowable range for pH of 6.5 to 9.0 standard units, or as occurring naturally; the EPA's recommended pH range of drinking water is from 6.5 to 8.5 standard units (table 17). The pH of water samples collected during WYs 2013–19 by PWSB did not exceed 8.5; however, the pH was less than 6.5 in 60 percent of all samples collected in the Scituate Reservoir drainage area (table 18). Low pH values (usually less than 6.5 standard units) are common in New England streams and result primarily from the low pH of precipitation (National Atmospheric Deposition Program, 2021); the low buffering capacity of the soil material in the Scituate Reservoir drainage area, as indicated by low streamwater alkalinities (median value in drainage area is 5.3 mg/L as $CaCO_3$), also 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 17). 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; for this reason, DOC is a factor in water treatment. More than 90 percent of samples collected at 28 stations exceeded the SDWR for color of 15 PCU during WYs 2013–19 (table 18).

Turbidity values in tributaries in the drainage area were predominantly below the EPA proposed reference turbidity value of 1.68 NTU for minimally affected conditions in the region (U.S. Environmental Protection Agency, 2000; fig. 10*C*). Forty-four percent of samples collected at Moswansicut Stream South (USGS station 01115167; PWSB station 22; fig. 1) exceeded 1.68 NTU (table 18); this station drains an area with the second highest impervious cover (21 percent) and the highest road density (11 mi/mi^2). However, turbidity values at Brandy Brook (USGS station 01115180; PWSB station 1) and Quonapaug Brook (USGS streamgage 01115183; PWSB station 6) exceeded 1.68 NTU in 31 and 39 percent of samples, respectively, and these subbasins do not have similar impervious-cover and road-density characteristics. At most stations (29 of the 37), the percentage of turbidity values greater than 1.68 NTU was less than 10 percent. These turbidity results indicate that the water quality of tributaries in the Scituate Reservoir drainage area is minimally affected by suspended particles relative to streamwater in the Northeastern Coastal Zone ecoregion of the United States, as noted previously.

Constituent Concentrations

RIDEM water-quality standards for class AA waters establish a maximum concentration of TP at 0.025 mg/L. Orthophosphate (a component and variable fraction of the total phosphorus) in streamwater was measured by PWSB during WYs 2013–19; the percentage of concentrations greater than the RIDEM standard for TP by subbasin ranged from 0 to 71 percent of samples collected from each station (table 18). Median orthophosphate concentrations (table 13) were typically around or below the RIDEM TP standard value of 0.025 mg/L (fig. 10*H*). Phosphorus concentrations that exceed the standard could be of concern because phosphorus can contribute to excessive plant and algae growth.

TP was measured in base-flow and stormflow samples collected by the USGS during WYs 2016–19 at five stations. TP concentrations exceeded 0.025 mg/L in 3 to 46 percent of samples. TP in storm samples exceeded the standard value more frequently than TP in base-flow samples at four out of the five stations (table 19). At Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19; fig. 1), and Quonapaug Brook (USGS streamgage 01115183; PWSB station 6), TP concentrations were not significantly different between stormflow and base-flow samples (table 12).

A single PWSB sample, collected during the winter at Moswansicut Stream South, exceeded the EPA SDWR for Cl (250 mg/L) and the EPA CCC for Cl (230 mg/L) with a concentration of 288 mg/L. Instantaneous Cl concentrations estimated at 14 stations from continuous records of specific conductance represent a much broader range and distribution of flow conditions than are measured in the fixed-frequency PWSB samples. These estimated Cl concentrations indicate that Quonapaug Brook (USGS streamgage 01115183; PWSB station 6; fig. 1) and Unnamed Tributary to Regulating Reservoir (USGS station 01115120; PWSB station 18) exceeded the CCC infrequently during WYs 2013–19 for short-lived periods ranging from 10 minutes to 26 hours—approximately 11 exceedances were documented at Quonapaug Brook and 29 at the Unnamed Tributary to Regulating Reservoir. The CMC (860 mg/L) was exceeded at Quonapaug Brook once, for 40 minutes during a snow and rain event in March 2017. Most exceedances of estimated Cl concentrations greater than the CCC at Quonapaug Brook resulted during winter and early spring (December through March); however, the longest duration of CCC exceedance resulted during early fall when streamflow was extremely low (<0.01 ft^3/s). At Unnamed Tributary to Regulating Reservoir, CCC exceedances resulted more frequently and typically for longer durations during June and July (2018–19) than in winter months (fig. 13). Unnamed Tributary to Regulating Reservoir has periods of no streamflow annually during the summer; therefore, Cl concentration estimates were based on the available record. For most of the summer months between 2013 and 2018, no streamflow record (and, therefore, no specific-conductance record) was available (fig. 13). The estimated Cl concentrations at Quonapaug Brook and Unnamed Tributary to Regulating Reservoir indicate that Cl concentrations that exceed the CCC result during winter runoff events over short periods (10 minutes and 26 hours) but may persist chronically during low, base-flow-dominated streamflow periods in summer and fall. Estimated instantaneous Cl concentrations did not exceed the CCC at the remaining 12 stations (table 1) equipped to continuously monitor specific conductance during WYs 2013–19. Whereas some exceedances of the CCC and CMC values occurred, they did not persist over intervals that exceeded the averaging periods applied for these criteria (4 days for the CCC and 1 hour for the CMC).

Table 19. Percentage of samples collected by U.S. Geological Survey at five monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19, with total phosphorus concentrations not meeting water-quality standards.

[Water-quality data collected by U.S. Geological Survey (USGS; Spaetzel and Smith, 2022). PWSB, Providence Water Supply Board; mg/L, milligram per liter; P, phosphorus; >, greater than]

PWSB station number (fig. 1)	USGS station number (table 1)	Sample type	Total phosphorus >0.025 mg/L as P (percent)
16	01115098	Base flow	0
		Stormflow	5
14	01115110	Base flow	14
		Stormflow	64
15	01115114	Base flow	11
		Stormflow	66
[1]19	01115170	Base flow	11
		Stormflow	11
[1]6	01115183	Base flow	38
		Stormflow	52

[1]Stormflow sample total phosphorus concentrations are not significantly different from base-flow sample concentrations.

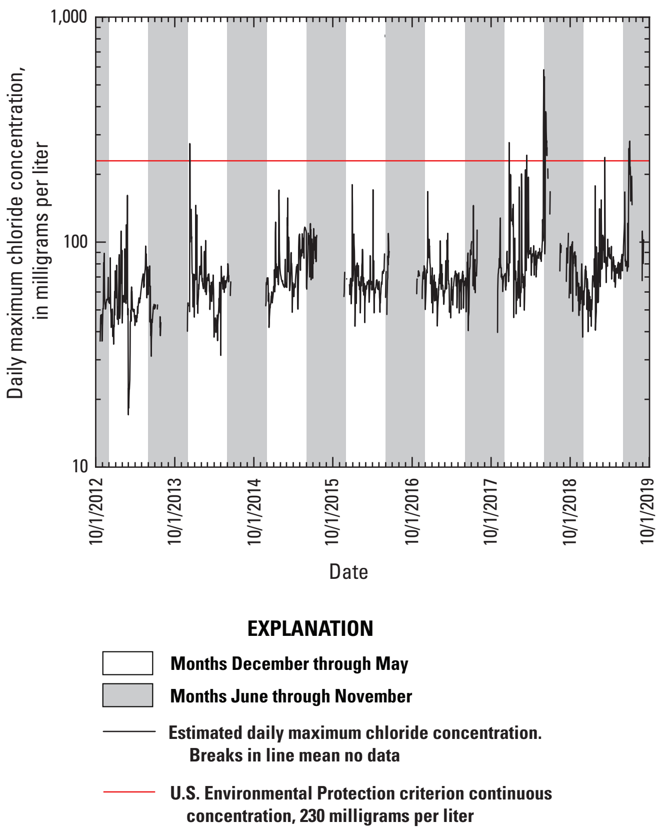


Figure 13. Daily maximum concentrations of chloride, estimated from continuous records of specific conductance for Unnamed Tributary to Regulating Reservoir (Unnamed Brook A), in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

Trends in Water-Quality Properties and Constituent Concentrations

Trends in pH, turbidity, color, alkalinity, Cl, nitrite, and orthophosphate (tables 20–25, in back of report) data collected by PWSB were examined for the 18-year recent study period of WYs 2002–19 (shorter period) and for the 37-year period of WYs 1983–2019 (longer period); however, for some constituents, the earliest available results are between WYs 1985 and 1996 (tables 26–28). The longer period referred to herein indicates the earliest available data through WY 2019. Trends in USGS estimated Cl and Na concentrations and loads were also determined for WYs 2009–19 and WYs 2015–19 (tables 29 and 30, respectively). Trends during WYs 2002–19 (shorter period) reflect more recent trends in water-quality properties and constituent concentrations, whereas trends during the WYs 1983–2019 (longer period) may reflect ongoing or past changes in water-quality properties and constituent concentrations. Total coliform bacteria, *E. coli*, and nitrate concentrations are described across periods of different analytical methods; trend test results for these constituents are not reported because of analytical changes described in previous sections.

Water-Quality Properties

Significant positive trends in pH were identified for samples collected at 27 stations for the shorter period (WYs 2002–19) and at 26 stations during the longer period described above (WYs 1983–2019) (tables 20 and 21; fig.14*A*). One significant negative trend in pH was identified for the longer period at Toad Pond (USGS station 01115177; PWSB station 31); no significant negative trends were detected in the shorter period. Station 31, Toad Pond (USGS station 01115177; PWSB station 31), has the highest pH measurements recorded (greater than 8.5 standard units), all of which resulted at the beginning of the monitoring period, in the years 1983–85, but it is also characterized with the fewest measurements during the recent period, which makes the trend results difficult to interpret (table 26). Positive 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). Positive trends in pH since this time have also been documented in streams in New Hampshire (Hubbard Brook Experimental Forest) and in kettle ponds on Cape Cod, Massachusetts (Fuss and others, 2015; Smith and others, 2016).

Significant positive trends in color were identified for samples from 28 of 37 stations during the longer period. Significant trends in color were identified in samples from eight stations during the shorter period, of which seven trends were positive (table 20 and fig.14*B*). Because color is likely to have a natural source, such as dissolved organic material, or suspended or colloidal metals such as iron or manganese, positive 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.

Significant trends in turbidity were identified at 13 stations for WYs 1983–2019 and 12 stations for WYs 2002–19 (fig. 14*C*; tables 20 and 21). During the longer period, trends were positive at 6 stations and negative at 7 stations. Trends were predominantly positive in the shorter period. Positive trends in turbidity were identified at 10 stations for the shorter period; 6 of these stations did not have significant turbidity trends for WYs 1983–2019. At two stations (USGS station 01115119, and USGS station 01115274), trends for both periods were significant but differed in direction. Although turbidity values were low (commonly less than 1 NTU) throughout the Scituate Reservoir drainage area, data collected at 27 percent of the stations indicate values increased during the more recent period (WYs 2002–19).

Significant trends in alkalinity, like trends in pH, were primarily positive during WYs 2002–19 and WYs 1983–2019 (fig. 14*D*; tables 22 and 23) and may be related in part to the relatively low pH of precipitation in this region of the country. Positive trends in alkalinity are common in the northeastern United States and have been associated with increasing pH and chemical weathering of bedrock, soils, and structures containing concrete in the urban environment (Kaushal and

Table 26. Number of samples to assess time trends in water-quality properties, measured by Providence Water Supply Board, in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). The number of trend seasons was based on the frequency of sampling, which was either monthly or quarterly. USGS, U.S. Geological Survey; Start WY, the first water year in which the parameter was measured; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Trend seasons	Start WY	pH count		Color count		Turbidity count	
				Start–2019	2002–19	Start–2019	2002–19	Start–2019	2002–19
24	01115190	12	1983	410	198	405	198	411	198
25	01115200	4	1983	232	56	225	54	232	56
26	01115185	4	1983	234	62	227	60	235	62
27	011151845	4	1983	171	40	167	38	170	39
28	01115265	12	1983	411	203	406	203	411	203
29	01115271	12	1983	374	167	369	167	375	167
35	01115187	12	1996	246	189	246	189	246	189
1	01115180	12	1983	417	200	412	200	413	200
2	01115181	4	1983	133	33	128	31	131	33
3	01115280	12	1983	384	182	379	182	383	182
4	01115400	12	1983	402	184	396	184	402	184
5	01115184	4	1983	222	62	222	60	230	62
6	01115183	12	1983	382	180	384	180	390	180
7	01115297	12	1983	414	201	409	201	414	201
8	01115276	12	1983	371	157	353	157	358	157
9	01115275	4	1983	243	61	234	59	242	61
30	01115350	4	1983	226	54	218	52	226	54
31	01115177	4	1983	155	14	118	13	160	14
32	01115178	4	1988	158	55	156	53	157	55
33	01115182	4	1988	157	53	155	51	156	53
36	--	4	1999	73	55	71	53	73	55
37	--	4	1999	71	54	69	52	71	54
19	01115170	12	1983	374	178	374	178	379	178
20	01115160	12	1983	359	166	353	166	359	166
21	01115165	4	1983	206	44	199	42	206	44
22	01115167	12	1983	358	165	371	166	364	166
34	01115164	4	1998	56	45	54	43	56	45
23	011151843	12	1983	358	170	358	170	364	170
13	01115176	12	1983	397	189	397	189	403	189
14	01115110	12	1983	376	175	370	175	376	175
15	01115114	12	1983	383	183	384	184	390	184
16	01115098	12	1983	419	198	405	198	419	198
17	01115119	4	1983	192	39	181	37	197	39
18	01115120	4	1983	167	34	163	32	171	34
10	01115274	12	1983	360	173	356	173	360	173
11	01115273	4	1983	194	49	190	47	196	49
12	011152745	4	1983	194	38	176	36	192	38

Table 27. Number of samples available to assess time trends in alkalinity and chloride concentrations, measured in data collected by the Providence Water Supply Board, in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). The number of trend seasons was based on the frequency of sampling, which was either monthly or quarterly. None of the alkalinity or chloride results were censored. USGS, U.S Geological Survey; Start WY, the first water year in which the constituent was measured; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Trend seasons	Alkalinity			Chloride		
			Start WY	Count		Start WY	Count	
				Start–2019	2002–19		Start–2019	2002–19
24	01115190	12	1983	404	198	1983	411	198
25	01115200	4	1983	227	56	1983	233	57
26	01115185	4	1983	227	61	1983	235	62
27	011151845	4	1983	169	40	1983	172	40
28	01115265	12	1983	406	203	1983	412	203
29	01115271	12	1983	368	167	1983	375	167
35	01115187	12	1996	246	189	1996	246	189
1	01115180	12	1983	406	200	1983	418	200
2	01115181	4	1983	131	33	2008	22	22
3	01115280	12	1983	378	182	1983	383	182
4	01115400	12	1983	394	184	1983	400	183
5	01115184	4	1983	223	61	1983	229	62
6	01115183	12	1983	384	180	1983	390	180
7	01115297	12	1983	409	201	1983	414	201
8	01115276	12	1983	353	157	1983	354	157
9	01115275	4	1983	235	60	1983	240	61
30	01115350	4	1983	219	53	1983	226	54
31	01115177	4	1983	155	14	1983	161	14
32	01115178	4	1988	157	54	1988	158	55
33	01115182	4	1988	157	53	1988	158	54
36	--	4	1999	71	53	1999	71	54
37	--	4	1999	70	53	1999	71	54
19	01115170	12	1983	373	178	1983	379	178
20	01115160	12	1983	353	166	1983	359	166
21	01115165	4	1983	201	44	1983	207	45
22	01115167	12	1983	359	166	1983	365	166
34	01115164	4	1998	56	45	1998	57	46
23	011151843	12	1983	356	170	1983	363	170
13	01115176	12	1983	397	189	1983	403	189
14	01115110	12	1983	370	175	1983	375	175
15	01115114	12	1983	384	184	1983	390	184
16	01115098	12	1983	412	198	1983	418	198
17	01115119	4	1983	193	40	1983	190	40
18	01115120	4	1983	165	34	1983	169	34
10	01115274	12	1983	356	173	1983	360	173
11	01115273	4	1983	191	48	1983	194	49
12	011152745	4	1983	187	39	1983	194	39

Table 28. Number of samples and percentage of censored results used in tests for trends in nitrite and orthophosphate concentrations measured by the Providence Water Supply Board in the Scituate Reservoir drainage area, Rhode Island, water years 1985–2019.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). The number of trend seasons was based on the frequency of sampling, which was either monthly or quarterly. The percentage of censored values reported by the laboratory for nitrite and the percentage of uniformly censored results for orthophosphate are provided. USGS, U.S. Geological Survey; Start WY, the first water year in which the constituent was measured; mg/L, milligram per liter; N, nitrogen; P, phosphorus; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Trend seasons	Nitrite					Orthophosphate				
			Start WY	Start–2019		2002–19		Start WY	Start–2019		2002–19	
				Count	Percent censored at 0.001 mg/L as N	Count	Percent censored at 0.001 mg/L as N		Count	Percent uniformly censored at 0.0065 mg/L as P	Count	Percent uniformly censored at 0.0065 mg/L as P
24	01115190	12	1985	358	13.4	197	0.0	1996	255	25.1	197	22.8
25	01115200	4	1985	180	27.2	56	0.0	1996	75	14.7	55	14.5
26	01115185	4	1985	184	25.0	62	1.6	1996	79	19.0	60	15.0
27	011151845	4	1985	135	30.4	40	2.5	1997	51	15.7	40	12.5
28	01115265	12	1985	357	14.6	201	1.0	1996	264	16.7	202	13.4
29	01115271	12	1985	322	16.8	167	1.8	1996	218	27.5	166	19.3
35	01115187	12	1996	246	2.0	189	1.1	1998	222	21.6	188	18.1
1	01115180	12	1985	364	14.6	200	2.0	1996	260	15.0	199	13.1
2	01115181	4	1985	108	33.3	33	0.0	1997	40	22.5	33	24.2
3	01115280	12	1985	333	15.3	182	2.2	1996	237	15.2	180	14.4
4	01115400	12	1985	350	15.7	184	1.6	1996	243	39.1	183	36.1
5	01115184	4	1985	178	30.3	61	1.6	1996	81	17.3	61	18.0
6	01115183	12	1985	338	16.0	180	1.7	1996	232	15.1	178	11.8
7	01115297	12	1985	363	13.5	201	0.5	1996	258	14.3	199	13.1
8	01115276	12	1985	306	18.0	157	1.9	1997	204	31.9	157	26.8
9	01115275	4	1985	190	26.3	61	0.0	1996	81	17.3	61	18.0
30	01115350	4	1985	175	28.6	54	0.0	1996	70	14.3	53	13.2
31	01115177	4	1994	38	0.0	14	0.0	1997	19	0.0	15	0.0
32	01115178	4	1994	88	0.0	55	0.0	1996	72	13.9	55	14.5
33	01115182	4	1994	86	2.3	53	3.8	1997	65	7.7	53	7.5
36	--	4	1999	73	4.1	55	5.5	1999	73	20.5	55	16.4
37	--	4	1999	71	8.5	54	11.1	1999	70	25.7	53	24.5
19	01115170	12	1994	248	0.4	178	0.6	1996	228	39.5	178	30.9
20	01115160	12	1985	310	15.8	166	0.6	1996	218	9.6	165	9.1
21	01115165	4	1985	157	29.3	44	0.0	1996	60	21.7	44	15.9

Table 28. Number of samples and percentage of censored results used in tests for trends in nitrite and orthophosphate concentrations measured by the Providence Water Supply Board in the Scituate Reservoir drainage area, Rhode Island, water years 1985–2019.—Continued

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). The number of trend seasons was based on the frequency of sampling, which was either monthly or quarterly. The percentage of censored values reported by the laboratory for nitrite and the percentage of uniformly censored results for orthophosphate are provided. USGS, U.S. Geological Survey; Start WY, the first water year in which the constituent was measured; mg/L, milligram per liter; N, nitrogen; P, phosphorus; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Trend seasons	Nitrite					Orthophosphate				
			Start WY	Start–2019		2002–19		Start WY	Start–2019		2002–19	
				Count	Percent censored at 0.001 mg/L as N	Count	Percent censored at 0.001 mg/L as N		Count	Percent uniformly censored at 0.0065 mg/L as P	Count	Percent uniformly censored at 0.0065 mg/L as P
22	01115167	12	1994	240	0.0	166	0.0	1996	220	11.8	166	11.4
34	01115164	4	1998	56	0.0	45	0.0	1998	56	25.0	45	17.8
23	011151843	12	1994	228	1.3	170	1.2	1996	208	40.9	170	36.5
13	01115176	12	1994	266	1.5	189	1.6	1996	244	30.3	189	24.3
14	01115110	12	1985	325	16.9	175	1.7	1996	226	17.3	171	14.0
15	01115114	12	1994	259	1.2	184	1.1	1996	239	12.1	183	9.8
16	01115098	12	1985	368	15.2	198	1.5	1996	258	28.3	196	23.0
17	01115119	4	1994	74	0.0	39	0.0	1996	54	37.0	39	28.2
18	01115120	4	1985	127	33.1	34	2.9	1997	42	4.8	33	3.0
10	01115274	12	1985	311	18.0	172	5.2	1997	220	20.9	171	21.1
11	01115273	4	1985	152	30.9	49	0.0	1997	60	18.3	49	10.2
12	011152745	4	1985	143	35.7	38	0.0	1997	50	16.0	38	10.5

Table 29. Significance levels (*p* values) and Theil-Sen slope estimates of seasonal Kendall tests for time trends in monthly estimated chloride and sodium concentrations at 14 stations in Scituate Reservoir drainage area, Rhode Island, water years 2009–19.

[Monthly mean concentrations are flow-weighted averages of daily concentrations estimated from continuous specific-conductance records (U.S. Geological Survey, 2020b and table 10). PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; mg/L, milligram per liter; CI, 95-percent confidence interval; <, less than]

PWSB station number (fig. 1)	USGS station number (table 1)	Chloride				Sodium			
		p value	Slope (mg/L per year)	Lower CI (mg/L per year)	Upper CI (mg/L per year)	*p* value	Slope (mg/L per year)	Lower CI (mg/L per year)	Upper CI (mg/L per year)
Barden Reservoir subbasin									
24	01115190	<0.001*	1.08	0.71	1.47	<0.001*	0.65	0.43	0.89
28	01115265	<0.001*	0.56	0.32	0.91	<0.001*	0.32	0.18	0.50
35	01115187	<0.001*	0.58	0.41	0.82	<0.001*	0.40	0.28	0.55
Direct runoff subbasin									
3	01115280	<0.001*	1.24	0.74	1.60	<0.001*	0.67	0.40	0.84
5	01115184	<0.001*	0.99	0.69	1.26	<0.001*	0.51	0.37	0.66
6	01115183	0.045	0.49	0.00	1.15	0.043	0.30	0.00	0.70
7	01115297	0.157	0.07	−0.03	0.16	0.163	0.04	−0.01	0.09
8	01115276	0.200	0.14	−0.07	0.31	0.216	0.08	−0.04	0.18
9	01115275	0.702	0.07	−0.31	0.46	0.669	0.04	−0.19	0.28
Moswansicut Reservoir subbasin									
19	01115170	<0.001*	2.98	2.67	3.46	<0.001*	1.76	1.58	2.05
Regulating Reservoir subbasin									
14	01115110	<0.001*	0.40	0.27	0.52	<0.001*	0.23	0.15	0.30
15	01115114	<0.001*	1.59	0.85	2.21	<0.001*	0.91	0.49	1.30
16	01115098	<0.001*	1.52	1.03	2.06	<0.001*	0.78	0.53	1.06
18	01115120	<0.001*	2.55	1.66	3.50	<0.001*	1.45	0.94	1.99

*Significant positive trend defined by a *p* value less than 0.05, a positive slope, and a 95-percent confidence interval about the slope that does not include zero.

others, 2013; Kaushal and others, 2017). Fewer significant trends were detected in the recent period than in the longer period.

Constituent Concentrations

Thirty-two significant trends in Cl concentrations were positive during WYs 1983–2019; three trends, at Westconnaug Brook (USGS streamgage 01115276; PWSB station 8; fig. 1) and Bear Tree Brook (USGS station 01115275; PWSB station 9) in the Direct runoff subbasin and Unnamed Tributary to Westconnaug Reservoir (USGS station 01115273; PWSB station 11), were identified as negative trends (fig. 14*E*). The significant negative trend at Bear Tree Brook is likely because of a salt-storage facility being covered during the late 1980s. The median Cl concentrations at Bear Tree Brook during WYs 1983–90 (prior to covering) and WYs 1991–2019 (post covering) were 125 mg/L and 59 mg/L, respectively. Twenty-five positive trends were significant for WYs 2002–19; at the remaining stations, significant trends were not identified. All stations in the Barden Reservoir and Regulating Reservoir subbasins, except for Unnamed Tributary to Regulating Reservoir (USGS station 01115120; PWSB station 18), had significant positive trends during both periods. The significant negative trends in Cl concentrations at several stations during WYs 2003–12, previously identified by Smith (2015b), were not present in the trend analyses for WYs 2002–19. This difference between the two periods suggests changes to State road winter maintenance methods during that timeframe did not produce observable changes in tributary Cl concentrations (Smith, 2015b). Deicing application methods used on locally maintained roads in the Scituate Reservoir drainage area are unknown. Accumulation of Cl and Na in groundwater may obscure the effects of improved management practices over the short-term (Kelly and others, 2019).

Tests for trends also were applied to USGS estimated average monthly Cl and Na concentrations and loads for WYs 2009–19. Significant positive trends in Cl and Na concentrations were identified for 10 of the 14 stations equipped with continuous specific- conductance monitors (table 29). The average slope of the significant trends was 1.35 mg/L per year. Trends detected in PWSB Cl concentrations for WYs 2002–19 generally agreed with trends identified with

Table 30. Significance levels (*p* values) and Theil-Sen slope estimates of seasonal Kendall tests for time trends in monthly estimated chloride and sodium loads at 14 stations in Scituate Reservoir drainage area, Rhode Island, water years 2009–19.

[Monthly mean loads are flow-weighted averages of daily concentrations estimated from continuous specific-conductance records multiplied by the monthly mean streamflow (U.S. Geological Survey, 2020b and table 10). PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; kg, kilogram; CI, 95-percent confidence interval; <, less than]

PWSB station number (fig. 1)	USGS station number (table 1)	Chloride				Sodium			
		p value	Slope (kg per year)	Lower CI (kg per year)	Upper CI (kg per year)	*p* value	Slope (kg per year)	Lower CI (kg per year)	Upper CI (kg per year)
Barden Reservoir subbasin									
24	01115190	0.006 *	296	69	623	0.007*	171	42	373
28	01115265	0.016*	630	81	1233	0.021*	340	42	777
35	01115187	0.029*	920	71	1913	0.021*	615	88	1187
Direct runoff subbasin									
3	01115280	0.271	57	−55	205	0.357	26	−36	117
5	01115184	<0.001*	124	58	195	<0.001*	64	23	115
6	01115183	0.840	−23	−219	203	0.840	−15	−129	121
7	01115297	0.544	24	−61	124	0.669	13	−50	89
8	01115276	0.033*	246	47	533	0.029*	155	30	334
9	01115275	0.669	33	−71	141	0.669	19	−40	81
Moswansicut Reservoir subbasin									
19	01115170	0.381	155	−239	903	0.381	88	−143	535
Regulating Reservoir subbasin									
14	01115110	0.056	151	−6	439	0.092	87	−9	247
15	01115114	0.073	369	−21	963	0.080	210	−24	575
16	01115098	0.144	410	−128	999	0.157	203	−97	550
18	01115120	0.010*	73	4	149	0.011*	41	2	85

*Significant positive trend defined by a *p* value less than 0.05, a positive slope, and a 95-percent confidence interval about the slope that does not include zero.

estimated Cl concentrations for WYs 2009–19, except for Quonapaug Brook (USGS streamgage 01115183; PWSB station 6) and Unnamed Tributary to Regulating Reservoir (USGS station 01115120; PWSB station 18). Quonapaug Brook had a significant positive trend based on PWSB data over WYs 2002–19 with a slope confidence interval of 0.21 to 0.82 mg/L per year and a median slope of 0.50 mg/L per year (table 22). The slope confidence interval and median determined based on USGS estimates were similar (0.0 to 0.70 mg/L per year with median slope 0.30 mg/L per year) but included a lower confidence interval of 0.0 mg/L; thus, the trend was not considered significant. Fewer stations (six) had significant positive trends in Cl and Na loads, indicating that whereas concentrations are generally increasing, loads are not uniformly increasing (tables 29 and 30).

Orthophosphate concentration data were generally not available until WY 1996 or 1997 and were highly censored after uniform censoring at 0.0065 mg/L as P (table 28). Four positive trends were identified in the longer period (WY 1996–2019; table 25; fig. 14*F*). One negative trend was identified in the slightly shorter period of WY 2002–19 (table 24; fig. 14*F*); however, this trend was identified at Toad Pond (USGS station 01115117; PWSB station 31; fig. 1), which is characterized by the fewest samples (*n*=19; table 28). The high percentage of censored results at each station diminishes the power of the statistical test for trend (table 28; Helsel and others, 2020).

One trend was significant for nitrite concentrations over the longer period in samples collected at Ponaganset River (USGS streamgage 01115187; PWSB station 35; fig. 1; table 25). Percentages of censored data varied widely among stations but ranged from 0 to 35.7 percent, with an average among stations of 15 percent (table 28). Concentration data that are near the method detection limit tend to be variable, and results can often be improperly interpreted (for example, false-positive detections). Because nitrite is an intermediate product of processes such as nitrification and denitrification (Hem, 1985; Brandt and others, 2017), in the absence of a significant environmental change (such as a new or increased source of nitrogen contaminant loading), observable trends in these data were not expected.

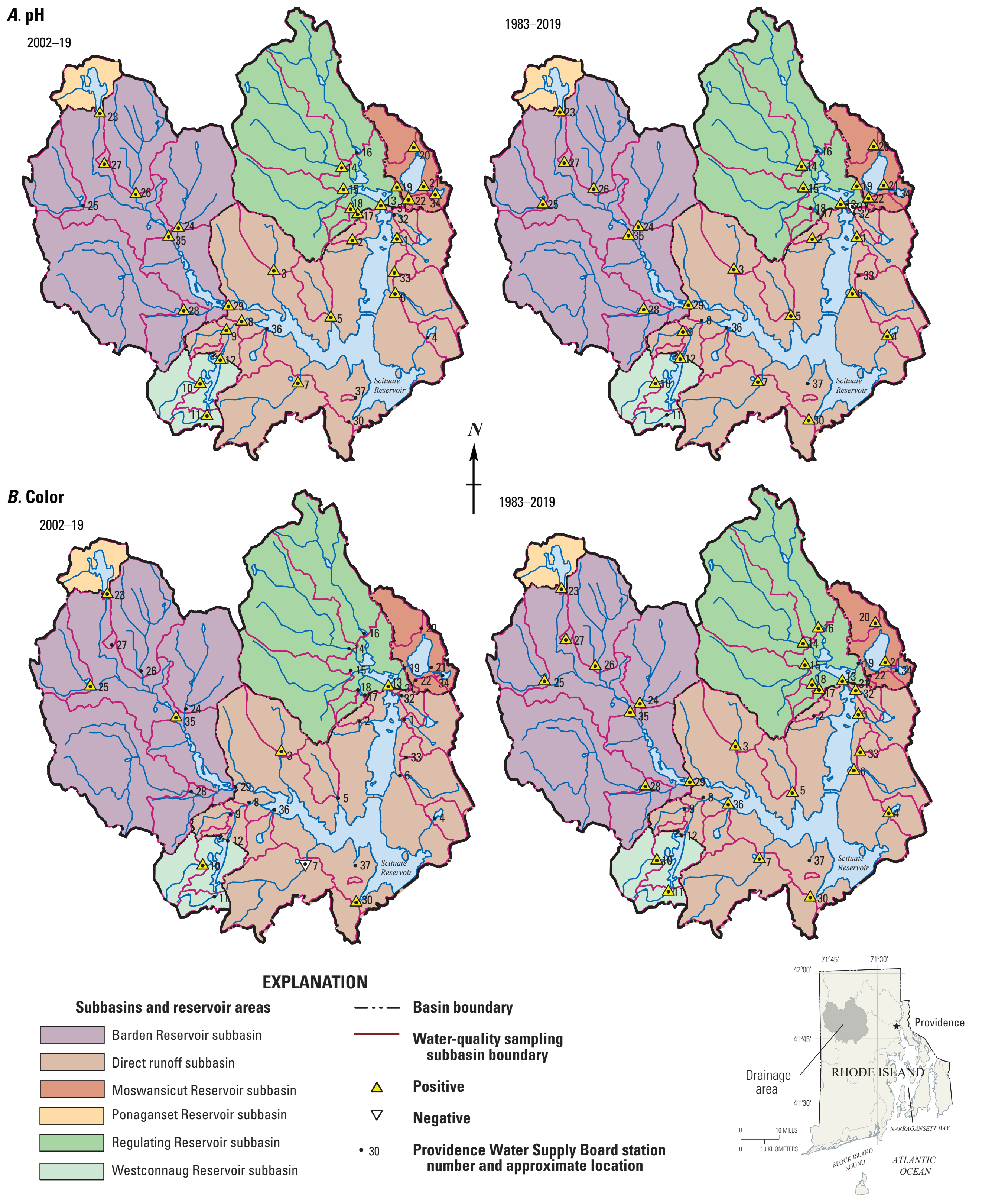


Figure 14. Time trends of *A*, pH, *B*, color, *C*, turbidity, *D*, alkalinity, *E*, chloride, and *F*, orthophosphate in water-quality data collected by the Providence Water Supply Board at 37 monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2002–19 and 1983 (or earliest available data) to 2019. The trend direction is indicated by the triangle orientation and color; if there is no triangle at a station location, then no trend was identified. Station names are given in table 1.

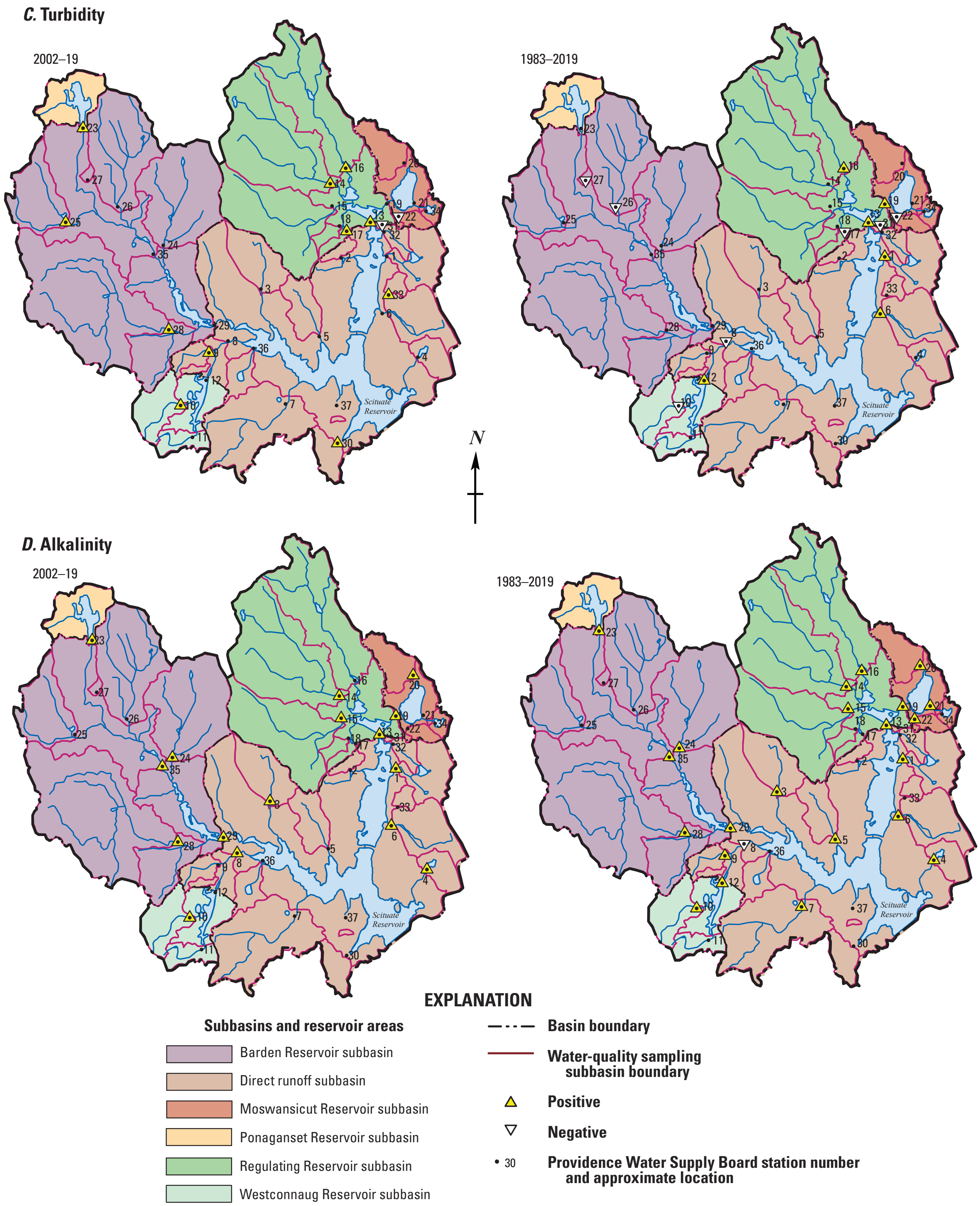


Figure 14.—Continued

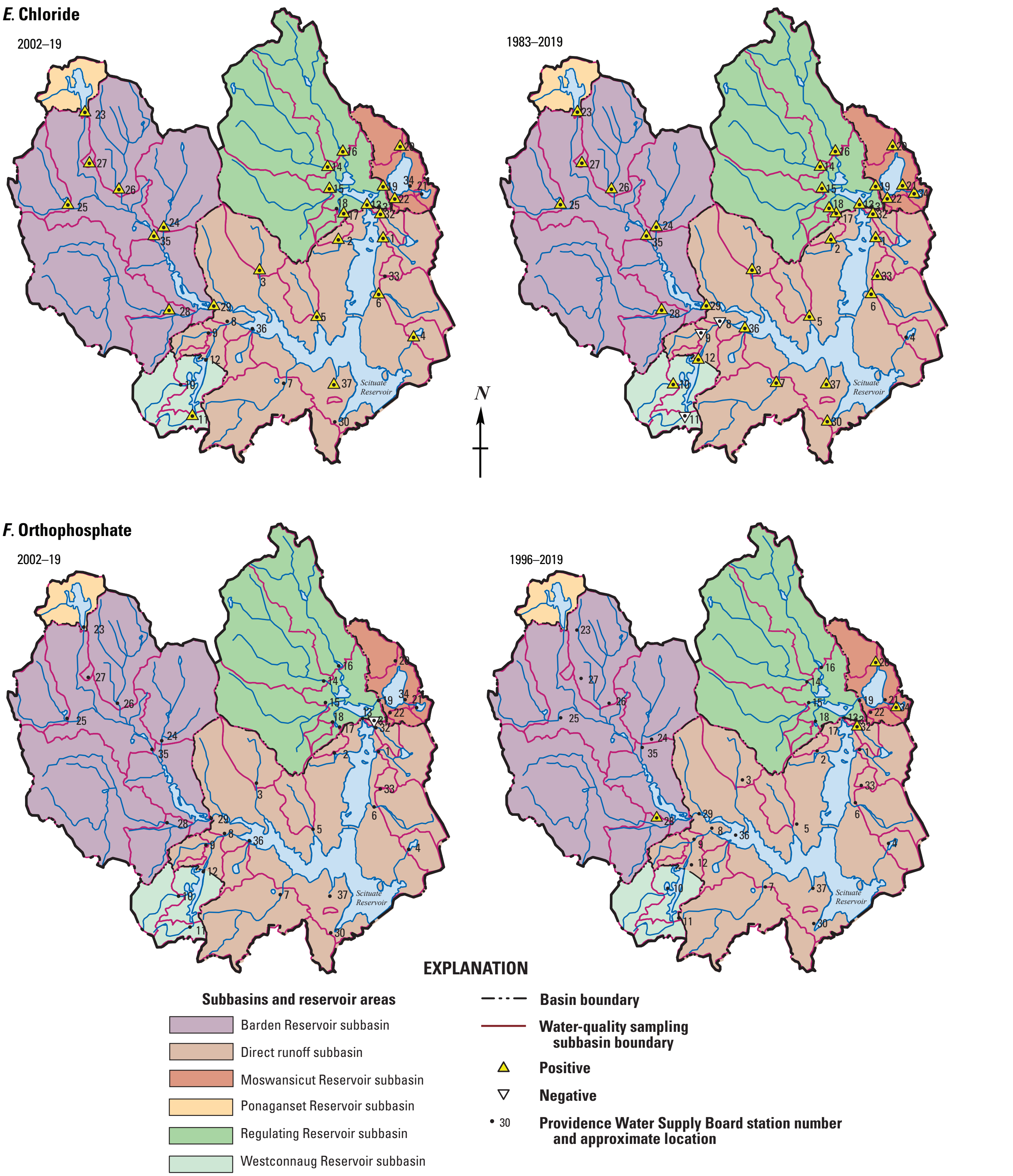


Figure 14.—Continued

Nitrate and Bacteria Concentrations

Nitrate concentration time series indicate that concentrations increased sharply after October 2014, a timeframe that coincides with a transition to a different analytical method and laboratory (fig. 15). Trends tests performed for each station in a previous study (Smith, 2015b) indicated that negative trends in nitrate concentrations were observed at most stations between WYs 1987 and 2012, and concentration time series like those in figure 15 indicate that these negative trends continued up until the change in analytical method and laboratory. Because of the negative trends in nitrate concentrations observed in PWSB data during WYs 1987 to 2014, and in the absence of a methodological change (or some other known appreciable change), comparison of concentrations before and after October 2014 would likely reflect different central tendencies. However, the decrease in the percentage of samples less than or equal to 0.05 mg/L (the uniform reporting limit) and the increase in median concentration from 0.03 to 0.07 mg/L reflect a large positive trend shift in nitrate concentrations throughout the basin (table 31). Trends that span the transitional period (to a new method and laboratory) cannot be meaningfully interpreted without appropriate quality-assurance/quality-control data to characterize the effect of this analytical change.

Shifts in the distribution of total coliform bacteria concentrations were observed and coincident with method changes (fig. 16; table 32). Prior to July 2012 (the date of the first analytical method transition), 8.7 percent of total coliform concentrations were equal to or greater than 2,400 CFU/100 mL (table 32). For data collected from July 2012 through August 2016 and September 2016 through September 2019, 22 and 27 percent of total coliform concentrations were equal to or greater than 2,400 CFU/100 mL, respectively. Similarly, the percentage of total coliform concentrations less than or equal to 10 CFU/100 mL decreased from 28 percent in data collected through June 2012 to 1.1 percent in samples collected between September 2016 and September 2019. *E. coli* concentrations do not reflect changes of similar magnitudes but were subject to the same analytical changes and, similarly to the total coliform bacteria concentration data mentioned previously, lack quality-assurance/quality-control data to compare method results. Prior to July 2012, 5.4 percent of *E. coli* concentrations were greater than or equal to 2,400 CFU/100 mL and 51 percent were less than or equal to 10 CFU/100 mL. After the first method change, the percentage of concentrations greater than or equal to 2,400 CFU/100 mL decreased to 1.7 percent and the percentage of concentrations less than or equal to 10 CFU/100 mL decreased by 5 percentage points (table 32). The time series of total coliform bacteria concentrations shown in figure 16 exemplify the trends observed at most stations in the basin—no trend observed in concentrations between 1983 and 2012, followed by an abrupt transition to increasing concentrations, which coincides with the first change in analytical methods. Although the data collected after July 2012 indicate that concentrations of total coliform bacteria are increasing within the tributary subbasins, it is not possible to assess trends over periods that span the methodological changes without additional quality assurance/quality-control data.

Loads and Yields of Selected Constituents

The potential adverse effects of a chemical constituent on reservoir water depend on the total amount of the constituent received and on the constituent concentrations in tributary waters. The 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 measured in PWSB samples for all sampling dates during WYs 2013–19 at 23 stations with available streamflow data. The median daily loads and yields for selected constituents were also determined (tables 33 and 34, in back of report). Daily and annual loads were also computed for Cl and Na based on the estimation of instantaneous concentrations derived from continuous specific-conductance records at 14 stations. The average loads and yields of Cl and Na were calculated for the 14 stations equipped with continuous specific-conductance monitors

Table 31. Summary of nitrate concentrations measured in samples collected by the Providence Water Supply Board in the Scituate Reservoir drainage area, Rhode Island, to compare periods with different analytical methods and laboratories.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Nitrate was measured in samples beginning in 1987 at most stations. Method references are listed in table 5. mg/L, milligram per liter; N, nitrogen; LR, low range; PWSB, Providence Water Supply Board; NO_3, nitrate.]

Period	Method	Number of samples	Percent of samples less than or equal to 0.05 mg/L as N	Median concentration (mg/L as N)
Beginning of sample collection through September 2014	Hach Nitrate LR Method at PWSB laboratory	7,559	62	0.03
October 2014 through September 2019	Standard Method 4500-NO_3-part F at contract laboratory	1,130	42	0.07

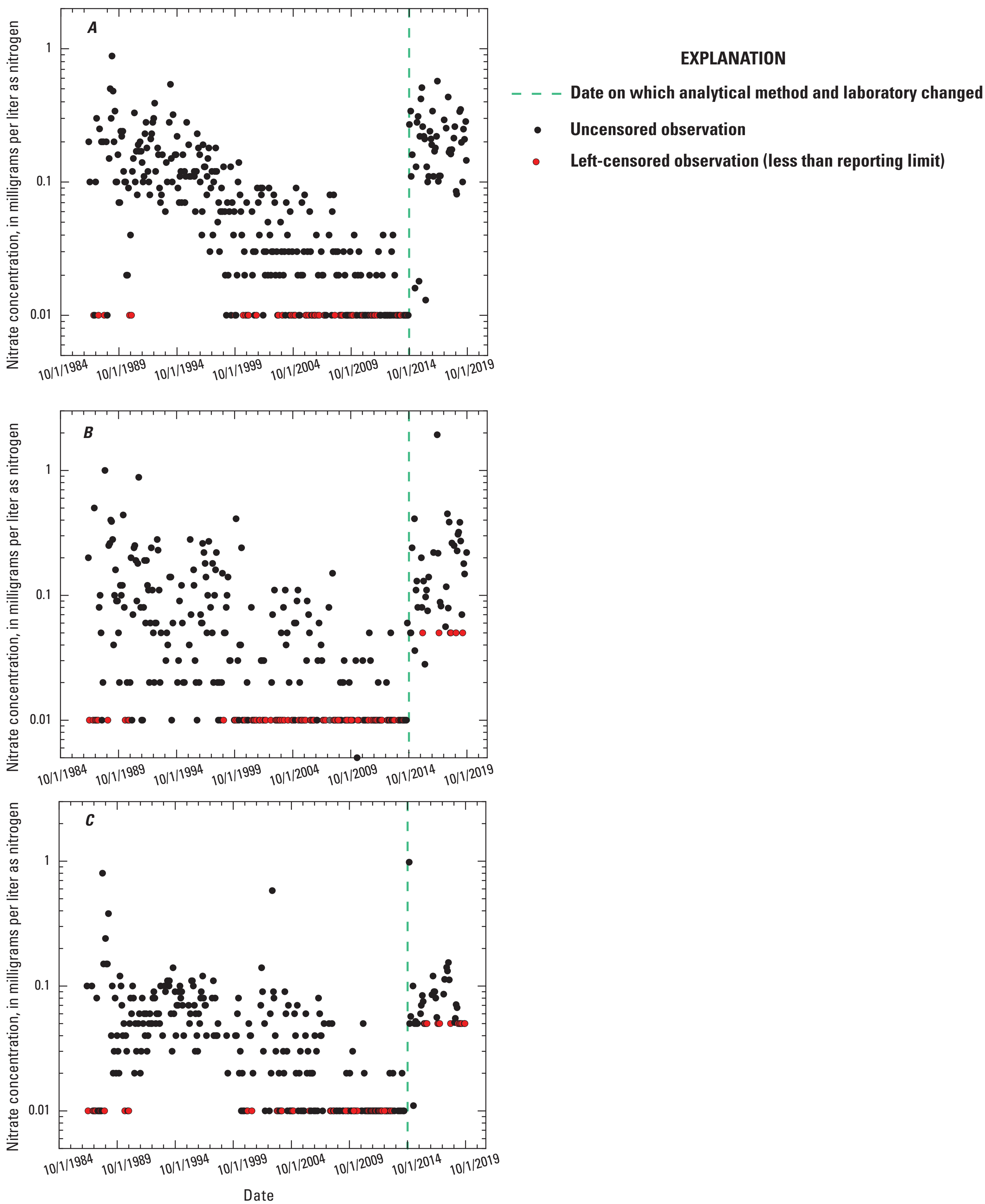


Figure 15. Concentrations of nitrate measured in samples collected by the Providence Water Supply Board (PWSB) at *A*, Brandy Brook (U.S. Geological Survey [USGS] station 01115180; PWSB station 1), *B*, Unnamed Tributary 1 to Moswansicut Reservoir (USGS station 01115160; PWSB station 20), and *C*, Ponaganset Reservoir (USGS station 011151843; PWSB station 23) in the Scituate Reservoir drainage area, Rhode Island, for water years 1987–2019. Locations of stations are shown in figure 1.

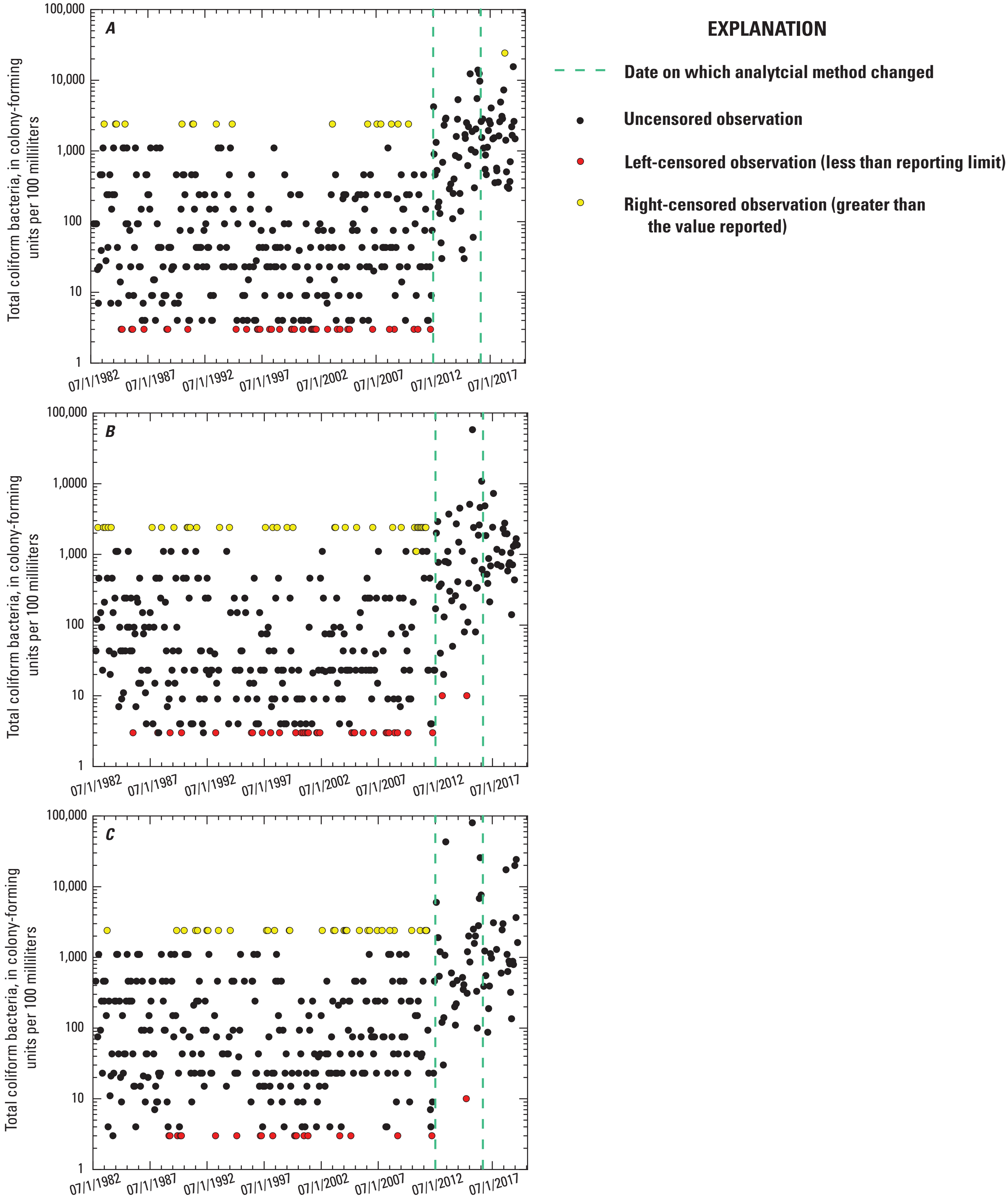


Figure 16. Concentrations of total coliform bacteria measured in samples collected by the Providence Water Supply Board (PWSB) at *A*, Dolly Cole Brook (U.S. Geological Survey [USGS] station 01115190; PWSB station 24), *B*, Cork Brook (USGS station 01115280; PWSB station 3), and *C*, Huntinghouse Brook (USGS station 01115110; PWSB station 14) in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019. Locations of stations are shown in figure 1.

Table 32. Summary of total coliform bacteria and *Escherichia coli* bacteria concentrations measured in samples collected by the Providence Water Supply Board in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019, to compare periods with different analytical methods.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Total coliform bacteria and *Escherichia coli* bacteria were measured in samples beginning in 1983 and 1996, respectively. Method analytical limits are described in table 5. CFU/100 mL, colony-forming unit per 100 milliliters]

Period	Method	Total coliform bacteria				*Escherichia coli*			
		Number of samples	Percent greater than or equal to 2,400 CFU/100 mL	Percent less than or equal to 10 CFU/100 mL	Median concentration (CFU/100 mL)	Number of samples	Percent greater than or equal to 2,400 CFU/100 mL	Percent less than or equal to 10 CFU/100 mL	Median concentration (CFU/100 mL)
Beginning of sample collection through June 2012	Standard Method 9221, multiple tube fermentation	8,634	8.7	28	43	4,166	5.4	51	9
July 2012 through August 2016	Standard Method 9222, m-coliblue broth	909	22	4.3	460	908	1.7	46	20
September 2016 through September 2019	Standard Methods 9223 B, Colilert media	719	27	1.1	1,020	719	1.4	57	10

(table 35, in back of report). Concentrations of nutrients and suspended sediment measured in USGS base-flow and flow-proportional composite stormflow samples (table 36, in back of report) over WYs 2016–19 at five stations were used to estimate annual loads and yields. Annual loads and yields of nutrients and sediment were estimated at these five stations on the basis of mean concentrations and annual volumes of base flow and stormflow (table 37, in back of report). For constituents with a sufficiently strong concentration-flow relation (defined as a concentration-model-adjusted R^2 greater than or equal to 0.20; Aulenbach and others, 2022), loads were also estimated at these five stations using a regression-model method (tables 38 and 39, in back of report).

Providence Water Supply Board Daily Loads and Yields, Water Years 2013–19

Chloride

Median daily Cl yields varied by an order of magnitude among the monitoring stations in the drainage area (table 34). The median daily loads and yields ranged from 9.1 to 1,200 kg/d and 19 to 410 kg/d/mi^2, respectively (tables 33 and 34). The largest median daily yields were observed at Bear Tree Brook (USGS station 01115275; PWSB station 9; fig. 1) and Unnamed Tributary to Regulating Reservoir (USGS station 01115120; PWSB station 18; fig. 1). High Cl yields may be observed at Bear Tree Brook because of the location of a formerly uncovered salt-storage facility within the subbasin drainage area (Nimiroski and others, 2008; Smith, 2015b); these effects were also observed in Cl concentrations and Cl loads and yields estimated with USGS data. Unnamed Tributary to Regulating Reservoir drains an area with the highest percentage of impervious cover and the second highest road density (among stations for which loads were estimated). Relatively high Cl yields equal to 130 and 170 kg/d/mi^2 in the Moswansicut subbasin, as compared with other values, reflect the greater percentages of developed land uses, imperviousness, and road density within the subbasin (table 3). Kent Brook (USGS station 01115400; PWSB station 4) had the lowest median Cl yield at 19 kg/d/mi^2, as well as the lowest density of roads (0.7 mi/mi^2).

Nutrients

Median daily loads and yields of nitrite, nitrate, and orthophosphate varied throughout the basin (tables 33 and 34). Median loads and yields of nitrate at most stations were reported as ranges because of the high frequency of censored data below reporting limits of 0.01 mg/L as N and 0.05 mg/L as N. Median yields ranged from between 2.6 and 3.0 to 19 g/d/mi^2 for nitrite and from less than 120 up to 2,300 g/d/mi^2 for nitrate (table 34). Median daily load and yield ranges with a lower bound of 0 g/d/mi^2 indicate that more than half of the nitrate concentrations measured at the site were censored below the reporting limit. Orthophosphate yields ranged from 29 to 170 g/d/mi^2 and were not uniformly high or low within reservoir subbasins. The median yields for the Scituate Reservoir drainage area were 5.1 g/d/mi^2 for nitrite, 75 to 150 g/d/mi^2 for nitrate, and 65 g/d/mi^2 for orthophosphate, respectively. Nutrient yields varied from station to station even within reservoir subbasins with similar land uses. The highest yields of nitrite, nitrate, and orthophosphate were observed at stations with high imperviousness, residential land use, and road density, but other stations with similar land-use characteristics had lower yields.

Bacteria

Median daily loads and yields of bacteria in the Scituate Reservoir drainage area varied by two orders of magnitude; however, most stations had total coliform yields greater than or equal to 20,000 million colony-forming units per day per square mile (MCFU/d/mi^2; table 34). As documented in earlier sections, notable increases in bacteria concentrations around 2012 may be associated with methodological changes. The median loads and yields of total coliform bacteria computed for WYs 2013–19 are an order of magnitude higher than those reported for WYs 2003–12 (Smith, 2015b); the median load and yield for the Scituate Reservoir drainage area increased from 2,100 MCFU/d and from 1, 400 MCFU/d/mi^2 to 33,000 MCFU/d and 21,000 MCFU/d/mi^2, respectively. The highest bacteria yields were observed at Unnamed Tributary to Regulating Reservoir, which also had the highest median Cl, nitrite, and orthophosphate yields. This tributary drains a small drainage area (0.28 mi^2) but has high percentages of imperviousness and residential, commercial and industrial, and other urban land uses, as well as the highest road density (5.3 mi/mi^2) among stations for which daily loads were estimated. Median daily yields of *E. coli* at each station were less than 2,000 MCFU/d/mi^2 at all stations, which is low overall compared to yields of *E. coli* for sewage-contaminated streamwater or streamwater affected by stormwater runoff in an urban environment that could be more than an order of magnitude higher (Breault and others, 2002).

U.S. Geological Survey Loads and Yields of Chloride and Sodium, Water Years 2013–19

Average daily loads and yields of Cl and Na were computed with streamflow and estimated concentrations based on specific conductance at 14 stations for WYs 2013–19 (table 35). Average daily loads and yields (herein referred to as USGS daily 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 PWSB (herein referred to as PWSB daily loads) because the continuous-record-estimated loads and yields represented a broader range and distribution of hydrologic conditions than the daily mean streamflow data associated with individual samples and contained information from all runoff events, including snowmelts.

The sums of USGS daily average loads of Cl and Na in the Scituate Reservoir drainage area for WYs 2013–19 were 7,200 kg/d and 4,400 kg/d, respectively (table 35). Daily average yields of Cl and Na ranged from 42 to 310 kg/d/mi^2 and 28 to 180 kg/d/mi^2, respectively. Bear Tree Brook (USGS station 01115275; PWSB station 9; fig. 1) had the highest average Cl and Na daily yields at 310 kg/d/mi^2 and 180 kg/d/mi^2, respectively. The average daily yields of Cl and Na for the drainage areas above the 14 USGS stations, which represent nearly 66 percent of the Scituate Reservoir drainage area, were 150 kg/d/mi^2 and 87 kg/d/mi^2, respectively (table 35). The average Cl yields observed at most stations in the Scituate Reservoir drainage area were within ranges estimated for surface waters in the northeastern United States. Yields of Cl in surface water in the glaciated northern United States were estimated to range from 16 kg/d/mi^2 in forested areas to 220 kg/d/mi^2 in urbanized areas (Mullaney and others, 2009). Average yields of Cl and Na at six stations in the Scituate Reservoir drainage area were within the range (or within 2 kg/d/mi^2 of the lower Na estimate) of Cl and Na yields estimated in the drinking-water supply area for Cambridge, Mass., which ranged from 160 kg/d/mi^2 and 99 kg/d/mi^2, respectively, in a low-density residential area to 1,700 and 970 kg/d/mi^2, respectively, in an area with higher percentages of commercial land use, roadway, and imperviousness (Smith, 2017). Bear Tree Brook had the highest average yield, at 310 kg/d/mi^2, which is likely the result of a formerly uncovered (prior to late 1980s) salt-storage site located within the Bear Tree Brook drainage area (Nimiroski and Waldron, 2002; Smith, 2015b). Except for the drainage area for Bear Tree Brook, estimated average daily yields for Cl and Na at the 14 USGS stations in the Scituate Reservoir drainage area tended to be greatest in the northeastern part of the drainage area (for Na, see fig.17) that contains greater percentages of developed land uses and impervious surfaces.

The spatial distributions of yields for Cl were similar to the distributions of yields for Na; however, the yields for Cl were about 1.6 times higher than the yields for Na. The difference in magnitude between the yields is primarily explained by the difference in the molecular mass of the two elements because the ratio of Na to Cl in water samples was nearly 1:1, reflecting its halite (salt) mineral source and nonreactivity in the environment.

The USGS average daily loads of Cl for WYs 2013–19 were compared to the PWSB average daily loads of Cl (arithmetic average of intermittent daily loads for WYs 2013–19; fig. 18). The PWSB average loads of Cl differed from the USGS average daily loads of Cl by 0.8 to 65 percent. At Quonapaug Brook (USGS streamgage 01115183; PWSB station 6; fig. 1), Wilbur Hollow Brook (USGS station 01115297; PWSB station 7), Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19), and Rush Brook (USGS streamgage 01115114; PWSB station 15), the PWSB average Cl loads differed from the USGS average Cl loads by less than 5 percent and were within the 95-percent confidence interval about the USGS daily Cl loads (fig. 18). These data indicate that the collection of periodic (monthly at these stations) samples by PWSB was sufficient to characterize the average daily Cl load at these four stations over a 7-year period. At the remaining 10 stations, the difference between the PWSB daily Cl loads and the USGS daily Cl loads ranged from 5.9 to 65 percent and the PWSB load was not within the 95-percent confidence interval of the USGS load (fig. 18). The difference between the PWSB daily Cl loads and the USGS daily Cl loads only exceeded 25 percent at Unnamed Tributary to Regulating Reservoir (USGS station 01115120; PWSB station 18; fig. 1). The lowest average daily load was determined at this station with only 12 samples (median number of samples at other stations was 70) during WYs 2013–19. Infrequent sampling and daily mean streamflow were not sufficient to characterize the average daily Cl load at station 18 over the 7-year period. The PWSB average daily Cl load at this station was greater than the USGS daily Cl load because samples were not consistently collected during summer months when Cl loads generally were small (generally less than 50 kg/d), despite some high Cl concentrations during summer low flows. Except for stormflow periods, the Unnamed Tributary to Regulating Reservoir was often dry during the summer or streamflow was too low to collect samples during scheduled visits by the PWSB. In the absence of these low-load estimates, the PWSB daily Cl loads likely were overestimated at this station during WYs 2013–19. The dissimilarities between load estimates were not necessarily surprising considering the difference in the magnitude of data used to estimate the loads in application of both methods. The collection of tens of thousands of discrete measurements of specific-conductance values at each station better reflects the range and distribution of environmental conditions than the collection and analysis of monthly or quarterly grab samples.

U.S. Geological Survey Loads and Yields of Nutrients and Sediment, Water Years 2016–19

Annual loads and yields of TP, DP, TN, DN, and SSC were estimated at USGS streamgages on Peeptoad Brook (USGS streamgage 01115098; PWSB station 16; fig. 1), Huntinghouse Brook (USGS streamgage 01115110; PWSB station 14), Rush Brook (USGS streamgage 01115114; PWSB station 15), Quonapaug Brook (USGS streamgage 01115183; PWSB station 6), and below the outlet of Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19). These five stations have drainage areas that range in size from 1.96 to 6.29 mi^2 with percentages of residential land use, forested area, and impervious cover that range from 8.7 to 20.7 percent, 54.6 to 84.7 percent, and 3.7 to 9.9 percent, respectively (tables 2 and 3). Two notable distinctions among these stations are that the Peeptoad Brook station is located near the outlet of a small pond (Peeptoad

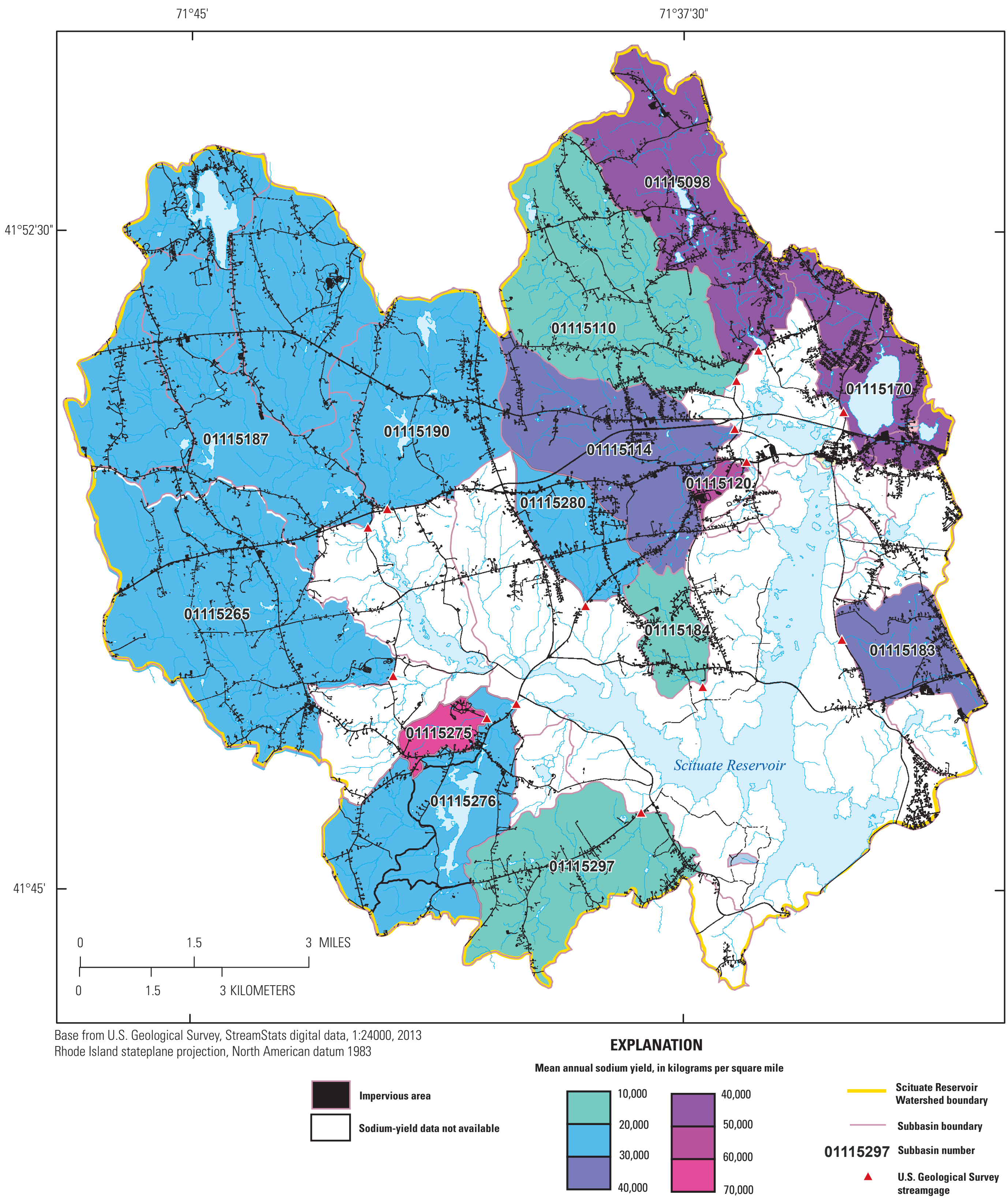


Figure 17. Spatial distribution of sodium yields for 14 subbasins in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

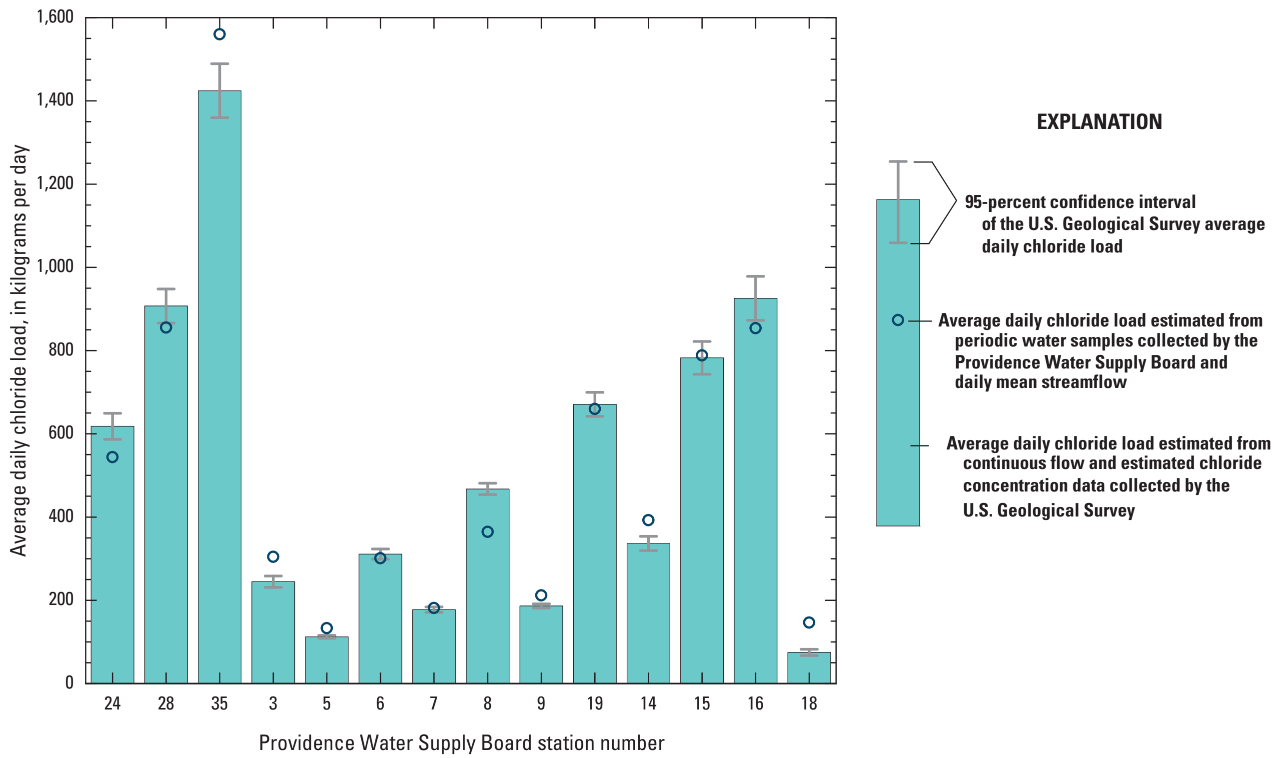


Figure 18. Average daily chloride loads estimated from continuous measurements of flow and estimated concentration data and average daily chloride loads estimated from water-quality samples and daily mean streamflow at 14 Providence Water Supply Board stations in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19. Locations of stations are shown in figure 1.

Pond, surface area approximately 0.015 mi^2) and the Moswansicut Reservoir station is located near the outlet of the Moswansicut Reservoir (surface area approximately 0.45 mi^2), which is reflected in the percentages of water in each of these subbasins (table 3). The combined drainage areas of Peeptoad Brook, Huntinghouse Brook, Rush Brook, and Moswansicut Reservoir make up 87 percent of the area that drains into the Regulating Reservoir. The Regulating Reservoir was identified as stressed because of elevated concentrations (above background levels) of N and P documented in calendar years 2009–10 (ESS Group Inc., 2011). Similarly, the water-quality sample data collected by the PWSB indicated that Quonapaug Brook contained elevated concentrations of nutrients (above background levels) and high turbidity compared to other monitoring stations in the drainage area (fig. 10*C*). The Quonapaug Brook monitoring station drains 1.96 mi^2, which represents 2.2 percent of the overall drainage area to the Scituate Reservoir and includes forested wetlands immediately upstream of the monitoring stations. As described in previous sections, the forested wetlands were reclassified as forested area under the most recent RIGIS (2015) land-use dataset, so they are not represented on figure 2. Loads were estimated for a short period (compared to other estimated periods), WYs 2016–19, but covered a range of annual mean streamflows (fig. 19*F*). Based on the 25-year streamflow record available at the Peeptoad Brook streamgage, WYs 2017–18 had annual mean streamflows (11.0 and 10.3 ft^3/s) similar to the 25-year average (10.5 ft^3/s). WY 2016 was a considerably drier year than WY 2019; at each site, annual mean streamflow in WY 2019 was two to three times greater than in WY 2016. Load estimates for all stations and constituents were lowest in WY 2016, highest in WY 2019, and moderate in WYs 2017 and 2018, which likely reflect closer to average hydrologic conditions (fig. 19). The percentage of annual streamflow that occurred during storm events, referred to as the stormflow percentage, at the five stations was between 50 and 79 percent during WYs 2016–19 (table 37). Annual mean streamflow was proportioned into base-flow and stormflow components to identify the distribution of load sources. Stormflow loads made up more than half of the annual loads of all constituents at all stations (table 37). The percentages of nutrient and sediment loads conveyed in stormflow were typically lowest at Moswansicut Reservoir (from 55 to 62 percent) and Quonapaug Brook (from 60 to 71 percent; table 37).

Concentrations of TP, TN, DN, and suspended sediment in stormflow composite samples were generally higher and more variable than concentrations in base-flow samples (fig. 20; table 36). DP varied little between flow conditions and sampling events except in the case of Rush Brook (tables 12 and 36). The mean of TP base-flow concentrations during WYs 2016–19 was lowest at Rush Brook (0.013 mg/L; USGS streamgage 01115114; PWSB station 15; fig. 1) and highest at Quonapaug Brook (0.021 mg/L; USGS streamgage 01115183; PWSB station 6); however, TP concentrations were not significantly different between base-flow and stormflow composite samples at Quonapaug. The highest mean TP concentration

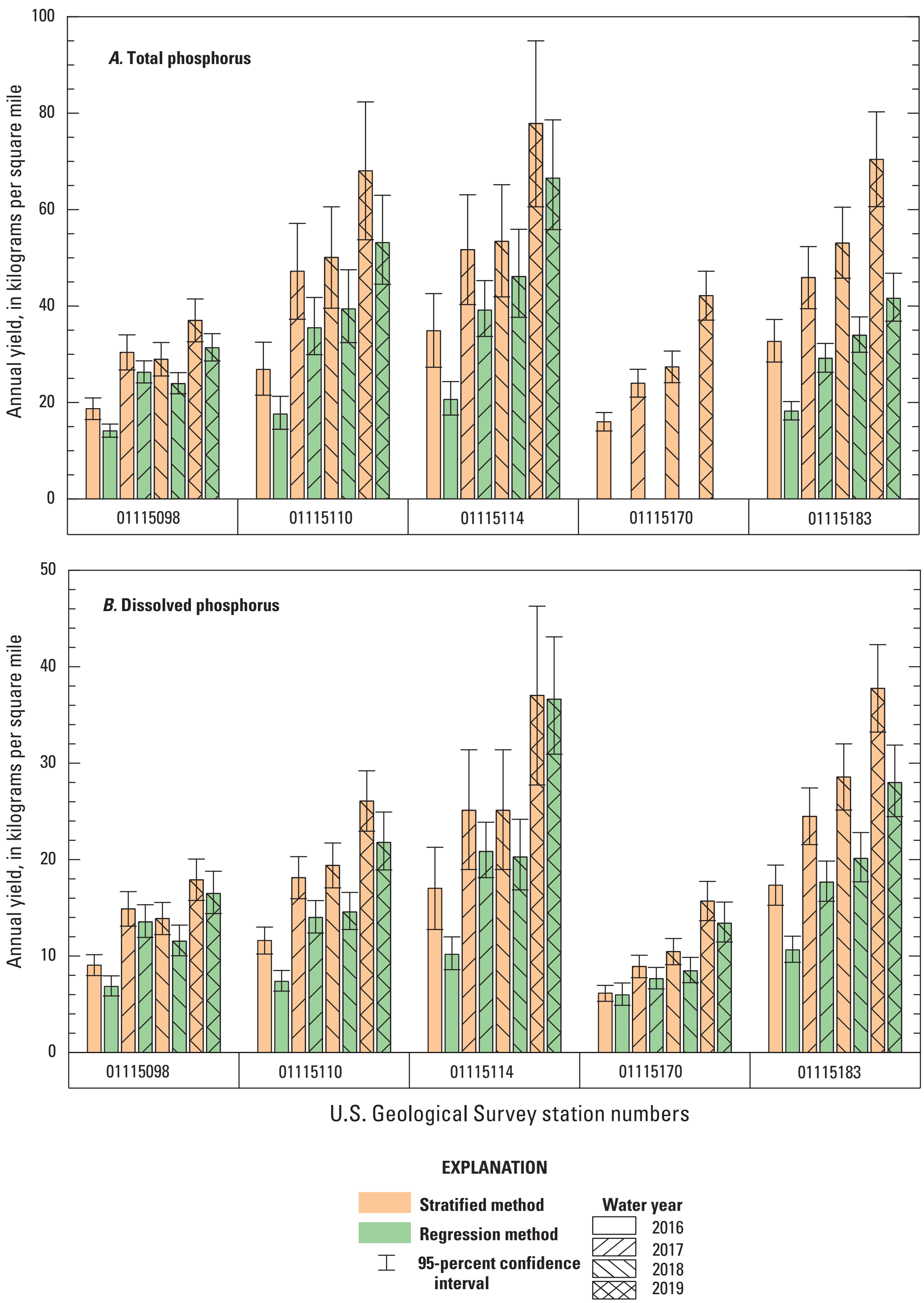
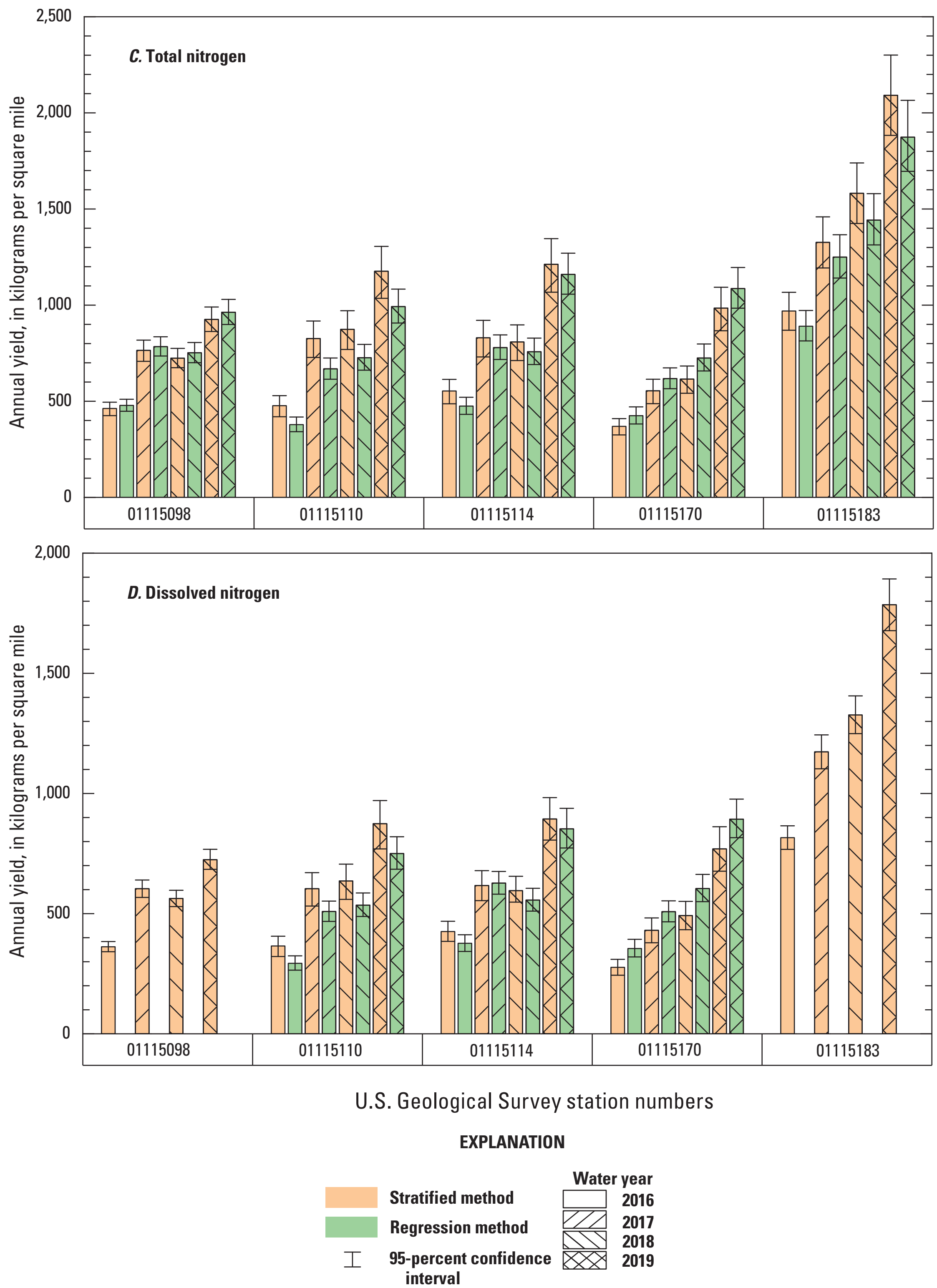


Figure 19. Annual yields of *A*, total phosphorus, *B*, dissolved phosphorus, *C*, total nitrogen, *D*, dissolved nitrogen, and *E*, suspended sediment; and *F*, annual mean streamflow at five stations in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19. Station names and Providence Water Supply Board station numbers are given in table 1; locations are shown in figure 1. Annual loads are given in tables 37 and 38.



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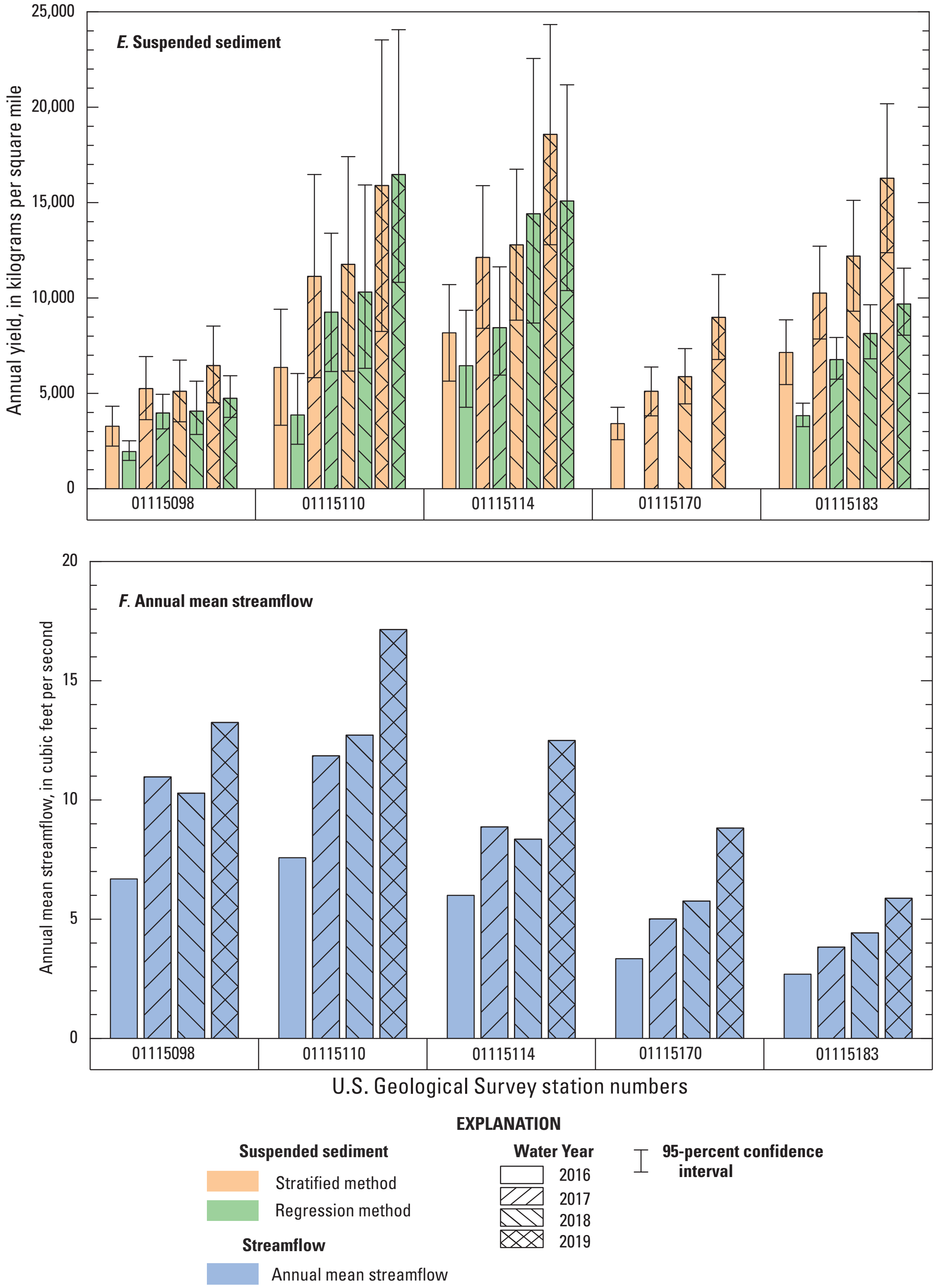

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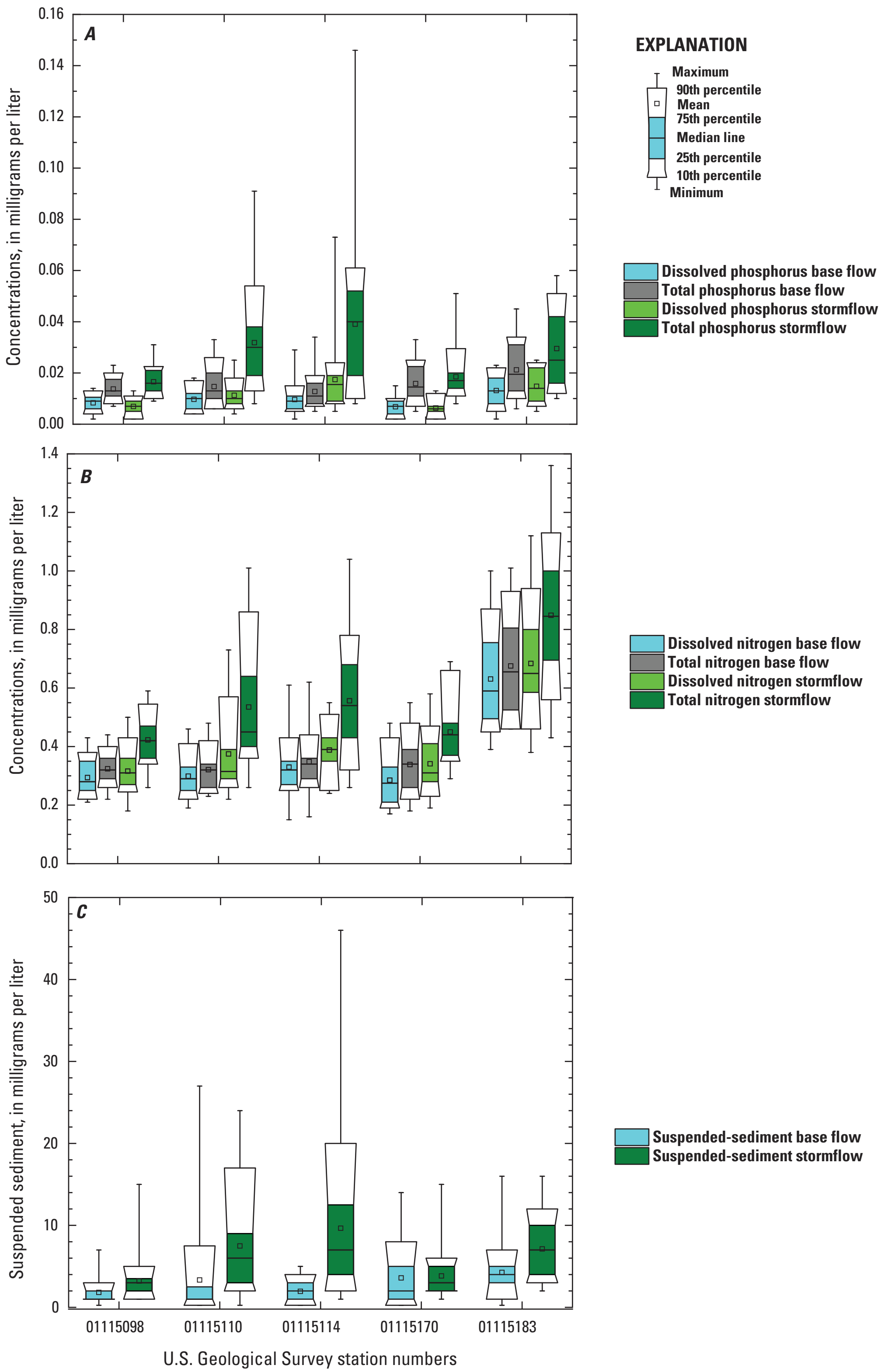

Figure 20. Distributions of concentrations of *A*, total and dissolved phosphorus, *B*, total and dissolved nitrogen, and *C*, suspended sediment in samples collected during base-flow and stormflow conditions at five U.S. Geological Survey streamgages in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19. Station names and Providence Water Supply Board station numbers are given in table 1; locations are shown in figure 1.

in stormflow samples was determined for Rush Brook. Concentrations of DP were generally lowest at Moswansicut Reservoir (0.006 mg/L; USGS streamgage 01115170; PWSB station 19). Concentrations of TN were significantly different between base-flow and stormflow composite samples for all sites, and mean concentrations were generally similar among stations except for Quonapaug Brook with a mean base-flow TN concentration of 0.68 mg/L and a mean stormflow concentration of 0.85 mg/L, which were the highest mean TN concentrations among the five stations. Concentrations of TN were predominantly composed of dissolved-nitrogen species; concentrations of PN were typically low (median concentration at all sites was less than reporting limit of 0.030 mg/L), and generally from only 3 to 6 percent of the computed TN concentrations were composed of PN. Mean SSC in base-flow samples was similarly low (2 or 4 mg/L) across stations; mean stormflow composite concentrations ranged from 3 to 10 mg/L but were not significantly different from flow conditions at Moswansicut Reservoir (fig. 20; table 36).

Annual loads of TP and DP ranged from 36 to 330 kg/yr and 19 to 170 kg/yr, respectively, as estimated by the regression method during WYs 2016–19 (table 38). The stratified annual load estimates for TP and DP ranged from 52 to 430 kg/yr and 20 to 170 kg/yr, respectively (table 37). The relation between concentration and flow was sufficient (R^2>0.2) to apply the regression method for each station except in the case of TP at Moswansicut Reservoir (USGS streamgage 01115170; PWSB station 19; table 39; fig. 1). Maximum loads and yields resulted in WY 2019 with the highest annual mean streamflow at each station (table 38; fig. 19). The percentage of load attributed to stormflow ranged from 55 to 89 percent for TP and 55 to 83 percent for DP. Annual yields ranged from 14 to 67 kg/yr/mi^2 for TP and 6.0 to 37 kg/yr/mi^2 for DP based on the regression estimates and 16 to 78 kg/yr/mi^2 for TP and 6.2 to 38 kg/yr/mi^2 for DP based on the stratified method (figs. 19*A–B*). Moswansicut Reservoir generally had the lowest yields of both DP and TP despite having the highest land-use percentages associated with development and impervious surfaces. The station is located just downstream of the Moswansicut Reservoir outlet; the reservoir traps sediment and sediment-bound phosphorus, and in-reservoir biological processes likely consume bioavailable forms of phosphorus, producing lower DP and TP yields. Average annual TP yields at Peeptoad Brook and Moswansicut Reservoir were similar to the mean annual yield of TP in the Cambridge, Mass., drinking-water source area for WYs 2013–15 (31 kg/yr/mi^2; Smith, 2017).

Annual loads of TN and DN ranged from 1,400 to 6,200 kg/yr and 1,200 to 4,700 kg/yr, respectively, as estimated with the regression method (table 38). Annual loads of TN and DN estimated with the stratified method were 1,200 to 7,400 kg/yr and 900 to 5,500 kg/yr (table 37). The relation between TN concentration and flow was sufficient at all sites to use the regression method, but DN was correlated with flow at only three of the five stations. The percentages of the annual stormflow loads of TN and DN ranged from 62 to 83 percent and 60 to 79 percent, respectively, which were the lowest ranges among the five constituents. Annual yields for WYs 2016–19 ranged from 370 to 2,100 kg/yr/mi^2 for TN and from 280 to 1,800 kg/yr/mi^2 for DN based on the stratified method, and annual yields ranged from 380 to 1,900 kg/yr/mi^2 for TN and from 290 to 890 kg/yr/mi^2 for DN based on regression models (DN estimates with regression models excluded for two sites; figs. 19*C–D*).

The combined loads from the stations draining to Regulating Reservoir estimated by the stratified method ranged from 480 kg/yr to 1,100 kg/yr for TP and from 220 to 470 kg/yr for DP over WYs 2016–19. The TP and DP load and yield estimates indicate that about half of the TP load is composed of DP. Estimated combined loads for stations above the Regulating Reservoir in WY 2019 were approximately equal to the TP loading threshold identified by ESS Group Inc. (2011) as resulting in eutrophication in the Regulating Reservoir (1,114 kg/yr). The load estimates for WYs 2016–19 indicate that in wetter than average years, this threshold may be exceeded.

Annual loads of SSC ranged from 7,500 kg/yr to 104,000 kg/yr based on the regression method models and from 11,100 kg/yr to 100,000 kg/yr with a median of 30,600 kg/yr based on the stratified method (tables 37 and 38). The relation between flow and SSC was too weak (R^2 value less than 0.2) at the Moswansicut Reservoir outlet station (USGS streamgage 01115170; PWSB station 19; fig. 1) to use the regression method, likely because of the trapping of sediment in the Moswansicut Reservoir. Sediment loads were generally highest at Rush Brook (USGS streamgage 01115114; PWSB station 15) and Huntinghouse Brook (USGS streamgage 01115110; PWSB station 14), where stormflow percentages (the percentage of annual flow volume that was stormflow) were generally highest. The percentage of the annual sediment loads that were attributed to stormflow varied from site to site, with a minimum of 55 percent at the Moswansicut Reservoir and a maximum of 93 percent at Rush Brook. The lower stormflow SSC load at Moswansicut Reservoir reflects the relatively invariable (not changing) and low concentrations of sediment transported out of the reservoir. Average annual yields of SSC ranged from 2,000 kg/yr/mi^2 to 16,500 kg/yr/mi^2 based on regression method models and from 3,300 kg/yr/mi^2 to 18,600 kg/yr/mi^2 based on the stratified method (fig. 19*E*).

Load estimates calculated using the regression method and the stratified method were compared by computing the absolute relative percent differences (RPD) between load estimates for the same site and constituent. The RPDs between annual load estimates ranged from 1 percent to 60 percent with a median of 18 percent. In 82 percent of the comparisons, the stratified method resulted in a higher annual load than the regression method. However, the methods generally produced load estimates and 95-percent confidence intervals of similar magnitudes (fig. 19). The 95-percent confidence intervals determined for each method, when expressed as percentages of the load estimate, were typically within 2 to 3 percentage points of one another. In 31 percent of the comparisons, the loads estimated by the stratified method fell within the

95-percent confidence intervals of the loads determined by the regression method. SSC and TP loads had the largest range in RPDs between the two methods (stratified and regression) and the largest 95-percent confidence intervals. One advantage of the stratified method is that it is simple to implement and can be applied to any dataset with enough samples to appropriately characterize the central tendency of constituent concentration under a range of flow conditions. The use of the regression model methodology is only appropriate when concentration and flow (or another continuously monitored variable, such as turbidity) are sufficiently correlated. Regression-based estimates for DN at Quonapaug Brook (USGS streamgage 01115183; PWSB station 6; fig. 1) and Peeptoad Brook (USGS streamgage 01115098; PWSB station 16) and for SSC and TP at Moswansicut Reservoir were not produced because of the failure to meet this requirement.

Accuracy of Load Estimates

The accuracy of annual load and yield estimates in this study was affected by errors associated with sample collection and with processing and analytical techniques. The accuracy of load estimates is related to the size of each dataset and the range of measured flows and constituent concentrations. Loads determined with the stratified method were also affected by estimation of the central tendency for nutrient and suspended-sediment concentrations. The accuracy of nutrient and suspended-sediment loads estimated with LOADEST regression models was affected by the strength of the concentration-flow relation and capacity of selected explanatory variables to explain variation in loads. Accuracy of annual loads estimated from continuous records of streamflow and specific conductance was affected by the accuracy and range of measured flow and specific conductance, and by the accuracy of the relations between specific conductance and the constituent concentrations.

Concentration precision or bias can vary from sample to sample based on the uniformity of the constituent concentrations throughout the stream cross section and the sample-collection method. Typically, less error is associated with dissolved constituents that tend to be evenly distributed throughout the water column than with constituents, such as TP, that tend to be associated with SSC. Concentration error also can result during sample processing from contamination, nonuniform sample splitting, and sample degradation. Analytical method errors often vary, with lower constituent concentrations near the detection level of the method, which are often less accurate than concentrations higher than the laboratory reporting level. Concentrations of major ions, TP, DP, TN, DN, and suspended sediment measured in this study generally were higher than the laboratory reporting limits. As discussed previously, replicate sample comparisons are used to assess precision of concentration data and field blanks are used to assess bias caused by contamination (Mueller and others, 2015).

Loads are calculated from streamflow and concentration data. Therefore, the error associated with streamflow records is inherent in load estimates, regardless of the method used to determine these estimates. The 95-percent confidence intervals for annual load estimates in this study do not account for streamflow uncertainty; however, a general characterization of streamflow data uncertainty can be made. The USGS rates the accuracy of streamflow records based on the performance of the gage-height recorder, the accuracy and range of discharge (streamflow) measurements, and the stability of the stage-discharge relation at a given station. Accuracy ratings assigned to streamflow records may vary over time or range of flow and indicate the difference between the computed and true values of discharge (Kennedy, 1983). For example, a USGS rating of “good” indicates that 95 percent of the daily streamflow values are within 5 to 10 percent of the true values. The accuracy of streamflow data for larger streams in the Scituate Reservoir drainage area such as the Ponaganset River (USGS streamgage 01115187; PWSB station 35) tends to be higher than for the many small tributaries, where the ratio of the cross section of streamflow to the wetted perimeter of the streambed is larger and changes in the shape of the stream channel result more frequently from debris and scour. In general, most continuous records of streamflow collected in the Scituate Reservoir drainage area have mean errors at the 95-percent confidence interval of plus or minus 15 percent, as documented in annual water year summaries for each USGS streamgage available through NWIS (U.S. Geological Survey, 2020b).

Uncertainties about the annual nutrient and sediment loads, as well as model regression statistics, provide information on the quality of the load model developed in LOADEST (tables 38 and 39). The upper and lower 95-percent confidence intervals, based on the SEP, reflect model-parameter uncertainty and random error. The SEP, in percentage for load estimates, ranged from 6 to 43 percent with a median of 13 percent. Larger errors were typically associated with TP and SSC loads. The LOADEST model R^2 values are generally high, ranging from 0.90 to 0.99, because they are the R^2 values associated with the load model (eq. 4). The load model relates flow to load, and because flow is inherently on both sides of the equation, the model R^2 will always be high. The adjusted R^2 of the concentration-flow models, ranging from 0.25 to 0.82, is a better indicator of the strength of the relation between concentration and flow (eq. 4; however, the right side is concentration as opposed to load). The adjusted R^2 values reflect the portion of the variance in the concentration data that is explained by the selected model. The residual variances, which ranged from 0.031 to 0.511, indicate the amount of variance the model could not accurately simulate. Residual variance values were less than or equal to 0.06 for all TN and DN models, and the three highest values were associated with models for SSC load (table 39). Model residuals were evaluated for normality based on the probability plot correlation coefficient (PPCC) and visual inspection of normal-probability plots. The AMLE and MLE methods implemented in

LOADEST are appropriate for datasets with normally distributed model residuals (Runkel and others, 2004). PPCC values were between 0.951 and 0.997; however, for three models, the PPCC test failed at the 95-percent confidence level, indicating the model residuals were not normal (table 39). Because the PPCC values themselves were still near to 1.00 and visual inspection of normal-probability plots indicated deviation from normality was relatively minimal, the models were not rejected. The LOADEST input data, model coefficients, and diagnostic statistics are available in the companion data release (Spaetzel and Smith, 2022).

Summary

Water-quality and streamflow data collected by the Providence Water Supply Board (PWSB) and U.S. Geological Survey (USGS) during all or part of the period from October 1, 1982, to September 30, 2019, water years (WYs) 1983–2019, were used to characterize water-quality conditions, evaluate trends in these conditions, and estimate loads and yields of selected constituents in the Scituate Reservoir drainage area, Rhode Island. Water-quality and streamflow data collected at 37 surface-water monitoring stations by the PWSB were analyzed to determine water-quality conditions and constituent loads in the drainage area. Median values for pH, color, turbidity, alkalinity, chloride, nitrite, nitrate, total coliform bacteria, *Escherichia coli* (*E. coli*), and orthophosphate were calculated for WYs 2013–19 for all monitoring stations. Values of physical water-quality properties and concentrations of constituents were compared with State and Federal water-quality standards and guidelines and were related to streamflow and basin characteristics. Trends in water quality, including physical water-quality properties and concentrations of constituents, were investigated for WYs 2002–19 and a longer period of WYs 1983–2019. Daily loads and yields (loads per unit area) of total coliform bacteria, *E. coli*, chloride, nitrite, nitrate, and orthophosphate, based on PWSB data, were calculated for all sampling dates during WYs 2013–19 for 23 monitoring stations with streamflow data. Daily loads and yields of chloride and sodium were also estimated at 14 stations equipped with continuous specific-conductance monitors during WYs 2013–19. Annual loads and yields of phosphorus, nitrogen, and suspended sediment were estimated at five monitoring stations using flow-proportional composite stormflow samples and discrete base-flow samples from WYs 2016–19. Annual estimates were determined based on streamflow and a measure of the central tendency of concentration and using a regression-model method.

Tributaries in the Scituate Reservoir drainage area for WYs 2013–19 were slightly acidic (median pH of all stations equal to 6.3 standard units) with median values of color equal to 39 platinum-cobalt units and median concentrations of chloride, nitrite, nitrate, and orthophosphate equal to 25 milligrams per liter (mg/L), 0.002 mg/L as nitrogen, 0.05 mg/L as nitrogen, and 0.02 mg/L as phosphorus, respectively. Turbidity and alkalinity values were low with medians of 0.60 nephelometric turbidity units and 5.3 mg/L as calcium carbonate, respectively. Total coliform bacteria and *E. coli* were detected in most samples from all stations. Median concentration of total coliform bacteria was high—725 colony-forming units per 100 milliliters—but *E. coli* median concentration was low—13 colony-forming units per 100 milliliters.

Median values of pH, turbidity, and alkalinity and median concentrations of chloride and nitrite 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 and road density in the subbasins of monitoring stations, likely reflecting the effects of deicing compounds applied to roadways and parking lots during winter maintenance. Median concentrations of alkalinity also correlated positively with the percentage of impervious land use. *E. coli* correlated positively with percentage of wetlands, but no other significant correlations were identified between land use and bacteria concentrations. Streamflows were predominantly 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 result during warmer low-flow conditions late in the water year (August and September). 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 or accumulating over longer periods. Whereas 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. Less than 10 statistically significant correlations were identified between streamflow and concentrations of orthophosphate or nitrate.

Positive trends in pH were identified at most of the monitoring stations for WYs 1983–2019 and may reflect regional reductions in acid precipitation. Many positive trends in alkalinity also were identified for both the WYs 1983–2019 and WYs 2002–19 periods and may be linked to chemical weathering of bedrock, overlying soils, and structures containing concrete. Significant positive trends in chloride at most stations during WYs 1983–2019 and WYs 2002–19 were identified. One negative trend and four positive trends were identified for nitrite and orthophosphate, respectively, during WYs 1983–2019. These concentrations were typically near or at their respective reporting limits. Statistical tests for trend were not performed on total coliform bacteria, *E. coli*, and nitrate concentrations because of analytical method changes that coincide with abrupt shifts in the magnitude and distribution of concentration data. The effect of analytical method changes cannot be quantitatively determined because replicate samples measured with both methods are not available. Because the effect of the analytical changes cannot be

quantified, there is no way to determine if changes in concentrations through time and across different methods are attributable to environmental changes or analytical changes.

The median of daily loads and yields of chloride, nitrite, nitrate, orthophosphate, and bacteria determined for each PWSB sampling date varied across the 37 monitoring stations for WYs 2013–19. Yields tended to be highest in the Moswansicut and Regulating Reservoir subbasins located in the northeastern part of the Scituate Reservoir drainage area. Loads and yields of chloride and sodium estimated from continuous records of specific conductance reflect similar spatial patterns identified in loads and yields estimated from discrete chloride measurements. The total loads of chloride and sodium in the Scituate Reservoir drainage area were 7,200 kilograms per day and 4,400 kilograms per day, respectively.

Annual loads and yields of phosphorus, nitrogen, and suspended sediment were estimated using regression and stratified methods for four tributaries to the Regulating Reservoir (which drain 87 percent of the contributing area to Regulating Reservoir) and for Quonapaug Brook, which feeds directly into the Scituate Reservoir (Quonapaug Brook drainage area is 2.2 percent of overall drainage area to Scituate Reservoir). The median annual yields given here are reported from the stratified method results because the regression method was only used for subbasin constituents with a sufficient relation between concentration and streamflow (defined as a concentration-model-adjusted R^2 greater than or equal to 0.20). The mean annual yields of total phosphorus and total nitrogen at each of the five stations ranged from 16 to 78 kilograms per square mile (kg/mi^2) and 370 to 2,100 kg/mi^2, respectively. Maximum loads and yields resulted in WY 2019, which had the highest annual mean streamflow at each station. Mean annual yields of dissolved phosphorus, total nitrogen, and dissolved nitrogen were highest at Quonapaug Brook in the Direct runoff subbasin but mean annual yields of total phosphorus and suspended sediment were highest at Rush Brook in the Regulating Reservoir subbasin. Total nitrogen loads were predominantly composed of dissolved nitrogen. Mean annual yields of total nitrogen ranged from 630 to 850 kg/mi^2 in the Regulating Reservoir subbasin and mean annual yield at Quonapaug Brook was 1,500 kg/mi^2. Mean annual yields of suspended sediment ranged from 5,000 to 13,000 kg/mi^2. More than half of the nutrient and sediment loads occurred during stormflow. The two load-estimation methods generally produced loads of similar magnitudes, and in about 31 percent of the comparisons, the loads estimated with the stratified method were within the 95-percent confidence intervals of the loads determined with the regression method.

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Table 20. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in water-quality properties, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2002–19.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; CI, 95-percent confidence interval; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	pH				Color				Turbidity			
		p value	Slope (standard units per year)	Lower CI (standard units per year)	Upper CI (standard units per year)	*p* value	Slope (PCU per year)	Lower CI (PCU per year)	Upper CI (PCU per year)	*p* value	Slope (NTU per year)	Lower CI (NTU per year)	Upper CI (NTU per year)
Barden Reservoir subbasin													
24	01115190	<0.001*	0.031	0.025	0.037	0.439	0.000	−0.167	0.443	0.299	0.002	−0.003	0.009
25	01115200	0.077	0.013	−0.002	0.028	0.004*	1.375	0.375	2.468	0.004*	0.013	0.004	0.023
26	01115185	0.001*	0.023	0.010	0.035	0.192	0.375	−0.206	1.232	0.054	0.006	0.000	0.013
27	011151845	0.007*	0.021	0.006	0.035	0.275	−0.095	−0.384	0.083	0.608	0.002	−0.004	0.010
28	01115265	<0.001*	0.025	0.017	0.031	0.015	0.833	0.000	1.667	0.002*	0.008	0.003	0.013
29	01115271	<0.001*	0.025	0.018	0.033	0.301	0.162	−0.038	0.625	0.117	0.004	−0.001	0.010
35	01115187	<0.001*	0.019	0.013	0.026	0.002*	0.500	0.107	0.958	0.027	0.006	0.000	0.010
Direct runoff subbasin													
1	01115180	<0.001*	0.015	0.010	0.022	0.951	0.000	−0.838	0.738	0.330	0.006	−0.007	0.021
2	01115181	0.003*	0.020	0.006	0.030	0.964	0.000	−0.429	0.333	0.394	0.003	−0.005	0.009
3	01115280	<0.001*	0.014	0.009	0.020	0.003*	0.625	0.167	1.000	0.021	0.004	0.000	0.008
4	01115400	0.083	0.006	0.000	0.015	0.145	−0.143	−0.400	0.000	0.104	0.004	0.000	0.010
5	01115184	0.007*	0.014	0.004	0.025	0.919	0.000	−1.000	1.667	0.216	0.008	−0.006	0.020
6	01115183	<0.001*	0.020	0.015	0.027	0.472	0.385	−0.816	1.701	0.180	0.011	−0.004	0.026
7	01115297	<0.001*	0.019	0.014	0.025	0.007†	−0.938	−1.727	−0.156	0.034	−0.009	−0.017	0.000
8	01115276	<0.001*	0.039	0.030	0.047	0.844	0.000	−0.250	0.173	0.022	0.004	0.000	0.008
9	01115275	0.036	0.011	0.000	0.025	0.025	1.000	0.000	1.618	<0.001*	0.018	0.010	0.030
30	01115350	0.978	0.000	−0.010	0.014	0.024*	1.275	0.162	2.572	0.018*	0.012	0.002	0.022
31	01115177	0.247	−0.012	−0.084	0.014	1.000	0.000	−3.657	2.242	0.006†	−0.030	−0.212	−0.016
32	01115178	0.325	0.008	−0.006	0.025	0.834	0.000	−0.917	1.200	0.049	0.020	0.000	0.040
33	01115182	0.005*	0.014	0.004	0.029	0.173	0.591	−0.127	1.274	0.033	0.010	0.000	0.023
36	--	0.459	0.007	−0.010	0.022	0.120	0.250	0.000	0.645	0.076	0.005	0.000	0.012
37	--	0.371	0.004	−0.004	0.011	0.310	0.100	−0.155	0.500	0.356	0.003	−0.004	0.010

Table 20. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in water-quality properties, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2002–19.—Continued

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; CI, 95-percent confidence interval; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	pH				Color				Turbidity			
		p value	Slope (standard units per year)	Lower CI (standard units per year)	Upper CI (standard units per year)	*p* value	Slope (PCU per year)	Lower CI (PCU per year)	Upper CI (PCU per year)	*p* value	Slope (NTU per year)	Lower CI (NTU per year)	Upper CI (NTU per year)
Moswansicut Reservoir subbasin													
19	01115170	0.002[*]	0.010	0.003	0.015	0.010	−0.375	−0.600	0.000	0.538	−0.004	−0.016	0.009
20	01115160	<0.001[*]	0.024	0.019	0.032	0.280	−0.429	−1.971	0.162	0.156	0.006	−0.002	0.015
21	01115165	0.018[*]	0.013	0.003	0.021	0.440	−0.556	−2.098	0.500	0.840	0.003	−0.020	0.027
22	01115167	<0.001[*]	0.010	0.005	0.015	0.070	−0.364	−0.667	0.000	0.034[†]	−0.017	−0.036	−0.001
34	01115164	0.048	0.009	0.000	0.019	0.746	−0.155	−1.339	0.744	0.410	0.009	−0.009	0.027
Ponaganset Reservoir subbasin													
23	011151843	<0.001[*]	0.053	0.046	0.060	<0.001[*]	0.408	0.286	0.508	<0.001[*]	0.013	0.009	0.015
Regulating Reservoir subbasin													
13	01115176	<0.001[*]	0.014	0.006	0.021	<0.001[*]	0.500	0.217	0.750	<0.001[*]	0.015	0.009	0.023
14	01115110	<0.001[*]	0.018	0.010	0.023	0.476	0.083	−0.250	0.500	0.001[*]	0.010	0.004	0.014
15	01115114	<0.001[*]	0.015	0.008	0.022	0.067	0.392	0.000	0.915	0.523	0.002	−0.005	0.010
16	01115098	0.703	0.000	−0.005	0.003	0.032	0.273	0.000	0.647	0.005[*]	0.010	0.003	0.017
17	01115119	<0.001[*]	0.026	0.014	0.036	0.402	0.594	−1.000	2.273	0.024[*]	0.015	0.004	0.029
18	01115120	0.013[*]	0.017	0.004	0.030	0.788	−0.455	−2.500	2.000	0.701	0.006	−0.035	0.030
Westconnaug Reservoir subbasin													
10	01115274	<0.001[*]	0.038	0.030	0.043	0.001[*]	0.455	0.200	0.800	<0.001[*]	0.006	0.004	0.009
11	01115273	<0.001[*]	0.021	0.012	0.031	0.011	−1.250	−2.500	0.000	0.208	0.007	−0.004	0.021
12	011152745	<0.001[*]	0.031	0.016	0.057	0.475	−0.967	−5.825	1.159	0.422	−0.009	−0.039	0.019

[*]Significant positive trend defined by a *p* value less than 0.05, a positive slope, and a 95-percent confidence interval about the slope that does not include zero.

[†]Significant negative trend defined by a *p* value less than 0.05, a negative slope, and a 95-percent confidence interval about the slope that does not include zero.

Table 21. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in water-quality properties, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; CI, 95-percent confidence interval; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	pH				Color				Turbidity			
		p value	Slope (standard units per year)	Lower CI (standard units per year)	Upper CI (standard units per year)	*p* value	Slope (PCU per year)	Lower CI (PCU per year)	Upper CI (PCU per year)	*p* value	Slope (NTU per year)	Lower CI (NTU per year)	Upper CI (NTU per year)
Barden Reservoir subbasin													
24	01115190	<0.001*	0.022	0.020	0.024	<0.001*	0.286	0.167	0.389	0.122	0.001	0.000	0.004
25	01115200	<0.001*	0.010	0.005	0.014	<0.001*	0.577	0.400	0.788	0.841	0.000	−0.002	0.003
26	01115185	<0.001*	0.017	0.013	0.021	<0.001*	0.400	0.237	0.584	<0.001†	−0.005	−0.007	−0.002
27	011151845	<0.001*	0.011	0.006	0.014	<0.001*	0.203	0.111	0.309	<0.001†	−0.005	−0.008	−0.002
28	01115265	<0.001*	0.007	0.004	0.010	<0.001*	1.667	1.429	2.000	0.655	0.000	−0.001	0.002
29	01115271	<0.001*	0.013	0.010	0.015	<0.001*	0.526	0.429	0.652	0.061	−0.002	−0.004	0.000
35	01115187	<0.001*	0.014	0.010	0.018	<0.001*	0.625	0.400	0.909	0.784	0.000	−0.004	0.003
Direct runoff subbasin													
1	01115180	<0.001*	0.008	0.005	0.011	<0.001*	1.000	0.727	1.250	<0.001*	0.011	0.007	0.016
2	01115181	<0.001*	0.012	0.008	0.016	0.123	0.105	0.000	0.200	0.033	−0.003	−0.006	0.000
3	01115280	<0.001*	0.012	0.010	0.014	<0.001*	0.571	0.443	0.696	0.109	−0.001	−0.002	0.000
4	01115400	<0.001*	0.010	0.008	0.013	<0.001*	0.250	0.167	0.316	0.286	−0.001	−0.003	0.001
5	01115184	<0.001*	0.010	0.006	0.013	<0.001*	0.800	0.500	1.068	0.935	0.000	−0.003	0.003
6	01115183	<0.001*	0.018	0.015	0.020	<0.001*	0.955	0.625	1.296	<0.001*	0.008	0.004	0.013
7	01115297	<0.001*	0.011	0.009	0.013	<0.001*	0.725	0.476	1.000	0.050	−0.003	−0.006	0.000
8	01115276	0.111	−0.002	−0.005	0.000	0.581	0.000	0.000	0.067	<0.001†	−0.004	−0.005	−0.003
9	01115275	<0.001*	0.009	0.005	0.012	0.143	0.160	−0.053	0.366	0.084	0.002	0.000	0.006
30	01115350	<0.001*	0.011	0.008	0.014	<0.001*	0.500	0.165	0.790	0.815	0.000	−0.003	0.003
31	01115177	0.002†	−0.012	−0.025	−0.004	0.130	0.263	−0.071	0.556	<0.001†	−0.069	−0.114	−0.032
32	01115178	0.073	0.005	0.000	0.011	<0.001*	0.714	0.333	1.103	0.711	−0.001	−0.009	0.007
33	01115182	0.016	0.005	0.000	0.009	<0.001*	0.389	0.167	0.611	0.846	0.000	−0.004	0.003
36	--	0.145	0.009	−0.002	0.020	<0.001*	0.385	0.144	0.667	0.163	0.003	−0.001	0.008
37	--	0.063	0.008	0.000	0.015	0.037	0.243	0.000	0.589	0.607	0.002	−0.004	0.007

Table 21. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in water-quality properties, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019.—Continued

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; CI, 95-percent confidence interval; PCU, platinum-cobalt unit; NTU, nephelometric turbidity unit; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	pH				Color				Turbidity			
		p value	Slope (standard units per year)	Lower CI (standard units per year)	Upper CI (standard units per year)	*p* value	Slope (PCU per year)	Lower CI (PCU per year)	Upper CI (PCU per year)	*p* value	Slope (NTU per year)	Lower CI (NTU per year)	Upper CI (NTU per year)
Moswansicut Reservoir subbasin													
19	01115170	<0.001[*]	0.012	0.009	0.014	0.032	0.071	0.000	0.143	<0.001[*]	0.011	0.008	0.014
20	01115160	<0.001[*]	0.007	0.004	0.010	<0.001[*]	1.208	0.785	1.667	0.249	−0.002	−0.005	0.001
21	01115165	<0.001[*]	0.007	0.004	0.010	<0.001[*]	0.577	0.308	0.907	0.956	0.000	−0.005	0.006
22	01115167	<0.001[*]	0.006	0.004	0.008	0.797	0.000	−0.111	0.077	<0.001[†]	−0.032	−0.040	−0.024
34	01115164	0.063	0.008	−0.001	0.016	0.500	0.125	−0.373	0.884	1.000	0.000	−0.010	0.016
Ponaganset Reservoir subbasin													
23	011151843	<0.001[*]	0.038	0.036	0.041	<0.001[*]	0.250	0.214	0.300	0.638	0.000	−0.002	0.001
Regulating Reservoir subbasin													
13	01115176	<0.001[*]	0.006	0.003	0.009	<0.001[*]	0.375	0.300	0.462	0.006[*]	0.003	0.001	0.005
14	01115110	<0.001[*]	0.008	0.006	0.010	<0.001[*]	0.467	0.357	0.571	0.082	0.002	0.000	0.004
15	01115114	<0.001[*]	0.013	0.011	0.016	<0.001[*]	0.833	0.700	1.000	0.153	−0.002	−0.005	0.000
16	01115098	0.080	0.001	0.000	0.003	<0.001[*]	0.467	0.367	0.556	<0.001[*]	0.004	0.002	0.006
17	01115119	0.977	0.000	−0.004	0.004	<0.001[*]	0.667	0.272	1.078	0.001[†]	−0.009	−0.016	−0.004
18	01115120	0.062	0.003	0.000	0.008	0.002[*]	0.526	0.181	1.000	0.829	−0.001	−0.008	0.007
Westconnaug Reservoir subbasin													
10	01115274	<0.001[*]	0.017	0.014	0.019	<0.001[*]	0.250	0.167	0.333	0.001[†]	−0.002	−0.004	−0.001
11	01115273	0.152	−0.003	−0.009	0.001	<0.001[*]	1.838	1.307	2.423	0.369	−0.002	−0.006	0.002
12	011152745	<0.001[*]	0.027	0.022	0.032	0.918	0.000	−0.369	0.479	<0.001[*]	0.010	0.005	0.015

[*]Significant positive trend defined by a *p* value less than 0.05, a positive slope, and a 95-percent confidence interval about the slope that does not include zero.

[†]Significant negative trend defined by a *p* value less than 0.05, a negative slope, and a 95-percent confidence interval about the slope that does not include zero.

Table 22. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in alkalinity and chloride concentrations, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2002–19.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; CI, 95-percent confidence interval; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Alkalinity				Chloride			
		p value	Slope (mg/L as $CaCO_3$ per year)	Lower CI (mg/L as $CaCO_3$ per year)	Upper CI (mg/L as $CaCO_3$ per year)	*p* value	Slope (mg/L per year)	Lower CI (mg/L per year)	Upper CI (mg/L per year)
Barden Reservoir subbasin									
24	01115190	<0.001*	0.09	0.07	0.10	<0.001*	0.48	0.30	0.65
25	01115200	0.260	0.03	−0.03	0.09	0.002*	0.27	0.10	0.42
26	01115185	0.307	0.03	−0.02	0.09	0.017*	0.47	0.13	0.96
27	011151845	0.019	0.03	0.00	0.09	<0.001*	0.55	0.34	0.77
28	01115265	<0.001*	0.06	0.04	0.08	<0.001*	0.32	0.14	0.49
29	01115271	<0.001*	0.07	0.05	0.10	<0.001*	0.37	0.23	0.47
35	01115187	<0.001*	0.08	0.05	0.10	<0.001*	0.48	0.39	0.57
Direct runoff subbasin									
1	01115180	<0.001*	0.14	0.10	0.19	<0.001*	0.31	0.23	0.39
2	01115181	0.587	0.02	−0.05	0.10	0.033*	2.76	0.83	6.10
3	01115280	<0.001*	0.04	0.02	0.07	<0.001*	0.64	0.37	0.93
4	01115400	0.011*	0.05	0.01	0.10	<0.001*	0.17	0.10	0.22
5	01115184	0.062	0.06	0.00	0.13	0.004*	0.56	0.14	1.20
6	01115183	<0.001*	0.23	0.16	0.30	0.001*	0.50	0.21	0.82
7	01115297	0.066	0.04	0.00	0.08	0.304	0.05	−0.05	0.15
8	01115276	<0.001*	0.06	0.03	0.08	0.039	0.10	0.00	0.19
9	01115275	0.097	0.05	−0.01	0.10	0.140	−0.66	−2.03	0.21
30	01115350	0.168	0.03	−0.01	0.07	0.889	0.05	−0.41	0.77
31	01115177	0.478	0.25	−0.89	0.79	0.723	−1.55	−4.49	4.75
32	01115178	0.468	0.02	−0.04	0.10	<0.001*	0.33	0.17	0.51
33	01115182	1.000	0.00	−0.11	0.14	0.848	0.02	−0.21	0.23
36	--	0.062	0.05	0.00	0.09	0.257	0.10	−0.06	0.22
37	--	0.550	0.02	−0.03	0.06	0.013*	0.20	0.05	0.26
Moswansicut Reservoir subbasin									
19	01115170	<0.001*	0.08	0.05	0.10	<0.001*	1.66	1.33	1.95
20	01115160	<0.001*	0.15	0.11	0.19	<0.001*	2.09	1.65	2.68
21	01115165	0.712	0.04	−0.16	0.14	0.127	0.50	−0.15	1.05
22	01115167	0.050	0.07	0.00	0.14	<0.001*	0.98	0.35	1.65

Table 22. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in alkalinity and chloride concentrations, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2002–19.—Continued

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; CI, 95-percent confidence interval; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Alkalinity				Chloride			
		p value	Slope (mg/L as $CaCO_3$ per year)	Lower CI (mg/L as $CaCO_3$ per year)	Upper CI (mg/L as $CaCO_3$ per year)	*p* value	Slope (mg/L per year)	Lower CI (mg/L per year)	Upper CI (mg/L per year)
Moswansicut Reservoir subbasin—Continued									
34	01115164	0.427	−0.12	−0.34	0.14	0.327	0.38	−0.35	0.95
Ponaganset Reservoir subbasin									
23	011151843	<0.001*	0.07	0.06	0.09	<0.001*	0.60	0.50	0.70
Regulating Reservoir subbasin									
13	01115176	<0.001*	0.08	0.03	0.12	<0.001*	0.70	0.51	0.92
14	01115110	<0.001*	0.11	0.05	0.16	<0.001*	0.45	0.37	0.53
15	01115114	<0.001*	0.11	0.06	0.17	<0.001*	1.11	0.61	1.58
16	01115098	0.058	0.05	0.00	0.11	<0.001*	0.73	0.53	0.94
17	01115119	0.132	0.09	−0.02	0.26	0.007*	0.79	0.16	1.18
18	01115120	0.300	0.12	−0.09	0.30	0.235	1.02	−1.04	3.11
Westconnaug Reservoir subbasin									
10	01115274	<0.001*	0.06	0.05	0.08	0.174	0.14	−0.05	0.31
11	01115273	0.059	0.04	0.00	0.10	0.019*	0.16	0.02	0.40
12	011152745	0.510	0.02	−0.05	0.10	0.136	−1.33	−2.52	0.46

*Significant positive trend defined by a *p* value less than 0.05, a positive slope, and a 95-percent confidence interval about the slope that does not include zero.

Table 23. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in alkalinity and chloride concentrations, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021).Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; CI, 95-percent confidence interval; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Alkalinity				Chloride			
		p value	Slope (mg/L as $CaCO_3$ per year)	Lower CI (mg/L as $CaCO_3$ per year)	Upper CI (mg/L as $CaCO_3$ per year)	*p* value	Slope (mg/L per year)	Lower CI (mg/L per year)	Upper CI (mg/L per year)
Barden Reservoir subbasin									
24	01115190	<0.001*	0.044	0.036	0.052	<0.001*	0.52	0.48	0.57
25	01115200	0.060	0.011	0.000	0.028	<0.001*	0.18	0.14	0.23
26	01115185	0.080	0.012	0.000	0.029	<0.001*	0.49	0.40	0.58
27	011151845	0.011	0.019	0.000	0.033	<0.001*	0.23	0.16	0.28
28	01115265	<0.001*	0.025	0.014	0.034	<0.001*	0.54	0.49	0.60
29	01115271	<0.001*	0.023	0.014	0.030	<0.001*	0.42	0.39	0.45
35	01115187	<0.001*	0.040	0.025	0.058	<0.001*	0.61	0.55	0.68
Direct runoff subbasin									
1	01115180	<0.001*	0.078	0.060	0.100	<0.001*	0.18	0.16	0.21
2	01115181	0.442	0.007	−0.012	0.032	0.033*	2.76	0.83	6.10
3	01115280	<0.001*	0.038	0.029	0.050	<0.001*	0.74	0.65	0.81
4	01115400	<0.001*	0.075	0.062	0.089	0.057	0.01	0.00	0.03
5	01115184	0.011*	0.021	0.003	0.042	<0.001*	0.31	0.22	0.40
6	01115183	<0.001*	0.133	0.111	0.155	<0.001*	0.63	0.54	0.73
7	01115297	<0.001*	0.038	0.025	0.050	<0.001*	0.15	0.12	0.18
8	01115276	<0.001†	−0.030	−0.043	−0.020	<0.001†	−0.37	−0.46	−0.30
9	01115275	<0.001*	0.055	0.028	0.078	<0.001†	−2.27	−2.73	−1.57
30	01115350	0.139	0.008	0.000	0.024	<0.001*	0.38	0.27	0.49
31	01115177	0.030	0.174	0.000	0.314	0.118	1.00	−0.21	2.12
32	01115178	0.242	0.014	−0.009	0.044	<0.001*	0.20	0.14	0.26
33	01115182	0.982	0.000	−0.040	0.041	<0.001*	0.16	0.09	0.21
36	--	0.065	0.025	0.000	0.060	<0.001*	0.18	0.10	0.26
37	--	0.948	0.000	−0.025	0.033	0.003*	0.16	0.06	0.23
Moswansicut Reservoir subbasin									
19	01115170	<0.001*	0.071	0.060	0.081	<0.001*	0.75	0.68	0.84
20	01115160	<0.001*	0.050	0.033	0.063	<0.001*	1.34	1.19	1.47
21	01115165	<0.001*	0.108	0.077	0.150	<0.001*	0.50	0.35	0.64
22	01115167	<0.001*	0.080	0.058	0.100	<0.001*	0.65	0.50	0.80

Table 23. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in alkalinity and chloride concentrations, measured by Providence Water Supply Board, in samples collected at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1983–2019.—Continued

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021).Trend direction indicated by the sign of the slope. USGS, U.S. Geological Survey; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; CI, 95-percent confidence interval; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Alkalinity				Chloride			
		p value	Slope (mg/L as $CaCO_3$ per year)	Lower CI (mg/L as $CaCO_3$ per year)	Upper CI (mg/L as $CaCO_3$ per year)	*p* value	Slope (mg/L per year)	Lower CI (mg/L per year)	Upper CI (mg/L per year)
Moswansicut Reservoir subbasin—Continued									
34	01115164	0.217	−0.114	−0.270	0.055	0.007*	0.64	0.18	0.96
Ponaganset Reservoir subbasin									
23	011151843	<0.001*	0.037	0.029	0.045	<0.001*	0.46	0.43	0.48
Regulating Reservoir subbasin									
13	01115176	<0.001*	0.052	0.037	0.067	<0.001*	0.60	0.53	0.66
14	01115110	<0.001*	0.037	0.019	0.056	<0.001*	0.25	0.22	0.28
15	01115114	<0.001*	0.077	0.056	0.096	<0.001*	0.77	0.63	0.91
16	01115098	<0.001*	0.057	0.040	0.075	<0.001*	0.71	0.64	0.79
17	01115119	0.595	−0.007	−0.040	0.022	<0.001*	0.66	0.50	0.83
18	01115120	0.803	−0.005	−0.058	0.044	<0.001*	0.77	0.49	1.04
Westconnaug Reservoir subbasin									
10	01115274	<0.001*	0.017	0.009	0.025	<0.001*	0.54	0.48	0.61
11	01115273	0.625	−0.005	−0.035	0.017	0.003†	−0.19	−0.31	−0.04
12	011152745	<0.001*	0.079	0.050	0.110	<0.001*	0.69	0.44	1.04

*Significant positive trend defined by a *p* value less than 0.05, a positive slope, and a 95-percent confidence interval about the slope that does not include zero.

†Significant negative trend defined by a *p* value less than 0.05, a negative slope, and a 95-percent confidence interval about the slope that does not include zero.

Table 24. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in nitrite and orthophosphate concentrations measured in samples collected by Providence Water Supply Board at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2002–19.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. −2.1E−04 means -2.1×10^{-4} = −0.00021. USGS, U.S. Geological Survey; mg/L, milligram per liter; N, nitrogen; CI, 95-percent confidence interval; P, phosphorus; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Nitrite				Orthophosphate			
		p value	Slope (mg/L as N per year)	Lower CI (mg/L as N per year)	Upper CI (mg/L as N per year)	*p* value	Slope (mg/L as P per year)	Lower CI, (mg/L as P per year)	Upper CI (mg/L as P per year)
				Barden Reservoir subbasin					
24	01115190	0.964	0	0	0	0.619	0	−4.1E−04	7.5E−05
25	01115200	0.006	0	0	0	0.912	0	−5.9E−04	7.2E−04
26	01115185	0.583	0	0	0	1.000	0	−1.4E−03	1.2E−03
27	011151845	0.747	0	0	0	0.260	−5.4E−04	−2.0E−03	4.1E−04
28	01115265	0.386	0	0	0	0.354	0	−2.1E−04	7.2E−04
29	01115271	1.000	0	0	0	0.638	0	−4.9E−04	2.2E−04
35	01115187	0.544	0	0	0	0.331	0	−5.0E−04	0
				Direct runoff subbasin					
1	01115180	0.874	0	0	0	0.459	0	−1.7E−04	5.4E−04
2	01115181	0.740	0	0	0	0.899	0	−9.1E−04	7.0E−04
3	01115280	0.547	0	0	0	0.458	0	−8.2E−04	2.7E−04
4	01115400	0.234	0	0	0	0.700	0	−3.3E−04	0
5	01115184	0.827	0	0	0	0.470	−2.7E−04	−1.6E−03	5.9E−04
6	01115183	0.283	0	0	0	0.568	0	−2.5E−04	5.0E−04
7	01115297	<0.001	0	−7.1E−05	0	0.222	−2.5E−04	−7.2E−04	0
8	01115276	0.052	0	0	0	0.299	0	−5.4E−04	0
9	01115275	0.015	0	0	7.1E−05	0.568	−1.0E−04	−1.4E−03	5.5E−04
30	01115350	0.974	0	0	0	1.000	0	−5.4E−04	6.5E−04
31	01115177	0.530	−2.1E−04	−6.7E−04	2.4E−04	0.004†	−2.2E−03	−4.0E−03	−8.0E−04
32	01115178	0.147	0	0	0	0.336	5.8E−04	−7.9E−04	1.6E−03
33	01115182	0.790	0	0	0	0.889	0	−1.2E−03	8.2E−04
36	--	0.182	0	0	0	0.604	0	−1.1E−03	5.8E−04
37	--	0.107	0	0	0	0.277	2.8E−04	−2.9E−04	2.0E−03

Table 24. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in nitrite and orthophosphate concentrations measured in samples collected by Providence Water Supply Board at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 2002–19.—Continued

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. −2.1E−04 means -2.1×10^{-4} = −0.00021. USGS, U.S. Geological Survey; mg/L, milligram per liter; N, nitrogen; CI, 95-percent confidence interval; P, phosphorus; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Nitrite				Orthophosphate			
		p value	Slope (mg/L as N per year)	Lower CI (mg/L as N per year)	Upper CI (mg/L as N per year)	*p* value	Slope (mg/L as P per year)	Lower CI, (mg/L as P per year)	Upper CI (mg/L as P per year)
Moswansicut Reservoir subbasin									
19	01115170	0.002	0	0	0	0.321	0	−5.4E−04	0
20	01115160	0.620	0	0	0	0.011	9.3E−04	0	1.6E−03
21	01115165	0.617	0	0	0	0.709	0	−6.5E−04	1.2E−03
22	01115167	0.716	0	−7.1E−05	1.4E−04	0.418	2.5E−04	−3.3E−04	9.3E−04
34	01115164	0.183	0	0	8.2E−05	0.206	5.9E−04	−3.2E−04	1.6E−03
Ponaganset Reservoir subbasin									
23	011151843	0.501	0	0	0	0.860	0	0	2.5E−04
Regulating Reservoir subbasin									
13	01115176	0.331	0	0	0	0.225	0	−5.4E−04	0
14	01115110	0.228	0	0	0	0.698	0	−5.4E−04	3.6E−04
15	01115114	0.471	0	0	0	0.168	−3.3E−04	−7.2E−04	0
16	01115098	0.501	0	0	0	0.457	0	0	4.7E−04
17	01115119	0.203	0	0	0	1.000	0	−1.5E−03	1.0E−03
18	01115120	0.106	0	0	1.4E−04	0.588	3.7E−04	−8.2E−04	1.8E−03
Westconnaug Reservoir subbasin									
10	01115274	0.957	0	0	0	0.290	−2.6E−04	−8.6E−04	0
11	01115273	0.855	0	0	0	0.840	0	−6.1E−04	9.3E−04
12	011152745	0.541	0	0	0	0.683	0	−8.0E−04	8.2E−04

[†]Significant negative trend defined by a *p* value less than 0.05, a negative slope, and a 95-percent confidence interval about the slope that does not include zero.

Table 25. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in nitrite and orthophosphate concentrations measured in samples collected by Providence Water Supply Board at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1985–2019 and 1996–2019.

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. −2.0E−04 means -2.0×10^{-4} = −0.00020; USGS, U.S. Geological Survey; mg/L, milligram per liter; N, nitrogen; CI, 95-percent confidence interval; P, phosphorus; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Nitrite				Orthophosphate			
		p value	Slope (mg/L as N per year)	Lower CI (mg/L as N per year)	Upper CI (mg/L as N per year)	*p* value	Slope (mg/L as P per year)	Lower CI, (mg/L as P per year)	Upper CI (mg/L as P per year)
Barden Reservoir subbasin									
24	01115190	0.828	0	0	0	0.301	0	0	2.5E−04
25	01115200	0.019	0	0	1.7E−05	0.346	0	0	5.9E−04
26	01115185	0.107	0	0	0	0.066	4.7E−04	0	1.2E−03
27	011151845	0.137	0	0	0	1.000	0	−6.5E−04	9.3E−04
28	01115265	0.119	0	0	0	<0.001*	5.4E−04	2.3E−04	8.2E−04
29	01115271	0.461	0	0	0	0.008	2.3E−04	0	4.9E−04
35	01115187	<0.001†	−2.0E−04	−5.0E−04	−9.1E−05	0.129	0	0	4.7E−04
Direct runoff subbasin									
1	01115180	0.648	0	0	0	0.029	2.5E−04	0	5.4E−04
2	01115181	0.116	0	0	0	0.976	0	−6.5E−04	4.7E−04
3	01115280	0.229	0	0	0	0.221	0	0	4.8E−04
4	01115400	0.390	0	0	0	0.241	0	0	2.3E−04
5	01115184	0.455	0	0	2.3E−05	0.684	0	−3.4E−04	6.5E−04
6	01115183	0.071	0	0	1.8E−05	0.007	3.4E−04	0	6.6E−04
7	01115297	0.563	0	0	0	0.261	0	0	3.6E−04
8	01115276	0.429	0	0	0	0.073	1.5E−04	0	3.7E−04
9	01115275	0.165	0	0	2.3E−05	0.909	0	−6.6E−04	3.8E−04
30	01115350	0.269	0	0	0	0.118	3.4E−04	0	8.2E−04
31	01115177	0.308	−1.1E−04	−3.4E−04	8.1E−05	0.406	−3.3E−04	−1.8E−03	6.8E−04
32	01115178	0.034	0	−8.3E−05	0	0.001*	9.9E−04	4.0E−04	1.6E−03
33	01115182	0.016	0	0	0	0.711	0	−5.9E−04	7.3E−04
36	--	0.383	0	0	0	0.323	1.9E−04	−2.4E−04	7.5E−04
37	--	0.165	0	0	0	0.111	5.0E−04	0	1.4E−03

Table 25. Significance levels (*p* values) and Theil-Sen slopes of seasonal Kendall tests for time trends in nitrite and orthophosphate concentrations measured in samples collected by Providence Water Supply Board at monitoring stations in the Scituate Reservoir drainage area, Rhode Island, water years 1985–2019 and 1996–2019.—Continued

[Water-quality data collected by Providence Water Supply Board (PWSB; Smith, 2015a, b, 2016, 2018c, d, 2019b, 2021). Trend direction indicated by the sign of the slope. −2.0E−04 means -2.0×10^{-4} = −0.00020; USGS, U.S. Geological Survey; mg/L, milligram per liter; N, nitrogen; CI, 95-percent confidence interval; P, phosphorus; <, less than; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Nitrite				Orthophosphate			
		p value	Slope (mg/L as N per year)	Lower CI (mg/L as N per year)	Upper CI (mg/L as N per year)	*p* value	Slope (mg/L as P per year)	Lower CI, (mg/L as P per year)	Upper CI (mg/L as P per year)
Moswansicut Reservoir subbasin									
19	01115170	<0.001	0	−4.3E−05	0	0.002	2.2E−04	0	4.3E−04
20	01115160	0.110	0	0	2.1E−05	<0.001*	8.2E−04	3.6E−04	1.3E−03
21	01115165	0.033	0	0	7.1E−05	0.037	5.4E−04	0	1.0E−03
22	01115167	0.216	0	−9.5E−05	0	0.062	3.4E−04	0	8.2E−04
34	01115164	0.498	0	0	3.1E−05	0.002*	8.2E−04	2.3E−04	1.6E−03
Ponaganset Reservoir subbasin									
23	011151843	<0.001	0	0	0	0.165	0	0	2.7E−04
Regulating Reservoir subbasin									
13	01115176	<0.001	0	0	0	0.113	0	0	3.0E−04
14	01115110	0.016	0	0	0	0.075	2.0E−04	0	5.4E−04
15	01115114	<0.001	0	0	0	0.202	0	0	4.7E−04
16	01115098	0.416	0	0	0	0.002	2.7E−04	0	5.4E−04
17	01115119	<0.001	−6.7E−05	−1.3E−04	0	0.142	3.3E−04	0	9.3E−04
18	01115120	0.072	0	0	3.3E−05	0.034	8.2E−04	0	1.9E−03
Westconnaug Reservoir subbasin									
10	01115274	0.104	0	0	0	0.403	0	0	3.8E−04
11	01115273	0.085	0	0	5.4E−05	0.405	2.2E−04	−3.2E−04	8.9E−04
12	011152745	0.376	0	0	1.7E−05	0.288	2.6E−04	−2.2E−04	8.2E−04

*Significant positive trend defined by a *p* value less than 0.05, a positive slope, and a 95-percent confidence interval about the slope that does not include zero.

†Significant negative trend defined by a *p* value less than 0.05, a negative slope, and a 95-percent confidence interval about the slope that does not include zero.

Table 33. Median daily loads of chloride, nitrite, nitrate, orthophosphate, and bacteria, in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB; Smith, 2015a, 2016, 2018c, d, 2019b, 2021). Ranges of loads are reported for cases with significant numbers of censored observations. USGS, U.S. Geological Survey; kg/d, kilogram per day; N, nitrogen; g/d, gram per day; P, phosphorus; CFU×10⁶/d, millions of colony-forming units per day; *E. coli, Escherichia coli*; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Chloride (kg/d)	Nitrite (as N) (g/d)	Nitrate (as N) (g/d)	Orthophosphate (as P) (g/d)	Total coliform bacteria (CFUx10⁶/d)	*E. Coli* (CFUx10⁶/d)
Barden Reservoir subbasin							
24	01115190	370	18	160–660	220	97,000	1,400–2,100
25	01115200	190	16	240–480	260	88,000	1,100–2,700
26	01115185	350	14	3.3–460	530	110,000	510–1,500
28	01115265	570	54	190–900	600	100,000	4,000–5,500
35	01115187	1,200	71	770–2,200	820	340,000	4,500–8,000
Direct runoff subbasin							
1	01115180	66	13	600	120	32,000	890–1,000
3	01115280	160	5.3–5.5	350–360	94	25,000	530–640
4	01115400	16	3.7	0–100	25	6,700	1.4–380
5	01115184	79	8.8	230	50	26,000	22–550
6	01115183	260	17	610–730	150	38,000	2,400
7	01115297	120	30	81–450	240	96,000	4,200
8	01115276	240	23	0–730	270	48,000	0–1,900
9	01115275	210	8.8	1,300	53	29,000	780–830
32	01115178	26	3.3	310	64	13,000	360
33	01115182	9.1	0.72–0.93	40	21	4,400	120–140
Moswansicut Reservoir subbasin							
19	01115170	410	16	230–320	120	11,000	0–1,300
21	01115165	51	4.6	690	43	19,000	220
Regulating Reservoir subbasin							
14	01115110	290	27	470–810	400	140,000	7,300
15	01115114	600	17	250–340	230	74,000	3,100
16	01115098	490	24	520–550	180	66,000	620–1,800
18	01115120	110	5.4	250	48	18,000	520
Westconnaug Reservoir subbasin							
10	01115274	130	7.6	0–230	96	33,000	400–730
11	01115273	21	9.2	0–190	85	21,000	580–640
Scituate Reservoir drainage area							
Minimum	--	9.1	0.72–0.93	0–100	21	4,400	0–360
Median	--	190	14	240–460	120	33,000	580–1,300
Maximum	--	1,200	71	770–2,200	820	340,000	7,300

Table 34. Median daily yields of chloride, nitrite, nitrate, orthophosphate, and bacteria in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

[Water-quality data are from samples collected and analyzed by Providence Water Supply Board (PWSB; Smith, 2015a, 2016, 2018c, d, 2019b, 2021). Ranges of yields are reported for cases with significant numbers of censored observations; USGS, U.S. Geological Survey; kg/d/mi², kilogram per day per square mile; N, nitrogen; g/d/mi², gram per day per square mile; P, phosphorus; CFU×10⁶/d/mi², millions of colony-forming units per day per square mile; *E. coli, Escherichia coli*; --, not applicable]

PWSB station number (fig. 1)	USGS station number (table 1)	Chloride (kg/d/mi²)	Nitrite (as N) (g/d/mi²)	Nitrate (as N) (g/d/mi²)	Orthophosphate (as P) (g/d/mi²)	Total coliform bacteria (CFUx10⁶/d/mi²)	*E. Coli* (CFUx10⁶/d/mi²)
Barden Reservoir subbasin							
24	01115190	75	3.7	33–140	46	20,000	280–430
25	01115200	79	6.8	100–200	110	37,000	440–1,100
26	01115185	81	3.3	0.77–110	120	25,000	120–350
28	01115265	66	6.1	22–100	68	11,000	460–630
35	01115187	84	5.1	55–160	58	24,000	320–570
Direct runoff subbasin							
1	01115180	42	8.6	380	74	20,000	560–640
3	01115280	86	2.8–3.0	180–190	50	13,000	280–340
4	01115400	19	4.3	0–120	29	7,900	1.6–450
5	01115184	62	7.0	190	40	21,000	17–440
6	01115183	130	8.9	310–370	75	19,000	1,200
7	01115297	28	7.0	19–100	55	22,000	960
8	01115276	47	4.4	0–140	53	9,300	0–360
9	01115275	340	14	2,100	85	47,000	1300
32	01115178	58	7.3	700	140	28,000	800
33	01115182	33	2.6–3.3	140	74	16,000	430–500
Moswansicut Reservoir subbasin							
19	01115170	130	5.0	72–100	38	3,300	0–400
21	01115165	170	15	2,300	140	62,000	750
Regulating Reservoir subbasin							
14	01115110	46	4.3	75–130	63	23,000	1,200
15	01115114	130	3.7	54–72	50	16,000	650
16	01115098	99	4.9	100–110	37	13,000	130–400
18	01115120	410	19	900	170	65,000	1,900
Westconnaug Reservoir subbasin							
10	01115274	90	5.1	0–150	65	22,000	270–490
11	01115273	30	13	0–260	120	29,000	810–880
Scituate Reservoir drainage area							
Minimum	--	19	2.6–3.0	0–120	29	3,300	0–340
Median	--	79	5.1	75–150	65	21,000	440–630
Maximum	--	410	19	2,300	170	65,000	1,900

Table 35. Average daily chloride and sodium concentrations, loads, and yields estimated based on streamflow and estimated concentration data collected at 14 Providence Water Supply Board stations in the Scituate Reservoir drainage area, Rhode Island, water years 2013–19.

[Average daily concentrations estimated from continuous specific-conductance records and concentrations of chloride and sodium (U.S. Geological Survey, 2020b and table 10). Mean annual concentrations were calculated by dividing the sum of the annual loads by the total discharge for the period. PWSB, Providence Water Supply Board; USGS, U.S. Geological Survey; Cl, chloride; Na, sodium; mg/L, milligram per liter; kg/d/mi^2, kilogram per day per square mile

PWSB station number (fig. 1)	USGS station number (table 1)	Concentration		Load		Yield	
		Cl (mg/L)	Na (mg/L)	Cl (kg/d)	Na (kg/d)	Cl (kg/d/mi^2)	Na (kg/d/mi^2)
Barden Reservoir subbasin							
24	01115190	31.4	19.3	620	380	130	78
28	01115265	28.2	16.9	910	560	100	64
35	01115187	23.9	15.0	1,400	880	100	63
Direct runoff subbasin							
3	01115280	41.8	24.3	240	150	130	80
5	01115184	27.5	15.9	110	68	87	54
6	01115183	46.5	28.0	310	190	160	97
7	01115297	11.3	7.40	180	120	42	28
8	01115276	24.7	15.5	470	300	91	58
9	01115275	60.1	35.6	190	110	310	180
Moswansicut Reservoir subbasin							
19	01115170	51.6	30.7	670	400	210	120
Regulating Reservoir subbasin							
14	01115110	14.7	8.9	340	210	54	33
15	01115114	55.3	33.0	780	470	170	100
16	01115098	44.0	25.4	920	540	180	110
18	01115120	65.6	37.5	75	43	270	150
Scituate Reservoir drainage area							
Average concentrations and yields and total loads		38	22	7,200	4,400	150	87

Table 36. Mean concentrations of total phosphorus, dissolved phosphorus, total nitrogen, dissolved nitrogen, and suspended sediment measured in discrete base-flow samples and stormflow composite samples in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19.

[Water-quality data available in Spaetzel and Smith (2022). Station information in table 1. Dissolved nitrogen concentrations were measured in samples that were filtered with a 0.65-micrometer pore size disc filter instead of the customary 0.45-micrometer filter. CI, confidence interval; mg/L, milligram per liter]

Constituent	Base-flow samples				Stormflow composite samples			
	Number of samples	Mean	Lower 95-percent CI	Upper 95-percent CI	Number of samples	Mean	Lower 95-percent CI	Upper 95-percent CI
01115098, Peeptoad Brook								
Total phosphorus, mg/L	24	0.014	0.012	0.016	30	0.017	0.015	0.019
[1]Dissolved phosphorus, mg/L	24	0.008	0.007	0.010	29	0.007	0.006	0.008
Total nitrogen, mg/L	25	0.32	0.30	0.35	30	0.42	0.39	0.45
[1]Dissolved nitrogen, mg/L	25	0.29	0.27	0.32	30	0.32	0.29	0.34
Suspended-sediment concentration, mg/L	25	2	1	2	24	3	2	4
01115110, Huntinghouse Brook								
Total phosphorus, mg/L	19	0.015	0.011	0.018	33	0.032	0.025	0.038
[1]Dissolved phosphorus, mg/L	17	0.010	0.008	0.012	32	0.011	0.009	0.013
Total nitrogen, mg/L	19	0.32	0.29	0.35	32	0.54	0.47	0.60
Dissolved nitrogen, mg/L	19	0.30	0.27	0.33	32	0.37	0.33	0.42
Suspended-sediment concentration, mg/L	19	2	1	3	29	7	5	10
01115114, Rush Brook								
Total phosphorus, mg/L	26	0.013	0.010	0.015	35	0.039	0.030	0.048
Dissolved phosphorus, mg/L	23	0.010	0.007	0.012	34	0.017	0.013	0.022
Total nitrogen, mg/L	24	0.35	0.31	0.39	34	0.56	0.50	0.62
Dissolved nitrogen, mg/L	24	0.33	0.29	0.37	34	0.39	0.36	0.42
Suspended-sediment concentration, mg/L	27	2	1	2	32	10	6	13
01115170, Moswansicut Reservoir								
[1]Total phosphorus, mg/L	24	0.016	0.013	0.019	30	0.019	0.015	0.022
[1]Dissolved phosphorus, mg/L	25	0.007	0.005	0.008	29	0.006	0.005	0.008
Total nitrogen, mg/L	25	0.34	0.30	0.38	29	0.45	0.41	0.49
Dissolved nitrogen, mg/L	26	0.29	0.25	0.32	29	0.34	0.30	0.38
[1]Suspended-sediment concentration, mg/L	25	4	2	5	24	4	3	5
01115183, Quonapaug Brook								
[1]Total phosphorus, mg/L	22	0.021	0.017	0.026	36	0.030	0.024	0.035
[1]Dissolved phosphorus, mg/L	22	0.013	0.010	0.016	34	0.015	0.012	0.017
Total nitrogen, mg/L	24	0.68	0.60	0.75	36	0.85	0.77	0.92
[1]Dissolved nitrogen, mg/L	24	0.63	0.56	0.70	36	0.68	0.63	0.74
Suspended sediment concentration, mg/L	23	4	3	5	31	7	6	8

[1]Base-flow and stormflow samples are not statistically different; mean of combined samples was used for load estimation.

Table 37. Annual mean streamflow and total phosphorus, dissolved phosphorus, total nitrogen, dissolved nitrogen, and suspended sediment annual loads estimated for five subbasins in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19.

[Water-quality and streamflow data collected by U. S. Geological Survey (USGS; Spaetzel and Smith, 2022). Dissolved nitrogen concentrations were measured in samples that were filtered with a 0.65-micrometer pore size disc filter instead of the customary 0.45-micrometer filter. PWSB, Providence Water Supply Board; ft^3/s, cubic foot per second; kg, kilogram; CI, confidence interval, expressed as a percent about the annual load; ±, plus or minus; kg/mi^2, kilogram per square mile]

PWSB station number (fig. 1)	USGS station number (table 1)	Water year	Annual mean streamflow (ft^3/s)	Stormflow percentage	Total phosphorus (kg)	Dissolved phosphorus (kg)	Total nitrogen (kg)	Dissolved nitrogen (kg)	Suspended sediment (kg)
16	01115098	2016	6.7	65	93	45	2,300	1,800	16,300
		2017	11	61	150	74	3,800	3,000	26,100
		2018	10	68	140	69	3,600	2,800	25,400
		2019	13	64	180	89	4,600	3,600	32,100
		95-percent CI (percent)			±12	±12	±7	±6	±32
		Storm-load percentage			69	65	70	65	76
		Mean annual yield (kg/mi^2)			29	14	720	560	5,000
14	01115110	2016	7.6	60	170	73	3,000	2,300	40,000
		2017	12	78	300	110	5,200	3,800	70,000
		2018	13	76	320	120	5,500	4,000	74,000
		2019	17	77	430	160	7,400	5,500	100,000
		95-percent CI (percent)			±21	±12	±11	±11	±48
		Storm load percentage			86	74	83	79	86
		Mean annual yield (kg/mi^2)			48	19	840	620	11,000
15	01115114	2016	6.0	67	160	80	2,600	2,000	38,400
		2017	8.9	68	240	120	3,900	2,900	57,000
		2018	8.4	79	250	120	3,800	2,800	60,100
		2019	13	76	370	170	5,700	4,200	87,300
		95-percent CI (percent)			±22	±25	±11	±10	±31
		Storm load percentage			89	83	81	76	93
		Mean annual yield (kg/mi^2)			54	26	850	630	13,000
19	01115170	2016	3.3	50	52	20	1,200	900	11,100
		2017	5.0	51	78	29	1,800	1,400	16,600
		2018	5.8	54	89	34	2,000	1,600	19,100
		2019	8.8	59	140	51	3,200	2,500	29,200
		95-percent CI (percent)			±12	±13	±11	±12	±25
		Storm load percentage			55	55	62	60	55
		Mean annual yield (kg/mi^2)			27	10	630	490	5,800
6	01115183	2016	2.7	54	64	34	1,900	1,600	14,000
		2017	3.8	57	90	48	2,600	2,300	20,100
		2018	4.4	62	100	56	3,100	2,600	23,900
		2019	5.9	63	140	74	4,100	3,500	31,900
		95-percent CI (percent)			±14	±12	±10	±6	±24
		Storm load percentage			60	60	65	60	71
		Mean annual yield (kg/mi^2)			51	27	1,500	1,300	11,000

Table 38. Annual loads of nutrients and sediment estimated using load-regression models at five subbasins in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19.

[Water-quality and streamflow data collected by U. S. Geological Survey (USGS; Spaetzel and Smith, 2022). Station indicated by USGS streamgage number and short name (table 1). Not all constituent loads were estimated at each site. Dissolved nitrogen concentrations were measured in samples that were filtered with a 0.65-micrometer pore size disc filter instead of the customary 0.45-micrometer filter. kg/yr, kilogram per year; TP, total phosphorus; DP, dissolved phosphorus; TN, total nitrogen; SSC, suspended-sediment concentration; DN, dissolved nitrogen]

Constituent	Water year	Annual load (kg/yr)	Lower confidence interval (kg/yr)	Upper confidence interval (kg/yr)
		01115098, Peeptoad Brook		
TP	2016	70	64	77
	2017	130	120	140
	2018	120	110	130
	2019	160	140	170
DP	2016	34	29	39
	2017	67	59	76
	2018	57	50	66
	2019	82	72	93
TN	2016	2,400	2,200	2,500
	2017	3,900	3,600	4,200
	2018	3,700	3,500	4,000
	2019	4,800	4,500	5,100
SSC	2016	9,700	7,400	12,500
	2017	19,700	15,600	24,600
	2018	20,200	14,100	28,000
	2019	23,600	18,600	29,400
		01115110, Huntinghouse Brook		
TP	2016	110	91	130
	2017	220	190	260
	2018	250	200	300
	2019	330	280	400
DP	2016	46	40	53
	2017	88	78	99
	2018	92	80	100
	2019	140	120	160
TN	2016	2,400	2,200	2,600
	2017	4,200	3,900	4,600
	2018	4,600	4,200	5,000
	2019	6,200	5,700	6,800
DN	2016	1,800	1,700	2,000
	2017	3,200	2,900	3,500
	2018	3,400	3,100	3,700
	2019	4,700	4,300	5,200
SSC	2016	24,300	14,700	38,000
	2017	58,200	38,700	84,300
	2018	64,800	39,700	100,000
	2019	104,000	68,000	151,000

Table 38. Annual loads of nutrients and sediment estimated using load-regression models at five subbasins in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19.—Continued

[Water-quality and streamflow data collected by U. S. Geological Survey (USGS; Spaetzel and Smith, 2022). Station indicated by USGS streamgage number and short name (table 1). Not all constituent loads were estimated at each site. Dissolved nitrogen concentrations were measured in samples that were filtered with a 0.65-micrometer pore size disc filter instead of the customary 0.45-micrometer filter. kg/yr, kilogram per year; TP, total phosphorus; DP, dissolved phosphorus; TN, total nitrogen; SSC, suspended-sediment concentration; DN, dissolved nitrogen]

Constituent	Water year	Annual load (kg/yr)	Lower confidence interval (kg/yr)	Upper confidence interval (kg/yr)
		01115114, Rush Brook		
TP	2016	97	82	110
	2017	180	160	210
	2018	220	180	260
	2019	310	260	370
DP	2016	48	40	56
	2017	98	85	110
	2018	95	79	110
	2019	170	140	200
TN	2016	2,200	2,000	2,400
	2017	3,700	3,400	4,000
	2018	3,600	3,200	3,900
	2019	5,400	5,000	6,000
DN	2016	1,800	1,600	1,900
	2017	3,000	2,700	3,200
	2018	2,600	2,400	2,800
	2019	4,000	3,600	4,400
SSC	2016	30,300	20,100	44,000
	2017	39,700	28,000	54,700
	2018	67,800	40,800	106,000
	2019	70,900	48,800	99,500
		01115170, Moswansicut Reservoir		
DP	2016	19	16	23
	2017	25	21	29
	2018	28	24	32
	2019	44	37	51
TN	2016	1,400	1,200	1,500
	2017	2,000	1,800	2,200
	2018	2,300	2,100	2,600
	2019	3,500	3,200	3,900
DN	2016	1,200	1,000	1,300
	2017	1,600	1,500	1,800
	2018	2,000	1,800	2,200
	2019	2,900	2,600	3,200
		01115183, Quonapaug Brook		
TP	2016	36	32	40
	2017	57	52	63
	2018	67	60	74
	2019	82	72	92

Table 38. Annual loads of nutrients and sediment estimated using load-regression models at five subbasins in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19.—Continued

[Water-quality and streamflow data collected by U. S. Geological Survey (USGS; Spaetzel and Smith, 2022). Station indicated by USGS streamgage number and short name (table 1). Not all constituent loads were estimated at each site. Dissolved nitrogen concentrations were measured in samples that were filtered with a 0.65-micrometer pore size disc filter instead of the customary 0.45-micrometer filter. kg/yr, kilogram per year; TP, total phosphorus; DP, dissolved phosphorus; TN, total nitrogen; SSC, suspended-sediment concentration; DN, dissolved nitrogen]

Constituent	Water year	Annual load (kg/yr)	Lower confidence interval (kg/yr)	Upper confidence interval (kg/yr)
01115183, Quonapaug Brook—Continued				
DP	2016	21	18	24
	2017	35	31	39
	2018	39	35	45
	2019	55	48	62
TN	2016	1,800	1,600	1,900
	2017	2,400	2,200	2,700
	2018	2,800	2,600	3,100
	2019	3,700	3,300	4,000
SSC	2016	7,500	6,400	8,800
	2017	13,300	11,300	15,500
	2018	16,000	13,400	18,900
	2019	19,000	15,800	22,700

Table 39. Selected model statistics for nutrient and sediment regression models developed at five stations in the Scituate Reservoir drainage area, Rhode Island, water years 2016–19.

[Model statistics also reported in Spaetzel and Smith (2022). Station indicated by U.S. Geological Survey streamgage number and short name (table 1). Potential parameters given by equation 4. R^2, coefficient of determination; PPCC, probability plot correlation coefficient; *p* value, significance level, where a value less than 0.05 indicates the residuals are not normally distributed at the 95-percent confidence level; TP, total phosphorus; DP, dissolved phosphorus; TN, total nitrogen; DN, dissolved nitrogen; SSC, suspended-sediment concentration]

Constituent	Samples	Concentration-model-adjusted R^2	Load model R^2	Number of parameters	Residual variance	PPCC	PPCC *p* value
01115098, Peeptoad Brook							
TP	54	0.603	0.986	4	0.044	0.972	0.017
DP	53	0.346	0.947	4	0.110	0.989	0.365
TN	55	0.396	0.991	2	0.031	0.997	0.968
SSC	49	0.507	0.941	4	0.234	0.983	0.147
01115110, Huntinghouse Brook							
TP	52	0.644	0.979	4	0.145	0.968	0.011
DP	49	0.552	0.982	4	0.091	0.990	0.494
TN	51	0.683	0.993	4	0.043	0.996	0.960
DN	51	0.487	0.992	4	0.045	0.996	0.953
SSC	48	0.570	0.932	4	0.511	0.981	0.130
01115114, Rush Brook							
TP	61	0.815	0.988	4	0.111	0.988	0.218
DP	57	0.609	0.979	3	0.126	0.988	0.257
TN	58	0.715	0.994	4	0.041	0.994	0.747
DN	58	0.444	0.993	4	0.041	0.996	0.886
SSC	59	0.625	0.957	3	0.401	0.990	0.358
01115170, Moswansicut Reservoir							
DP	54	0.251	0.903	3	0.151	0.981	0.127
TN	54	0.479	0.988	4	0.048	0.990	0.503
DN	55	0.471	0.988	3	0.047	0.987	0.234
01115183, Quonapaug Brook							
TP	58	0.764	0.975	5	0.074	0.995	0.833
DP	56	0.607	0.959	4	0.107	0.951	0.001
TN	60	0.257	0.983	4	0.060	0.992	0.556
SSC	54	0.683	0.960	5	0.136	0.996	0.936

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