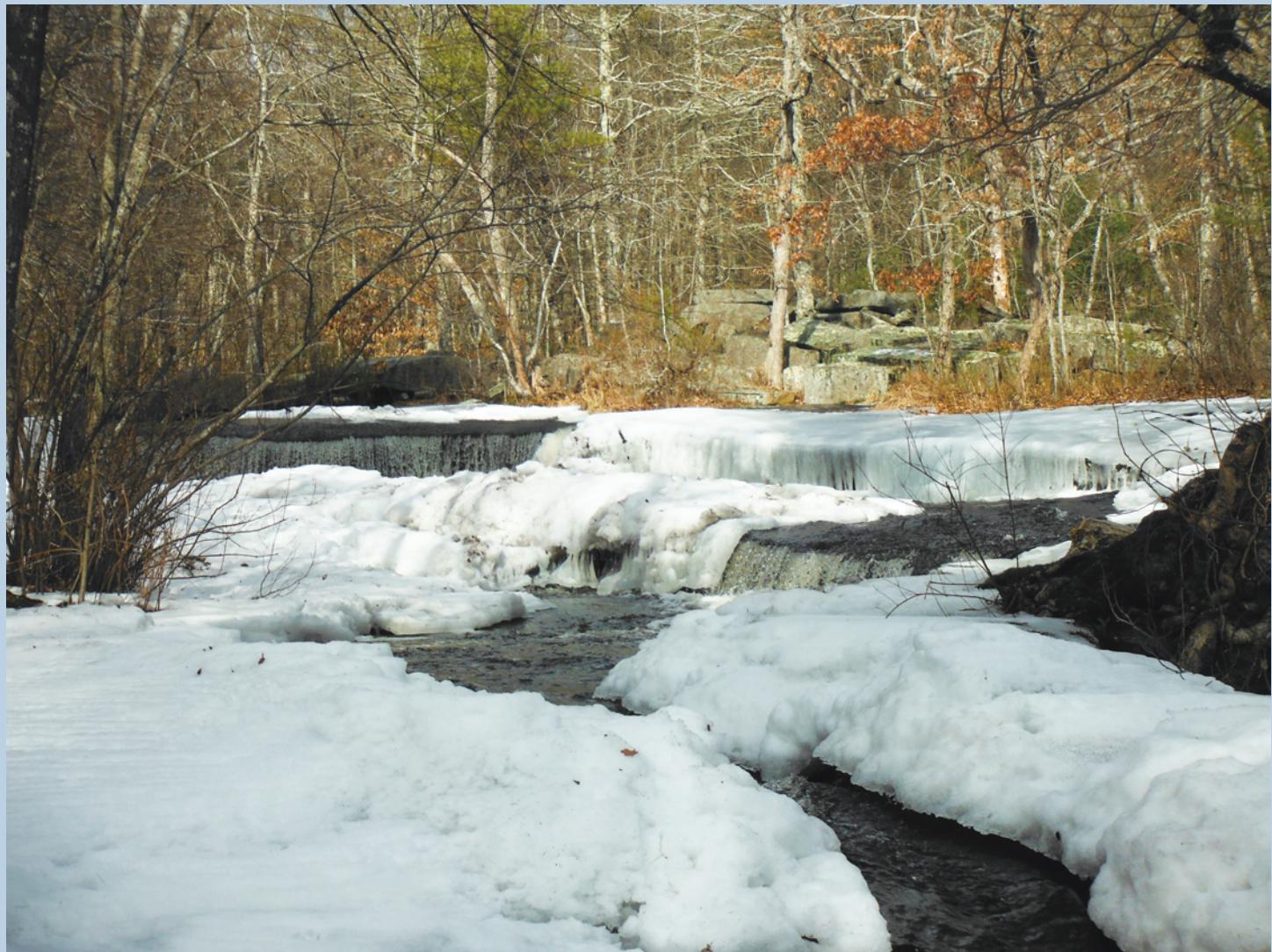


Prepared in cooperation with the Rhode Island Water Resources Board

# Equations for Estimating Selected Streamflow Statistics in Rhode Island



Scientific Investigations Report 2014–5010

**Front cover.** Photograph of Wood River at Escoheag, Rhode Island (USGS partial-record station 01117720), also known as Stepstone Falls in the Arcadia Management Area in Rhode Island.

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By Gardner C. Bent, Peter A. Steeves, and Andrew M. Waite

Prepared in cooperation with the Rhode Island Water Resources Board

Scientific Investigations Report 2014–5010

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

**U.S. Department of the Interior**  
SALLY JEWELL, Secretary

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

**U.S. Geological Survey, Reston, Virginia: 2014**

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## Conversion Factors, Datum, and Abbreviations

Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
Flow rate		
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
cubic foot per second per square mile [(ft <sup>3</sup> /s)/mi <sup>2</sup> ]	0.01093	cubic meter per second per square kilometer [(m <sup>3</sup> /s)/km <sup>2</sup> ]

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

Altitude, as used in this report, refers to distance above the vertical datum.

## Abbreviations

### Agencies

CLEAR	University of Connecticut—Center for Land Use Education and Research
MAGIC	University of Connecticut—Map and Geographic Information Center
MassGIS	Massachusetts Office of Geographic Information
NRCS	Natural Resources Conservation Service
RIDEM	Rhode Island Department of Environmental Management
RIGIS	Rhode Island Geographic Information System
RIWRB	Rhode Island Water Resources Board
USGS	U.S. Geological Survey

## Basin Characteristics

DRNAREA	Drainage area, in square miles
STRDENSE	Stream density, in miles per square mile

## Miscellaneous

7Q2	7-day, 2-year low-flow frequency
7Q10	7-day, 10-year low-flow frequency
BCF	bias correction factor
GIS	geographic information system
GNWISQ	Get National Water Information System Streamflow
LTG	long-term streamgage
MOVE.1	Maintenance of Variance Extension, type 1
MSE	mean square error
NWIS	National Water Information System—USGS
NED	National Elevation Dataset—USGS
NHD	National Hydrography Dataset—USGS
PRISM	Parameter-Elevation Regressions on Independent Slopes Model—Climate Group, Oregon State University
<i>r</i>	Pearson's correlation coefficient
<i>R</i> <sup>2</sup>	coefficient of determination
RI-ABF	Rhode Island Aquatic Base-Flow Methodology
RMSE	root mean square error
SSURGO	Soil Survey Geographic Database—Natural Resources Conservation Service
STG	short-term streamgage
WLS	weighted least-squares regression analysis
WREG	weighted-multiple-linear regression program

# Equations for Estimating Selected Streamflow Statistics in Rhode Island

By Gardner C. Bent, Peter A. Steeves, and Andrew M. Waite

## Abstract

Regional regression equations were developed for estimating selected natural—unaffected by alteration—streamflows of specific flow durations and low-flow frequency statistics for ungaged stream sites in Rhode Island. Selected at-site streamflow statistics are provided for 41 long-term streamgages, 21 short-term streamgages, and 135 partial-record stations in Rhode Island, eastern Connecticut, and southeastern and south-central Massachusetts. The regression equations for estimating selected streamflow statistics and the at-site statistics estimated for each of the 197 sites may be used by Federal, State, and local water managers in addressing water issues in and near Rhode Island.

Multiple and simple linear regression equations were developed to estimate the 99-, 98-, 95-, 90-, 85-, 80-, 75-, 70-, 60-, 50-, 40-, 30-, 25-, 20-, 15-, 10-, 5-, 2-, and 1-percent flow durations and the 7Q2 (7-day, 2-year) and 7Q10 (7-day, 10-year) low-flow-frequency statistics. An additional 49 selected statistics, for which regression equations were not developed, also were estimated for the long- and short-term streamgages and partial-record stations for flow durations between the 99.99 and 0.01 percent and for the mean annual, mean monthly, and median monthly streamflows. A total of 70 selected streamflow statistics were estimated for 41 long-term streamgages, 21 short-term streamgages, and 135 partial-record stations in and near Rhode Island. Estimates of the long-term streamflow statistics for the 21 short-term streamgages and 135 partial-record stations were developed by the Maintenance of Variance Extension, type 1 (MOVE.1), record-extension technique.

The equations used to estimate selected streamflow statistics were developed by relating the 19 flow-duration and 2 low-flow-frequency statistics to 31 different basin characteristics (physical, land-cover, and climatic) at the 41 long-term and 19 of 21 short-term streamgages (a total of 60 streamgages) in and near Rhode Island. The 135 partial-record stations were not used in the regression analyses. The regression analyses were done by using a user-weighted least-squares technique in the weighted-multiple-linear regression program for the 90- to 1-percent flow-duration statistics. For the 99-, 98-, and 95-percent flow durations and the 7Q2 and 7Q10 statistics, left-censored regression analyses were used to

account for zero flows at a few streamgages. The regression analyses determined that two basin characteristics—drainage area and stream density—were the only significant explanatory variables for 16 of the 19 flow-duration and the 2 low-flow regression equations. For the 10-, 15-, and 20-percent flow-duration regression equations, drainage area was the only significant explanatory variable. The standard error of the estimate for the 21 regression equations ranged from 17.58 to 141.83 percent. The 99- to 85-percent flow durations and the low-flow statistics 7Q2 and 7Q10 had the highest standard errors of the estimate, ranging from 48.68 to 141.83 percent. The standard error of the estimate for the medium- to high-flow statistics—the 80- to 1-percent flow durations—ranged from 17.58 to 37.65 percent, with the standard errors for the 60- to 1-percent flow durations all being less than about 21 percent. Data also are provided to allow the user to calculate the 90-percent prediction intervals for the 21 streamflow statistics.

The equations, which are based on data from streams with little to no flow alterations, will provide an estimate of the natural flows for a selected site. They will not estimate flows for altered sites with dams, surface-water withdrawals, groundwater withdrawals (pumping wells), diversions, and wastewater discharges. If the equations are used to estimate streamflow statistics for altered sites, the user should adjust the flow estimates for the alterations. The regression equations should be used only for ungaged sites with drainage areas between 0.52 and 294 square miles and stream densities between 0.94 and 3.49 miles per square mile; these are the ranges of the explanatory variables in the equations.

## Introduction

Flow statistics for streams are crucial for water-resources planning, management, and permitting to ensure adequate water for consumptive use, water-quality standards, recreation, and aquatic habitat. For example, the minimum 7-day-average flow that has a probability of occurring once every 10 years (7Q10) is a streamflow statistic frequently referenced by regulatory agencies as a threshold criterion for waste-load assimilation of point discharges and other water-resource-protection issues. Information on streamflow

## 2 Equations for Estimating Selected Streamflow Statistics in Rhode Island

statistics is critical for water-resource managers who make decisions, especially during drought periods. For example, in Rhode Island (fig. 1), drought periods occurred during 1930–31, 1941–45, 1949–50, 1963–67, 1980–81, and 1987–88 (Walker and Lautzenheiser, 1991). Most of these drought periods correspond to intervals when the annual mean streamflow was well below the long-term mean annual streamflow records for Branch River at Forestdale, R.I. (01111500), and Pawcatuck River at Wood River Junction, R.I. (01117500) (figs. 2 and 3), in northern and southern Rhode Island, respectively. Other shorter periods of low flow similar to those during the drought period noted previously can be seen in 1957, 1985, 1995, 2002, and 2008 (fig. 3).

In Rhode Island, instream flow standards have become more of a critical topic since the early 2000s with reports on how to develop these standards by the Rhode Island Water Resources Board (RIWRB) Water Allocation Program Advisory Committee (2004). The State developed a modified Aquatic Baseflow (RI-ABF) Methodology (Rhode Island Department of Environmental Management, Office of Water Resources, 2005) to assist in developing these instream streamflow standards. The RI-ABF methodology includes a site-specific standard that allows for maximum sustainable use of the State's waters but that is also protective of the biological, chemical, and physical integrity of those waters. A draft describing a streamflow-depletion methodology (Rhode Island Department of Environmental Management, Office of Water Resources, 2010) was developed to determine the maximum volume of water that can be extracted from a stream (whether as direct stream withdrawals or indirect groundwater withdrawals) yet leave sufficient streamflow to maintain habitat conditions essential to a healthy aquatic ecosystem.

Additionally, the Rhode Island Department of Environmental Management (RIDEM) and Rhode Island Water Resources Board Streamflow Committee (2004) made recommendations for a streamgage network to allow proper management of the State's water resources. The streamgage network is intended to provide streamflow data for the development of regression equations for estimated streamflow statistics at ungaged sites in Rhode Island.

This study was done from 2007–11 by the U.S. Geological Survey (USGS) in cooperation with the RIWRB. This study provides the RIWRB; RIDEM; Providence Water Supply Board; other federal, state, county, city, and town agencies; nongovernmental and private organizations; and the public with regression equations for estimating selected streamflow statistics for ungaged stream sites and at-site streamflow statistics for long- and short-term streamgages and partial-record stations in and near Rhode Island. Streamflow statistics can inform planning, management, and permitting decisions related to ensuring adequate water for consumptive use, water-quality standards, recreation, and aquatic habitat in Rhode Island. In addition, the streamflow statistics can be used by the RIWRB in identifying water sources where uses might exceed the safe yield under the Rhode Island General Laws 46–15.7–3.

## Purpose and Scope

This report describes regression equations developed for estimating selected statistics for streamflows in Rhode Island from basin, land-use, and climatological characteristics. The selected streamflow statistics estimated with the regression equations are for natural flow conditions (unaltered streamflows). The report provides estimates of selected streamflow statistics for long- and short-term streamgages and partial-record stations in and near Rhode Island. Streamflow statistics for which regression equations were developed include the 99-, 98-, 95-, 90-, 85-, 80-, 75-, 70-, 60-, 50-, 40-, 30-, 25-, 20-, 15-, 10-, 5-, 2-, and 1-percent flow durations and the 7Q2 (7-day, 2-year) and 7Q10 (7-day, 10-year) low-flow frequencies. An evaluation of the accuracies of the equations and the limitations for their use are provided with example applications. Additionally, estimated statistics are provided for long- and short-term streamgages and partial-record stations for other selected flow durations between the 99.99- and 0.01-percentiles and for the mean annual, mean monthly, and median monthly streamflows; however, regression equations were not developed for these statistics.

## Previous Studies

Klever (1996) estimated the 99-, 98-, 97-, 95-, 90-, 85-, 80-, 70-, 60-, 50-percent flow durations, 7Q10, and mean monthly streamflows for August, February, April, and May for 16 partial-record stations in northern Rhode Island. Cervione and others (1993) calculated the 80-, 90-, 95-, 98-, and 99-percent flow durations for 25 partial-record stations in southern Rhode Island. Cervione and others (1993) also presented a regression equation to estimate the 7Q10 for selected streams in Rhode Island. The equation does not provide an estimate of the potential error of the 7Q10 and is based on only 4 continuous-record streamgages in southwestern Rhode Island, 5 streamgages in eastern Connecticut, 8 streamgages in western Connecticut, 2 streamgages in western Massachusetts, and 2 streamgages in eastern New York with data through water year 1991. Currently (2014) selected streamflow statistics may be estimated for about 25 continuous-record streamgages, 10 discontinued streamgages, and about 90 partial-record stations throughout Rhode Island. Wandle and Randall (1994) developed regression equations for estimating the 7Q2 and 7Q10 for central New England, which includes Rhode Island. Seven of the 51 streamgages used in the regression analyses were in Rhode Island. Ries (1990) estimated mean annual runoff from major drainage areas in Rhode Island and Massachusetts to Narragansett Bay. Additionally, Haecker (2000) provided estimates of base flow at selected streams in Rhode Island.

In the adjacent States of Connecticut and Massachusetts, several additional studies have published regression equations for estimating selected low-flow statistics over the last

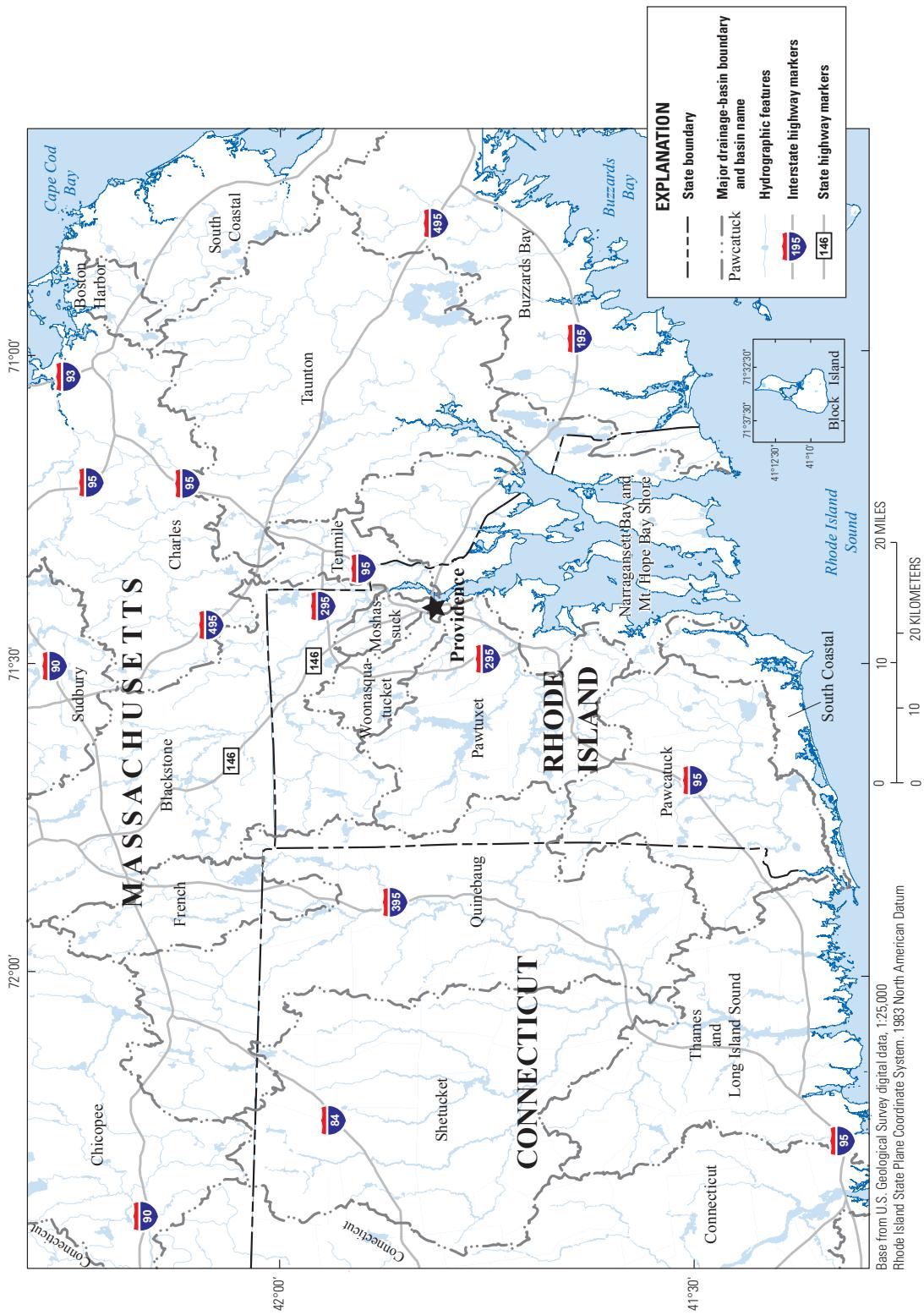


Figure 1. Locations of the drainage basins in the study area in and near Rhode Island.

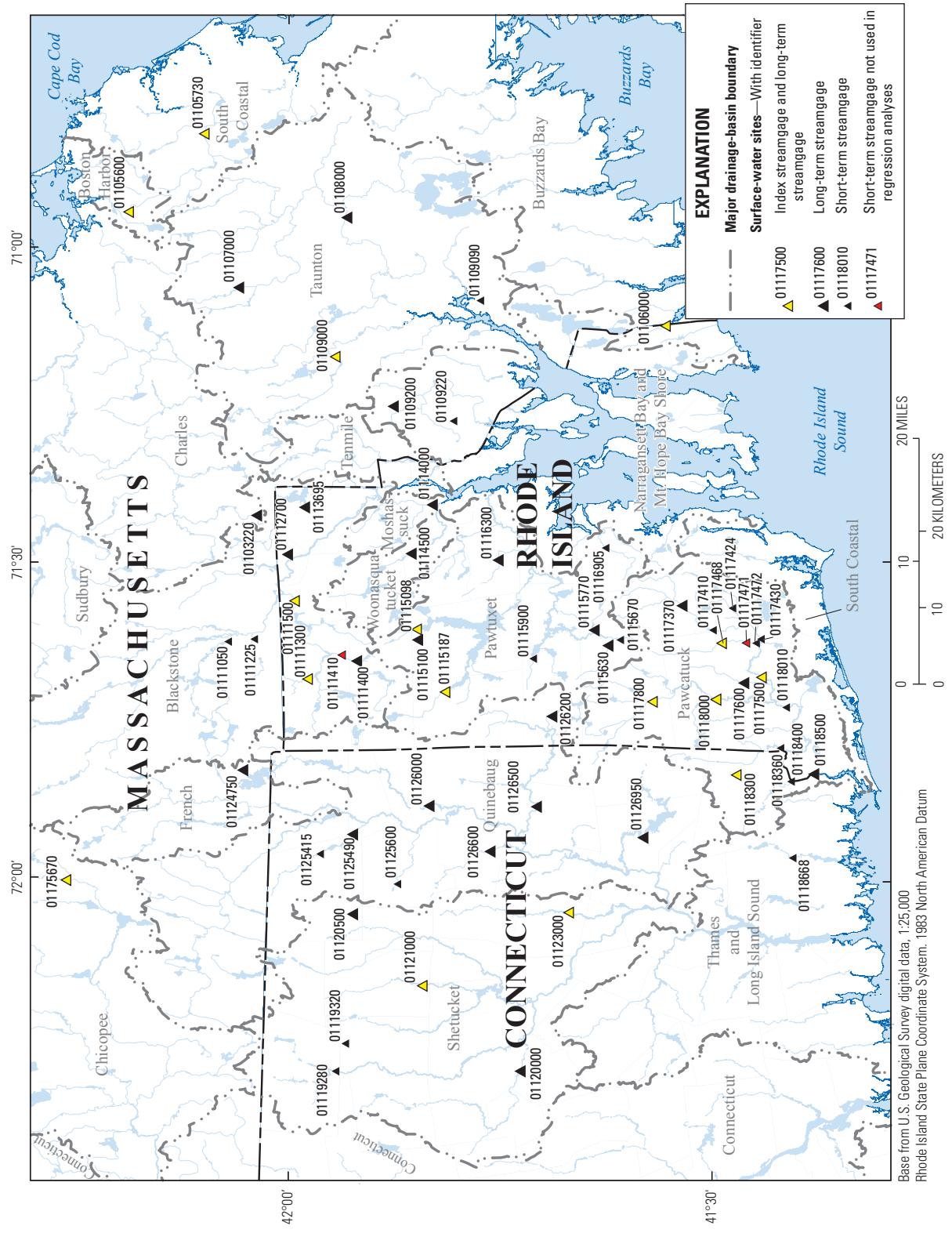
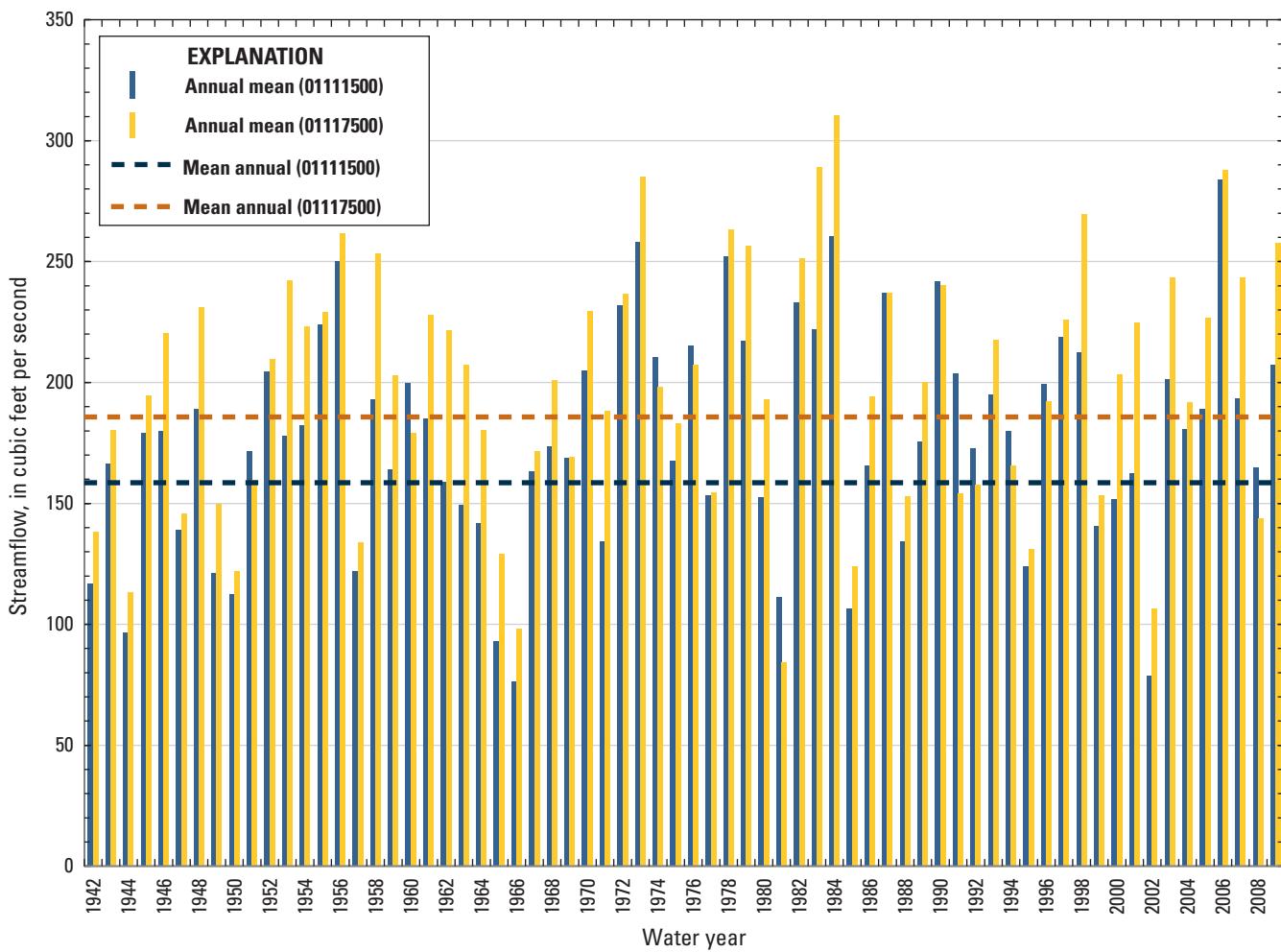


Figure 2. Locations of the index, long-term, and short-term streamgages in and near Rhode Island.



**Figure 3.** Annual mean streamflows at the streamgages Branch River at Forestdale, R.I. (01111500), and Pawcatuck River at Wood River Junction, R.I. (01117500), for water years 1942–2009.

20 years. Ahearn (2008 and 2010) and Ahearn and others (2006) provided estimated streamflow statistics and regression equations for various flow durations, 7Q2, 7Q10, and seasonal flows based on aquatic habitat needs in Connecticut. Fennessey and Vogel (1990), Vogel and Kroll (1990), Ries (1990), Risley (1994), Ries (1994a, 1994b, 1997, and 1999), Ries and Friesz (2000), Ries and others (2000), and Archfield and others (2010) provided estimated streamflow statistics and regression equations for various flow durations, 7Q2, and 7Q10 in Massachusetts. Armstrong and others (2008) provided regression equations for estimating median monthly streamflows in Massachusetts. Bent and Archfield (2002) and Bent and Steeves (2006) provided logistic regression equations for estimating the probability of a stream flowing perennially in Massachusetts.

## Description of Study Area

Rhode Island encompasses 1,045 square miles ( $\text{mi}^2$ ) in the northeastern United States (fig. 1). Altitudes range from sea level (defined as the North American Vertical Datum of 1988) in coastal areas to 812 feet (ft) above sea level in the northwest. Altitudes generally increase from southeast to northwest in Rhode Island. The climate is humid and temperate. Average annual precipitation ranged from 40 to 53 inches (in.) during 1971–2000 and is fairly evenly distributed throughout the months (National Oceanic and Atmospheric Administration, 2002). Average annual temperature ranged from 48 to 52 °F; the minimum ranged from 26 to 33 °F in January, and the maximum ranged from 71 to 73 °F in July (National Oceanic and Atmospheric Administration, 2002).

## 6 Equations for Estimating Selected Streamflow Statistics in Rhode Island

About half of the annual precipitation is returned to the atmosphere through evaporation and plant transpiration, with the remainder becoming groundwater recharge or stream runoff.

Surficial deposits that overlie bedrock in most of Rhode Island were deposited mainly during the last glacial period but can include areas of recent flood-plain alluvium deposits. In this report, these surficial deposits are classified as either till (which includes till or bedrock, sandy till over sand, and end-moraine deposits) or outwash (stratified) deposits (which includes sand and gravel, coarse sand, fine-grained sand, and flood-plain alluvium deposits) (fig. 4). Till (also known as ground moraine) is an unsorted, unstratified mixture of clay, silt, sand, gravel, cobbles, and boulders that were deposited by glaciers, commonly on top of bedrock throughout much of the State. Surficial till is primarily found in upland areas but can also be found at depth in river valleys. Outwash deposits include sorted and layered glaciofluvial and glaciolacustrine deposits. Glaciofluvial deposits are material of all grain sizes (clay, silt, sand, gravel, and cobbles) deposited by glacial meltwater streams in outwash plains and river valleys. Glaciolacustrine deposits generally consist of clay, silt, and fine sand deposited in temporary lakes that formed after the retreat of the glacial ice sheet. Outwash deposits are more widespread in central and southern Rhode Island than in eastern, northern, and western Rhode Island (fig. 4) (Trench, 1991; DeSimone and Ostiguy, 1999, p. 4). The outwash deposits are mainly along the major river valleys, and the till deposits and exposed bedrock are in the upland areas. In the southern coastal area of the State is a large mixed deposit (fig. 4), often referred to as the Charlestown moraine, that acts as a physical barrier to surface-water flow heading south and sends it toward the southwest to a point of discharge into the Atlantic Ocean (Masterson and others, 2007; Friesz, 2010; and Bent and others, 2011).

Land in Rhode Island is primarily forested outside of the Providence metropolitan area (fig. 5). The Providence metropolitan area is generally bound by Interstates I-95, I-295, and I-195 and the State border with Massachusetts (fig. 1) and consists primarily of moderate- to high-density housing and commercial and industrial facilities (fig. 5). From 1970 to 1995 there was a 47-percent increase in the developed land area in Rhode Island, with the greatest increases in the areas of residential, commercial, and industrial land (Rhode Island Statewide Planning Program, 2000).

Rhode Island is within the central highlands, coastal lowlands, and coastal plain physiographic provinces (Denny, 1982). The central highlands physiographic province is limited to west central and northwestern areas of the State. The remainder of the State is within the coastal lowlands physiographic province, excluding Block Island, which is within the coastal plain province. Rhode Island is entirely within the Northeast Coastal Zone of the U.S. Environmental Protection Agency (EPA) (2006) level III ecoregions, excluding Block Island, which is within the Atlantic Coastal Pine Barrens ecoregion. The level III ecoregions are delineated on

the basis of geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology.

Block Island (fig. 1—*inset map*), which is about 10 miles (mi) south of the mainland coast of Rhode Island, was not included in the study area because the topographic map of Block Island for the 12-mi<sup>2</sup> island shows no streams. Veeger and Johnston (1996) reported that streams are absent throughout most of the island, except for a few springs along the base of the sea cliffs on the southern part of the island.

## Development of the Streamflow Statistics and Basin Characteristics Datasets

Historical streamflow data for USGS streamgages are available in the USGS National Water Information System (NWIS) database at the Web site <http://waterdata.usgs.gov/nwis>. These streamflow data can be analyzed to determine particular statistics—such as flow durations, flow frequencies, and monthly and annual statistics—which are used by water managers throughout the country. Basin characteristics for physical, land-use, and climatological data are developed with geographic information system (GIS) data layers from Federal, State, and local government agencies and non-governmental agencies.

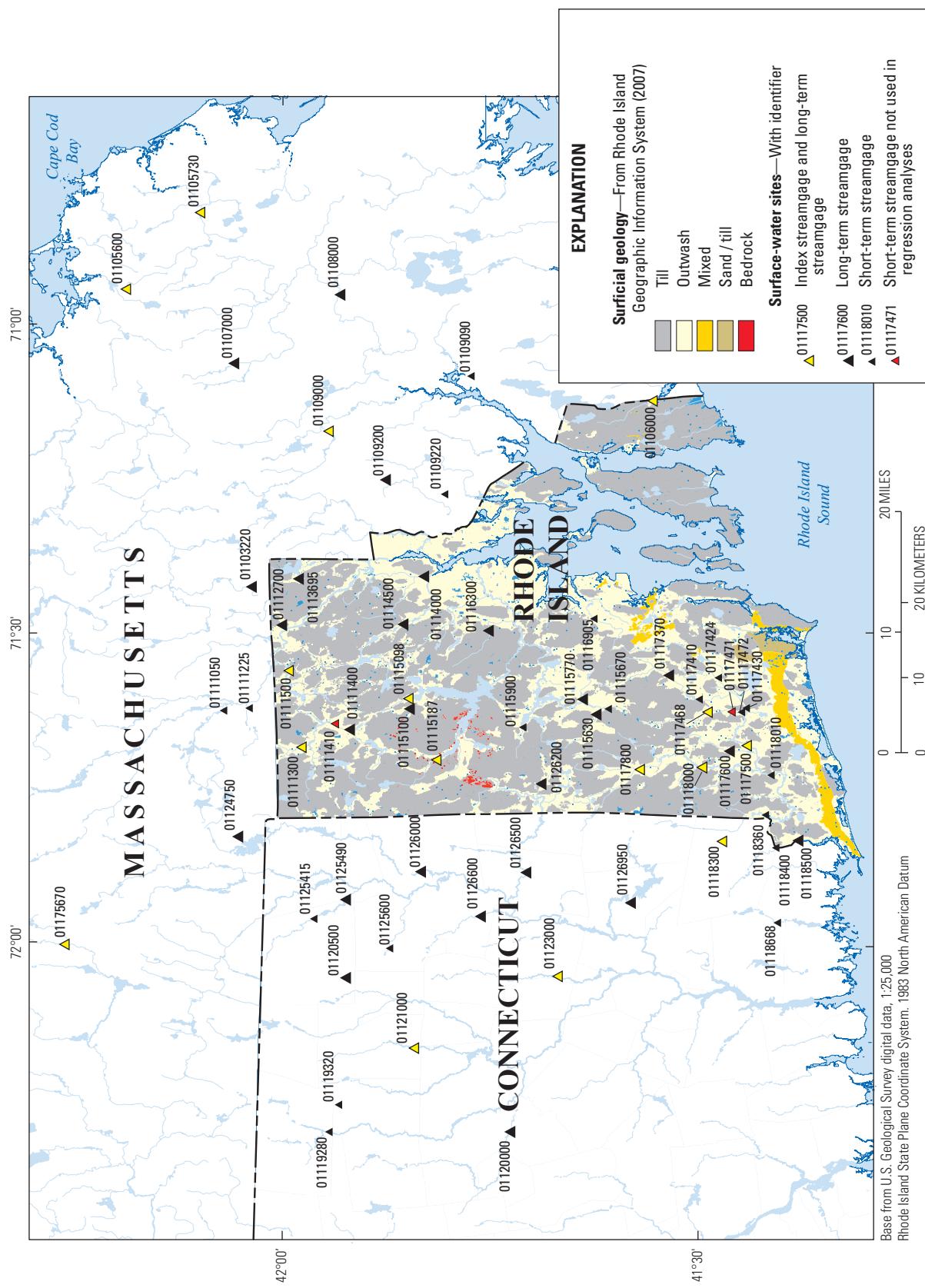
## Site Selection

All active and discontinued long- and short-term streamgages and partial-record stations in Rhode Island, eastern Connecticut, and southeastern and south-central Massachusetts were evaluated for possible use in the regional regression analyses. Long-term streamgages were defined as those having 8 or more years of record (both water years<sup>1</sup> and climatic years<sup>2</sup>) through water year 2006. Short-term streamgages were defined as those having fewer than 8 years of record through water year 2009. Partial-record stations were considered if they had at least 10 streamflow measurements through water year 2006. Sites in eastern Connecticut and southeastern and south-central Massachusetts were limited to those within about 25 mi of the Rhode Island border. All of the sites in the three States considered are within the Northeast Coastal Zone of the U.S. Environmental Protection Agency Ecoregion level III (2006) and are based on geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology.

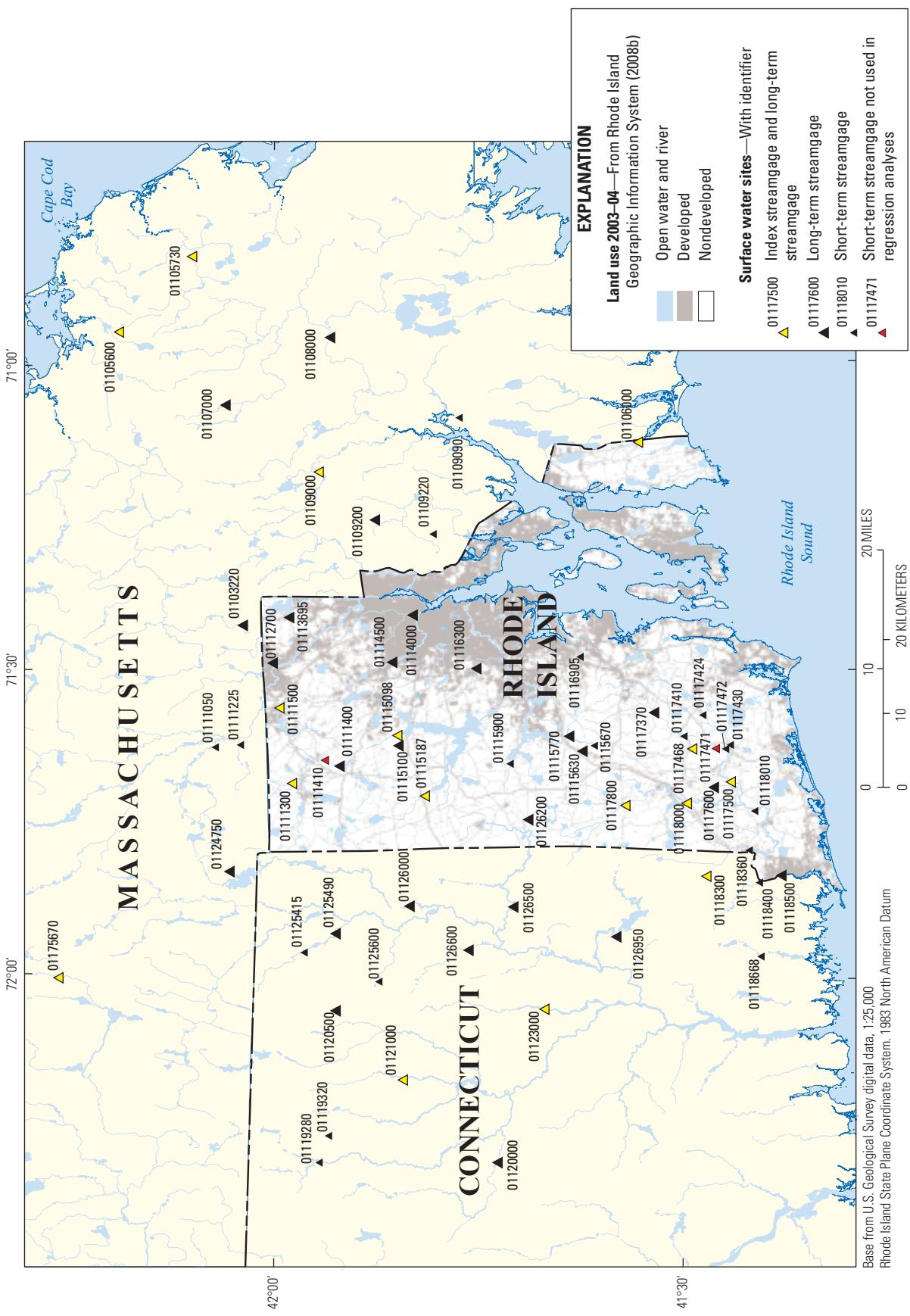
All potential sites were evaluated for flow alteration processes such as water withdrawals, diversions, flood

<sup>1</sup>A water year is the 12-month period beginning October 1 and ending September 30. It is numbered by the calendar year in which it ends.

<sup>2</sup>A climatic year is the 12-month period beginning April 1 and ending March 31. It is numbered by the calendar year in which it ends.



**Figure 4.** Surficial geology in Rhode Island.



**Figure 5.** General land use in Rhode Island.

control, and wastewater discharge. Those sites with known flow-altered processes within their drainage basins that were significant enough to clearly change the recorded daily mean streamflows for more than several days during each water year were excluded from the dataset. The final list of sites included 41 long-term streamgages (22 in Rhode Island, 10 in Connecticut, and 9 in Massachusetts), 21 short-term streamgages (11 in Rhode Island, 6 in Connecticut, and 4 in Massachusetts), and 135 partial-record stations (95 in Rhode Island, 25 in Connecticut, and 15 in Massachusetts).

## Flow Duration

Flow durations represent the percentage of time that a given flow is equaled or exceeded without regard to the sequence of recorded flows (Searcy, 1959). Typically, flow durations characterize the range of flow rates for the period over which data were collected. Flow durations were computed for complete water years for the entire period of record for 41 long-term streamgages (table 1 and fig. 2) with 8 or more complete water years of record. Flow durations are computed by sorting the daily mean streamflows for the period of record from largest to smallest and assigning each streamflow value a rank, starting with 1 for the largest value. The frequencies of exceedance are then computed by using the Weibull plotting-position formula (Weibull, 1939):

$$P = 100 * [M / (n + 1)] \quad (1)$$

where

- $P$  is the probability that a given streamflow will be equaled or exceeded (percent of time),
- $M$  is the ranked position (dimensionless), and
- $n$  is the number of events (daily mean streamflow values) for the period of record (dimensionless).

Examples of flow-duration curves are provided for the Adamsville Brook at Adamsville, R.I. (01106000), and for the Beaver River near Usquepaug, R.I. (01117468), streamgages (fig. 6). The drainage areas to these streamgages are similar in size, about 9 mi<sup>2</sup>, and their record lengths are fairly similar—38 and 36 years, respectively—but both show distinctly different flows over much of the flow-duration curve. These differences are the results of their different periods of record, physical basin characteristics, land-use characteristics, and (or) climatic factors.

The program Make Plotting Position (MkPP) (Granato, 2009) computed the selected flow durations by using the Weibull plotting-position formula. The selected flow durations range from 99.99 to 0.01 percent, with the number of selected durations increasing in the extreme percentile ranges (99.99 to 90 and 10 to 0.01) (table 2). These selected flow durations were considered to most accurately define the flow-duration

curve for a streamgage or for estimating streamflows at an ungaged site. The streamflow data to be used in the MkPP program were downloaded for complete water years during the streamgages' periods of record through water year 2006 by using the computer program Get National Water Information System Streamflow (GNWISQ) (Granato, 2009). For the streamgages Miscoe Brook near Franklin, Mass. (01103220), Catamint Brook at Cumberland, R.I. (01113695), and Queen River at Liberty Road, at Liberty, R.I. (01117370), data through water year 2009 were used, so that these streamgages could be used in this study as long-term streamgages (8 or more complete water years of record) instead of being used as short-term streamgages with estimated statistics. Estimated streamflows for the selected flow durations at the long-term streamgages are presented in table 3.

**Table 3.** Estimated streamflow statistics for long- and short-term streamgages in and near Rhode Island.

[Available separately at [http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010\\_bent\\_table03.xlsx](http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010_bent_table03.xlsx)]

## Low-Flow Frequency

Low-flow frequencies typically are computed for streamgages by use of annual series of selected low flows based on the lowest mean streamflow for a specified number of consecutive days (Riggs, 1972). Any combination of number of days of mean minimum flow and years of recurrence may be used to determine the low-flow frequencies. The annual series for the determination of low-flow frequencies for this study was based on a climatic year. Use of a climatic year rather than a water year allows for an analysis of an uninterrupted low-flow period; in Rhode Island, this low-flow period typically occurs from early August through mid-October.

Low-flow frequencies were computed for selected days and frequencies for 41 long-term streamgages (table 1 and fig. 2) with 8 or more complete climatic years. Low-flow frequencies are based on the D-day, Y-year frequency statistic of daily mean streamflow. This statistic is the minimum consecutive D-day mean streamflow that is expected to occur once in any Y-year period, or that has a probability of 1/Y of not being exceeded in any given year. The two commonly used indexes of low-flow frequencies were determined for this report: the 7-day, 2-year low-flow frequency (7Q2) and the 7-day, 10-year low-flow frequency (7Q10). The 7Q2 is the annual minimum average streamflow for 7 consecutive days that has a probability of 0.50 (1/recurrence interval) of not being exceeded in a given year. The 7Q10 is the annual minimum average streamflow for 7 consecutive days that has a probability of 0.10 of not being exceeded in a given year. The 7Q10 is commonly used in regulating waste disposal to streams by many States (U.S. Environmental Protection Agency, 1986).

**Table 1.** Description of long- and short-term streamgages in and near Rhode Island.

[Locations of USGS stations shown in figure 2. River basins shown in figure 1. Numbers and names of index streamgages in bold and highlighted in light gray. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; p, present; Ave., Avenue; Rd., Road; Rt., Route; ft, feet; LTG, long-term streamgage; Index, index streamgage; Index, index streamgage; GIS, geographic information system; NWIS, National Water Information System]

USGS station no.	Station name	River basin	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi <sup>2</sup> ) <sup>1</sup>	Period of record	Number of complete water years used in analyses	Number of complete climatic years used in analyses	Streamgage type	Remarks
01103220	Miscoe Brook near Franklin, MA	Charles	42.04093	-71.42673	1.17	2000-09	9	8	LTG	--
<b>01105600</b>	<b>Old Swamp River near South Weymouth, MA</b>	Boston Harbor	42.19038	-70.94477	4.39	1966-p	40	39	Index and LTG	--
01105730	<b>Indian Head River at Hanover, MA</b>	South Coastal	42.10066	-70.82254	30.10	1966-p	40	39	Index and LTG	Some flow alteration by mills and ponds upstream
01106000	<b>Adamsville Brook at Adamsville, RI</b>	Buzzards Bay	41.55844	-71.12921	8.09	1940-78 and 1987	38	37	Index and LTG	--
01107000	Dorchester Brook near Brockton, MA	Taunton	42.06149	-71.06588	4.88	1963-74	11	11	LTG	--
01108000	Taunton River near Bridgewater, MA	Taunton	41.93399	-70.95643	261.52	1929-76, 1985-88, and 1996-p	58	57	LTG	Some flow alteration by reservoirs and powerplants upstream and diversions for municipal supplies
<b>01109000</b>	<b>Wading River near Norton, MA</b>	Taunton	41.94760	-71.17672	43.66	1925-p	81	80	Index and LTG	Some flow alteration by reservoirs and powerplants upstream and diversions for municipal supplies
01109090	Rattlesnake Brook near Assonet, MA	Taunton	41.777677	-71.08921	4.28	2007-09	3	3	STG	--
01109200	West Branch Palmer River near Rehoboth, MA	Narragansett Bay and Mt. Hope Bay Shore	41.87955	-71.25449	4.64	1962-74	11	10	LTG	--
01109220	Palmer River at South Rehoboth, MA	Narragansett Bay and Mt. Hope Bay Shore	41.80927	-71.27783	31.23	2006-09	4	4	STG	Occasional flow alteration by fish ladder upstream
01111050	Mumford River at Uxbridge, MA	Blackstone	42.07510	-71.62590	56.16	2004-06	2	2	STG	--
01111225	Emerson Brook near Uxbridge, MA	Blackstone	42.04454	-71.62201	7.47	2007-09	2	2	STG	--
<b>01111300</b>	<b>Nimpuc River near Harrisville, RI</b>	Blackstone	41.98121	-71.68590	15.83	1964-91, 94-p	40	39	Index and LTG	--
01111400	Chepachet River at Chepachet, RI	Blackstone	41.92288	-71.65757	17.46	1965-73	8	8	LTG	--
<sup>2</sup> 01111410	Chepachet River west of Gazzza Road at Gazzaville, RI	Blackstone	41.94093	-71.64812	19.10	1973-75 and 2004-05	2	1	STG	--

**Table 1.** Description of long- and short-term streamgages in and near Rhode Island.—Continued

[Locations of USGS stations shown in figure 2. River basins shown in figure 1. Numbers and names of index streamgages in bold and highlighted in light gray. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; p, present; Ave., Avenue; Rd., Road; Rt., Route; ft, feet; LTG, long-term streamgage; Index, index streamgage; STG, short-term streamgage; GIS, geographic information system; NWIS, National Water Information System]

USGS station no.	Station name	River basin	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi <sup>2</sup> ) <sup>1</sup>	Period of record	Number of complete water years used in analyses	Number of complete climatic years used in analyses	Streamgage type	Remarks
<b>01111500</b>	<b>Branch River at Forestdale, RI</b>	Blackstone	41.99649	-71.56256	91.22	1940–p	66	66	Index and LTG	Some flow alteration by ponds upstream
01112700	Blackstone River Tributary at Woonsocket, RI	Blackstone	42.00510	-71.48923	2.22	1965–74	9	6	LTG	—
01113695	Catamin Brook at Cumberland, RI	Blackstone	41.98510	-71.41367	3.51	1999–2009	10	5	LTG	—
01114000	Moshassuck River at Providence, RI	Moshassuck	41.83399	-71.41061	23.36	1963–p	43	42	LTG	Some flow alteration
01114500	Woonasquatucket River at Centerdale, RI	Woonasquatucket	41.85899	-71.48728	37.70	1941–p	65	64	LTG	Some flow alteration by reservoirs upstream
<b>01115098</b>	<b>Peepoard Brook at Elmdale Rd. near North Scituate, RI</b>	Pawtuxet	41.85260	-71.60618	4.96	1994–p	12	10	Index and LTG	—
01115100	Mosquitohawk Brook near North Scituate, RI	Pawtuxet	41.85149	-71.62284	3.05	1965–74	9	4	LTG	—
<b>01115187</b>	<b>Ponaganset River at South Foster, RI</b>	Pawtuxet	41.81871	-71.70507	14.02	1994–p	12	12	Index and LTG	—
01115630	Nooseneck River at Nooseneck, RI	Pawtuxet	41.62677	-71.63256	8.20	1964–81 and 2007–p	17	17	LTG	—
01115670	Congdon River near Nooseneck, RI	Pawtuxet	41.61232	-71.62284	4.46	2007–p	3	3	STG	—
01115770	Carr River near Nooseneck, RI	Pawtuxet	41.64316	-71.60784	6.74	1964–80 and 2007–12	15	15	LTG	Some flow diversions for municipal supply upstream
01115900	Flat River near Coventry, RI	Pawtuxet	41.71454	-71.65257	9.09	1961–64	2	2	STG	—
01116300	Furnace Hill Brook at Cranston, RI	Pawtuxet	41.75649	-71.49728	3.91	1964–74	9	7	LTG	—
01116905	Hunt River 250 ft downstream of Fry Brook at Frenchtown, RI	Hunt	41.63000	-71.47889	16.25	2007–p	2	2	STG	Some flow alteration by municipal supplies upstream
01117370	Queen River at Liberty Rd. at Liberty, RI	Pawcatuck	41.53899	-71.56867	19.30	1999–p	11	10	LTG	Occasional flow withdrawals for irrigation upstream
01117410	Usquepaug River at Rt. 138 at Usquepaug, RI	Pawcatuck	41.50260	-71.60784	33.05	1999–2004	4	4	STG	Occasional flow withdrawals for irrigation upstream
01117424	Chickasheen Brook at West Kingston, RI	Pawcatuck	41.48038	-71.57340	4.82	2002–04	2	2	STG	Occasional flow withdrawals for irrigation upstream

**Table 1.** Description of long- and short-term streamgages in and near Rhode Island.—Continued

[Locations of USGS stations shown in figure 2. River basins shown in figure 1. Numbers and names of index streamgages in bold and highlighted in light gray. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; p, present; Ave., Avenue; Rd., Road; Rt., Route; ft, feet; LTG, long-term streamgage; Index, index streamgage; STG, short-term streamgage; GIS, geographic information system; NWIS, National Water Information System]

USGS station no.	Station name	River basin	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi <sup>2</sup> ) <sup>1</sup>	Period of record	Number of complete water years used in analyses	Number of complete climatic years used in analyses	Streamgage type	Remarks
01117430	Pawcatuck River at Rt. 2 at Kenyon, RI	Pawcatuck	41.44621	-71.62117	72.41	1958–60, 2002–04, and 2007–p	3	3	STG	Some flow alteration by municipal supplies and withdrawals for irrigation upstream
<b>01117468</b>	<b>Beaver River near Usquepaug, RI</b>	Pawcatuck	41.49260	-71.62812	9.18	1974–p	31	31	Index and LTG	—
01117471	Beaver River at Shannock Hill Road near Shannock, RI	Pawcatuck	41.46427	-71.62784	11.90	2002–04	2	2	STG	Occasional flow withdrawals for irrigation upstream
01117472	Beaver River at Kenyon, RI	Pawcatuck	41.45232	-71.62812	12.36	1975–79	3	3	STG	Occasional flow withdrawals for irrigation upstream
<b>01117500</b>	<b>Pawcatuck River at Wood River Junction, RI</b>	Pawcatuck	41.44510	-71.68090	99.33	1940–p	65	65	Index and LTG	Occasional flow alteration by ponds and mills upstream and withdrawals for irrigation upstream
01117600	Meadow Brook near Carolina, RI	Pawcatuck	41.46649	-71.69007	5.09	1965–74 and 2002–04	11	9	LTG	Occasional flow withdrawals for irrigation upstream
<b>01117800</b>	<b>Wood River near Arcadia, RI</b>	Pawcatuck	41.57399	-71.72062	35.17	1964–81, 83–p	41	40	Index and LTG	—
<b>01118000</b>	<b>Wood River at Hope Valley, RI</b>	Pawcatuck	41.49816	-71.71646	73.47	1941–p	65	65	Index and LTG	Some flow alteration by ponds upstream
01118010	Pawcatuck River at Burdickville, RI	Pawcatuck	41.41621	-71.72896	204.33	2002–04	2	2	STG	Occasional flow alteration by ponds and mills upstream and withdrawals for irrigation upstream
<b>01118300</b>	<b>Pendleton Hill Brook near Clarks Falls, CT</b>	Pawcatuck	41.47482	-71.83424	3.99	1959–p	48	47	Index and LTG	—
01118360	Ashaway River at Ashaway, RI	Pawcatuck	41.42343	-71.79174	28.27	2002–04	2	2	STG	—
01118400	Shunock River at North Stonington, CT	Pawcatuck	41.41010	-71.84479	16.31	2002–04	2	2	STG	—
01118500	Pawcatuck River at Westerly, RI	Pawcatuck	41.38371	-71.83312	293.88	1940–p	65	65	LTG	Some flow alteration by municipal supplies, ponds, mills, and withdrawals for irrigation upstream

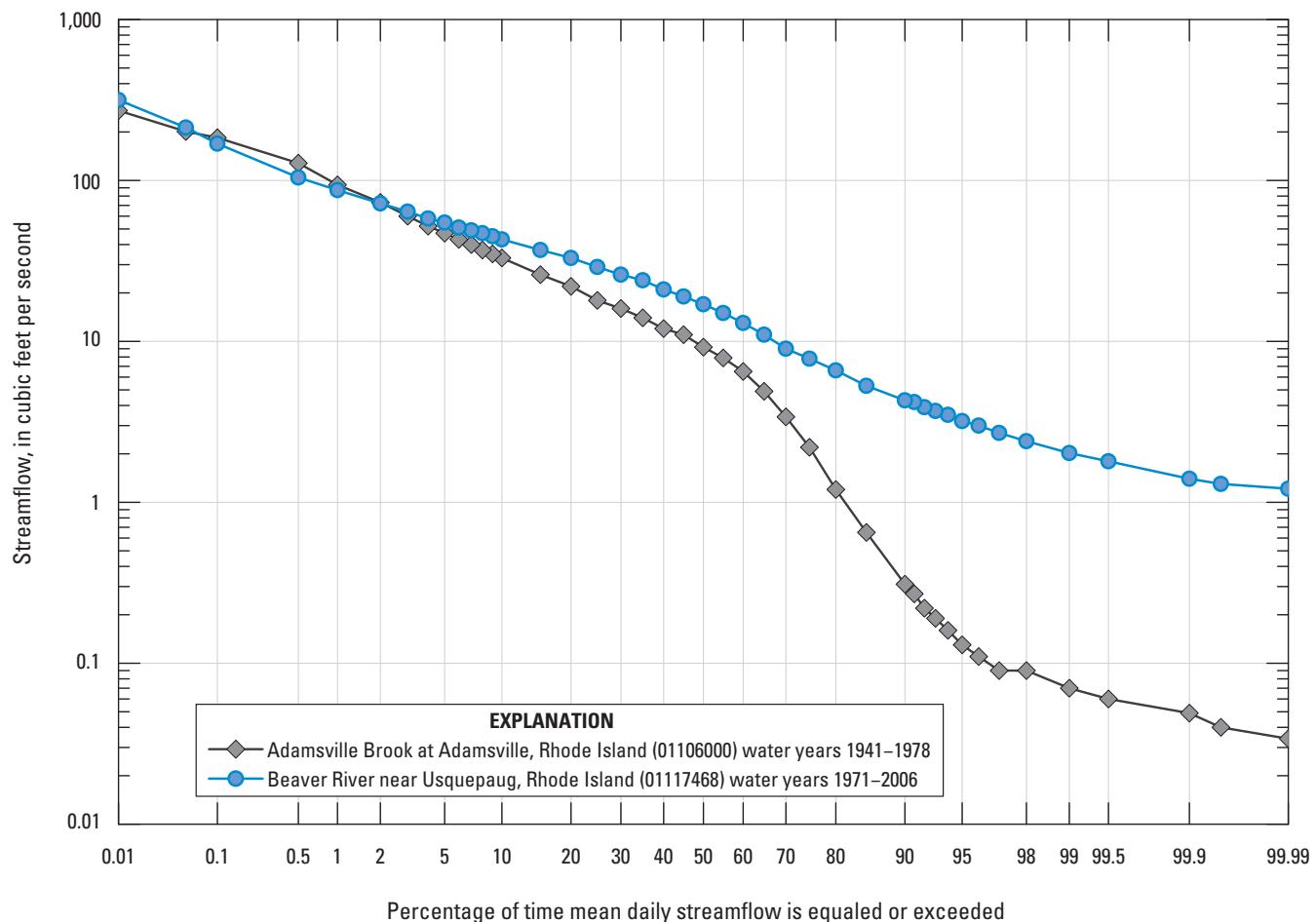
**Table 1.** Description of long- and short-term streamgages in and near Rhode Island.—Continued

[Locations of USGS stations shown in figure 2. River basins shown in figure 1. Numbers and names of index streamgages in bold and highlighted in light gray. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; p, present; Ave., Avenue; Rd., Road; Rt., Route; ft, feet; LTG, long-term streamgage; Index, index streamgage; NWIS, National Water Information System]

USGS station no.	Station name	River basin	Latitude (decimal degree)	Longitude (decimal degree)	Drainage area (mi <sup>2</sup> ) <sup>1</sup>	Period of record	Number of complete water years used in analyses	Number of complete climatic years used in analyses	Streamgage type	Remarks
01118668	Whitford Brook below Williams Brook near Old Mystic, CT	Long Island Sound	41.40788	-71.96396	13.29	2000–02	3	3	STG	—
01119280	Willimantic River at Stafford Springs, CT	Shetucket	41.94537	-72.30452	52.83	1963–67	5	5	STG	—
01119320	Roaring Brook near Stafford Springs, CT	Shetucket	41.93426	-72.26091	15.15	1961–66	5	5	STG	—
01120000	Hop River near Columbia, CT	Shetucket	41.772760	-72.30230	74.54	1932–71	39	38	LTG	—
01120500	Safford Brook near Woodstock Valley, CT	Shetucket	41.92649	-72.05702	4.17	1951–81	31	28	LTG	—
<b>01121000</b>	<b>Mount Hope River near Warrenville, CT</b>	Shetucket	41.84371	-72.16897	29.00	1941–p	66	65	Index and LTG	Occasional flow alteration by ponds upstream
<b>01123000</b>	<b>Little River near Hanover, CT</b>	Shetucket	41.67177	-72.05230	29.99	1952–p	55	54	Index and LTG	—
01124750	Browns Brook near Webster, MA	French	42.05676	-71.83035	0.52	1963–77	15	7	LTG	—
01125415	Muddy Brook at Childs Hill Rd. near Woodstock, CT	Quinebaug	41.96565	-71.96202	19.94	1979–83	4	4	STG	—
01125490	Little River at Harrisville, CT	Quinebaug	41.92760	-71.93007	35.73	1962–71	10	9	LTG	—
01125600	Mashamoquet Brook at Abington, CT	Quinebaug	41.87426	-72.00924	11.02	1962–63	1	1	STG	—
01126000	Fivemile River at Killingly, CT	Quinebaug	41.83732	-71.88535	57.91	1937–71	33	33	LTG	Some flow alteration
01126200	Bucks Horn Brook at Greene, RI	Quinebaug	41.69316	-71.74340	5.49	1965–74	9	8	LTG	—
01126500	Moosup River at Moosup, CT	Quinebaug	41.71038	-71.88591	83.32	1933–71	39	38	LTG	Some flow alteration
01126600	Blackwell Brook near Brooklyn, CT	Quinebaug	41.76538	-71.95646	16.97	1964–76	13	12	LTG	—
01126950	Pachaug River at Pachaug, CT	Quinebaug	41.58482	-71.93341	53.26	1962–73	12	10	LTG	Some flow alteration
<b>01175670</b>	<b>Sevenmile River near Spencer, MA</b>	Chicopee	42.26509	-72.00480	8.81	1960–p	45	45	Index and LTG	Occasional flow alteration by ponds upstream

<sup>1</sup>Drainage areas (in mi<sup>2</sup>) were determined with a GIS and do not supersede areas listed in the USGS NWIS database.

<sup>2</sup>Short-term streamgage not used in regression analyses.



**Figure 6.** Flow-duration curves at the streamgages Adamsville Brook at Adamsville, R.I. (01106000), and Beaver River near Usquepaug, R.I. (01117468).

Daily streamflow data were downloaded by using the USGS database software ADAPS (Automatic Data Processing System). The streamflow data were downloaded for complete climatic years during the period of record through water year 2006. The input streamflow data were formatted, managed, and displayed by using the USGS computer software programs Input and Output for a Watershed Data Management (IOWDM) file (Lumb and others, 1990) and ANNIE (Flynn and others, 1995). The computer program Surface Water Statistics (SWSTAT) (<http://water.usgs.gov/software/SWSTAT/>) (A.M. Lumb, W.O. Thomas, Jr., and K.M. Flynn, U.S. Geological Survey, written commun., 1997) was used to determine the annual low-flow frequency statistics for the USGS streamgages. SWSTAT ranks the seasonal and annual series of minimum mean n-day streamflows and then fits them to a log-Pearson Type III distribution. A resulting line of fit is then plotted through the values. The annual series were then checked for trends, but no trends were evident in the annual

7-day low flows at the long-term streamgages with more than 50 years of record. Some long-term streamgages with less than 50 years of record showed no clear trend, a slight upward trend over time, or a slight downward trend over time. The results were highly variable, and no clear trend could be identified for the annual 7-day low flows in Rhode Island. The estimated 7Q2 and 7Q10 flows for the long-term streamgages are presented in table 3. An example of the fit of the log-Pearson Type III distribution to the annual 7-day low flow is provided for the Branch River at Forestdale, R.I. (01111500), streamgage (fig. 7).

## Annual and Monthly Statistics

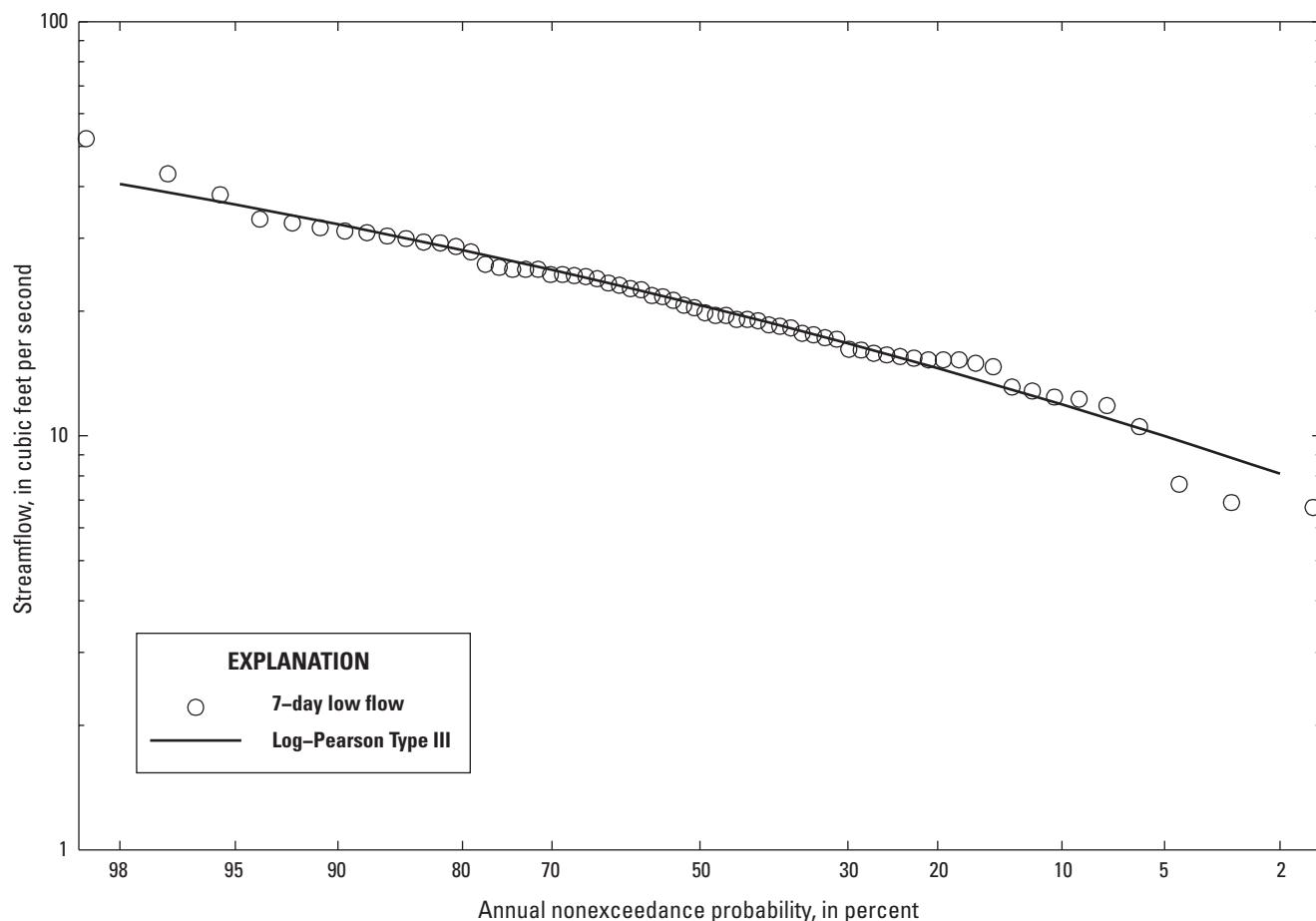
The streamflow statistics mean annual, mean monthly, and median monthly streamflows also were computed by using The Nature Conservancy (2007) computer program

**Table 2.** List of selected streamflow statistics computed for long- and short-term streamgages and partial-record stations in and near Rhode Island.

[Streamflow statistics for which regression equations are presented in this study are in bold and highlighted in light gray.]

Streamflow statistic	Streamflow statistic
<b>Flow duration</b>	<b>Low-flow frequency</b>
199.99	7Q2
199.95	7Q10
99.9	
99.5	
<b>99</b>	<b>Mean annual</b>
<b>98</b>	
97	
96	
<b>95</b>	<b>Mean monthly</b>
94	October
93	November
92	December
91	January
<b>90</b>	February
<b>85</b>	March
<b>80</b>	April
<b>75</b>	May
<b>70</b>	June
65	July
<b>60</b>	August
55	September
<b>50</b>	<b>Median monthly</b>
45	October
<b>40</b>	November
35	December
<b>30</b>	January
<b>25</b>	February
<b>20</b>	March
<b>15</b>	April
<b>10</b>	May
9	June
8	July
7	August
6	September
<b>5</b>	
4	
3	
<b>2</b>	
<b>1</b>	
0.5	
0.1	
<sup>1</sup> 0.05	
<sup>1</sup> 0.01	

<sup>1</sup>Could not be calculated for long- and short-term streamgages where there were less than 10,000 daily mean streamflow values available.



**Figure 7.** Example of the fit of the log-Pearson Type III distribution to the annual 7-day low flow at the streamgage Branch River at Forestdale, R.I. (01111500), for water years 1941–2006.

Indicators of Hydrologic Alteration (IHA). Data for 41 long-term streamgages (table 1 and fig. 2) were downloaded from NWISweb by using GNWISQ (Granato, 2009). Streamflow statistics were computed for 41 long-term streamgages with at least 8 or more complete water years of record (table 3). Eight years is the minimum length of record needed for obtaining this information. The longer a period of record for a streamgage, the more information that data can provide to the users, and the more any influence of extended wet or dry periods on the streamflow data tends to be minimized. Thus, for this study, the term “long-term streamgages” refers to those affected by little to no upstream flow alterations and with at least 8 years of record. The August median flow is an important statistical measure for fisheries and often is used for summer maintenance of aquatic habitat in New England streams (U.S. Fish and Wildlife Service, 1981).

## Flow Statistics for Long-Term Streamgages

Flow statistics for long-term streamgages are critical for understanding water resources in an area, especially for those streamgages whose upstream basins included few or no flow alterations. The records from these streamgages can provide information on the variability of annual, seasonal, and daily streamflows, potential trends, low flows, and peak flows. Those long-term streamgages affected the least by upstream flow alterations and with at least 10 years of record are referred to as index streamgages. The records from index streamgages were those records determined to be acceptable for use in extending the records for short-term streamgages and partial-record stations.

## Flow Statistics for Short-Term Streamgages and Partial-Record Stations

Estimates of streamflow often are needed for short-term streamgages, whose periods of record may not represent long-term hydrologic conditions, and for partial-record stations with only a limited number of streamflow measurements. Through correlation and streamflow-record extension techniques, streamflow statistics for the short-term streamgages and partial-record stations can be estimated. Estimates can be made on the basis of the relation between daily mean streamflows at the short-term streamgages and the concurrent daily mean streamflows at nearby index streamgages. For this study, only short-term streamgages (table 1 and fig. 2) and partial-record stations (table 4, in back of report and fig. 8) with little to no flow alteration and, respectively, at least 1 year of record and 10 streamflow measurements, in and near Rhode Island were used. For short-term streamgages and partial-record stations, daily mean streamflows and miscellaneous streamflow measurements, respectively, are related to the concurrent daily mean streamflows at nearby index streamgages. The index streamgage selected for the relation to a short-term streamgage or partial-record station is based on proximity, similarity of the physical, land-cover, land-use, surficial-deposits, and climatological characteristics between the two sites, and the linearity and Pearson's correlation coefficient ( $r$ ) of the relation between streamflows. For this study, the relation is defined by use of a streamflow-record extension technique known as the Maintenance of Variance Extension, type 1 (MOVE.1) (Hirsch, 1982).

The selection of index streamgages used for estimating streamflows at short-term streamgages and partial-record stations must satisfy several criteria: (1) the flow is essentially natural (very little to no alteration), (2) most or all of the period of record coincides with that for short-term streamgages and partial-record stations, and (3) the period of record is greater than 10 years. For this study, 16 long-term streamgages were identified as possible index streamgages (table 1 and fig. 2). Of the 16 index streamgages, 9 were located in Rhode Island, 3 in Connecticut, and 4 in Massachusetts. Only the Adamsville Brook at Adamsville, R.I. (01106000), streamgage is not currently (2014) operated. After this streamgage was discontinued in 1978, it was operated continuously for part of the 1987 water year, and concurrent streamflow measurements were made (on the same day) during water years 1992–93 and 2003–04 with streamflow measurements at nearby partial-record stations.

Scatterplots of log-transformed streamflow at each short-term streamgage and partial-record station in relation to concurrent log-transformed daily mean streamflow at each of the 16 index streamgages were made by using Microsoft Excel and the computer program SREF (Granato, 2009) to determine the nature and quality of the relations between the streamflows. For partial-record stations with zero-flow measurements, a value of 0.01 cubic feet per second ( $\text{ft}^3/\text{s}$ ) for the zero-flow measurement was used for computation of the

logarithms. Graphical plots of the relations of the data were evaluated to make sure they were linear. Generally, the relation with the highest correlation coefficient between the streamflows at the short-term streamgage or partial-record station and the index streamgage was used. For this study, the MOVE.1 technique (Hirsch, 1982) was then used to provide an equation that related streamflow at the short-term streamgage or partial-record station to the concurrent streamflow at the index streamgage. The MOVE.1 equation is

$$Y_i = Y + \frac{S_y}{S_x} (X_i - X) \quad (1)$$

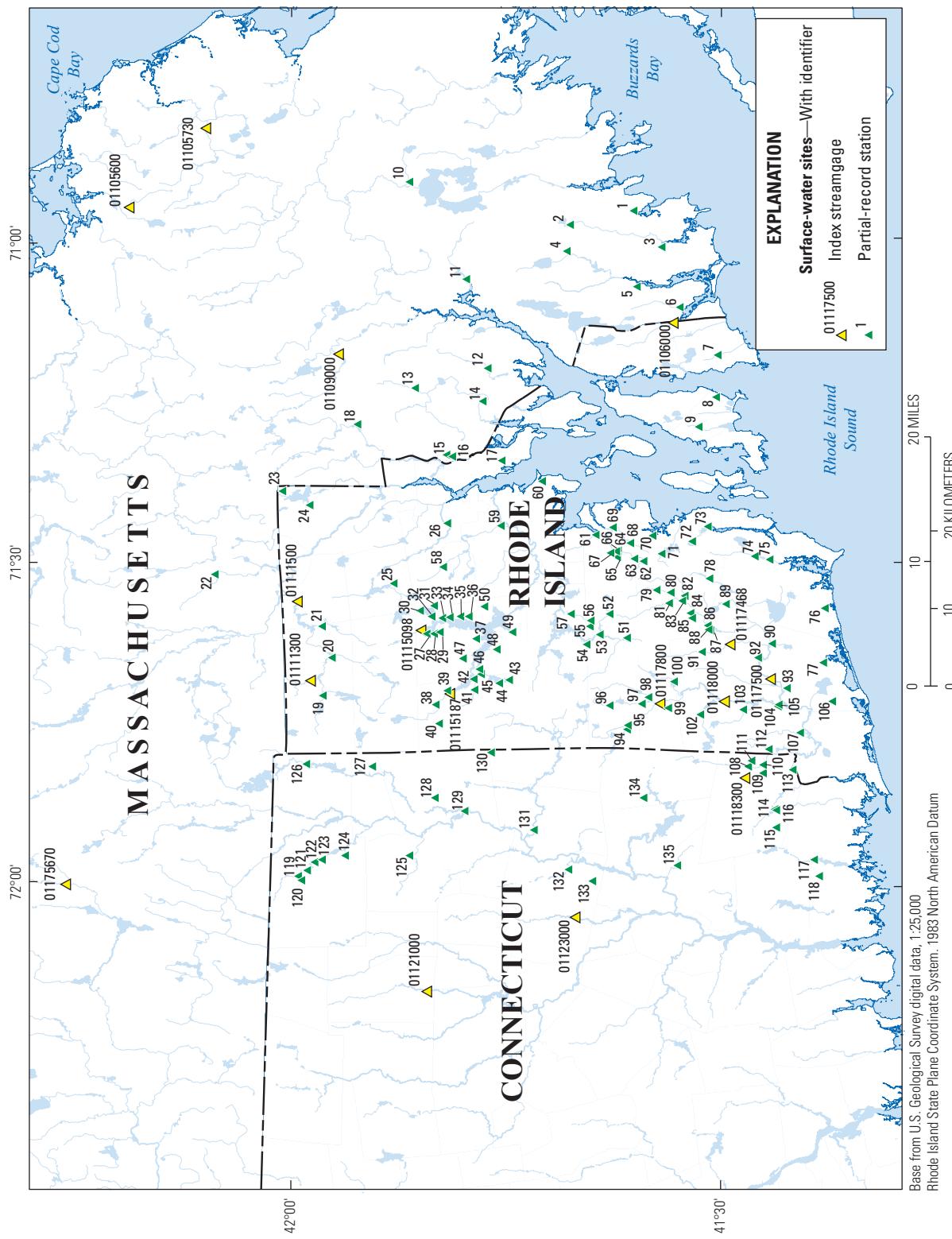
where

$Y_i$  is the streamflow or streamflow statistic at the short-term streamgage or partial-record station,  
 $X_i$  is the streamflow or streamflow statistic at the index streamgage,  
 $Y$  is the mean of the daily mean streamflows or streamflow measurements at the short-term streamgage or partial-record station, respectively,  
 $X$  is the mean of the concurrent daily mean streamflows at the index streamgage,  
 $S_y$  is the standard deviation of the daily mean streamflows or streamflow measurements at the short-term streamgage or partial-record station, respectively, and  
 $S_x$  is the standard deviation of the concurrent daily mean streamflows at the index streamgage.

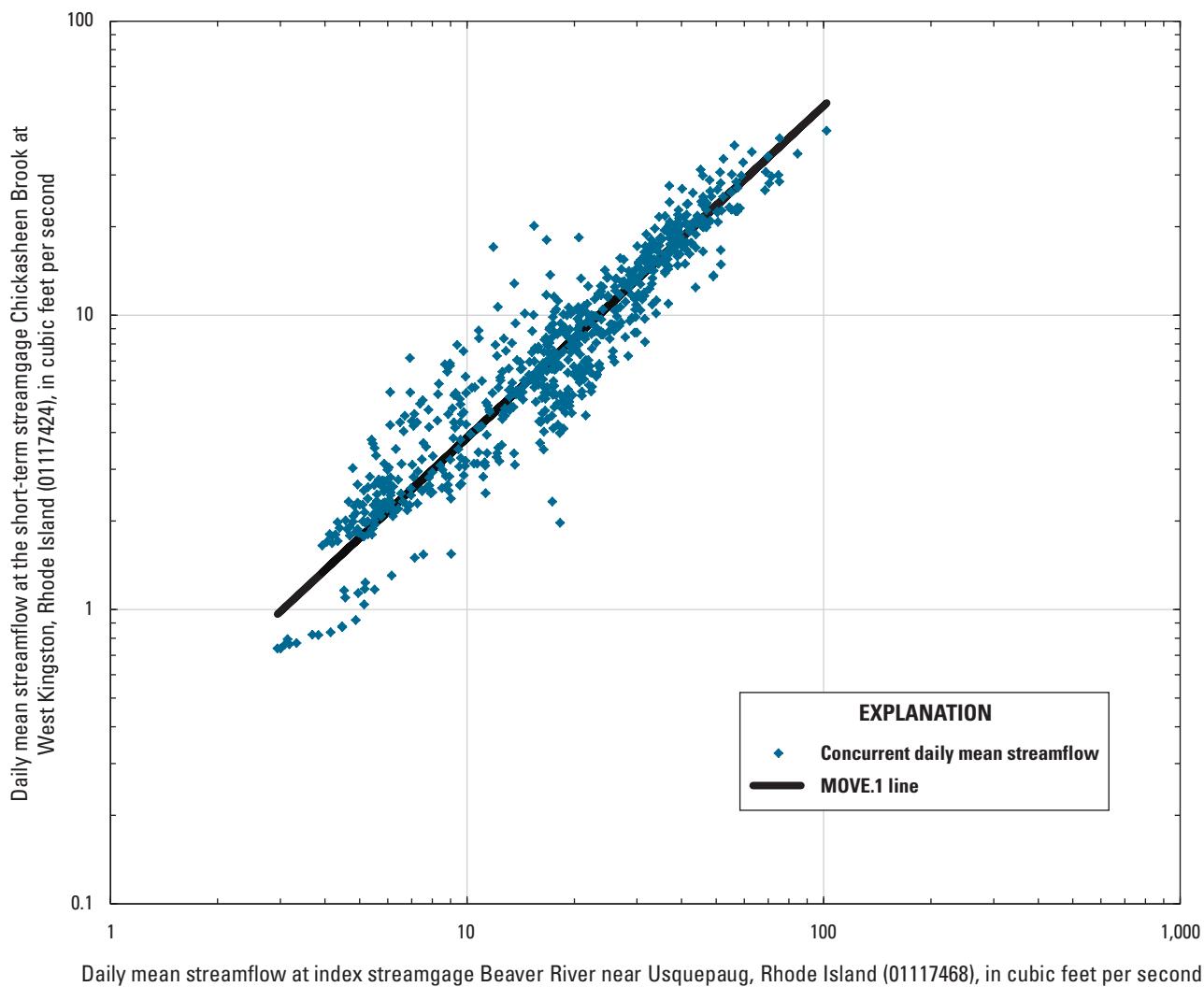
The streamflow data used in the MOVE.1 equation is base-10 log transformed, and the resulting streamflow ( $Y$ ) must then be re-transformed back to arithmetic units.

Examples of the MOVE.1 relation for the short-term streamgage Chickasheen Brook at West Kingston, R.I. (01117424), to the index streamgage Beaver River near Usquepaug, R.I. (01117468), and for the partial-record station Burnt Swamp Brook near Grant Mills, R.I. (01113670), to the index streamgage Wading River near Norton, Mass. (01109000), are shown in figures 9 and 10, respectively.

Streamflow statistics were estimated by using the MOVE.1 record-extension technique for 21 short-term streamgages (table 1 and fig. 2) and 135 partial-record stations in and near Rhode Island (table 4, in back of report and fig. 8). The index streamgage selected for estimating selected streamflow statistics at the short-term streamgage or partial-record station, the correlation coefficient describing that relation, and the number of data points used in the analyses are listed in table 5 (in back of report). Additionally, information about the relation between the sites, such as the minimum, maximum, and range of the flow duration(s) for which a daily mean streamflow at a short-term or streamflow measurement at a partial-record station were used in the analysis, also



**Figure 8.** Locations of the partial-record stations in and near Rhode Island. Partial-record station numbers are listed in table 4 (in back of report).



**Figure 9.** Example of Maintenance of Variance Extension, type 1 (MOVE.1), relation between concurrent daily mean streamflows at the short-term streamgage Chickasheen Brook at West Kingston, R.I. (01117424), and the index streamgage Beaver River near Usquepaug, R.I. (01117468).

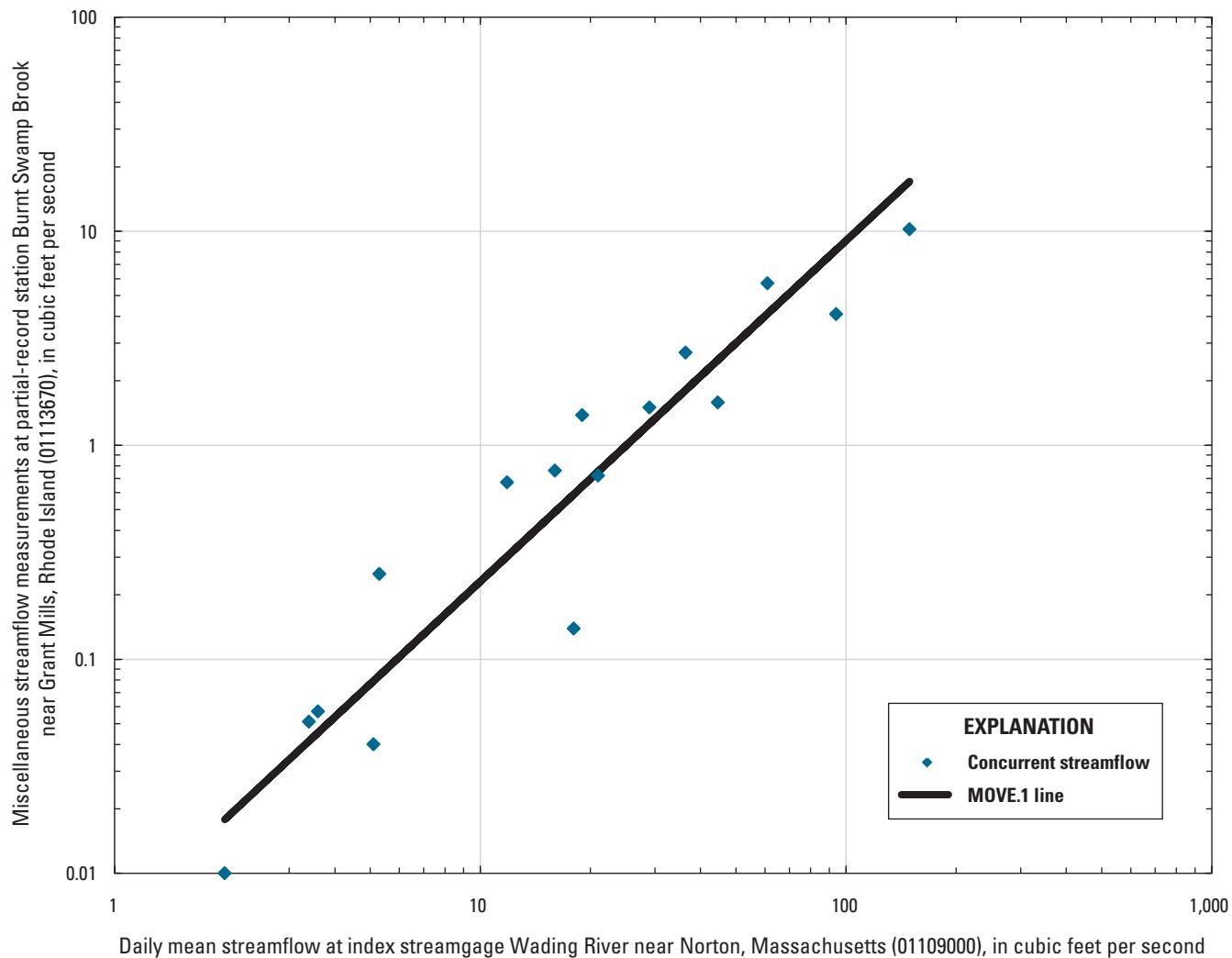
is presented in the table 5 (in back of report). Analyses for several partial-record stations in and near Rhode Island are not presented in the report because (1) the best correlation coefficients were less than 0.80; (2) the record had fewer than 10 streamflow measurements; (3) the streamflow measurements covered less than 50 percent of the range of the flow-duration curve; or (4) known alterations in the drainage basin could have affected streamflows. Results of the estimated streamflow statistics for 21 short-term streamgages and for 135 partial-record stations are in tables 3 and 6, respectively.

**Table 6.** Estimated streamflow statistics for partial-record stations in and near Rhode Island.

[Available separately at [http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010\\_bent\\_table06.xlsx](http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010_bent_table06.xlsx)]

## Basin Characteristics for Streamgages and Partial-Record Stations

The characteristics of streamflow are directly related to a drainage basin's physical, land-cover, land-use, geologic, and climatic characteristics. Characteristics of the drainage basin were selected for use as potential explanatory variables in the regression analysis on the basis of their theoretical relations to streamflows, the results of previous streamflow studies in similar hydrologic regions, and the feasibility of determining the basin characteristics with digital datasets and GIS technology. Measuring the basin characteristics with GIS technology facilitates automation of the process and the process of solving the regional regression equations by using the USGS StreamStats Web-based application.



**Figure 10.** Example of Maintenance of Variance Extension, type 1 (MOVE.1), relation between concurrent miscellaneous streamflow measurements at the partial-record station Burnt Swamp Brook near Grant Mills, R.I. (01113670), and daily mean streamflows at the index streamgage Wading River near Norton, Mass. (01109000).

The geospatial data layers for calculation of basin characteristics are as follows: (1) total length of streams data are from the National Hydrography Dataset (NHD) (U.S. Geological Survey, 2007a); (2) elevation data, also used for slope calculations, are from the National Elevation Dataset (NED) (U.S. Geological Survey, 2007b); (3) land-cover and land-use data are from Rhode Island Geographic Information System (RIGIS) (Rhode Island Geographic Information System, 2008a), the Massachusetts Office of Geographic Information (MassGIS) (Massachusetts Office of Geographic Information, 2009), and the University of Connecticut—Center for Land Use Education and Research (CLEAR) (University of Connecticut—Center for Land Use Education and Research, 2007a); (4) impervious-cover data are from RIGIS (Rhode Island Geographic Information System, 2008b), MassGIS (Massachusetts Office of Geographic Information, 2007a), and CLEAR (University of Connecticut—Center for

Land Use Education and Research, 2007b); (5) surficial-geology data (1:24,000 scale) are from RIGIS (Rhode Island Geographic Information System, 2007), MassGIS (Massachusetts Office of Geographic Information, 2007b), and the University of Connecticut—Map and Geographic Information Center (MAGIC) (University of Connecticut—Map and Geographic Information Center, 2007); (6) soil hydrologic group data are from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO) (Natural Resources Conservation Service, 2007); and (7) climatic (precipitation and temperature 1971–2000) are from the Parameter-Elevation Relationships on Independent Slopes Model (PRISM) Climate Group, Oregon State University (2007). The basin boundaries for the 41 long-term and 21 short-term streamgages and 135 partial-record stations were overlaid on areal coverages of the basin

characteristics of interest to determine the characteristics' values for the upstream basin to each site.

A GIS database was set up to store the characteristics of the drainage basins for the streamgages used in the regression analysis. The data layer from the NHD for total length of streams (U.S. Geological Survey, 2007a) was edited. Where a stream had more than one flow path (for example, around an island or in outlets from wetland areas), coverage was limited to only one flow path. Also, any stream segment shown crossing a basin boundary other than at the basin outlet was deleted so that all stream segments were within the basin boundary. This data layer for edited total length of streams was used with the basin characteristic data for drainage area (represented by the variable DRNAREA<sup>3</sup>) to determine the basin characteristic data for stream density (represented by the variable STRDENED<sup>3</sup>), which is the edited total length of streams divided by the drainage area. The names, units of measure, and sources of data for each measured basin characteristic are listed in table 7. The basin characteristics for long- and short-term streamgages and partial-record stations are in tables 8 and 9, respectively.

**Table 8.** Basin characteristics for long- and short-term streamgages in and near Rhode Island.

[Available separately at [http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010\\_bent\\_table08.xlsx](http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010_bent_table08.xlsx)]

**Table 9.** Basin characteristics for partial-record stations in and near Rhode Island.

[Available separately at [http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010\\_bent\\_table09.xlsx](http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010_bent_table09.xlsx)]

## Equations for Estimating Selected Streamflow Statistics

Streamflow information for ungaged sites is critical for Federal, state, county, city, and town agencies; nongovernmental and private organizations; and individuals and public groups dealing with water-resources issues. Flow-frequency and duration-streamflow statistics for streams at ungaged sites can be estimated by using several methods. These methods include (1) a drainage-area ratio and (2) a regression equation relating streamflow statistics to basin characteristics. Additionally, streamflow statistics may be estimated for an ungaged site with at least 10 miscellaneous streamflow measurements by the correlation of measured streamflows with concurrent daily mean streamflows at nearby continuous-record streamgages (index streamgages) followed by the streamflow-record-extension technique known as the Maintenance of Variance Extension, type 1 (MOVE.1) (Hirsch, 1982).

<sup>3</sup>USGS StreamStats basin-characteristics label ([http://streamstatsags.cr.usgs.gov/ss\\_defs/basin\\_char\\_defs.aspx](http://streamstatsags.cr.usgs.gov/ss_defs/basin_char_defs.aspx)).

## Drainage-Area Ratio Methods

The drainage-area ratio method is based on the assumption that the streamflow at an ungaged site is the same per unit drainage-basin area as that at a nearby hydrologically similar streamgage with little to no flow alteration of the upstream basin. Drainage areas to the ungaged site and the streamgage are determined from topographic maps or the USGS StreamStats web application (<http://streamstats.usgs.gov/index.html>). Streamflow statistics are computed for the streamgage, and then the statistics (streamflow values) are divided by the drainage area to determine the streamflow for each statistic per unit area in cubic feet per second per square mile (ft<sup>3</sup>/s/mi<sup>2</sup>) at the streamgage. These values are multiplied by the drainage area to the ungaged site to obtain estimated statistics for that site. This method is most commonly applied if the index streamgage is on the same stream as the ungaged site because the accuracy of the method depends on the proximity of the two sites, on similarities in drainage area, and on other physical and climatic characteristics of their drainage basins.

Several studies have provided estimates of the maximum difference in drainage areas for which the use of the drainage-area ratio method would generate more accurate estimates of streamflow statistics than the use of regression equations. Guidelines have been provided for estimating peak-flow statistics, and usually the recommendation has been that the drainage area to the ungaged site should be 0.5 to 1.5 times the drainage area to the index streamgage (Choquette, 1988, p. 41; Koltun and Roberts, 1990, p. 6; Lumia, 1991, p. 34; Bisese, 1995, p. 13; Koltun and Whitehead, 2002, p. 22; and Martin and Arihood, 2010, p. 28). One report (Koltun and Schwartz, 1987, p. 32) recommended a narrower range of 0.85 to 1.15 times the drainage area of the index streamgage for estimating low flows at ungaged sites in Ohio. Ries and Friesz (2000), however, determined that the drainage-area ratio method could be used to estimate low-flow statistics for ungaged sites in Massachusetts if the drainage area for an ungaged site was between 0.3 and 1.5 times the drainage area of the index streamgage site. They found that this method was generally as accurate as or more accurate than regression equations for this range of drainage areas.

In the drainage-area ratio method, the streamflow values are transferred from a streamgage to the ungaged site by the following formula:

$$Q_u = Q_g \times \left( \frac{DRNAREA_u}{DRgNAREA_g} \right) \quad (2)$$

where

$Q_u$  is the estimated streamflow at the ungaged site,

$Q_g$  is the streamflow at the streamgage,

$DRNAREA_u$  is the drainage area at the ungaged site, and

$DRNAREA_g$  is the drainage area at the streamgage.

**Table 7.** List of basin characteristics determined for long- and short-term streamgages and partial-record stations in and near Rhode Island.

[The geospatial datalayers for calculation of basin characteristics are as follows: total length of streams data are from an edited version of the National Hydrography Dataset (U.S. Geological Survey, 2007a); elevation data, also used for slope calculations, are from the National Elevation Dataset (NED) (U.S. Geological Survey, 2007b); land-cover and land-use data (2003/2004) are from the Rhode Island Geographic Information System (RIGIS) (Rhode Island Geographic Information System, 2008a), the Massachusetts Office of Geographic Information (MassGIS) (Massachusetts Office of Geographic Information, 2009), and the University of Connecticut Center for Land Use Education and Research (CLEAR) (University of Connecticut Center for Land Use Education and Research, 2007a); impervious-cover data are from RIGIS (Rhode Island Geographic Information Systems, 2008b), MassGIS (Massachusetts Geographic Information System, 2007a), and CLEAR (University of Connecticut Center for Land Use Education and Research, 2007b); surficial-geology data (1:24,000 scale) are from RIGIS (Rhode Island Geographic Information System, 2007), MassGIS (Massachusetts Office of Geographic Information, 2007b), and the University of Connecticut Map and Geographic Information Center (MAGIC) (University of Connecticut Map and Geographic Information Center, 2007); soil hydrologic group data are from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO) (Natural Resources Conservation Service, 2007); and climatic data (precipitation and temperature 1971–2000) are from the Parameter-Elevation Relationships on Independent Slopes Model (PRISM) Climate Group, Oregon State University (2007). NAVD 88, North American Vertical Datum of 1988; NAD 83, North American Datum of 1983]

#### Physical characteristics

Drainage area (DRNAREA <sup>1</sup> ), in square miles
Basin perimeter, in miles
Total length of streams, in miles
Stream density (STRDENED <sup>1</sup> ) (total length of streams divided by drainage area), in miles per square mile
Stream slope between 10 and 85 percent of the main channel river length, in percent
Mean basin slope, in percent
Maximum basin elevation, in feet relative to NAVD 88
Minimum basin elevation, in feet relative to NAVD 88
Mean basin elevation, in feet relative to NAVD 88
Basin relief (maximum minus minimum basin elevation), in feet
Basin outlet elevation, in feet relative to NAVD 88
Basin centroid location—easting, state plane feet, relative to NAD 83
Basin centroid location—northing, state plane feet, relative to NAD 83
Basin outlet location—easting, state plane feet, relative to NAD 83
Basin outlet location—northing, state plane feet, relative to NAD 83

#### Areal proportions of land-cover, land-use, and surficial-deposits characteristics

Forested land, in percent
Agricultural land, in percent
Water bodies, in percent
Forested wetlands, in percent
Nonforested wetlands, in percent
Total wetlands (forested and nonforested), in percent
Impervious land, in percent
Urban land (high-density residential, commercial, industrial, and transportation land use), in percent
Sand and gravel deposits, in percent
NRCS SSURGO soil hydrologic groups A, B, C, and D, in percent

#### Climatological characteristics

PRISM Precipitation 1971–2000, drainage-basin average for mean annual, in inches
PRISM Temperature 1971–2000, drainage-basin average for mean annual maximum, in degrees Celsius

<sup>1</sup>USGS Streamstats basin characteristics label ([http://streamstatsags.cr.usgs.gov/ss\\_defs/basin\\_char\\_defs.aspx](http://streamstatsags.cr.usgs.gov/ss_defs/basin_char_defs.aspx)).

Eash and Barnes (2012) did a comparison of estimates of the 7-day 10-year low flow by using regional regression equations, the drainage-area ratio method, and the weighted drainage-area ratio method to estimates from streamflow records for 48 streamgages (31 pairs of streamgages) on the same rivers in Iowa. They found that the weighted drainage-area ratio provided the best estimate if the drainage area to the ungaged site was between 0.4 and 1.5 times the drainage area to the streamgage.

In the weighted drainage-area ratio method, the streamflow values are transferred from a streamgage to the ungaged site by using the following formula:

$$Q_{uw} = Q_{ur} \times \left( \left( \frac{Q_{gs}}{Q_{gr}} \right) - \left( \frac{2 \times |DRNAREA| \times \left( \left( \frac{Q_{gs}}{Q_{gr}} \right) - 1 \right)}{DRNAREA_g} \right) \right) \quad (3)$$

where

- $Q_{uw}$  is the weighted estimated streamflow at the ungaged site,
- $Q_{ur}$  is the streamflow at the ungaged site estimated from the regression equation,
- $Q_{gs}$  is the streamflow at the streamgage estimated from measured data,
- $Q_{gr}$  is the streamflow at the streamgage estimated from the regression equation,
- $|DRNAREA|$  is the absolute value of the difference between the drainage areas to the streamgage ( $DRNAREA_g$ ) and the ungaged site ( $DRNAREA_u$ ),
- $DRNAREA_g$  is the drainage area to the streamgage, and
- $DRNAREA_u$  is the drainage area to the ungaged site.

As  $\frac{Q_{gs}}{Q_{gr}}$  approaches 1, or the difference in drainage areas approaches 50 percent, the weighting factor approaches 1 and no longer has an effect on the regression equation estimate for the ungaged site. Additionally, both the drainage-area and weighted drainage-area ratio methods may not be applicable for ungaged sites where changes in the physical, land-cover, land-use, surficial-deposits, or climatological characteristics or alterations to streamflows between the ungaged site and the streamgage are substantial. The error associated with estimates based on the drainage-area and weighted drainage-area ratio methods can not be calculated.

## Regional Regression Analyses

Studies to develop regional regression equations for estimating streamflow statistics at ungaged sites have been done in many states throughout the U.S. and specifically in

the states adjacent to Massachusetts. Multiple regression analyses provide a mathematical equation for estimating a response (dependent) variable—streamflow statistic—from one or more explanatory (independent) variable(s), such as basin characteristics. Ideally, the development of regression equations involves the use of streamflow data from a large number of long-term streamgages on unaltered streams evenly distributed across the region of interest and with a range of basin characteristics. But in many cases, the number of streamgages representing unaltered flow is limited, the streamgage network is often biased toward representing larger streams or rivers, the network is unevenly distributed geographically, and the range of basin characteristics upstream of streamgages does not cover the complete range found in the region. In Rhode Island, the number of streamgages on streams with little to no flow alteration is limited; for this reason, nearby streamgages in eastern Connecticut and southeastern and south-central Massachusetts were also included. The records for these streamgages were used to develop regional regression equations for estimating selected streamflow statistics at ungaged sites in Rhode Island.

Multiple regression is used to create equations that relate streamflow statistics for streamgages to the physical, land-cover, land-use, surficial-deposit, and climatological characteristics of their upstream drainage areas. Once an optimal equation has been determined, a streamflow statistic at a nearby ungaged site in a basin with similar characteristics can then be estimated by applying the equation to the ungaged site.

The basic equation describing a linear multiple regression analysis is

$$Y_i = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_n X_n + e_i \quad (4)$$

where

- $Y_i$  is the response (dependent) variable (estimated streamflow statistic) for the ungaged site  $i$ ,
- $b_0$  to  $b_n$  are the coefficients determined in the analysis,
- $X_i$  to  $X_n$  are the explanatory (independent) variables (basin characteristics) for the ungaged site  $i$ , and
- $e_i$  is the residual error or difference between the observed and estimated response variables for ungaged site  $i$ .

Linear regression analysis is based on the following assumptions: (1) the mean of the residuals ( $e_i$ ) is zero, (2) the variance of the residuals is constant, (3) the residuals are normally distributed, and (4) the residuals are independent of each other. In addition to these assumptions, the selected explanatory variables ( $X$ ) should have a physical basis as predictors of the streamflow statistic, the explanatory variables (basin characteristics) in the equation should not be highly correlated with each other, and the signs of the terms of the equation should make hydrological sense. For example, the variable drainage area should have a positive coefficient because an

increase in drainage area should result in an increase in the value of the streamflow statistic.

In almost all regionalization studies to determine low-flow and peak-flow statistics, the response and explanatory variable datasets are skewed. As a consequence, the data need to be transformed to ensure that the mean of the residuals equals zero. In many studies, a logarithmic transformation is used. A base10 log-transformed multiple regression equation has the form

$$\log Y_i = b_0 + b_1 \log X_1 + b_2 \log X_2 + \dots + b_n \log X_n + e_i \quad (5)$$

After the coefficients have been determined through regression analysis, the equation is transformed back to its original units in a form that can be used to estimate a specific streamflow statistic at an ungaged site. The retransformed equation has the following form:

$$Y_i = 10^{b_0} + X_1^{b_1} + X_2^{b_2} + \dots + X_n^{b_n} + 10^{e_i} \quad (6)$$

A linear regression equation provides an unbiased estimate of the mean response of the response variable. Although estimates provided by equation 5 are unbiased, these estimates are in log units, whereas estimates in the original units are needed to calculate specific streamflow statistics at an ungaged site. Estimates from equation 6 are in the original units. However, this equation predicts the median, instead of the mean, value of the response variable. A streamflow statistic based on a median creates an estimate that is biased and tends to be lower than the mean (Ries and Friesz, 2000). Bias correction factors (BCFs) were used in some studies in Massachusetts and New Hampshire to remove the bias from the estimate (Ries, 1994a and b; Ries and Friesz, 2000; Flynn, 2003a and b, and Archfield and others, 2010). In other studies (Risley, 1994; Stuckey, 2006; Armstrong and others, 2008; and Ahearn, 2010), BCFs were not used, likely because they were generally very small. In this study, BCFs were also not used, because if they were, then the streamflows estimated from the regression equations would not have an equal chance of being higher or lower than their actual values (Julie Kiang, U.S. Geological Survey, oral commun., 2011).

## Development of Regression Equations

In regional regression studies, explanatory and response variables often need to be transformed before the regression equation is created to ensure a linear relation. Scatterplots, correlation tables, and linear regression analyses were done by applying the statistical software Minitab (2003) to the selected streamflow statistics at long-term and short-term streamgages (table 3) and the basin characteristics (table 8) to determine if variable transformations were needed. The scatterplots indicated that a log transformation was needed to meet the assumptions of linear regression. Thus, the logarithmic (base-10) transformation was selected and applied to

streamflow statistics (response variables) and basin characteristics (explanatory variables) to linearize the relation between the explanatory variables and the response variables, to ensure equal variance about the regression line, and to decrease the spread of the data.

Several potential explanatory variables (basin characteristics) for the drainage basin upstream of a few streamgages had one or a few values of zero. The variables were generally limited to land-cover, land-use or surficial deposits characteristics of the drainage basin, such as forested land, water bodies, wetlands, impervious land, and sand and gravel deposits. To logarithmically (base-10) transform all the values of that basin characteristic, a constant value of 0.01, 0.10, or 1.00 (depending on the lowest values other than the zero values) was added to all values of that basin characteristic.

Scatterplots of logarithmic (base-10) transformed basin characteristics were then examined to determine if particular characteristics were correlated with other characteristics (*r*) (table 10). If two basin characteristics were found to have a moderate or strong correlation (an absolute value of Pearson's *r* greater than or equal to 0.50), then those basin characteristics were tested separately in the variable-selection process of the regression analyses. This separate testing was done to eliminate redundant basin characteristics in the variable-selection process. For example, the basin characteristics denoted as "drainage area" and "total length of streams" had very strong correlations of *r*=0.98 and higher (table 10). For this reason, these basin characteristics were tested separately in the variable-selection process.

**Table 10.** Pearson's correlation coefficients for basin characteristics evaluated as potential explanatory variables for regression equations for estimating selected streamflow statistics for long- and short-term streamgages in Rhode Island.

[Available separately at [http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010\\_bent\\_table10.xlsx](http://pubs.usgs.gov/sir/2014/5010/tables/sir2014-5010_bent_table10.xlsx)]

For the initial regression analyses of the selected potential explanatory variables, the automated statistical procedures called "best subsets" and "stepwise" were used in Minitab (2003). Both selection procedures determined the statistical contribution that was entered in the equation for each of the explanatory variables (basin characteristics), and variables were retained or deleted based on their statistical importance.

In the procedure "best subsets" (Minitab, 2003), the two equations with the highest coefficients of determination (*R*<sup>2</sup>), the Mallow's *Cp* closest to the number of explanatory variables plus the constant 1, and the lowest root mean square errors were evaluated for each of the possible combinations of selected explanatory variables to determine the best possible combinations of the explanatory variables. The procedure identified the best two combinations of explanatory variables for models with a specified number of explanatory variables. With this procedure, each explanatory variable can be included or excluded independently of the other explanatory variables.

Efroymson's stepwise selection procedure (Efroymson, 1960), is similar to forward selection, which involves testing explanatory variables one by one and including them in the equation if they are statistically significant; however, as each new variable is added to the subset, partial correlations are considered to determine whether any of the variables in the subset should be dropped. In the procedure "stepwise" (Minitab, 2003), the procedure essentially outputs the best potential combination of explanatory variables (which have  $T$ -statistic values whose absolute values are greater than or equal to 2.00 and  $p$ -values less than or equal to 0.05) for models with increasing numbers of explanatory variables until no additional variables meet the criteria for  $T$ -statistic values and  $p$ -values. Additionally for each model,  $R^2$ , Mallow's  $C_p$ , and  $s$  (root mean square error) are presented to assist in evaluation of the models. In these analyses, basin characteristics that were found to be highly correlated (absolute value of  $r$  greater than or equal to 0.50) were entered only one at a time during the "best subsets" and "stepwise" procedures to prevent regression problems.

If the two "best subsets" and "stepwise" procedures identified the same set of basin characteristics, then the top few potential explanatory variables were further evaluated with the ordinary-least-squares (OLS) regression procedure. For the explanatory variables, the  $p$ -value,  $T$ -statistic value, and VIF (variance inflation factor) statistics were evaluated. For the model output parameters  $R^2$ ,  $s$ , PRESS statistic, unusual observations (large standard residuals and (or)  $X$  values with large influence), and the Durbin-Watson statistic were evaluated. The histogram, normal probability, and graphs of the residuals as functions of the fitted values and the order of the data also were evaluated. Additionally, the statistic named "high influence," the Cook's Distance statistic, and the DFITS statistic were evaluated.

After the evaluation of selected streamflow statistics estimated for the short-term streamgages (table 3) and partial-record stations (table 6), only the short-term streamgages were selected for inclusion with the 41 long-term streamgages for the regression analysis. Two of the 21 short-term streamgages were not included in the regression analyses because the record for another streamgage nearby on the same river was longer, and the drainage areas and basin characteristics of the two streamgages were similar. Exclusion of these two streamgages removed redundancy of those streamflow statistics and basin characteristics in the regression analyses. The two short-term streamgages excluded were Chepachet River near Gazzaville, R.I. (01111410), and Beaver River at Shannock Hill Road near Shannock, R.I. (01117471) (fig. 2).

The partial-record stations were not included in the regression analyses because of several factors:

1. The 135 partial-record stations had from 11 to 87 streamflow measurements for use in the MOVE.1 relation with an index streamgage for estimating long-term streamflow statistics, whereas a 1-year of continuous record at a streamgage would provide 365 daily mean streamflow

values for use in the MOVE.1 relation with an index streamgage for estimating long-term statistics.

2. Weighting procedures for partial-record stations have differed among previous studies. For example, Stuckey (2006) assigned 1 year of record to partial-record stations for every year when a streamflow measurement was made, whereas Ahearn (2010) assigned 5 years of record to partial-record stations for every year when a measurement was made. Either of these weighting procedures could result in more years of record for a partial-record station than for a short-term streamgage which was operated for 1 or more years. If the number of streamflow measurements for a partial-record station were divided by 365 days, the partial-record station would have so little weight that its effect in the regression analyses would be negligible.
3. Boxplots of selected basin characteristics for partial-record stations were compared with boxplots for the long-term and short-term streamgages, and the comparison showed that the partial records did not expand the range of the basin characteristics.
4. The computer program entitled "Displaying Redundant Partial Record Sites—drprs" (Charles Berenbrock and Ken Eng, U.S. Geological Survey, written commun., 2009) was used to evaluate the data from the partial-record stations for possible use in the regional regression analyses. Results showed that the range between the minimum and maximum values for the basin characteristics were adequately covered by data from the long- and short-term streamgages. Additionally, the program showed that there were no areal gaps within the study area that could have been covered by the partial-record stations.
5. The regression equations might be overly influenced by estimated streamflow statistics from a large number of partial-record stations with small drainage areas.
6. The streamflow statistics for the index streamgages are already included in the regression analyses, and they also were used to estimate the long-term streamflow statistics for the short-term streamgages that are also included in the analyses.

## Weighting Procedures

For flow-duration statistics, a weighted procedure similar to that used by Ahearn (2010) in Connecticut and Stuckey (2006) in Pennsylvania was used. The weight factor for the record of each streamgage used in the regression analyses was increased in proportion to the length of the record. The weight was assigned by multiplying the number of years in the period of record by the total number of streamgages in the study and dividing the product by the total number of years of record for all streamgages in the study. For example, the weight for

the short-term streamgage Ashaway River at Ashaway, R.I. (01118360), with the equivalent of 2 years of record would be 0.0882 [(2 years  $\times$  60 streamgages)  $\div$  (1,361 total years)], whereas the weight for Adamsville Brook at Adamsville, R.I. (01106000), with the equivalent of 38 years of record would be 1.6752 [(38 years  $\times$  60 streamgages)  $\div$  (1,361 total years)].

## Final Regression Equations

The response variables (flow duration and low-flow-frequency statistics) included some zero flows for the lower flow statistics at some streamgages. Of the 60 streamgages' statistics used in the regression analyses, 4 had zero flow at the 7Q10, and 99- and 98-percent flow durations. Two streamgages also had zero flow at the 7Q2 and 95-percent flow duration (table 3). The value of zero cannot be logarithmically transformed, but logarithmic transformation of streamflow statistics (that are not normally distributed) is needed to develop regression equations.

The method of handling the zero values in a regression analysis depends on the number of streamgages in the dataset with response variables equal to zero. If the number is sufficient, logistic regression or a Tobit model can be used (Tasker, 1989; Ludwig and Tasker, 1993; Kroll and Stedinger, 1999; Horthess, 2006). If the number is small, left-censored regression analysis, which uses an adjusted maximum-likelihood estimation (Cohn, 1988, and Helsel, 2005) or a method that adds a small constant value (0.01, 0.10, and 1.00) to all response variables in a dataset, is used (Kroll and Stedinger, 1999).

Given the small number of streamgage in this study with zero-flow statistics for the 7Q10 and 7Q2 and 99-, 98-, and 95-percent flow durations, left-censored regression analyses were used to develop the regression equations for these streamflow statistics. The left-censored regression analyses were done by using USGS library S-Plus for Windows (Lorenz and others, 2011) in the program TIBCO Spotfire S-Plus (TIBCO Software, Inc., 2008). This procedure in S-Plus uses the adjusted maximum-likelihood estimation, which is recommended for data that is log-normally distributed. The adjusted maximum-likelihood estimation is described by Cohn (1988) and Helsel (2005).

For the flow-duration statistics 90-, 85-, 80-, 75-, 70-, 60-, 50-, 40-, 30-, 25-, 20-, 15-, 10-, 5-, 2-, and 1-percent, the final regression equations were developed by using the user-weighted least-squares (WLS) regression technique in the weighted-multiple-linear regression (WREG) program (Eng and others, 2009).

The regression analyses determined that drainage area (represented by the variable DRNAREA) ( $\text{mi}^2$ ) was a significant explanatory variable in all 21 of the regression equations. Drainage area generally is the most significant explanatory variable in all regional streamflow regression equations, whether for low flows, peak flows, mean annual, mean monthly, or median monthly statistics. The final regression equations for the 21 streamflow statistics are listed in table 11.

Stream density (STRDENSE) ( $\text{mi}/\text{mi}^2$ ), which is the total length of streams (mi) divided by the drainage area ( $\text{mi}^2$ ), also was a significant explanatory variable in all but 3 of the 21 regression equations. The three streamflow statistics for which STRDENSE was not significant were the 20-, 15-, and 10-percent flow durations. Stream density is less commonly a significant explanatory variable than drainage area but has been used in low-flow regression equations for a region of Pennsylvania (Stuckey, 2006), logistic regression equations for estimating the probability of a stream flowing perennially in Massachusetts (Bent and Archfield, 2002), and peak-flow equations for Rhode Island (Zarriello and others, 2012).

Stream density had a negative coefficient in several regression equations for estimating low flows in Pennsylvania (Stuckey, 2006) and in the logistic regression equation for estimating the probability of streams flowing perennially in Massachusetts (Bent and Archfield, 2002). Zarriello and others (2012) found stream density to have a positive coefficient in the regression equations for estimating peak flows in Rhode Island. The coefficient for STRDENSE in this study changed from negative in the low-flow regression equations to positive in the high-flow equations. For example, the coefficient for STRDENSE decreased from -2.29 in the equation for the 99-percent flow duration to -0.18 in the equation for the 25-percent flow duration, and then increased from +0.18 at the 5-percent flow duration to +0.49 at the 1-percent flow duration (table 11). At high-flow durations, a greater stream density allows runoff to be quickly routed out of the basin (less water being available during lower flows) through its larger network of flow paths; the increasing streamflow is represented by the positive coefficient. STRDENSE is not a significant explanatory variable between the 20- and 10-percent flow durations because the coefficient is changing from positive to negative; as a result, its effect on streamflow is minimal. At low-flow durations, a greater stream density in a basin allows base flow to be routed out of the basin earlier in the runoff recession (less base flow being available during lower flows) through its larger network of flow paths intercepting the water table; the decreasing streamflow is represented by the negative coefficient.

The standard error of the estimate for the 21 regression equations ranged from 17.58 to 141.83 percent (table 11). The low-flow statistics—the 99- to 85-percent flow durations and 7Q2 and 7Q10—had higher standard errors of the estimate, ranging from 48.68 to 141.83 percent. The standard error of the estimate for the medium- to high-flow statistics—the 80- to 1-percent flow durations—ranged from 17.58 to 37.65 percent, with the standard errors for the 60- to 1-percent flow durations all being less than about 21 percent. Although the standard errors of the estimate are high for the low-flow statistics, they are similar to those calculated for regional regression equations developed to estimate low-flow statistics in Connecticut (Ahearn, 2010) and Massachusetts (Ries and Friesz, 2000). Additionally, high standard errors of the estimate for low-flow equations are common in statewide studies throughout the U.S. The user-WLS regression

**Table 11.** Summary of regression equations and measures of model accuracy for estimating selected streamflow statistics in Rhode Island.

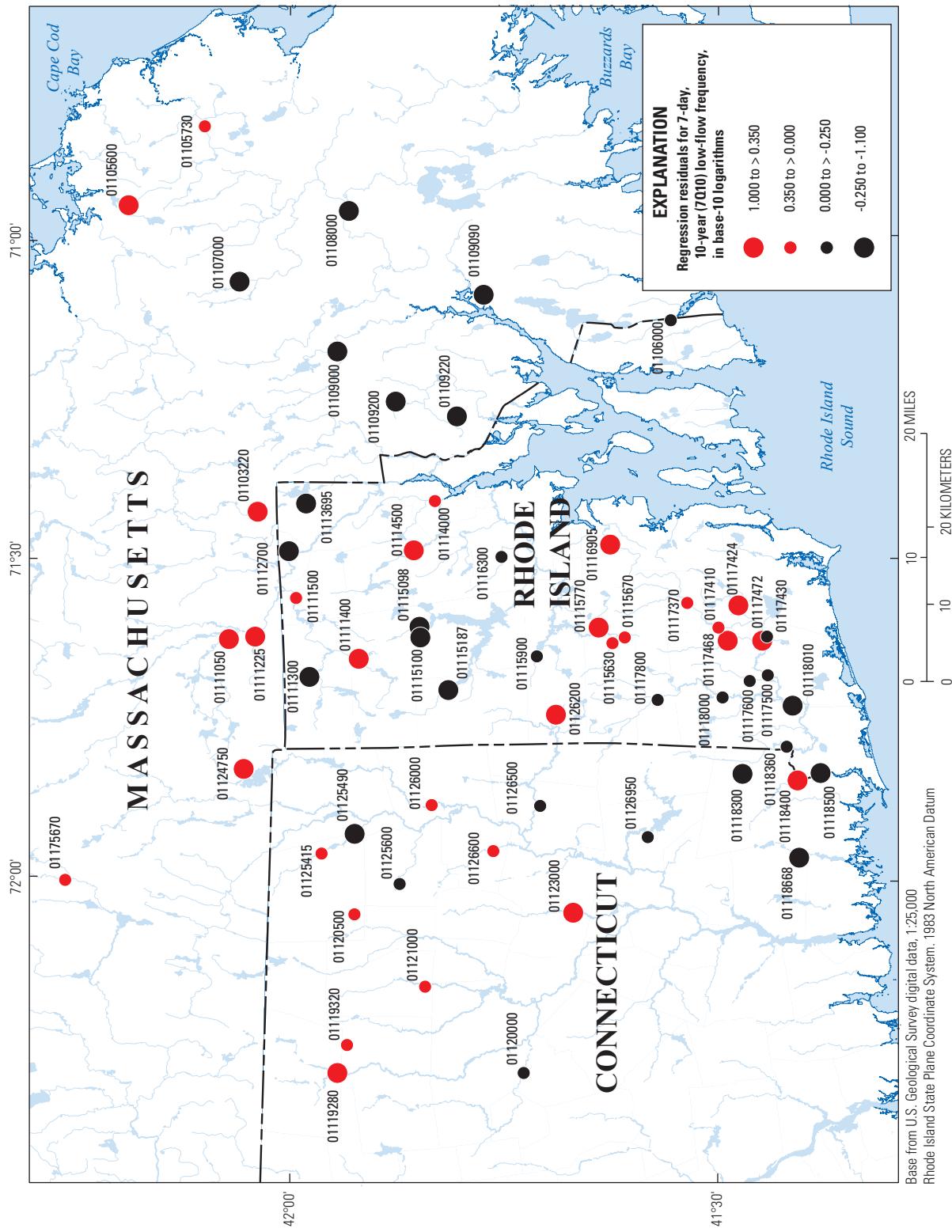
[DRNAREA, drainage area in square miles; STRDENED, drainage density in miles per square mile; WLS, weighted-least-squares regression; WREG, weighted-multiple-linear regression (Eng and others, 2009); S+, statistical software program in S programming language (TIBCO Software, Inc., 2008); --, no data available]

Stream-flow statistic	Regression equation	Number of stations	Standard error of the estimate (base-10 logarithm)	Standard error of the estimate (percent)	Standard error of prediction (base-10 logarithm)	Standard error of prediction (percent)	Regression method
Flow duration							
1	$9.3325(\text{DRNAREA})^{0.94}(\text{STRDENED})^{0.49}$	60	0.0909	21.15	0.0915	21.31	User WLS–WREG
2	$7.4131(\text{DRNAREA})^{0.96}(\text{STRDENED})^{0.36}$	60	0.0820	19.06	0.0827	19.21	User WLS–WREG
5	$5.4954(\text{DRNAREA})^{0.98}(\text{STRDENED})^{0.18}$	60	0.0840	19.52	0.0846	19.67	User WLS–WREG
10	$4.3652(\text{DRNAREA})^{1.00}$	60	0.0758	17.58	0.0762	17.67	User WLS–WREG
15	$3.4674(\text{DRNAREA})^{1.01}$	60	0.0766	17.78	0.0770	17.87	User WLS–WREG
20	$2.7542(\text{DRNAREA})^{1.02}$	60	0.0785	18.22	0.0789	18.32	User WLS–WREG
25	$2.6915(\text{DRNAREA})^{1.03}(\text{STRDENED})^{-0.18}$	60	0.0768	17.83	0.0774	17.96	User WLS–WREG
30	$2.3442(\text{DRNAREA})^{1.04}(\text{STRDENED})^{-0.23}$	60	0.0789	18.31	0.0795	18.45	User WLS–WREG
40	$1.8621(\text{DRNAREA})^{1.05}(\text{STRDENED})^{-0.29}$	60	0.0778	18.07	0.0784	18.20	User WLS–WREG
50	$1.4791(\text{DRNAREA})^{1.05}(\text{STRDENED})^{-0.39}$	60	0.0803	18.65	0.0809	18.79	User WLS–WREG
60	$1.0715(\text{DRNAREA})^{1.07}(\text{STRDENED})^{-0.50}$	60	0.0887	20.65	0.0894	20.80	User WLS–WREG
70	$0.6761(\text{DRNAREA})^{1.13}(\text{STRDENED})^{-0.68}$	60	0.1080	25.25	0.1088	25.44	User WLS–WREG
75	$0.5248(\text{DRNAREA})^{1.17}(\text{STRDENED})^{-0.84}$	60	0.1304	30.72	0.1314	30.96	User WLS–WREG
80	$0.4074(\text{DRNAREA})^{1.21}(\text{STRDENED})^{-1.01}$	60	0.1581	37.65	0.1593	37.95	User WLS–WREG
85	$0.2951(\text{DRNAREA})^{1.26}(\text{STRDENED})^{-1.18}$	60	0.2003	48.68	0.2025	49.27	User WLS–WREG
90	$0.1995(\text{DRNAREA})^{1.35}(\text{STRDENED})^{-1.48}$	60	0.2894	74.76	0.2915	75.45	User WLS–WREG
95	$0.1006(\text{DRNAREA})^{1.48}(\text{STRDENED})^{-1.80}$	60	0.3659	101.67	--	--	Left censored–S+
98	$0.0591(\text{DRNAREA})^{1.58}(\text{STRDENED})^{-2.08}$	60	0.4018	116.35	--	--	Left censored–S+
99	$0.0441(\text{DRNAREA})^{1.64}(\text{STRDENED})^{-2.29}$	60	0.4560	141.83	--	--	Left censored–S+
Low-flow frequency							
7Q2	$0.1104(\text{DRNAREA})^{1.48}(\text{STRDENED})^{-1.91}$	60	0.3918	112.10	--	--	Left censored–S+
7Q10	$0.0311(\text{DRNAREA})^{1.71}(\text{STRDENED})^{-2.53}$	60	0.4537	140.65	--	--	Left censored–S+

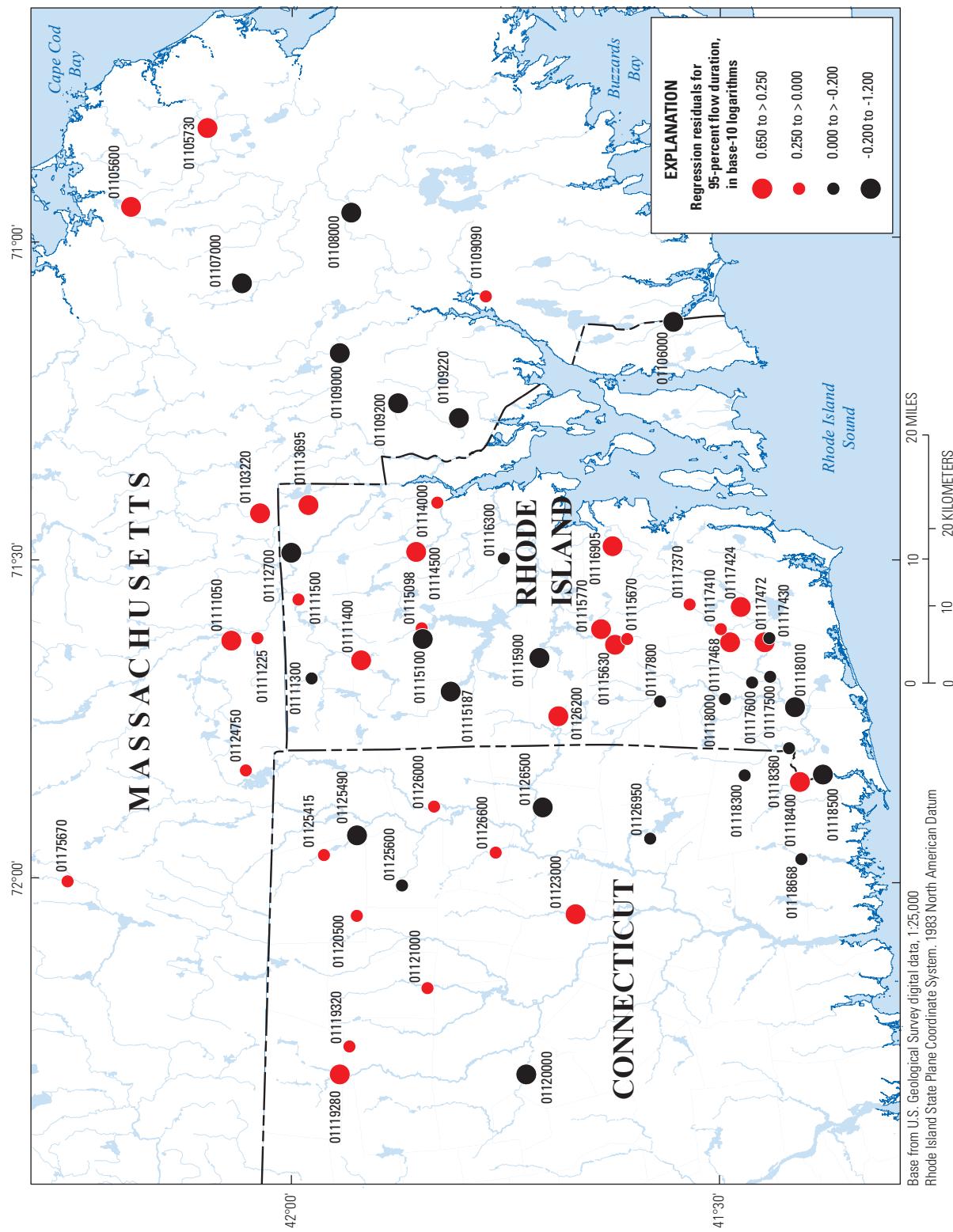
technique in the WREG program or in the left-censored regression analyses do not calculate the  $R^2$ .

A review of areal plots of the residuals (differences between streamflow statistics estimated from measured streamflow and those estimated from the regression equations) for the 7Q10 low-flow frequency and the 95-, 75-, 50-, 25-, and 5-percent flow-duration statistics at the 60 streamgages did not indicate any strong regional biases (clear groups of negative or positive residuals) (figs. 11A–F). Additionally, plots of the streamflow statistics estimated from measured streamflow (observed data) as functions of the same statistics estimated from the regression equations (predicted data) are presented in figures 12A–F. For the lower flows (7Q10 and 95-percent flow duration), the range of the data is clearly wider than that for medium and higher flows—for example,

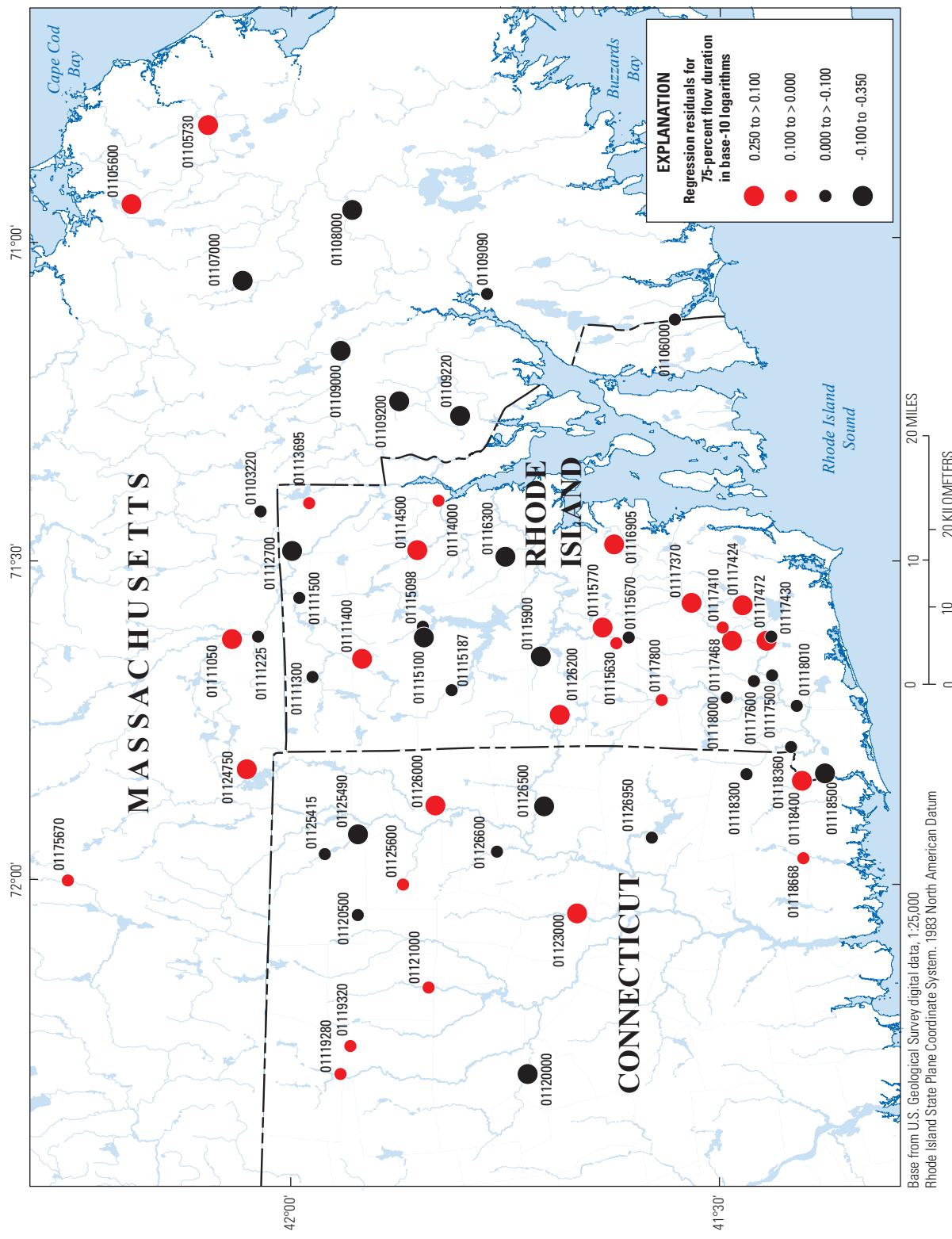
at the 50-percent flow duration (at which the flow is equal or exceeded 50 percent of the time). Again, a wide range between observed and predicted data is generally found in all studies to develop regional regression equations for estimating low flows; the higher standard errors of the estimate—48.68 to 141.83 percent—for the 99- to 85-percent flow durations and 7Q2 and 7Q10 regression equations also reflect this wide range (table 11). In figures 12A and B (7Q10 and 95-percent flow durations, respectively), the data for streamflows less than 0.10 ft<sup>3</sup>/s clearly show a wide range. For streamflows less than 0.10 ft<sup>3</sup>/s there is possibly a small bias towards the regression equations, which generated values higher than the measured streamflows. In addition, the values for streamflows greater than about 50 ft<sup>3</sup>/s indicate a small amount of bias towards the regression equations. In the other plots for the



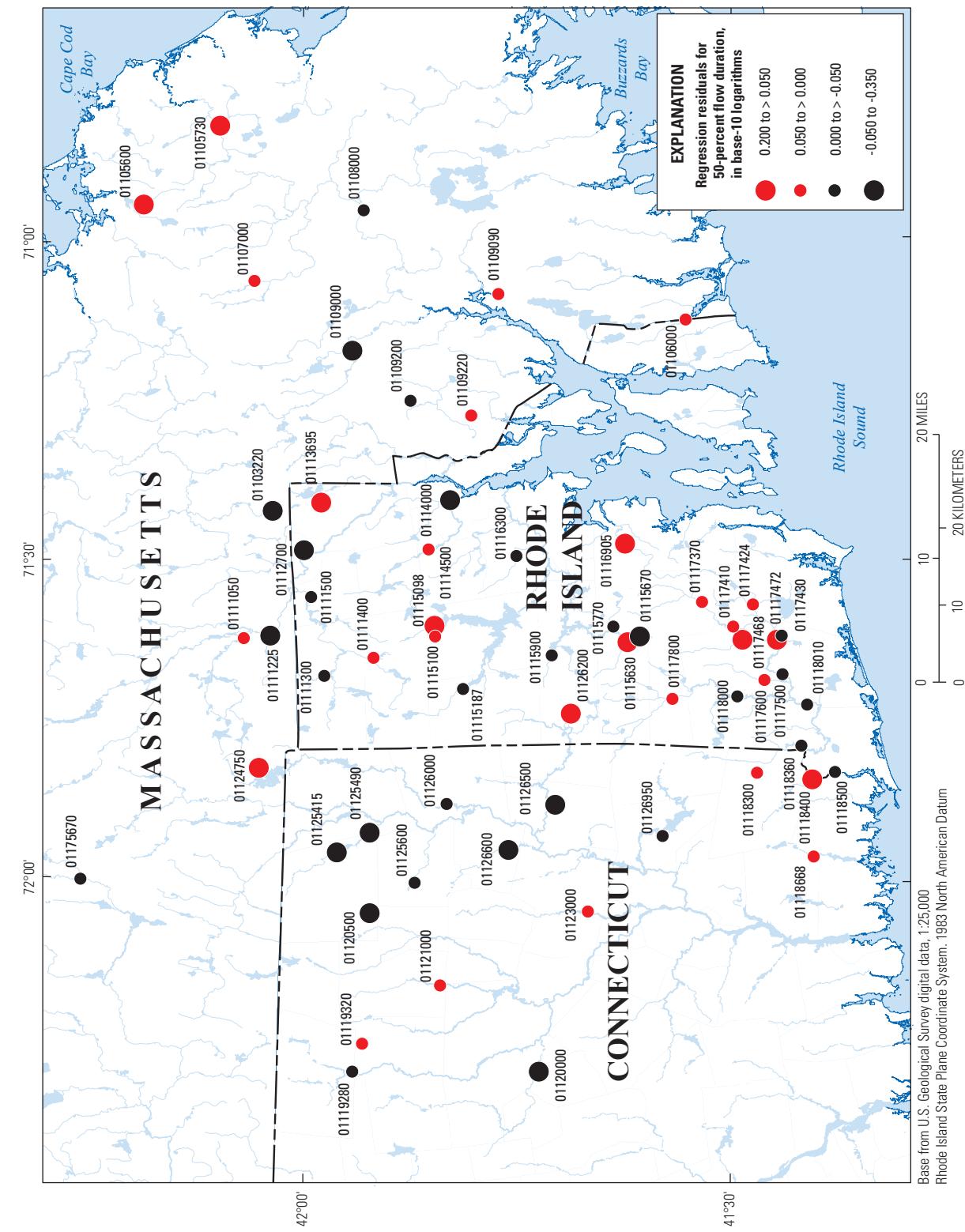
**Figure 11.** The residuals between measured streamflows and streamflows calculated by regression equations for the A, 7010 low-flow frequency, and B, 95-, C, 75-, D, 50-, E, 25-, and F, 5-percent flow durations for long-term and short-term streamgages in and near Rhode Island.



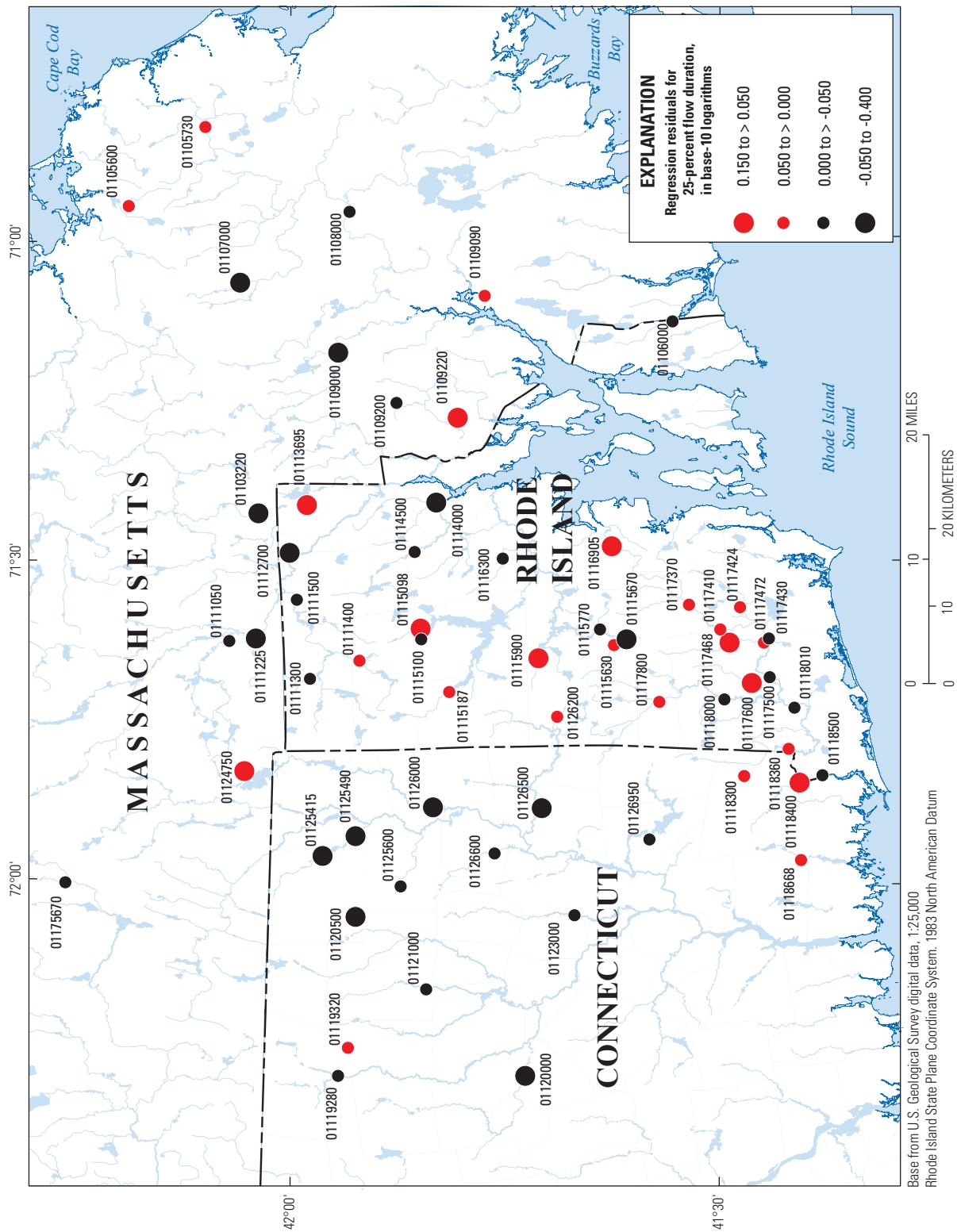
**Figure 11.** The residuals between measured streamflows and streamflows calculated by regression equations for the A, 7Q10 low-flow frequency, and B, 95, C, 75, D, 50, E, 25, and F, 5-percent flow durations for long-term and short-term streamgages in and near Rhode Island.—Continued



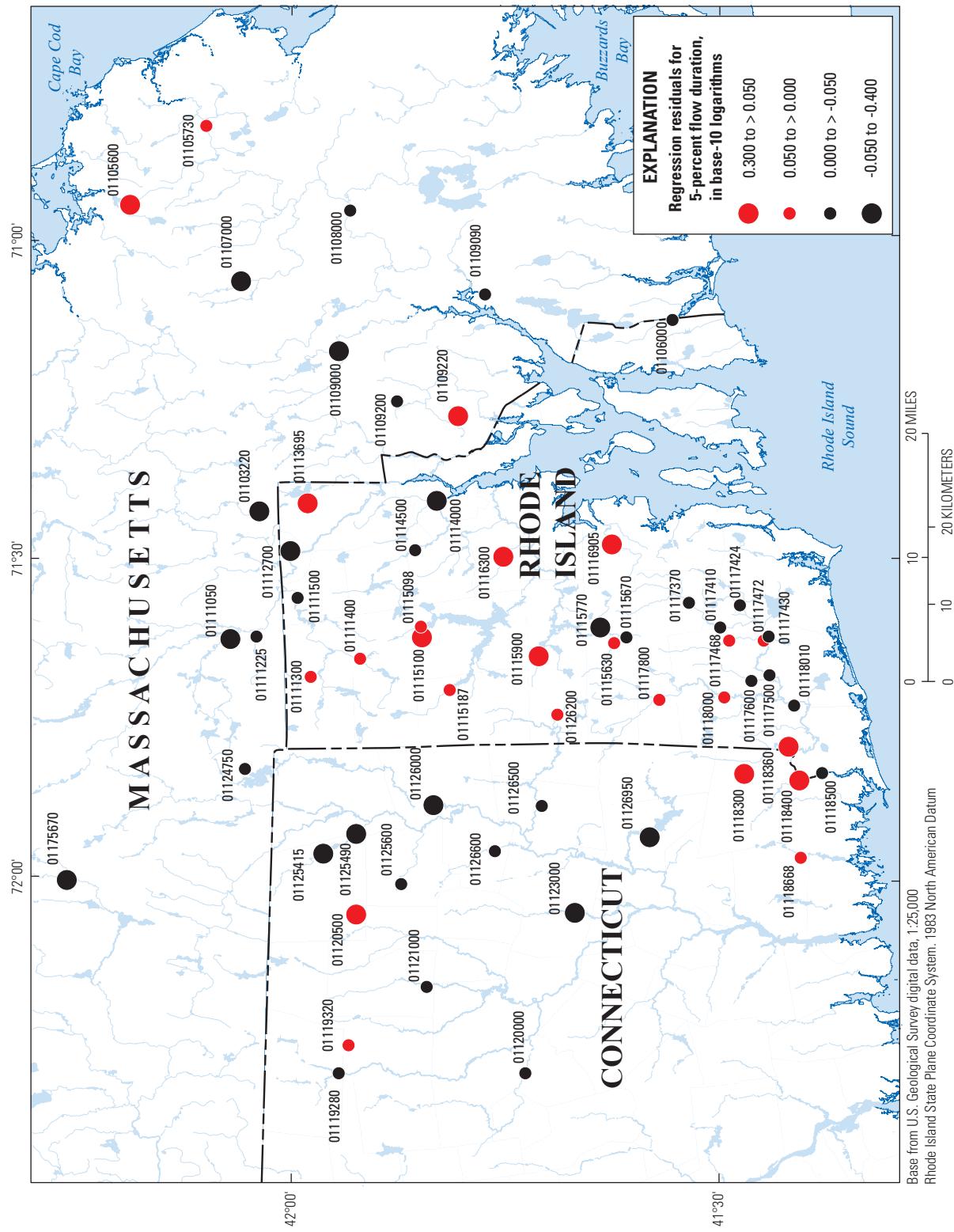
**Figure 11.** The residuals between measured streamflows and streamflows calculated by regression equations for the *A*, *7Q10* low-flow frequency, and *B*, *95*-, *C*, *75*-, *D*, *50*-, *E*, *25*-, and *F*, *5*-percent flow durations for long-term and short-term streamgages in and near Rhode Island.—Continued



**Figure 11.** The residuals between measured streamflows and streamflows calculated by regression equations for the A, 7Q10 low-flow frequency, and B, 95, C, 75, D, 50, E, 25, and F, 5-percent flow durations for long-term and short-term streamgages in and near Rhode Island.—Continued

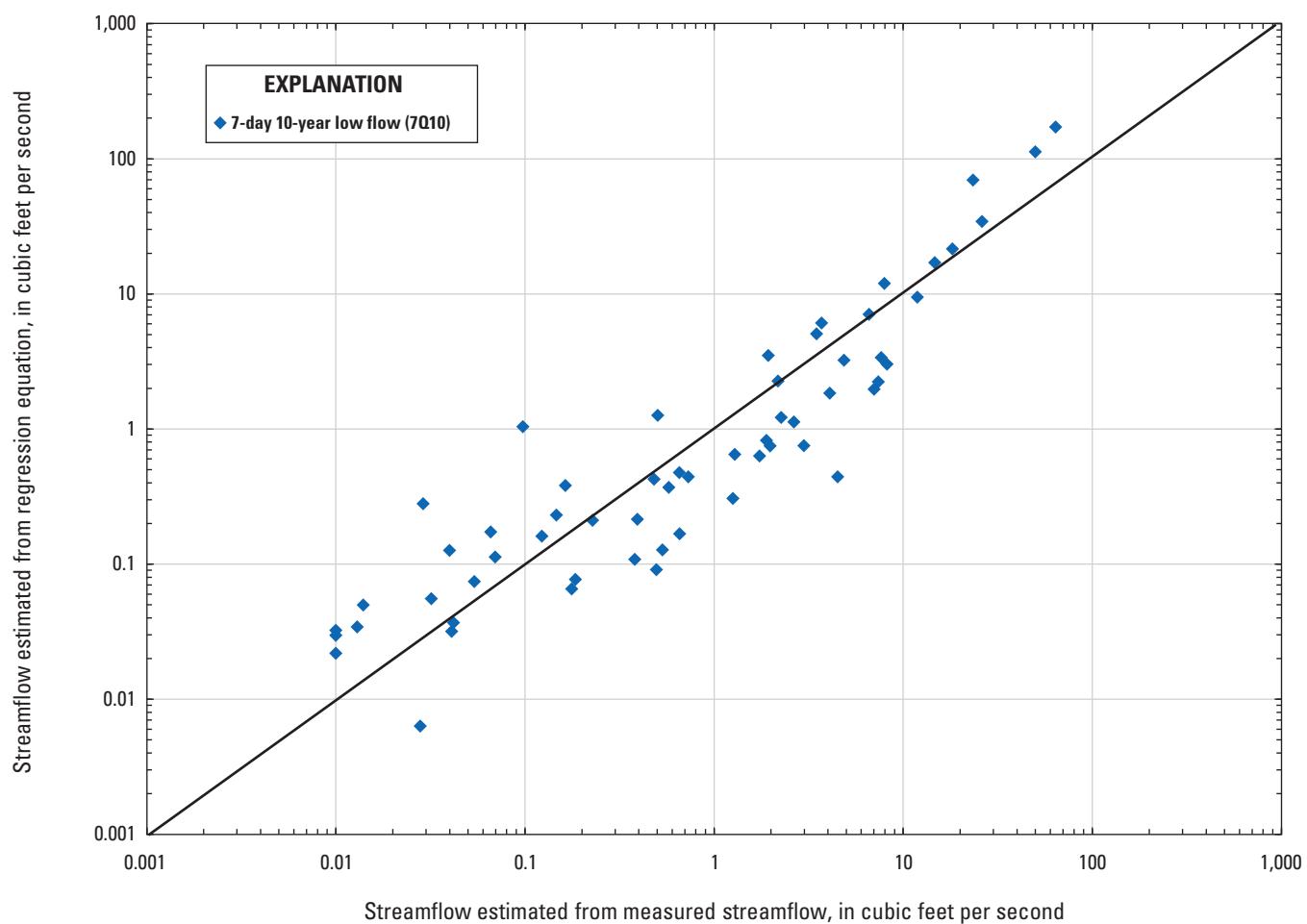


**Figure 11.** The residuals between measured streamflows and streamflows calculated by regression equations for the *A*, *7010* low-flow frequency, and *B*, *95*-, *C*, *75*-, *D*, *50*-, *E*, *25*-, and *F*, *5*-percent flow durations for long-term and short-term streamgages in and near Rhode Island.—Continued

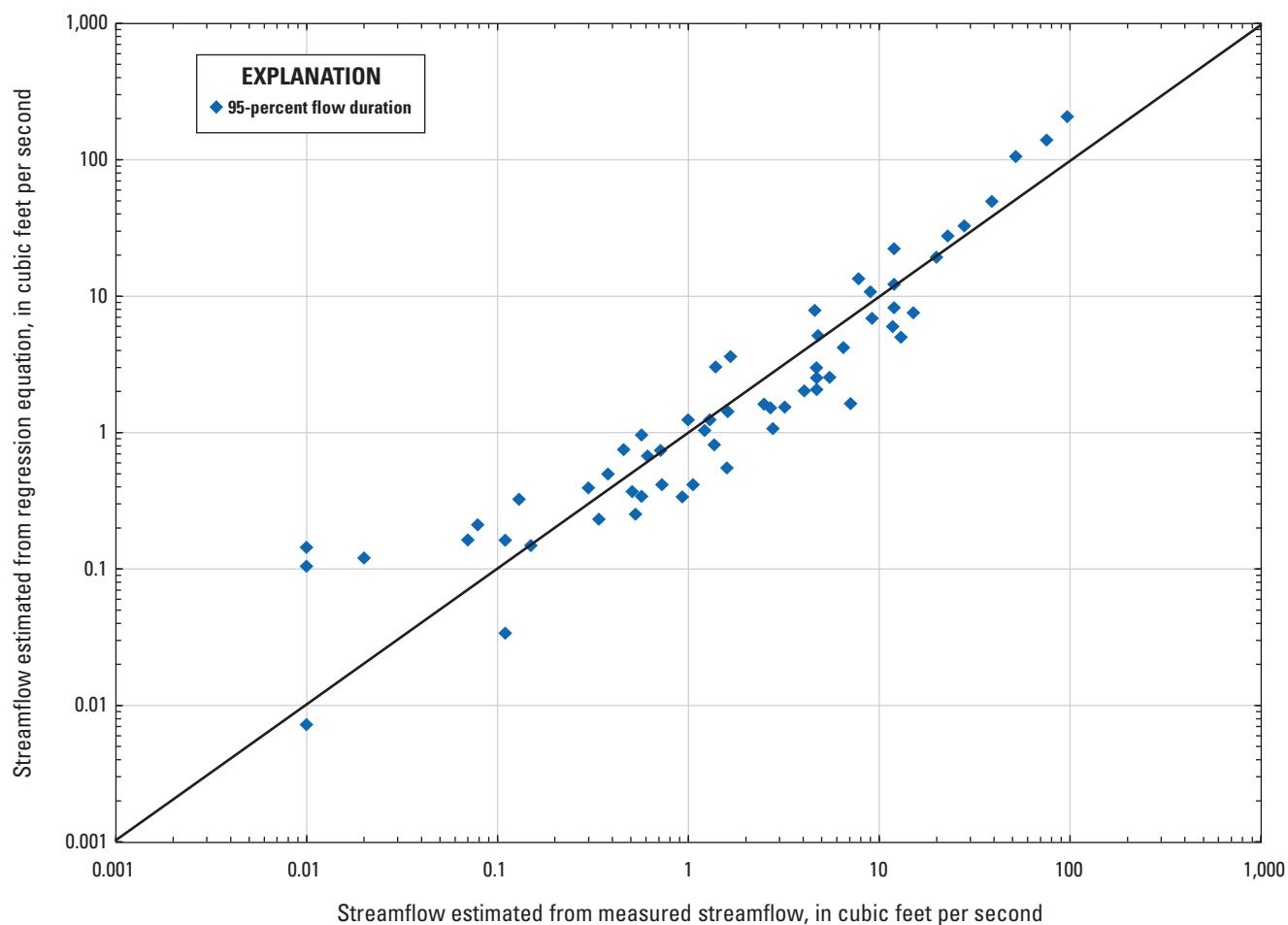


**Figure 11.** The residuals between measured streamflows and streamflows calculated by regression equations for the A, 7Q10 low-flow frequency, and B, 95-, C, 75-, D, 50-, E, 25-, and F, 5-percent flow durations for long-term and short-term streamgages in and near Rhode Island.—Continued

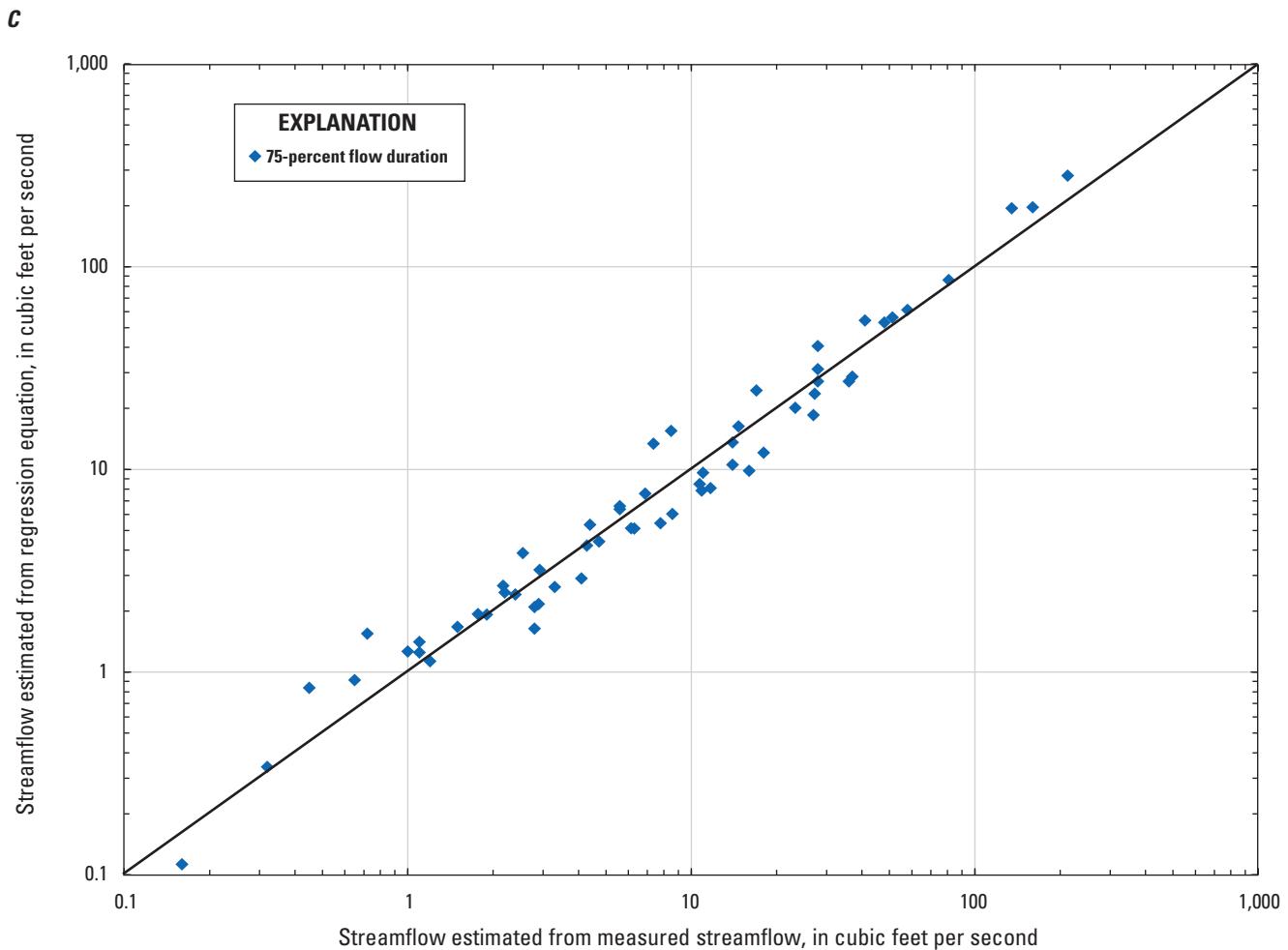
A



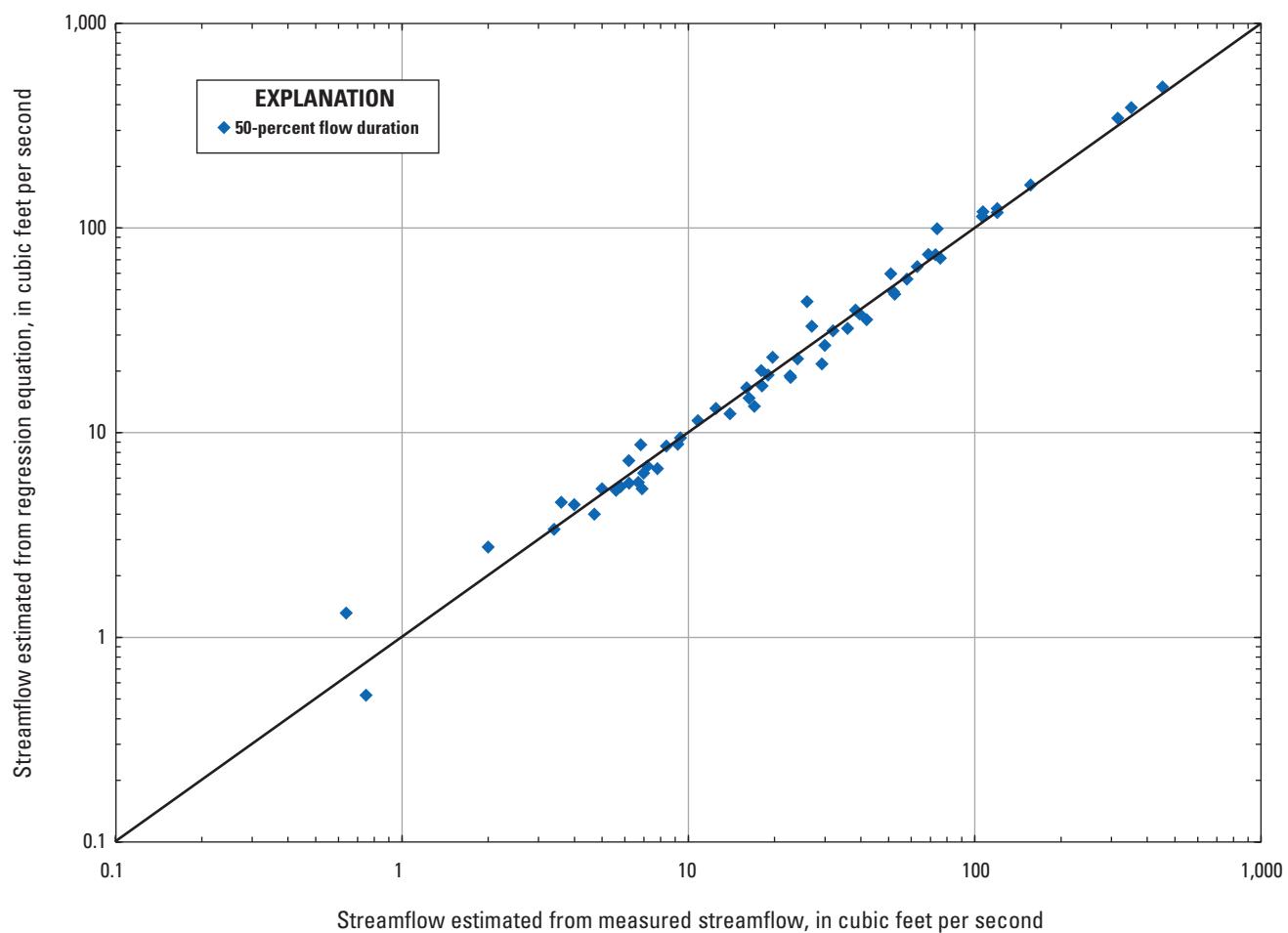
**Figure 12.** Comparisons of the *A*, 7Q10 low-flow frequency, and *B*, 95-, *C*, 75-, *D*, 50-, *E*, 25-, and *F*, 5-percent flow durations estimated from measured streamflow and regression equations for long-term and short-term streamgages in and near Rhode Island.

**B**

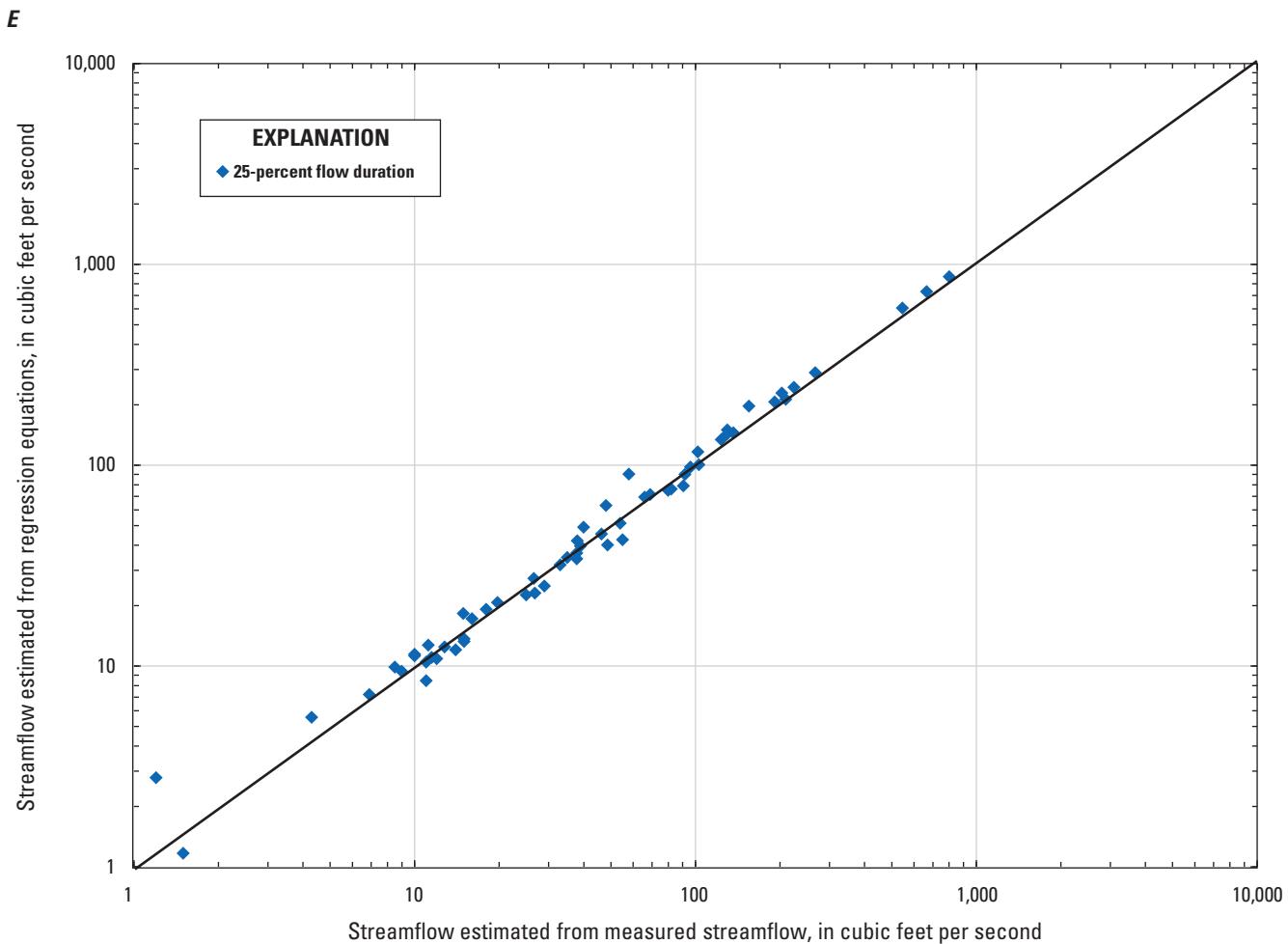
**Figure 12.** Comparisons of the *A*, 7Q10 low-flow frequency, and *B*, 95-, *C*, 75-, *D*, 50-, *E*, 25-, and *F*, 5-percent flow durations estimated from measured streamflow and regression equations for long-term and short-term streamgages in and near Rhode Island.—Continued



**Figure 12.** Comparisons of the *A*, 7Q10 low-flow frequency, and *B*, 95-, *C*, 75-, *D*, 50-, *E*, 25-, and *F*, 5-percent flow durations estimated from measured streamflow and regression equations for long-term and short-term streamgages in and near Rhode Island.—Continued

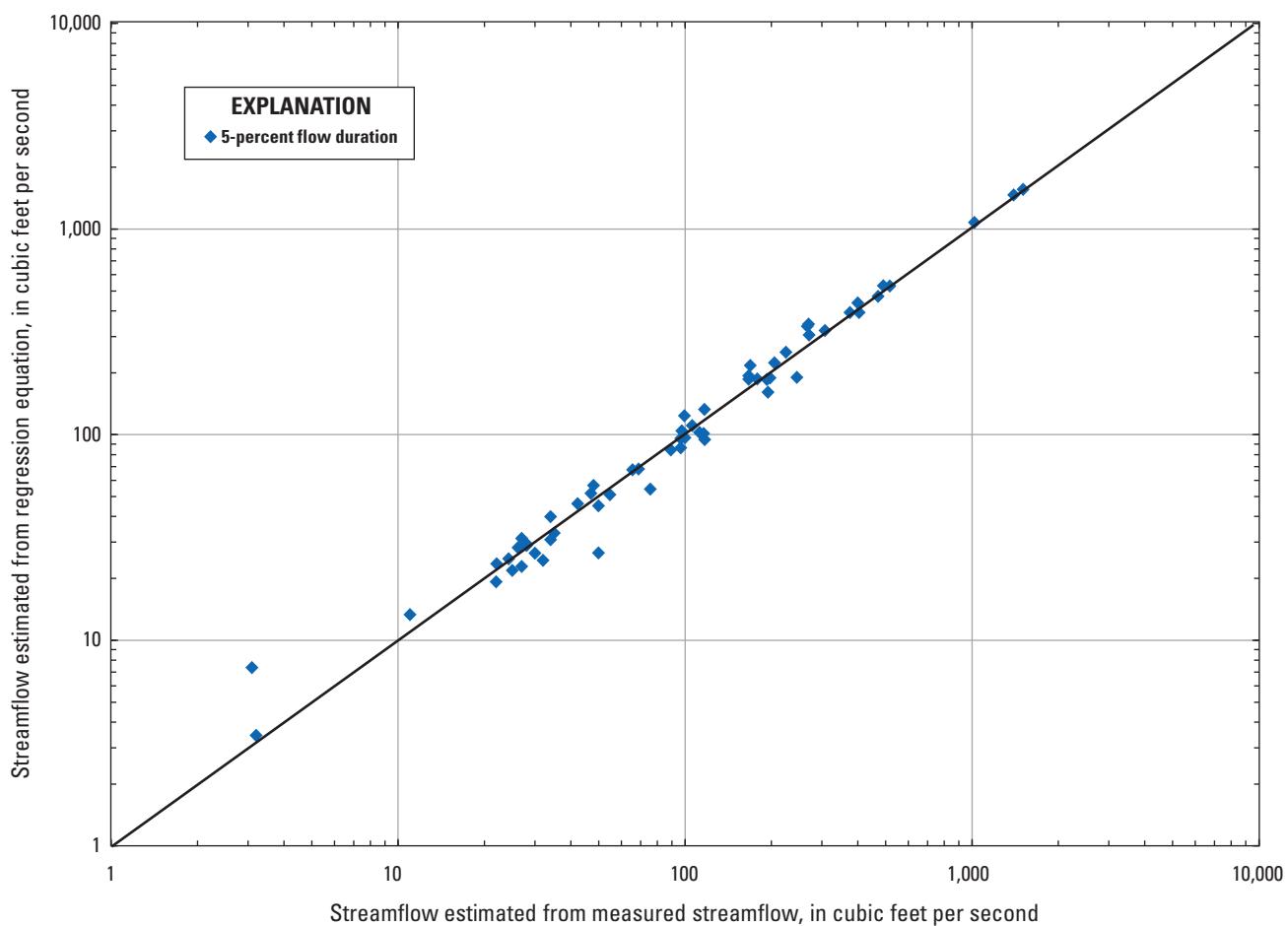
**D**

**Figure 12.** Comparisons of the *A*, 7Q10 low-flow frequency, and *B*, 95-, *C*, 75-, *D*, 50-, *E*, 25-, and *F*, 5-percent flow durations estimated from measured streamflow and regression equations for long-term and short-term streamgages in and near Rhode Island.—Continued



**Figure 12.** Comparisons of the *A*, 7Q10 low-flow frequency, and *B*, 95-, *C*, 75-, *D*, 50-, *E*, 25-, and *F*, 5-percent flow durations estimated from measured streamflow and regression equations for long-term and short-term streamgages in and near Rhode Island.—Continued

F



**Figure 12.** Comparisons of the A, 7Q10 low-flow frequency, and B, 95-, C, 75-, D, 50-, E, 25-, and F, 5-percent flow durations estimated from measured streamflow and regression equations for long-term and short-term streamgages in and near Rhode Island.—Continued

75-, 50-, 25-, and 5-percent flow durations (figs. 12C–F), no clear bias of the streamflow values generated by regression equations with respect to measured streamflows is evident. Maps showing the residuals between measured streamflows and streamflows calculated by regression equations for the *A*, 7Q10 low-flow frequency, and *B*, 95-, *C*, 75-, *D*, 50-, *E*, 25-, and *F*, 5-percent flow durations for long-term and short-term streamgages in and near Rhode Island.

## Prediction Intervals

Prediction intervals indicate the uncertainty inherent in use of the equations. At the 90-percent confidence level, prediction intervals can be calculated for estimates obtained from the regression equations. The assurance is 90 percent that the true value of the streamflow statistic for an ungaged site will be within the prediction interval. The lower and upper boundaries of the 90-percent prediction intervals can be computed by

$$Q_{LPI} = \left( \frac{Q}{T} \right) \leq Q \leq (Q \times T) = Q_{UPI}, \quad (7)$$

where

- $Q$  is the estimated streamflow statistic for the site,
- $Q_{LPI}$  is the estimated lower boundary of the 90-percent prediction interval,
- $Q_{UPI}$  is the estimated boundary of the upper 90-percent prediction interval, and
- $T$  is the 90-percent prediction interval determined from equation 8 below.

$$T = 10^{\left[ t_{(\alpha/2, n-p)} \times S_i \right]} \quad (8)$$

where

- $t_{(\alpha/2, n-p)}$  is the critical value from the student's *t* distribution,
- $\alpha$  is the alpha level ( $\alpha = 0.10$  for 90-percent prediction intervals),
- $n-p$  is the number of degrees of freedom with  $n$  data values (for 60 streamgages) used in the regression analysis,
- $p$  is the number of parameters in the equation (equal to the number of explanatory variables or basin characteristics plus one), and
- $S_i$  is computed from equation 9 below.

Critical values from the student's *t* distribution are listed in many introductory statistics textbooks.

The value of  $S_i$  is computed using the equation

$$S_i = \left[ \gamma^2 + (x_i \times U \times x_i') \right]^{0.5} \quad (9)$$

where

- $\gamma^2$  is the model-error variance (equal to the root mean square error (RMSE) squared),
- $x_i$  is a row vector of the logarithms of the basin characteristics for site  $i$  which has been augmented by a 1 as the first element,
- $U$  is the covariance matrix for the regression coefficients, and
- $x_i'$  is the transpose of  $x_i$  (Ludwig and Tasker, 1993).

The values of  $t_{(\alpha/2, n-p)}$  and  $U$  needed for equations 8 and 9 for the 21 regression equations are presented in table 12. The values of  $\gamma^2$  needed in equation 9 can be calculated by squaring the value of the user-weighted WLS–RMSE or the left-censored regression–RMSE (base-10 logarithm) in table 12.

## Example Computations

Two example computations of selected regression equations and the 90-percent prediction intervals of the estimates are provided. The first computation is provided for Dunderry Brook at Meetinghouse Lane at Little Compton, R.I. (01106110) (fig. 8 and table 4, in back of report). The values of the explanatory variables used in the regression equation for the 90-percent flow duration (table 11) were a drainage area (DRNAREA) of 1.26 mi<sup>2</sup> ( $x_1$ ) and a stream density (STRDENSE) of 2.96 mi/mi<sup>2</sup> ( $x_2$ ) (table 9). Substituting the values in the equation for the 95-percent flow duration produces

$$Q_{90} = 0.1995 \times (1.26 \text{ mi}^2)^{1.35} \times (2.96 \text{ mi}/\text{mi}^2)^{-1.48} = 0.055 \text{ ft}^3/\text{s}.$$

Calculation of the 90-percent prediction intervals use equations 7–9. The calculation starts with equation 9, then goes to equation 8, and then equation 7. Data needed for equations 8 and 9 are in table 12.

For equation 9 the model error variance,  $\gamma^2$ , equals the user-weighted WLS–RMSE (base-10 logarithm) (table 12) squared,  $\gamma^2 = (0.2894)^2 = 0.0838$ , and  $U$  also comes from table 12.

$$U = \begin{bmatrix} 0.225593836 & -0.070349579 & -0.395675480 \\ -0.070349579 & 0.053112461 & 0.021187091 \\ -0.395675480 & 0.021187091 & 1.175994738 \end{bmatrix}$$

$$x_i \times U \times x_i' = (((1 \times 0.225593836) + ((\log 10 (1.26 \text{ mi}^2)) \times -0.070349579) + ((\log 10 (2.96 \text{ mi}/\text{mi}^2)) \times -0.395675480)) \times 1) + (((1 \times -0.070349579) + ((\log 10 (1.26 \text{ mi}^2)) \times 0.053112461) + ((\log 10 (2.96 \text{ mi}/\text{mi}^2)) \times 0.021187091)) \times (\log 10 (1.26 \text{ mi}^2))) + (((1 \times -0.395675480) + ((\log 10 (1.26 \text{ mi}^2)) \times 0.021187091) + ((\log 10 (2.96 \text{ mi}/\text{mi}^2)) \times 1.175994738)) \times (\log 10 (2.96 \text{ mi}/\text{mi}^2)))$$

$$x_i \times U \times x_i' = (((0.2256) + (-0.0071) + (-0.1865)) \times 1) + (((-0.0703) + (0.0053) + (0.0010)) \times 0.1004) + (((-0.3957) + (0.0021) + (0.5542)) \times 0.4713))$$

$$x_i \times U \times x_i' = (0.0320 \times 1) + (-0.0640 \times 0.1004) + (0.1606 \times 0.4713)$$

$$x_i \times U \times x_i' = (0.0320) + (-0.0064) + (0.0757) = 0.1013$$

$$S_i = [\gamma^2 + (x_i \times U \times x_i')]^{0.5} = [0.0838 + 0.1013]^{0.5} = [0.1851]^{0.5} = 0.4302$$

For equation 8, the value of  $t$  from the student's  $t$  distribution  $= t_{(0.10/2, 60-3)} = 1.672$  (table 12).

$$T = 10^{[t_{(n/2, n-p)} \times S_i]} = 10^{[1.672 \times 0.4302]} = 10^{[0.7193]} = 5.2396$$

For equation 7,

$$Q_{LPI} = Q_{90}/T = 0.055/5.2396 = 0.010 \text{ ft}^3/\text{s}$$

$$Q_{UPI} = Q_{90} \times T = 0.055 \times 5.2396 = 0.288 \text{ ft}^3/\text{s}$$

$$Q_{LPI} \leq Q_{90} \leq Q_{UPI} = 0.010 \text{ ft}^3/\text{s} \leq 0.055 \text{ ft}^3/\text{s} \leq 0.288 \text{ ft}^3/\text{s}.$$

The second example computation is provided for Fisherville Brook at Liberty Church Rd. near Exeter, R.I. (01117360) (fig. 8 and table 4, in back of report). The values of the explanatory variables used in the regression equation

for the 7Q10 low-flow frequency (table 11) were a drainage area (DRNAREA) of 8.09  $\text{mi}^2$  ( $x_1$ ) and a stream density (STRDENSE) of 1.51  $\text{mi}/\text{mi}^2$  ( $x_2$ ) (table 9). Substituting the values in the equation for the 7Q10 low-flow frequency produces

$$Q_{7Q10} = 0.0311 \times (8.09 \text{ mi}^2)^{1.71} \times (1.51 \text{ mi}/\text{mi}^2)^{-2.53} = 0.391 \text{ ft}^3/\text{s}$$

The calculation starts with equation 9, then goes to equation 8, and then equation 7. Data needed for equations 8 and 9 are in table 12.

For equation 9 the model error variance,  $\gamma^2$ , equals the left-censored regression-RMSE (base-10 logarithm) (table 12) squared,  $\gamma^2 = (0.4853)^2 = 0.2355$ , and  $U$  also comes from table 12.

$$U = \begin{bmatrix} 0.225593836 & -0.070349579 & -0.395675480 \\ -0.070349579 & 0.053112461 & 0.021187091 \\ -0.395675480 & 0.021187091 & 1.175994738 \end{bmatrix}$$

$$x_i \times U \times x_i' = (((1 \times 0.225593836) + ((\log_{10}(8.09 \text{ mi}^2)) \times -0.070349579) + ((\log_{10}(1.51 \text{ mi/mi}^2)) \times -0.395675480)) \times 1) + (((1 \times -0.070349579) + ((\log_{10}(8.09 \text{ mi}^2)) \times 0.053112461) + ((\log_{10}(1.51 \text{ mi/mi}^2)) \times 0.021187091)) \times (\log_{10}(8.09 \text{ mi}^2))) + (((1 \times -0.395675480) + ((\log_{10}(8.09 \text{ mi}^2)) \times 0.021187091) + ((\log_{10}(1.51 \text{ mi/mi}^2)) \times 1.175994738)) \times (\log_{10}(1.51 \text{ mi/mi}^2)))$$

$$x_i \times U \times x_i' = (((0.2256) + (-0.0639) + (-0.0708)) \times 1) + (((-0.0703) + (0.0482) + (0.0038)) \times 0.9079) + (((-0.3957) + (0.0192) + (0.2105)) \times 0.1790))$$

$$x_i \times U \times x_i' = (0.0909 \times 1) + (-0.0183 \times 0.9079) + (-0.1660 \times 0.1790)$$

$$x_i \times U \times x_i' = (0.0909) + (-0.0166) + (-0.0297) = 0.0446$$

$$S_i = [\gamma^2 + (x_i \times U \times x_i')]^{0.5} = [0.2355 + 0.0446]^{0.5} = [0.2801]^{0.5} = 0.5292$$

The value of  $t$  from the student's  $t$  distribution =  $t_{(0.10/2, 60-3)} = 1.672$  (table 12).

$$T = 10^{[t_{(0.10/2, 60-3)} \times S_i]} = 10^{[1.672 \times 0.5292]} = 10^{[0.8848]} = 7.6701$$

For equation 7,

$$Q_{LPI} = Q_{90}/T = 0.391/7.6701 = 0.051 \text{ ft}^3/\text{s}$$

$$Q_{UPI} = Q_{90} \times T = 0.391 \times 7.6701 = 3.00 \text{ ft}^3/\text{s}$$

$$Q_{LPI} \leq Q_{7Q10} \leq Q_{UPI} = 0.051 \text{ ft}^3/\text{s} \leq 0.391 \text{ ft}^3/\text{s} \leq 3.00 \text{ ft}^3/\text{s}.$$

## Limitations of Regression Equations

Use of the regression equations presented in this report in determining selected streamflow statistics is limited by the range of the basin-characteristics data used to develop the equations and by the accuracy of the estimates. These equations should not be used for the determination of streamflow statistics at ungaged sites for which the basin characteristics are outside the range of those used to develop the regression equations. The ranges of the basin-characteristics data used as explanatory variables to develop the flow-duration and low-flow-frequency regression equations are listed in table 13, and the corresponding accuracies of the estimates calculated by these equations are in table 11. The use of these regression equations requires that the physical and climatic basin characteristics be determined in a GIS based on the same datasets (table 13) that were used to develop the equations outlined in this report.

The equations, which are based on data from streams with little to no flow alteration, will give estimates only of the natural flows for a selected site. They will not give estimates of altered flow for sites where the flow is affected by structures and artificial processes such as dams, surface-water withdrawals, groundwater withdrawals (pumping wells), diversions, and wastewater discharges. To apply the equations to streamflow data for such sites, the user should adjust the estimates for the alterations accordingly. The equations are not applicable in areas of Rhode Island where groundwater contributing areas and surface-water drainage areas to stream sites differ appreciably. In these areas, groundwater can flow from one surface-water drainage area into another; therefore, for basins whose groundwater contributing areas are larger than their surface-water drainage areas, the equations would likely underestimate streamflows. Conversely, for areas whose groundwater-contributing areas are smaller than their surface-water drainage areas, the equation would likely overestimate streamflows. Several areas in Rhode Island where groundwater contributing areas and surface-water drainage areas to stream sites differ appreciably include Queens Fort Brook in the Usquepaug-Queen River Basin (Allen and others, 1966; Dickerman and others, 1997; Barlow and Dickerman, 2001; Granato and others, 2003; Zarriello and Bent, 2004; and Bent and others, 2011), Mishnock River and Old Hickory Brook in the Big River Basin (Granato and others, 2003; and Granato and Barlow, 2005), several coastal rivers in the Hunt-Annaquatuck-Pettaquamscutt River Basin (Rosenschein and others, 1968; Barlow and Dickerman, 2001; and Barlow and Bent, 2004).

**Table 12.** Information needed for calculating the 90-percent prediction intervals for estimates of selected statistics calculated by regression equations for streamflows in Rhode Island.

[Flow duration is percentage of time that streamflow was equalled or exceeded. p, number of parameters is equal to the number of explanatory variables plus one; t, student's *t* distribution; WLS, weighted-least-squares regression; RMSE, root mean square error; MSE, mean square error; U, covariance matrix for the regression coefficients. DRNAREA, drainage area in square miles; STRDENE, drainage density in miles per square mile; --, none; 7Q2, the annual minimum average streamflow for 7 consecutive days that has a 0.50 probability of not being exceeded in a given year; 7Q10, the annual minimum average streamflow for 7 consecutive days that has a 0.10 probability of not being exceeded in a given year]

Streamflow statistic type	Streamflow statistic	Regression equation	Number of explanatory variables	p	alpha	t	User-weighted WLS-MSE (percent)	User-weighted WLS-RMSE (base-10 logarithm)	User-weighted WLS-RMSE (base-10 logarithm)	Left-censored regression-MSE (percent)	Left-censored regression-RMSE (base-10 logarithm)	Left-censored regression-MSE (percent)	Left-censored regression-RMSE (base-10 logarithm)	U
Flow duration	1	$9.3325(\text{DRNAREA})^{0.94}(\text{STRDENE})^{0.49}$	60	2	3	0.10	1.672	21.15	0.0909	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	2	$7.4131(\text{DRNAREA})^{0.96}(\text{STRDENE})^{0.36}$	60	2	3	0.10	1.672	19.06	0.0820	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	5	$5.4954(\text{DRNAREA})^{0.98}(\text{STRDENE})^{0.18}$	60	2	3	0.10	1.672	19.52	0.0840	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	10	$4.3652(\text{DRNAREA})^{1.00}$	60	1	2	0.10	1.6715	17.58	0.0758	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	15	$3.4674(\text{DRNAREA})^{1.01}$	60	1	2	0.10	1.6715	17.78	0.0766	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	20	$2.7542(\text{DRNAREA})^{1.02}$	60	1	2	0.10	1.6715	18.22	0.0785	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	25	$2.6915(\text{DRNAREA})^{1.03}(\text{STRDENE})^{0.18}$	60	2	3	0.10	1.672	17.83	0.0768	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	30	$2.3442(\text{DRNAREA})^{1.04}(\text{STRDENE})^{0.23}$	60	2	3	0.10	1.672	18.31	0.0789	--	--	0.225593836	-0.070349579	-0.395675480

## Equations for Estimating Selected Streamflow Statistics in Rhode Island

**Table 12.** Information needed for calculating the 90-percent prediction intervals for estimates of selected statistics calculated by regression equations for streamflows in Rhode Island.—Continued

[Flow duration is percentage of time that streamflow was equalled or exceeded; p, number of parameters is equal to the number of explanatory variables plus one; t, student's *t* distribution; WLS, weighted-least-squares regression; RMSE, root mean square error; MSE, mean square error; DRNAREA, drainage area in square miles; STRDENE, drainage density in miles per square mile; --, none; 7Q2, the annual minimum average streamflow for 7 consecutive days that has a 0.50 probability of not being exceeded in a given year; 7Q10, the annual minimum average streamflow for 7 consecutive days that has a 0.10 probability of not being exceeded in a given year]

Streamflow statistic type	Stream-flow statistic	Regression equation	Number of explanatory variables	Number of stations	p	alpha	t	User-weighted WLS-MSE (percent)	User-weighted WLS-RMSE (base-10 logarithm)	User-weighted WLS-RMSE (base-10 logarithm) (percent)	Left-censored regression-MSE (percent)	Left-censored regression-RMSE (base-10 logarithm)	Left-censored regression-RMSE (base-10 logarithm) (percent)	U
Flow duration	40	$1.8621(\text{DRNAREA})^{1.05}(\text{STRDENE})^{0.29}$	60	2	3	0.10	1.672	18.07	0.0778	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	50	$1.4791(\text{DRNAREA})^{1.05}(\text{STRDENE})^{0.39}$	60	2	3	0.10	1.672	18.65	0.0803	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	60	$1.0715(\text{DRNAREA})^{1.07}(\text{STRDENE})^{0.50}$	60	2	3	0.10	1.672	20.65	0.0887	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	70	$0.6761(\text{DRNAREA})^{1.13}(\text{STRDENE})^{0.68}$	60	2	3	0.10	1.672	25.25	0.1080	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	75	$0.5248(\text{DRNAREA})^{1.17}(\text{STRDENE})^{0.84}$	60	2	3	0.10	1.672	30.72	0.1304	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	80	$0.4074(\text{DRNAREA})^{1.21}(\text{STRDENE})^{1.01}$	60	2	3	0.10	1.672	37.65	0.1581	--	--	0.225593836	-0.070349579	-0.395675480
Flow duration	85	$0.2951(\text{DRNAREA})^{1.26}(\text{STRDENE})^{1.18}$	60	2	3	0.10	1.672	48.86	0.2009	--	--	0.225593836	-0.070349579	-0.395675480

**Table 12.** Information needed for calculating the 90-percent prediction intervals for estimates of selected statistics calculated by regression equations for streamflows in Rhode Island.—Continued

[Flow duration is percentage of time that streamflow was equalled or exceeded. p, number of parameters is equal to the number of explanatory variables plus one; t, student's *t* distribution; WLS, weighted-least-squares regression; RMSE, root mean square error; MSE, mean square error; U, covariance matrix for the regression coefficients. DRNAREA, drainage area in square miles; STRDENE, drainage density in miles per square mile; --, none; 7Q2, the annual minimum average streamflow for 7 consecutive days that has a 0.50 probability of not being exceeded in a given year; 7Q10, the annual minimum average streamflow for 7 consecutive days that has a 0.10 probability of not being exceeded in a given year]

Streamflow statistic type	Streamflow statistic	Regression equation	Number of explanatory variables	p	alpha	t	User-weighted WLS-MSE (percent)	User-weighted WLS-RMSE (base-10 logarithm)	User-weighted WLS-RMSE (base-10 logarithm)	Left-censored regression-MSE (percent)	Left-censored regression-RMSE (base-10 logarithm)
Flow duration	90	0.1995(DRNAREA) <sup>1.35</sup> (STRDENE) <sup>1.48</sup>	60	2	3	0.10	1.672	74.76	0.2894	--	0.225593836
Flow duration	95	0.1006(DRNAREA) <sup>1.48</sup> (STRDENE) <sup>1.80</sup>	60	2	3	0.10	1.672	--	--	-0.070349579	-0.070349579
Flow duration	98	0.0591(DRNAREA) <sup>1.58</sup> (STRDENE) <sup>2.08</sup>	60	2	3	0.10	1.672	--	--	116.35	0.4018
Flow duration	99	0.0441(DRNAREA) <sup>1.64</sup> (STRDENE) <sup>2.29</sup>	60	2	3	0.10	1.672	--	--	141.83	0.4560
Low-flow frequency	7Q2	0.1104(DRNAREA) <sup>1.48</sup> (STRDENE) <sup>1.91</sup>	60	2	3	0.10	1.672	--	--	88.75	0.3310
Low-flow frequency	7Q10	0.0311(DRNAREA) <sup>1.71</sup> (STRDENE) <sup>2.53</sup>	60	2	3	0.10	1.672	--	--	157.66	0.4853

**Table 13.** Range of basin characteristics used as explanatory variables in the regression equations for estimating selected streamflow statistics in Rhode Island.

[DRNAREA, drainage area; STRDENED, drainage density; mi<sup>2</sup>, square miles; mi/mi<sup>2</sup>, miles per square mile]

Explanatory variable	Minimum value	Maximum value
Drainage area (DRNAREA) (mi <sup>2</sup> )	0.52	294
Drainage density (STRDENED) (mi/mi <sup>2</sup> )	0.94	3.49

and Barlow and Ostiguy, 2007), and the South Coastal Basin (Friesz, 2004; Masterson and others, 2007; and Friesz, 2010). The regression equations are not applicable to other areas of Rhode Island having known appreciable differences between surface-water drainage areas and groundwater contributing areas. Additionally, the equation is not applicable to streams with losing reaches. Losing streams are defined as streams or stream reaches that lose water to the groundwater system (Winter and others, 1998, p. 9–10 and 16–17). Generally, a stream reach is losing where the groundwater table does not intersect the streambed in the channel (the water table is below the streambed) during low-flow periods. Losing stream reaches commonly begin where the stream flows from an area of the basin underlain by till or bedrock onto an area underlain by stratified deposits (where hillsides meet river valleys). At such junctures, a stream can lose a substantial amount of water through its streambed. The accuracies of the regression equations are functions of the quality of the data used in to develop the equations. These data include the streamflow data used to estimate the statistics, information about possible unknown flow alterations to the stream above a site, and the measured basin characteristics. Basin characteristics used in the development of the regression equations are limited by the accuracy of the digital data layers available and used at the time (2014) of this study. In the future, geospatial data layers of basin characteristics (table 7) likely will be more detailed and accurate and at higher resolution, for stream networks from the USGS NHD (<http://nhd.usgs.gov/>); elevation from USGS NED (<http://ned.usgs.gov/>); land cover, land use, and surficial geology from RIGIS (<http://www.edc.uri.edu/rigis/default.html>), MassGIS (<http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/>), MAGIC (<http://magic.lib.uconn.edu/>), and University of Connecticut CLEAR (<http://clear.uconn.edu/projects/landscape/>); soils from NRCS SSURGO (<http://soils.usda.gov/survey/geography/ssurgo/>); and climate from the PRISM Climate Group, Oregon State University (<http://www.prism.oregonstate.edu/>).

## StreamStats Application and Considerations for Additional Study

The USGS National StreamStats Web-based application (<http://water.usgs.gov/osw/streamstats/>; Ries, 2007, and Turnipseed and Ries, 2007) includes a map-based interface that allows a user to click on the centerline for any stream site, which causes the application to calculate selected streamflow statistics and the 90-percent prediction intervals from the equations for that ungaged stream site. The application also provides the user with the basin-characteristic values that were used to calculate the regression equations. The regression equations' basin-characteristic values for a user-selected stream site are determined by the use of digital map data from ArcGIS (geographic information system software from the Environmental Systems Research Institute, Inc. (Esri) (<http://www.esri.com/>)). The output includes a map of the drainage-basin boundary determined for the stream site, the values of the GIS-measured basin characteristics, the estimated streamflow statistics, and prediction intervals for the estimates. The user can also click on streamgage and partial-record station symbols and be provided selected streamflow statistics and basin characteristics from a database for that site.

As considerations for additional study, the 21 selected regression equations for streamflow statistics (table 11), as well as the 90-percent prediction intervals, could be incorporated into the USGS National StreamStats Web-based application. The at-site estimates of the selected streamflow statistics at the long- and short-term streamgages and partial-record stations could also be put into the StreamStats database for retrieval. Another consideration is that new basin characteristics that were not available for this study could be tested as potential explanatory variables. These digital data layers likely would improve the accuracy of the measured basin characteristics used as explanatory variables to estimate selected streamflow statistics in Rhode Island but only after re-examination of the regression equations.

## Summary and Conclusions

The equations for estimating selected streamflow statistics may be used by Federal, State, and local water managers in addressing numerous water issues. This report documents the development of regression equations by the U.S. Geological Survey (USGS), in cooperation with the Rhode Island Water Resources Board, that can be used statewide for determining selected statistics for streamflows unaffected by alterations at ungaged sites in Rhode Island. Multiple and simple linear regression equations were developed to estimate the 99-, 98-, 95-, 90-, 85-, 80-, 75-, 70-, 60-, 50-, 40-, 30-, 25-, 20-, 15-, 10-, 5-, 2-, and 1-percent flow durations and the frequency statistics 7Q2 (7-day, 2-year) and 7Q10 (7-day, 10-year). An additional 49 selected statistics also were estimated for long- and short-term streamgages and partial-record stations for flow

durations between the 99.99 and 0.01 percent, and the mean annual, mean monthly, and median monthly streamflows. Data also are provided to allow the user to calculate the 90-percent prediction intervals for the 21 streamflow statistics.

A total of 70 selected streamflow statistics were determined for 41 long-term streamgages (with 8 or more water and climatic years of record), 21 short-term streamgages (with 1 to 7 water and climatic years of record), and 135 partial-record stations (with more than 11 miscellaneous streamflow measurements) in Rhode Island, eastern Connecticut, and southeastern and south-central Massachusetts. Estimates of the long-term streamflow statistics for 21 short-term streamgages and 135 partial-record stations were developed by using the Maintenance of Variance Extension, type 1 (MOVE.1), technique. This technique involved fitting the MOVE.1 equation for daily mean streamflows at short-term streamgages and miscellaneous streamflow measurements at partial-record stations to concurrent daily mean streamflows at the 16 index streamgages. In general, the index streamgage which provided the relation with the highest Pearson's correlation coefficient ( $r$ ) and the most linear plot of the data was selected.

The regression analyses for developing equations to estimate selected streamflow statistics related the 19 flow-duration and 2 low-flow frequency statistics to 31 different drainage-basin characteristics (physical, land-cover, and climatic characteristics) for 41 long-term and 19 of 21 short-term streamgages (60 total streamgages) in Rhode Island and nearby in Connecticut and Massachusetts. Two of the 21 short-term streamgages were excluded from the regression analyses because the period of record for another streamgage nearby on the same river was longer; this longer record was used in the analyses. In addition, the drainage areas and basin characteristics of the two streamgages were similar. Use of the streamflow records, drainage areas, and basin characteristics for both sites would have produced redundant data points in the regression analyses. The 135 partial-record stations were not used in the regression analyses.

A user-weighted least-squares (WLS) regression technique in the weighted-multiple-linear regression (WREG) program was used in the regression analyses for the 90- to 1-percent flow durations. Left-censored regression analyses were used to account for zero flows at the 99- and 98-percent and 7Q10 flow durations (for four streamgages) and at the 95-percent and 7Q2 flow durations (for two streamgages). Coefficients of determination ( $R^2$ ) are not determined when the user-WLS regression technique is used in WREG or in the left-censored regression analyses.

The regression analyses determined that the basin characteristics drainage area (DRNAREA) and stream density (total length of streams divided by the drainage area) (STRDENED) were the only significant explanatory variables for 16 of the 19 flow-duration and the 2 low-flow-frequency regression equations. For the other three flow-duration (10-, 15-, and 20-percent) equations, drainage area was the only significant explanatory variable.

The standard error of the estimate for the 21 regression equations ranged from 17.58 to 141.83 percent. The low-flow statistics for the 99- to 85-percent flow durations and 7Q2 and 7Q10 had the highest standard errors of the estimate, ranging from 48.68 to 141.83 percent. The standard error of the estimate for the medium- to high-flow statistics—the 80- to 1-percent flow durations—ranged from 17.58 to 37.65 percent, with the standard errors for the 60- to 1-percent flow durations all being less than about 21 percent.

The equations, which are based on data from streams with little to no flow alteration, will give an estimate of only the natural flows at a selected site. They will not give an estimate of altered flows at a site where the streamflow is affected by structures and artificial processes such as dams, surface-water withdrawals, groundwater withdrawals (pumping wells), diversions, and wastewater discharges. If the equations are used to estimate statistics for sites where streamflow has been altered, the user should adjust the estimates accordingly. The regression equations should be used only for ungaged sites with drainage areas between 0.52 and 294 square miles ( $\text{mi}^2$ ) and stream densities between 0.94 and 3.49 miles per square miles ( $\text{mi}/\text{mi}^2$ ). The equations are not applicable (1) for Block Island because there are no streams on the island, (2) in areas where groundwater-contributing areas and surface-water drainage areas to stream sites differ appreciably, and (3) for losing stream reaches where the stream may flow from of a till and bedrock hillside into a sand and gravel river valley.

As considerations for additional study, the 21 regression equations developed for this study, as well as the 90-percent prediction intervals of the estimate, could be added to the USGS National StreamStats Web-based application (<http://water.usgs.gov/osw/streamstats/>). The 21 selected streamflow statistics, plus the additional statistics: 24 flow durations between the 99.99 and 0.01 percent, mean annual flow, and 12 mean and median monthly flows estimated for the long- and short-term streamgages and partial-record stations also could be incorporated into the StreamStats database.

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## **Tables 4, 5**

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**Table 4.** Description of partial-record stations in and near Rhode Island.

[Station no.: locations of partial-record stations shown by number in figure 8. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; p, present; --, none; NWIS, National Water Information System]

Sta-tion no.	USGS station no.	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drain-age area (mi <sup>2</sup> )	Water years with streamflow measurements	Number of streamflow measurements through water year 2006	Remarks
1	01105928	Buttonwood Brook near South Dartmouth, MA	41.60427	-70.95559	3.00	1972–74, 1992, and 2003	15	--
2	01105930	Paskamanset River at Turner Pond near New Bedford, MA	41.67871	-70.97726	8.14	1991–93 and 2003	26	--
3	01105935	Destruction Brook near South Dartmouth, MA	41.57233	-71.01254	2.70	1972–74, 1991–93, and 2003	30	--
4	01105937	Shingle Island River near North Dartmouth, MA	41.68205	-71.01754	8.55	1957, 1972–74, 1991–93, 1995–96, and 2003	34	--
5	01105950	Kirby Brook near Head of Westport, MA	41.60066	-71.07310	3.71	1965, 1972–74, 1992, and 2003	16	--
6	01106005	Angeline Brook near Head of Westport, MA	41.55149	-71.10504	3.27	1972–74, 1992, and 2003	16	--
7	01106110	Dundery Brook, Meetinghouse Lane at Little Compton, RI	41.50733	-71.17949	1.26	2004	14	--
8	01106130	Little Creek, Green End Avenue, near Whitehall, RI	41.50927	-71.24505	1.42	2004	14	--
9	01106150	Bailey Brook, Forest Avenue, near Middletown, RI	41.53982	-71.29116	1.28	2004	14	--
10	01107400	Fall Brook near Middleborough, MA	41.86538	-70.90837	9.21	1966–68, 1978–81, and 1983	36	--
11	01109087	Assonet River at Assonet, MA	41.79927	-71.05977	20.7	1986–88 and 1990–91	22	--
12	01109135	Cole River near Swansea, MA	41.77510	-71.19866	7.74	1986–88, 1996, and 2003	22	--
13	01109185	East Branch Palmer River near Rehoboth, MA	41.86010	-71.22922	5.17	1992–94 and 2003	13	--
14	01109225	Rocky Run near Rehoboth, MA	41.78121	-71.25333	7.24	1972–74, 1979–81, 1983, 1986–88, and 1994–96	42	--
15	01109270	Runnings River at Seekonk, MA	41.82371	-71.33283	4.12	1972–74, 1982–83, 1992, and 2003	20	--
16	01109280	Runnings River, Fall River Avenue, at Seekonk, MA	41.81649	-71.33561	5.88	1986–88	17	--
17	01109290	Annawamscott Brook, Rt. 103, at Peck Corner, RI	41.75955	-71.34311	1.14	2004	14	--
18	01109381	Speedway Brook at Attleboro, MA	41.92704	-71.28505	2.86	1992–94, and 2003	13	--
19	01111261	Clear River at North Road at Laurel Hill, RI	41.96704	-71.70868	12.5	1993–95, and 2003	16	--
20	01111330	Clear River at Oakland, RI	41.95677	-71.64923	45.4	1993–94, and 2003	16	--
21	01111470	Tarklin Brook at Oak Valley, RI	41.96871	-71.60034	9.25	1993–94 and 2002–03	18	--
22	01112190	Muddy Brook at South Milford, MA	42.09315	-71.51923	6.23	1978, 1985–86, 1994–97, and 2003	21	--
23	01113670	Burnt Swamp Brook near Grants Mills, RI	42.01399	-71.38978	4.67	1986, 1993–94, and 2003	17	--
24	01113710	Ash Swamp Brook at Nate Whipple Highway at Diamond Hill, RI	41.98260	-71.41200	4.27	1993–97	26	Occasional flow alteration by upstream reservoir
25	01114400	Stillwater River at Pleasant View Road at Spragueville, RI	41.88510	-71.53312	12.8	1993–94 and 2003	16	

**Table 4.** Description of partial-record stations in and near Rhode Island.—Continued

[Station no.: locations of partial-record stations shown by number in figure 8. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; p, present; --, none; NWIS, National Water Information System]

Sta- tion no.	USGS station no.	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drain- age area (mi <sup>2</sup> )	Water years with streamflow measure- ments	Number of streamflow measurements through water year 2006	Remarks
26	01115010	Woonasquatucket River at Providence, RI	41.82232	-71.43978	48.0	1986–88	18	Occasional flow alteration by upstream reservoir
27	01115110	Huntinghouse Brook at Elmdale Road at North Scituate, RI	41.84677	-71.61173	6.23	1993–2007 and 2009–p	83	Operated as a continuous streamgage since water year 2009–p
28	01115114	Rush Brook near Elmdale Road near North Scituate, RI	41.83760	-71.61201	4.70	1998–2006 and 2009–p	55	Operated as a continuous streamgage since water year 2009–p
29	01115120	Unnamed Tributary to Regulating Reservoir near North Scituate, RI	41.83149	-71.60895	0.28	1994–2006 and 2009–p	79	Operated as a continuous streamgage since water year 2009–p
30	01115160	Blanchard Brook near North Scituate, RI	41.85427	-71.57534	1.18	1995 and 2000	11	--
31	01115165	Unnamed Tributary to Moswansicut Pond near North Scituate, RI	41.83816	-71.56840	0.30	1994–95, 2003, and 2009–11	17	--
32	01115170	Moswansicut Stream near North Scituate, RI	41.84093	-71.58451	3.25	1994–95 and 2000–p	57	Operated as a continuous streamgage since water year 2009–p
33	01115178	Pine Swamp Brook at Rt. 116 at North Scituate, RI	41.82871	-71.58701	0.45	1993–95, 2003, and 2009–p	16	--
34	01115180	Brandy Brook at Rt. 116 at Saundersville, RI	41.81954	-71.58590	1.57	1993–2006 and 2009–p	83	--
35	01115182	Halls Estate Brook at Rt. 116 near North Scituate, RI	41.80760	-71.58534	0.28	1993–95, 2003, and 2009–p	20	--
36	01115183	Quonapaug Brook at Rt. 116 near North Scituate, RI	41.79760	-71.58479	1.96	1993–p	84	Operated as a continuous streamgage since water year 2009–p
37	01115184	Spruce Brook near North Scituate, RI	41.78871	-71.62006	1.22	1994–2007 and 2009–p	80	Operated as a continuous streamgage since water year 2009–p
38	01115185	Winsor Brook at Winsor Road near South Foster, RI	41.83621	-71.72257	4.33	1993–95, 1998–2007, and 2009–11	73	--
39	01115190	Dolly Cole Brook at Old Danielson Pike at South Foster, RI	41.82232	-71.70035	4.90	1993–p	87	Operated as a continuous streamgage since water year 2009–p
40	01115200	Shippee Brook Tributary at North Foster, RI	41.83149	-71.75229	2.37	1994–95, 2003, and 2009–11	18	--

**Table 4.** Description of partial-record stations in and near Rhode Island.—Continued

[Station no.: locations of partial-record stations shown by number in figure 8. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; p, present; --, none; NWIS, National Water Information System]

Sta-tion no.	USGS station no.	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drain-age area (mi <sup>2</sup> )	Water years with streamflow measurements	Number of streamflow measurements through water year 2006	Remarks
41	01115265	Hemlock Brook at King Road near Foster, RI	41.79065	-71.69868	8.72	1996–p	66	Operated as a continuous streamgage since water year 2009–p
42	01115270	Hemlock Brook at Hemlock Road near Clayville, RI	41.79149	-71.68229	10.6	1993–94 and 2003	14	--
43	01115273	Unnamed Tributary to Westconnaug Reservoir near Clayville, RI	41.75038	-71.68312	0.72	1994–95, 2003, and 2009–10	20	--
44	01115274	Westconnaug Brook at Isthmus Road near Clayville, RI	41.76149	-71.68812	1.48	1994–95, 2003, and 2009–11	20	--
45	01115275	Bear Tree Brook near Clayville, RI	41.78260	-71.67479	0.62	1994–95, 2000–07, and 2009–p	60	Operated as a continuous streamgage since water year 2009–p
46	01115276	Westconnaug Stream at Plainfield Pike, RI	41.78538	-71.66729	5.18	1994–95, 2003, and 2008–p	19	Operated as a continuous streamgage since water year 2009–p
47	01115280	Cork Brook at Rockland Scituate Road near Clayville, RI	41.80399	-71.64979	1.79	1993–p	86	Operated as a continuous streamgage since water year 2009–p
48	01115297	Wilbur Hollow Brook at Old Plainfield Pike near Clayville, RI	41.76482	-71.63562	4.33	1993–p	86	Operated as a continuous streamgage since water year 2009–p
49	01115350	Coventry Brook at Rt. 12 near Clayville, RI	41.74621	-71.60979	0.78	1993–95	15	--
50	01115400	Kent Brook at Rt. 116 at Waterman Four Corners, RI	41.77954	-71.56951	0.85	1986, 1993–95, and 2009–11	19	--
51	01115700	Congdon River Tributary near Nooseneck, RI	41.61288	-71.61784	0.48	1995–99	31	--
52	01115730	Carr River near Washington, RI	41.63371	-71.58062	2.30	1995 and 1997–99	24	--
53	01115800	Big River near Nooseneck, RI	41.64482	-71.61284	22.5	1993–99 and 2007–12	50	Operated as a continuous streamgage during water years 2007–12
54	01115830	Bear Brook near Coventry, RI	41.66038	-71.62784	3.98	1961–63 and 1996–99	38	--
55	01115963	Old Hickory Brook near Washington, RI	41.65649	-71.59951	0.28	1996–99	30	--
56	01115965	Lake Mishnock outflow near Washington, RI	41.65566	-71.59062	0.29	1996–99	30	--
57	01115970	Mishnock River near Washington, RI	41.67899	-71.58062	3.02	1961–63 and 1996–99	39	--
58	01116602	Pocasset River, Memorial Avenue, at Johnston, RI	41.82760	-71.50784	2.99	2004	14	--
59	01116609	Pocasset River at Cranston, RI	41.75982	-71.44339	19.9	2004	14	--
60	01116635	Old Mill Creek at Warwick, RI	41.71205	-71.37533	5.38	1986–88 and 2003	22	--

**Table 4.** Description of partial-record stations in and near Rhode Island.—Continued

[Station no.: locations of partial-record stations shown by number in figure 8. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; p, present; --, none; NWIS, National Water Information System]

Sta- tion no.	USGS station no.	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drain- age area (mi <sup>2</sup> )	Water years with streamflow mea- surements	Number of streamflow measurements through water year 2006	Remarks
61	01116750	Maskerchug River, Boston Post Road, East Greenwich, RI	41.65010	-71.45784	5.73	1986–88 and 2003	22	--
62	01116800	Scabbletown Brook near Davisville, RI	41.59427	-71.49339	1.33	1961–63 and 1995–97	29	--
63	01116820	Hunt River Tributary near Davisville, RI	41.60427	-71.49306	1.31	1961–63 and 1995–97	26	--
64	01116850	Hunt River at Davisville, RI	41.62371	-71.48200	5.80	1961–63, 1991, and 1995–97	16	--
65	01116875	Frenchtown Brook at Rt. 2 near Davisville, RI	41.62482	-71.49228	6.56	1995–97	17	--
66	01116880	Frenchtown Brook at Davisville, RI	41.62593	-71.48367	6.98	1961–63, 1991, and 1995–97	16	--
67	01116895	Fry Brook near East Greenwich, RI	41.63232	-71.48673	3.09	1995–97	18	--
68	01116950	Sandhill Brook at Davisville, RI	41.60955	-71.47034	1.77	1961–63, 1995–97, and 2003	18	--
69	01116980	Sandhill Brook near East Greenwich, RI	41.62927	-71.44700	3.64	1961–64, 1995–97, and 2003	17	--
70	01117050	Cocumusso Brook near Wickford, RI	41.58371	-71.45895	1.41	1995–97	18	--
71	01117070	Annaquaticket River at Wickford Junction, RI	41.57343	-71.48784	2.87	1961–63, 1996–97, and 2003	16	--
72	01117170	Mattatuxet River at Allenton, RI	41.53788	-71.46867	1.62	1961–64, 1995–97, and 2003	18	--
73	01117200	Mattatuxet River near Saunderstown, RI	41.51955	-71.44506	4.76	1961–64 and 1995–97	24	--
74	01117230	Saugatucket River at Peacedale, RI	41.46482	-71.49089	9.20	2004	14	--
75	01117237	Saugatucket River, Church Street, at Peacedale, RI	41.44760	-71.49700	15.1	2004	14	--
76	01117260	Unnamed Tributary to Card Ponds near Perryville, RI	41.38260	-71.57145	2.08	2004	14	--
77	01117285	King Tom Pond inlet near Charlestown, RI	41.38455	-71.65362	2.54	1966 and 2004	16	--
78	01117336	Chipuxet River near West Kingston, RI	41.51760	-71.52334	6.35	1959–60, 1972, 1980, and 2002–2004	19	--
79	01117354	Queen River, Rt. 102, at Exeter, RI	41.57871	-71.54312	2.77	1993 and 2000–04	29	--
80	01117355	Queen River at William Reynolds Road near Exeter, RI	41.56260	-71.54784	3.74	1959–60, 1988–93, and 1999–02	63	Occasional flow alterations by upstream withdrawals for irrigation
81	01117360	Fisherville Brook at Liberty Church Road near Exeter, RI	41.56427	-71.56451	8.09	1959–60, 1988–93, and 2000–04	65	--
82	01117367	Queens Fort Brook near intersection of Dawley and School Lands Roads near Exeter, RI	41.54649	-71.55256	3.90	2000–03	29	--
83	01117368	Queen River at Dawley Road near Exeter, RI	41.54871	-71.56034	18.1	1993 and 2000–02	23	--
84	01117375	Unnamed Tributary to Queen River at Mail Road at Liberty, RI	41.53899	-71.57951	0.77	1988–91 and 1999–2004	48	--
85	01117380	Locke Brook at Mail Road at Liberty, RI	41.53732	-71.58756	4.20	1959–60, 1989–91, 1993, and 2000–04	61	--

**Table 4.** Description of partial-record stations in and near Rhode Island.—Continued

[Station no.: locations of partial-record stations shown by number in figure 8. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; p, present; --, none; NWIS, National Water Information System]

Sta-tion no.	USGS station no.	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drain-age area (mi <sup>2</sup> )	Water years with streamflow measurements	Number of streamflow measurements through water year 2006	Remarks
86	01117385	Rake Factory Brook at Glen Rock Road at Glen Rock, RI	41.51899	-71.59895	0.28	1988–91 and 1999–2004	51	--
87	01117390	Glen Rock Brook at Glen Rock Road at Glen Rock, RI	41.51649	-71.60590	2.82	1989–91, 1993, and 2000–04	59	--
88	01117400	Sherman Brook at Glen Rock Road at Glen Rock, RI	41.51788	-71.60451	1.03	1989–91, 1993, and 2000–04	58	--
89	01117421	Chickasheen Brook at Rt. 2 at West Kingston, RI	41.49843	-71.56478	3.28	2002–04	14	--
90	01117450	Pasquiset Brook at Rt. 2 at Kenyon, RI	41.44399	-71.62701	6.02	1966–67, 1974, 1976, 1980, and 2002–04	20	--
91	01117465	Beaver River near Wyoming, RI	41.52566	-71.63923	5.25	1966–67, 1974, 1976, 1991, and 2002–04	22	--
92	01117480	Taney Brook at Carolina, RI	41.46066	-71.64784	1.61	1966–67 and 2002–04	18	--
93	01117700	Cedar Swamp Brook at Wood River Junction, RI	41.42704	-71.69507	4.81	1966–67 and 2002–04	18	--
94	01117720	Wood River at Escoheag, RI	41.61260	-71.76635	11.3	1966–67, 1991, and 2002–04	20	--
95	01117740	Kelley Brook at Escoheag, RI	41.61232	-71.75312	4.40	1966–67, 1991, and 2002–04	20	--
96	01117750	Factory Brook near Summit, RI	41.63316	-71.72229	1.16	1966 and 2002–04	15	--
97	01117760	Flat River at Plain Road near Arcadia, RI	41.59566	-71.72007	8.22	1979, 1982, and 2002–04	15	--
98	01117780	Breakheart Brook, Frosty Hollow Road, near Arcadia, RI	41.58788	-71.70951	6.56	1966–67, 1979, 1982, 1991–92, and 2002–04	22	--
99	01117840	Parris Brook at Blitzkrieg Trail near Arcadia, RI	41.56510	-71.72590	6.61	1966–67, 1979, 1991, and 2002–04	22	--
100	01117860	Roaring Brook at Arcadia, RI	41.55843	-71.68507	5.04	1966–67, 1991, and 2002–04	21	--
101	01117900	Brushy Brook near Hope Valley, RI	41.52871	-71.73646	3.64	1966–67, 1977, 1979, 1991, and 2002–04	21	--
102	01117950	Moscow Brook near Hope Valley, RI	41.52732	-71.73618	6.21	1966–67, 1977, 1979, 1991, and 2002–04	22	--
103	01118006	Canonchet Brook, Rockville-Alton Road, Hope Valley, RI	41.47760	-71.72923	6.61	1977, 1979, 1980, 1991, and 2002–04	19	--
104	01118008	Wood River Tributary at Alton, RI	41.43760	-71.72312	2.05	1977 and 2002–04	15	--
105	01118009	Wood River near Alton, RI	41.43621	-71.72090	88.3	1977, 1979–81, 1991, and 2002–04	18	--

**Table 4.** Description of partial-record stations in and near Rhode Island.—Continued

[Station no.: locations of partial-record stations shown by number in figure 8. USGS, U.S. Geological Survey; no., number; mi<sup>2</sup>, square miles; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; p., present; --, none; NWIS, National Water Information System]

Station no.	USGS station no.	Station name	Latitude (decimal degrees)	Longitude (decimal degrees)	Drainage area (mi <sup>2</sup> ) <sup>1</sup>	Water years with streamflow measurements	Number of streamflow measurements through water year 2006	Remarks
106	01118022	Perry-Healy Brook at Klondike Road near Bradford, RI	41.37454	-71.71590	2.36	2002–04	13	--
107	01118055	Tomaquag Brook at Rt. 216 at Bradford, RI	41.41111	-71.76417	6.71	1991 and 2002–04	16	--
108	01118255	Green Fall River at Laurel Glen, CT	41.47232	-71.81618	7.58	1963–67 and 2002–04	24	--
109	01118340	Wyassup Brook at Rt. 216 at Clarks Falls, CT	41.45472	-71.82667	11.5	2002–04	14	--
110	01118350	Green Fall River at Clarks Falls, CT	41.45482	-71.81396	20.0	1961–73	25	--
111	01118352	Glade Brook near Laurel Glen, CT	41.46815	-71.80813	1.83	1965–67 and 2002–04	18	--
112	01118355	Paramenter Brook near Hopkinton, RI	41.44760	-71.79035	2.45	1966–67 and 2002–04	17	--
113	01118365	Lewis Pond Outlet near Potter Hill, RI	41.42038	-71.82174	1.60	1966–67 and 2002–04	18	--
114	01118373	Shunock River at North Stonington, RI	41.44093	-71.88229	7.77	1965 and 2002–04	15	--
115	01118375	Assekonk Brook near North Stonington, CT	41.43871	-71.91035	1.70	1963–65 and 2002–04	26	--
116	01118380	Assekonk Brook at North Stonington, CT	41.43871	-71.88424	3.88	1963–65 and 2002–04	22	--
117	01118700	Whitford Brook at Old Mystic, CT	41.39482	-71.96063	15.0	1961–73	23	--
118	01118750	Haleys Brook near Old Mystic, CT	41.38899	-71.98391	4.41	1962–65, 1967, 1969–75, 1977–78, and 1984	33	--
119	01125260	Muddy Brook at Rt. 197 at North Woodstock, CT	41.99565	-71.99063	7.47	1962 and 1979–81	21	--
120	01125300	English Neighborhood Brook at North Woodstock, CT	41.99093	-71.99702	4.47	1961–75, 1977–78, and 1984	39	--
121	01125400	Muddy Brook at East Woodstock, CT	41.98426	-71.98063	12.9	1961–63 and 1979–81	30	--
122	01125404	Muddy Brook near East Woodstock, CT	41.97649	-71.96896	16.2	1979–81	18	--
123	01125411	Muddy Brook near Woodstock, CT	41.96732	-71.96396	18.0	1979–81	19	--
124	01125440	Mill Brook at South Woodstock, CT	41.94038	-71.95730	6.73	1961–63 and 1982–83	22	--
125	01125650	Wappoquia Brook near Pomfret, CT	41.86593	-71.95785	4.27	1961–75, 1977–78, and 1984	39	--
126	01125800	Fivemile River near East Thompson, CT	41.98649	-71.81535	10.5	1961–73	19	--
127	01125900	Cady Brook at East Putnam, CT	41.90899	-71.81924	8.33	1961–75, 1977–79, and 1984	32	--
128	01126100	Whetstone Brook at Elmville, CT	41.83621	-71.86674	13.7	1961–63	12	--
129	01126111	Fivemile River at Danielson, CT	41.80204	-71.88702	74.8	1962, 1991–95, 1997–99, and 2001	30	--
130	01126300	Quaduck Brook at North Sterling, CT	41.77177	-71.79618	8.21	1960–64	15	--
131	01126510	Moosup River near Central Village, CT	41.72065	-71.91618	87.8	1962 and 2000–01	12	--
132	01126700	Kitt Brook near Canterbury, CT	41.68065	-71.97785	9.99	1961–75	27	--
133	01126800	Cory Brook near Canterbury, CT	41.65260	-71.99563	5.73	1961–63	13	--
134	01126920	Mount Misery Brook near Voluntown, CT	41.59343	-71.86391	7.95	1961–63	13	--
135	01127100	Broad Brook near Preston City, CT	41.55399	-71.97035	12.3	1961–65 and 1967–75	27	--

<sup>1</sup>Drainage areas (in mi<sup>2</sup>) were determined with a GIS and do not supersede areas listed in the USGS NWIS database.

## Equations for Estimating Selected Streamflow Statistics in Rhode Island

**Table 5.** Summary of data used by the Maintenance of Variance Extension, type 1 (MOVE.1), record-extension technique to estimate long-term streamflow statistics for short-term streamgages and partial-record stations in and near Rhode Island.

[USGS station no.: locations of short-term streamgages shown in figure 2 and described in table 1. Locations of partial-record stations shown in figure 8 and described in table 4 (in back of report). USGS, U.S. Geological Survey; no., number; MOVE.1, Maintenance of Variance Extension, type 1; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; ft, foot; --, none]

Sta- tion no.	USGS station no.	Station name and location	Number of wa- ter years with daily mean streamflow or streamflow measure- ments used in relation		Number of zero-flow measure- ments used in relation		MOVE.1 index stream- gage relation	Correlation coefficient between streamflow data at site and index stream- gage	Approximate minimum- flow duration covered by streamflow data, in percent	Approximate maximum- flow duration covered by streamflow data, in percent	Approximate total flow- duration range covered by streamflow data, in percent
			in relation	in relation	in relation	in relation					
Short-term streamgages											
--	01109090	Rattlesnake Brook near Assonet, MA	2	639	--	01115098	0.92	99.5	0.1	99.4	
--	01109220	Palmer River at South Rehoboth, MA	3	950	--	01115098	0.94	99.5	0.1	99.4	
--	01111050	Mumford River at Uxbridge, MA	2	731	--	01117800	0.91	99.0	0.1	98.9	
--	01111225	Emerson Brook near Uxbridge, MA	2	758	--	01111500	0.94	99.5	0.5	99.0	
--	01111410	Chepachet River west of Gazzaville, RI	5	1,496	--	01123000	0.89	99.0	0.1	99.0	
--	01115670	Congdon River near Nooseneck, RI	2	731	--	01117468	0.94	98.0	0.5	97.5	
--	01115900	Flat River near Coventry, RI	3	914	--	01109000	0.92	99.5	0.5	99.0	
--	01116905	Hunt River, 250 ft downstream of Fry Brook, at Frenchtown, RI	2	548	--	01117468	0.95	99.5	0.5	99.0	
--	01117410	Usquepaug River at Rt. 138 at Usquepaug, RI	5	1,761	--	01117468	0.98	99.5	0.1	99.4	
--	01117424	Chickashen Brook at West Kingston, RI	4	811	--	01117468	0.94	96.0	1.0	95.0	
--	01117430	Pawcatuck River at Rt. 2 at Kenyon, RI	5	1,828	--	01117500	0.99	99.9	1.0	98.9	
--	01117471	Beaver River at Shannock Hill Road near Shannock, RI	3	800	--	01117468	0.98	96.0	1.0	95.0	
--	01117472	Beaver River at Kenyon, RI	4	1,188	--	01117468	0.97	98.0	0.1	97.9	
--	01118010	Pawcatuck River at Burdickville, RI	4	863	--	01117500	0.99	99.9	1.0	98.9	
--	01118360	Ashaway River at Ashaway, RI	4	853	--	01117800	0.96	99.0	0.1	98.9	
--	01118400	Shunock River at North Stonington, RI	3	807	--	01117800	0.97	94.0	0.1	93.9	
--	01118668	Whitford Brook below Williams Brook near Old Mystic, CT	5	1,158	--	01118300	0.95	99.5	0.5	99.0	
--	01119280	Willimantic River at Stafford Springs, CT	5	1,826	--	01123000	0.92	100.0	0.5	99.5	
--	01119320	Roaring Brook near Stafford Springs, CT	6	1,887	--	01121000	0.94	99.5	0.5	99.0	
--	01125415	Muddy Brook at Childs Hill Road near Woodstock, CT	5	1,801	--	01121000	0.93	99.0	0.1	99.0	
--	01125600	Mashamoquet Brook at Abington, CT	2	548	--	011175670	0.92	99.5	0.5	99.0	
Partial-record stations											
1	01105928	Buttonwood Brook near South Dartmouth, MA	5	15	1	01106000	0.89	100.0	20.0	80.0	
2	01105930	Paskamanset River at Turner Pond near New Bedford, MA	4	26	--	01109000	0.90	99.5	20.0	79.5	
3	01105935	Destruction Brook near South Dartmouth, MA	7	27	--	01105600	0.93	98.0	45.0	53.0	
4	01105937	Shingle Island River near North Dartmouth, MA	10	32	--	01109000	0.85	98.0	20.0	78.0	
5	01105950	Kirby Brook near Head of Westport, MA	6	16	1	01106000	0.90	95.0	20.0	75.0	

**Table 5.** Summary of data used by the Maintenance of Variance Extension, type 1 (MOVE.1), record-extension technique to estimate long-term streamflow statistics for short-term streamgages and partial-record stations in and near Rhode Island.—Continued

[USGS station no.: locations of short-term streamgages shown in figure 2 and described in table 1. Locations of partial-record stations shown in figure 8 and described in table 4 (in back of report). USGS, U.S. Geological Survey; no., number; MOVE.1, Maintenance of Variance Extension, type 1; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; ft, foot; --, none.]

Station no.	USGS station no.	Station name and location	Number of winter years with daily mean streamflow or streamflow measurements used in relation in relation	Number of streamflows or streamflow measurements used in relation	Number of zero-flow measurements used in relation	MOVE.1 index streamgage	Correlation coefficient between streamflow data at site and index	Approximate minimum-flow duration covered by streamflow data, in percent	Approximate maximum-flow duration covered by streamflow data, in percent	Approximate total flow-range covered by streamflow data, in percent, in percent
Partial-record stations—Continued										
6	01106005	Angeline Brook near Head of Westport, MA	5	16	1	01106000	0.94	100.0	20.0	80.0
7	01106110	Dundery Brook, Meetinghouse Lane at Little Compton, RI	1	13	--	01106000	0.97	80.0	15.0	65.0
8	01106130	Little Creek, Green End Avenue, near Whitehall, RI	1	14	--	01106000	0.95	85.0	15.0	70.0
9	01106150	Bailey Brook, Forest Avenue, near Middletown, RI	1	13	--	01109000	0.96	91.0	8.0	83.0
10	01107400	Fall Brook near Middleborough, MA	8	36	--	01109000	0.96	99.5	0.0	99.5
11	01109087	Assonet River at Assonet, MA	5	22	--	01109000	0.93	98.0	0.1	97.9
12	01109135	Cole River near Swansea, MA	4	15	--	01106000	0.92	80.0	1.0	79.0
13	01109185	East Branch Palmer River near Rehoboth, MA	4	13	1	01109000	0.92	99.5	9.0	90.5
14	01109225	Rocky Run near Rehoboth, MA	13	38	--	01109000	0.93	99.5	9.0	90.5
15	01109270	Runnings River at Seekonk, MA	7	20	--	01109000	0.96	85.0	0.5	84.5
16	01109280	Runnings River, Fall River Avenue, at Seekonk, MA	3	17	--	01109000	0.94	93.0	0.1	92.9
17	01109290	Annawamsicut Brook, Rt. 103, at Peck Corner, RI	1	14	--	01109000	0.94	91.0	8.0	83.0
18	01109381	Speedway Brook at Attleboro, MA	4	13	--	01109000	0.94	99.5	15.0	84.5
19	01111261	Clear River at North Road at Laurel Hill, RI	4	15	--	01111500	0.84	96.0	20.0	76.0
20	01111330	Clear River at Oakland, RI	3	15	--	01111500	0.95	96.0	20.0	76.0
21	01111470	Tarklin Brook at Oak Valley, RI	3	12	--	01111300	0.95	92.0	35.0	57.0
22	01112190	Muddy Brook at South Milford, MA	8	21	--	01111300	0.92	99.0	30.0	69.0
23	01113670	Burnt Swamp Brook near Grants Mills, RI	4	16	--	01109000	0.94	99.0	15.0	84.0
24	01113710	Ash Swamp Brook at Nate Whipple Highway at Diamond Hill, RI	5	26	--	01105730	0.96	99.5	2.0	97.5
25	01114400	Stillwater River at Pleasant View Road at Spragueville, RI	3	16	--	01109000	0.94	99.5	15.0	84.5
26	01115010	Woonasquatucket River at Providence, RI	3	18	--	01111500	0.97	90.0	0.1	90.0
27	01115110	Huntinghouse Brook at Elmdale Road at North Scituate, RI	12	73	7	01115187	0.97	98.0	0.1	97.9
28	01115114	Rush Brook near Elmdale Road near North Scituate, RI	9	54	2	01115187	0.95	98.0	2.0	96.0
29	01115120	Unnamed Tributary to Regulating Reservoir near North Scituate, RI	13	69	21	01117468	0.90	98.0	2.0	96.0
30	01115160	Blanchard Brook near North Scituate, RI	2	11	2	01115187	0.99	96.0	20.0	76.0

## Equations for Estimating Selected Streamflow Statistics in Rhode Island

**Table 5.** Summary of data used by the Maintenance of Variance Extension, type 1 (MOVE.1), record-extension technique to estimate long-term streamflow statistics for short-term streamgages and partial-l-record stations in and near Rhode Island.—Continued

[USGS station no.: locations of short-term streamgages shown in figure 2 and described in table 1. Locations of partial-record stations shown in figure 8 and described in table 4 (in back of report). USGS, U.S. Geological Survey; no., number; MOVE.1, Maintenance of Variance Extension, type 1; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; ft, foot; --, none]

Sta- tion no.	USGS station no.	Station name and location	Number of wa- ter years with daily mean streamflow or streamflow measure- ments used in relation in relation	Number of daily mean stream- flows or streamflow measure- ments used in relation in relation	Correlation coefficient between streamflow data at site and index stream- gauge	Approximate minimum- flow duration covered by streamflow data, in percent	Approximate maximum- flow duration covered by streamflow data, in percent	Approximate total flow- duration range covered by streamflow data, in percent
Partial-record stations—Continued								
31	01115165	Unnamed Tributary to Moswansicut Pond near North Scituate, RI	3	16	0.94	100.0	30.0	70.0
32	01115170	Moswansicut Stream near North Scituate, RI	8	48	0.88	98.0	1.0	97.0
33	01115178	Pine Swamp Brook at Rt. 116 at North Scituate, RI	3	13	0.94	99.0	15.0	84.0
34	01115180	Brandy Brook at Rt. 116 at Saundersville, RI	12	71	0.95	98.0	1.0	97.0
35	01115182	Halls Estate Brook at Rt. 116 near North Scituate, RI	3	15	0.91	99.0	30.0	69.0
36	01115183	Quonapaug Brook at Rt. 116 near North Scituate, RI	12	70	0.94	98.0	4.0	94.0
37	01115184	Spruce Brook near North Scituate, RI	12	73	0.94	98.0	0.1	97.9
38	01115185	Winsor Brook at Winsor Road near South Foster, RI	11	61	0.96	98.0	2.0	96.0
39	01115190	Dolly Cole Brook at Old Danielson Pike at South Foster, RI	13	82	0.91	99.0	0.5	98.5
40	01115200	Shippee Brook Tributary at North Foster, RI	2	11	0.96	96.0	30.0	66.0
41	01115265	Hemlock Brook at King Road near Foster, RI	11	66	0.96	98.0	2.0	96.0
42	01115270	Hemlock Brook at Hemlock Road near Clayville, RI	3	14	0.93	99.5	35.0	64.5
43	01115273	Unnamed Tributary to Westconnaug Reservoir near Clayville, RI	2	11	0.98	98.0	20.0	78.0
44	01115274	Westconnaug Brook at Isthmus Road near Clayville, RI	2	11	0.92	98.0	20.0	78.0
45	01115275	Bear Tree Brook near Clayville, RI	8	52	0.87	98.0	2.0	96.0
46	01115276	Westconnaug Stream at Plainfield Pike, RI	3	17	0.92	100.0	30.0	70.0
47	01115280	Cork Brook at Rockland Scituate Road near Clayville, RI	12	77	0.97	98.0	0.1	97.9
48	01115297	Wilbur Hollow at Old Plainfield Pike near Clayville, RI	14	86	0.92	100.0	4.0	96.0
49	01115350	Coventry Brook at Rt. 12 near Clayville, RI	3	15	0.89	100.0	45.0	55.0
50	01115400	Kent Brook at Rt. 116 at Waterman Four Corners, RI	2	12	0.94	99.5	45.0	54.5
51	01115700	Congdon River Tributary near Nooseneck, RI	5	30	0.95	97.0	5.0	92.0
52	01115730	Carr River near Washington, RI	4	23	0.94	98.0	4.0	94.0
53	01115800	Big River near Nooseneck, RI	7	50	0.97	98.0	1.0	97.0
54	01115830	Bear Brook near Coventry, RI	4	30	0.87	94.0	7.0	87.0
55	01115963	Old Hickory Brook near Washington, RI	4	30	0.85	94.0	7.0	87.0
56	01115965	Lake Mishnock outflow near Washington, RI	4	29	0.86	97.0	8.0	89.0
57	01115970	Mishnock River near Washington, RI	4	30	0.83	94.0	7.0	87.0
58	01116602	Pocasset River, Memorial Avenue, at Johnston, RI	1	14	0.95	85.0	25.0	60.0
59	01116609	Pocasset River at Cranston, RI	1	14	0.92	85.0	25.0	60.0
60	01116635	Old Mill Creek at Warwick, RI	4	22	0.87	85.0	0.5	84.5

**Table 5.** Summary of data used by the Maintenance of Variance Extension, type 1 (MOVE.1), record-extension technique to estimate long-term streamflow statistics for short-term streamgages and partial-record stations in and near Rhode Island.—Continued

[USGS station no.: locations of short-term streamgages shown in figure 2 and described in table 1. Locations of partial-record stations shown in figure 8 and described in table 4 (in back of report). USGS, U.S. Geological Survey, no., number; MOVE.1, Maintenance of Variance Extension, type 1; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; ft, foot; --, none]

Sta- tion no.	USGS station no.	Station name and location	Number of wa- ter years with daily mean streamflow or streamflow measure- ments used in relation in relation	Number of daily mean stream- flows or streamflow measure- ments used in relation	Num- ber of zero-flow measure- ments used in relation	MOVE.1 index stream- gage	Correlation coefficient between streamflow data at site and index	Approximate maximum- flow duration covered by streamflow data, in percent	Approximate total flow- duration range covered by streamflow data, in percent
Partial-record stations—Continued									
61	01116750	Maskerchugg River, Boston Post Road, East Greenwich, RI	3	20	--	01117468	0.95	98.0	0.5
62	01116800	Scabletton Brook near Davisville, RI	3	18	--	01115098	0.98	95.0	5.0
63	01116820	Hunt River Tributary near Davisville, RI	3	17	--	01117800	0.95	99.0	4.0
64	01116850	Hunt River at Davisville, RI	7	15	--	01118300	0.81	99.0	20.0
65	01116875	Frenchtown Brook at Rt. 2 near Davisville, RI	3	17	--	01117800	0.98	99.0	4.0
66	01116880	Frenchtown Brook at Davisville, RI	7	15	--	01109000	0.92	98.0	15.0
67	01116895	Fry Brook near East Greenwich, RI	3	16	--	01118300	0.95	95.0	6.0
68	01116950	Sandhill Brook at Davisville, RI	7	18	--	01118300	0.89	97.0	20.0
69	01116980	Sandhill Brook near East Greenwich, RI	8	17	--	01118300	0.89	95.0	20.0
70	01117050	Cocomusso Brook near Wickford, RI	3	18	--	01118300	0.96	95.0	6.0
71	01117070	Annaquabucket River at Wickford Junction, RI	5	14	--	01118300	0.87	97.0	20.0
72	01117170	Mattatuxet River at Allenton, RI	8	17	--	01123000	0.87	99.5	25.0
73	01117200	Mattatuxet River near Saunderstown, RI	3	17	--	01117468	0.84	93.0	5.0
74	01117230	Saugatucket River at Peacedale, RI	1	14	--	01117468	0.98	91.0	15.0
75	01117237	Saugatucket River, Church Street, at Peacedale, RI	1	14	--	01117468	0.98	91.0	15.0
76	01117260	Unnamed Tributary to Card Ponds near Perryville, RI	1	14	--	01117468	0.82	91.0	15.0
77	01117285	King Tom Pond Inlet near Charlestowm, RI	2	14	--	01123000	0.88	92.0	25.0
78	01117336	Chipuxet River near West Kingston, RI	4	15	--	01117468	0.90	99.5	10.0
79	01117354	Queen River, Rt. 102, at Exeter, RI	5	26	--	01117468	0.96	98.0	2.0
80	01117355	Queen River at William Reynolds Road near Exeter, RI	10	60	--	01117468	0.96	97.0	7.0
81	01117360	Fisherville Brook at Liberty Church Road near Exeter, RI	11	62	--	01117468	0.97	98.0	4.0
82	01117367	Queens Fort Brook near intersection of Dawley and School Lands Roads near Exeter, RI	4	28	1	01117468	0.92	98.0	2.0
83	01117368	Queen River at Dawley Road near Exeter, RI	4	23	--	01117468	0.99	98.0	5.0
84	01117375	Unnamed Tributary to Queen River at Mail Road at Liberty, RI	10	46	11	01117468	0.93	99.5	8.0
85	01117380	Locke Brook at Mail Road at Liberty, RI	9	56	--	01117468	0.97	98.0	4.0

## Equations for Estimating Selected Streamflow Statistics in Rhode Island

**Table 5.** Summary of data used by the Maintenance of Variance Extension, type 1 (MOVE.1), record-extension technique to estimate long-term streamflow statistics for short-term streamgages and partial-record stations in and near Rhode Island.—Continued

[USGS station no.: locations of short-term streamgages shown in figure 2 and described in table 1. Locations of partial-record stations shown in figure 8 and described in table 4 (in back of report). USGS, U.S. Geological Survey; no., number; MOVE.1, Maintenance of Variance Extension, type 1; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; ft, foot; --, none]

Station no.	USGS station no.	Station name and location	Number of water years with daily mean streamflow or streamflow measurements used in relation in relation	Number of daily mean streamflows or streamflow measurements used in relation	Correlation coefficient between streamflow data at site and index streamgage	Approximate minimum-flow duration covered by streamflow data, in percent	Approximate maximum-flow duration covered by streamflow data, in percent	Approximate total flow-duration range covered by streamflow data, in percent
Partial-record stations—Continued								
86	01117385	Rake Factory Brook at Glen Rock, RI	10	41	17	0.91	99.5	6.0
87	01117390	Glen Rock Brook at Glen Rock, RI	9	59	--	0.91	98.0	2.0
88	01117400	Sherman Brook at Glen Rock, RI	9	55	--	0.91	98.0	3.0
89	01117421	Chickasheen Brook at Rt. 2 at West Kingston, RI	2	12	--	0.91	92.0	10.0
90	01117450	Pasquiset Brook at Rt. 2 at Kenyon, RI	7	18	--	0.91	99.9	15.0
91	01117465	Beaver River near Wyoming, RI	8	22	--	0.91	99.5	15.0
92	01117480	Taney Brook at Carolina, RI	5	18	--	0.91	99.5	15.0
93	01117700	Cedar Swamp Brook at Wood River Junction, RI	5	17	--	0.91	99.5	15.0
94	01117720	Wood River at Escoheag, RI	6	20	--	0.91	99.5	20.0
95	01117740	Kelley Brook at Escoheag, RI	5	18	--	0.91	95.0	20.0
96	01117750	Factory Brook near Summit, RI	2	13	--	0.91	91.0	20.0
97	01117760	Flat River at Plain Road near Arcadia, RI	4	14	--	0.91	98.0	20.0
98	01117780	Breakheart Brook, Frosty Hollow Road, near Arcadia, RI	8	21	--	0.91	98.0	20.0
99	01117840	Parris Brook at Blitzkrieg Trail near Arcadia, RI	7	22	--	0.91	99.5	20.0
100	01117860	Roaring Brook at Arcadia, RI	6	21	--	0.91	98.0	20.0
101	01117900	Brushy Brook near Hope Valley, RI	8	21	--	0.91	99.5	15.0
102	01117950	Moscow Brook near Hope Valley, RI	8	22	--	0.91	98.0	15.0
103	01118006	Canonchet Brook, Rockville-Alton Road, Hope Valley, RI	7	19	--	0.91	99.5	10.0
104	01118008	Wood River Tributary at Alton, RI	3	14	--	0.91	98.0	10.0
105	01118009	Wood River near Alton, RI	8	18	--	0.91	99.5	40.0
106	01118022	Perry-Healy Brook at Klondike Road near Bradford, RI	3	12	--	0.91	98.0	10.0
107	01118055	Tomaquag Brook at Rt. 216 at Bradford, RI	4	16	--	0.91	98.0	10.0
108	01118255	Green Fall River at Laurel Glen, CT	8	23	--	0.91	99.5	20.0
109	01118340	Wyassup Brook at Rt. 216 at Clarks Falls, CT	3	14	--	0.91	99.5	20.0
110	01118350	Green Fall River at Clarks Falls, CT	13	25	--	0.91	99.0	0.5

**Table 5.** Summary of data used by the Maintenance of Variance Extension, type 1 (MOVE.1), record-extension technique to estimate long-term streamflow statistics for short-term streamgages and partial-record stations in and near Rhode Island.—Continued

[USGS station no.: locations of short-term streamgages shown in figure 2 and described in table 1. Locations of partial-record stations shown in figure 8 and described in table 4 (in back of report). USGS, U.S. Geological Survey; no., number; MOVE.1, Maintenance of Variance Extension, type 1; CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Rt., Route; ft, foot; --, none]

Sta- tion no.	USGS station no.	Station name and location	Number of wa- ter years with daily mean stream- flow or streamflow measure- ments measure- ments used in relation in relation	Number of daily mean stream- flows or streamflow measure- ments measure- ments used in relation in relation	MOVE.1 index stream- gage used in relation	Correlation coefficient between streamflow data at site and index stream- gage in percent	Approximate maximum- flow duration covered by streamflow data, in percent	Approximate total flow- duration range covered by streamflow data, in percent
Partial-record stations—Continued								
111	01118352	Glade Brook near Laurel Glen, CT	5	17	1	01118300	0.97	99.5
112	01118355	Paramenter Brook near Hopkinton, RI	5	17	--	01118300	0.98	99.0
113	01118365	Lewis Pond Outlet near Potter Hill, RI	4	17	--	01117800	0.95	99.0
114	01118373	Shunock River at North Stonington, RI	3	14	--	01117800	0.98	98.0
115	01118375	Assekonk Brook near North Stonington, CT	6	26	1	01118300	0.89	99.9
116	01118380	Assekonk Brook at North Stonington, CT	5	20	--	01118300	0.96	95.0
117	01118700	Whitford Brook at Old Mystic, CT	13	23	--	01118300	0.96	99.0
118	01118750	Haleys Brook near Old Mystic, CT	15	33	--	01118300	0.98	98.0
119	01125260	Muddy Brook at Rt. 197 at North Woodstock, CT	4	21	--	01121000	0.97	99.0
120	01125300	English Neighborhood Brook at North Woodstock, CT	18	39	--	01121000	0.96	99.0
121	01125400	Muddy Brook at East Woodstock, CT	6	30	--	01121000	0.97	99.0
122	01125404	Muddy Brook near East Woodstock, CT	4	18	--	01121000	0.94	91.0
123	01125411	Muddy Brook near Woodstock, CT	3	19	--	01121000	0.97	91.0
124	01125440	Mill Brook at South Woodstock, CT	5	22	--	01123000	0.92	98.0
125	01125650	Wappoqua Brook near Ponfret, CT	18	39	--	01121000	0.97	98.0
126	01125800	Fivemile River near East Thompson, CT	13	19	--	01121000	0.97	99.0
127	01125900	Cady Brook at East Putnam, CT	19	32	--	01123000	0.95	98.0
128	01126100	Whetstone Brook at Elmville, CT	3	11	--	01123000	0.96	98.0
129	01126111	Fivemile River at Danielson, CT	10	30	--	01123000	0.89	99.5
130	01126300	Quaduck Brook at North Sterling, CT	5	14	--	01121000	0.99	99.0
131	01126510	Moosup River near Central Village, CT	2	8	--	01115187	0.99	94.0
132	01126700	Kitt Brook near Canterbury, CT	15	27	--	01121000	0.98	99.0
133	01126800	Cory Brook near Canterbury, CT	3	13	--	01118300	0.95	97.0
134	01126920	Mount Misery Brook near Voluntown, CT	3	13	--	01123000	0.96	98.0
135	01127100	Broad Brook near Preston City, CT	14	25	--	01118300	0.97	97.0



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