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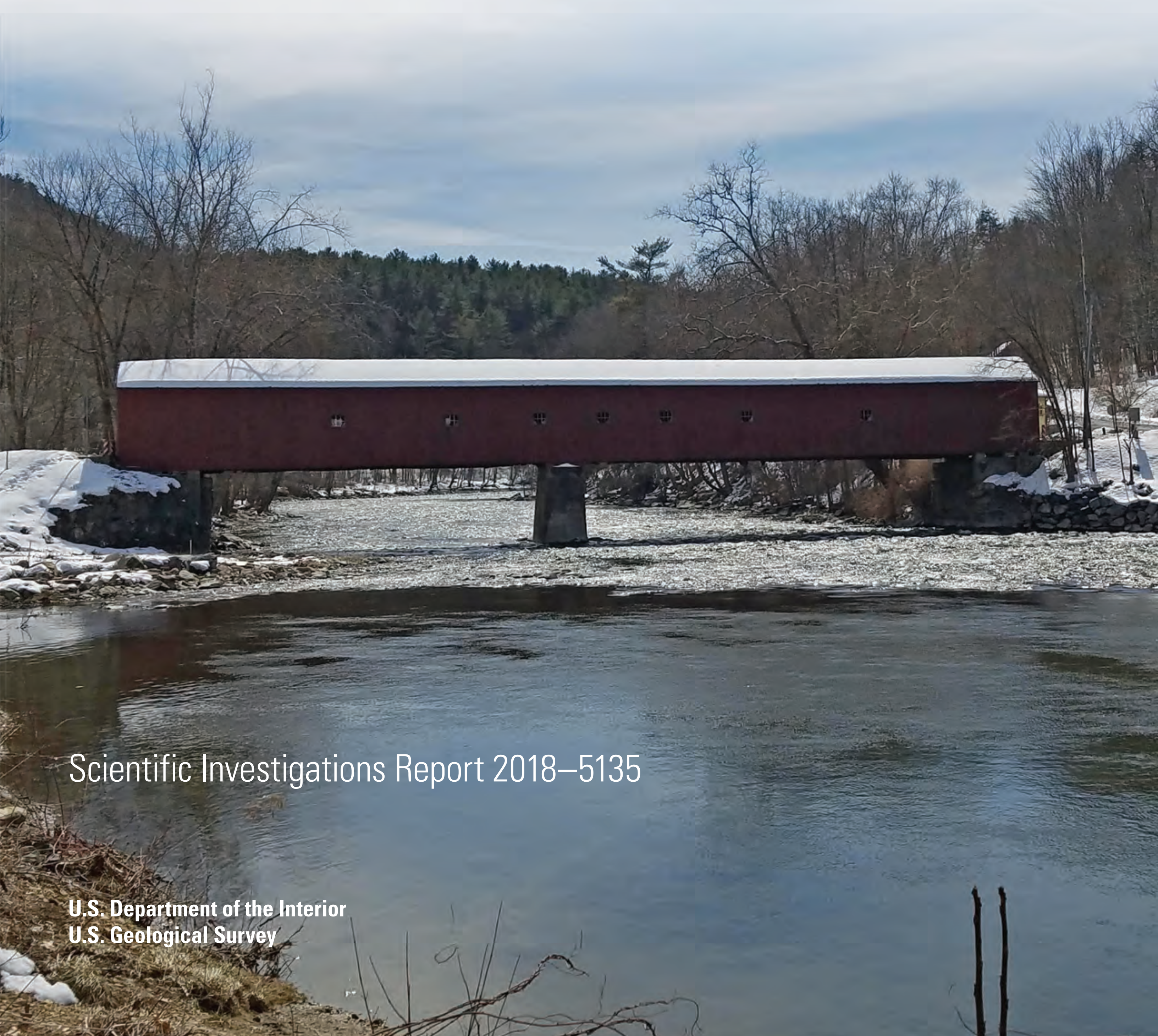
Connecticut Department of Energy and Environmental Protection

The Connecticut Streamflow and Sustainable Water Use Estimator: A Decision-Support Tool To Estimate Water Availability at Ungaged Stream Locations in Connecticut



Scientific Investigations Report 2018–5135

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

Cover. West Cornwall Covered Bridge spanning the Housatonic River near Cornwall, Connecticut. Photograph by Tracey Thayer, used with permission.

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U.S. Geological Survey
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Conversion Factors

U.S. customary units to International System of Units

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^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per hour (in/h)	0.0254	meter per hour (m/h)

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Datum

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).

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

Abbreviations

CT DEEP	Connecticut Department of Energy and Environmental Protection
CT SSWUE	Connecticut Streamflow and Sustainable Water Use Estimator
GIS	geographic information system
GUI	graphical user interface
NRMSE	normalized root-mean-square error
NSE	Nash-Sutcliffe efficiency
RG	reference streamgage
USGS	U.S. Geological Survey

The Connecticut Streamflow and Sustainable Water Use Estimator: A Decision-Support Tool To Estimate Water Availability at Ungaged Stream Locations in Connecticut

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Abstract

Freshwater streams in Connecticut are subject to many competing demands, including public water supply; agricultural, commercial, and industrial water use; and ecosystem and habitat needs. In recent years, drought has further stressed Connecticut's water resources. To sustainably allocate and manage water resources among these competing uses, Federal, State, and local water-resource managers require data and modeling tools to estimate the water availability at a variety of temporal and spatial scales for planning purposes. The Connecticut Streamflow and Sustainable Water Use Estimator (CT SSWUE), developed by the U.S. Geological Survey in cooperation with the Connecticut Department of Energy and Environmental Protection, is a decision-support tool for estimating daily unaltered streamflow and sustainable water use at ungaged sites in Connecticut.

The CT SSWUE estimates unaltered daily mean streamflow and water-use-adjusted streamflow for the period from October 1, 1960, to September 30, 2015, and the monthly sustainable net withdrawal at ungaged sites in Connecticut. Unaltered streamflow is the estimated daily mean streamflow in a drainage basin in the absence of any water withdrawals or wastewater discharges and with minimal human development. Sustainable net withdrawal is the maximum net withdrawal (withdrawal minus wastewater discharges) that can be drawn from a basin without critically depleting the water available through natural streamflow patterns. Sustainable net withdrawal is defined for this study as the difference between the unaltered daily mean streamflow and a user-defined target minimum streamflow.

Weighted least squares and Tobit regression techniques were used to develop equations for estimating streamflow at ungaged sites at 19 streamflow quantiles with exceedance probabilities ranging from 0.005 to 99.995 percent. Regressions were based on streamflow quantiles and basin characteristics from 36 reference streamgages in and around Connecticut. Four basin characteristics—drainage area, mean of the soil permeability, mean of the average annual precipitation, and ratio of the length of streams that overlay sand and gravel deposits to the total length of streams in the basin—are used as explanatory variables in the equations. At an ungaged site, interpolation between the streamflow quantiles estimated from the regression equations produces a continuous flow-duration curve. A time series of daily mean streamflow at an ungaged site is then estimated by assuming that for each day, the streamflow quantile occurs on the same date at both a reference streamgage and the ungaged site.

In a remove-one cross validation, estimated unaltered daily mean streamflow agreed well with observed values at reference streamgages, with a few exceptions. Nash Sutcliffe efficiency ranged from −0.43 to 0.97 with a median value of 0.88. The normalized root-mean-square error ranged from 16.6 to 120.4 percent with a median value of 34.5 percent.

An empirical method for estimating 95-percent prediction intervals for unaltered daily and monthly mean streamflow was developed and tested by using the cross-validation data. Prediction intervals for unaltered daily mean streamflow at the cross-validation reference streamgages performed well in most cases. Gaged streamflow values from the cross-validation data fell within the prediction intervals a median 96.6 percent of the time for daily mean time series and 93.9 percent of the time for monthly mean time series.

The CT SSWUE computes water-use-adjusted streamflow using spatially referenced water-use information provided by the Connecticut Department of Energy and Environmental Protection. Available water-use information included permitted and registered water withdrawals and permitted wastewater discharges during 1998 to 2015 for the Thames River Basin and central coastal drainage basins. Water-use information was incorporated into the U.S. Geological Survey StreamStats web application for Connecticut and can be used for computing water-use-adjusted streamflow and sustainable net withdrawal at selected points of interest. Altered daily streamflow is computed by applying average daily withdrawals and wastewater discharges to the water balance equation. Average daily surface water withdrawals and wastewater discharges are applied directly to the daily water balance equation. Time-lagged alterations on streamflow from groundwater withdrawals or wastewater discharges are estimated by using a response-coefficient method developed from results of previously published, calibrated groundwater models.

Introduction

Given competing demands for water and a long history of development in Connecticut, water-resource managers need data and modeling tools to better understand the water resources of many drainage basins in the State. The Connecticut General Assembly established a Water Planning Council in 2001 to address issues involving water companies, water resources, and State policies regarding the future of the State's drinking water supply. State legislation requires the Water Planning Council to develop a State water plan that would balance the needs of public water supply, economic development, recreation, and ecological health (Public Act 14–163). The plan was submitted to the Connecticut Legislature on January 24, 2018. In 2005, the Connecticut General Assembly passed Public Act 05–142 (CGS §26–141a and b), which required the Connecticut Department of Energy and Environmental Protection (CT DEEP) to update standards for maintaining minimum streamflow targets in rivers and streams. The act required these standards to balance river and stream ecology, wildlife, and recreation while providing for public health, flood control, industry, public utilities, water supply, public safety, agriculture, and other lawful uses of water. In 2011, the State of Connecticut adopted new Stream Flow Standards and Regulations (RCSA §26–141b).

Balancing human needs for water with the needs for water in sustaining healthy ecosystems requires an understanding of the natural streamflow at a given site and the human alterations to that streamflow. The seasonal and annual variability of streamflow in Connecticut can complicate plans for sustainable water management. Daily streamflow can vary over several orders of magnitude throughout the year, with the lowest streamflow occurring during the summer months, when water withdrawals are typically the highest. This combination of low flows and large water withdrawals can negatively affect aquatic communities and streamflow habitats (Poff and Zimmerman, 2010; Armstrong and others, 2011).

Since 2005, when the General Assembly required CT DEEP to update streamflow standards, the U.S. Geological Survey (USGS), in cooperation with CT DEEP, conducted several studies that contributed to planning and management of Connecticut water resources (Ahearn, 2008, 2010). As part of the ongoing process of implementing streamflow standards, new methods and tools are needed for describing and quantifying streamflow and sustainable water use. The U.S. Geological Survey, in cooperation with CT DEEP, developed a tool for the estimation of water availability by leveraging work done by the USGS for estimating water availability in Massachusetts (Archfield and others, 2010) and as part of the USGS StreamStats program (U.S. Geological Survey, 2017b). The Connecticut Streamflow and Sustainable Water Use Estimator (CT SSWUE) is a decision-support tool that estimates unaltered and water-use-adjusted streamflow and computes the sustainable net withdrawal at ungaged sites in Connecticut under various water-use scenarios.

Methods for estimating unaltered daily mean streamflow were developed and documented by Archfield and others (2010) and have been replicated in other statewide or regional applications (Stuckey and others, 2012; Gazoorian, 2015; Lorenz and Ziegeweid, 2016; Stuckey, 2016). The flow-duration curve for an ungaged basin in Connecticut can be estimated by using regression equations developed and described in this report. The estimated flow-duration curve can be transformed into a time series of daily mean streamflow by using the QPPQ method (Fennessey, 1994), which uses the time series at a reference streamgage site to assign a date to the estimated streamflow quantiles at the ungaged site. The QPPQ method has been successfully used in several studies (Hughes and Smakhtin, 1996; Smakhtin, 1999; Smakhtin and Masse, 2000; Mahamoud, 2008; Shu and Ouarda, 2012; Linhart and others, 2013). An empirical method for estimating prediction intervals for estimates of unaltered daily and monthly mean streamflow (Farmer and Levin, 2018) was also tested and implemented in this study.

Natural streamflow patterns are affected by upstream surface-water and groundwater withdrawals and wastewater discharges within the basin. The CT SSWUE can compute water-use-adjusted streamflow time series in order to assess the potential effects of a water-use scenario across the range of historical hydrologic conditions. Reported water withdrawals and wastewater discharges during the years 1998 to 2015 were compiled from registered and permitted sources from the Thames River Basin and central coastal basins for use with the CT SSWUE (see the section "Reported Water Use"). Users may add additional withdrawal or wastewater discharge information for the basin of interest for scenario testing. Water-use information was entered into the USGS StreamStats web application (U.S. Geological Survey, 2012), which provides a monthly water-use summary for the basin of interest.

Users may input a minimum monthly streamflow target for the basin of interest in order to estimate the sustainable net withdrawal. For the purpose of this report, sustainable net withdrawal is defined as the maximum amount of water that can be withdrawn from a basin during the drought of record, without causing the streamflow to be depleted past the minimum flow target. The target minimum streamflow can be a percentage of unaltered flow, or it can be a specific monthly flow set by the user.

This report documents the data and methods used to develop the CT SSWUE, which estimates streamflow and sustainable net withdrawal at ungaged sites in Connecticut. The report explains the multistep process of estimating unaltered, daily mean streamflow, including the development of regression equations for 19 streamflow quantiles, the interpolation of the regressed streamflow quantiles into a continuous flow-duration curve, the transformation of the flow-duration curve into a time series of daily mean streamflows using the QPPQ method, and the process used to estimate 95-percent prediction intervals for unaltered daily and monthly mean streamflow. The report then documents the water-use data compiled for use with the CT SSWUE and the method for calculating water-use-adjusted streamflow. The graphical user interface (GUI) and the limitations of the application of the CT SSWUE are also described.

Estimation of Unaltered, Daily Mean Streamflow

The CT SSWUE estimates unaltered, daily mean streamflow for the 55 water-year[1] period from October 1, 1960, through September 30, 2015. The multistep process used to estimate a time series of unaltered daily mean streamflow involves several statistical and geostatistical methods. In the first step, regression equations are used to estimate streamflow at selected quantiles along the flow-duration curve. A continuous flow-duration curve is produced by interpolating between the regression-based quantiles. Next, the QPPQ method (Fennessey, 1994) is used to transform the flow-duration curve into a daily time series using a reference streamgage that is hydrologically similar to the ungaged basin and has minimally altered streamflow.

Regional Regression Equations for Estimating Streamflow Quantiles

Regional equations to estimate streamflow quantiles for an ungaged site with minimal streamflow alteration were developed by using streamflow records from selected streamgages and their respective physical and climatic basin characteristics. Regression equations relating basin characteristics to streamflow were developed for exceedance probabilities of 0.005, 0.4, 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 85, 90, 95, 99, 99.6, and 99.995 percent. The intermediary streamflow quantiles are determined by interpolation to obtain a continuous flow-duration curve. The CT SSWUE transforms each exceedance probability in the flow-duration curve to a normal Z-score by using equation 26.2.23 documented by Abramowitz and Stegun (1964) and linearly interpolates the log-transformed streamflow quantiles from the regression equations across the Z-scores. The Z-score transformation is needed in order to linearize the high degree of curvature at the high and low ends of the flow-duration curve. Log-linear interpolation of streamflow quantiles without this transformation can exhibit bias at high and low flows (Archfield and others, 2012).

Streamgage Selection and Basin Characteristics

Streamgages with minimally altered flow in Connecticut and adjacent, physiographically similar areas in Massachusetts, Rhode Island, and New York were considered as potential streamgages for this study. Of the sites considered, 36 streamgages were selected for use in the development of the regression equations for estimating streamflow quantiles (fig. 1; appendix 1). The selection criteria for inclusion in the regression equation development required the streamgage to have a minimum of 15 water years of complete record and the basin to be unaffected by appreciable water withdrawals, wastewater discharges, and streamflow regulation resulting in more than a diurnal fluctuation in streamflow. To accurately characterize the lowest streamflows, the streamgages were also required to be active through the historic drought of the 1960s (Weiss, 1991). The 36 streamgages selected for use in regression development had from 15 to 103 water years of daily, mean streamflow observations. The streamgages selected are spatially well distributed in and near Connecticut (fig. 1).

Streamflow quantiles for each of the streamgages were computed by ranking the daily streamflows and computing the exceedance probability (Vogel and Fennessey, 1994). Streamflow quantiles were determined at the 0.005-, 0.4-, 1-, 5-, 10-, 15-, 20-, 30-, 40-, 50-, 60-, 70-, 80-, 85-, 90-, 95-, 99-, 99.6-, and 99.995-percent exceedance probabilities (table 1). Several of the streamgages shown in table 1 did not have records long enough for estimating the 0.005- and 99.995-percent exceedance probabilities. Equations for these two streamflow quantiles used only the 16 sites that had sufficiently long streamflow records for computing the exceedance probabilities.

Table 1. Streamflow for selected exceedance probabilities for streamgages used in the development of the Connecticut Streamflow and Sustainable Water Use Estimator.

[Table available for download at https://doi.org/10.3133/sir20185135]

A total of 128 physical and climatic basin characteristics (appendix 2) were compiled for the initial explanatory analysis of potential variables in the regression equations. The basin characteristics included variables describing land-use type, terrain, infiltration, basin and stream morphology, and climate. The source datasets of the basin characteristics are shown in appendix 2. Location coordinates were converted to the Connecticut State Plane Coordinate System in feet prior to calculation of basin characteristics.

The geographic information system (GIS) dataset of surficial geology (sand and gravel deposits) required some manipulation to create a uniform GIS dataset that covered the entire study area. Surficial geology datasets were unique to each State and classified sand and gravel deposits differently. Each State's surficial geology dataset was modified to be similar to Connecticut's stratified drift dataset (Connecticut Department of Environmental Protection, 2009). For Rhode Island, the State's glacial deposits dataset (Rhode Island Geographic Information System, 1989) was edited, and areas attributed as “water,” “bedrock,” “till,” and “unknown” were removed. For New York, areally applicable surficial geology datasets (Cadwell and others, 1986) were obtained, and areas attributed as “water,” “artificial fill,” “swamp deposits,” “till,” and “bedrock”—features that were not sand and gravel

[1]A water year extends from October 1 to September 30 and is designated by the calendar year in which it ends.

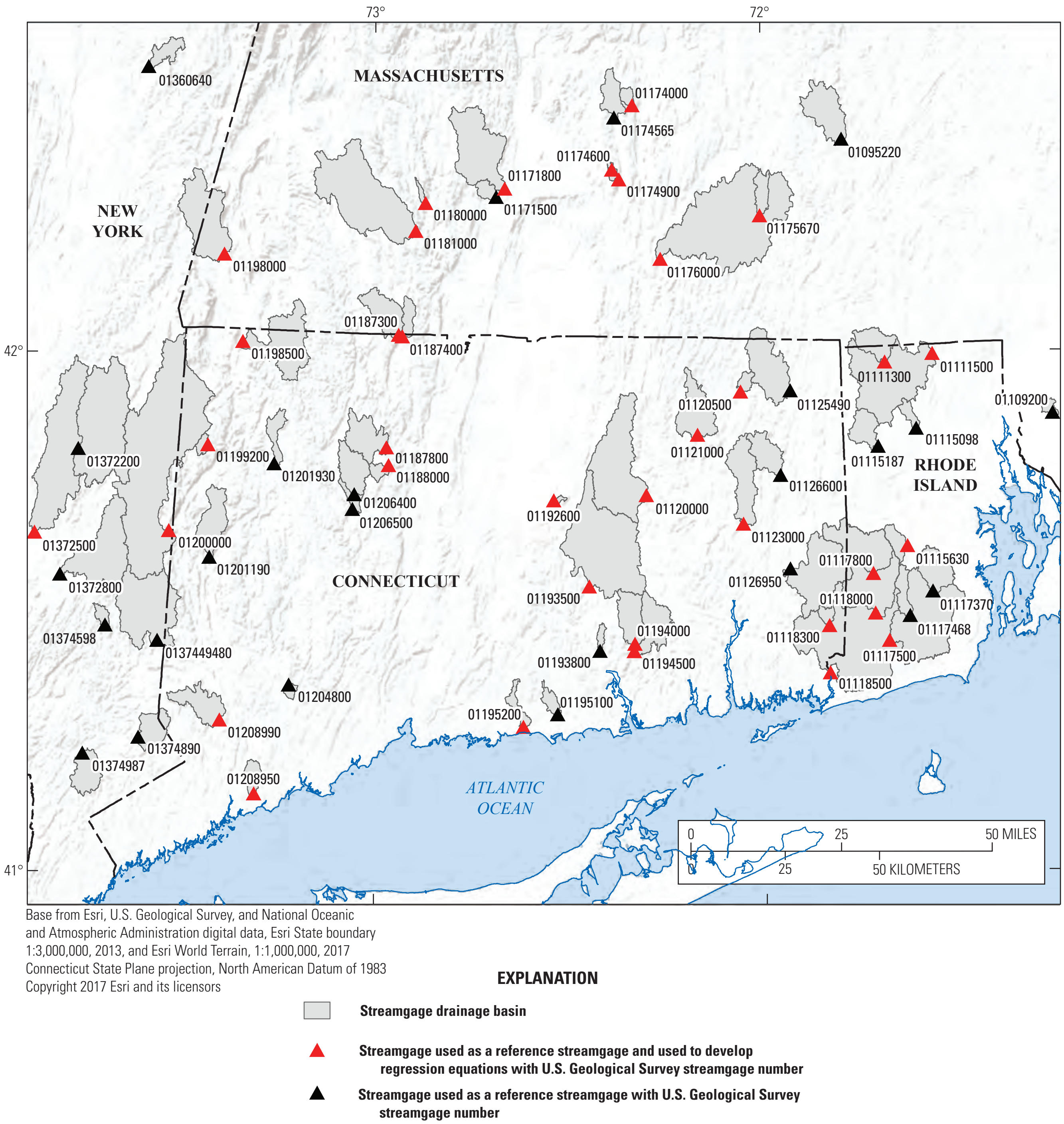


Figure 1. Locations of 61 U.S. Geological Survey reference streamgages with drainage basins, including 36 streamgages used for developing regression equations in the Connecticut Streamflow and Sustainable Water Use Estimator, Connecticut and vicinity.

deposits—were removed. For Massachusetts, two surficial geology datasets were used. Because the higher resolution dataset (1:24,000) did not cover part of the study area, the lower resolution (1:250,000) dataset (U.S. Geological Survey, 1999, 2015) was substituted in the missing areas. Glacial stratified deposits as well as alluvium and other postglacial deposits of sand and gravel were extracted to make a dataset similar to that of Connecticut. The datasets representing sand and gravel deposits for each State were then merged for use in regression equation development.

The ratio of the length of streams that overlay sand and gravel deposits to the total length of streams in the basin was computed as a potential explanatory variable (appendix 2). The length of streams in the basin was determined by using the National Hydrography Dataset (U.S. Geological Survey, 2017a) flowlines attribute with pipelines and coastline removed. These flowlines were intersected with the GIS dataset of sand and gravel deposits described previously.

Model Development and Verification

Regression equations were developed for estimating streamflow at the 0.005-, 0.4-, 1-,5-, 10-, 15-, 20-, 30-, 40-, 50-, 60-, 70-, 80-, 85-, 90-, 95-, 99-, 99.6-, and 99.995-percent exceedance probabilities (table 1), and the 128 basin characteristics (appendix 2) were used as potential explanatory variables. The logarithms of the variables were computed to help linearize the relations between quantiles and characteristics. Regression equations for most streamflow quantiles were developed by using weighted least squares regression techniques (table 2). Because several streamgages had streamflows of zero cubic feet per second (ft^3/s) for the 99- and 99.6-percent exceedance probabilities, and because the regressions were done on the logarithms of variables, the regression analyses for these two exceedance probabilities were done by using the Tobit regression model, which treats streamflow values of zero cubic feet per second as censored values. Weights used in the weighted least square regression analysis were computed as the ratio of number of days of daily mean flow to the average number of days of flow of the 16 or 36 streamgages used in each regression analysis.

The regression results provide equations for estimating the values of dependent variables from one or more independent variables. The regression equations take the general form

$$\log_{10} Y_P = b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_j X_j, \tag{1}$$

where

- $\log_{10} Y_P$ is the logarithm of the magnitude of the daily mean streamflow having an exceedance probability of P percent,
- X_1 to X_j are the basin characteristics, and
- b_0 to b_j are coefficients developed from the regression analysis.

Since transformations to the explanatory and response variables are logarithmic, equation 1 can be manipulated to take the form

$$Y_P = 10^{b_0} X_1^{b_1} X_2^{b_2} \ldots X_j^{b_j}. \tag{2}$$

The statistical software SAS (SAS Institute Inc., 2009) was used to develop the regression equations. Stepwise regression was used to narrow the 128 basin characteristics to a smaller pool of potentially significant basin characteristics. The final set of explanatory variables in the equations was chosen according to the goodness of fit of individual regression equations and the overall ability of the group of regression equations to produce a monotonic flow-duration curve. Daily streamflows are complex, and physical and climatic processes affect parts of the flow-duration curve differently; hence, over the range of the flow-duration curve, different variables are related to different streamflow quantiles. Regression equations for streamflow quantiles developed independently from each other and with different sets of explanatory variables may not produce a flow-duration curve in which streamflow continuously decreases with increasing exceedance probability. In order to enforce the monotonic structure of the flow-duration curve, a consistent set of explanatory variables was chosen across most of the streamflow quantiles. Although most regression coefficients in the regression equations were significantly different from zero at the 0.05 significance level, others were allowed to exceed the 0.05 significance level in order to retain consistency across the regression equations and produce a monotonic relation of streamflow to exceedance probability.

Explanatory variables used in the final suite of regression equations include drainage area in square miles, average annual precipitation in inches, mean soil permeability in inches per hour, and the ratio of the lengths of streams in the basin overlaying sand and gravel deposits to the total length of streams (tables 2 and 3). Because basin characteristics affect high and low streamflow quantiles in different ways, the full set of selected basin characteristics was not used in every regression equation. Drainage area was used as an explanatory variable in all the equations. For all streamflow exceedance probabilities except the 99.995-percent probability, the basinwide mean of the soil permeability in inches per hour (U.S. Geological Survey, 1995) was used in the equations. For streamflow exceedance probabilities from 0.005 to 15 percent, average annual precipitation from 1981 to 2010, in inches (PRISM Climate Group, 2012c), was included in the equation. For streamflow exceedance probabilities from 20 to 99.995 percent, the ratio of the length of streams in the basin that overlay sand and gravel deposits to the total length of streams in the basin was included in the regression equation—1.0 is added to the ratio before it is applied to the regression equation.

The coefficient of determination (R^2) for the 19 regression equations ranged from 0.761 to 0.997, and the root-mean-square error ranged from 0.036 to 0.559 (table 2). Model

Table 2. Number of streamgages, regression methods, explanatory variables, estimated regression coefficients, and regression diagnostics for the regression equations for estimating daily mean streamflow at selected exceedance probabilities in ungaged, unaltered streams in Connecticut and vicinity.

[%, percent; WLS, weighted least squares; --, not applicable to the regression equation]

Exceedance probability	0.005%	0.4%	1%	5%	10%	15%	20%	30%	40%	50%	60%	70%	80%	85%	90%	95%	99%	99.6%	99.995%
General regression information																			
Number of streamgages used to develop regression equation	16	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	16
Regression method	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	WLS	Tobit	Tobit	WLS
Root-mean-square error, in logarithmic units	0.0942	0.0834	0.0686	0.0405	0.0357	0.0376	0.0392	0.0424	0.0469	0.0507	0.0567	0.0670	0.0930	0.116	0.141	0.189	0.294	0.375	0.559
Coefficient of determination, R^2, adjusted for the number of predictor variables	0.965	0.980	0.987	0.996	0.997	0.997	0.996	0.996	0.995	0.994	0.993	0.991	0.984	0.977	0.968	0.951	--	--	0.761
Regression coefficient value																			
Constant term	−5.88	−2.95	−2.77	−1.67	−1.06	−0.742	0.321	0.104	−0.068	−0.226	−0.399	−0.643	−0.985	−1.19	−1.41	−1.71	−2.23	−2.41	−3.02
Drainage area, in square miles	0.780	0.895	0.915	0.962	0.985	0.996	0.999	1.01	1.01	1.02	1.02	1.04	1.07	1.09	1.12	1.17	1.27	1.31	1.34
Basinwide mean of the mean permeability, in inches per hour	−1.03	−0.46	−0.381	−0.133	0.0168	0.112	0.191	0.299	0.367	0.400	0.416	0.440	0.479	0.498	0.490	0.444	0.273	0.185	--
Basinwide mean of the average annual precipitation, in inches	5.16	2.72	2.48	1.52	1.00	0.707	--	--	--	--	--	--	--	--	--	--	--	--	--
Ratio of length of streams intersecting sand and gravel deposits to total length of streams[1]	--	--	--	--	--	--	0.0149	0.0800	0.147	0.244	0.419	0.747	1.26	1.56	1.97	2.60	3.95	4.15	6.69

[1]One is added to ratio before applying it in regression equations.

Table 3. Basin characteristics used to develop the regression equations for estimating daily mean streamflow at selected exceedance probabilities for ungaged, unaltered streams in Connecticut and vicinity.

[USGS, U.S. Geological Survey; mi^2, square mile; RI, Rhode Island; CT, Connecticut; MA, Massachusetts; NY, New York]

USGS streamgage number	Streamgage name	Drainage area, in mi^2	Basinwide mean of average annual precipitation, in inches	Basinwide mean of soil permeability, in inches per hour	Ratio of length of streams intersecting sand and gravel deposits to total length of streams
01111300	Nipmuc River near Harrisville, RI	15.9	49.5	4.98	0.587
01111500	Branch River at Forestdale, RI	91.2	50.2	5.08	0.367
01115630	Nooseneck River at Nooseneck, RI	8.20	48.9	3.60	0.781
01117500	Pawcatuck River at Wood River Junction, RI	100	50.3	6.90	0.620
01117800	Wood River near Arcadia, RI	35.3	48.3	6.26	0.448
01118000	Wood River Hope Valley, RI	74.6	48.3	6.06	0.398
01118300	Pendleton Hill Brook near Clarks Falls, CT	4.01	48.0	4.93	0.163
01118500	Pawcatuck River at Westerly, RI	294	48.5	6.45	0.492
01120000	Hop Brook near Columbia, CT	74.5	48.4	4.12	0.224
01120500	Safford Brook near Woodstock Valley, CT	4.17	47.5	2.78	0.067
01121000	Mount Hope River near Warrenville, CT	29.0	47.5	3.44	0.085
01123000	Little River near Hanover, CT	30.0	48.4	4.32	0.321
01171500	Mill River at Northampton, MA	52.6	49.3	3.20	0.406
01174000	Hop Brook near New Salem, MA	3.48	52.2	4.78	0.068
01174600	Cadwell Creek near Pelham, MA	0.62	48.7	4.78	0.000
01174900	Cadwell Creek near Belchertown, MA	2.55	48.6	4.78	0.000
01175670	Sevenmile River near Spencer, MA	8.91	47.9	3.85	0.380
01176000	Quaboag River at West Brimfield, MA	149	48.1	3.78	0.402
01180000	Sykes Brook at Knightville, MA	1.69	48.8	1.81	0.000
01181000	West Branch Westfield at Huntington, MA	93.9	50.8	2.55	0.159
01187300	Hubbard River near West Hartland, CT	20.6	51.9	2.67	0.018
01187400	Valley Brook near West Hartland, CT	7.38	51.5	3.27	0.288
01187800	Nepaug River near Nepaug, CT	23.5	53.2	4.06	0.310
01188000	Bunnell Brook near Burlington, CT	4.20	53.1	4.84	0.632
01192600	South Branch Salmon Brook at Buckingham, CT	0.95	45.8	9.10	0.561
01193500	Salmon River near East Hampton, CT	101	49.5	3.79	0.266
01194000	Eightmile River at North Plain, CT	20.2	50.6	4.05	0.195
01194500	East Branch Eightmile River near North Lyme, CT	22.4	50.4	4.62	0.283
01195200	Neck River near Madison, CT	6.60	49.6	5.42	0.235
01198000	Green River near Great Barrington, MA	51.0	46.5	2.36	0.378
01198500	Blackberry River at Canaan, CT	45.5	50.1	3.74	0.338
01199200	Guinea Brook at West Woods Road at Ellsworth, CT	3.5	48.7	3.90	0.011
01200000	Ten Mile River near Gaylordsville, CT	200	46.1	3.33	0.247
01208950	Sasco Brook near Southport, CT	7.38	48.6	5.67	0.056
01208990	Saugatuck River near Redding, CT	20.7	50.7	4.02	0.278
01372500	Wappinger Creek near Wappingers Falls, NY	183	45.1	2.45	0.263

Table 4. Ranges of explanatory variables used in the development of the regression equations for estimating daily mean streamflow at selected exceedance probabilities for ungaged, unaltered streams in Connecticut and vicinity.

Basin characteristic	Minimum	Mean	Maximum
Drainage area, in square miles	0.62	49.8	294
Basinwide mean of average annual precipitation, in inches	45.1	49.2	53.2
Basinwide mean of soil permeability, in inches per hour	1.81	4.33	9.10
Ratio of length of streams intersecting sand and gravel deposits to total length of streams	0.000	0.286	0.781

residuals were generally homoscedastic and normally distributed, and variables in the final equations had variance-inflation factors of less than 1.5, indicating minimal correlation between the independent variables (Freund and Littell, 2000).

The regression equations are applicable to sites on streams in the study area with minimally developed basins and no upstream flow alteration or water use. Use of the equations is appropriate to sites with basin characteristics that are within the range of basin characteristics used in the development of the equations. The ranges of drainage-basin characteristics used in the analysis are shown in table 4. If independent variables used in the regression equations are outside of these ranges, the accuracy of the predictions is unknown.

Estimation of Streamflow Time Series by Use of a Reference Streamgage

The CT SSWUE estimates a time series of streamflow at an ungaged basin by using the QPPQ method (Fennessey, 1994; Archfield and others, 2010). The QPPQ method assumes that for each day, the exceedance probability of the streamflow at the ungaged site is equal to the exceedance probability at a selected reference streamgage (fig. 2). The QPPQ method transforms the flow-duration curve at the ungaged site to a time series by equating the date of each streamflow quantile in the flow-duration curve for the ungaged site with the date of the same quantile at a reference streamgage. For example, in figure 2, the QPPQ method assumes the streamflow quantile for the 10-percent exceedance probability at the ungaged site (fig. 2*C*) occurs on the same date as the streamflow quantile for the 10-percent exceedance probability at the reference streamgage (figs. 2*A* and *B*). In this way, a date can be assigned to all the streamflow quantiles of the flow-duration curve for the ungaged basin.

Reference Streamgages Included in the Study Area

A network of 61 streamgages with 55-year daily mean streamflow records (water years 1961 to 2015) are included in the CT SSWUE as potential reference streamgages for the QPPQ process of transforming the flow-duration curve at an ungaged site into a daily time series (fig. 1; appendix 1). Streamgages were selected as reference streamgages according to the following criteria: (1) a minimum of 10 years of record and (2) no or minimum regulation, flow augmentation, or water-supply/industrial withdrawals in the upstream basin. Reference streamgages did not have to be active during the 1960s drought. The network of reference streamgages includes the 36 streamgages used in developing the regression equations and an additional 25 streamgages that meet the criteria for a reference streamgage.

Reference streamgages were selected from available streamgages in Connecticut and adjacent, physiographically similar areas in Massachusetts, Rhode Island, and New York (fig. 1; appendix 1). The reference streamgages are spatially well distributed in and near Connecticut. The streamflow data available for the 61 streamgages ranged from 10 to 103 years and were downloaded from the USGS National Water Information System (NWIS) (https://waterdata.usgs.gov/nwis).

The QPPQ method requires that reference streamgages have daily streamflow records for the 55-year period (October 1, 1960, to September 30, 2015). The records for 48 of the 61 reference streamgages (appendix 3) were extended by using the maintenance of variance extension, type 3 (MOVE.3), technique (Vogel and Stedinger, 1985) to ensure that all reference streamgages had a period of streamflow record from October 1, 1960, through September 30, 2015. The record extension was done with the Streamflow Record Extension Facilitator, version 1.0, software (Granato, 2009). When extending the record for a streamgage, the streamgage used for extending record was selected on the basis of available record and the best possible correlation of daily mean streamflows. Reference streamgages and streamgages used for record extension are listed in appendix 3.

Selection of a Reference Streamgage for an Ungaged Site

The performance of the QPPQ method in estimating a daily time series depends upon the similarity between the ungaged site and the chosen reference streamgage. The ideal reference streamgage is the one with the most streamflow values correlated to those at the ungaged site. The CT SSWUE uses the map-correlation method developed by Archfield and Vogel (2010) to select the reference streamgage whose streamflows have the highest predicted correlation to the ungaged basin. The Pearson *r* correlation coefficient (Helsel and Hirsch, 2002) was computed for the logarithm of daily streamflows between all 61 pairs of reference streamgages

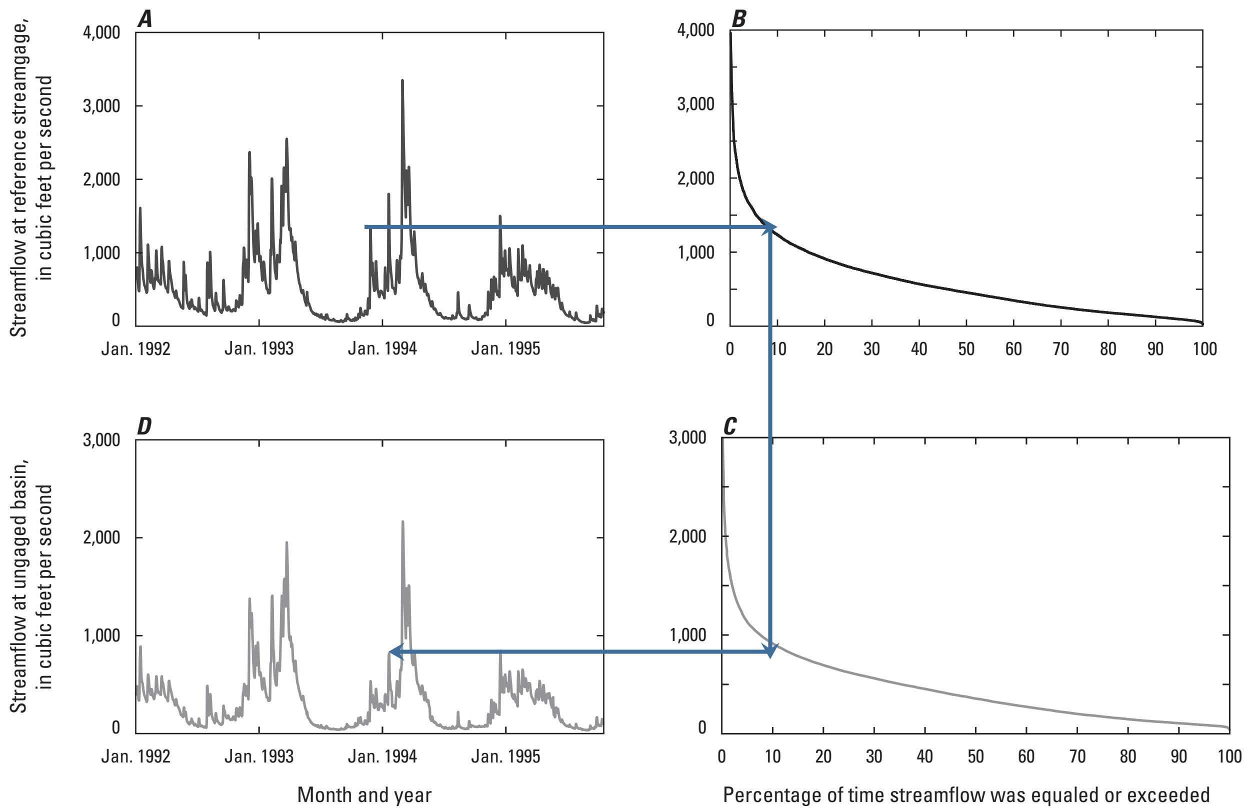


Figure 2. Translation of a flow-duration curve to a time series of streamflow estimated by the Connecticut Streamflow and Sustainable Water Use Estimator using the QPPQ method, including *A*, observed time series at a reference streamgage, *B*, flow-duration curve at the reference streamgage, *C*, flow-duration curve for an ungaged basin, and *D*, estimated time series for the ungaged basin. (Modified from Archfield and others, 2010.)

and ungaged sites in the CT SSWUE. The Pearson *r* values were spatially interpolated through kriging. For each reference streamgage, a spherical variogram model (Isaaks and Srivastava, 1989) was computed that estimated the Pearson *r* correlation between the reference streamgage and the ungaged site. When running the CT SSWUE for an ungaged basin, the reference streamgage with the highest predicted correlation to the ungaged basin is selected as the reference streamgage to be used for the QPPQ method. Example variogram maps are shown in figure 3. For the variogram of streamgage 01208990, Saugatuck River near Redding, Conn. (fig. 3*A*), the areas with the higher estimated correlations are in southwestern Connecticut. For the variogram of streamgage 01194000, Eightmile River at North Plain, Conn., estimated correlations are highest in south-central Connecticut.

Accuracy and Uncertainty of Estimated Unaltered Streamflow

The accuracy of estimated unaltered, daily mean streamflow time series was assessed at each of the 61 reference streamgages by using a remove-one cross validation. For each reference streamgage, regression equations and the set of variograms used in the reference streamgage selection process were refit to exclude the streamgage from the dataset. Daily mean streamflow at the removed reference streamgage was then estimated from the refit regression and QPPQ process and compared with gaged streamflow at the site. Results from the cross validation represent estimated daily mean streamflows at a basin that was not used in the development of the model.

Estimated daily mean streamflow values agreed overall with observed values. The Nash-Sutcliffe efficiency (NSE) and normalized root-mean-square error (NRMSE) were computed for each of the 61 reference streamgages in the cross validation for the CT SSWUE period of record (water years 1961–2015), excluding any part of the time series of gaged streamflow for which record-extension techniques were used (fig. 4). NRMSE is calculated as the root-mean-square error divided by the range (maximum minus minimum) of the time series and is expressed as a percentage. NSE values ranged from −0.43 to 0.97 with a median value of 0.88. NRMSE values ranged from 16.5 to 119.7 percent with a median of 34.6 percent. Figure 5 shows the observed and estimated daily and monthly mean streamflows for the two reference streamgages with the highest and lowest NSE values (01121000, Mount Hope River near Warrenville, Conn., and 01192600, South Branch Salmon Brook at Buckingham, Conn., respectively). Streamgage

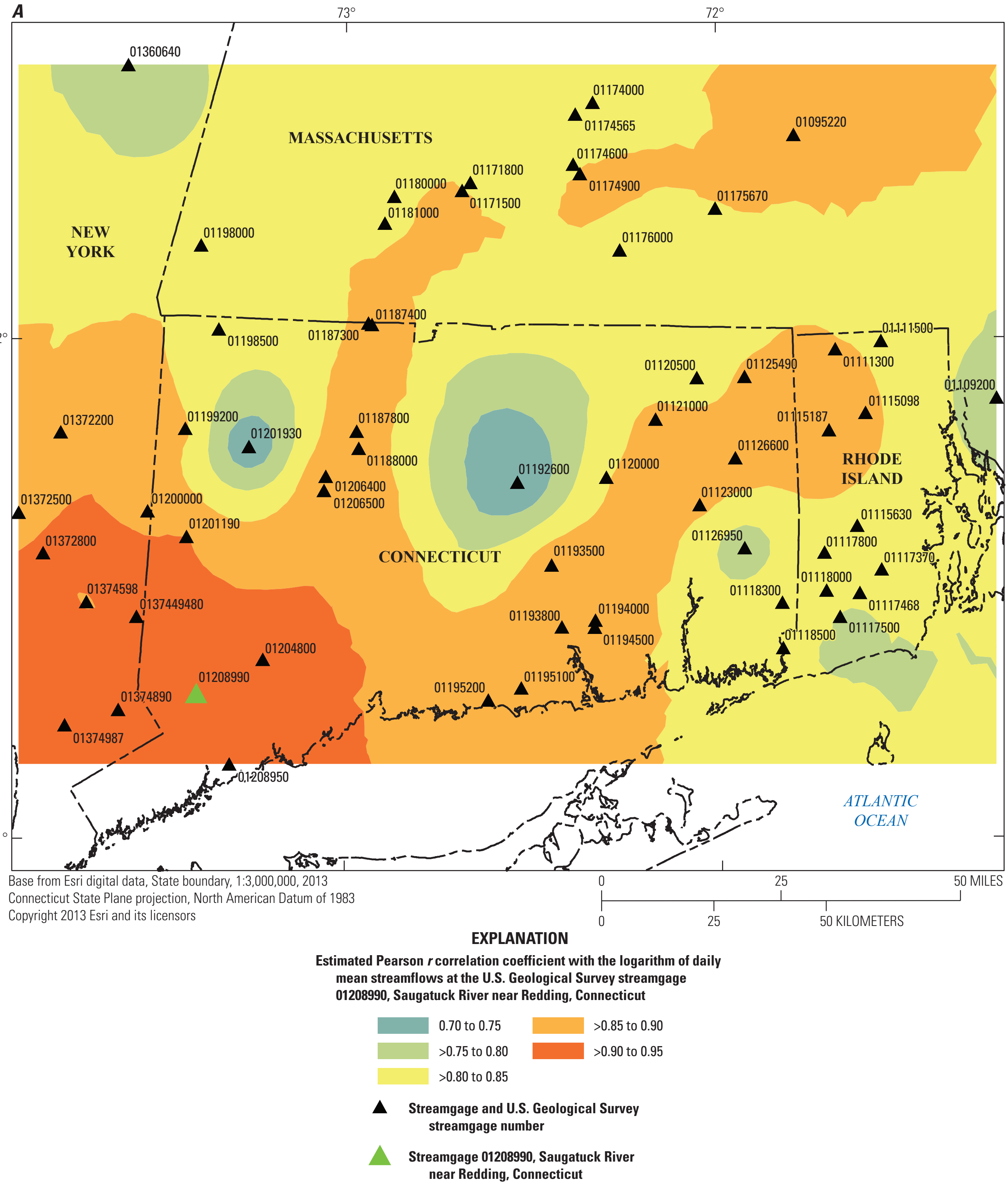


Figure 3. Estimated Pearson *r* correlation coefficients for streamgages in the study area with the logarithm of daily mean streamflow at the U.S. Geological Survey streamgages *A*, 01208990, Saugatuck River near Redding, Conn., and *B*, 01194000, Eightmile River at North Plain, Conn., from October 1, 1960, to September 30, 2015.

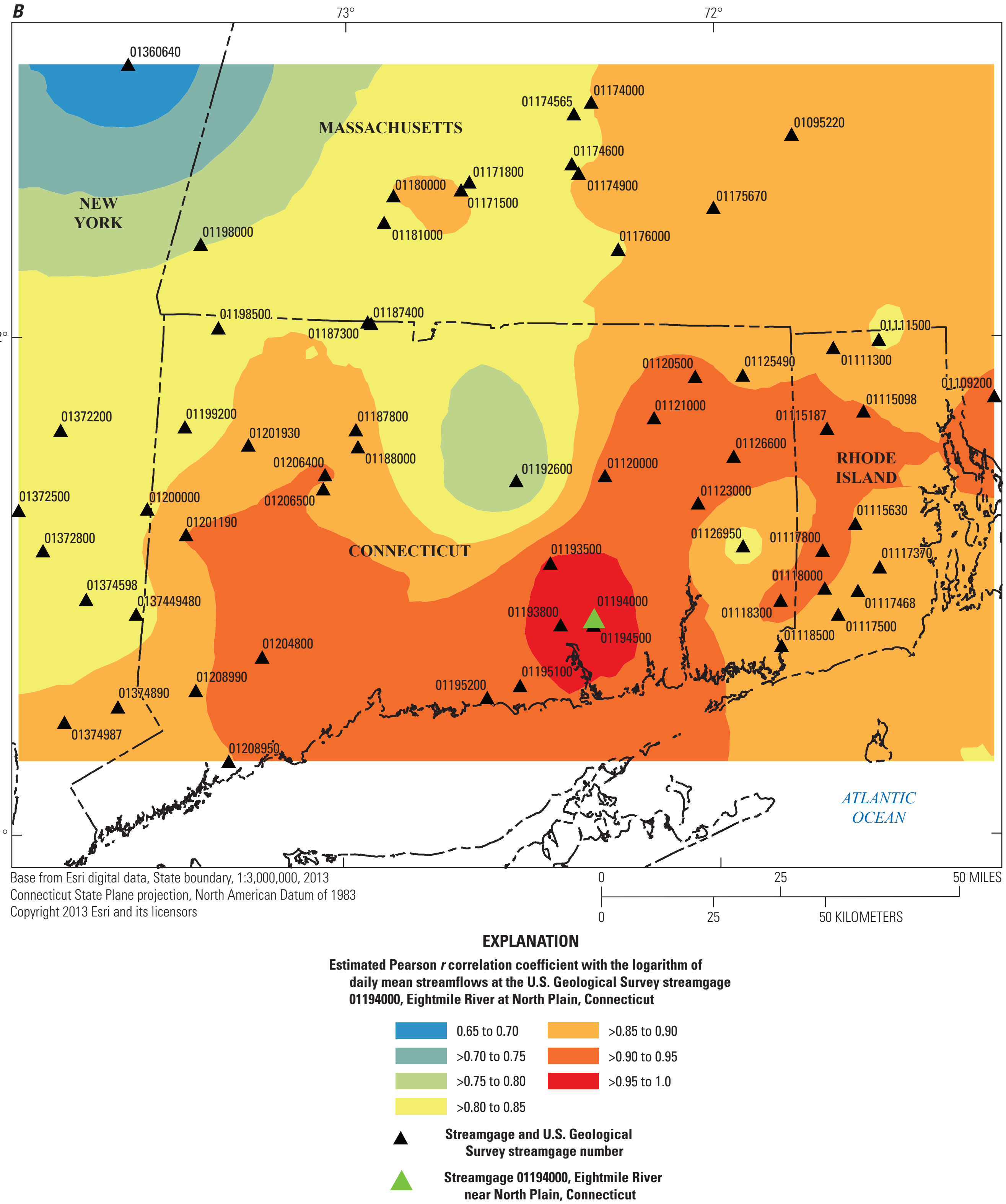


Figure 3. Estimated Pearson r correlation coefficients for streamgages in the study area with the logarithm of daily mean streamflow at the U.S. Geological Survey streamgages *A*, 01208990, Saugatuck River near Redding, Conn., and *B*, 01194000, Eightmile River at North Plain, Conn., from October 1, 1960, to September 30, 2015.—Continued

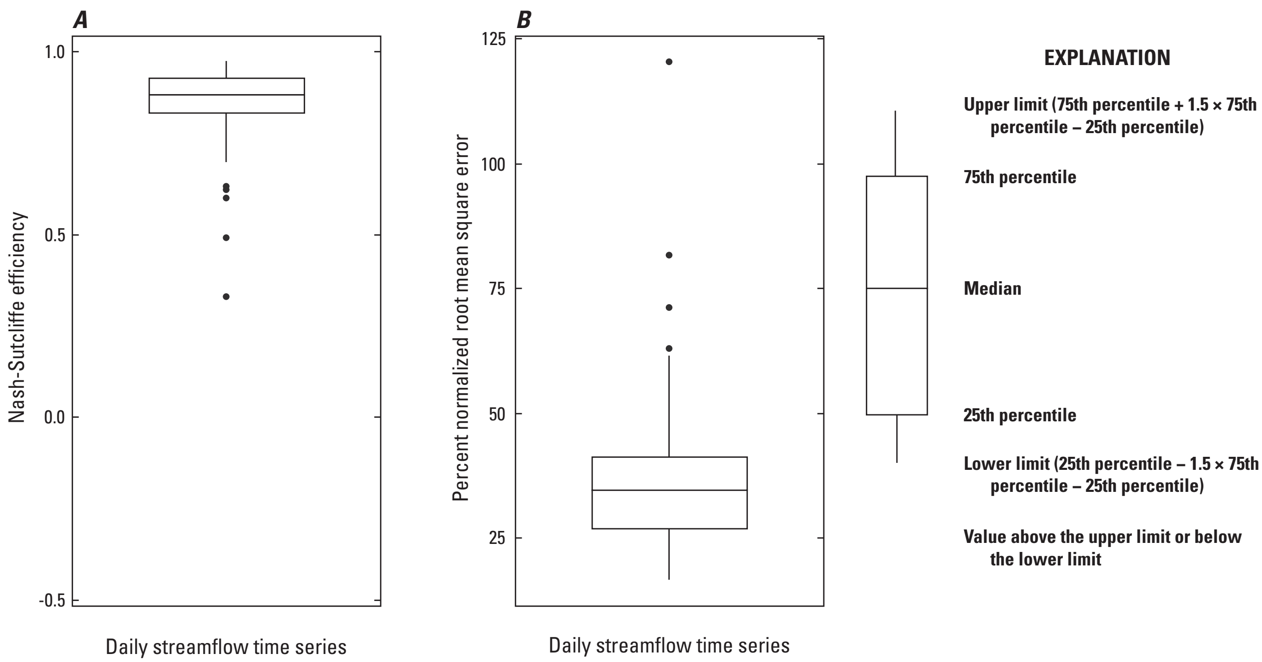


Figure 4. The distributions of *A*, Nash-Sutcliffe efficiency and *B*, normalized root-mean-square error for observed and estimated daily mean streamflow at 61 U.S. Geological Survey streamgages from October 1, 1960, to September 30, 2015, Connecticut and vicinity.

01192600 at South Branch Salmon Brook in Buckingham, Conn. (fig. 1), performed more poorly than other streamgages in the cross validation, with an NSE value of −0.43 and NRMSE of 119.7 percent. Low flows at this site were higher than predicted (fig. 5). The basin for this streamgage has the highest soil permeability of all the reference streamgage sites and is also one of the smallest sites (table 3). Having these basin characteristics at the extreme ends of the ranges may have contributed to high uncertainty in estimated streamflow at this site. Additionally, difficulties associated with measuring low flows in small basins may be a source of increased measurement error in the gaged data at this site.

Daily mean streamflow values are often aggregated for analysis or decision-making purposes. The CT SSWUE summarizes the simulation results as the mean or median for each month, computed as the mean of all the monthly means or median of all the monthly medians for that month over all years of simulation. Figure 6 shows a comparison of the mean of the monthly means for gaged data with the mean of the monthly means for estimated streamflow for all 61 reference streamgages, using the cross-validation data previously described. The mean of the monthly means estimated by the CT SSWUE showed good agreement with the mean for gaged data. The percent errors of the estimated means of the monthly means were unbiased overall and typically ranged between −20 percent and +20 percent. Percent errors were higher in July through October because of lower streamflows during the summer and early fall months.

Uncertainty in the time series of estimated unaltered daily mean streamflow comes primarily from (1) the regression equations and interpolation process used to estimate the continuous flow-duration curve and (2) the reference streamgage selection and QPPQ process used to create the time series of daily mean streamflow. Because uncertainty comes from several different statistical and modeling processes, standard statistical methods for quantifying the uncertainty and confidence intervals of SSWUE-estimated unaltered streamflow are not valid (Archfield and others, 2010). Instead, the CT SSWUE uses a procedure developed by Bourgin and others (2015) and modified by Farmer and Levin (2018) to estimate 95-percent prediction intervals for estimates of daily and monthly average streamflow. The process to construct prediction intervals for daily streamflow estimates at an ungaged site is described below and illustrated in figure 7:

1. Select five reference streamgages (RG_n) with the highest predicted correlation to the ungaged basin as predicted by the map-correlation method (fig. 7*A*). Streamflow at these five basins is then estimated with the CT SSWUE as if they were ungaged basins.

2. For each RG_n selected in step 1, select the five reference streamgages ($RG_{n,m}$) that have a predicted correlation to the RG_n that is closest in value to the correlation between the ungaged basin and RG_n (fig. 7*B*).

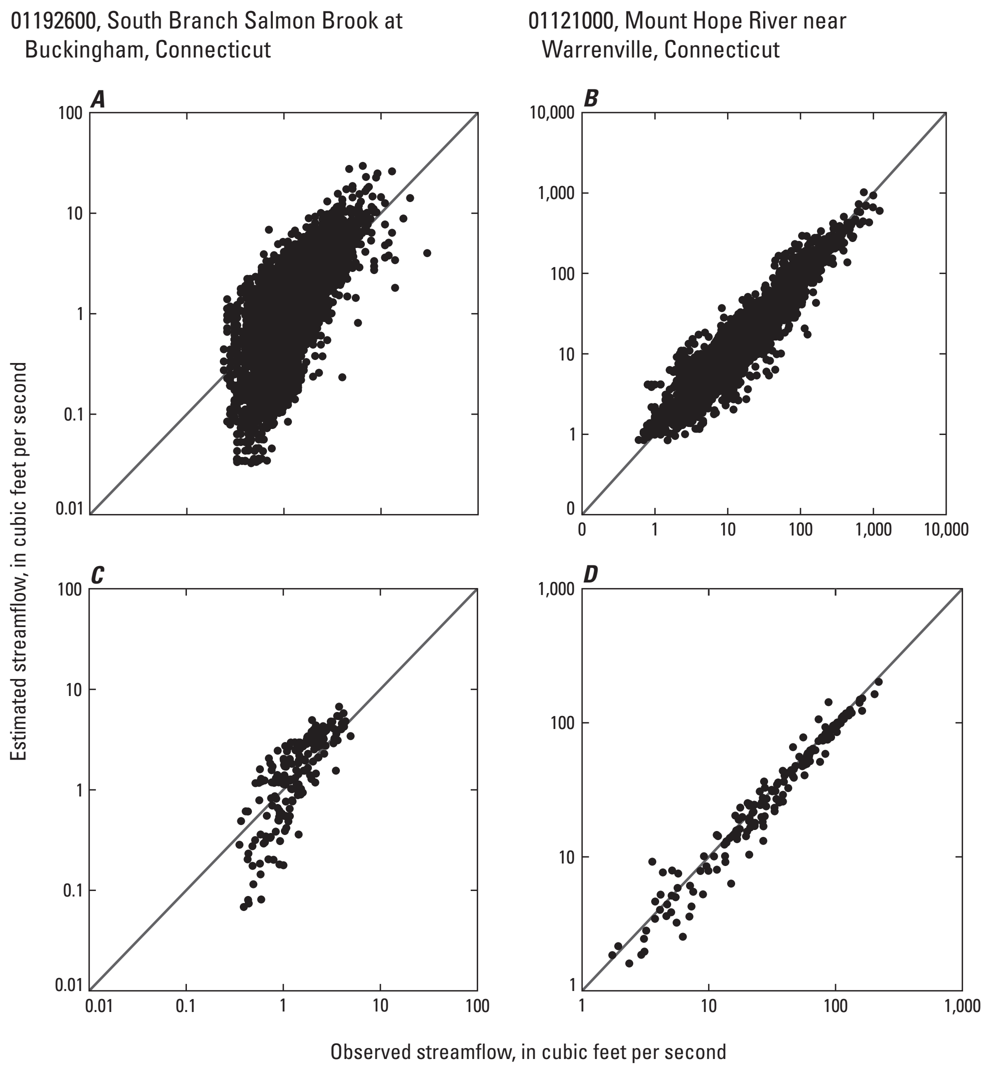


Figure 5. Observed and estimated *A–B*, daily mean streamflow and *C–D*, monthly mean streamflow for U.S. Geological Survey streamgages 01192600, South Branch Salmon Brook at Buckingham, Conn., and 01121000, Mount Hope River near Warrenville, Conn., from October 1, 1960, to September 30, 2015.

3. Use regression equations from a remove-one cross validation to estimate the flow-duration curve at each RG_n, and then perform the QPPQ by using each $RG_{n,m}$ to produce 5 estimated time series of streamflow at each of the 5 RG_n, for a total of 25 daily time series simulations.

4. For each of the 25 simulated daily time series, compute the error ratio as the observed divided by the estimated streamflow for each day of the period of record, and group the error ratios from all 25 time series by month (fig. 7*C*).

5. For each month, the error ratios at the 97.5 and 2.5 percentiles (red dots in fig. 7*C*) are computed from the distribution of error ratios for that month. Upper and lower prediction-interval bounds for each daily streamflow value at the ungaged basin are computed by multiplying simulated streamflow at the ungaged basin by the error ratios at the 97.5 and 2.5 percentiles for the corresponding month.

The prediction interval for a streamflow value on a given day is a range of values that should include the actual streamflow value with an acceptable confidence level. The method used for estimating prediction intervals for a daily mean streamflow value assumes that the prediction errors at sites that are highly correlated to the ungaged site will have a similar distribution at the ungaged site. Prediction intervals for both daily and monthly average streamflow were computed for each reference streamgage in a remove-one cross validation for the CT SSWUE period of record, excluding any periods for which record-extension techniques were used. The performance of the prediction-interval procedure was evaluated by computing the coverage ratio, defined as the percentage of days in the period of record in which the gaged daily streamflow was within the prediction interval. For example, 95-percent prediction intervals should have a coverage ratio of roughly 95 percent at a given site (about 19,070 of 20,075 days in a 55-year record). Coverage ratios ranged from 82.2 percent to 99.9 percent with a median of 96.6 percent

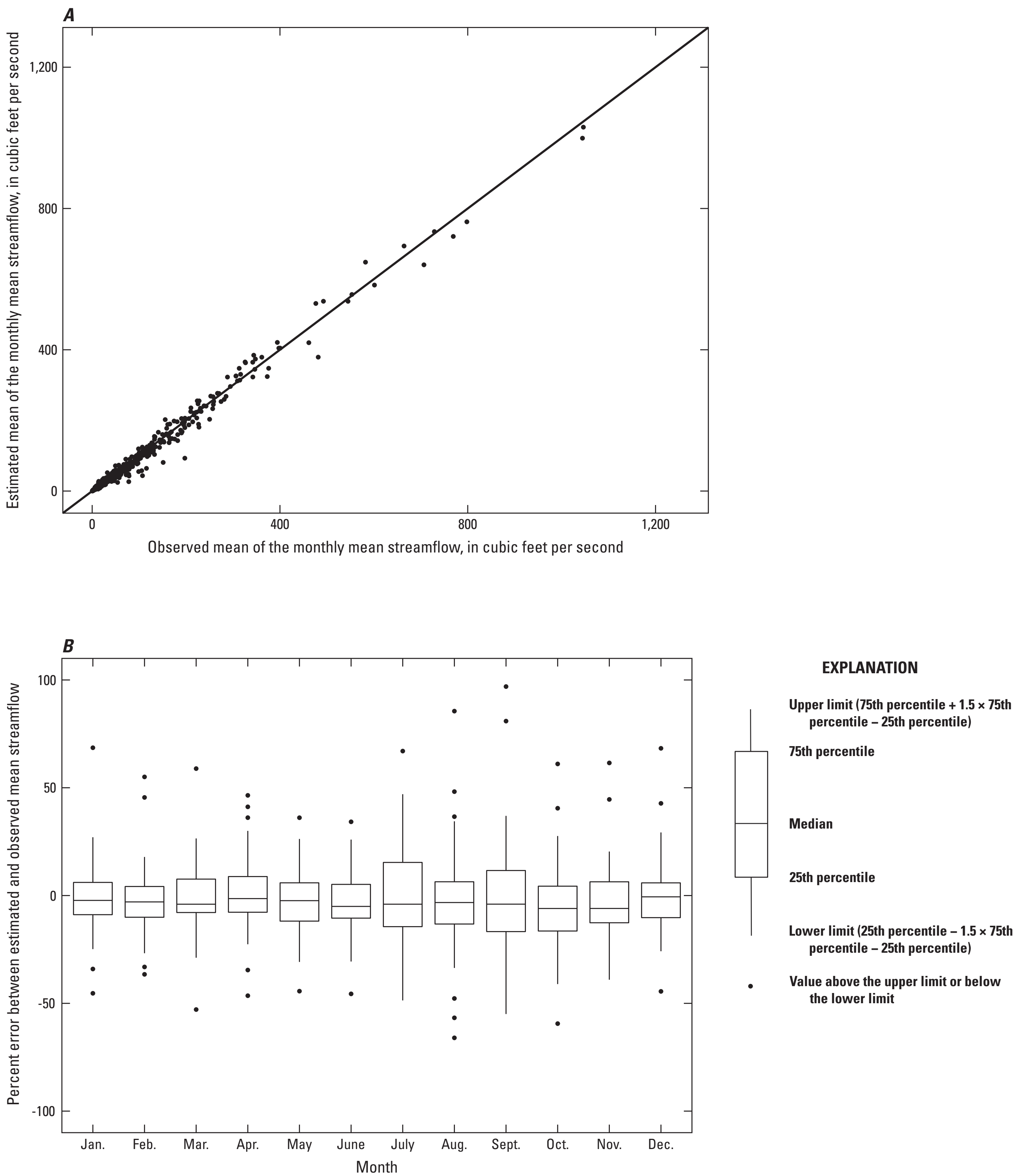


Figure 6. The observed and estimated mean of the monthly mean streamflow and *B*, the percent error of the estimated mean of the monthly mean streamflow for 61 U.S. Geological Survey streamgages used as reference streamgages in the Connecticut Streamflow and Sustainable Water Use Estimator, from October 1, 1960, to September 30, 2015, Connecticut and vicinity.

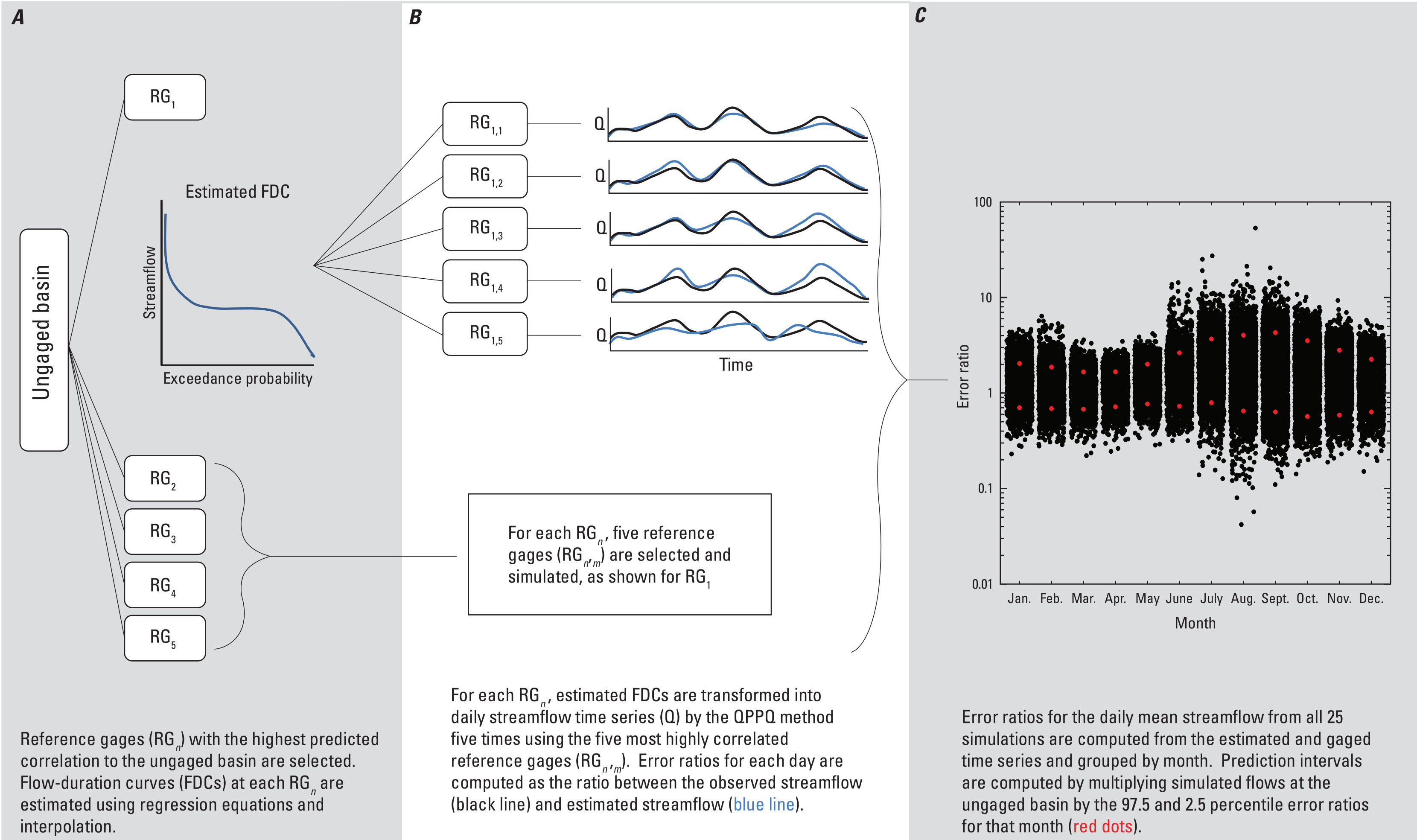


Figure 7. Schematic diagram of the process used to compute 95-percent prediction intervals for daily unaltered streamflows estimated by the Connecticut Streamflow and Sustainable Water Use Estimator. *A*, Flow-duration curves are estimated for five reference streamgages (RG_n) that are most highly correlated to the ungaged basin. *B*, Five reference streamgages ($RG_{n,m}$) are selected for each RG_n and used to estimate a time series of daily mean streamflow for RG_n. *C*, Daily error ratios are computed from the observed and estimated daily mean time series and compiled by month. The error ratios at the 97.5 and 2.5 percentiles for each month are computed.

for daily prediction intervals and ranged from 69.8 percent to 100.0 percent with a median of 93.9 percent for monthly streamflows (fig. 8). Prediction intervals performed better for daily time series than monthly time series. This is likely due to the larger sample size of the error ratio distributions used to characterize the 97.5 and 2.5 percentiles in the daily time series. Investigation into the performance and refinement of the prediction-interval procedure is an area of ongoing research. For the current (2018) CT SSWUE application, the performance at most sites was adequate to provide the user with a reasonable measure of uncertainty in estimated unaltered daily and monthly mean streamflow values.

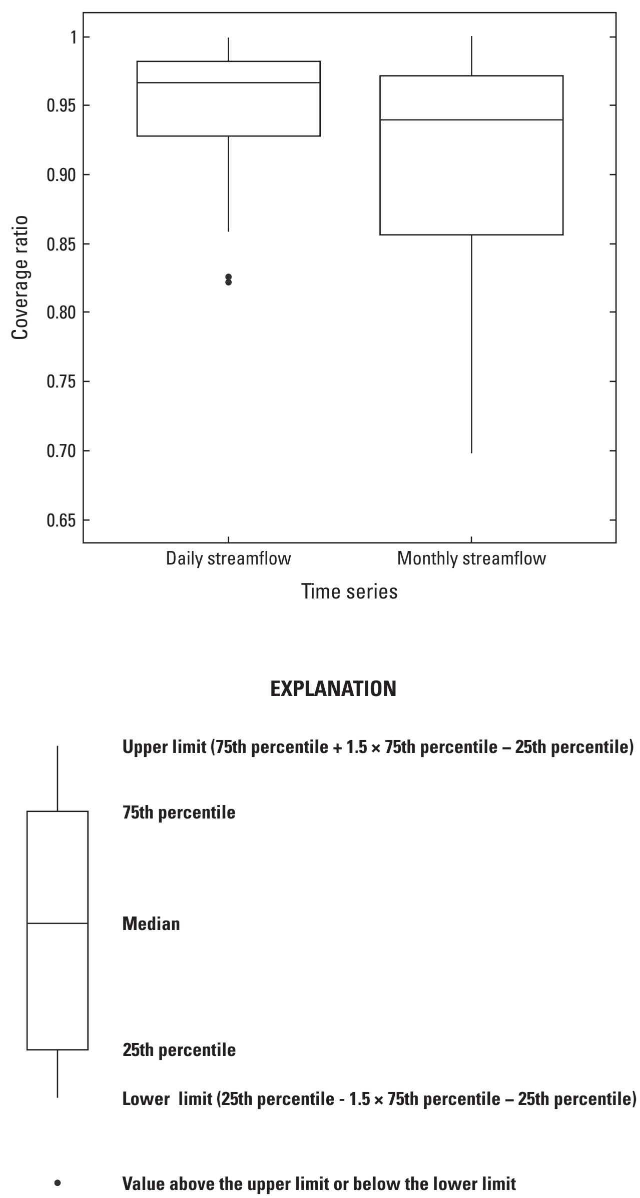


Figure 8. The coverage ratio for prediction intervals for daily and monthly mean time series of estimated unaltered streamflow at 61 reference streamgages used in the Connecticut Streamflow and Sustainable Water Use Estimator, from October 1, 1960, to September 30, 2015, Connecticut and vicinity. The coverage ratio is the percentage of days in the period of record in which the gaged daily streamflow was within the prediction interval.

Estimation of Daily Water-Use-Adjusted Streamflow

The CT SSWUE computes water-use-adjusted streamflow at a user-defined location on the basis of average monthly water use within the basin. Daily water-use-adjusted streamflow is computed by adding the average daily wastewater discharges and subtracting the average daily water withdrawals of all permitted water-use sources from the estimated unaltered daily mean streamflow:

$$Q_A = Q_U + Q_D - Q_W, \tag{3}$$

where

Q_A is the daily water-use-adjusted streamflow, in cubic feet per second;

Q_U is the daily unaltered streamflow, in cubic feet per second;

Q_D is the average daily discharge from all permitted wastewater discharges within the basin, in cubic feet per second; and

Q_W is the average daily withdrawal from all permitted surface-water or groundwater sources within the basin, in cubic feet per second.

Average daily water use for each month is applied to the entire 55-year time series of estimated unaltered daily mean streamflow to produce a time series of daily water-use-adjusted streamflow. This time series of water-use-adjusted streamflow allows the user to determine if current water use is likely to deplete streamflow to below the user-defined minimum target level under a range of historical hydrologic conditions, including drought periods. Many factors other than water use can affect streamflow, and water-use-adjusted streamflow is not intended to represent actual historical or gaged streamflow in a basin. The water-use-adjusted streamflow time series does not take into account variability in water use from year to year, changes in streamflow due to upstream dams or culverts, or the effects of impervious surface or land-use change within the basin.

Time-Lagged Streamflow Depletion From Groundwater Withdrawals

The timing of streamflow alteration from groundwater withdrawals is affected by many factors, including the distance of the well to the stream and the transmissivity of the aquifer. When groundwater withdrawal volumes vary in time, there may be a delay in the timing of the corresponding streamflow alteration. The CT SSWUE estimates the time-lagged streamflow alteration from groundwater withdrawals using algorithms developed for the USGS Hydrologic Drought Decision Support System (HyDroDSS) (Granato, 2014). Monthly groundwater response coefficients range from 0.0 to 1.0 and proportion each monthly water-use volume to the month of pumping and the 11 following months. For example, a response coefficient of 1.0 in the first month of pumping indicates that streamflow depletion in that month is equal to the volume of pumping. A response coefficient of 0.5 in the first month indicates that streamflow depletion in the first month of pumping is only 50 percent of the pumping volume for that month and that the rest of the pumping volume would cause depletions in subsequent months. Groundwater withdrawals cause reductions in evapotranspiration as well as reductions in streamflow, so the total depletions from groundwater withdrawals commonly are one or more percentage points smaller than the withdrawals (Barlow and Dickerman, 2001; DeSimone and others, 2002; Eggleston, 2004; Granato and Barlow, 2005; Bent and others, 2011; Barlow and Leake, 2012). Therefore, the final response-coefficient values for each groundwater site were adjusted so that they sum to 99.5 percent.

Because the effects of pumping may persist for several months after pumping, the streamflow depletion for a given month is equal to the depletions caused by the current month's pumping plus the continuing effects of the previous 11 months of pumping. The total streamflow depletion from a groundwater source for a given month is computed as

$$Qs = \sum_{k=1}^{12} r_k \, Qw_k \, , \tag{4}$$

where

- Qs is the streamflow depletion from a single groundwater pumping site for a given month,
- r_k is the response coefficient for the pumping site,
- Qw_k is the average pumping rate for month for the current and prior 11 months (k), and
- k is an index for the current month and the preceding 11 months of pumping.

Total streamflow depletion for a given month is equal to the sum of depletions from all individual groundwater sources within the basin. Surface water withdrawals are assigned a response coefficient of 1.0, which corresponds to an immediate alteration in streamflow with no persisting effect on streamflow in subsequent months.

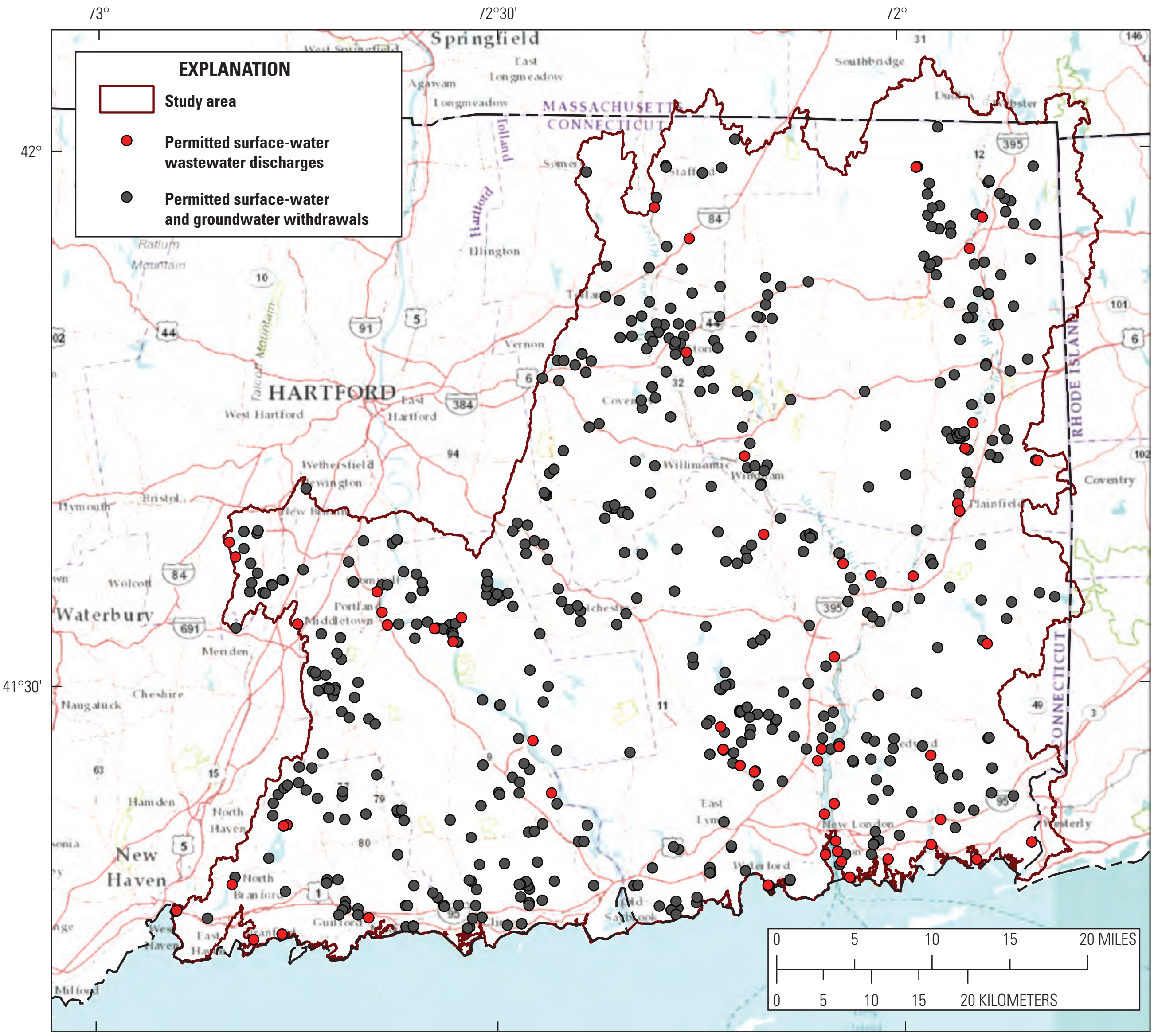
Response-coefficient values were compiled from results of calibrated three-dimensional MODFLOW models for 108 groundwater sites documented in 7 USGS modeling studies in Rhode Island and central and eastern Massachusetts (Barlow and Dickerman, 2001; DeSimone and others, 2002; Eggleston, 2004; Granato and Barlow, 2005; Bent and others, 2011; Eggleston and others, 2012; Granato, 2014). The 12-month response-coefficient patterns were selected for each groundwater withdrawal or return flow site on the basis of the distance and diffusivity of each site. Groundwater sites that are close to a stream in high-transmissivity aquifers have a rapid altered-flow response. Sites that are distant from the stream or sites in low-transmissivity aquifers have a slow altered-flow response. The 108 groundwater sites were classified into groups with similar transmissivities and stream distances, and average response coefficients from many wells were used to identify depletion patterns and select monthly response-coefficient values for each group. Default values for aquifer transmissivity were assigned to groundwater well locations in Connecticut on the basis of GIS digital data layers of surficial aquifer information (Connecticut Department of Environmental Protection, 2008). The shortest flow path from each groundwater well location to the nearest water body or stream within the basin was computed from digital elevation data (U.S. Geological Survey, 2017b).

Reported Water Use

Georeferenced, reported water-use data from registered and permitted withdrawal sources and permitted wastewater discharge sources within the Thames River Basin and central coastal drainage basins (fig. 9) were compiled for use in estimating water-use-adjusted streamflow and sustainable net withdrawal at ungaged sites. Wastewater discharge data were included for 57 sites permitted under the National Pollutant Discharge Elimination System for the year 2015. Water withdrawal data for 345 sites were compiled from CT DEEP databases of permitted and registered water, with reported data spanning various years from 1998 to 2015. The Water Diversion Policy Act, in section 22a–368 of the Connecticut General Statutes, outlines the requirements for registering and permitting individual and general withdrawals (Connecticut Department of Energy and Environmental Protection, n.d.). The sites in these databases were supplemented by additional sites that had withdrawal data from 2006–15 that were reported to the CT DEEP Utilities Regulatory Authority (CT PURA) in the required annual reports for certain water utilities (63 sites) and by public water-supply systems (181 sites) too small to be included in the CT DEEP permitting system. The small public water-supply systems had estimated withdrawal data for the 2015 calendar year (Dieter and Maupin, 2017). Water withdrawals were reported as either annual volumes (disaggregated into constant average daily withdrawals) or monthly average daily withdrawals for each year of data.

For some registered, permitted water withdrawals, no reported data were available. The registered or permitted daily volumes were used as the daily water withdrawal volumes for these sites (91 sites). Of the total registered and permitted sites, 17 were known to be inactive as of 2015, and for these sites the withdrawal values were set to zero.

Three large public water supply systems in the study area are composed of withdrawal sites, diversion tunnels, points



Base from Esri, DeLorme, U.S. Geological Survey, and National Park Service digital data, Esri State boundary, 1:3,000,000, 2013, and Esri World Reference, 2017
Connecticut State Plane projection, North American Datum of 1983
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Figure 9. Locations of permitted water withdrawals and wastewater discharges in central and eastern Connecticut used in the Connecticut Streamflow and Sustainable Water Use Estimator.

of tunnel discharge back into other surface-water bodies, and final withdrawal to the public-supply treatment and distribution facilities. The CT SSWUE water-use database includes each of these withdrawal and wastewater discharge volumes.

Reported water-use data were incorporated into the USGS StreamStats web application for Connecticut for use with the CT SSWUE. For a user-defined location, StreamStats provides a summary of average monthly use for all upstream withdrawals and wastewater discharges that were included in the State's database. Water-use information is reported on a basinwide scale, and information regarding the location or water use of a specific source is not available to the user. Data for residential wells and septic discharges were not available at the time of model development and are not included in the StreamStats water-use summaries. Users have the option to alter or update the water-use information for their basin of interest within the CT SSWUE.

Using the Connecticut Streamflow and Sustainable Water Use Estimator to Estimate Daily Streamflow and Sustainable Net Withdrawal

The CT SSWUE software was developed in Microsoft Access with a menu-driven GUI, which was designed be used in conjunction with the USGS StreamStats web application. Geoprocessing steps, including basin delineation, computation of basin characteristics, and the compilation of a monthly water-use summary for the ungaged basin, are performed in StreamStats by the user before the CT SSWUE is run. Data exported from StreamStats are accessed by the CT SSWUE, which computes the daily unaltered and water-use-adjusted streamflows and sustainable net withdrawal. The CT SSWUE software and user manual (Granato and Levin, 2018a, b) are available at https://doi.org/10.5066/P9V6ARUS and https://doi.org/10.3133/ofr20181169, respectively.

Limitations

The use and interpretation of estimated streamflow from the CT SSWUE has several limitations. The regression equations are applicable to sites whose basin characteristics fall within the ranges used for equation development (table 4). If basin characteristics at an ungaged site are outside of these ranges or are computed from different geospatial datasets than those described in the “Streamgage Selection and Basin Characteristics” section, the accuracy of the predicted flow-duration curve is unknown. The CT SSWUE is not applicable along the main stem of the Connecticut River (fig. 9) because the size of the drainage area is outside the applicable range for regression equations.

Estimated water-use-adjusted daily streamflows for the 55-year period from October 1, 1960, to September 30, 2015, do not account for changes in streamflow due to upstream dams or culverts, impervious surface, or changes in land use over time. Use of the CT SSWUE in basins with large reservoirs may not adequately reflect the water availability at the location of interest because of regulation and water storage in upstream impoundments.

Water-use information within the USGS StreamStats web application for Connecticut is not available for the entire State and does not include data from some water-use sources. Volumes of withdrawals from private domestic wells, septic discharge, and permitted groundwater discharge were not available for inclusion in the CT SSWUE. Additionally, water-use information is not available for areas outside of Connecticut. Users of the CT SSWUE may add this information, if known, when running the application if the basin of interest crosses State boundary lines.

Estimates of altered streamflow include uncertainty in the reported water-use volumes and in the method used to estimate time-lagged streamflow depletion from groundwater withdrawals. Water-use data are self-reported with unknown uncertainty and may have variable precision and accuracy. Aquifer properties used for groundwater withdrawal sites were estimated from existing digital data layers that provide ranges of transmissivity for large geographical areas and have unknown uncertainty in their applicability to a specific well location. Groundwater response coefficients for groundwater withdrawal sites were developed by using calibrated groundwater models in Massachusetts and Rhode Island. Although the hydraulic properties of aquifers in Connecticut are similar to those in the calibrated study areas, the applicability of the response coefficients in Connecticut was not tested.

Summary

Water-resource managers need information regarding water availability and the potential effect of water-use practices on the natural flow regime at ungaged locations. The Connecticut Streamflow and Sustainable Water Use Estimator (CT SSWUE), developed by the U.S. Geological Survey in cooperation with the Connecticut Department of Energy and Environmental Protection, is a statewide decision-support tool that estimates water availability under both unaltered and water-use scenarios over a range of historical hydrologic conditions.

The CT SSWUE provides estimates of daily unaltered and water-use-adjusted streamflow for a 55-year period from October 1, 1960, to September 30, 2015, using a combination of statistical and transfer methods. Weighted least squares and Tobit regression techniques were used to develop equations for estimating 19 streamflow quantiles ranging from 0.005 to 99.995 percent at ungaged sites. The drainage-basin characteristics—drainage area, mean of the soil permeability, mean of the average annual precipitation, and ratio of the length of streams that overlay sand and gravel deposits to the total length of streams in the basin—are used as explanatory variables in the equations. A continuous, daily flow-duration curve for an ungaged site is produced by interpolating the streamflow values among the regression-estimated streamflow quantiles. The flow-duration curve is converted to a daily time series by using the QPPQ method, which assumes that streamflow quantiles at the ungaged site and a reference streamgage site occur on the same day. A network of reference (minimally altered flow) streamgages, which includes the 36 streamgages used in developing the regression equations and an additional 25 streamgages, is used to assign a streamflow quantile to each day of the simulation period. A reference streamgage is identified by using a map-correlation method, which predicts the correlation between streamflows at the ungaged site and the reference streamgage site.

The accuracy of estimated daily unaltered streamflows was assessed through a remove-one cross validation at each of the 61 reference streamgages. For daily streamflows, Nash-Sutcliffe efficiency ranged from −0.43 to 0.97 with a median value of 0.88, and the normalized root-mean-square error ranged from 16.6 to 120.4 with a median value of 34.5 percent. Uncertainty in estimates of daily unaltered streamflow arises from multiple sources in the CT SSWUE, including uncertainty associated with the regression equations used to estimate streamflow quantiles, interpolation of the continuous flow-duration curve, and the QPPQ method. Prediction intervals for estimates of unaltered daily and monthly mean streamflows are produced by using an empirical method. Prediction intervals computed for the 61 cross-validation streamgages contained the observed daily streamflow adequately at most sites, with median coverage ratios of 96.6 percent for daily streamflow and 93.9 percent for monthly streamflow.

Water-use-adjusted daily streamflow is computed by the CT SSWUE by adding basinwide average daily wastewater discharges and subtracting water withdrawals. Monthly reported water-use volumes for all permitted surface-water and groundwater withdrawals in the Thames River Basin and central coastal basins for the years 1998 to 2015 were compiled and entered into the U.S. Geological Survey StreamStats web application for Connecticut, which provides summaries of average monthly water use for user-selected ungaged basins. Time-lagged effects of groundwater withdrawals are estimated by using response coefficients developed from published, calibrated three-dimensional groundwater models.

The CT SSWUE computer application was developed in Microsoft Access with a graphical user interface and is designed to be used in conjunction with the Connecticut StreamStats web application. Geoprocessing steps needed for the CT SSWUE, such as basin delineation, compilation of basin characteristics, and basinwide water-use summaries are performed in StreamStats prior to running the CT SSWUE. Data exported from StreamStats are then used in the CT SSWUE application to compute daily streamflow and sustainable net withdrawal. CT SSWUE unaltered and water-use-adjusted streamflows are summarized by month along with user-specified streamflow targets and sustainable net withdrawal estimates for the ungaged basin of interest, and users may export daily and monthly time series of estimated streamflows and prediction intervals.

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Appendix 1. Reference Streamgages and Periods of Record Used for the Connecticut Streamflow and Sustainable Water Use Estimator

Appendix 2. Basin Characteristics Tested for Use in the Regression Equations for Estimating Streamflow at Ungaged Sites With the Connecticut Streamflow and Sustainable Water Use Estimator

Appendix 3. Dates of Station Record and Dates of Extended Record for Reference Streamgages Used by the Connecticut Streamflow and Sustainable Water Use Estimator

Table 1.1. Reference streamgages and periods of record used for the Connecticut Streamflow and Sustainable Water Use Estimator.

[All streamgages are shown in figure 1. USGS, U.S. Geological Survey; mi², square mile; MA, Massachusetts; RI, Rhode Island; CT, Connecticut; NY, New York]

USGS stream-gage number	Streamgage name	[1]Drainage area, in mi²	Latitude	Longitude	Stream-gage used in regres-sion	[2]Period of record, in water years	Years of record
01095220	Stillwater River near Sterling, MA	29.1	42°24′39″	71°47′29″	No	1995–2015	21
01109200	West Branch Palmer River near Rehoboth, MA	4.29	41°52′46″	71°15′16″	No	1964–74	11
01111300	Nipmuc River near Harrisville, RI	15.9	41°58′52″	71°41′9″	Yes	1965–91, 1994–2015	49
01111500	Branch River at Forestdale, RI	91.2	41°59′47″	71°33′45″	Yes	1941–2015	75
01115098	Peeptoad Brook at Elmdale Road near Westerly, RI	4.96	41°51′9″	71°36′22″	No	1995–2014	20
01115187	Ponaganset River at South Foster, RI	14.0	41°49′8″	71°42′18″	No	1995–2015	21
01115630	Nooseneck River at Nooseneck, RI	8.20	41°37′36″	71°37′57″	Yes	1965–81, 2008–15	25
01117370	Queen River at Liberty Road at Liberty, RI	19.5	41°32′20″	71°34′7″	No	1999–2015	17
01117468	Beaver River near Usquepaug, RI	9.36	41°29′33″	71°37′40″	No	1976–2015	40
01117500	Pawcatuck River at Wood River Junction, RI	100	41°26′43″	71°40′52″	Yes	1942–2012, 2014–15	73
01117800	Wood River near Arcadia, RI	35.3	41°34′26″	71°43′15″	Yes	1965–81, 1983–2015	50
01118000	Wood River Hope Valley, RI	74.6	41°29′53″	71°42′58″	Yes	1942–2015	74
01118300	Pendleton Hill Brook near Clarks Falls, CT	4.01	41°28′29″	71°50′3″	Yes	1959–2015	57
01118500	Pawcatuck River at Westerly, RI	294	41°23′1″	71°49′60″	Yes	1942–2015	74
01120000	Hop Brook near Columbia, CT	74.5	41°43′39″	72°18′8″	Yes	1933–71	39
01120500	Safford Brook near Woodstock Valley, CT	4.17	41°55′33″	72°3′30″	Yes	1951–81	31
01121000	Mount Hope River near Warrenville, CT	29.0	41°50′37″	72°10′8″	Yes	1941–2015	75
01123000	Little River near Hanover, CT	30.0	41°40′17″	72°3′9″	Yes	1952–2015	64
01125490	Little River at Harrisville, CT	35.7	41°55′40″	71°55′48″	No	1962–71, 2012–15	15
01126600	Blackwell Brook near Brooklyn, CT	17.0	41°45′54″	71°57′23″	No	1964–76	13
01126950	Pachaug River at Pachaug, CT	53.0	41°35′4″	71°56′2″	No	1962–73	12
01171500	Mill River at Northampton, MA	52.6	42°19′8″	72°39′54″	Yes	1940–2015	76
01171800	Bassett Brook near North Hampton, MA	5.56	42°18′10″	72°41′15″	No	1964–74	11
01174000	Hop Brook near New Salem, MA	3.48	42°28′43″	72°20′2″	Yes	1949–82	34
01174565	West Branch Swift River near Shutesbury, MA	12.7	42°27′18″	72°22′54″	No	1985, 1996–2015	21
01174600	Cadwell Creek near Pelham, MA	0.62	42°21′17″	72°23′16″	Yes	1962–94	33
01174900	Cadwell Creek near Belchertown, MA	2.55	42°20′8″	72°22′11″	Yes	1962–97	36
01175670	Sevenmile River near Spencer, MA	8.91	42°15′53″	72°0′17″	Yes	1962–2015	54
01176000	Quaboag River at West Brimfield, MA	149	42°10′57″	72°15′48″	Yes	1913–2015	102
01180000	Sykes Brook at Knightville, MA	1.69	42°17′28″	72°52′13″	Yes	1946–73	28
01181000	West Branch Westfield at Huntington, MA	93.9	42°14′14″	72°53′45″	Yes	1936–2015	80
01187300	Hubbard River near West Hartland, CT	20.6	42°2′15″	72°56′21″	Yes	1939–55, 1957–2015	76
01187400	Valley Brook near West Hartland, CT	7.38	42°2′3″	72°55′47″	Yes	1941–72	32

Table 1.1. Reference streamgages and periods of record used for the Connecticut Streamflow and Sustainable Water Use Estimator.—Continued

[All streamgages are shown in figure 1. USGS, U.S. Geological Survey; mi^2, square mile; MA, Massachusetts; RI, Rhode Island; CT, Connecticut; NY, New York]

USGS streamgage number	Streamgage name	[1]Drainage area, in mi^2	Latitude	Longitude	Streamgage used in regression	[2]Period of record, in water years	Years of record
01187800	Nepaug River near Nepaug, CT	23.5	41°49′14″	72°58′13″	Yes	1922–55, 1958–72, 1999–2001	52
01188000	Bunnell Brook near Burlington, CT	4.20	41°47′10″	72°57′53″	Yes	1932–2015	84
01192600	South Branch Salmon Brook at Buckingham, CT	0.95	41°43′6″	72°32′23″	Yes	1961–76	16
01193500	Salmon River near East Hampton, CT	101	41°33′8″	72°26′58″	Yes	1929–2015	87
01193800	Hemlock Valley Brook at Hadlyme, CT	2.74	41°25′42″	72°25′21″	No	1961–76	16
01194000	Eightmile River at North Plain, CT	20.2	41°26′30″	72°19′58″	Yes	1938–66, 2008–15	37
01194500	East Branch Eightmile River near North Lyme, CT	22.4	41°25′39″	72°20′5″	Yes	1938–81, 2002–15	58
01195100	Indian River near Clinton, CT	5.62	41°18′22″	72°31′52″	No	1983–2013	31
01195200	Neck River near Madison, CT	6.60	41°16′57″	72°37′9″	Yes	1962–81	20
01198000	Green River near Great Barrington, MA	51.0	42°11′31″	73°23′27″	Yes	1952–71, 1995–96, 2008–15	30
01198500	Blackberry River at Canaan, CT	45.5	42°1′26″	73°20′29″	Yes	1950–71	22
01199200	Guinea Brook at West Woods Road at Ellsworth, CT	3.5	41°49′28″	73°25′48″	Yes	1961–81	21
01200000	Ten Mile River near Gaylordsville, CT	200	41°39′32″	73°31′43″	Yes	1931–87, 1992–99, 2001–15	80
01201190	West Aspetuck River at Sand Road near New Milford, CT	23.8	41°36′29″	73°25′28″	No	1963–72	9
01201930	Marshepaug River near Milton, CT	9.45	41°47′21″	73°15′32″	No	1968–81	14
01204800	Copper Mill Brook near Monroe, CT	2.45	41°21′46″	73°13′6″	No	1959–76	18
01206400	Leadmine Brook near Harwinton, CT	19.7	41°43′47″	73°3′10″	No	1961–73	13
01206500	Leadmine Brook near Thomaston, CT	24.5	41°42′7″	73°3′27″	No	1931–59	29
01208950	Sasco Brook near Southport, CT	7.38	41°9′10″	73°18′22″	Yes	1965–2015	51
01208990	Saugatuck River near Redding, CT	20.7	41°17′40″	73°23′42″	Yes	1965–2015	51
01360640	Valatie Kill near Nassau, NY	9.50	42°33′7″	73°35′29″	No	1991–2014	24
01372200	Wappinger Creek near Clinton Corners, CT	93.9	41°48′54″	73°45′46″	No	1958–75	18
01372500	Wappinger Creek near Wappingers Falls, NY	183	41°39′10″	73°52′23″	Yes	1929–2015	87
01372800	Fishkill Creek at Hopewell Junction, NY	57.3	41°34′21″	73°48′23″	No	1964–75	12
0137449480	East Branch Croton River near Putnam Lake, NY	64.8	41°26′50″	73°33′22″	No	1996–2015	20
01374598	Horse Pound Brook near Lake Carmel, NY	3.91	41°28′33″	73°41′22″	No	1997–2015	19
01374890	Cross River near Cross River, NY	17.1	41°15′37″	73°36′7″	No	1997–2015	19
01374987	Kisco River below Mount Kisco, NY	17.5	41°13′43″	73°44′37″	No	1996–2008	13

[1]Drainage area determined from a geographical information system and digital datasets and may not match previously published drainage area.

[2]Period of record includes all years with complete daily streamflow record.

Table 2.1. Basin characteristics tested for use in the regression equations for estimating streamflow at ungaged sites with the Connecticut Streamflow and Sustainable Water Use Estimator.

[ft, foot; °C, degrees Celsius; NED, National Elevation Dataset; WBD, Watershed Boundary Dataset; NHD, National Hydrography Dataset; NLCD, National Land Cover Database; PRISM, PRISM Climate Group; NWI, National Wetlands Inventory; gSSURGO, Gridded Soil Survey Geographic; STATSGO, State Soil Geographic; --, no data]

Basin characteristic	Computation method	Unit	Data source
Drainage area	--	Square miles	NED[1], WBD[2]
Perimeter of basin	--	Miles	--
Mean elevation	Basinwide mean	Feet	NED[1]
Maximum elevation in basin	--	Feet	NED[1]
Minimum elevation in basin	--	Feet	NED[1]
Relief (maximum elevation minus minimum elevation)	--	Feet	NED[1]
Relative relief (relief divided by perimeter)	--	Feet per mile	NED[1]
Percent of the basin having elevation greater than 400 ft	Areal percent	Percent	NED[1]
Percent of the basin having elevation greater than 600 ft	Areal percent	Percent	NED[1]
Percent of the basin having elevation greater than 800 ft	Areal percent	Percent	NED[1]
Percent of the basin having elevation greater than 1,000 ft	Areal percent	Percent	NED[1]
Percent of the basin having elevation greater than 1,200 ft	Areal percent	Percent	NED[1]
Percent of the basin having elevation greater than 1,400 ft	Areal percent	Percent	NED[1]
Percent of the basin having elevation greater than 1,600 ft	Areal percent	Percent	NED[1]
Mean basin slope	Basinwide mean	Percent	NED[1]
Mean basin aspect	Basinwide mean	Degrees	NED[1]
Percent of basin with a slope greater than 30 percent	Areal percent	Percent	NED[1]
Percent of basin with a slope greater than 30 percent and an aspect of 315–45 degrees	Areal percent	Percent	NED[1]
Percent of basin with a slope greater than 30 percent and an aspect of 45–135 degrees	Areal percent	Percent	NED[1]
Percent of basin with a slope greater than 30 percent and an aspect of 135–225 degrees	Areal percent	Percent	NED[1]
Percent of basin with a slope greater than 30 percent and an aspect of 225–315 degrees	Areal percent	Percent	NED[1]
Percent of basin with an aspect of 315–45 degrees	Areal percent	Percent	NED[1]
Percent of basin with an aspect of 45–135 degrees	Areal percent	Percent	NED[1]
Percent of basin with an aspect of 135–225 degrees	Areal percent	Percent	NED[1]
Percent of basin with an aspect of 225–315 degrees	Areal percent	Percent	NED[1]
Easting of basin centroid in Connecticut State Plane coordinates	--	Feet	--
Northing of basin centroid in Connecticut State Plane coordinates	--	Feet	--
Compaction ratio (perimeter to the perimeter of a circle having area equal to the drainage area)	--	--	--
Average physiographic region by area	Basinwide mean	Region category	Fenneman[3]
Sum of stream lengths (pipelines and coastline removed from dataset)	--	Miles	NHD[4]
Stream density (sum of stream lengths divided by drainage area)	--	Miles per square mile	NHD[4]
Percent of basin covered by streams and rivers	Areal percent	Percent	NHD[4]
Percent of basin covered by swamps	Areal percent	Percent	NHD[4]
Percent of basin covered by lakes and ponds	Areal percent	Percent	NHD[4]
Percent of basin covered by lakes, ponds, and reservoirs	Areal percent	Percent	NHD[4]
Percent of basin covered by swamps, lakes, ponds, and reservoirs	Areal percent	Percent	NHD[4]

Table 2.1. Basin characteristics tested for use in the regression equations for estimating streamflow at ungaged sites with the Connecticut Streamflow and Sustainable Water Use Estimator.—Continued

[ft, foot; °C, degrees Celsius; NED, National Elevation Dataset; WBD, Watershed Boundary Dataset; NHD, National Hydrography Dataset; NLCD, National Land Cover Database; PRISM, PRISM Climate Group; NWI, National Wetlands Inventory; gSSURGO, Gridded Soil Survey Geographic; STATSGO, State Soil Geographic; --, no data]

Basin characteristic	Computation method	Unit	Data source
Percent of basin covered by forest	Areal percent	Percent	NLCD[5]
Percent of basin covered by barren land	Areal percent	Percent	NLCD[5]
Percent of basin covered by developed land	Areal percent	Percent	NLCD[5]
Percent of basin covered by crops	Areal percent	Percent	NLCD[5]
Percent of basin covered by grasses and pasture	Areal percent	Percent	NLCD[5]
Percent of basin covered by grasses, pasture, and crops	Areal percent	Percent	NLCD[5]
Percent of basin covered by open water	Areal percent	Percent	NLCD[5]
Percent of basin covered by shrubland	Areal percent	Percent	NLCD[5]
Percent of basin covered by wetland or open water	Areal percent	Percent	NLCD[5]
Percent of basin with imperviousness greater than or equal to 1	Areal percent	Percent	NLCD[6]
Percent of basin with imperviousness greater than or equal to 20	Areal percent	Percent	NLCD[6]
Percent of basin with imperviousness greater than or equal to 40	Areal percent	Percent	NLCD[6]
Percent of basin with imperviousness greater than or equal to 60	Areal percent	Percent	NLCD[6]
Percent of basin with imperviousness greater than or equal to 80	Areal percent	Percent	NLCD[6]
Mean of percent tree canopy	Areal percent	Percent	NLCD[5]
Percent of basin with percent tree canopy greater than or equal to 20	Areal percent	Percent	NLCD[5]
Percent of basin with percent tree canopy greater than or equal to 40	Areal percent	Percent	NLCD[5]
Percent of basin with percent tree canopy greater than or equal to 60	Areal percent	Percent	NLCD[5]
Percent of basin with percent tree canopy greater than or equal to 80	Areal percent	Percent	NLCD[5]
1-year, 60-day rainfall	Basinwide mean	Inches	Atlas 14[7]
1-year, 45-day rainfall	Basinwide mean	Inches	Atlas 15[7]
1-year, 30-day rainfall	Basinwide mean	Inches	Atlas 16[7]
1-year, 10-day rainfall	Basinwide mean	Inches	Atlas 17[7]
1-year, 3-day rainfall	Basinwide mean	Inches	Atlas 18[7]
1-year, 24-hour rainfall	Basinwide mean	Inches	Atlas 19[7]
1-year, 6-hour rainfall	Basinwide mean	Inches	Atlas 20[7]
1-year, 2-hour rainfall	Basinwide mean	Inches	Atlas 21[7]
5-year, 60-day rainfall	Basinwide mean	Inches	Atlas 22[7]
5-year, 24-hour rainfall	Basinwide mean	Inches	Atlas 23[7]
10-year, 60-day rainfall	Basinwide mean	Inches	Atlas 24[7]
10-year, 45-day rainfall	Basinwide mean	Inches	Atlas 25[7]
10-year, 30-day rainfall	Basinwide mean	Inches	Atlas 26[7]
10-year, 20-day rainfall	Basinwide mean	Inches	Atlas 27[7]
10-year, 10-day rainfall	Basinwide mean	Inches	Atlas 28[7]
10-year, 3-day rainfall	Basinwide mean	Inches	Atlas 29[7]
10-year, 24-hour rainfall	Basinwide mean	Inches	Atlas 30[7]
10-year, 12-hour rainfall	Basinwide mean	Inches	Atlas 31[7]
10-year, 6-hour rainfall	Basinwide mean	Inches	Atlas 32[7]
10-year, 2-hour rainfall	Basinwide mean	Inches	Atlas 33[7]
10-year, 5-minute rainfall	Basinwide mean	Inches	Atlas 34[7]

Table 2.1. Basin characteristics tested for use in the regression equations for estimating streamflow at ungaged sites with the Connecticut Streamflow and Sustainable Water Use Estimator.—Continued

[ft, foot; °C, degrees Celsius; NED, National Elevation Dataset; WBD, Watershed Boundary Dataset; NHD, National Hydrography Dataset; NLCD, National Land Cover Database; PRISM, PRISM Climate Group; NWI, National Wetlands Inventory; gSSURGO, Gridded Soil Survey Geographic; STATSGO, State Soil Geographic; --, no data]

Basin characteristic	Computation method	Unit	Data source
25-year, 45-day rainfall	Basinwide mean	Inches	Atlas 35[7]
Average annual precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average January precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average February precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average March precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average April precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average May precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average June precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average July precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average August precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average September precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average October precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average November precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average December precipitation, 1981–2010	Basinwide mean	Inches	PRISM[8]
Average annual maximum daily temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average annual mean daily temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average annual minimum daily temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean January temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean February temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean March temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean April temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean May temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean June temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean July temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean August temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean September temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean October temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean November temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Average mean December temperature, 1981–2010	Basinwide mean	°C	PRISM[8]
Percent of basin that is lakes and ponds	Areal percent	Percent	NWI[9]
Percent of basin that is lakes, ponds, and swamps	Areal percent	Percent	NWI[9]
Percent of basin that is swamps	Areal percent	Percent	NWI[9]
Percent of basin that is wetland (palustrine, riverine, or lacustrine)	Areal percent	Percent	NWI[9]
Mean annual runoff	Basinwide mean	Inches	OFR 96-395[10]
Percent of basin covered by soil classified as drought-vulnerable soil	Areal percent	Percent	gSSURGO[11]
Average available water storage in total soil profile	Basinwide mean	Millimeters	gSSURGO[11]
Percent of basin with available water storage greater than 150 millimeters	Areal percent	Percent	gSSURGO[11]
Average available water capacity	Basinwide mean	Inches per inch	STATSGO[12]
Average liquid limit in percent soil moisture by weight	Basinwide mean	Percent	STATSGO[12]
Basinwide mean of the STATSGO hydrologic character of soil classification	Basinwide mean	--	STATSGO[12]

Table 2.1. Basin characteristics tested for use in the regression equations for estimating streamflow at ungaged sites with the Connecticut Streamflow and Sustainable Water Use Estimator.—Continued

[ft, foot; °C, degrees Celsius; NED, National Elevation Dataset; WBD, Watershed Boundary Dataset; NHD, National Hydrography Dataset; NLCD, National Land Cover Database; PRISM, PRISM Climate Group; NWI, National Wetlands Inventory; gSSURGO, Gridded Soil Survey Geographic; STATSGO, State Soil Geographic; --, no data]

Basin characteristic	Computation method	Unit	Data source
Basinwide mean of the STATSGO quality of soil drainage classification	Basinwide mean	--	STATSGO[12]
Low value for the range in depth to seasonally high water table	Basinwide mean	Feet	STATSGO[13]
High value for the range in depth to seasonally high water table	Basinwide mean	Feet	STATSGO[13]
Low value for range in the total soil thickness	Basinwide mean	Feet	STATSGO[13]
High value for range in the total soil thickness	Basinwide mean	Feet	STATSGO[13]
Mean permeability	Basinwide mean	Inches per hour	STATSGO[12]
Low value for the range in permeability	Basinwide mean	Inches per hour	STATSGO[13]
High value for the range in permeability	Basinwide mean	Inches per hour	STATSGO[13]
Percent of basin with glacial stratified coarse deposits and alluvium deposits	Basinwide mean	Percent	Stratified deposits[14]
Streams intersecting glacial stratified coarse deposits and alluvium deposits	Length	Miles	Stratified deposits[14]
Streams intersecting glacial stratified coarse deposits and alluvium deposits per square mile of drainage area	Ratio	Miles per square mile	Stratified deposits[14]
Ratio of the length of streams intersecting glacial stratified coarse deposits and alluvium deposits to the total length of streams	Ratio	--	Stratified deposits[14]

[1]U.S. Geological Survey (2017a).

[2]Natural Resources Conservation Service (2001).

[3]Fenneman and Johnson (1946).

[4]U.S. Geological Survey (2017b).

[5]Homer and others (2015).

[6]Xian and others (2011).

[7]Perica and others (2015).

[8]PRISM Climate Group (2012a, b).

[9]U.S. Fish and Wildlife Service (2016).

[10]Cohen and Randall (1998).

[11]Natural Resources Conservation Service (2014).

[12]U.S. Geological Survey (1995).

[13]Wolock (1997).

[14]Cadwell and others (1986), Connecticut Department of Environmental Protection (2009), Rhode Island Geographic Information System (1989), and U.S. Geological Survey (1999, 2015).

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Table 3.1. Dates of station record and dates of extended record for reference streamgages used by the Connecticut Streamflow and Sustainable Water Use Estimator.

[All streamgages are shown in figure 1. USGS, U.S. Geological Survey; MA, Massachusetts; RI, Rhode Island; CT, Connecticut; NY, New York; NA, not applicable]

USGS streamgage number	Streamgage name	Dates of station record	Dates of extended record	Streamgage used for record extension
01095220	Stillwater River near Sterling, MA	4/22/1994 to 9/30/2015	10/1/1960 to 4/21/1994	01176000
01109200	West Branch Palmer River near Rehoboth, MA	10/27/1962 to 9/30/1974	10/1/1960 to 10/26/1962, 10/1/1991 to 9/30/1993	01118300
			10/1/1974 to 9/30/1991, 10/1/1993 to 9/30/2015	01111300
01111300	Nipmuc River near Harrisville, RI	3/1/1964 to 9/30/1991, 10/1/1993 to 09/30/2015	10/1/1960 to 2/29/1964, 10/1/1991 to 9/30/1993	01111500
01111500	Branch River at Forestdale, RI	10/1/1960 to 9/30/2015	NA	NA
01115098	Peeptoad Brook at Elmdale Road near Westerly, RI	6/23/1994 to 9/30/2015	10/1/1960 to 6/22/1994	01111500
01115187	Ponaganset River at South Foster, RI	3/22/1994 to 9/30/2015	10/1/1960 to 3/21/1994	01111500
01115630	Nooseneck River at Nooseneck, RI	11/26/1963 to 9/30/1981, 3/17/2007 to 9/30/2015	10/1/1960 to 11/25/1963, 10/1/1981 to 9/30/1982	01118000
			10/1/1982 to 3/16/2007	01117800
01117370	Queen River at Liberty Road at Liberty, RI	10/1/1998 to 9/30/2015	10/1/1960 to 9/30/1998	01118000
01117468	Beaver River near Usquepaug, RI	12/4/1974 to 9/30/2015	10/1/1960 to 12/3/1974	01117500
01117500	Pawcatuck River at Wood River Junction, RI	10/1/1960 to 4/1/2013, 8/1/2013 to 9/30/2015	4/2/2013 to 7/31/2013	01118500
01117800	Wood River near Arcadia, RI	1/23/1964 to 9/30/1981, 10/1/1982 to 9/30/2015	10/1/1960 to 1/22/1964, 10/1/1981 to 9/30/1982	01118000
01118000	Wood River Hope Valley, RI	10/1/1960 to 9/30/2015	NA	NA
01118300	Pendleton Hill Brook near Clarks Falls, CT	10/1/1960 to 9/30/2015	NA	NA
01118500	Pawcatuck River at Westerly, RI	10/1/1960 to 9/30/2015	NA	NA
01120000	Hop Brook near Columbia, CT	10/1/1960 to 10/6/1971	10/7/1971 to 09/30/2015	01121000
01120500	Safford Brook near Woodstock Valley, CT	10/1/1960 to 10/7/1981	10/8/1981 to 9/30/2015	01121000
01121000	Mount Hope River near Warrenville, CT	10/1/1960 to 9/30/2015	NA	NA
01123000	Little River near Hanover, CT	10/1/1960 to 9/30/2015	NA	NA
01125490	Little River at Harrisville, CT	8/1/1961 to 9/30/1971, 6/10/2011 to 9/30/2015	10/1/1960 to 7/31/1961, 10/1/1971 to 6/9/2011	01121000
01126600	Blackwell Brook near Brooklyn, CT	10/1/1963 to 10/5/1976	10/1/1960 to 9/30/1963, 10/6/1976 to 9/30/2015	01123000
01126950	Pachaug River at Pachaug, CT	8/1/1961 to 10/4/1973	10/1/1960 to 7/31/1961, 10/1/1981 to 9/30/1982	01118000
			10/5/1973 to 9/30/1981, 10/1/1982 to 9/30/2015	01117800
01171500	Mill River at Northampton, MA	10/1/1960 to 9/30/2015	NA	NA
01171800	Bassett Brook near North Hampton, MA	11/1/1962 to 9/30/1974	10/1/1960 to 10/31/1962, 10/1/1974 to 09/30/2015	01171500
01174000	Hop Brook near New Salem, MA	10/1/1960 to 9/30/1982	10/1/1982 to 9/30/1997	01174900
			10/1/1997 to 9/30/2015	01171500
01174565	West Branch Swift River near Shutesbury, MA	11/8/1983 to 9/30/1985, 4/1/1995 to 9/30/2015	10/1/1960 to 11/7/1983, 10/1/1985 to 3/31/1995	01171500

Table 3.1. Dates of station record and dates of extended record for reference streamgages used by the Connecticut Streamflow and Sustainable Water Use Estimator.—Continued

[All streamgages are shown in figure 1. USGS, U.S. Geological Survey; MA, Massachusetts; RI, Rhode Island; CT, Connecticut; NY, New York; NA, not applicable]

USGS streamgage number	Streamgage name	Dates of station record	Dates of extended record	Streamgage used for record extension
01174600	Cadwell Creek near Pelham, MA	7/13/1961 to 9/30/1994	10/1/1960 to 7/12/1961, 10/1/1997 to 9/30/2015	01174000
			10/1/1994 to 9/30/1997	01174900
01174900	Cadwell Creek near Belchertown, MA	7/13/1961 to 9/30/1997	10/1/1960 to 7/12/1961	01174000
			10/1/1997 to 9/30/2015	01174565
01175670	Sevenmile River near Spencer, MA	12/1/1960 to 9/30/2015	10/1/1960 to 11/30/1960	01176000
01176000	Quaboag River at West Brimfield, MA	10/1/1960 to 9/30/2015	NA	NA
01180000	Sykes Brook at Knightville, MA	10/1/1960 to 7/18/1974	7/19/1974 to 9/30/2015	01171500
01181000	West Branch Westfield at Huntington, MA	10/1/1960 to 9/30/2015	NA	NA
01187300	Hubbard River near West Hartland, CT	10/1/1960 to 9/30/2015	NA	NA
01187400	Valley Brook near West Hartland, CT	10/1/1960 to 9/30/1972	10/1/1972 to 9/30/2015	01187300
01187800	Nepaug River near Nepaug, CT	10/1/1960 to 9/30/1972, 10/1/1998 to 9/30/2001	10/1/1972 to 9/30/1998, 10/1/2001 to 9/30/2015	01188000
01188000	Burlington Brook near Burlington, CT	10/1/1960 to 9/30/2015	NA	NA
01192600	South Branch Salmon Brook at Buckingham, CT	10/1/1960 to 9/30/1976	10/1/1976 to 9/30/2015	01117468
01193500	Salmon River near East Hampton, CT	10/1/1960 to 9/30/2015	NA	NA
01193800	Hemlock Valley Brook at Hadlyme, CT	10/1/1960 to 10/5/1976	10/6/1976 to 10/6/1981, 10/1/2001 to 6/13/2007	01194500
			10/7/1981 to 9/30/2001	01193500
			6/14/2007 to 9/30/2015	01194000
01194000	Eightmile River at North Plain, CT	10/1/1960 to 9/30/1966, 6/14/2007 to 9/30/2015	10/1/1966 to 10/6/1981, 10/1/2001 to 6/13/2007	01194500
			10/7/1981 to 9/30/2001	01193500
01194500	East Branch Eightmile River near North Lyme, CT	10/1/1960 to 10/6/1981, 10/1/2001 to 9/30/2015	10/7/1981 to 9/30/2001	01193500
01195100	Indian River near Clinton, CT	11/4/1981 to 9/30/2013	10/1/1960 to 9/30/1966 10/1/2013 to 9/30/2015	01194000
			10/1/1966 to 10/6/1981	01194500
			10/7/1981 to 11/3/1981	01193500
01195200	Neck River near Madison, CT	9/1/1961 to 11/2/1981	10/1/1960 to 8/31/1961, 10/1/2001 to 9/30/2015	01194500
			11/3/1981 to 9/30/2001	01193500
01198000	Green River near Great Barrington, MA	10/1/1960 to 9/30/1971, 3/24/1994 to 9/30/1996, 8/23/2007 to 9/30/2015	10/1/1971 to 3/23/1994, 10/1/1996 to 8/22/2007	01181000
01198500	Blackberry River at Canaan, CT	10/1/1960 to 10/20/1971	10/21/1971 to 9/30/2015	01187300
01199200	Guinea Brook at West Woods Road at Ellsworth, CT	10/1/1960 to 10/30/1981	10/31/1981 to 9/30/2000, 10/1/2001 to 9/30/2015	01187300
			10/1/2000 to 9/30/2001	01203805

Table 3.1. Dates of station record and dates of extended record for reference streamgages used by the Connecticut Streamflow and Sustainable Water Use Estimator.—Continued

[All streamgages are shown in figure 1. USGS, U.S. Geological Survey; MA, Massachusetts; RI, Rhode Island; CT, Connecticut; NY, New York; NA, not applicable]

USGS streamgage number	Streamgage name	Dates of station record	Dates of extended record	Streamgage used for record extension
01200000	Ten Mile River near Gaylordsville, CT	10/1/1960 to 4/4/1988, 4/23/1988 to 2/7/1989, 11/2/1990 to 12/19/1990, 10/1/1991 to 9/30/1999, 10/1/2000 to 9/30/2015	4/5/1988 to 4/22/1988, 2/8/1989 to 11/1/1990, 12/20/1990 to 9/30/1991, 10/1/1999 to 9/30/2000	01372500
01201190	West Aspetuck River at Sand Road near New Milford, CT	10/1/1962 to 9/30/1972	10/1/1960 to 9/30/1962, 10/1/1972 to 4/4/1988, 4/23/1988 to 2/7/1989, 11/2/1990 to 12/19/1990, 10/1/1991 to 9/30/1999, 10/1/2000 to 9/30/2015	01200000
			4/5/4988 to 4/22/1988, 2/8/1989 to 11/1/1990, 12/20/1990 to 9/30/1991, 10/1/1999 to 9/30/2000	01372500
01201930	Marshepaug River near Milton, CT	10/1/1967 to 10/30/1981	10/1/1960 to 9/30/1967	01187400
			10/31/1981 to 9/30/2015	01187300
01204800	Copper Mill Brook near Monroe, CT	10/1/1960 to 10/4/1976	10/5/1976 to 9/30/2015	01208990
01206400	Leadmine Brook near Harwinton, CT	10/1/1960 to 10/1/1973	10/2/1973 to 9/30/1998, 10/1/2001 to 9/30/2015	01188000
			10/1/1998 to 9/30/2001	01187800
01206500	Leadmine Brook near Thomaston, CT	NA	10/1/1960 to 9/30/1972, 10/1/1998 to 9/30/2001	01187800
			10/1/1972 to 9/30/1998, 10/1/2001 to 9/30/2015	01188000
01208950	Sasco Brook near Southport, CT	10/1/1964 to 9/30/2015	10/1/1960 to 9/30/1964	01204800
01208990	Saugatuck River near Redding, CT	10/1/1964 to 9/30/2015	10/1/1960 to 9/30/1964	01204800
01360640	Valatie Kill near Nassau, NY	10/1/1990 to 9/30/2014	10/1/1960 to 10/20/1971	01198500
			10/21/1971 to 9/30/1991	01181000
			10/1/2014 to 9/30/2015	01198000
01372200	Wappinger Creek near Clinton Corners, CT	10/1/1960 to 12/31/1975	1/1/1976 to 9/30/2015	01372500
01372500	Wappinger Creek near Wappingers Falls, NY	10/1/1960 to 9/30/2015	NA	NA

Table 3.1. Dates of station record and dates of extended record for reference streamgages used by the Connecticut Streamflow and Sustainable Water Use Estimator.—Continued

[All streamgages are shown in figure 1. USGS, U.S. Geological Survey; MA, Massachusetts; RI, Rhode Island; CT, Connecticut; NY, New York; NA, not applicable]

USGS streamgage number	Streamgage name	Dates of station record	Dates of extended record	Streamgage used for record extension
01372800	Fishkill Creek at Hopewell Junction, NY	10/1/1960 to 11/30/1960, 4/1/1961 to 11/30/1961, 4/1/1962 to 11/30/1962, 4/1/1963 to 12/31/1975	12/1/1960 to 3/31/1961, 12/1/1961 to 3/31/1962, 12/1/1962 to 3/31/1963, 1/1/1976 to 2/7/1989, 11/2/1990 to 12/19/1990, 10/1/1991 to 9/30/1999, 10/1/2000 to 09/30/2015	01200000
			2/8/1989 to 11/1/1990, 12/20/1990 to 9/30/1991, 10/1/1999 to 9/30/2000	01372500
0137449480	East Branch Croton River near Putnam Lake, NY	10/1/1995 to 9/30/2015	10/1/1960 to 9/30/1964	01200000
			10/1/1964 to 9/30/1995	01208990
01374598	Horse Pound Brook near Lake Carmel, NY	8/16/1996 to 9/30/2015	10/1/1960 to 9/30/1964	01200000
			10/1/1964 to 8/15/1996	01208990
01374890	Cross River near Cross River, NY	12/8/1995 to 9/30/2015	10/1/1960 to 9/30/1964	01193500
			10/1/1964 to 12/7/1995	01208990
01374987	Kisco River below Mount Kisco, NY	10/21/1995 to 6/30/2009	10/1/1960 to 9/30/1964	01193500
			10/1/1964 to 10/20/1995, 7/1/2009 to 9/30/2015	01208990

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