LOW-FLOW CHARACTERISTICS OF SELECTED STREAMS IN RHODE ISLAND

By Michael A. Cervione, Jr., Alisa R. Richardson, and Lawrence A. Weiss

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Sea level--In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.
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ABSTRACT

The 7-day, 10-year flow (7Q10) is the most commonly used statistical low-flow index in Rhode Island for water-resources planning and management. Flow-duration values are also important indicators of low flows. Methods for estimating the 7Q10 flow and flow-duration values of streams in Rhode Island at partial-record sites and ungaged sites are based on the knowledge that low flows are sustained almost entirely by the discharge of water from adjacent aquifers.

Discharge was determined at 25 low-flow partial-record sites. Relations were developed between base-flow discharges at the partial-record sites and daily mean discharges at eight continuous-record stations. The 7Q10 and flow-duration values at each partial-record site were established by transferring the 7Q10 flow and the selected flow-duration values from the selected continuous-record station through the regression line.

A regression equation was developed relating the percentage of underlying stratified drift and till in the contributing drainage area to the 7Q10 flow at 21 long-term continuous-record sites in and around Rhode Island. Coarse-grained stratified drift yields significantly more water to streams during low flow than does till. The regression equation is 7Q10 flow = 0.67 (area of stratified drift) + 0.03 (area of till). The standard error of estimate is 2.6 cubic feet per second, which is equivalent to 40 percent of the mean value, and the correlation coefficient is 0.97.

INTRODUCTION

Low-flow characteristics of streams are important in the planning and development of water resources. Planners and managers in Rhode Island are concerned that excessive withdrawal of water from streams or adjacent aquifers could severely affect the quantity of streamwater during low-flow periods. Sufficient streamflows are necessary for dilution of effluent from wastewater-treatment plants, for induced recharge to aquifers that are sources of public supply, and for maintenance of aquatic life in and the aesthetic quality of the streams.

The 7-day, 10-year flow (7Q10) is the discharge at the 10-year recurrence interval taken from a frequency curve of annual values of the lowest mean discharge for 7 consecutive days (the 7-day low flow). For low flow, the recurrence interval is the average interval of time between occurrences of a flow less than a given magnitude. A 10-year low-flow discharge is a value that, on the average, will be less than, once every 10 years. In Rhode Island, surface-water quality standards have been developed for the 7Q10 flow. Information on the 7Q10 flow and other flow characteristics of streams, such as flow duration, is readily available at locations where streamflow data have been systematically collected for a number of years. However, planners and managers frequently need to estimate the 7Q10 flow and flow-duration values at ungaged sites or at sites for which streamflow data are limited.

In 1991, the U.S. Geological Survey (USGS), in cooperation with the Rhode Island Department of Environmental Management (RIDEM), began a study of low-flow characteristics of streams in the Pawcatuck and Hunt River basins to develop methods for estimating the 7Q10 flow at ungaged sites or at sites where only a few discharge measurements have been made.

Purpose and Scope

The purposes of this report are to (1) describe the methods used to estimate the 7Q10 flow and selected flow-duration values of selected streams in the Pawcatuck and Hunt River basins in Rhode Island, and (2) present the results of the application of these methods to the available data. Instantaneous discharges at 25 partial-record sites and streamflow data from 8 long-term continuous-record streamflow-gaging stations in these basins were used to estimate low-flow characteristics. The 7Q10 flow at partial-record sites was estimated from correlations with long-term stations. A regression equation based on the percentage of stratified drift and till in the drainage basins of the long-term stations was developed to estimate 7Q10 flows at ungaged sites.

Physical and Climatological Setting

The Pawcatuck River basin encompasses 317 mi^2, 254 mi^2 of which is in southwestern Rhode Island and 63 mi^2 is in southeastern Connecticut (fig. 1). Major tributaries to the Pawcatuck River in Rhode Island include the Chipuxet, Usquepaug, Queen, Beaver, and Wood Rivers.

The Pawcatuck River basin is sparsely developed. The northwestern part of the basin consists of forested and rural uplands. Steep-sided hills of bedrock or till-covered bedrock rise 400 to 600 ft above sea level. Stream valleys are narrow, and stratified-drift deposits that underlie the larger valleys are long and sinuous (Trench, 1991). Hills in the eastern and southern parts of the basin are till covered and are generally 200 to 300 ft above sea level. Stream valleys are wide and flat or gently rolling and are underlain by extensive deposits of stratified drift. Farmland dominates these wide valleys, and large swamps border the streams in some areas (Trench, 1991).

The Hunt River basin encompasses 27 mi^2 in central Rhode Island (fig. 1). The river, which flows northeastward towards Narragansett Bay, is tidal near its mouth. The major tributary to the Hunt River is Frenchtown Brook. The Hunt River basin includes dense commercial and residential areas as well as sparsely settled areas. Land-development pressures in the area are high, and continued development may affect the quantity and quality of water in the Hunt River basin.

The cold winters and warm summers in the Pawcatuck and Hunt River basins are typical of the climate in southern New England. The basins are affected by prevailing westerly winds that cross the State. Both basins are also exposed to occasional coastal storms that travel along the Atlantic seaboard and that sometimes reach hurricane intensity. The temperature, moderated by Narragansett Bay and the Atlantic Ocean, causes most winter precipitation to be rain rather than snow. The basins are characterized by an even distribution of approximately 40 to 50 in. of precipitation during the year. The ranges of daily and annual temperatures are large, and considerable

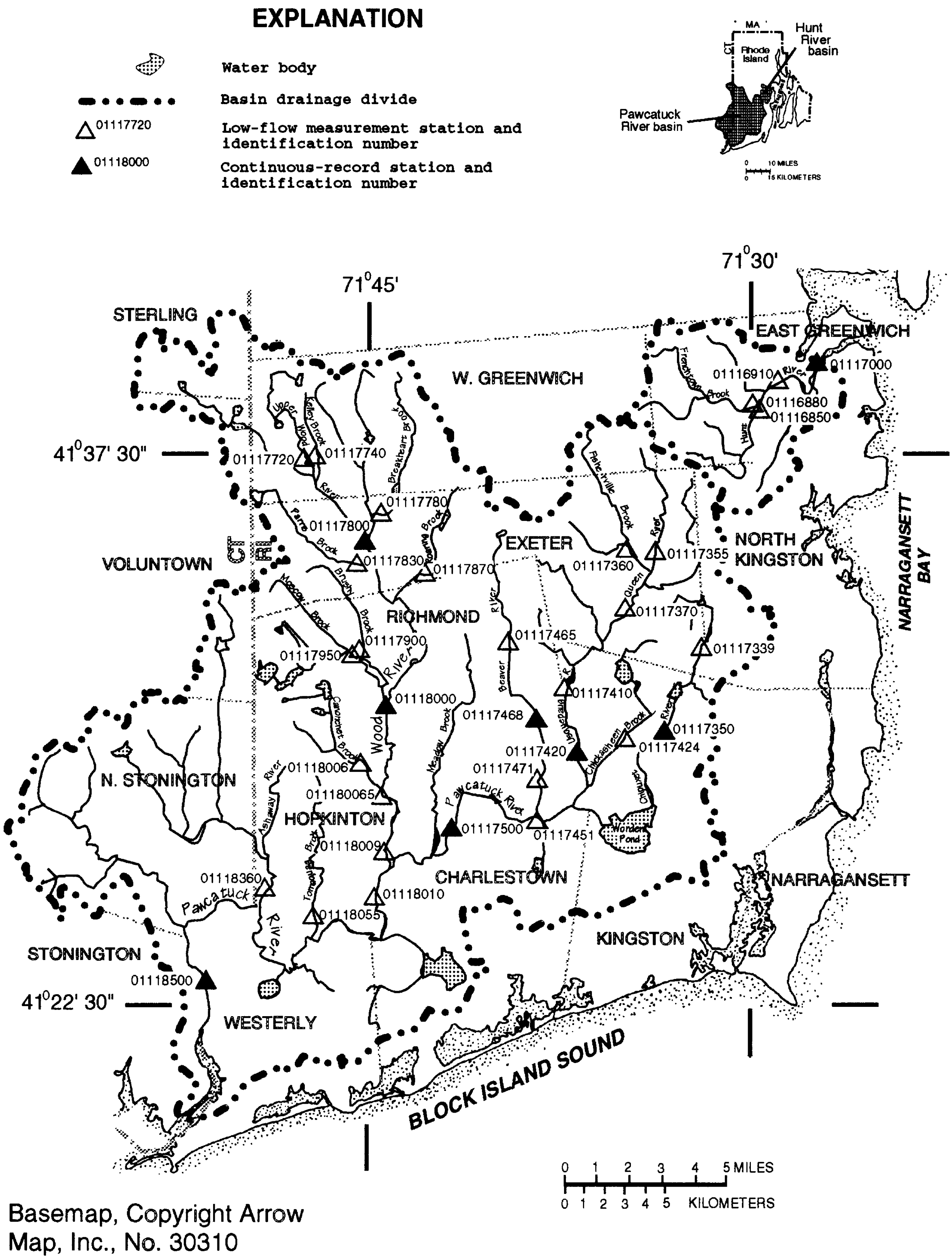

Figure 1. Location of the Pawcatuck and Hunt River basins and data-collection stations.

changes in weather can occur in short periods of time (National Oceanic and Atmospheric Administration, 1960-90).

Acknowledgments

Personnel from RIDEM provided valuable hydrologic information used in partial-record-site selection. Special thanks go to Christopher Deacutis and Robert Richardson of RIDEM, who reviewed the report and offered helpful perspective and comments.

STREAMFLOW-GAGING STATIONS

Streamflow-gaging stations can be of two types: (1) long-term continuous-record streamflow-gaging stations, where sufficient streamflow data have been collected and analyzed so that streamflow statistics, such as low-flow frequency and flow duration, can be accurately and reliably computed; and (2) partial-record sites, where a limited amount of data has been collected. Data collected at low-flow partial-record sites can be correlated with data from long-term continuous-record stations to estimate low-flow streamflow statistics at the partial-record sites.

Long-Term Continuous-Record Stations

Eight long-term streamflow-gaging stations are presently operated in the Pawcatuck and Hunt River basins. Records for these eight stations have been published in USGS water-data reports, an annual series published under various titles, but presently called "Water Resources Data, Massachusetts and Rhode Island." Water-data reports for water years[1] 1961-90, the years included in this study, are listed in "References Cited." Information about streamflow-gaging stations in the Pawcatuck and Hunt River basins, including station identification number, period of record, drainage area, and area underlain by coarse-grained stratified drift, is listed in table 1; station locations are shown in figure 1.

Low-Flow Partial-Record Sites

Twenty-five partial-record sites were used in this study. The sites consist of those that were established specifically for this study and previously established sites where flow measurements were made before 1991. Sites were selected with the general goal of geographic coverage within the Pawcatuck and Hunt River basins and with the particular goal of having partial-record sites downstream from areas where water is being pumped from the stream or adjacent aquifer for agricultural irrigation. Sites were also located upstream from these areas in an attempt to determine the magnitude of the effect of pumping. Information about low-flow partial-record sites used in this study, including station identification number, period of record, drainage area, and area underlain by coarse-grained stratified drift, is listed in table 2; site locations are shown on figure 1.

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[1]Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1990, is called the "1990 water year."

Table 1. Long-term continuous-record streamflow-gaging stations in the Pawcatuck and Hunt River basins

[Stratified-drift information from Rhode Island Department of Environmental Management; water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1990, is called the "1990 water year"; mi^2, square miles]

Station identification number	Station name	Period of record (water years)	Drainage area (mi^2)	Area underlain by coarse-grained stratified drift (mi^2)
01117000	Hunt River near East Greenwich, R.I.	1941-91	23.0	11.0
01117350	Chipuxet River at West Kingston, R.I.	1974-91	9.99	4.18
01117420	Usquepaug River near Usquepaug, R.I.	1976-91	36.1	12.0
01117468	Beaver River near Usquepaug, R.I.	1976-91	8.87	2.10
01117500	Pawcatuck River at Wood River Junction, R.I.	1941-91	100	41.9
01117800	Wood River near Arcadia, R.I.	1965-91[a]	35.2	8.35
01118000	Wood River at Hope Valley, R.I.	1942-91	72.4	20.1
01118500	Pawcatuck River at Westerly, R.I.	1942-91	295	[b]

[a]No record for water year 1982.

[b]Area not computed; station affected by regulation and diversion.

LOW-FLOW CHARACTERISTICS

Statistics that describe the low-flow characteristics of streams in this report are (1) flow duration, where daily flows are equaled or exceeded for a specified percentage of the time, and (2) the 7Q10 flow.

Duration of exceedence of low flows can be presented by a flow-duration curve, which is a cumulative-frequency curve showing the percentage of time daily flows were equaled or exceeded during a given period. It combines, in one curve, the flow characteristics of a stream throughout the range of flow, without regard to the sequence of occurrence. If the period on which the curve is based represents the long-term flow of a stream, the curve can be used to predict the distribution of future flows for water-power, water-supply, or water-quality studies. Differences in geology affect the low-flow ends[2] of flow-duration curves of streams; therefore, duration curves are useful in appraising the geologically affected low-flow characteristics of drainage basins (Searcy, 1959). Regulation also affects the low-flow ends of flow-duration curves of streams; here, appraisal of that part of the flow-duration curve can give an indication of the magnitude of the regulation.

Frequency of exceedence of low flows can be expressed by low-flow frequency curves computed from annual streamflow data at long-term streamflow-gaging stations. Low-flow frequency statistics are used to estimate the probability of future occurrences of the specified low flow on the basis of assumed probability distribution. The accuracy of the computed statistics depends on the

[2]The low-flow end of a flow-duration curve, as used in this report, is that part of the curve that represents flows exceeded from 80 to 99 percent of the time.

Table 2. Low-flow partial-record sites in the Pawcatuck and Hunt River basins

[Stratified drift information from Rhode Island Department of Environmental Management; period of record includes water years with measurements only; water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1990, is called the "1990 water year"; mi², square miles; R, streamflow regulated site (area of stratified drift not computed)]

Station identification number	Station name	Period of record (water years)	Drainage area (mi²)	Area underlain by coarse-grained stratified drift (mi²)
01116850	Hunt River at Davisville, R.I.	1961-63, 1991	5.97	3.36
01116880	Frenchtown Brook at Davisville, R.I.	1961-63, 1991	6.85	3.13
01116910	Hunt River at East Greenwich, R.I.	1961-63, 1991	17.3	7.27
01117339	Chipuxet River at Slocum, R.I.	1959, 1991	6.01	2.70
01117355	Queen River near Exeter, R.I.	1988-91	3.69	R
01117360	Fisherville Brook near Liberty, R.I.	1988-91	8.03	R
01117370	Queen River at Liberty, R.I.	1988-91	19.1	R
01117410	Usquepaug River at Usquepaug, R.I.	1988-91	32.8	10.1
01117424	Chickasheen Brook at West Kingston, R.I.	1959, 1991	3.98	R
01117451	Pawcatuck River at Kenyon, R.I.	1991	79.5	30.2
01117465	Beaver River at Hillsdale Road near Usquepaug, R.I.	1966, 1976, 1991	5.53	.81
01117471	Beaver River near Kenyon, R.I.	1966, 1976, 1991	11.2	3.12
01117720	Upper Wood River at Escoheag, R.I.	1966-67, 1991	11.4	R
01117740	Kelley Brook near Escoheag, R.I.	1966-67, 1991	4.20	R
01117780	Breakheart Brook near Lewis City, R.I.	1966, 1978, 1991	6.68	R
01117830	Parris Brook near Arcadia, R.I.	1966-67, 1991	5.01	R
01117870	Roaring Brook at Arcadia, R.I.	1978, 1991	5.01	0.07
01117900	Brushy Brook near Moscow, R.I.	1966, 1978, 1991	3.71	R
01117950	Moscow Brook near Hope Valley, R.I.	1966, 1978, 1991	6.37	R
01118006	Canonchet Brook near Woodville, R.I.	1976, 1991	5.46	R
011180065	Wood River at Woodville, R.I.	1991	80.2	23.6
01118009	Wood River at Alton, R.I.	1976, 1978, 1991	85.7	25.0
01118010	Pawcatuck River near Charleston, R.I.	1971, 1991	205	80.2
01118055	Tomaquag River near Ashaway, R.I.	1966-67, 1991	5.39	R
01118360	Ashaway River at Ashaway, R.I.	1991	28.6	R

length of record at the site. The base period used in this study, 30 years, is considered statistically to be a long record (Searcy, 1959).

The flow-duration curve for several periods at a long-term continuous-record station on the Wood River at Hope Valley, R.I. is shown in figure 2. One set of values plotted in figure 2 is for the full period of record (March 1, 1941 through September 30, 1990). Another set plotted represents the base period used for this study (October 1, 1960 through September 30, 1990). A third set of values represents a concurrent period for the Wood River gaging station (October 1, 1964 through September 30, 1990). As can be seen from the graph, the differences between values of flow for various record lengths are minimal. This similarity among the plotted sets of values

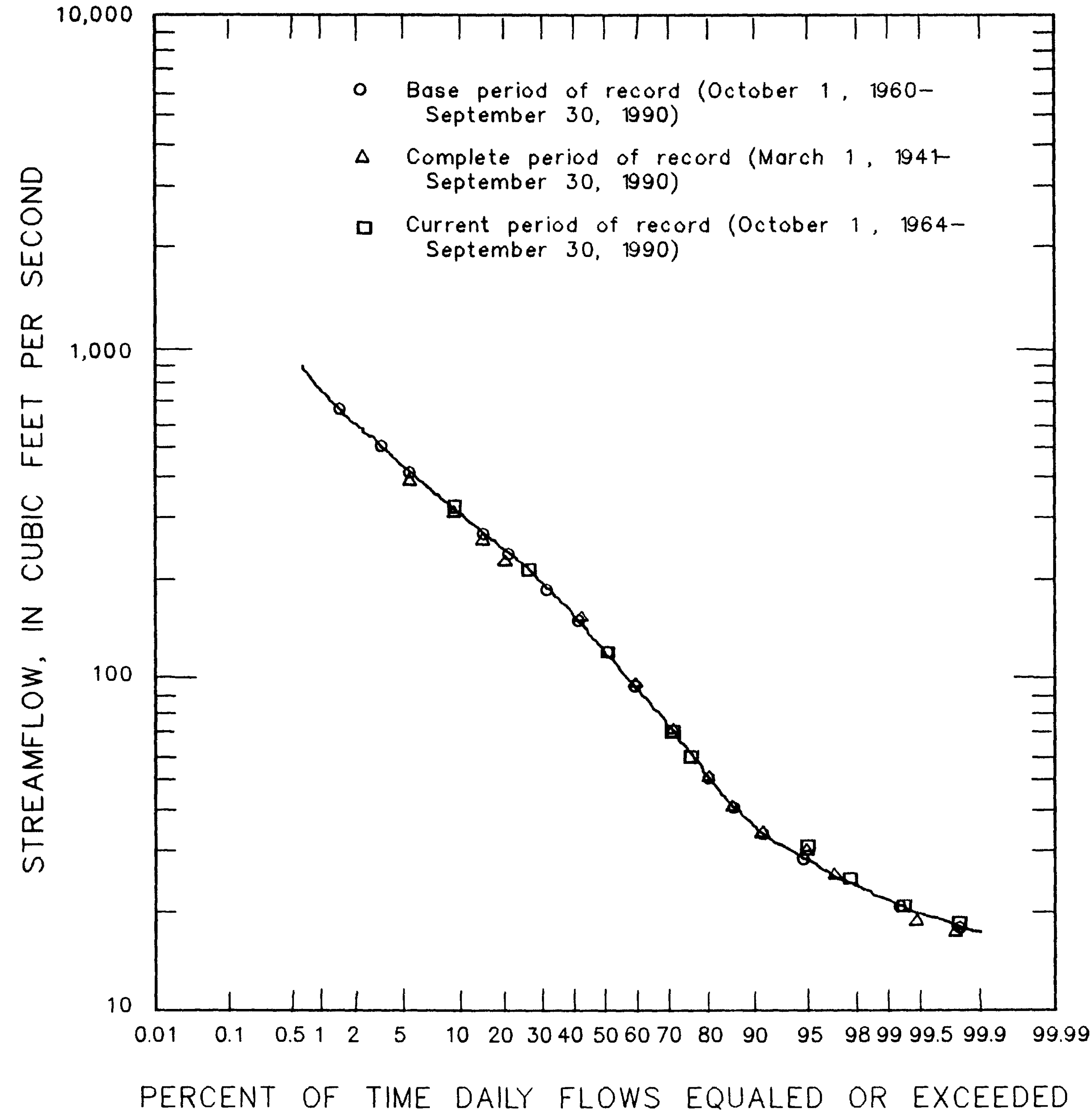

Figure 2. Flow-duration curve for the base period of study and flow-duration values for different periods of record at Wood River at Hope Valley, Rhode Island.

greatly minimizes the errors involved in extending a streamflow record for a short time period to a longer time period.

Factors Affecting Low Flow of Streams

Various factors affect the low flow of streams in Rhode Island. Natural flow is streamflow that is unaffected by dam regulations and other manmade controls, or by diversions from the stream channel or adjacent aquifers that affect the availability of water for downstream users. In Rhode Island, natural low streamflows are sustained by ground-water discharge. This discharge, called ground-water runoff, is a major source of streamflow throughout the year, except during and immediately after large storms, when most of the flow is derived from surface runoff. During prolonged dry periods, some aquifers become depleted and some streams cease to flow. Some streams in Rhode Island are affected by artificial withdrawal (the pumping of water from adjacent aquifers). Partial-record sites were established on these streams to evaluate the effects of pumping on downstream flows. Low streamflows in Rhode Island are most common during the growing season, when precipitation is captured and used by plants. In Rhode Island, streamflows are generally lowest in August and September.

The geology of a drainage basin significantly affects the time distribution of streamflow and, particularly, the low-flow characteristics. Basins in Rhode Island and adjacent parts of New England and New York are underlain by three major water-bearing geologic units or aquifers: stratified drift, till, and bedrock. Stratified drift is an unconsolidated sediment composed of interbedded layers of gravel, sand, silt, and clay. Stratified-drift deposits are commonly located in valleys that served as drainageways for glacial meltwater or were the sites of temporary glacial lakes. The stratified drift in a basin can be further characterized as coarse grained (predominantly fine sand to gravel) or fine grained (predominantly very fine sand, silt, and clay). Till is an unconsolidated, nonstratified, heterogeneous sediment deposited directly by glacial ice. Till, averaging less than 10 ft thick, overlies most bedrock in Rhode Island (Trench, 1991). Bedrock, which underlies every drainage basin, is discontinuously covered by till or is covered by till and stratified drift. Surficial geologic maps for all parts of the study area, available at the RIDEM office in Providence, show the areal distribution of these units.

Coarse-grained stratified drift has relatively high hydraulic conductivities and storage coefficients and, consequently, forms the most productive aquifers among the three geologic units. Previous studies, summarized by Cervione and others (1972), indicate that average annual recharge from precipitation and average annual ground-water runoff (about 30-percent flow duration) are approximately three times greater in areas underlain by coarse-grained stratified drift than in areas underlain by till or bedrock. A study of the relation between surficial geology and the time distribution of streamflow (Thomas, 1966) quantified the geology of a drainage area and the magnitude and frequency of low flows in New England. In this study, daily flows from several continuous-record stream-gaging stations were evaluated with respect to the geology of the drainage basin. The results indicate that a basin underlain completely by stratified drift yields 100 times more water per square mile of drainage area during dry conditions (about 99-percent flow duration) than does a basin underlain completely by till.

Estimating Low-Flow Characteristics

The base period for which the low-flow characteristics of Rhode Island streams were determined is October 1, 1960 through September 30, 1990. A correlation technique, based on a comparison of flow-duration curves, was used to determine the reference-period 7Q10 flow at stations with less than the required 30-year record. A nearby gaging station that had been operating throughout the 30-year reference period in a basin with similar geologic characteristics was selected. Flow-duration curves for this long-term station were plotted for (1) the 30-year reference period and (2) the period concurrent with the record at the station of interest. The two curves indicated a similar distribution of streamflow for the reference period and the shorter concurrent period. The station with less than the 30 years of record was adjusted accordingly.

Partial-Record Sites

At each of the 25 low-flow partial-record sites used in this study, staff (stage) gages were installed, reference points were established, and a minimum of four discharge measurements were made under base-flow conditions at a range of flow duration from about 80 to 99 percent. A point of zero flow[3] was determined for most of the sites. As a result, rating curves for all 25 sites were well defined for the low flows. Two additional discharges for each site were estimated from stage readings at base-flow conditions and from the rating curves.

Discharge measurements and discharges estimated from stage readings were plotted against concurrent flows at comparable long-term gages, and correlation curves for the 25 sites were established. Flow-duration curves for the 25 partial-record sites were then drawn from the relation of the appropriate long-term gage as determined from each correlation curve. The 7Q10 flow at each site was obtained from the correlation curve at the point where the 7Q10 flow occurred at the long-term station. A summary of flow-duration values and the 7Q10 flow at the 25 partial-record sites is given in table 3.

Ungaged Sites

Regionalization is a method of transferring known streamflow characteristics determined for long-term streamflow-gaging stations to ungaged areas or partial-record sites where characteristics are unknown (Riggs, 1968).

An effective way for statistically defining the dependency of a streamflow characteristic on one or more independent variables, such as area of stratified drift or area of till, is to develop an equation by multiple-regression techniques. Once the equation that adequately defines the relation is derived, the characteristic of interest can be estimated for any site, provided that the site meets the established criteria and that the appropriate values of the independent variables can be determined.

[3]A point of zero flow represents the stage reading at the lowest point in a stream channel where the discharge is zero. It is useful in defining the lowest end of a rating curve.

Table 3. Summary of flow-duration values and the 7-day, 10-year flow at low-flow partial-record sites in the Pawcatuck and Hunt River basins

[Flow data are for base period from October 1, 1960 through September 30, 1990; 7Q10, 7-day 10-year flow (obtained by correlation with long-term station)]

Station identification number	Station name	Streamflow at given percent duration, in cubic feet per second					7Q10, in cubic feet per second
		80	90	95	98	99	
01116850	Hunt River at Davisville, R.I.	3.6	2.0	1.4	0.86	0.62	2.5
01116880	Frenchtown Brook at Davisville, R.I.	3.4	2.2	1.6	1.3	1.1	2.4
01116910	Hunt River at East Greenwich, R.I.	8.3	4.7	3.2	2.0	1.4	5.9
01117339	Chipuxet River at Slocum, R.I.	2.9	1.6	1.1	.69	.50	2.0
01117355	Queen River near Exeter, R.I.	1.6	1.1	.79	.61	.52	.37
01117360	Fisherville Brook near Liberty, R.I.	3.4	2.2	1.6	1.3	1.1	.80
01117370	Queen River at Liberty, R.I.	10	6.5	4.8	3.7	3.2	2.3
01117410	Usquepaug River at Usquepaug, R.I.	15	9.1	6.5	4.8	4.0	4.9
01117424	Chickasheen Brook at West Kingston, R.I.	1.3	.95	.76	.63	.56	.29
01117451	Pawcatuck River at Kenyon, R.I.	43	32	26	21	19	19
01117465	Beaver River at Hillsdale Road near Usquepaug, R.I.	3.3	2.1	1.6	1.2	1.0	.73
01117471	Beaver River near Kenyon, R.I.	10	6.7	5.0	3.9	3.3	2.4
01117720	Upper Wood River at Escoheag, R.I.	2.7	0.96	0.46	0.22	0.14	0.11
01117740	Kelley Brook near Escoheag, R.I.	1.2	.49	.26	.14	.09	.04
01117780	Breakheart Brook near Lewis City, R.I.	3.6	2.5	2.0	1.5	1.3	.94
01117830	Parris Brook near Arcadia, R.I.	2.0	.92	.54	.31	.23	.05
01117870	Roaring Brook at Arcadia, R.I.	1.7	.98	.69	.50	.42	.30
01117900	Brushy Brook near Moscow, R.I.	.79	.53	.40	.30	.25	.14
01117950	Moscow Brook near Hope Valley, R.I.	.19	.13	.11	.09	.08	.06
01118006	Canonchet Brook near Woodville, R.I.	2.7	1.8	1.4	1.1	.95	.70
011180065	Wood River at Woodville, R.I.	24	16	13	11	9.8	13
01118009	Wood River at Alton, R.I.	60	41	33	27	25	15
01118010	Pawcatuck River near Charleston, R.I.	152	111	91	74	65	49
01118055	Tomaquag River near Ashaway, R.I.	2.9	2.0	1.6	1.3	1.2	.86
01118360	Ashaway River at Ashaway, R.I.	11	7.0	5.3	4.2	3.8	2.5

The regionalization method used in this study is based on a regression model developed by Cervione and others (1982). The conceptual model used in the regression can be stated as follows: The 7Q10 flow at any site on a stream is dependent on the percentage of upstream drainage area underlain by coarse-grained stratified drift and the percentage underlain by till-covered bedrock.

This relatively simple model and resulting analysis incorporates the following assumptions (Cervione and others, 1982):

1. The 7Q10 flow at any site on any stream unaffected by significant withdrawals or inputs is derived entirely from ground-water runoff.
2. The water-bearing units that contribute to ground-water runoff can be aggregated into two broad classes: coarse-grained stratified drift, characterized by relatively high ground-water storage per unit area and relatively high transmissivity; and till-covered bedrock, which also includes minor areas of fine-grained stratified drift, characterized by relatively low ground-water storage per unit area and relatively low transmissivity.
3. The magnitude of the 7Q10 flow is a function of the amount of ground-water runoff from each water-bearing unit if the areal extent of each unit is used as a basin characteristic.
4. The extent of the ground-water and surface-water drainage areas contributing to the streamflow are coincident and are defined by the topographic drainage divides.
5. Areal differences in ground-water evapotranspiration are not large enough to affect the 7Q10 flow significantly.
6. The spatial location of coarse-grained stratified drift and till are insignificant to the model.

The 7Q10 flow was determined for 21 long-term streamflow-gaging stations in southern New England and New York by means of the log-Pearson type III techniques (Riggs, 1968). The 21 streamflow-gaging stations used in the analysis were selected after a careful screening of many long-term stations. Stations were not used if the flow pattern was affected by significant withdrawal or input, as determined by records from water users and verified by evaluating the lower part of the flow-duration curves. Stations were also not used if their drainage areas included substantial areas of urbanization.

Only four gaging stations in Rhode Island met the criteria for selection. In order to have adequate streamflow data for regression analysis, several gaging stations from outside of the State were selected: two stations in western Massachusetts, 13 in Connecticut, and 2 in eastern New York. These additional stations are in areas hydrologically and geologically similar to those in Rhode Island. Drainage areas at these streamflow-gaging stations ranged from 4.02 to 121 mi^2. The gaging stations used in the regression analysis, including station identification numbers, station name, period of record, drainage area, area underlain by coarse-grained stratified drift, area underlain by till-covered bedrock, the 7Q10 flow as determined from streamflow records, and the 7Q10 flow as determined from regression equations are listed in table 4; their locations are shown in figure 3.

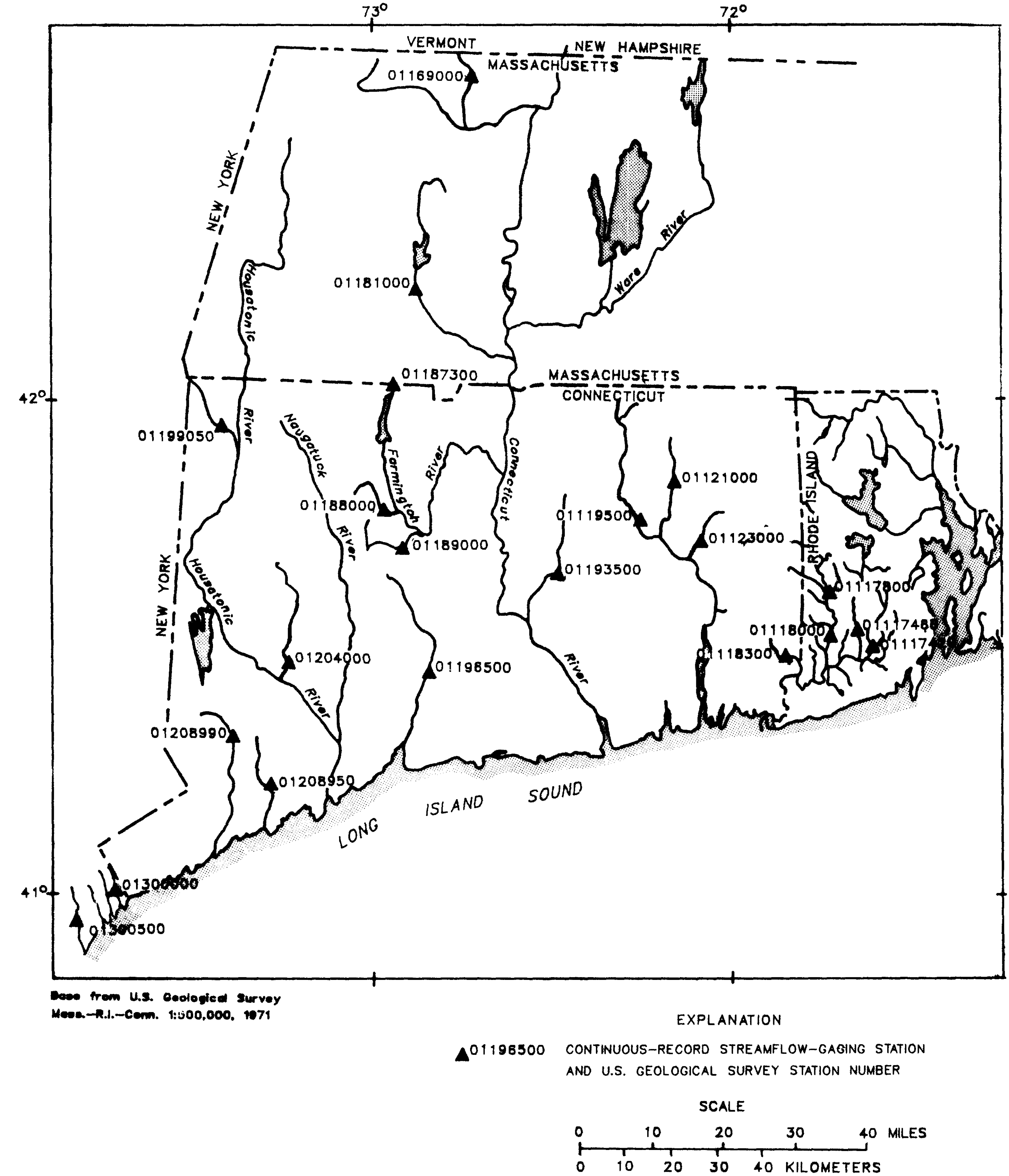

Figure 3. Locations of streamflow-gaging stations used for regression analysis.

A regression equation that describes the relation between the 7Q10 flow at gaging stations and the percentage of upstream drainage area underlain by coarse-grained stratified drift and till-covered bedrock was computed by a procedure in the Statistical Analysis System Users Guide (Helwig and Council, 1979) referred to as "stepwise." The model adds the flow contribution from the area of coarse-grained stratified drift to the flow contribution from the area of till-covered bedrock.

The resultant equation is

$$7Q10 = 0.67A_{sd} + 0.03A_{till} \quad (1)$$

where $7Q10$ is the 7-day, 10-year low flow, in cubic feet per second;
A_{sd} is the drainage area underlain by coarse-grained stratified drift, in square miles; and
A_{till} is the drainage area underlain by till-covered bedrock, in square miles.

The regression equation has a standard error of estimate of 2.6 ft^3/s, which is equivalent to 40 percent of the mean value, and a correlation coefficient of 0.97.

This equation can be used to estimate the 7Q10 flow at ungaged sites because it represents the actual physical system, expresses the water-yielding characteristics of each major aquifer in realistic percentages, and has a reasonable standard error of estimate. The standard error of estimate reflects the number of stations used, the physical model, and the accuracy of measuring drainage areas and the distribution of geologic materials (Cervione and others, 1982).

The 7Q10 flow is dominated by runoff from the coarse-grained stratified-drift aquifer. As an example, two sites in Rhode Island that have about the same size drainage basins have considerably different 7Q10 flows: Beaver River at Hillsdale Road near Usquepaug has a drainage area of 5.53 mi^2 and an area underlain by stratified drift of 0.81 mi^2; Roaring Brook at Arcadia has a drainage area of 5.01 mi^2 and an area underlain by stratified drift of 0.07 mi^2 (table 2). The regression equation yields a 7Q10 flow of 0.68 ft^3/s for Beaver River and 0.20 ft^3/s for Roaring Brook. The larger area underlain by stratified drift for the Beaver River site (approximately 15 percent of the basin compared to less than 2 percent for Roaring Brook) accounts for the 7Q10 flow being more than three times as large.

SUMMARY

The 7Q10 flow (the discharge at the 10-year recurrence interval taken from a frequency curve of annual values of the lowest mean discharge for 7 consecutive days) can be estimated by either of two methods for any site on a stream in Rhode Island that does not drain an area having appreciable urbanization.

Discharge measurements made during periods of low base flow at an ungaged or partial-record site can be plotted against concurrent flows at an appropriate long-term streamflow-gaging station. The 7Q10 flow for the site can be obtained from this relation. This method was applied at 25 partial-record sites.

Table 4. Streamflow-gaging stations used for regression analysis

[Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1990, is called the "1990 water year"; mi², square miles, ft³/s, cubic feet per second; flow data are for base period from October 1, 1960 through September 30, 1990]

Station identification number	Station name	Period of record (water years)	Drainage area (mi²)	Area underlain by coarse-grained stratified drift (mi²)	Area underlain by till-covered bedrock (mi²)	7-day, 10-year flow (ft³/s)	
						From streamflow records	From regression equation
01117420	Usquepaug River near Usquepaug, R.I.	1976-91	36.1	12.0	24.1	6.2	8.8
01117468	Beaver River near Usquepaug, R.I.	1976-91	8.87	2.10	6.77	1.8	1.6
01117800	Wood River near Arcadia, R.I.	1965-91[a]	35.2	8.35	26.8	7.8	6.4
01118000	Wood River at Hope Valley, R.I.	1942-91	72.4	20.1	52.3	21	15
01118300	Pendleton Hill Brook near Clarks Falls, Conn.	1959-91	4.02	.3	3.72	.04	.31
01119500	Willimantic River near Coventry, Conn.	1932-91	121	21.5	99.5	17	17
01121000	Mount Hope River near Warrenville, Conn.	1941-91	28.6	1.20	27.4	1.1	1.6
01123000	Little River near Hanover, Conn.	1952-91	30.0	5.30	24.7	4.4	4.3
01169000	North River at Shattuckville, Mass.	1940-91	89.0	3.60	85.4	9.0	5.0
01181000	West Branch Westfield River at Huntington, Mass.	1936-91	94.0	2.10	91.9	6.2	4.2
01187300	Hubbard River near West Hartland, Conn.	1939-91[b]	19.9	0	19.9	.54	.60
01188000	Burlington Brook near Burlington, Conn.	1932-91	4.10	1.37	2.73	.57	1.0
01189000	Pequabuck River near Forestville, Conn.	1942-91	45.8	16.0	29.8	13	12
01193500	Salmon River near East Hampton, Conn.	1929-91	100	14.8	85.2	5.1	12
01196500	Quinnipiac River at Wallingford, Conn.	1931-91	115	42.7	72.3	31	31
01199050	Salmon Creek at Lime Rock, Conn.	1962-91	29.4	4.80	24.6	3.4	4.0
01204000	Pomperaug River at Southbury, Conn.	1933-91	75.1	9.80	65.3	6.0	8.5
01208950	Sasco Brook near Southport, Conn.	1965-91	7.38	.14	7.24	.04	.31
01208990	Saugatuck River near Redding, Conn.	1965-91	21.0	.10	20.9	.04	.70
01300000	Blind Brook at Rye, N.Y.	1945-89	9.20	.23	8.97	.53	.42
01300500	Beaver Swamp Brook at Mamaroneck, N.Y.	1945-89	4.71	.24	4.47	.13	.29

[a]No record for water year 1982.

[b]No record for water year 1956.

Areas of coarse-grained stratified drift and till-covered bedrock underlying the drainage basin can be computed and substituted into a regression equation. The equation, which describes the relation between the 7Q10 flow and the percentage of upstream drainage area underlain by coarse-grained stratified drift and till-covered bedrock, was computed by use of data from 21 long-term streamflow-gaging stations. The estimating equation indicates that drainage basins underlain by large amounts of stratified drift will yield relatively large low flows compared to basins underlain by predominately till or bedrock.

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