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Mean Annual Streamflow at Reference-Stream Sites in Three Ecological Subregions of Massachusetts

By PAUL J. FRIESZ and KERNELL G. RIES, III

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CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic feet per second
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic feet per second
square mile (mi^2)	2.590	square kilometer

Mean Annual Streamflow at Reference-Stream Sites in Three Ecological Subregions of Massachusetts

By *Paul J. Friesz* and *Kernell G. Ries, III*

Abstract

Streamflow at 24 reference-stream sites in 3 ecological subregions of Massachusetts was quantified by calculating mean annual streamflow and mean annual streamflow per square mile. The three ecological subregions—Narragansett/Bristol Lowland, Worcester/Monadnock Plateau, and Vermont Piedmont—are located in southeastern, north-central, and northwestern Massachusetts, respectively. The drainage areas of the reference-stream sites are entirely contained within their respective ecological subregion.

Streamflow measurements at the reference-stream sites were related to streamflow at selected continuous streamflow-gaging stations to estimate mean annual streamflow indicative of long-term conditions. Mean annual streamflows calculated at the reference-stream sites ranged from 8.33 to 40.7 cubic feet per second in the Narragansett/Bristol Lowland ecological subregion, from 6.27 to 42.2 cubic feet per second in the Worcester/Monadnock Plateau ecological subregion, and from 3.24 to 17.2 cubic feet per second in the Vermont Piedmont ecological subregion. Mean annual streamflows per square mile at the reference-stream sites ranged from 1.25 to 2.21 in the Narragansett/Bristol Lowland ecological subregion, from 1.17 to 2.32 in the Worcester/Monadnock Plateau ecological subregion, and from 1.46 to 2.61 in the Vermont Piedmont ecological subregion.

INTRODUCTION

The ecoregional framework developed by Omernik (1987) has been proposed as a basis for determining attainable chemical and biological conditions for streams and other aquatic resources. The approach is based on the premise that the character of an aquatic ecosystem depends largely on the character of the landscape it drains and that major landscape features, such as land-surface form, soil type, potential natural vegetation, and land use vary on a regional scale. The Massachusetts Department of Environmental Protection (MDEP), in conjunction with the U.S. Environmental Protection Agency (USEPA), has refined the 2 ecological regions described for Massachusetts into 13 ecological subregions (Griffith and others, 1994). Although these subregions still retain some heterogeneity in factors that can affect water quality and biotic characteristics, the framework is considered to be an improvement over the national-scale ecological regions, and it provides more homogeneous units for inventorying, monitoring, and assessing surface waters than hydrologic or political units (Omernik and Griffith, 1991).

The MDEP is in the process (1998) of testing whether biological data can be sorted into distinct stream classes by ecological subregions. Their 1996 pilot study to develop numeric biocriteria entailed sampling fish and macroinvertebrates at 26 reference-stream sites distributed within 3 ecological subregions. The MDEP plans to analyze the relation between reference-stream size and the richness of macroinvertebrate and fish taxa (Robert Haynes, Massachusetts

Department of Environmental Protection, oral commun., 1998). Locations of the three ecological subregions in Massachusetts—Narragansett/Bristol Lowland, Worcester/Monadnock Plateau, and Vermont Piedmont—are shown in figure 1 (at back of report).

This report presents the results of a study conducted by the U.S. Geological Survey (USGS), in cooperation with the MDEP, Division of Watershed Management, to quantify the size of the reference-stream sites by determining the mean annual streamflow and corresponding mean annual streamflow per unit area at 24 of the 26 sites. Results are based on streamflow measurements made at the reference-stream sites during 1996 and 1997 for this study and from historical data available in USGS data bases.

MEAN ANNUAL STREAMFLOW AT REFERENCE-STREAM SITES IN THREE ECOLOGICAL SUBREGIONS

The drainage areas of the 24 reference-stream sites for which mean annual streamflow are calculated, in general, have minimal human activity and have little or no streamflow regulation. All or most of the drainage areas of the reference-stream sites are within Massachusetts except for one site; however, the drainage areas of all the reference-stream sites are entirely within their respective ecological subregions. Descriptions of the reference-stream sites from the three ecological subregions for which mean annual streamflows are calculated are presented in table 1 (at back of report) and the locations of the reference-stream sites are shown in figure 2 (at back of report).

Streamflow measurements made at the reference-stream sites for this study and available historical measurements were related to same-day mean daily streamflows at continuous streamflow-gaging stations near the reference-stream sites. The drainage areas for the gaging stations have topographic, geologic, and climatic conditions similar to those for the drainage areas of the reference-stream sites. The relations were used to estimate mean annual streamflows that represent long-term conditions at the reference-stream sites. The accuracy of the long-term values estimated for the reference-stream sites increases with increased record lengths at the gaging stations. Descriptions of the streamflow-gaging stations that were used to calculate mean annual streamflows at the reference-stream sites are given in table 2 (at back of report), and the locations of the stations are shown in figure 1.

The relations between streamflow at the reference-stream sites and the gaging stations were determined either by application of a mathematical method, called Maintenance of Variance Extension, Type 1 (MOVE.1) developed by Hirsch (1982) or by application of a graphical-correlation technique developed by Searcy (1959). Plots of log-transformed data were made to determine the quality of the relation and if the relation was linear or curved. If the relation was linear, then the MOVE.1 method was used to provide an equation that relates streamflow at the reference-stream site to that at the gaging station. Mean annual streamflow computed at the gaging station using complete water years[1] of record was entered into the equation to determine the long-term mean annual streamflow at the reference-stream site. If the plots showed a curved relation, then the graphical-correlation technique was used by drawing a best-fit curve through the data points; this curve was used to relate streamflow at the reference-stream site to that at the gaging station. Only one reference-stream site, West Branch Tully River at Blissville (01165080), indicated a curved relation between streamflow at the reference-stream site and streamflow at the gaging stations against which it was plotted.

[1]A water year is the 12-month period beginning October 1 and ending September 30 and is designated by the calendar year in which it ends.

Because streamflows measured at a reference-stream site can correlate well with streamflow from more than one gaging station, multiple gaging stations were used to estimate mean annual streamflow. The multiple estimates of mean annual streamflow calculated for each reference-stream site were combined to obtain the single best estimate for that site. The multiple estimates were combined by weighting each individual estimate by its variance and then the weighted estimates were averaged to obtain the minimum variance estimate. The variances of the estimates are a function of the length of record at the gaging station, the number of streamflow measurements at the reference-stream sites, and the standard error of estimate of the MOVE.1 equation or the curve drawn through the data. A detailed description of the method and equations used to weight the individual estimates to obtain the best estimate for a streamflow site is given by Ries (1997, p. 4–6).

Information concerning the analysis for each reference-stream site is shown in table 1 and includes the number of streamflow measurements and the gaging stations used to calculate the mean annual streamflow and the standard error of the final estimate, in percent. Streamflow measurements made at the reference-stream sites for this study were reported in the USGS water-resources data report for Massachusetts and Rhode Island (Socolow and others, 1998). The standard error of the mean annual streamflow estimates was calculated using equation 3 in Ries (1997, p. 6); standard errors of the mean annual streamflows range from 3.70 percent to 28.8 percent (table 1). A comparison of standard error of the estimates among ecological subregions indicates that the average standard errors in the Narragansett/Bristol Lowland ecological subregion (15.6 percent) exceeded those in the Worcester/Monadnock Plateau ecological subregion (11.6 percent) and Vermont Piedmont ecological subregion (12.3 percent). These differences may be the result of increased regulation and withdrawals of water in the densely populated eastern part of the State, either in the drainage areas of the reference-stream sites, the gaging stations, or both.

Streamflow measurements were not made at one reference-stream site, Bear River below Drakes Brook near Conway (01169508), which is at the confluence of two reference-stream sites, Bear River at Pine Hill Road near Conway (01169506) and Drakes Brook near Conway (01169507) (fig. 2*C*). The mean annual streamflow at this reference-stream site was derived by summing the mean annual streamflows calculated for its two tributaries.

Mean annual streamflow and mean annual streamflow per unit area, representative of long-term conditions at the 24 reference-stream sites, are listed in the last two columns of table 1. Mean annual streamflow per unit area for each reference-stream site was determined by dividing the mean annual streamflow by the drainage area. Mean annual streamflow ranged from 8.33 to 40.7 ft^3/s in the Narragansett/Bristol Lowland ecological subregion, 6.27 to 42.2 ft^3/s in the Worcester/Monadnock Plateau ecological subregion, and 3.24 to 17.2 ft^3/s in the Vermont Piedmont ecological subregion. Mean annual streamflow per unit area ranged from 1.25 to 2.21 $ft^3/s/mi^2$ and averaged 1.69 $ft^3/s/mi^2$ in the Narragansett/Bristol Lowland ecological subregion, ranged from 1.17 to 2.32 $ft^3/s/mi^2$ and averaged 1.64 $ft^3/s/mi^2$ in the Worcester/Monadnock Plateau ecological subregion, and ranged from 1.46 to 2.61 $ft^3/s/mi^2$ and averaged 2.02 $ft^3/s/mi^2$ in the Vermont Piedmont ecological subregion. The average of the mean annual streamflow per unit area for the reference-stream sites in the Vermont Piedmont ecological subregion exceeded the average for the other two subregions probably because average annual precipitation in areas of high relief in western Massachusetts exceeds the average annual precipitation in the central and eastern parts of the State (Knox and Nordenson, 1955).

SUMMARY

Two ecological regions delineated for Massachusetts were refined into 13 ecological subregions by the MDEP and the USEPA. The MDEP is currently (1998) assessing whether biological data can be sorted into distinct stream classes by ecological subregion. This report quantifies the streamflow of 24 reference-stream sites in 3 ecological subregions by providing estimates of mean annual streamflow and mean annual streamflow per unit area. The drainage areas of the reference-stream sites have minimal human activity and are entirely encompassed within their respective ecological subregions. The ecological subregions where the reference-stream sites are located are the Narragansett/Bristol Lowland in southeastern Massachusetts, the Worcester/Monadnock Plateau in north-central Massachusetts, and the Vermont Piedmont in northwestern Massachusetts.

Streamflow measurements made at the reference-stream sites during 1996 and 1997 for this study, along with available historical measurements, were related to same-day mean daily streamflow at selected continuous streamflow-gaging stations to estimate long-term mean annual streamflow. Relations between streamflow at the reference-stream sites and nearby gaging stations were developed using either a mathematical method or a graphical-correlation technique, depending on whether the relation was linear or curved. Multiple estimates of mean annual streamflow, determined by relating the reference-stream site to more than one gage, were combined to obtain the single best estimate. Standard errors of the estimated mean annual streamflows for the reference-stream sites ranged from 3.70 to 28.8 percent. The average standard error of the estimates at the reference-stream sites in the Narragansett/Bristol Lowland ecological subregion (15.6 percent) exceeded those in the Worcester/Monadnock Plateau ecological subregion (11.6 percent) and Vermont Piedmont ecological subregion (12.3 percent), probably because of more streamflow regulation and withdrawals in the eastern part than in the central and western parts of the State.

Mean annual streamflows determined for the reference-stream sites ranged from 8.33 to 40.7 ft^3/s in the Narragansett/Bristol Lowland ecological subregion, from 6.27 to 42.2 ft^3/s in the Worcester/Monadnock Plateau ecological subregion, and from 3.24 to 17.2 ft^3/s in the Vermont Piedmont ecological subregion. The reference-stream sites have a wide range in the size of their drainage areas, therefore, the mean annual streamflows were divided by the drainage areas for the reference-stream sites to compare differences in streamflow per unit of drainage area. Mean annual streamflows per unit area at the reference-stream sites ranged from 1.25 to 2.21 $ft^3/s/mi^2$ in the Narragansett/Bristol Lowland ecological subregion, from 1.17 to 2.32 $ft^3/s/mi^2$ in the Worcester/Monadnock Plateau ecological subregion, and from 1.46 to 2.61 $ft^3/s/mi^2$ in the Vermont Piedmont ecological subregion. The average of the mean annual streamflow per unit area for the reference-stream sites in the Vermont Piedmont ecological subregion (2.02 $ft^3/s/mi^2$) exceeded the average for the Narragansett/Bristol Lowland ecological subregion (1.69 $ft^3/s/mi^2$) and the Worcester/Monadnock ecological subregion (1.64 $ft^3/s/mi^2$), probably because average annual precipitation in areas of high relief in western Massachusetts exceeds that of the central and eastern parts of the State.

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Figures and Tables

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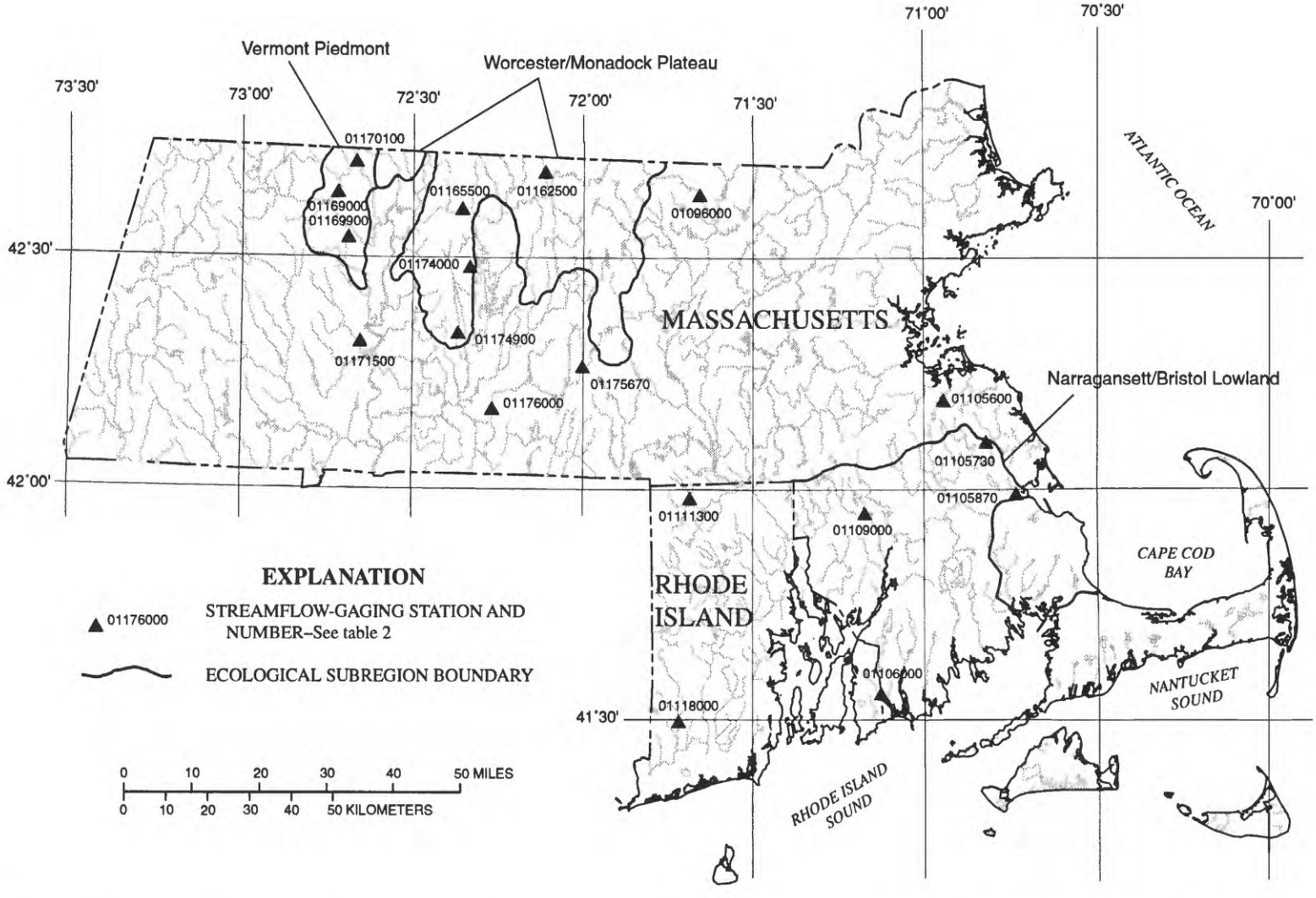

Figure 1. Boundaries of three ecological subregions in Massachusetts and locations of continuous streamflow-gaging stations in Massachusetts and Rhode Island used for correlation with the reference-stream sites.

Table 1. Descriptions of the reference-stream sites in three ecological subregions of Massachusetts including a summary of the mean annual streamflow analysis

[**USGS station No.:** Locations shown in figure 2. Latitude and longitude are given in degrees, minutes, seconds. No., number; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; $ft^3/s/mi^2$, cubic foot per second per square mile; mi^2, square mile. --, not applicable]

USGS station No.	Reference-stream site	Latitude ° ′ ″	Longitude ° ′ ″	Drainage area (mi^2)	Number of measurements used in relation	Streamflow-gaging stations used in relation	Standard error of estimate (percent)	Mean annual streamflow (ft^3/s)	Mean annual streamflow per square mile ($ft^3/s/mi^2$)
Narragansett/Bristol Lowland Ecological Subregion									
01105914	Mattapoisett River at Tinkham Lane near Mattapoisett, Mass.	41 41 06	70 50 28	18.2	14	01105730 01105870 01109000 01111300	15.6	40.7	2.21
01105937	Shingle Island River near North Dartmouth, Mass.	41 40 55	71 01 05	8.59	29	01105730 01105870 01106000 01109000 01111300 01118000	12.9	16.5	1.92
01105947	Bread and Cheese Brook at Head of Westport, Mass.	41 38 00	71 03 46	9.25	24	01105870 01106000 01109000 01111300 01118000	15.3	15.7	1.70
01109135	Cole River near Swansea, Mass.	41 46 30	71 11 57	7.77	18	01105730 01105870 01109000 01111300	8.5	12.6	1.62
01109205	West Branch Palmer River at Perryville, Mass.	41 51 42	71 15 33	6.75	5	01105600 01105730 01105870 01109000 01111300 01118000	22.4	8.44	1.25
01109223	Rocky Run at Martin Street at Rehoboth, Mass.	41 47 51	71 14 23	5.72	5	01105600 01105730 01105870 01109000 01111300 01118000	19.1	8.33	1.46
Worcester/Monadnock Plateau Ecological Subregion									
01164100	Boyce Brook near Royalston, Mass.	42 41 50	72 12 45	4.72	5	01096000 01162500 01169900 01170100 01174900 01175670	7.00	6.27	1.33
01164400	Lawrence Brook near Royalston, Mass.	42 39 01	72 12 02	26.8	6	01096000 01162500 01169900 01170100	10.4	42.2	1.57
01165080	West Branch Tully River at Blissville, Mass.	42 40 16	72 16 32	5.98	6	01096000 01162500 01170100	17.3	7.61	1.27
01166100	Whetstone Brook at Wendell Depot, Mass.	42 35 21	72 21 31	4.90	17	01162500 01165500 01171500 01174000 01174900 01175670	10.2	7.80	1.59
01166600	Mormon Hollow Brook near Farley, Mass.	42 34 16	72 25 55	3.96	5	01162500 01169900 01171500 01174900 01175670	3.70	7.44	1.88
01173900	Middle Branch Swift River at North New Salem, Mass.	42 32 45	72 19 10	4.76	10	01169900 01171500 01174900 01175670 01176000	15.9	8.92	1.87

Table 1. Descriptions of the reference-stream sites in three ecological subregions of Massachusetts including a summary of the mean annual streamflow analysis—*Continued*

USGS station No.	Reference-stream site	Latitude ° ′ ″	Longitude ° ′ ″	Drainage area (mi^2)	Number of measurements used in relation	Streamflow-gaging stations used in relation	Standard error of estimate (percent)	Mean annual streamflow (ft^3/s)	Mean annual streamflow per square mile ($ft^3/s/mi^2$)
Worcester/Monadnock Plateau Ecological Subregion—*Continued*									
01174350	East Branch Swift River near Quaker Drive at Petersham, Mass.	42 28 16	72 09 46	10.7	7	01162500 01169900 01171500 01174900 01175670 01176000	16.0	12.5	1.17
01174400	Moccasin Brook near Petersham, Mass.	42 28 17	72 09 44	6.69	5	01162500 01169900 01171500 01174900 01175670 01176000	8.97	15.5	2.32
01174560	West Branch Swift River at Cooleyville, Mass.	42 27 50	72 22 59	6.84	10	01169900 01171500 01174900 01175670	16.8	11.3	1.65
01174563	West Branch Swift River tributary at Cooleyville, Mass.	42 27 52	72 22 56	3.85	11	01169900 01171500 01174900 01175670	9.73	6.79	1.76
Vermont Piedmont Ecological Subregion									
01168700	Clark Brook near Shelburne Falls, Mass.	42 36 48	72 46 05	2.82	9	01169000 01169900 01170100	28.8	4.12	1.46
01168795	Foundry Brook near Foundry Village, Mass.	42 40 47	72 43 21	1.99	6	01169000 01169900 01170100	12.1	3.24	1.63
01168921	Tissdell Brook near Adamsville, Mass.	42 41 41	72 45 34	1.64	5	01169000 01169900 01170100	7.49	3.83	2.34
01169506	Bear River at Pine Hill Road near Conway, Mass.	42 32 23	72 43 43	5.57	6	01169000 01169900 01170100	8.92	10.7	1.92
01169507	Drakes Brook near Conway, Mass.	42 32 29	72 43 40	3.46	5	01169000 01169900 01170100	11.9	6.54	1.89
01169508	Bear River below Drakes Brook near Conway, Mass.	42 32 29	72 43 39	9.04	--	--	--	17.2	1.90
01170057	Roaring Brook near Green River, Vt.	42 44 26	72 40 29	2.66	5	01169000 01169900 01170100	9.30	6.49	2.44
01170905	Roaring Brook near Conway, Mass.	42 28 19	72 40 21	3.09	9	01169000 01169900 01170100	7.31	8.06	2.61

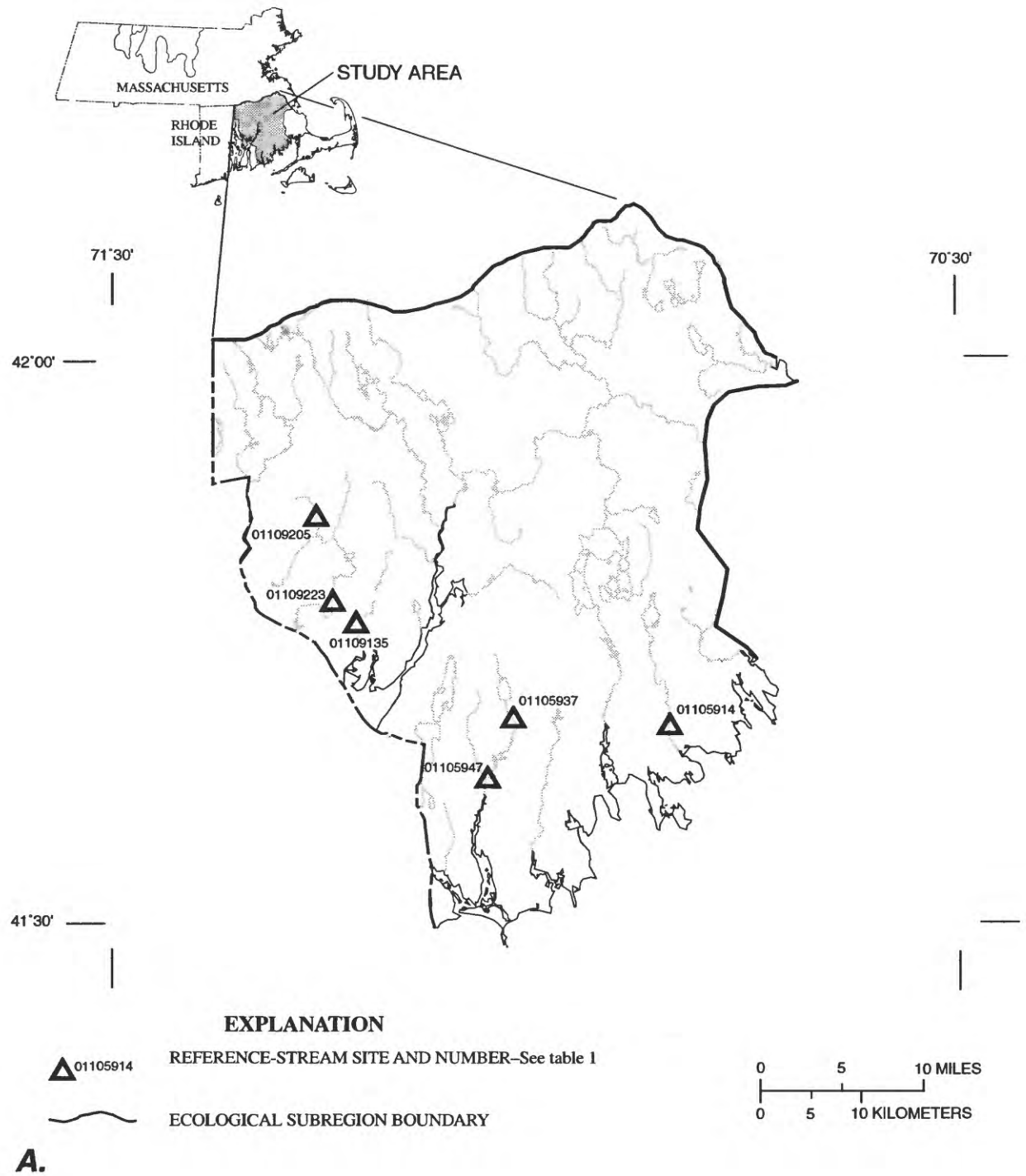

Figure 2. Locations of the reference-stream sites in (*A*) Narragansett/Bristol Lowland ecological subregion, (*B*) Worcester/Monadnock Plateau ecological subregion, and (*C*) Vermont Piedmont ecological subregion in Massachusetts.

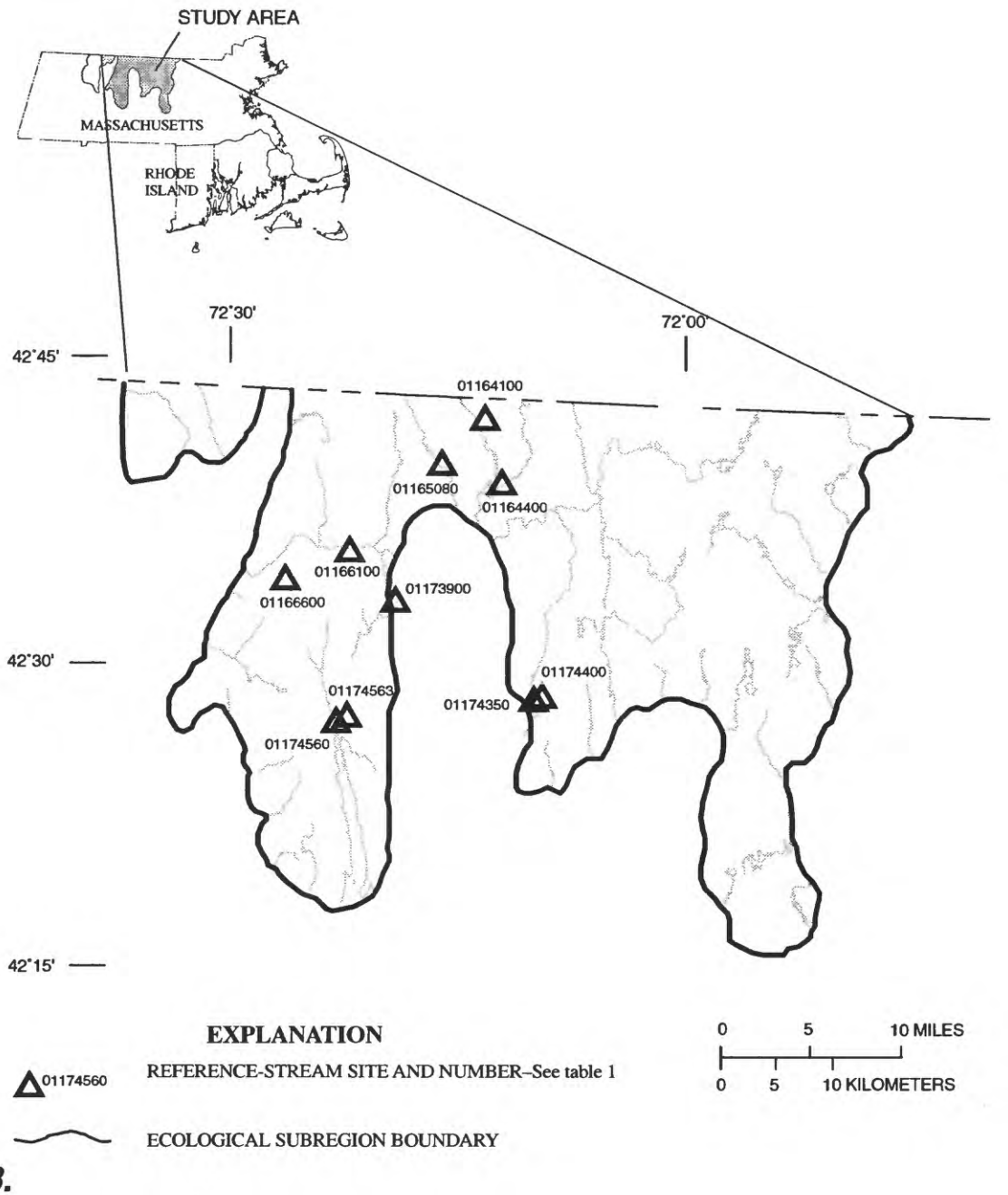

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Figure 2. Locations of the reference-stream sites in (*A*) Narragansett/Bristol Lowland ecological subregion, (*B*) Worcester/ Monadnock Plateau ecological subregion, and (*C*) Vermont Piedmont ecological subregion in Massachusetts—*Continued.*

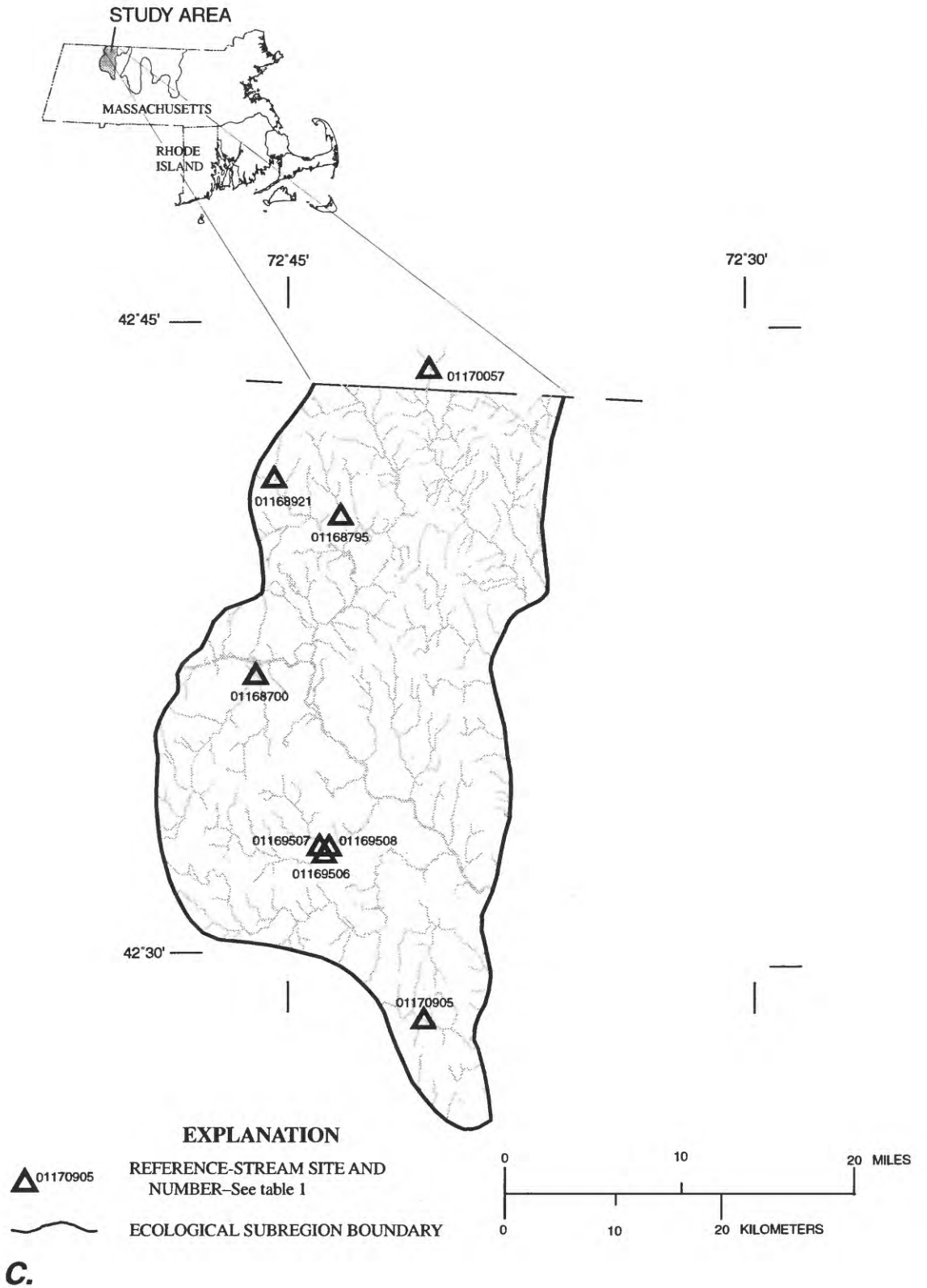

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Figure 2. Locations of the reference-stream sites in (*A*) Narragansett/Bristol Lowland ecological subregion, (*B*) Worcester/ Monadnock Plateau ecological subregion, and (*C*) Vermont Piedmont ecological subregion in Massachusetts—*Continued.*

Table 2. Description of streamflow-gaging stations in Massachusetts and Rhode Island used to calculate mean annual streamflow at the reference-stream sites

[USGS station No.: Locations shown in figure 1. Latitude and longitude are given in degrees, minutes, seconds. Water years begin October 1 and are designated by the calendar year in which they end. No., number; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; $ft^3/s/mi^2$, cubic foot per second per square mile; mi^2, square mile]

USGS station No.	Station name	Latitude ° ′ ″	Longitude ° ′ ″	Water years used in analysis	Drainage area (mi^2)	Mean annual streamflow (ft^3/s)	Mean annual streamflow per square mile ($ft^3/s/mi^2$)	Remarks
01096000	Squannacook River near West Groton, Mass.	42 38 03	71 39 30	1950–97	63.7	113	1.77	Occasional regulation by mill upstream.
01105600	Old Swamp River near South Weymouth, Mass.	42 11 25	70 56 43	1967–97	4.50	9.12	2.03	--
01105730	Indian Head River at Hanover, Mass.	42 06 02	70 49 23	1967–97	30.3	62.2	2.05	Some regulation by mills and dams upstream.
01105870	Jones River at Kingston, Mass.	41 59 27	70 44 03	1967–97	15.7	32.0	2.04	Flow regulated by dams upstream.
01106000	Adamsville Brook at Adamsville, R.I.	41 33 30	71 07 47	1941–78	8.01	14.3	1.78	--
01109000	Wading River near Norton, Mass.	41 56 51	71 10 38	1926–97	43.3	73.2	1.69	Flow regulated by dams and diversions upstream.
01111300	Nipmuc River near Harrisville, R.I.	41 58 52	71 41 11	1965–91, 1994–97	16.0	30.7	1.92	--
01118000	Wood River at Hope Valley, R.I.	41 29 53	71 43 01	1942–97	72.4	155	2.14	Some seasonal regulation by a pond upstream.
01162500	Priest Brook near Winchendon, Mass.	42 40 57	72 06 56	1917, 1919–34, 1937–97	19.4	33.0	1.70	--
01165500	Moss Brook at Wendell Depot, Mass.	42 36 10	72 21 36	1917–82	12.1	20.0	1.65	--
01169000	North River at Shattuckville, Mass.	42 38 18	72 43 32	1941–97	89.0	187	2.10	Occasional small diurnal fluctuation.
01169900	South River near Conway, Mass.	42 32 31	72 41 39	1967–97	24.1	52.6	2.18	Small diurnal fluctuation since 1982.
01170100	Green River near Colrain, Mass.	42 42 12	72 40 16	1968–97	41.4	90.4	2.18	--
01171500	Mill River at Northampton, Mass.	42 19 05	72 39 21	1940–97	54.0	98.2	1.82	--
01174000	Hop Brook near New Salem, Mass.	42 28 42	72 20 05	1949–82	3.39	6.13	1.81	--
01174900	Cadwell Creek near Belchertown, Mass.	42 20 08	72 22 12	1962–97	2.55	5.18	2.03	--
01175670	Sevenmile River near Spencer, Mass.	42 15 54	72 00 19	1962–97	8.68	15.2	1.75	Occasional regulation by ponds upstream.
01176000	Quaboag River at West Brimfield, Mass.	42 10 56	72 15 51	1913–97	150	249	1.66	Flood-retarding reservoirs upstream.