August Median Streamflows in Massachusetts

By KERNELL G. RIES III

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM, AND ABBREVIATIONS AND DEFINITIONS

CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.02832	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
inch (in)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:
°C = 5/9 × (°F - 32).

VERTICAL DATUM

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

ABBREVIATIONS AND DEFINITIONS

Organizations

MDFWELE	Massachusetts Department of Fish, Wildlife, and Environmental Law Enforcement
MDEM	Massachusetts Department of Environmental Management, Division of Water Resources
MDEP	Massachusetts Department of Environmental Protection, Office of Watershed Management
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Basin Characteristics

DAREA	Drainage area, in square miles
DRT/TST	Area of stratified drift per unit stream length, plus 0.1, in miles (square miles per mile)
GWHEAD	Surrogate for head in the stratified-drift aquifer, computed by subtracting the minimum basin elevation from the mean basin elevation, in feet
REGION	Region of similar August median streamflows

Miscellaneous

ABF	Aquatic Base Flow policy of the USFWS
BCF	Smearing estimate bias correction factor
GIS	Geographic information system computer software
GLS	Generalized-least-squares regression analysis
LFPR	Low-flow partial-record station
MSE	Mean square error
OLS	Ordinary-least-squares regression analysis
PRESS	Estimate of the prediction error sum of squares
WLS	Weighted-least-squares regression analysis

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Abstract

Since 1981, the U.S. Fish and Wildlife Service has used the August median streamflow as the summer-time minimum streamflow for maintenance of habitat for biota in New England streams; however, August median streamflows in Massachusetts were previously not well defined. This report provides information needed to evaluate the impact of use of this statistic for water-resources planning and management, and to estimate August median streamflows for ungaged streams in the State.

August median streamflows were determined for 37 streamflow-gaging stations and 59 low-flow partial-record stations with all or most of their drainage areas in Massachusetts and virtually natural flow conditions during low-flow periods. The monthly (August) median streamflows for the streamflow-gaging stations were determined from the daily mean streamflows for all years with complete records for August through climatic year 1994. Periods of records ranged from 2 to 81 years. August median streamflows for the low-flow partial-record stations were estimated by correlation of measured streamflows at the stations with same-day mean streamflows at nearby gaging stations. The estimates for the low-flow partial-record stations had a median standard error of 8.71 percent.

Flows in Massachusetts streams were, on average, equal to or less than the August median streamflow on 16 percent of all days. The Statewide median of the August median streamflow was 0.246 cubic foot per second per square mile; however, the median in the western region was 0.271 cubic foot per second per square mile and the median in the eastern region was 0.197 cubic foot per second per square mile. A third hydrologic region, the southeast coastal region, encompasses an area in which surficial geology is entirely stratified drift, and for which data were insufficient to determine August median streamflows. Because median values in the western and eastern regions had about a 15-fold range, use of the median for the region to estimate the flow per unit area for ungaged sites could result in substantial errors.

Weighted-least-squares regression analysis was used with data for the 96 stations to develop an equation for estimating August median streamflows for ungaged streams with natural flow conditions. Basin characteristics for the stations were measured from digital data bases.The actual or equivalent years of record for the stations were used as the weighting factor. The independent variables included in the equation were drainage area, area of stratified drift divided by total basin stream length plus 0.1, the difference between the mean basin elevation and the minimum basin elevation, and an indicator variable for the hydrologic region. The equation explained 95.1 percent of the variation in August median streamflows for stations used in the analysis. The standard error of estimate for the equation is 35.4 percent, and the standard error of prediction is 38.3 percent. Prediction intervals can be constructed for sites with basin characteristics within the ranges of those used in the regression analysis. The equation is not applicable in the southeast coastal region.

INTRODUCTION

In 1981, the U.S. Fish and Wildlife Service (1981) developed a "New England Aquatic Base Flow Policy" (ABF). The policy recommended use of the August median streamflow as the minimum streamflow for summertime maintenance of habitat for biota. This minimum streamflow was selected because "low-flow conditions occurring in August typically result in the most metabolic stress to aquatic organisms due to high water temperatures and diminished living space, dissolved oxygen, and food supply" (U.S. Fish and Wildlife Service, 1981). Higher flows than the August median were recommended at other times of the year, and site-specific studies were recommended where needed.

The ABF has been used for water-resources planning and management at various times by most New England States. Currently, environmental agencies of the State of Massachusetts [the Department of Environmental Management, Office of Water Resources (MDEM); the Department of Environmental Protection, Office of Watershed Management (MDEP); and the Department of Fisheries, Wildlife, and Environmental Law Enforcement (MDFWELE)] are attempting to develop a uniform policy for water-resources planning and management. One policy being considered is use of the ABF.

The USFWS recommended that the historical August median be used as the minimum streamflow at locations where this statistic can be determined from available flow data from unregulated streams. Where these data are not available, or where streamflows are regulated, an ABF of 0.5 $(ft^3/s)/mi^2$ of drainage area was prescribed. The policy provided that alternative minimum streamflows may be accepted by the USFWS if the applicant or sponsor of a project or activity that would affect streamflows adequately justifies their use.

The ABF was developed on the basis of an analysis of data for 48 streamflow-gaging stations in New England. Only those stations with drainage areas of 50 mi^2 or greater were included in the analysis, and only seven of the stations were in Massachusetts. Because so few sites used in the ABF analyses are in Massachusetts, and because most streams where the estimates would be needed have drainage areas less than 50 mi^2, better definition of the August median streamflow for Massachusetts streams was needed for State environmental agencies to evaluate the potential impact of use of the ABF to maintain minimum streamflows for biota. If State environmental agencies were to implement policy for planning and management of water resources, they also would need to be able to determine with reasonable confidence the unregulated August median streamflow for any Massachusetts stream.

This report describes a study done by the U.S. Geological Survey (USGS), in cooperation with the MDEM and MDEP, to better define August median streamflows in Massachusetts. The report provides State environmental agencies information needed to evaluate the potential impact of use of this statistic for water-resources planning and management, and to estimate August median streamflows for ungaged streams in the State. The specific purposes of this report are to (1) provide August median streamflows for sites on virtually unregulated streams in Massachusetts where the medians could be determined from available data, (2) describe how the August median streamflow per square mile of drainage area varies throughout the State, and (3) provide an equation that can be used to estimate August median streamflows for ungaged streams in Massachusetts.

The physical setting of Massachusetts as it relates to variation in August median streamflows are described, as are the data and methods used in the analyses. An example application of the equation used for determining August median streamflows for ungaged sites is provided, and limitations for use of the equation are discussed.

Previous Investigations

The U.S. Fish and Wildlife Service (1981) determined August median streamflows for the 48 sites in New England by computing the median of the annual series of August monthly mean streamflows for the period of record at each station. The USFWS then computed the August median streamflow per square mile of drainage area for each of the 48 sites, and used the average of these medians [0.48 $(ft^3/s)/mi^2$], rounded upward to the nearest one-tenth, as their recommended ABF of 0.5 $(ft^3/s)/mi^2$.

In 1987, Charles Ritzi Associates (1987) used data from the same gaging stations as those used by the USFWS, but computed August median streamflows from the daily mean streamflows for all August days during the period of record. Charles Ritzi Associates found that the mean of the August median streamflows computed in this manner was 0.40 $(ft^3/s)/mi^2$, and the median was between 0.33 and 0.38 $(ft^3/s)/mi^2$.

In a subsequent study, Kulik (1990, p. 10) stated that monthly mean streamflows, such as those used by USFWS to compute August median streamflows, can be substantially skewed by a small number of intense storm events, causing mean values to be higher than the medians. Kulik stated that "the median is a more useful statistic than the mean for describing the central tendency" of data with skewed distributions. Kulik (1990) also hypothesized that August median streamflows in New England varied regionally due to differences in physiographic basin features and climate. In his study, Kulik used virtually the same streamflow database as that used by the USFWS, except he computed August median streamflows for the sites from the daily mean streamflows for all August days during the period of record, the same method as that used by Charles Ritzi Associates (1987). Kulik analyzed variation in the streamflows with variation in rainfall, slope, land use, and topography, and found statistically significant differences among two physiographic regions. Kulik suggested that separate ABF criteria of 0.6 and 0.3 $(ft^3/s)/mi^2$ be used for Mountain Windward and Non-Mountain Windward regions, respectively.

Several investigators have used regression analysis to obtain equations for estimating low-flow statistics for ungaged New England streams, although none have developed an equation for estimating August median streamflows (Thomas, 1966; Johnson, 1970; Tasker, 1972; Parker, 1977; Dingman, 1978; Cervione and others, 1982; Male and Ogawa, 1982; Fennessey and Vogel, 1990; Vogel and Kroll, 1990; Cervione and other, 1993; Risley, 1994; and Ries, 1994a, 1994b). These investigators found drainage area—the land area that contributes streamflow to the location on the stream—to be the variable most highly correlated with low streamflow statistics. Direct or indirect measures of surficial geology (such as area of stratified drift, area of till, and ground-water factor), and measures of basin relief or elevation also were highly correlated with low streamflows. Precipitation was highly correlated to low-flow statistics when data from northern New England are included in the analyses.

Physical Setting

Massachusetts encompasses an area of 8,093 mi^2 in the northeastern United States. Massachusetts has a humid climate, with an average annual precipitation of about 45 in. that is fairly evenly distributed throughout the year. Average annual temperatures range from 50°F in coastal areas to 45°F in the western mountains. Average monthly temperatures in coastal areas range from about 30°F in February to about 71°F in July, and average monthly temperatures in the western parts of the State range from about 20°F in January to about 68°F in July (U.S. Commerce Department, National Oceanic and Atmospheric Administration, 1989). Altitudes range from sea level along the coast to almost 3,500 ft in the western mountains. Relief generally increases from east to west.

Flow in Massachusetts streams during the summer months comes from ground water discharged from aquifers in unconsolidated deposits adjacent to the streams, except during and for a short time after storms. This ground water is termed base flow. High-yielding aquifers usually are in stratified drift, which are coarse sand and gravel deposits along the valley floors of inland river basins and in coastal areas of southeastern Massachusetts. In addition to the high-yielding coarse sand and gravel deposits, stratified drift commonly contains layers of fine sand and clay that yield little water to adjacent streams. The stratified-drift deposits are usually surrounded by upland areas underlain by till with exposed bedrock outcrops. Till is an unsorted glacial deposit that consists of material ranging in size from clay to large boulders. Till yields little water to adjacent streams in comparison to yields from coarse-grained stratified drift. As a result, during summertime, streams in till areas tend to have less flow per unit of drainage area than streams in areas of stratified drift, and some small streams in till areas may go dry.

Acknowledgments

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DETERMINING AUGUST MEDIAN STREAMFLOWS FROM AVAILABLE FLOW DATA

August median streamflows for gaging stations were determined in the manner used by Charles Ritzi Associates (1987) and Kulik (1990). August daily mean streamflows for all complete Augusts for the period of record for each station were ordered from highest to lowest, and the streamflow that was equaled or exceeded 50 percent of the time was determined as the median for the station.

August median streamflows for low-flow partial-record stations (LFPRs) were determined by use of a mathematical method developed by Hirsch (1982). In this method, termed the MOVE.1 (Maintenance Of Variance Extension, type 1) method, a mathematical relation is determined between the logarithms-base 10 of streamflow measurements made at a partial-record site and the logarithms-base 10 of same-day mean streamflows recorded at nearby and hydrologically similar long-term streamflow-gaging stations. The logarithm of the August median streamflow at the gaging station is then entered into the equation that defines the relation to determine the corresponding median streamflow for the partial-record site. The logarithm-base 10 estimate is then exponentiated to obtain the final estimate in units of cubic feet per second. A thorough explanation of application of the MOVE.1 method is provided by Ries (1994a, p. 21-24).

Usually the measured streamflows at a partial-record station correlate well with more than one gaging station. When this happens, MOVE.1 relations can be developed with several gaging stations to estimate the August median streamflow for a single partial-record station, and multiple estimates will be obtained. Because these multiple estimates differ, a method was needed to combine the estimates into a single estimate. Tasker (1975) suggested that the best estimate of a streamflow statistic for a site is that which has the minimum variance. Tasker showed that by weighting independent estimates of a streamflow statistic for a site by the variances of the estimates and then averaging the weighted estimates, the resulting weighted average estimate has variance less than or equal to that of any of the independent estimates.

Hardison and Moss (1972) developed an equation for determining the variance of estimates of 7-day, T-year low flows that were obtained from an ordinary-least-squares (OLS) regression of the logarithms-base 10 of base-flow measurements at a LFPR to the logarithms-base 10 of daily mean discharges at a nearby, hydrologically similar gaging station. The parameters in the equation were the length of record at the gaging station, the number of base-flow measurements, and the standard error of estimate of the regression equation. Hardison and Moss' equation is

$$V_{T,U} = \frac{V_R}{M}\left[1 + \frac{1}{M-3} + \frac{z^2 M}{M-3} + \left(\frac{SE_{T,G}}{s_{B,G}}\right)^2\left(\frac{M}{M-3}\right)\right] + b^2 V_G, \quad (1)$$

where:

$V_{T,U}$ is the variance of the T-year low streamflow at the ungaged site, in log units;
V_G is the variance of the T-year low streamflow at the gaging station, in log units;
V_R is the variance about the regression line;
M is the number of base-flow measurements;
$SE_{T,G}$ is the standard error of the T-year low-flow at the gaging station, in log units, which equals the square root of V_G;
b is the slope of the ordinary-least-squares regression line of relation;

$s_{B,G}$ is the standard deviation of the logarithms-base 10 of the mean discharges at the gaging station on the same days the low-flow measurements were made at the ungaged site; and

z is the number of standard deviation units between the mean of the logarithms-base 10 of the same-day mean discharges at the gaging station and the logarithms-base 10 of the T-year low streamflow at the gaging station.

Hardison and Moss (1972) noted five assumptions in developing their equation:

1. The lower end of the true relation between the logarithms of the base-flow measurements at the low-flow site and the same-day mean streamflows at the gaging station is the same as the true relation between the logarithms of the respective annual low streamflows.
2. The relation between the logarithms of the annual low streamflows is the same as the relation between the logarithms of the 7-day low streamflows.
3. The time-sampling error in the 7-day low streamflow that is used to enter the regression equation is independent of the variation in the base-flow measurements used to define the equation.
4. The logarithms of the measured streamflows at the ungaged site and the same-day mean streamflows at the gaging station follow a bivariate normal distribution.
5. The *M* measurements made at the partial-record site are statistically independent estimates of the base-flow relation.

Hardison and Moss (1972) noted that the first four assumptions appeared to be reasonable under the conditions in which application of equation 1 was intended. They also noted that criteria could be applied for using only those measurements that can be reasonably assumed to be independent to define the relation, thereby, satisfying assumption 5. The criterion usually applied is that the base-flow measurements used in the relation be separated by significant storms (Stedinger and Thomas, 1985). Measurements of low flow at sites in Massachusetts generally have satisfied that criterion.

For this study, Hardison and Moss' equation was modified to obtain variances of estimates of August median streamflows determined from MOVE.1 equations. The modified equation, as with Hardison and Moss' original equation, does not take into account the additional variance from measurement errors at the LFPRs and errors in the daily streamflow records at the streamflow-gaging stations used in the relation. To apply the modified equation, assumption 2 above is not needed and assumptions 1 and 3 are restated as:

1. The lower end of the true relation between the logarithms of the base-flow measurements at the LFPR and the same-day mean streamflows at the gaging station is the same as the true relation between the logarithms of the August daily mean streamflows at the stations.
3. The time-sampling error in the August median streamflow that is used to enter the regression equation is independent of the variation in the base-flow measurements used to define the equation.

The modified equation is

$$V_{A,U} = \frac{V_R}{M}\left[1 + \frac{1}{M-3} + \frac{z^2 M}{M-3} + \left(\frac{SE_{A,G}}{s_{B,G}}\right)^2\left(\frac{M}{M-3}\right)\right] + b^2 V_{A,G}, \qquad (2)$$

where:

$V_{A,U}$ is the variance of the estimated August median streamflow at the ungaged site, in log units;

$V_{A,G}$ is the variance of the August daily mean streamflows at the gaging station, in log units;

V_R is the variance of the MOVE.1 or graphical relation between the concurrent discharges, determined by summing the squares of the differences between the logarithms-base 10 of the measured discharges and the corresponding values from the relation, then dividing by the quantity M-2;

M is the number of base-flow measurements;

$SE_{A,G}$ is the standard error of the August daily mean streamflows, in log units, at the gaging station, which equals the square root of $V_{A,G;}$

$s_{B,G}$ is the standard deviation of the logarithms-base 10 of the daily mean discharges at the gaging station concurrent with the low streamflow measurements made at the ungaged site;

z is the number of standard deviation units between the mean of the logarithms-base 10 of the same-day mean discharges at the gaging station and the logarithm-base 10 of the August median streamflow at the gaging station; and

b is computed as $r(s_{B,U}/s_{B,G})$, where r is the correlation coefficient between the low streamflow measurements made at the ungaged site and the same-day mean discharges at the gaging station, and $s_{B,U}$ is the standard deviation of the logarithms-base 10 of the low streamflow measurements made at the ungaged site.

For low-flow partial-record sites where estimates were obtained from relations with more than one streamflow-gaging station, the individual estimates were weighted by their variances, determined from equation 2, then the weighted estimates were averaged to obtain the minimum-variance estimate. A weighted final variance (V_w) was determined for the estimate, and the standard error (SE_f), in percent, of the final estimate was obtained from the equation (Ries, 1994b, p. 19)

$$SE_f = 100\sqrt{\exp(5.3018V_w) - 1}. \tag{3}$$

The equivalent years of record also was computed for estimates of August median streamflow for the LFPRs. The equivalent years of record is the length of time that a streamflow-gaging station would need to be operated at the location of the LFPR to obtain an estimate of the August median streamflow with equal accuracy. The equivalent years of record for LFPRs was computed from an equation developed by combining equations 7, 8, and 9 in Hardison and Moss (1972), and solving for the number of years of record. The resulting equation is:

$$N_U = \left(R_T^{\,2}SE_{A,G}^2k^2\left(\frac{s_{B,U}}{s_{B,G}}\right)^2\right)/\left(\frac{V_R}{M}\left(\frac{1+z^2}{K}\right)+\frac{b^2R_T^{\,2}SE_{A,G}^2}{N_G}\right), \tag{4}$$

where:

N_U is the equivalent years of record at the partial-record station;

N_G is the years of record at the streamflow-gaging station used in the relation;

K is from equation 3 of Hardison and Moss (1972),

$$K = (1+z^2)/\left[1+\frac{1}{M-3}+\frac{z^2M}{M-3}+\left(\frac{SE_{T,G}}{s_{B,G}}\right)^2\left(\frac{M}{M-3}\right)\right]; \tag{5}$$

k is from equation 9 of Hardison and Moss (1972),

$$k = \sqrt{r^2+\left(\frac{M-4}{M-2}\right)(1-r^2)}\ ;\text{ and} \tag{6}$$

R_T is a correction factor that depends on the streamflow statistic being estimated. For the case of the August median streamflow, R_T equals one.

All other variables in equation 4 are as previously defined. The value of R_T was determined by combining the equation that appears in table 1 of Hardison and Moss (1972),

$$R_T = (SE_{T,G}\sqrt{N})/I_v, \tag{7}$$

where I_v is the standard deviation of the logarithms of the annual low streamflows (in this case, it equals the standard deviation of the August daily mean streamflows), with the equation

$$SE_{T,G} = I_v \sqrt{\frac{1 + k_T^2/2}{N}} \tag{8}$$

from Hardison (1969, p. D212) to obtain

$$R^2 = 1 + k_T^2/2 . \tag{9}$$

In equations 8 and 9 above, k_T is the number of standard deviation units between the streamflow statistic and the mean of the data from which it is computed. From assumption 4 above, the daily mean streamflow values from which August median streamflows are computed are distributed log-normally. Because the mean and median of a normal distribution are the same, and k_T for the mean is zero, R^2 is always one for estimates of August median streamflows.

For LFPRs where estimates were obtained from relations with more than one streamflow-gaging station, the individual calculations of equivalent years of record were weighted by the variances of the estimated August median streamflows, determined from equation 2, then the individual weighted equivalent years of record were averaged to obtain the final weighted equivalent years of record for the LFPRs.

August median streamflows were determined for 96 streamflow-gaging stations and LFPRs, and analyzed to determine variation in August median streamflows per square mile and to develop an equation for predicting August median streamflows for ungaged sites in Massachusetts. Streamflows at all stations included in the analyses were virtually unregulated during low streamflow periods. Thirty-seven of the stations were streamflow-gaging stations, and 59 of them were LFPRs. Thirty-four of the streamflow-gaging stations were in Massachusetts and three of them were in bordering States, but had more than two-thirds of their drainage areas in Massachusetts. Two of the streamflow-gaging stations were in Rhode Island and one was in Connecticut. Names and descriptions of the streamflow-gaging stations used in the analyses are in table 1 (at back of report), along with names and descriptions for 14 other streamflow-gaging stations that were not used in the analyses, but data for these stations were used to aid in estimating August median streamflows for the LFPRs. All of the LFPRs were in Massachusetts. Names and descriptions of the LFPRs are in table 2 (at back of report). Locations of all stations are shown in figure 1.

The ABF policy of the USFWS states that "when inflow immediately upstream of a project falls below the prescribed flow release, the outflow be made no less than the inflow" (U.S. Fish and Wildlife Service, 1981). In effect, this policy requires that a project cease use of water whenever the streamflow falls below the August median. Streamflows at or below the August median, occur by definition, during one-half of all August days; however, streamflows below the August median commonly occur during other months. To determine the effect of the ABF policy on a long-term average basis, the flow-duration percentiles corresponding to the August median streamflow were determined for each streamflow-gaging station and LFPR used in the regression analysis. The mean and the median of the flow-duration percentiles were the same—the 84th percentile. Individual values ranged between the 80th and 89th percentiles, and about 67 percent of the values were between the 82th and 85th percentile. Because, on average, the August median flow for Massachusetts streams corresponds to the 84-percent duration streamflow, projects affected by the ABF policy would be required to cease operations, on average, 16 percent all days, or 58 days in an average year.

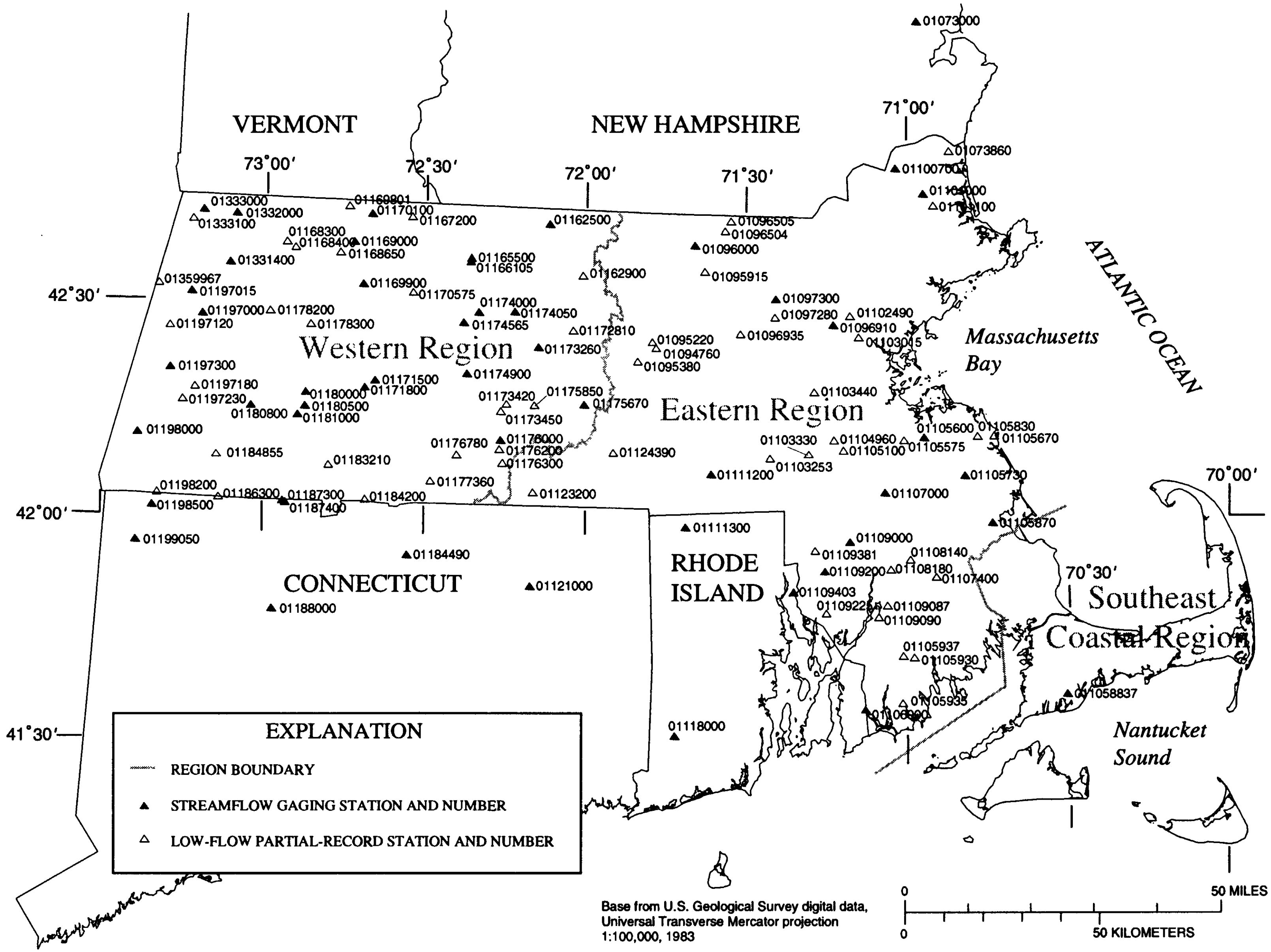

Figure 1. Locations of low-flow partial-record stations and streamflow-gaging stations used in the analyses and for correlation with the low-flow partial-record stations, and boundaries of streamflow regions determined from analysis of variation in August median streamflow per square mile.

VARIATION IN AUGUST MEDIAN STREAMFLOWS

August median streamflows determined for the 96 stations were divided by their respective drainage areas to determine the August median streamflow per square mile for each station. These medians were ordered from highest to lowest, and minimum, maximum, and quartiles of the range of medians for all stations were computed. The minimum August median streamflow was thus 0.040 $(ft^3/s)/mi^2$ at Dorchester Brook near Brockton, Mass. (station 01107000), and the maximum was 0.768 $(ft^3/s)/mi^2$ at South Branch Mill River near East Longmeadow, Mass. (station 01177360). August median streamflows were greater than or equal to 0.356 $(ft^3/s)/mi^2$ at one-quarter of the stations; less than 0.356 $(ft^3/s)/mi^2$ and greater than or equal to 0.246 $(ft^3/s)/mi^2$ at one-quarter of the stations; less than 0.246 $(ft^3/s)/mi^2$ and greater than or equal to 0.175 $(ft^3/s)/mi^2$ at one-quarter of the stations; and less than 0.175 $(ft^3/s)/mi^2$ at one-quarter of the stations.

The stations were divided into four groups based on the quartile in which their August median streamflow per square mile fell. The stations were then mapped, with different-sized circles denoting the groups, the smallest circle denoting stations with flows per square mile in the lowest quartile, and so forth (fig. 2). No clearly defined patterns were readily apparent on the map. The circle sizes generally were not grouped together, and large circles were adjacent to small circles. This indicated that local physical features of the basins for the stations were more important than regional features, such as rainfall, in controlling variation in August median streamflows. Some regional differences were apparent, however, when the State was divided roughly in halves along the line denoting 72 degrees longitude (fig. 2). The largest circles (largest quartile of the August median streamflow per square mile) occurred more than twice as often in the western half of the State as in the eastern half, and the smallest circles (smallest quartile) occurred more than twice as often in the eastern half of the State as in the western half. A *chi*-square test for differences between the medians of two samples was done on the two groups of data (Statware, Inc, 1990, p. 3-45). This test showed a statistical difference at the 95-percent confidence level between the median values of the two regions, with a *p*-value of 0.023, which means that there was a 2.3 percent probability of incorrectly rejecting the null hypothesis that the medians of the two groups are equal. As discussed in greater detail below and shown in figure 2, stations in the Southeast Coastal region were not included in the spatial analysis.

The dividing line at 72 degrees longitude roughly coincides with the boundary separating basins that drain to Massachusetts, Buzzards, and Narragansett Bays, with those that drain to Long Island Sound. A *chi*-square test of medians of the August median streamflow per square mile was done on groups divided between stations in basins that drain to Massachusetts, Buzzards, and Narragansett Bays, and stations that drain to Long Island Sound. Only one station, Little River at Richardson, Mass., in the French River Basin, was affected by the redefined grouping. This redefined grouping caused the *p*-level to increase to 0.039. The French River Basin drains into the Quinebaug River Basin, which subsequently drains into the Thames River Basin in Connecticut, where it ultimately drains into the far eastern extent of Long Island Sound. The 72-degree longitude line roughly bisects the Quinebaug River Basin in Massachusetts. Because basin characteristics in the Massachusetts parts of the French and Quinebaug River Basins, and August median streamflows per square mile for the two stations in these basins, are more similar to those of adjacent river basins to the east than to those of adjacent river basins to the north and west, the French and Quinebaug River Basins were included in the eastern group. This new grouping resulted in only one station, Stevens Brook at Holland, Mass., in the Quinebaug River Basin, being moved from the western region to the eastern region of the original grouping based on the 72-degree longitude line. The *p*-value for the test of the medians of this grouping decreased to 0.014.

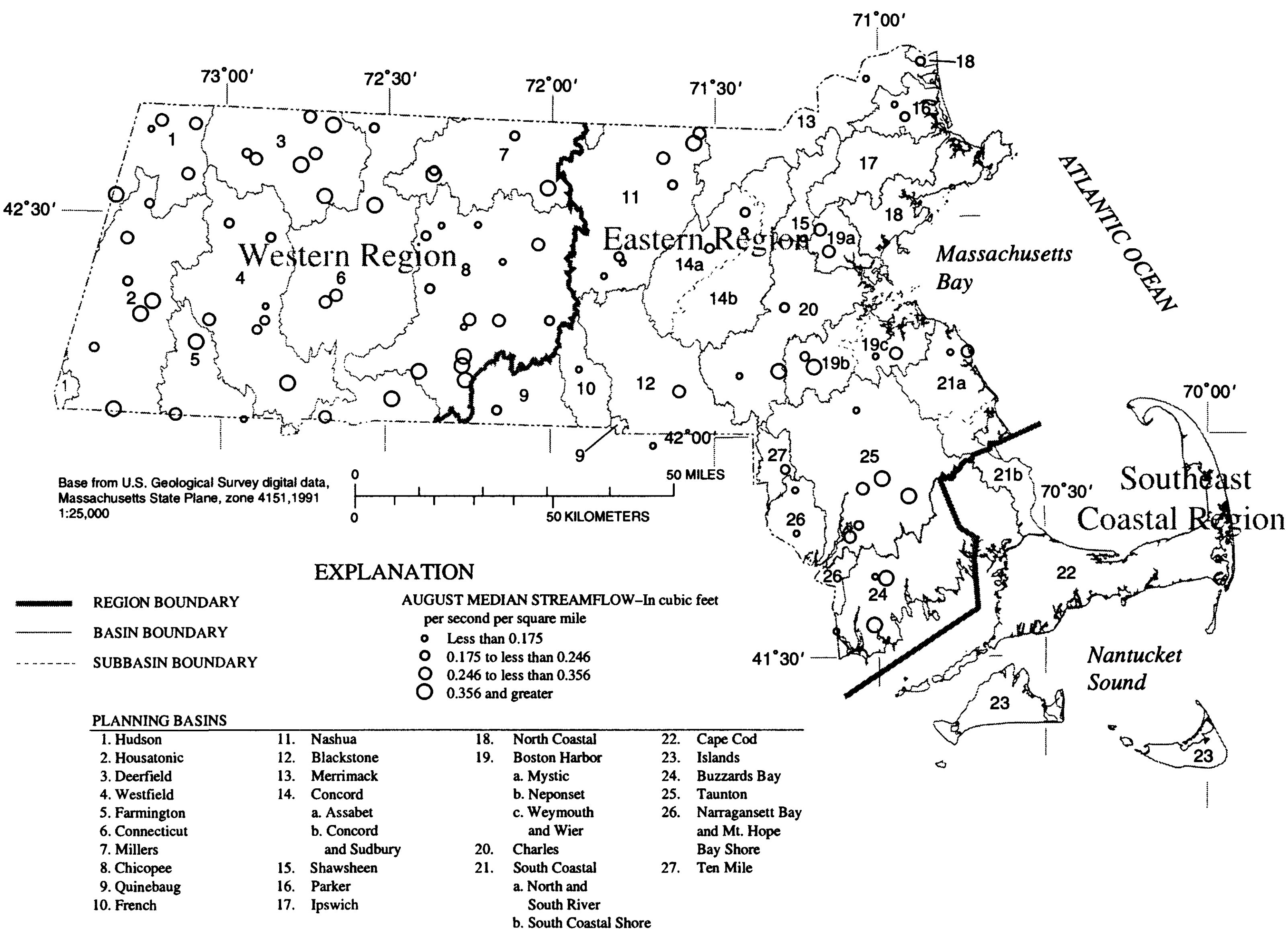

Figure 2. Magnitude of August median streamflow per square mile for stations used in the analyses, and boundaries of the streamflow regions and the 27 major river basins in Massachusetts.

The median of the August median streamflow for the 43 stations in the eastern region was 0.197 $(ft^3/s)/mi^2$, with a minimum of 0.040 $(ft^3/s)/mi^2$ and a maximum of 0.595 $(ft^3/s)/mi^2$, whereas the median for the 53 stations in the western region was 0.271 $(ft^3/s)/mi^2$, with a minimum of 0.056 $(ft^3/s)/mi^2$ and a maximum of 0.759 $(ft^3/s)/mi^2$. Because of the large range of the values in both regions (nearly 15-fold in the eastern region and nearly 14-fold in the western region), there would be little confidence in use of the regional median of the August median streamflow per square mile to estimate the value for a selected ungaged site in the region. Use of regression equations that account for differences in the physical characteristics of the ungaged basin as well as region differences would likely provide much better estimates of August median streamflows than use of regional medians.

Reasons for differences in flow per unit area between the eastern and western regions are complex. Normal annual precipitation in the western region of Massachusetts is about 47 in., whereas normal annual precipitation in the eastern region is about 45 in. (U.S. Commerce Department, National Oceanographic and Atmospheric Administration, 1994). A *chi*-square test showed that the approximate 2-inch difference in normal annual precipitation between the regions was not statistically different, although a more dense data network than currently exists in western Massachusetts might show greater differences in precipitation because of orographic effects in mountainous areas. Other drainage basin characteristics probably account for most of the differences between regions. Mean basin elevations and relief generally are lower, and proportions of water bodies and wetlands are larger in drainage basins in the eastern region than in the western region. Mean annual temperatures, as noted previously, are lower in the western region than in the eastern region. The lower temperatures, combined with smaller areas of wetlands and water bodies, and slightly larger annual precipitation, probably results in less evapotranspiration in the western region and more water available at times of low streamflow.

Previous studies have shown that low streamflows per unit area generally are larger for streams with larger percentages of stratified drift than streams with smaller percentages of stratified drift (Tasker, 1972; Cervione and others, 1993; Risley, 1994; and Ries, 1994a, 1994b). The median percentage of stratified drift for drainage areas for stations in the eastern region was 0.43, whereas the median percentage of stratified drift for drainage areas in the western region was 0.21. Because percentages of stratified drift generally are larger in eastern than in western Massachusetts, it may seem natural to assume that flows per unit of drainage area in eastern Massachusetts should generally be larger than those in western Massachusetts. However, August median streamflows per unit area of stratified drift were much lower in the eastern region than in the western region. The median of the August median streamflow per unit area of stratified drift in the eastern region was 0.62 $(ft^3/s)/mi^2$, whereas the median in the western region was 3.06 $(ft^3/s)/mi^2$. Much higher relief in the western region than in the eastern region probably explains most of the differences in streamflows per unit area of stratified drift because relief is the driving force that causes ground water to flow from the stratified drift to streams.

As noted above, stations in the eastern part of the Buzzards Bay Basin, the southern part of the South Coastal Shore Basin, Cape Cod, and the Islands were not included in the above analysis. Flows for most streams in this area, denoted the Southeast Coastal region, are highly affected by regulation, diversions, or the effects of cranberry bogs; therefore, streamflow characteristics for these streams are not readily transferrable to other streams. In addition, the region is underlain entirely by stratified-drift sediments, which are mostly coarse grained. Surface-water drainage boundaries often are not coincident with contributing areas of ground water for streams in the area. Because of these reasons, uncertainty in determinations of August median streamflow per square mile of drainage area in this region is much greater than in other parts of the State.

Most precipitation on the Southeast Coastal region infiltrates through the coarse-grained stratified drift to the ground-water system. When compared per unit of drainage area, streamflows in the Southeast Coastal region during heavy rains tend to be lower than streamflows in the other regions of Massachusetts, and streamflows during dry periods tend to be higher. As a result, August median streamflows per unit area probably are higher in general in the Southeast Coastal region than in the rest of the State.

For example, the August median streamflow for the Quashnet River at Waquoit Village, Mass. (station 011058837 in fig. 1) was 14.0 ft^3/s on the basis of 6 years of record. The surface drainage area for the station is 2.58 mi^2, but the ground-water contributing area is about 5.0 mi^2 (Barlow and Hess, 1993, p. 4). August median streamflow per square mile is either 5.43 $(ft^3/s)/mi^2$ if the surface boundary is used, or 2.80 $(ft^3/s)/mi^2$ if the ground-water boundary is used. Streamflows at this station are not highly regulated, but the station was not included in the analysis because streamflow per unit area from the Quashnet River is much greater than for any other station in the analysis. Inclusion of the Quashnet River in the analysis would likely cause overestimation of streamflows per unit area outside of the Southeast Coastal region. It is unknown whether the streamflow per square mile of drainage area for the Quashnet River is representative of the rest of the Southeast Coastal region.

DETERMINING AUGUST MEDIAN STREAMFLOWS WHERE FLOW DATA ARE NOT AVAILABLE

An equation was developed for use in estimating the August median streamflow for sites where-streamflow data are not available. The equation was developed by use of multiple-regression analysis with data for the 37 streamflow-gaging stations and 59 LFPRs listed in tables 1 and 2. The August median streamflow for each station was used as the dependent variable in the regression analysis, and various physical characteristics of the drainage areas associated with the stations were used as the independent variables. Also included in the regression analysis was an indicator variable for region, with stations in the eastern region given a value of 0, and stations in the western region given a value of 1. August median streamflows, physical characteristics for the stations, and regions are listed in table 3 (at the back of report).

Data Base

The period of record for the 37 gaging stations used in the analysis was from 2 to 81 years (table 1), with a median of 27 years. Data for the streamflow-gaging stations were analyzed through climatic year 1994[1] the most current year available when the analysis was done. Eight to 36 streamflow measurements were available for estimating August median streamflows for the 59 low-flow partial record sites (table 2), with a median of 16 measurements. The number of streamflow measurements ranged from 8 to 11 at one-quarter of the low-flow partial record sites, 12 to 16 at one-quarter of the sites, 17 to 22 at one-quarter of the sites, and 23 to 36 at one-quarter of the sites. Standard errors of the estimates of August median streamflow for the LFPRs used in the regression analyses ranged from 3.82 to 18.33 percent, with a median standard error of 8.71 percent. As the estimated August median streamflows for the low-flow partial-record sites decreased, the range of standard errors (in percent) increased. For example, standard errors for the 16 sites where estimated August median streamflows were greater than or equal to 5 ft^3/s ranged from 4.92 to 11.03 percent, whereas standard errors for the 14 sites where estimated August median streamflows were less than 1 ft^3/s ranged from 5.75 to 18.33 percent. Equivalent years of record for the LFPRs ranged from 0.3 to 4.6 years, with a median of 1.3 years.

Fewer unregulated gaging stations were available for use in the regression analysis in the eastern region than in the western region because drainage basins and water resources are much more heavily developed in the eastern region than in the western region. The data base included 11 gaging stations and 32 LFPRs in the eastern region, and 26 gaging stations and 27 LFPRs in the western region. Drainage areas for stations in the eastern region generally were smaller than those in the western region, with a median of 7.23 mi^2 in the eastern region and 12.7 mi^2 in the western region.

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[1]A climatic year begins April 1 of the year indicated, and ends March 31 of the following year.

Physical characteristics for the stations used in the analysis were determined from digital data bases by use of a geographic information system (GIS). Characteristics determined for the analysis include drainage area; area of stratified drift; total length of streams; maximum, minimum, and mean basin elevation; maximum, minimum, and mean elevation in stratified drift; and mean basin slope. Some of these characteristics were combined to determine additional characteristics for use in the analysis. Methods used to measure the above characteristics and to combine them to determine additional characteristics are the same as those explained in Ries (1994a, 1994b).

Drainage areas for some stations used in the regression analysis did not contain stratified-drift deposits. Because logarithms of the measured basin characteristics were used in the regression analysis, a constant of 0.1 was added to the stratified-drift areas. This constant also was added to areas of stratified drift per unit of total stream length (*DRT/TST*). The constant was chosen because its value is small with respect to the areas of stratified drift measured for most sites. Sensitivity tests done with constants ranging from 0.001 to 1.0 showed little effect on the regression results. The unadjusted stratified drift values are shown in table 3.

Regression Analysis

Weighted-least squares multiple-regression analysis (WLS) was used to determine the equation for predicting August median streamflow. Regression analysis procedures followed, diagnostic checks performed, and adjustment of estimates obtained from the equation for transformation bias, are the same as those described in Ries (1994a, p. 32-34). The general form of the equation is

$$\log Y_i = b_0 + b_1 \log X_{1,i} + b_2 \log X_{2,i} + \ldots + b_n \log X_{n,i} + b_R R_i + \varepsilon_i , \qquad (10)$$

where log signifies the base-10 logarithm. After retransforming by taking antilogs, the algebraically equivalent form is obtained

$$Y_i = 10^{b_0}\left(X_{1,i}^{b_1}\right)\left(X_{2,i}^{b_2}\right)\ldots\left(X_{n,i}^{b_n}\right)\left(10^{b_R R_i}\right)10^{\varepsilon_i}, \qquad (11)$$

where

Y_i is the dependent variable (in this case the August median streamflow) for site *i;*
$X_{1,i}$ to $X_{n,i}$ are the values of the *n* independent variables (basin characteristics) for the site;
R_i is the indicator variable for the region in which the site is located, with values of zero or one;
b_0 to b_n are the *n* regression model coefficients;
b_R is the coefficient for the indicator variable; and
ε_i is the residual error for the site.

Data for each streamflow-gaging station used in the regression analysis was weighted by its number of years of record. Data for each LFPR used in the analysis was weighted by its equivalent years of record, determined from equation 4. Actual weights used in the analysis were centered by subtracting the years of record for each station from the mean years of record for all stations, then dividing the result by the mean value. Additional weighting of the stations used in the regression analysis for non-constant variance of the regression residuals (heteroscedasticity) was not necessary. The weights also do not compensate for cross (spatial) correlation between the streamflows for the stations used in the regression analysis. Although generalized-least-squares regression analysis (GLS) could correct for cross correlation, it was not used for this study because potential gains in model precision did not justify the added effort for the GLS analysis. Vogel and Kroll (1990) used GLS to develop a regression equation to predict 7-day 10-year low flows for Massachusetts streams, and found that the regression model parameter estimates were nearly identical, and the decrease in prediction errors was marginal compared to a model developed by use of ordinary-least-squares regression analysis, which does not correct for differences in record length or cross-correlation. Cross correlation in Vogel and Kroll's model was 0.35. Stedinger and Tasker (1985) concluded that gains in model precision when GLS is used instead of WLS increase with decreasing standard error of estimate and increasing cross correlation. WLS and GLS models with large standard errors and low cross correlations were nearly identical. Cross correlation was expected to be low and standard error was expected to be moderate for the equation to predict August median streamflows on the basis of results of Vogel and Kroll (1990) and Ries (1994a and 1994b).

The all-possible-regressions selection procedure ALLREG of the Statit statistical computer software was used to select subsets of the independent variables for inclusion in the final regression equation (Statware, Inc., 1990). Minimization of Mallow's Cp was used as the selection criterion in the all-possible-regressions analysis (Neter and others, 1985, p. 421-429). The final model was selected on the basis of the following statistical parameters: (1) Mallow's Cp statistic; (2) R_{adj}^2, the percentage of the variation in the dependent variable explained by the independent variables, adjusted for the number of stations and independent variables used in the regression analysis; (3) the mean square error (MSE), the sample model error variance of the estimates for the stations included in the analysis; and (4) the PRESS statistic, an estimate of the prediction error sum of squares (Montgomery and Peck, 1982, p. 255). Diagnostic checks were done to test for model adequacy and violations of assumptions for regression analysis. The independent variables selected for the final model had to be statistically significant, and the signs and magnitudes of the coefficients had to be hydrologically reasonable.

Duan's (1983) "smearing estimate" of the mean residual error was used to reduce the bias that results when the final equation is retransformed from the logarithmic form (eq. 10) to the form that allows the streamflow estimates to be computed in units of cubic feet per second (eq. 11). The logarithmic equation provides estimates of the mean response of the dependent variable to the values of the independent variables for the site where the estimate is needed. The retransformed equation provides estimates of the median response, which tend to be lower for streamflow data. The smearing estimate bias correction factor (BCF) was needed to obtain unbiased estimates of the mean response in units of cubic feet per second. The BCF was applied by replacing the error term of equation 2 with the mean error of the retransformed residuals, yielding

$$Y_i = 10^{b_0}\left(X_{1,i}^{b_1}\right)\left(X_{2,i}^{b_2}\right)\ldots\left(X_{n,i}^{b_n}\right)\left(10^{b_R R_i}\right)\left(\frac{\sum_{i=1}^{N} 10^{\varepsilon_i}}{N}\right), \qquad (12)$$

where N is the number of stations used in the regression analysis. The smearing estimate is the last factor in parentheses in equation 12. It is determined by summing the antilogs of the residual errors from the regression analysis and then dividing the sum by the number of stations used in the regression analysis. Estimates obtained from the retransformed regression equation are multiplied by this value to provide reasonably unbiased estimates of the mean response of the dependent variable.

Equation to Predict August Median Streamflows

Basin characteristics for the best equation for predicting August median streamflows (Q_A) in Massachusetts were drainage area (*DAREA*), the area of stratified drift per unit of total stream length plus a constant of 0.1 (*DRT/TST*), and the difference between the mean basin elevation and the minimum basin (outlet) elevation (*GWHEAD*) as the independent variables, with the hydrologic region (*REGION*) used as an indicator variable. The equation is

$$Q_A = 0.1285 DAREA^{1.0687} GWHEAD^{0.2602} (DRT \S TST)^{0.7204} 10^{0.1353 REGION} . \tag{13}$$

The smearing estimate BCF, 1.0958, is included in the first coefficient in equation 13. The R_{adj}^2 for equation 13 is 95.2 percent, with MSE (model error variance, γ^2) equal to 0.02217 log units, and PRESS equal to 2.3313 log units. Another indication of the precision of the model is provided in figure 3, a plot of the observed August median streamflows for the stations used in the regression analysis against the estimates obtained from equation 13, corrected for transformation bias.

The standard error of regression for equation 13 is equal to 35.3 percent, and the standard error of prediction is equal to 38.1 percent. The standard error of regression is a measure of the precision with which the regression equation estimates the August median streamflow for the stations used in the analysis. The standard error of prediction indicates the precision with which estimates can be made for sites not used in the regression analysis. About 68 percent of streamflows estimated by use of the equation will have errors less than or equal to the standard errors noted.

Stations in the eastern region were given a *REGION* value of 0 in equation 13, and stations in the western region were given a value of 1. As a result, the last term in the equation becomes 1.0 for stations in the eastern region, and 1.3809 for stations in the western region. Equation 13 can be simplified by combining the intercept constant at the beginning of the right side of the equation with the constant for the appropriate region and the BCF constant, and restating equation 13 separately for the two regions. The equation for the eastern region becomes

$$Q_{A,E} = 0.1285 DAREA^{1.0687} GWHEAD^{0.2602} (DRT \S TST)^{0.7204} , \tag{14}$$

whereas the equation for the western region becomes

$$Q_{A,W} = 0.1754 DAREA^{1.0687} GWHEAD^{0.2602} (DRT \S TST)^{0.7204} . \tag{15}$$

Prediction intervals at the 90-percent confidence level can be calculated for estimates obtained from the regression equations above. Prediction intervals indicate the uncertainty inherent in use of the equations. Tasker and Driver (1988) have shown that a 100(1-α) prediction interval for the true value of a dependent variable obtained by use of regression equations corrected for bias can be computed by

$$\frac{1}{T}\left(\frac{Q_A}{BCF}\right) < Q_A < T\left(\frac{Q_A}{BCF}\right), \tag{16}$$

where Q_A is the predicted August median streamflow, *BCF* is the bias correction factor for the equation used to obtain Q_A, and *T* is computed as explained below.

A row vector, x_i, of logarithms of the basin characteristics for site *i* is augmented by a 1 as the first element to obtain $x_i = [1, \log_{10}(DAREA), \log_{10}(GWHEAD), \log_{10}(DRT/TST), REGION]$ for the site. The standard error of prediction for site *i* is then estimated as

$$S_i = [\gamma^2 + x_i U x_i']^{0.5} , \tag{17}$$

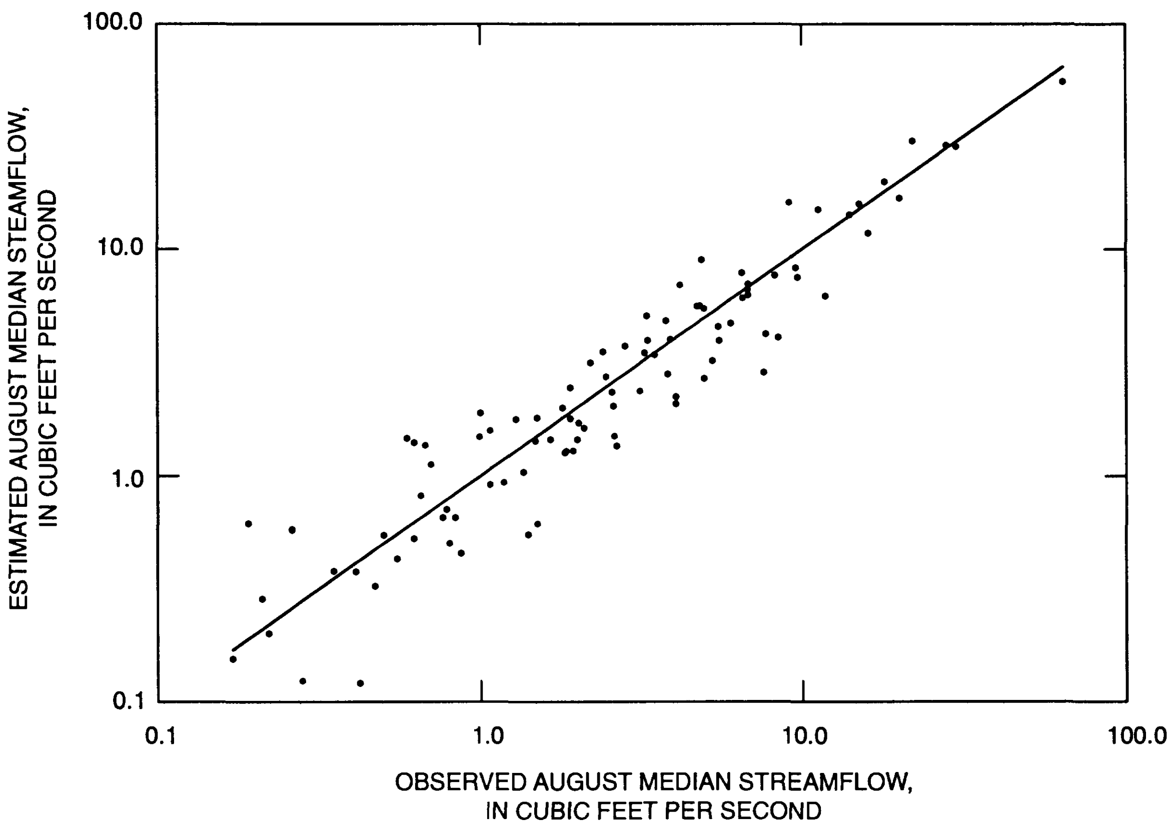

Figure 3. Observed August median streamflows for the stations used in the regression analysis plotted against values estimated by use of equation 13, corrected for transformation bias.

where γ^2 is the model error variance (0.02229), U is the covariance matrix for the regression coefficients

$$U = \begin{bmatrix} 0.015912 & 0.001154 & 0.007014 & 0.003452 & 0.004187 \\ 0.001154 & 0.001821 & -0.002388 & -0.002816 & 0.000371 \\ 0.007014 & -0.002388 & 0.006292 & 0.005200 & -0.002204 \\ 0.003452 & -0.002816 & 0.005200 & 0.018074 & 0.001617 \\ 0.004187 & 0.000371 & -0.002204 & 0.001617 & 0.002880 \end{bmatrix} \quad (18)$$

and x_i' is the transpose of x_i (Ludwig and Tasker, 1993). The value for T is then computed as

$$T = 10^{[1.662 S_i]} \,, \quad (19)$$

where 1,662 is the critical value from the t-distribution for a regression equation with 96 sites, 4 basin characteristics (including the indicator variable), and a 90-percent prediction interval (Iman and Conover, 1983).

The procedure necessary to obtain estimates and prediction intervals is explained by an example computation for an ungaged site on the Assabet River at Northborough (station 01096640, latitude 42°18′55″, longitude 71°38′05″). First, the necessary basin characteristics for the site are measured from the various GIS data layers. Values for drainage area (*DAREA*), area of stratified drift, total length of streams, mean basin altitude, and minimum basin altitude, are 19.7 mi^2, 6.99 mi^2, 40.6 mi, 404 ft, and 259 ft, respectively. *GWHEAD* is computed by subtracting the minimum basin altitude from the mean basin altitude, to obtain a value of 145 ft. *DRT/TST* is computed by dividing the stratified-drift area by the total stream length, and adding a constant of 0.1, to obtain a value of 0.2722 mi. Because the site is in the eastern region (fig. 2), the value for *REGION* in the equation is 0; therefore, equation 14 is used to compute the point estimate of the August median streamflow. Substituting the measured basin characteristics for the site into equation 14 yields

$$Q_A = 0.1285\,(19.7)^{1.0687}\,(145)^{0.2602}\,(0.2722)^{0.7204} = 4.44\ \text{ft}^3/\text{s}\,.$$

To determine a 90-percent prediction interval for this estimate, the x_i vector is

$$x_i = \{1, \log_{10}(19.7)\log_{10}(145), \log_{10}(0.2722), 0\}\ ,$$

the model error variance is $\gamma^2 = 0.02217$, and the covariance matrix, U, is obtained from equation 18. The standard error of prediction for the site, computed from equation 17, is

$$S_i = [0.02217 + 0.000953]^{0.5} = 0.15206\,,$$

and from equation 19,

$$T = 10^{[1.662\,(0.15206)]} = 1.78947\,.$$

Substituting the values above into equation 16, the 90-percent prediction interval for the site is

$$\frac{1}{1.78947}\left(\frac{4.44}{1.0958}\right) < Q_A < 1.78947\left(\frac{4.44}{1.0958}\right),$$

$$\text{or } 2.26 < Q_A < 7.25\,.$$

The 90-percent prediction interval is interpreted as follows: If 10 sites had the same basin characteristics as those for the Assabet River at Northborough, the true August median streamflow for nine of the sites (90 percent) would be between 2.26 and 7.25 ft^3/s; thus, assurance is 90 percent that the true value is in the given interval.

Equation 13, and thus equations 14 and 15, can be used to provide estimates of the August median streamflow under natural conditions for sites on streams in most of Massachusetts. Adjustments would need to be made for regulations and diversions to obtain estimates of the true flows for sites on streams where these activities are present. The measures of model adequacy provided above for equations 13 to 15, and the prediction intervals calculated by use of equations 16 to 19, indicate potential errors that can be expected when basin characteristics are within the ranges of those for the stations used in the regression analysis. Drainage areas (*DAREA*) for stations used in the regression analysis ranged from 1.57 to 150 mi^2. Values of *GWHEAD* ranged from 5 to 1,036 ft, and values of *DRT/TST* ranged from 0.1 to 0.821 mi. Estimates of August median streamflows obtained by use of the regression equations for sites on streams with basin characteristics outside the above-noted ranges could have substantial errors. The regression equations are not applicable in the Southeast Coastal region (fig. 2).

SUMMARY

August median streamflows were determined for 96 stations with all or most of their drainage areas in Massachusetts, including 37 streamflow-gaging stations and 59 low-flow partial-record stations (LFPRs). Periods of record for the streamflow-gaging stations ranged from 2 to 81 years, with a median record length of 27 years. Flows at the LFPRs were measured from 8 to 36 times, with a median of 16 measurements. Streamflows during August occur under virtually natural conditions at the 96 stations.

August median streamflows for gaging stations used in this study were calculated from the daily mean streamflows for all complete Augusts for the periods of record for the stations through climatic year 1994, whereas August median streamflows for gaging stations used in the study by the U.S. Fish and Wildlife Service (USFWS) to develop the Aquatic Base Flow (ABF) policy were determined by calculating the median of all August monthly mean streamflows for the periods of record. This difference in the method of calculating August median streamflows resulted in calculated medians for this study being lower than those calculated for the same stations by the USFWS.

Estimated August median streamflows for the LFPRs used in this study were determined by correlation of measured streamflows with same-day mean streamflows for selected gaging stations. Usually, measured streamflows for LFPRs were correlated to daily mean streamflows from more than one gaging station to obtain multiple estimates of the August median streamflow for the LFPRs. A method was devised whereby estimates obtained from the multiple correlations could be combined to obtain the final minimum-variance estimate for the station. Standard errors of the estimated August median streamflows for the LFPRs ranged from 3.82 to 18.33 percent, with a median standard error of 8.71 percent. Equivalent years of record for the estimates ranged from 0.3 years to 4.6 years, with a median of 1.3 years.

Water users affected by the ABF policy can be required to cease use of water when natural streamflows are less than the August median streamflow standard. Flow-duration percentiles corresponding to the August median streamflow were determined for each gaging station and LFPRs used in the analysis to determine the long-term operational effect of the ABF policy on projects subject to the policy. On average, the August median flow for Massachusetts streams corresponds to the 84-percent duration streamflow, with values ranging between the 80 and 89 flow-duration percentiles. Because of this, on average, water users subject to the policy could be required to cease use of water on 16 percent of all days, or 58 days in an average year.

August median streamflows per square mile determined for the 96 stations used in this study were lower than those determined for the stations used by the USFWS to develop the ABF policy, primarily due to differences in the methods used to determine the August median streamflows. The ABF policy recommends use of 0.5 $(ft^3/s)/mi^2$ as the minimum flow for maintenance of habitat for biota when the actual August median streamflow per square mile for a site cannot be determined from available data. August median streamflows determined for stations used in this study ranged from 0.040 to 0.759 $(ft^3/s)/mi^2$. The median August median streamflow for the stations, 0.246 $(ft^3/s)/mi^2$, was less than one-half the amount recommended in the ABF policy.

Although local physical features of the basins for the stations appeared to be more important than regional features in controlling variation in August median streamflows, a map of August median streamflows per square mile showed that the values were higher in western Massachusetts than in eastern Massachusetts. Statistical tests were used to divide the State into western and eastern regions for further analysis. The median of the August median streamflow for stations in the western region was 0.271 $(ft^3/s)/mi^2$, and the median in the eastern region was 0.197 $(ft^3/s)/mi^2$. August median streamflows in the eastern and western regions each had about a 15-fold spread, indicating that use of a single regional value to estimate streamflows per square mile for individual ungaged sites likely will result in substantial errors. Data were insufficient for analysis in the southeast coastal region of Massachusetts, which comprises almost all of the southern half of the South Coastal Basin, the eastern one-third of the Buzzards Bay Basin, Cape Cod, and the islands of Martha's Vineyard and Nantucket.

An equation was developed for use in estimating natural August median streamflows for ungaged sites on streams in Massachusetts from data for the 96 stations where August median streamflows were determined. The equation was developed by use of weighted-least-squares regression analysis, with the actual or equivalent years of record used as the weighting factor for each station in the analysis. August median streamflow was the dependent variable in the regression analysis and selected basin characteristics measured from digital data bases by use of GIS were the independent variables.

The basin characteristics that provided the best equation for predicting August median streamflows were drainage area, area of stratified drift per unit of total stream length plus 0.1, the difference in elevation between mean and minimum basin elevations, and the streamflow region. The basin characteristics were each positively correlated with August median streamflows. The equation explains 95.2 percent of the variation in August median streamflows for the stations used in the analysis. The standard error of regression for the equation is 35.3 percent, and the standard error of prediction is 38.1 percent. The equation is applicable throughout Massachusetts, except in the southeast coastal region, and where basin characteristics for sites where estimates are desired are outside the ranges of those for the stations used in the analysis. Where these conditions are met, 90-percent prediction intervals can be calculated for individual estimates obtained from the equation. August median streamflows and prediction intervals estimated by use of the equations in this report could have substantial errors for sites on streams with basin characteristics outside the ranges noted above.

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Table 1. Descriptions of streamflow-gaging stations used in the regression analysis and for correlation with low-flow partial record stations

[Periods of record shown are based on climatic years, which begin on April 1 of the year noted; USGS, U.S. Geological Survey.]

USGS station number	Latitude ° ' "	Longitude ° ' "	Station name	Period of record	Remarks
Gaging stations used in the regression analysis and for correlation with low-flow partial-record stations					
01096000	42 38 03	71 39 30	Squannacook River near West Groton, Mass.	1950-present	Occasional regulation by mill upstream
01096910	42 27 04	71 13 43	Boulder Brook at East Bolton, Mass.	1972-82	--
01097300	42 30 39	71 24 25	Nashoba Brook near Acton, Mass.	1964-present	--
01100700	42 48 41	71 01 59	East Meadow Brook near Haverhill, Mass.	1963-73	--
01101000	42 45 10	70 56 46	Parker River at Byfield, Mass.	1946-present	Occasional regulation by mill and ponds
01105600	42 11 25	70 56 43	Old Swamp River near South Weymouth, Mass.	1966-present	--
01106000	41 33 30	71 07 47	Adamsville Brook at Adamsville, R.I.	1941-77	--
01107000	42 03 41	71 03 59	Dorchester Brook near Brockton, Mass.	1963-73	--
01109200	41 52 46	71 15 18	West Branch Palmer River near Rehoboth, Mass.	1962-73	--
01111200	42 06 17	71 36 28	West River at West Hill Dam near Uxbridge, Mass.	1962-89	Flood-control dam upstream
01111300	41 58 52	71 41 11	Nipmuc River near Harrisville, R.I.	1964-90	--
01162500	42 40 57	72 06 56	Priest Brook near Winchendon, Mass.	1919-present	No daily record during August 1936
01165500	42 36 10	72 21 36	Moss Brook at Wendell Depot, Mass.	1917-81	
01166105	42 35 39	72 21 41	Whetstone Brook at Wendell Depot, Mass.	1986-90	--
01169000	42 38 18	72 43 32	North River at Shattuckville, Mass.	1940-present	Occasional small diurnal fluctuation
01169900	42 32 31	72 41 39	South River near Conway, Mass.	1967-present	Small diurnal fluctuation since 1982
01170100	42 42 12	72 40 16	Green River near Colrain, Mass.	1969-present	--
01171500	42 19 05	72 39 21	Mill River at Northampton, Mass.	1940-present	--
01171800	42 18 09	72 41 16	Bassett Brook near Northampton, Mass.	1963-73	--
01173260	42 23 52	72 08 51	Moose Brook near Barre, Mass.	1963-73	--
01174000	42 28 42	72 20 05	Hop Brook near New Salem, Mass.	1948-81	--
01174050	42 28 49	72 13 27	East Branch Fever River near Petersham, Mass.	1984-85	--
01174565	42 27 18	72 22 56	West Branch Swift River at Shutesbury, Mass.	1984-85	--
01174900	42 20 08	72 22 12	Cadwell Creek near Belchertown, Mass.	1962-present	--
01175670	42 15 54	72 00 19	Sevenmile River near Spencer, Mass.	1961-present	Occasional regulation by ponds upstream
01176000	42 10 56	72 15 51	Quaboag River at West Brimfield, Mass.	1913-present	Flood-retarding reservoirs upstream
01180000	42 17 27	72 52 15	Sykes Brook at Knightville, Mass.	1946-72	--
01180500	42 15 31	72 52 23	Middle Branch Westfield River at Goss Heights, Mass.	1910-89	Data for August 1965-6 not used due to construction of flood-control reservoir upstream.
01180800	42 15 49	73 02 48	Walker Brook near Becket Center, Mass.	1963-76	--
01181000	42 14 14	72 53 46	West Branch Westfield River at Huntington, Mass.	1936-present	--
01187400	42 02 03	72 55 49	Valley Brook near West Hartland, Conn.	1941-71	--
01197015	42 31 12	73 13 48	Town Brook at Bridge Street, Lanesborough, Mass.	1980-82	--

Table 1. Descriptions of streamflow-gaging stations used in the regression analysis and for correlation with low-flow partial record stations—*Continued*

USGS station number	Latitude ° ' "	Longitude ° ' "	Station name	Period of record	Remarks
Gaging stations used in the regression analysis and for correlation with low-flow partial-record stations—*Continued*					
01197300	42 20 59	73 17 56	Marsh Brook at Lenox, Mass.	1963-73	--
01198000	42 11 31	73 23 28	Green River near Great Barrington, Mass.	1952-70	--
01331400	42 35 20	73 06 48	Dry Brook near Adams, Mass.	1963-73	--
01332000	42 42 08	73 05 37	North Branch Hoosic River at North Adams, Mass.	1932-89	Infrequent small diurnal fluctuation
01333000	42 42 32	73 11 50	Green River at Williamstown, Mass.	1950-present	Infrequent small diurnal fluctuation
Gaging stations used for correlation with low-flow partial-record stations, but not used in the regression analysis.					
01073000	43 08 55	70 57 56	Oyster River near Durham, N.H.	1935-present	--
01105730	42 06 02	70 49 23	Indian Head River at Hanover, Mass.	1967-present	Some regulation by mills and ponds
01105870	41 59 27	70 44 03	Jones River at Kingston, Mass.	1967-present	Regulation by pond and cranberry bogs. Ground- and surface- water drainage boundaries are not coincident.
011058837	41 35 32	70 30 30	Quashnet River at Waquoit Village, Mass.	1989-present	Some regulation by cranberry bog. Ground- and surface-water drainage boundaries are not coincident.
01109000	41 56 51	71 10 38	Wading River near Norton, Mass.	1926-present	Regulation by lakes and ponds. Diversions to and from basin for municipal supplies.
01109403	41 49 51	71 21 06	Ten Mile River at East Providence, R.I.	1987-present	Regulations and diversions from reservior.
01118000	41 29 53	71 43 01	Wood River at Hope Valley, R.I.	1942-present	Seasonal regulation by pond since 1968. Regulation at low flow until 1952.
01121000	41 50 37	72 10 10	Mount Hope River near Warrenville, Conn.	1941-present	Occasional regulation by ponds.
01184490	41 54 50	72 33 00	Broad Brook at Broad Brook, Conn.	1962-present	Regulation by reservoir and mill.
01187300	42 02 14	72 56 22	Hubbard River near West Hartland, Conn.	1939-55, 1957-present	--
01188000	41 47 10	72 57 55	Burlington Brook near Burlington, Conn.	1932-present	--
01197000	42 28 10	73 11 49	East Branch Housatonic River at Coltsville, Mass.	1936-present	Flow regulated by powerplants and reservoir. Diversion for municipal supply.
01198500	42 01 26	73 20 32	Blackberry Brook at Canaan, Conn.	1950-71	--
01199050	41 56 32	73 23 29	Salmon Creek at Lime Rock, Conn.	1962-present	--

Table 2. Descriptions of low-flow partial-record stations where August median streamflows were estimated

Station number	Latitude ° ' "	Longitude ° ' "	Station name	Number of measurements	Gaging stations used for correlation	Standard error of estimate, percent
01073860	42 51 00	70 51 59	Smallpox Brook at Salisbury, Mass.	10	01101000, 01097300, 01096000, 01073000	6.49
01094760	42 23 49	71 46 48	Waushacum Brook near West Boylston, Mass.	10	01097300, 01096000, 01111300, 01175670	14.60
01095220	42 24 39	71 47 30	Stillwater River near Sterling, Mass.	23	01096000, 01097300, 01175670, 01162500, 01111200	8.46
01095380	42 23 00	71 50 12	Trout Brook near Holden, Mass.	19	01175670, 01097300, 01096000, 01162500, 01111200	12.54
01095915	42 34 26	71 37 43	Mulpus Brook near Shirley, Mass.	11	01097300, 01096000, 01162500, 01175670	11.82
01096504	42 40 03	71 33 55	Reedy Meadow Brook at East Pepperell, Mass.	17	01096000, 01097300, 01162500, 01101000	5.75
01096505	42 41 23	71 32 54	Unkety Brook near Pepperell, Mass.	22	01096000, 01097300, 01162500, 01101000	7.54
01096935	42 25 47	71 30 56	Elizabeth Brook at Wheeler Street at Stow, Mass.	12	01097300, 01096000, 01175670, 01111200, 01111300	9.07
01097280	42 28 07	71 24 31	Fort Pond Brook at West Concord, Mass.	16	01097300, 01105600, 01109000, 01111300, 01111200	7.92
01101100	42 43 31	70 54 54	Mill River near Rowley, Mass.	9	01101000, 01097300, 01073000	8.95
01102490	42 28 16	71 10 34	Shaker Glen Brook near Woburn, Mass.	13	01097300, 01105600, 01101000	10.85
01103015	42 25 20	71 08 59	Mill Brook at Arlington, Mass.	20	01097300, 01105600, 01101000	9.99
01103253	42 08 27	71 25 26	Chicken Brook near West Medway, Mass.	22	01111200, 01109000, 01111300, 01073000	10.15
01103330	42 09 03	71 18 18	Stop River near Medfield, Mass.	19	01111200, 01105600, 01109000, 01111300, 01097300	7.17
01103440	42 17 45	71 17 18	Fuller Brook at Wellesley, Mass.	18	01097300, 01111300, 01111200, 01109000	11.59
01104960	42 11 04	71 13 29	Germany Brook near Norwood, Mass.	18	01111200, 01111300, 01109000, 01105730, 01101000	8.71
01105100	42 09 36	71 11 47	Traphole Brook near Norwood, Mass.	26	01101000, 01111300, 01105730, 01105870, 01109000	3.82
01105575	42 11 02	71 00 42	Cranberry Brook at Braintree Highlands, Mass.	16	01105600, 01097300, 01105730, 01109000	18.33
01105670	42 11 35	70 43 44	Satuit River at Scituate, Mass.	9	01105600, 01105730, 01105870	11.40
01105830	42 11 30	70 46 49	First Herring Brook near Scituate Center, Mass.	16	01105600, 01111200, 01111300, 01109000, 01105730	15.85
01105930	41 40 43	70 58 39	Paskamanset River at Turner Pond near New Bedford, Mass.	23	01109000, 01105600, 01105730, 01111200, 01106000	11.54
01105935	41 34 20	71 00 47	Destruction Brook near South Dartmouth, Mass.	24	01109000, 01105600, 01105870, 01105730, 01111200	7.21
01105937	41 40 55	71 01 05	Shingle Island River near North Dartmouth, Mass.	25	01109000, 01105600, 01105730, 01111200, 01106000	14.81
01107400	41 51 55	70 54 32	Fall Brook near Middleboro, Mass.	36	01105600, 01111300, 01105730, 01109000	7.01
01108140	41 54 20	70 59 19	Poquoy Brook near North Middleboro, Mass.	16	01109000, 01105600, 01111300, 01105730	6.00
01108180	41 52 57	71 02 54	Cotley River at East Taunton, Mass.	14	01109000, 01105600, 01111300, 01105730	9.60
01109087	41 47 57	71 03 37	Assonet River at Assonet, Mass.	22	01109000, 01105730, 01097300, 01111200, 01111300	11.50
01109090	41 46 36	71 05 23	Rattlesnake Brook near Assonet, Mass.	11	01109000, 01111200, 01105730, 01118000, 01105870, 01106000	12.89
01109225	41 46 52	71 15 03	Rocky Run near Rehoboth, Mass.	36	01109000, 01118000, 01111200, 01111300, 01106000	14.00
01109381	41 55 37	71 17 08	Speedway Brook at Attleboro, Mass.	9	01109000, 01105730, 01097300	7.82
01123200	42 03 41	72 09 45	Stevens Brook at Holland, Mass.	22	01176000, 01175670, 01171500, 01187300, 01121000	10.42
01124390	42 09 16	71 54 47	Little River at Richardson Corners, Mass.	18	01175670, 01176000, 01111200, 01111300, 01121000	12.67
01162900	42 33 52	72 00 43	Otter River at Gardner, Mass.	18	01162500, 01165500, 01174000, 01174900, 01175670, 01096000	6.16
01167200	42 41 15	72 32 43	Fall River at Bernardston, Mass.	16	01169000, 01170100, 01169900, 01162500	10.79
01168300	42 38 12	72 56 10	Cold River near Zoar, Mass.	31	01169000, 01333000, 01169900, 01170100	7.84

Table 2. Descriptions of low-flow partial-record stations where August median streamflows were estimated—*Continued*

Station number	Latitude ° ' "	Longitude ° ' "	Station name	Number of measurements	Gaging stations used for correlation	Standard error of estimate, percent
01168400	42 37 28	72 54 27	Chickley River near Charlemont, Mass.	22	01170100, 01169900, 01169000, 01333000	5.78
01168650	42 36 47	72 46 10	Clesson Brook near Shelburne Falls, Mass.	24	01169000, 01169900, 01170100, 01333000, 01171500	4.92
01169801	42 43 15	72 44 37	South River at North Poland, Mass.	11	01169000, 01169900, 01170100, 01333000, 01171500	4.97
01170575	42 31 23	72 32 24	Sawmill Brook near Montague, Mass.	9	01162500, 01171500, 01169900, 01174900, 01174500	7.55
01172810	42 26 15	72 02 26	Canesto Brook near Barre, Mass.	10	01175670, 01162500, 01176000, 01174900	8.57
01173420	42 14 53	72 15 59	Muddy Brook at Ware, Mass.	9	01176000, 01175670, 01174900, 01174500	7.67
01173450	42 14 56	72 15 53	Flat Brook near Ware, Mass.	15	01162500, 01096000, 01171500, 01174900, 01175670	8.78
01175850	42 15 50	72 09 33	Mill River at West Brookfield, Mass.	12	01171500, 01176000, 01175670, 01174900	7.43
01176200	42 09 41	72 16 08	Kings Brook at West Brimfield, Mass.	14	01171500, 01176000, 01184490, 01121000	6.72
01176300	42 07 43	72 15 31	Foskett Mill Stream near Fentonville, Mass.	17	01171500, 01176000, 01184490, 01121000	4.05
01176780	42 08 52	72 24 00	Twelvemile Brook near North Wilbraham, Mass.	8	01176000, 01175670, 01171500, 01184490, 01121000	8.74
01177360	42 05 06	72 28 50	South Branch Mill River at Porter Road near East Longmeadow, Mass.	10	01176000, 01175670, 01174900, 01174500, 01184490	5.66
01178200	42 28 41	72 59 09	Westfield Brook at East Windsor, Mass.	17	01169900, 01181000, 01171500, 01180500, 01169000	9.28
01178300	42 26 50	72 51 29	Swift River at Swift River, Mass.	18	01169900, 01181000, 01171500, 01180500	10.86
01183210	42 07 05	72 48 01	Munn Brook near Westfield, Mass.	9	01187300, 01181000, 01171500, 01184490, 01188000	7.62
01184200	42 02 31	72 14 00	Still Brook near West Agawam, Mass.	18	01171500, 01181000, 01174900, 01175670, 01184490, 01121000	7.07
01184855	42 09 40	73 04 19	West Branch Farmington River near Otis, Mass.	10	01187300, 01171500, 01188000, 01181000, 01199050	10.10
01186300	42 02 37	73 08 13	Sandy Brook near Sandisfield, Mass.	14	01181000, 01187300, 01188000, 01180500, 01199050, 01197000	9.49
01197120	42 26 28	73 17 47	South West Branch Housatonic River at Pittsfield, Mass.	12	01197000, 01333000, 01181000, 01169900	11.03
01197180	42 17 59	73 12 53	Greenwater Brook at East Lee, Mass.	14	01197000, 01181000, 01187300, 01188000	5.70
01197230	42 16 13	73 15 06	Hop Brook near South Lee, Mass.	14	01181000, 01187300, 01188000, 01169900, 01199050	7.93
01198200	42 03 11	73 19 35	Konkapot River at Ashley Falls, Mass.	34	01181000, 01199050, 01198000, 01198500	5.43
01333100	42 41 16	73 13 50	Hemlock Brook near Williamstown, Mass.	14	01333000, 01332000	15.94
01359967	42 32 19	73 20 01	Kinderhook Creek at Hancock, Mass.	9	01197000, 01333000, 01199050, 01198000	7.39

Table 3. August median streamflows and basin characteristics for stations used in the regression analysis

[Flows are in cubic feet per second; areas are in square miles; lengths are in miles; slopes are in percent; elevations and GWHEAD are in feet; region 0 is eastern; region 1 is western; --- , no data]

Station number	August median flow	Drainage area	Total stream length	Mean basin slope	Strati-fied drift area	Mean basin elevation	Minimum basin elevation	Maximum basin elevation	Mean eleva-tion of drift	Minimum elevation of drift	Maximum elevation of drift	GWHEAD	Years of record	Region
01073860	0.35	1.83	3.75	0.82	1.79	50	26	115	50	26	115	24	0.4	0
01094760	.70	7.41	15.0	3.42	1.63	526	443	748	45	443	604	84	1.9	0
01095220	6.77	30.4	62.0	5.72	5.21	775	443	1998	569	443	1017	332	2.2	0
01095380	.99	6.79	13.2	3.99	1.95	767	548	1050	680	548	797	219	2.7	0
01095915	2.81	15.7	24.0	2.92	4.52	440	285	748	365	285	554	154	2.4	0
01096000	20.0	63.7	144	4.99	16.9	615	249	1447	401	249	1027	365	43	0
01096504	.83	1.92	2.14	1.93	1.52	253	192	397	241	192	299	61	1.0	0
01096505	2.02	6.84	12.6	2.28	4.62	243	180	450	225	180	348	63	1.3	0
01096910	.22	1.61	3.27	3.70	.18	433	299	548	338	299	397	135	11	0
01096935	3.49	16.9	43.1	3.85	5.51	357	197	597	274	197	499	160	1.3	0
01097280	3.78	24.9	61.4	2.21	7.70	254	128	450	220	128	397	126	1.3	0
01097300	2.46	12.6	32.5	2.25	7.45	238	158	463	216	158	338	80	29	0
01100700	.67	5.48	7.92	2.79	2.75	133	59	266	97	59	184	74	11	0
01101000	3.30	21.3	34.6	2.12	9.46	121	49	351	106	49	236	72	48	0
01101100	1.65	7.70	25.6	4.67	5.51	84	24	255	78	24	196	60	1.3	0
01102490	.87	3.05	6.89	2.95	.58	191	52	344	166	59	223	139	.7	0
01103015	1.83	5.35	10.6	3.21	2.26	195	30	348	169	30	249	165	1.0	0
01103253	1.18	7.23	17.6	2.56	1.08	267	174	397	225	174	348	93	2.9	0
01103330	7.61	12.8	25.4	1.76	7.43	198	142	338	194	143	292	56	1.3	0
01103440	.77	3.90	7.69	1.64	2.35	159	128	289	149	128	190	31	1.4	0
01104960	.41	2.37	3.65	1.30	.67	198	141	282	192	148	201	57	1.3	0
01105100	1.94	3.40	3.54	2.64	1.96	225	75	530	219	75	361	150	2.2	0
01105575	.28	1.72	2.88	1.11	.00	185	131	249	---	---	---	54	1.9	0
01105600	1.50	4.50	9.15	.50	1.19	147	98	197	139	98	148	48	26	0
01105670	.42	1.57	2.51	.79	.14	54	33	98	46	46	46	21	.7	0
01105830	.17	1.72	1.79	.57	.10	103	65	200	98	65	98	38	1.6	0
01105930	2.65	8.09	15.4	1.24	3.63	94	62	200	74	62	115	33	2.0	0
01105935	1.41	2.64	4.51	1.82	1.44	100	48	161	86	48	134	52	2.5	0
01105937	1.29	8.59	13.4	1.52	3.27	139	72	200	104	72	184	67	3.0	0
01106000	.65	7.99	17.6	1.51	.08	138	16	203	136	72	180	121	37	0
01107000	.19	4.71	10.6	1.06	.77	189	98	299	183	98	256	91	11	0
01107400	4.96	9.30	14.4	1.02	7.18	105	56	190	101	56	190	49	2.7	0
01108140	4.05	8.20	14.2	1.09	6.98	61	28	141	62	28	115	33	.9	0
01108180	2.10	7.48	11.9	.96	3.69	81	29	151	77	29	125	52	.8	0
01109087	4.81	20.7	28.3	1.35	8.88	113	23	200	88	23	197	90	1.4	0

Table 3. August median streamflows and basin characteristics for stations used in the regression analysis—*Continued*

Station number	August median flow	Drainage area	Total stream length	Mean basin slope	Strati-fied drift area	Mean basin elevation	Minimum basin elevation	Maximum basin elevation	Mean eleva-tion of drift	Minimum elevation of drift	Maximum elevation of drift	GWHEAD	Years of record	Region
01109090	1.07	4.22	5.38	1.80	1.29	152	52	299	133	52	295	99	0.7	0
01109200	.26	4.33	12.7	.29	2.78	120	102	266	120	102	134	18	11	0
01109225	.62	7.39	11.3	.99	2.78	98	49	200	81	49	98	49	.9	0
01109381	.62	2.86	3.73	.10	2.69	117	112	121	117	112	121	5	.5	0
01111200	6.80	27.8	44.0	4.43	8.42	405	240	630	313	240	453	166	28	0
01111300	2.40	16.0	30.0	3.14	4.50	532	361	758	447	361	548	171	27	0
01123200	.76	4.39	4.62	4.36	.18	969	699	1204	810	699	997	270	2.6	0
01124390	1.36	8.58	19.7	3.82	.00	844	586	1050	586	586	586	258	.6	0
01162500	3.80	19.4	33.6	3.56	1.26	1101	899	1798	951	899	1099	202	72	1
01162900	8.41	11.5	17.7	3.64	4.14	1063	902	1299	1010	902	1197	160	1.1	1
01165500	2.20	12.1	23.2	6.74	1.86	862	594	1519	706	594	902	268	65	1
01166105	2.60	5.22	14.2	7.39	1.24	934	499	1299	939	499	1079	435	5	1
01167200	4.18	26.0	37.9	10.6	1.60	854	394	1398	528	398	899	460	1.5	1
01168300	6.52	29.6	50.5	10.9	.20	1823	787	2799	998	791	1332	1036	4.6	1
01168400	8.21	27.1	49.4	12.1	.91	1551	597	2444	986	630	1676	954	1.9	1
01168650	6.80	18.1	29.3	11.1	2.17	1287	499	1899	872	499	1637	788	1.3	1
01169000	28.0	89.0	188	9.75	5.73	1414	499	2205	1024	499	1834	916	54	1
01169801	5.14	15.5	15.5	8.73	1.92	1278	797	1798	1142	797	1532	481	1.9	1
01169900	9.70	24.1	53.5	9.50	3.18	1123	499	1798	947	499	1512	624	27	1
01170100	16.0	41.4	84.2	9.52	1.48	1371	499	2398	1092	499	1972	872	25	1
01170575	7.71	13.2	27.2	8.79	2.25	850	299	1299	710	299	1099	551	.3	1
01171500	18.0	54.0	111	6.86	9.36	847	197	1598	560	197	1355	650	54	1
01171800	1.50	5.55	9.10	5.17	2.04	424	272	797	319	276	512	151	11	1
01172810	3.32	12.7	17.3	3.54	2.47	991	764	1283	919	764	1099	227	.3	1
01173260	.26	4.62	4.24	1.62	.00	1030	932	1178	932	932	932	101	11	1
01173420	6.54	19.0	33.4	5.44	4.54	706	456	1033	529	456	669	250	1.1	1
01173450	1.07	6.60	10.8	4.27	1.00	668	475	899	584	476	672	193	2.0	1
01174000	.50	3.39	7.96	6.65	.07	1033	794	1198	806	797	833	236	34	1
01174050	1.84	5.12	6.13	4.63	.72	872	699	1198	777	728	797	173	2	1
01174565	3.24	12.6	28.8	7.33	2.05	947	568	1299	810	568	1034	380	2	1
01174900	.55	2.55	5.15	6.18	.02	934	594	1099	901	892	909	340	32	1
01175670	1.80	8.68	17.2	5.36	1.10	870	636	1050	745	640	863	234	33	1
01175850	3.82	11.5	26.5	4.65	1.86	861	614	1099	716	614	810	247	2.3	1
01176000	64.0	150	325	4.40	31.6	810	397	1198	667	397	974	413	81	1
01176200	2.00	3.96	4.95	6.99	1.08	669	397	997	570	397	764	272	1.2	1
01176300	4.06	6.57	9.07	8.47	1.39	832	495	1145	636	495	997	337	.8	1

Table 3. August median streamflows and basin characteristics for stations used in the regression analysis—*Continued*

Station number	August median flow	Drainage area	Total stream length	Mean basin slope	Stratified drift area	Mean basin elevation	Minimum basin elevation	Maximum basin elevation	Mean elevation of drift	Minimum elevation of drift	Maximum elevation of drift	GWHEAD	Years of record	Region
01176780	6.00	13.6	18.0	5.52	2.82	580	295	997	507	295	879	285	0.6	1
01177360	5.25	6.92	8.64	3.20	4.57	332	243	850	270	243	348	89	.7	1
01178200	2.57	11.1	19.2	5.79	.22	1848	1397	2198	1490	1398	1568	451	2.0	1
01178300	4.95	22.9	38.8	4.86	.980	1479	992	1827	1304	994	1407	487	1.4	1
01180000	.21	1.74	2.55	9.80	.00	1088	699	1299	---	---	---	389	27	1
01180500	11.2	52.7	101	8.40	1.50	1378	495	2198	980	495	1621	882	76	1
01180800	.80	2.95	7.46	4.78	.12	1557	1299	1814	1322	1299	1388	258	14	1
01181000	22.0	94.0	166	8.74	3.90	1415	397	2162	1015	397	1614	1020	58	1
01183210	9.58	22.2	43.2	8.39	5.02	736	196	1398	436	196	1197	540	.8	1
01184200	1.48	5.27	12.3	2.77	2.68	278	197	597	245	197	295	81	1.2	1
01184855	11.8	22.2	38.0	5.26	2.42	1556	1162	2100	1330	1288	1398	394	.7	1
01186300	2.59	9.87	13.8	3.77	.59	1513	1299	1772	1444	1345	1506	214	1.2	1
01187400	1.00	7.37	12.2	11.0	.60	1075	591	1398	798	597	997	484	31	1
01197015	1.90	10.6	18.8	11.2	.62	1565	1119	2599	1242	1118	1650	446	3	1
01197120	5.53	20.4	24.0	8.29	.21	1375	1037	2100	1184	1155	1220	338	1.0	1
01197180	3.13	7.62	8.60	12.2	.88	1591	1096	2129	1359	1198	1499	495	.7	1
01197230	4.88	22.2	18.4	10.7	2.89	1383	887	1900	984	887	1411	496	1.0	1
01197300	.47	2.18	2.71	9.64	.11	1224	997	1798	1098	1096	1102	227	11	1
01198000	9.10	51.0	79.3	9.62	5.42	1174	699	1998	812	699	1296	475	19	1
01198200	30.0	61.0	62.3	6.99	9.90	1268	648	2005	890	648	1624	620	3.4	1
01331400	1.90	7.68	9.32	8.12	.31	1762	1198	2152	1264	1198	1378	565	11	1
01332000	14.0	40.9	58.5	13.4	3.10	1846	899	3045	1199	1027	2074	946	58	1
01333000	15.0	42.6	69.8	18.5	4.94	1556	660	3399	976	660	1476	896	43	1
01333100	.59	5.25	9.41	20.0	.54	1661	899	2746	1053	899	1273	762	3.7	1
01359967	5.48	14.2	19.7	17.6	1.54	1619	978	2545	1175	978	1499	641	1.3	1