**Estimating the Magnitude of Peak Flows for Steep Gradient Streams in New England**

**Dr. Jennifer Jacobs, PI**

**Prepared for**
**The New England Transportation Consortium**
**November 17, 2010**
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16. Abstract

Estimates of these flood events are used by the Federal, State, regional, and local officials to safely and economically design hydraulic structures as well as for effective floodplain management. The regression relationships developed to predict flows at ungauged sites do not always hold true for steep slope watersheds in New England. This study developed the regression relationships to predict peak flows for ungaged, unregulated steep streams in New England with recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. For watersheds having a main channel slope that exceeds 50 ft per mile, peak flows are well estimated by the watershed drainage area and the mean annual precipitation. For these steep watersheds, the series of regression equations was found to perform as well or better than the individual state regression equations.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimetres | mm |
| ft | feet | 0.305 | metres | m |
| yd | yards | 0.914 | metres | m |
| mi | miles | 1.61 | kilometres | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | millimetres squared | $mm^2$ |
| $ft^2$ | square feet | 0.093 | metres squared | $m^2$ |
| $yd^2$ | square yards | 0.836 | metres squared | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | kilometres squared | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | mililitres | mL |
| gal | gallons | 3.785 | Litres | L |
| $ft^3$ | cubic feet | 0.028 | metres cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | metres cubed | $m^3$ |

NOTE: Volumes greater than 1000 L shall be shown in $m^3$

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5(F-32)/9 | Celcius temperature | °C |

* SI is the symbol for the International System of Measurement

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimetres | 0.039 | inches | in |
| m | metres | 3.28 | feet | ft |
| m | metres | 1.09 | yards | yd |
| km | kilometres | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | millimetres squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | metres squared | 10.764 | square feet | $ft^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | kilometres squared | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | millilitres | 0.034 | fluid ounces | fl oz |
| L | litres | 0.264 | gallons | gal |
| $m^3$ | metres cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | metres cubed | 1.308 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams | 1.102 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | |
| °C | Celcius temperature | 1.8C+32 | Fahrenheit temperature | °F |

°F 32 98.6 212 °F
-40 0 40 80 120 180 200
-40 -20 0 20 40 60 80 100
°C 37 °C

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## ABSTRACT

Estimates of these flood events are used by the Federal, State, regional, and local officials to safely and economically design hydraulic structures as well as for effective floodplain management. The regression relationships developed to predict flows at ungauged sites do not always hold true for steep slope watersheds in New England. This study developed the regression relationships to predict peak flows for ungaged, unregulated steep streams in New England with recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. For watersheds having a main channel slope that exceeds 50 ft per mile, peak flows are well estimated by the watershed drainage area and the mean annual precipitation. No metric of watershed steepness provided a statistically significantly improvement to prediction capability. For these steep watersheds, the series of regression equations was found to perform as well or better than the individual state regression equations.

## 1. PURPOSE AND USE OF THIS REPORT

### 1.1 Introduction

Flood events can have a catastrophic effect on property, life and transportation routes. Estimates of these flood events are used by the Federal, State, regional, and local officials to safely and economically design hydraulic structures as well as for effective floodplain management. Where data are not available, regression relationships are often developed to predict flows at ungauged sites where no observed flood data are available for frequency analysis. Regression relationships have been published for all of the New England states by the United States Geological Survey (USGS) for predicting peak flows. According to Hodgkins (1999), these regression relationships do not always hold true for steep slope watersheds in New England. To address this need, the University of New Hampshire (UNH) and Tufts University in cooperation with the New England Transportation Consortium (NETC), conducted a study to estimate the peak-flow characteristics for steep streams in New England.

This report describes the results of a study to estimate the magnitudes of peak flows for ungaged, unregulated steep streams in New England. Regression relationships are presented which relate basin and climatic characteristics to peak flows for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. In addition, this report describes the methods used to develop the regression relationships. The methods presented here are for streams with natural flow conditions (unregulated) in locations where no streamflow is available and where slopes exceed 50 ft/mi. An evaluation of the equations and limitations for their use also is provided. Estimating peak flow for ungaged sites on regulated streams is not recommended using the results from this project.

## 1.2 Previous Studies

Previous studies have used regression analyses to provide estimates of high-flow-frequency statistics in New England. The USGS has developed regression equations for each state in New England. Regression equations are used to estimate a response variable (peak flow for a given recurrence interval) for an ungaged drainage basin by measuring explanatory variables (basin characteristics). Table 1 lists the basin characteristics used in current regression equations for each New England state as published in previous studies. Connecticut's USGS regression equations for computing peak flows from ungaged basins were developed using Log-Pearson Type III multiple regression analysis from records of 105 stream gauging stations with 10 to 45 years of continuous records (Ahearn, 2004). Connecticut's regression equation is a three parameter equation. As of 2010, the Connecticut Department of Transportation's Drainage Manual had not been revised to reflect the 2004 equations, although a directive has been issued for their use (personal communication, M. Hogan November 2010). The Maine Department of Transportation practices uses the 1999 USGS regression equations (Hodgkins, 1999) for watersheds with an area greater than 1 $mi^2$ and the rational method for watersheds with an area less than 0.5 $mi^2$. For watersheds between 0.5 $mi^2$ and 1.0 $mi^2$, regression equations or the rational method could be used. Based upon the USGS study conducted in Maine watersheds (Hodgkins, 1999), this study examines 14 other explanatory variables including drainage area, main-channel length, main-channel slope, mean basin elevation, percent forest cover, mean basin snowfall, percent area lakes and ponds, mean annual precipitation, and 24-hour, 2-year rain.

Table 1 Explanatory basin characteristics used to determine peak streamflow values by state and study.

| State | Explanatory Variables |
|---|---|
| Connecticut (Ahearn, 2004) | Drainage Area, Mean Basin Elevation, 24-hour Precipitation by Return Period |
| Maine (Hodgkins, 1999) | Drainage Area, Basin Wetlands |
| Massachusetts (Wandle, 1983) | Drainage Area, Basin Storage, Main-Channel Slope, Mean Basin Elevation |
| New Hampshire (Olson, 2009) | Drainage Area, Main-Channel Slope, 2-year, 24-hour Precipitation |
| Rhode Island (Wandle, 1983) | Drainage Area, Mean Basin Elevation, Forest Cover |
| Vermont (Olson, 2002) | Drainage Area, Basin Storage, 2-year, 24-hour Precipitation, Seasonal Snow, Mean Annual Precipitation, Altitude |

## 2. ESTIMATING THE MAGNITUDE OF PEAK FLOWS

### 2.1 Streamflow Data Used in This Study

To complete the main objective of this research, to develop a set of regional regression relationships to predict flood flows for steep slope watersheds, a set of watersheds and their basin characteristics was developed. All watersheds within New England having USGS historical peak flow data were considered for this analysis. From those sites, a subgroup of steep watersheds was identified based on the main channel slope. This group was further refined based on standard USGS selection criteria for gauging stations' streamflow data.

Upstream from each stream junction point (gauging station), the main channel is the stream that drains the most area and is usually considered the highest order stream. The slope is determined from the elevation at the points of 85 and 10 percent of the total length of the main channel above the point of interest. The main channel slope is computed as the difference in elevation, in feet, divided by the length, in miles, between the two points (Wandle, 1983). The main channel slope for each basin was determined using a Geographic Information System (GIS). While there is no clear definition of steep with respect to watersheds, Figure 1 shows the distribution of streams having slopes that exceed 50 ft/mi. Two threshold slopes were examined. A threshold of main channel slopes greater than 50 ft/mi included nearly 200 watersheds. A main channel slope steeper than 100 ft/mi included only 100 watersheds. The analysis was performed using the 50 ft/mi and the 100 ft/mi threshold.

The identified steep sloped watersheds were required to meet the Bulletin 17B guidelines (Interagency Advisory Committee, 1982). Bulletin 17B guidelines require that each stream gauging station have a sufficient record of at least 10 years of data. These stations cannot have flood flows that are altered by reservoir regulation or unusual events like dam failures. A station is considered significantly regulated if its drainage basin has storage that exceeds 4.5 million $ft^3$ per $mi^2$ (Benson, 1962). The peak-flow dataset used for statistical analysis at a gauging station must be a reliable and representative sample of random, homogeneous events.

Prior to calculating a flood flow, each site was reviewed to determine if the annual maximum stream flow observations follow the log Pearson type III distribution. While there are many measures and forms of outlier analysis for typical data, outliers were identified using L-moment diagrams and a discordancy statistic. L-moment analysis follows the approach introduced by Hosking (1990). Hosking and Wallis (1997) recommend using L-moments statistics to calculate a "discordancy" value as follows

For i=1:n

$$u_i = \begin{bmatrix} L - CV_i \\ L - skew_i \\ L - kurtosis_i \end{bmatrix}$$

where the vector for each n sites is the L-CV, L-skew, and L-kurtosis values for site i.

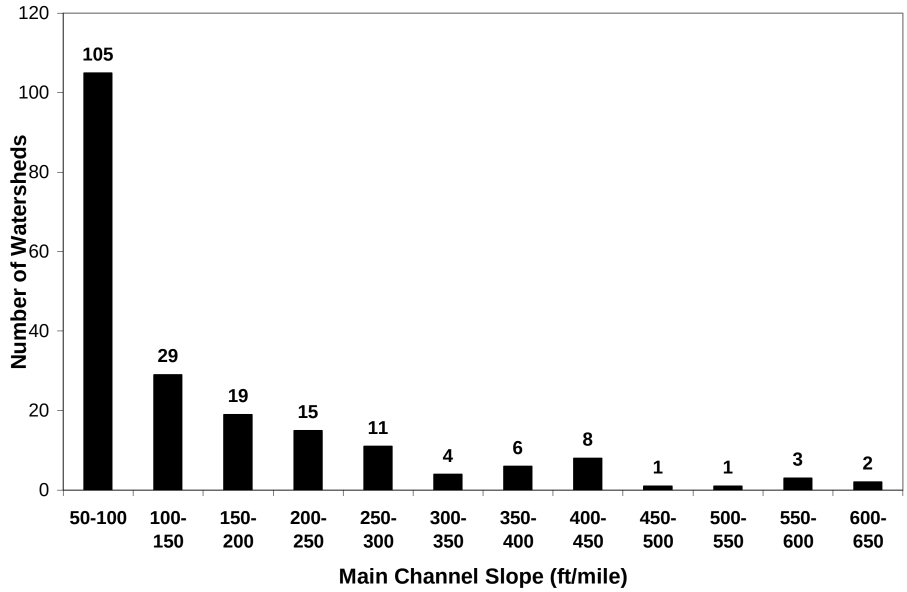



Figure 1. Distribution of main channel slopes for New England watersheds that exceed 50 ft/mi.

The averages of $L\text{-}CV_i$, $L\text{-}skew_i$, and $L\text{-}kurtosis_i$ are denoted as ubar where

$$ubar = \frac{1}{n}\sum_{i=1}^{n} u_i$$

and is a vector of the same dimensions as $u_i$ where the row entries are in that order. The A matrix is determined as

$$A = \sum_{i=1}^{n}\left[(u_i - ubar) * (u_i - ubar)^T\right]$$

where T indicates the transpose vector (1 x 3) which multiplies the original vector (3 x 1) for each site i. The resulting matrix A is a 3 x 3 matrix. Discordancy values are calculated for each site as

$$D_i = \frac{1}{3} * n * (u_i - ubar)^T * A^{-1}(u_i - ubar)$$

Hosking and Wallis recommend that sites with $D_i > 3$ be removed (Hosking and Wallis 1997). Ten sites exceeded that threshold. These sites were also identified as outliers in an L-moment diagram. Notably three Rhode Island watersheds all had high discordancy values and were removed from the analysis.

To ensure that time series of peak flow streamflow values did not have trends; the Mann-Kendall trend test (Helsel and Hirsch, 1992) was performed. Trends were not tested on stream-gaging stations with less than 15 years of record because a trend over a short period cannot be distinguished from serial correlation. The standard group significance level of 0.05 was applied using the Bonferroni correction for the 203 individual correlations with a significance level of 0.000246. Two stations were found to have trends and removed from this study; Middle B Westfield River at Goss Heights, MA (1180500) and Hubbard River nr. West Hartland, CT. (1187300).

Using the criteria described above, a database of 184 watersheds were selected for this study. The main channel slope for these 184 watersheds ranges from 50 – 625 ft/mile. The watersheds are distributed across each of the New England states except Rhode Island, as shown in Figure 2.

## 2.2 Flow-Frequency Characteristics at Stream-Gaging Stations

To determine the peak flows for the 2-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals, the Bulletin 17B approach was used. For each gauging station, the USGS historical annual peak streamflow data were downloaded. The peak flows for the different recurrence intervals were determined at each specified gauging station based on the Bulletin 17B guidelines. The Bulletin 17B guidelines account for zero flows, low outliers, historic peaks, regional information, confidence intervals, and expected quantile probabilities. A log Pearson type III distribution was fit to the peak discharges for each basin. The mean, standard deviation, and coefficient of skewness are calculated using the common base 10 logarithms of the peak discharges. Bulletin 17B uses a weighted skewness coefficient that is determined by combining the basin skewness value with a generalized skew coefficient. The generalized skew coefficient was developed for the steep watershed in this study according to the Bulletin 17B guidelines and adjusted for bias (Tasker and Stedinger, 1986). The PeakFQ software, developed by the USGS, was used for the computations. The peak flows for the 2-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals at USGS streamflow-gaging stations are listed in Appendix A.

## 2.3 Evaluation of Basin Characteristics

Regression equations are used to estimate a response variable (peak flow for a given recurrence interval) for an ungaged drainage basin by measuring explanatory variables (basin characteristics). Explanatory variables should make hydrologic sense, explain a significant amount of the variability of the response variable, and be reasonably easy to measure. From the regression equations developed and published in previous studies, the following basin characteristics were determined for each station:

- Drainage Area ($mi^2$),
- Basin Length (mi),
- Basin Perimeter (mi),
- Basin Slope (ft/mi),
- Relief (ft), Width (mi),
- Channel Length (mi),
- Main Channel Slope (ft/mi),
- Mean Annual Precipitation (in),
- Percent Basin Area of Lakes or Ponds,
- Soil Index,

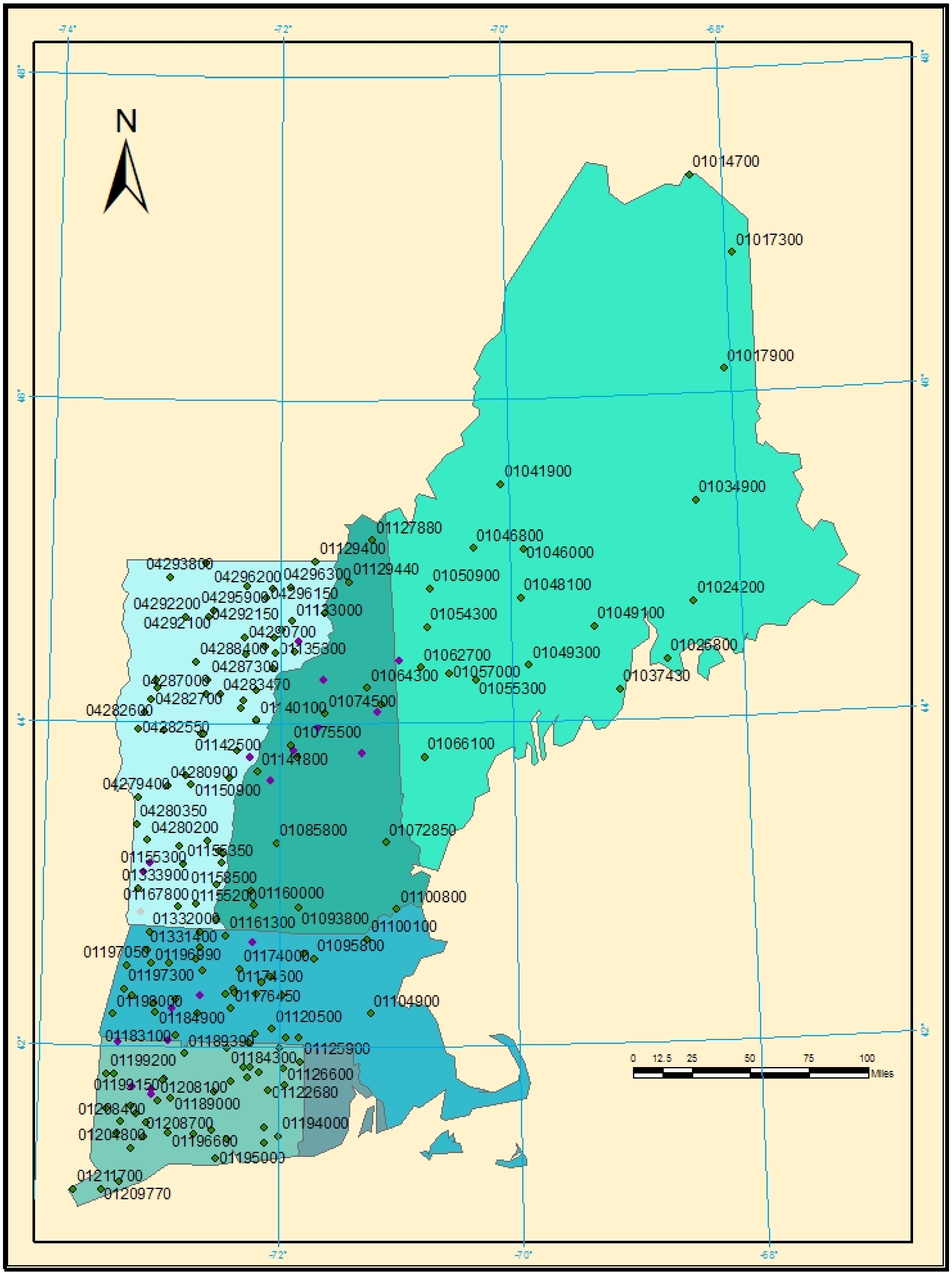



Figure 2. Locations and station numbers for those watersheds in New England used in the steep watershed regression analysis.

- Storage,
- Percent Forest,
- Mean Basin Snowfall, and
- 24-hr 2-year Rainfall Intensity.

Basin characteristics were derived based on two methods. The first method was by using recent basin characteristics developed by the USGS to develop state specific regression equations to determine flows for ungaged stations. This period of time, assures that the data are up to date and representative of the current basin characteristics. The second method of deriving the basin characteristics was to use Geographic Information System (GIS) coverages.

## 2.4 Regression Analysis

The next step in the development of regression equations was to identify basin characteristics that best describe the peak flows. The weighted least squares (WLS) technique was used (Helsel and Hirsch, 2002) to aid in the identification of the best variables. Peak flood discharge (response variable) was estimated from the basin characteristics (explanatory variables). Each gauging station in this study has a different peak flow record length (n). When developing the regression equations using WLS, the record length (n) was the weighting factor. In order to preserve linearity, a frequently used data transformation was made. Benson (1960) indicates that a logarithmic transformation is appropriate for hydrologic data. For this data, the base-10 logarithms (log) of the peak flood discharges and basin characteristics were used to develop the regression equations. The regression equations were formed in the statistical program JMP. A linear relationship is valid for the logarithms of physical characteristics and peak flow values. The regression relationship was performed on logarithmic transformations.

The preliminary step was to conduct a stepwise regression. This is a preliminary step because it tends to pick variables that confound several independent effects and build models that are hard to interpret in the real world. However, its major advantage is that it builds a model with a small number of predictor variables that produce a high $R^2$ value. Thus, the preliminary stepwise regression was used to choose the set of basin characteristics that describe the peak flow of interest. Once these variables were determined, then a weighted least square regression analysis was used to determine the model.

Several statistical tests were used to determine which parameters were left in the model and which ones were deleted. To test for multicollinearity of the explanatory variables, the variance inflation factor (VIF) was calculated to eliminate redundant variables. A VIF greater that 10, suggests that a parameter is highly correlated to another in the regression equation. Usually the parameter that is easiest to determine, is selected to remain in the regression equation analysis. Using the VIF, explanatory variables, basin perimeter, relief, width, and channel length, were found to be highly correlated with other variables and were removed from the analysis.

With the remaining explanatory variables, a stepwise WLS regression was performed to identify the best combination of transformed explanatory variable for the steep watersheds. The PRESS (prediction error sum of squares) statistic was used to identify the best combination of independent variables. Parameters were eliminated from the regression equation if they had a p-value greater than 0.05 (the standard threshold). In regression, the p-value indicates whether or not the addition of that variable is significant in predicting the response. It compares the model without that variable to a model including that variable and determines what the chance is that the observed difference would be seen by random chance. The lower the p-value, the greater influence the parameter has on predicting the peak flows. Those variables which were not significant were removed from the model. The remaining variables were Drainage Area, Basin Length, Mean Annual Precipitation, and Storage. Notably, the basin slope was not found to be a significant explanatory variable.

Once a preliminary regression equation was developed with a reduced number of parameters, Cook's D statistic and the DFFITS values (Helsel and Hirsh, 1993) were used to show the influence of individual stations on the regression equation. DFFITS is the scale difference between the predicted responses from the model constructed from all of the data and the predicted responses from the model constructed by settling the i-th observation aside. An individual station is said to show high influence when the following condition holds true, $\left|DFITS_i\right| \geq 2\sqrt{p/n}$ , where $p$ is the number of parameters used in the regression and $n$ is sample size of the dataset.

Using this method, there were several observations that had high influence for the 100 year return period regression which was used as the benchmark, but no spatial pattern was evident (Figure 3). There was some organization to the influential stations, with a cluster in northern NH and a few sites in the Berkshires. These sites exert a stronger influence on the position of the regression line than other observations. These sites exert a stronger influence on the position of the regression line than other observations. Some of these exert such a strong influence that they can cause errors in the regression equation because the line that is fit includes these outliers. This can also change the significance values of certain variables. The high influence sites were removed from the analysis (Helsel and Hirsch, 1993).

Having removed the high influence stations, a second stepwise regression was run to determine which parameters best described the peak flows because if the stations that were deleted were truly of high influence on the peak flows, then the parameters used to predict the peak flows in the new regression could be different. Thus, the stepwise WLS regression was repeated after removing the outlier sites. The variables Drainage Area and Mean Annual Precipitation were selected as the best possible combination of the explanatory variables.

Regression diagnostic tools were used to review the credibility of the WLS regression model. Residual plots, normality plots of the residuals, and the predicted versus observed flood values were reviewed. Regression residuals for the 100-yr model were plotted to identify regional patterns (Figure 4). No pattern was evident. The DFFITS, VIF and PRESS statistics were analyzed. All regression diagnostics indicated that the explanatory variables provide an excellent model.

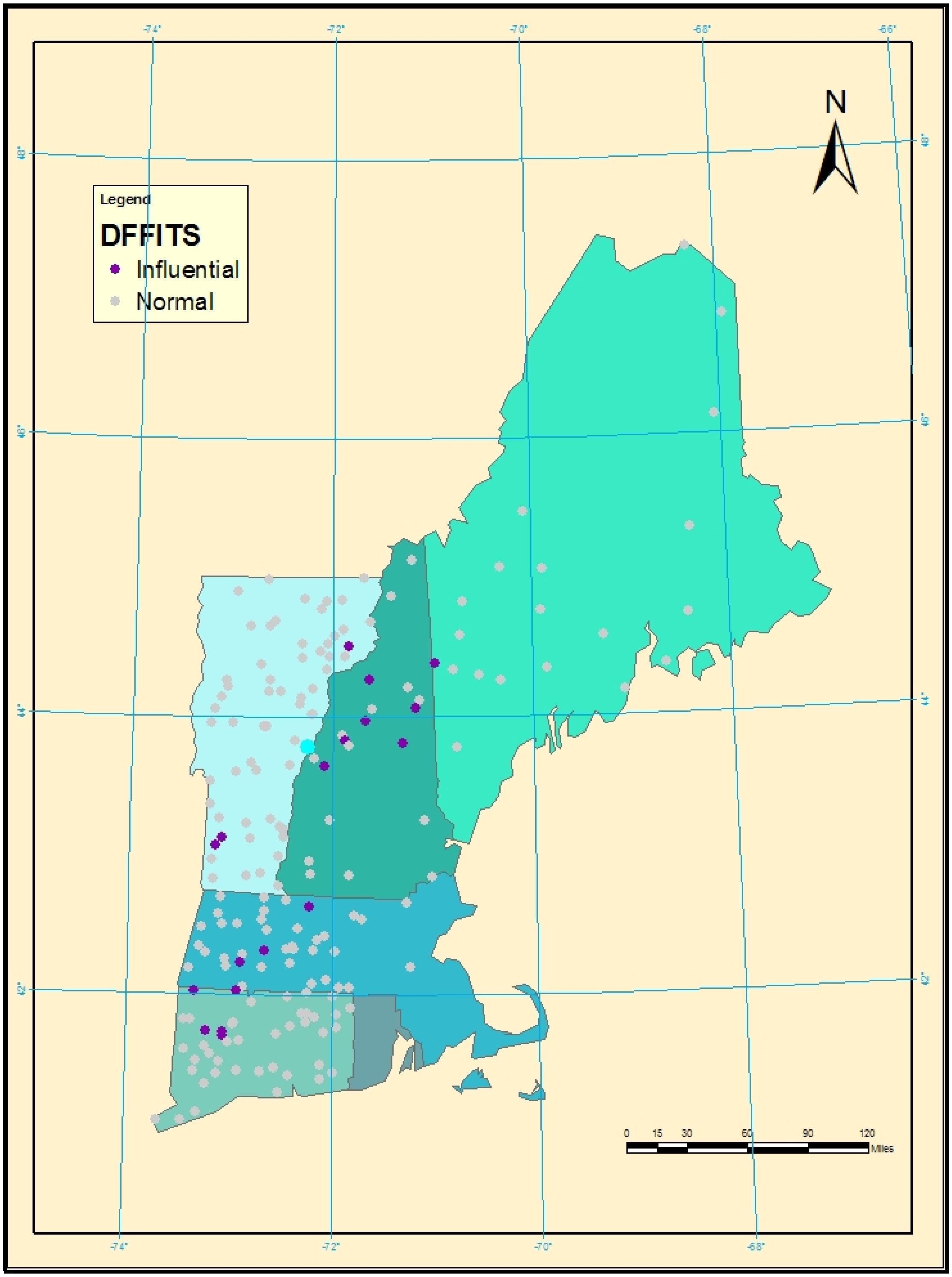



Figure 3. Influential stations based on DFFITS analysis for those watersheds in New England used in the steep watershed regression analysis.

The final regression model coefficients were determined using the weighted least square (WLS) regression technique. WLS is often used to maximize the efficiency of parameter estimation and allows one to use data sets with data points of varying quality. WLS is similar to Generalized Least-squares (GLS) regression in that both assume that the independent variables have different variances. GLS is used when independent variables have different variances and correlated errors. The Durbin-Watson statistic was used to evaluate the dependence of residuals. Because it did not show any positive or negative serial correlation, the WLS regression method was used to develop the final coefficients. When developing the regression equations using WLS, the record length in years (n) was the weighting factor. Therefore, those stations with a longer record length were given more influence on the predicted peak flow values. With the basin characteristic parameters that were generated in the stepwise regression process, a WLS regression was performed. The final peak-flow regression equations are presented in Table 2.

Table 2. Regression equations and their accuracy for estimating peak flows for steep, ungaged, unregulated drainage basins in New England. Steep is defined as a main channel slope that exceeds 50 ft per mile. [Q is peak flow, in cubic feet per second; A is drainage area, in square miles; P is mean annual precipitation in inches]

| Peak-flow regression equation by recurrence interval | Standard Error of the Estimate (percent) | | $(PRESS/n)^{1/2}$ (percent) | | Average Prediction Error (percent) | | Average Equivalent Yrs of Record |
|---|---|---|---|---|---|---|---|
| $Q_2=0.01601A^{0.889}P^{2.12}$ | 47.1% | -32.0% | 46.9% | -31.9% | 48.1% | -32.5% | 2.09 |
| $Q_5=0.01965A^{0.889}P^{2.19}$ | 45.1% | -31.1% | 44.8% | -30.9% | 46.1% | -31.6% | 3.03 |
| $Q_{10}=0.02430A^{0.891}P^{2.21}$ | 46.5% | -31.7% | 46.4% | -31.7% | 47.5% | -32.2% | 3.89 |
| $Q_{25}=0.03387A^{0.893}P^{2.20}$ | 50.4% | -33.5% | 50.7% | -33.7% | 51.5% | -34.0% | 4.73 |
| $Q_{50}=0.04372A^{0.895}P^{2.18}$ | 54.5% | -35.3% | 55.2% | -30.9% | 55.8% | -35.8% | 5.10 |
| $Q_{100}=0.05765A^{0.897}P^{2.15}$ | 59.4% | -37.3% | 60.5% | -37.7% | 60.8% | -37.8% | 5.29 |
| $Q_{500}=0.111A^{0.903}P^{2.08}$ | 73.4% | -42.3% | 75.3% | -43.0% | 75.1% | -42.9% | |

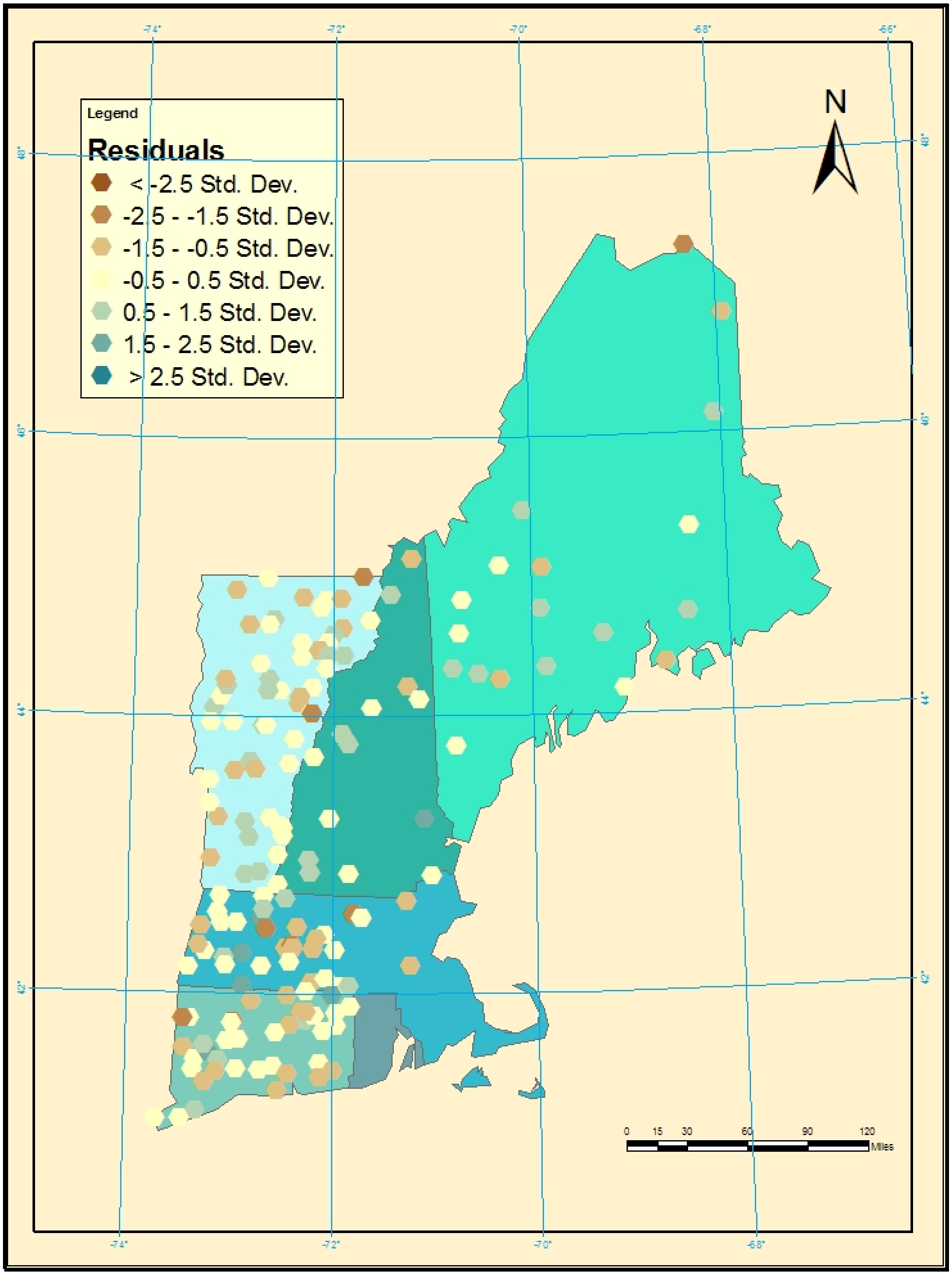



Figure 4. Residuals by stations for those watersheds in New England used in the steep watershed regression 100-yr model.

## 2.5 Application and Technique

Peak-flow regression equations for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years are presented in Table 2. The variables used in the equations are described in the table caption and below. Accuracy and limitations are discussed in the following section. All of the regression equations in this report are statistical models. They are not based directly on rainfall-runoff processes. For this reason, when applying these equations, the explanatory variables should be computed by the same methods that were used in the development of the equations. Using “more accurate” methods of computing the explanatory variables (for example, updating the annual precipitation or using local precipitation data) will result in peak-flow estimates of unknown accuracy.

The regression equations are applicable only to sites on steep, ungaged, unregulated streams in the New England watersheds. The explanatory variables are drainage area and annual average precipitation. Use of the equations should be limited to sites within the range of the explanatory variables as listed in Appendix A. Annual average precipitation ranged from 35.3 to 73.5 inches. Drainage area ranged from 0.21 to 130 square miles. Outside this range, the accuracy will likely be reduced, but its magnitude is unknown.

A - Drainage area - The contributing area, in square miles, of a drainage basin. The term “contributing” means that flow from an area could contribute flow to a study site on a stream. All units of drainage area, except square miles, will result in incorrect estimates of peak flows. The drainage area can be computed from a number of sources. A series of reports that lists drainage areas at selected points on many streams in New England have been published by the USGS. The drainage areas for most gaged watersheds are listed on the USGS National Water Information System website. Drainage areas can be computed from geographic information system (GIS) coverages or computed using the USGS StreamStats software (http://water.usgs.gov/osw/streamstats/, access November 2010).

P - Mean Annual Precipitation – The average annual precipitation, in inches, for the watershed. The mean annual precipitation should be obtained from the PRISM 1961 to 1990 maps because these maps were used in the development of the regression equations. These annual precipitation estimates were using the PRISM model (Daly et al. 1994, Daly et al. 1997). The PRISM estimates are part of a national effort by the USDA Natural Resources Conservation Service and Oregon State University to develop state-of-the-art precipitation maps for each state in the US, including Alaska and Hawaii. Data input to their model consisted of 1961-90 mean monthly precipitation from over 8000 NOAA Cooperative sites, SNOTEL sites, and selected state network stations. Data-sparse areas were supplemented by a total of about 500 shorter-term stations. A station was included in this data set if it had at least 20 years of valid data, regardless of its period of record. The annual maps were created by summing the 12 monthly maps. The annual maps underwent extensive peer-review by many state climatologists and other experts. Figure 5 shows the PRISM values for the New England states. The ArcInfo data product is available from http://www.prism.oregonstate.edu/products/ (accessed November 2010).

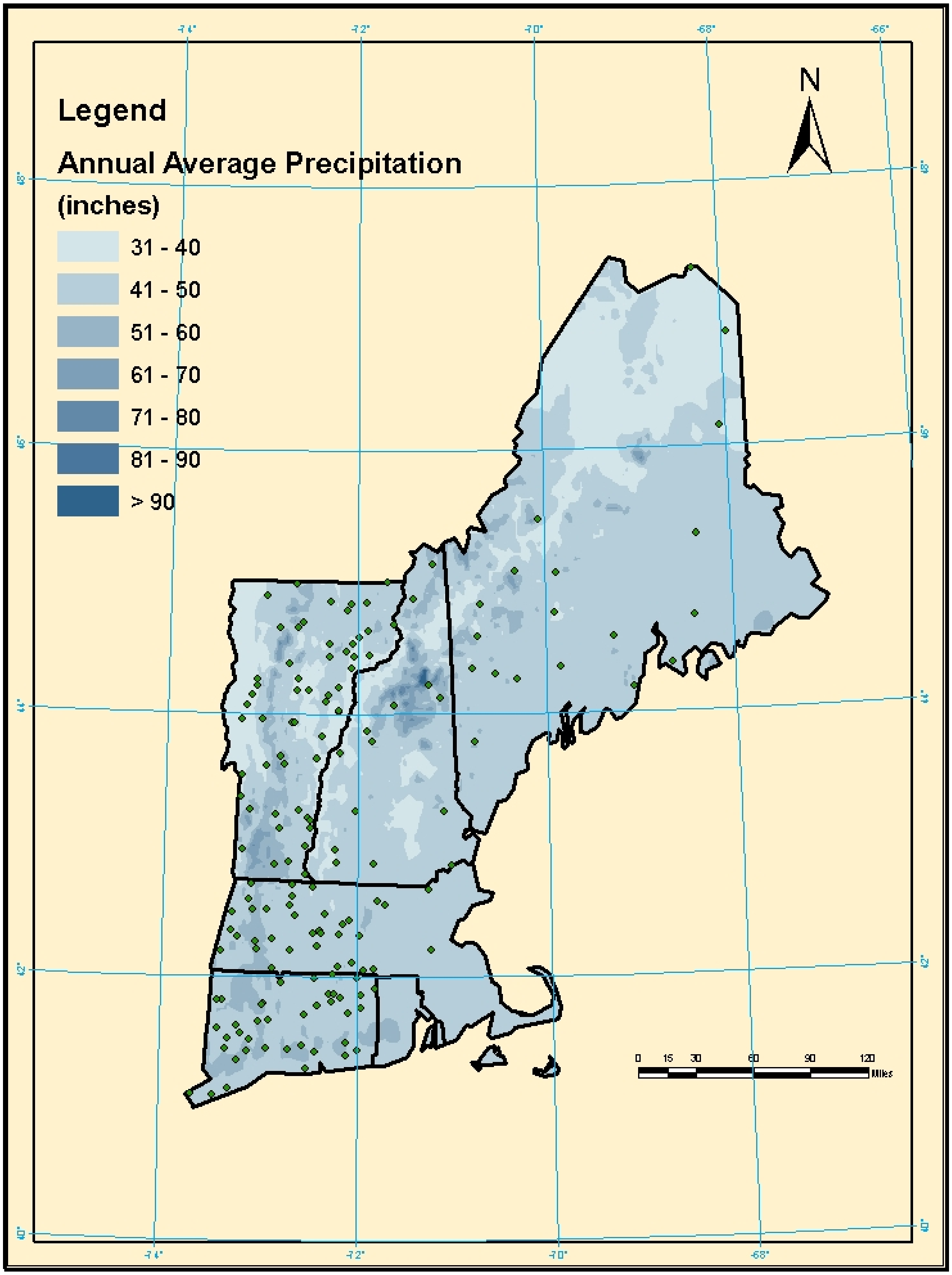



Figure 5. PRISM rainfall values and stations for those watersheds in New England used in the steep watershed regression.

### 2.6 Accuracy and Limitations

The first performance metric that was calculated was the Standard Error of the Estimate (Ser). Flynn (2003) summarizes SER as “The standard error of the estimate (*Ser*, in percent), is a measure of the average precision with which the regression equations estimate streamflow statistics for stream-gaging stations used to develop regression equations (Ries and Friesz, 2000). The standard error of estimate is a measure of the deviation of the observed data from the corresponding predictive data values and is similar to standard deviation for a normal distribution. Approximately 68 percent of the observed data will be contained within ± one standard error of the regression line.”

The second statistic was the Average Prediction Error (APE). Flynn (2003) summarizes APE as “The Average Prediction Error (APE), which is an overall measure of how accurately the regression model can predict streamflow statistics for ungaged sites where the average is taken from prediction sites with *X* variables identical to the observed data. Average Prediction Error represents an estimate of the average squared-model error for the *n* sites plus an estimate of the average squared error as a result of estimating the true model parameters from a sample of data.” Here “*X*” refers to the number of estimated parameters.

The Ser and APE calculations are often times used to calculate confidence intervals for the means of the different return periods. These are used as a standard deviation, which makes sense as they are an error of measure, and either or both can be used to generate the confidence intervals. Only one standard deviation is used to surround the mean, so it is a 67% confidence interval. These confidence intervals are reported as percentages of the means.

The PRESS statistic is an excellent overall measure of the regression equations. The PRESS statistic is a validation-type statistic. In summary, one station is removed from the data set and the remaining stations are used to recalculate the regression equation. This new equation is used to predict the value for the missing station and to determine the residual difference between that predicted and the observed value. The process is repeated for each station. The PRESS statistic is presented as confidence intervals based on percentages of the means.

The final statistic that was calculated is the Average Equivalent Years of Record (AEYR), following (Hardison, 1971). Hardison describes AEYR as “As the standard error of prediction of a streamflow characteristic depends largely on the variability of the annual event, it tends to be much larger in some sections of the country than in others. One way to remove this regional variability is to express the accuracy of prediction in terms of the equivalent years of record that would be required to give results of equal accuracy.” Essentially AEYR indicates how many years of peak flow data will be needed to get similar results to the regression.

A summary of the statistics is presented in Table 2. These statistics were also calculated for only those watersheds having basins slopes greater than 100 ft per mile for the 100-yr model (Table 2) and a two parameter regression model using only those watersheds having main channel slopes greater than 100 ft per mile. While model performance was nearly identical among the three approaches, the model presented in

Table 2 provides predictions for a greater range of channel slopes without compromising performance for the steep channels.

## 2.7 Steep Water Predictions Compared to USGS State Predictions

As noted in Section I of this report, each New England state has a set of regression equations to predict flood flows for watersheds in that state. In this section, the performance of the steep watershed regression equations is compared to that for the individual states. Of the steep watersheds used in this analysis, 131 watersheds were also used in the State regression studies. Flood flow predictions using the steep watershed regression equations (Table 2) and the appropriate State regression equation were compared to the USGS Bulletin 17B estimates of peak flows.

Figure 6 shows the Bulletin 17B flood flow estimates versus those predicted using the steep watershed regression estimates and the State regression equations by return period. The observed, Bulletin 17B flood flows, and the predicted values, using State USGS regression equations or Steep watershed regression equations, were compared using metrics described in Willmott (1982). Table 3 provides a quantitative analysis of the results. For the 2-, 5-, and 10-yr return periods, the steep watershed predictions are typically marginally better than the State estimates. The steep watershed formulations result in more significant improvements for the larger flood events. Thus for watersheds having main channel slopes that exceed 50 ft per mile, the single, steep watershed regression equations appear to be as good or better than the individual State regression equations. For the lower return periods, it appears that the floods are not large enough to be distinguished from typical New England conditions. This suggests that the watershed area dominates the peak flow predictions. Watershed area comes through consistently for all the state and steep watershed regressions. For the higher return periods, the new regression equations are consistently better than the existing state predictions.

The original motivation for this work was the finding by Hodgkins (1999) that the regression relationships developed for Maine did not always hold true for steep slope watersheds. In particular, Hodgkins (1999) identified three steep, NH watersheds as outliers: Ellis River near Jackson, N.H. (station number 01064300); Lucy Brook near North Conway, N.H. (01064400); and Cold Brook at South Tamworth, N.H. (01064800). For the current study, the latter two sites were removed from the analysis because their DFFITS values were extremely high. Ellis River near Jackson, N.H. (station number 01064300) was included in the analysis.

The current study's regression equations performed better than the USGS NH equations (Olson, 2009) for this site as compared to those flood flows estimated using Bulletin 17B. For the 2-yr return period, floods were 1444, 1211, and 1250 cfs for the USGS NH, this steep water study, and Bulletin 17B, respectively. For the 5-yr return period, floods were 2647, 2008, and 2030 cfs for the USGS NH, this steep water study, and Bulletin 17B, respectively. For the 10-yr return period, floods were 3666, 2719, and 2590 cfs for the USGS NH, this steep water study, and Bulletin 17B, respectively. For the 25-yr return period, floods were 4982, 3648, and 3330 cfs for the USGS NH, this steep water study, and Bulletin 17B, respectively. For the 50-yr return period, floods were 6053, 4342, and 3900 cfs for the USGS NH, this steep water study, and Bulletin 17B, respectively. For the 100-yr return period, floods were 7337, 5057, and 4480 cfs for the USGS NH, this steep water study, and Bulletin 17B, respectively. For the 500-yr return period, floods were 10223, 7311, and 5910 cfs for the USGS NH, this steep water study, and Bulletin 17B, respectively.

Regarding the two watersheds removed from both this study and the earlier study, Cold Brook at South Tamworth, N.H. and Lucy Brook near North Conway, N.H. (01064400), both these watersheds were relatively small and had measured 100-yr and 500-yr flood flows that were typically twice as large as the regression equation predictions for both this study and the NH USGS study. Cold Brook (01064800) only had 10 years of peak flows (WY 1964 to 1973) with only four of those flows in the April and early May time period when one would expect a typical snowmelt flood. Thus, the Cold Brook record may not be representative of the typical record for the other sites.

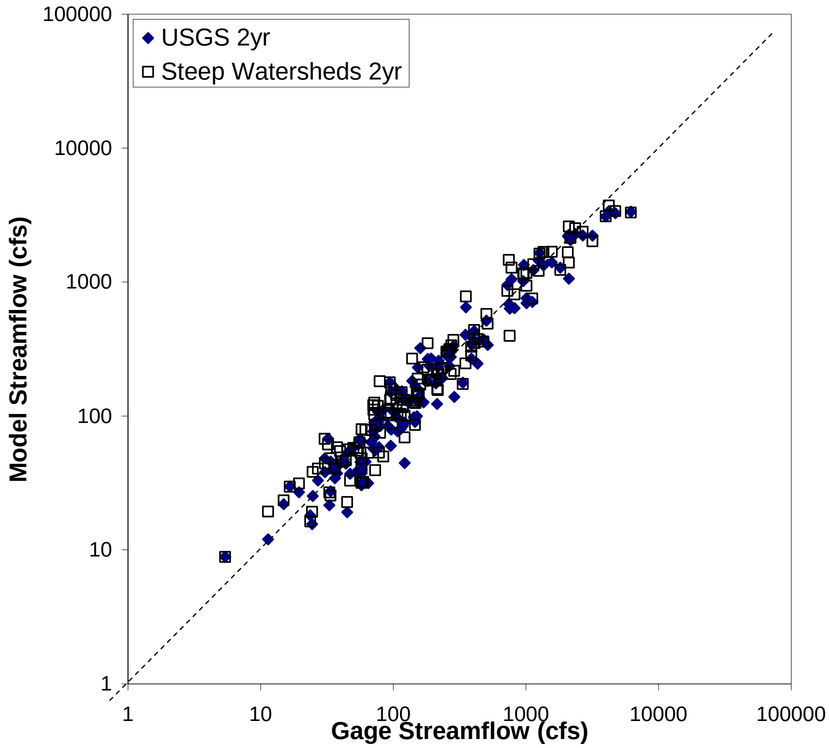
In contrast, Lucy Brook (01064400) had a longer period of record (WY 1965 to 1992) with a traditional flood regime. It is possible that there are gaging problems at this station. However, it appears more likely that the actual precipitation for Lucy Brook watershed differs from that estimated by PRISM. That watershed is relatively small and located in the Echo Lake, Cathedral Ledges area of the White Mountains just west of North Conway, NH. The PRISM precipitation does vary in this region in a manner that appears to account for topographic effects, but it clearly has Lucy Brook area receiving less precipitation than the Jackson, NH area directly north. If precipitation in Lucy Brook were similar to that for Ellis River (73.5 rather than 55 inches annually and 6.23 versus 4.45 inches in April) both the NH USGS and the steep watersheds regression approach would perform considerably better.

In summary, it appears precipitation variations matter in steep watersheds for extreme flood flows. For our region, those variations appear to be largely a function of topography (see Figure 5). Thus models which include precipitation or topography may perform better for regions in which there are variations in topography. Notably, all regression models except that for Maine include either precipitation or topography or both. However, the best means to determine the best estimate of precipitation is for these watersheds and its relationship to topography is still an open question. Because most regression relationships rely on the PRISM dataset for precipitation data, any errors caused by that dataset's ability to relate topography and precipitation will directly impact estimate of precipitation.

## 2.8 Conclusions and Recommendations

Estimates of these flood events are used by the Federal, State, regional, and local officials to safely and economically design hydraulic structures as well as for effective floodplain management. The regression relationships developed to predict flows at ungauged sites do not always hold true for steep slope watersheds in New England. This study developed the regression relationships to predict peak flows for ungaged, unregulated steep streams in New England with recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. For watersheds having a main channel slope that exceeds 50 ft per mile, peak flows are well estimated by the watershed drainage area and the mean annual precipitation. No metric of watershed steepness provided a statistically significantly improvement to prediction capability. For these steep watersheds, the series of regression equations was found to perform as well or better than the individual state regression equations.

For most of the study region, precipitation variations appear to be largely a function of topography. The present and all New England State regression models except that for Maine include either precipitation or topography or both. Thus models which include precipitation or topography may perform better for regions in which there are variations in topography. Because most regression relationships rely on the PRISM dataset for precipitation data, any errors caused by that dataset's ability to relate topography and precipitation will directly impact estimate of precipitation. Analyses that use regional precipitation data for future predictions may benefit from improved understanding of the PRISM dataset errors and enhanced characterization of regional precipitation data.


USGS 2yr
Steep Watersheds 2yr
Model Streamflow (cfs)
Gage Streamflow (cfs)
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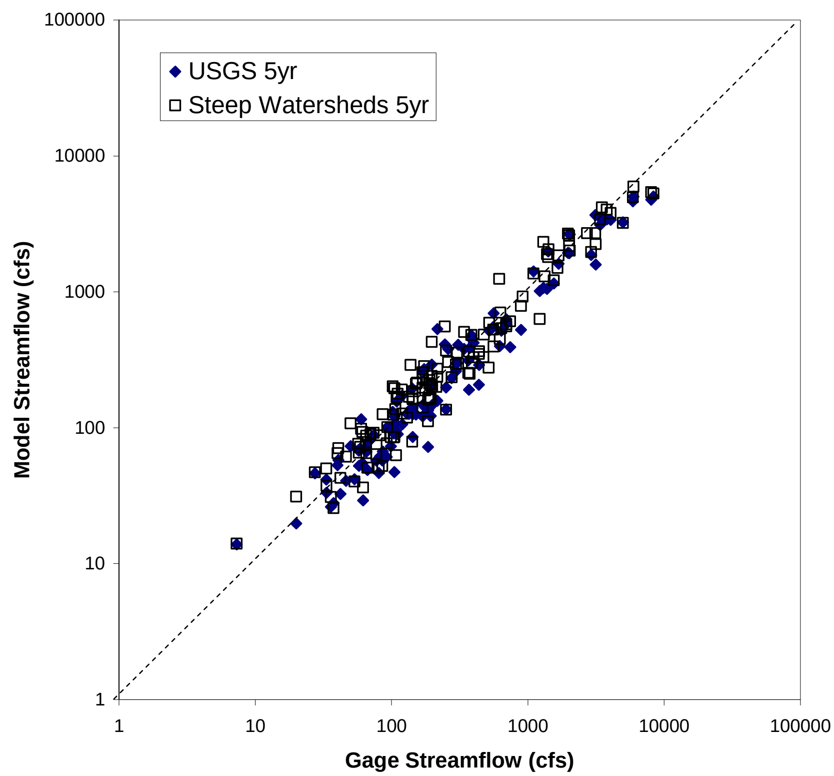
USGS 5yr
Steep Watersheds 5yr
Model Streamflow (cfs)
Gage Streamflow (cfs)
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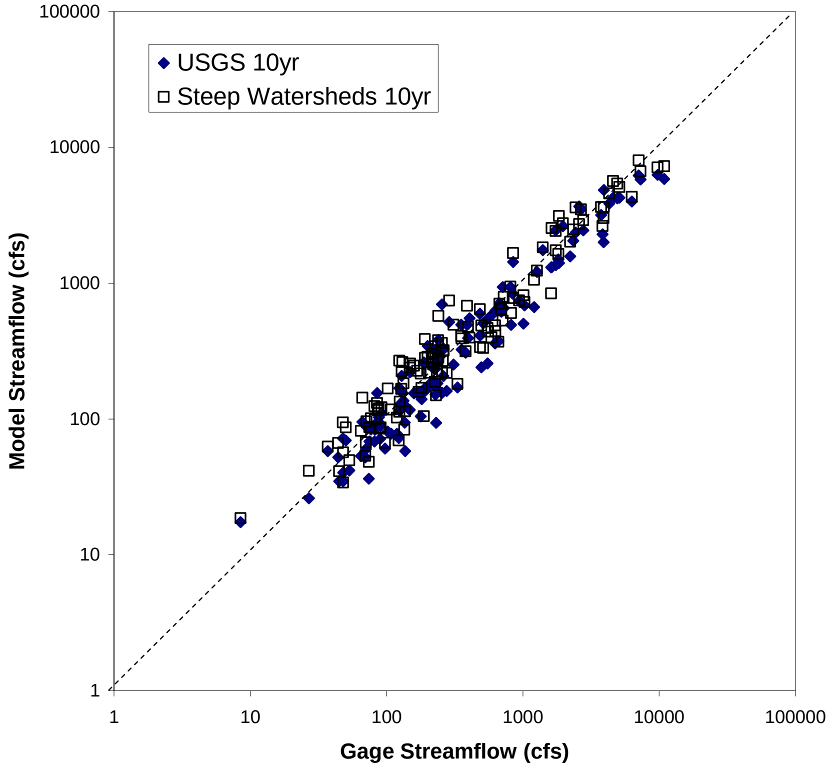

USGS 10yr
Steep Watersheds 10yr
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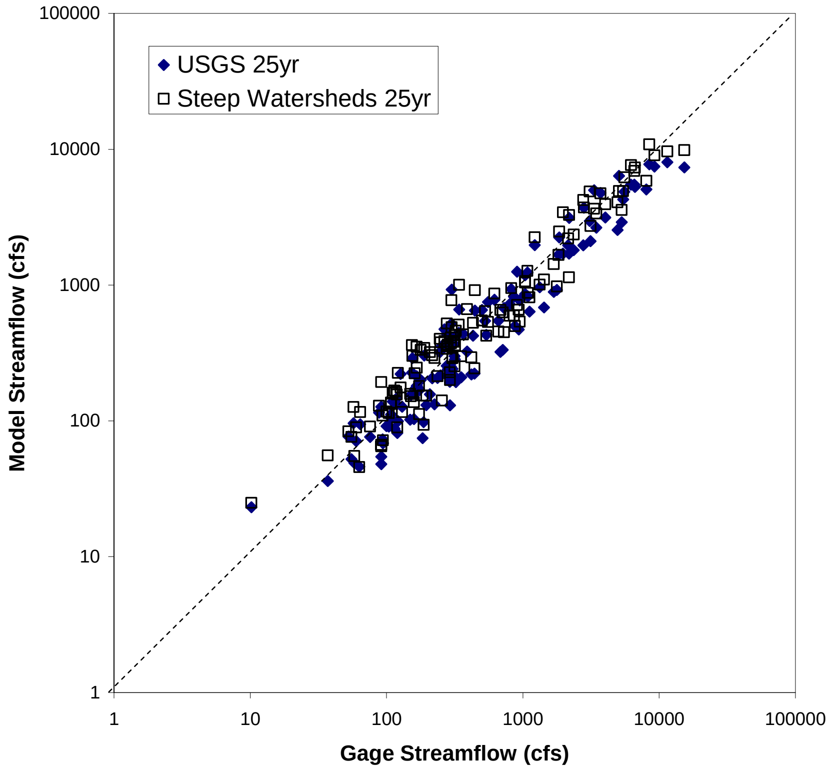
Model Streamflow (cfs)
Gage Streamflow (cfs)

USGS 25yr
Steep Watersheds 25yr
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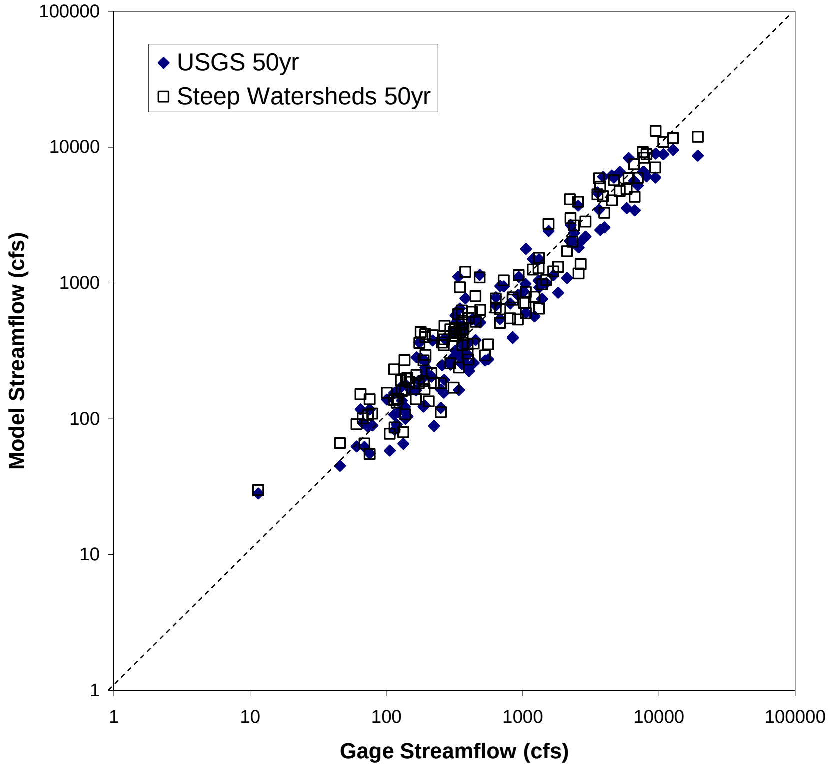
Model Streamflow (cfs)
Gage Streamflow (cfs)


USGS 50yr
Steep Watersheds 50yr
Model Streamflow (cfs)
Gage Streamflow (cfs)
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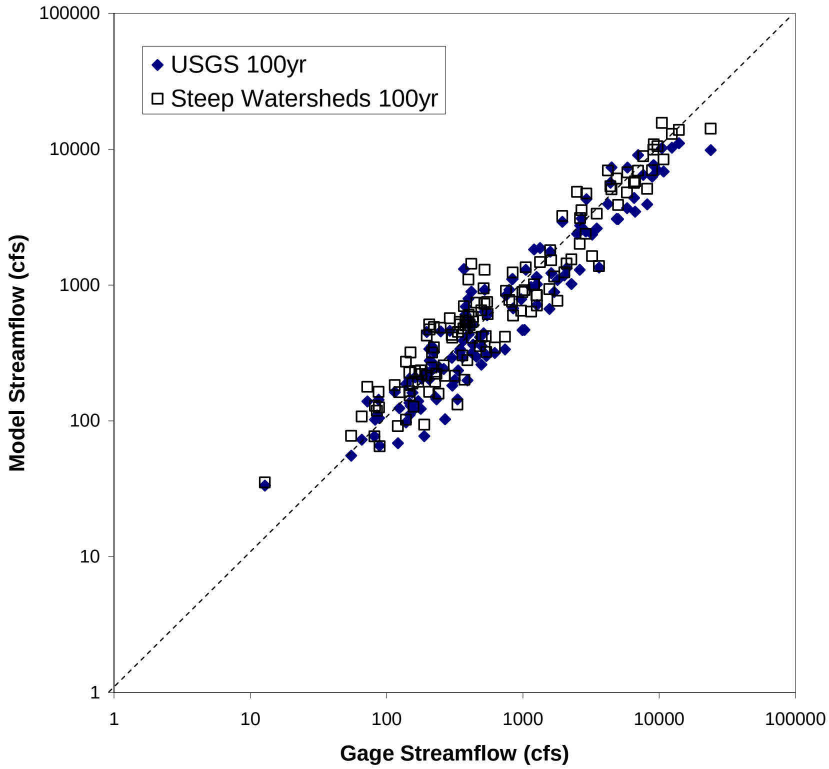
USGS 100yr
Steep Watersheds 100yr
Model Streamflow (cfs)
Gage Streamflow (cfs)
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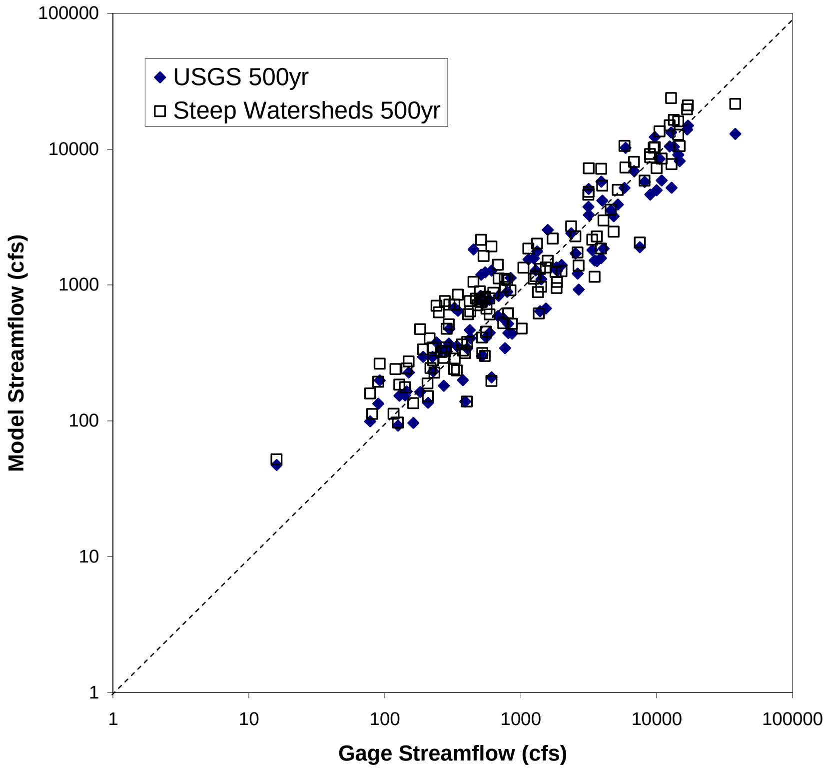


Figure 6. Bulletin 17B flood flow estimates versus those predicted using the steep watershed regression estimates and the State regression equations by return period.

Table 3. Regression equations and their accuracy for estimating peak flows for steep, ungaged, unregulated drainage basins in New England. Steep is defined as a main channel slope that exceeds 50 ft per mile. [N is the number of sites, O is observed; P is predicted, ave is the average flood flows, s.d. is the standard deviation of flood flows, a is the linear regression intercept, b is the linear regression slope, $R^2$ is the linear regression squared correlation, MAE is the mean absolute error, RMSE is root mean square error]. N, b, and $R^2$ are dimensionless. The remaining terms have the units of cfs.

| Return Period | Model | N | Ave O | Ave P | s.d. O | s.d. P | a | b | $R^2$ | MAE | RMSE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-yr | USGS | 131 | 515 | 443 | 978 | 734 | 72 | 0.72 | 0.924 | 125 | 346 |
| | Steep | 131 | 515 | 474 | 978 | 766 | 91 | 0.74 | 0.902 | 130 | 348 |
| 5-yr | USGS | 116 | 806 | 680 | 1541 | 1163 | 95 | 0.73 | 0.925 | 203 | 543 |
| | Steep | 116 | 806 | 749 | 1541 | 1275 | 108 | 0.79 | 0.923 | 186 | 475 |
| 10-yr | USGS | 131 | 1032 | 880 | 1852 | 1406 | 134 | 0.73 | 0.908 | 273 | 681 |
| | Steep | 131 | 1032 | 1020 | 1852 | 1652 | 137 | 0.86 | 0.921 | 234 | 534 |
| 25-yr | USGS | 131 | 1368 | 1148 | 2413 | 1804 | 185 | 0.70 | 0.886 | 394 | 962 |
| | Steep | 131 | 1368 | 1378 | 2413 | 2236 | 167 | 0.89 | 0.912 | 325 | 718 |
| 50-yr | USGS | 131 | 1658 | 1440 | 2896 | 2233 | 263 | 0.71 | 0.847 | 505 | 1228 |
| | Steep | 131 | 1658 | 1660 | 2896 | 2699 | 196 | 0.88 | 0.897 | 416 | 927 |
| 100-yr | USGS | 131 | 1986 | 1615 | 3447 | 2493 | 302 | 0.66 | 0.835 | 645 | 1584 |
| | Steep | 131 | 1986 | 1965 | 3447 | 3204 | 236 | 0.87 | 0.878 | 531 | 1201 |
| 500-yr | USGS | 101 | 3482 | 2596 | 5561 | 3588 | 645 | 0.56 | 0.755 | 1307 | 3134 |
| | Steep | 101 | 3482 | 3474 | 5561 | 5281 | 517 | 0.85 | 0.799 | 1200 | 2498 |

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## APPENDIX A

Table A.1 Magnitude and frequency discharges at stream-gaging stations used to determine flow characteristics of steep streams

Table A.2. Drainage areas and mean annual precipitation for gaging stations used in regression equations.

**Table A.1.** Magnitude and frequency discharges at stream-gaging stations used to determine flow characteristics of steep streams
[All streamgages are located on figure 2; USGS, U.S. Geological Survey; cfs, cubic feet per second; No., number; $mi^2$, square miles]

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01014700 | Factory Brook Near Madawaska, Me | 160 | 217 | 255 | 301 | 336 | 370 | 449 | 1964-1974 | 281 | 5.83 |
| 01017300 | Nichols Brook Near Caribou, Me | 106 | 169 | 216 | 278 | 327 | 379 | 507 | 1964-1973 | 281 | 3.94 |
| 01017900 | Marley Brook Near Ludlow, Me | 84 | 142 | 188 | 255 | 312 | 374 | 545 | 1964-1981 | 100 | 1.47 |
| 01024200 | Garland Brook Near Mariaville, Me | 411 | 694 | 939 | 1330 | 1680 | 2100 | 3370 | 1965-1982 | 619 | 9.79 |
| 01026800 | Frost Pond Brook Near Sedgwick, Me | 169 | 251 | 310 | 389 | 451 | 516 | 680 | 1964-1974 | 350 | 5.68 |
| 01034900 | Coffin Brook Near Lee, Me | 68 | 103 | 128 | 161 | 188 | 216 | 286 | 1964-1973 | 143 | 2.21 |
| 01037430 | Goose River At Rockport, Me | 387 | 558 | 674 | 823 | 936 | 1050 | 1320 | 1964-1973 | 624 | 8.32 |
| 01041900 | Mountain Brook Near Lake Parlin, Me | 217 | 375 | 512 | 728 | 922 | 1150 | 1840 | 1063-1974 | 918 | 3.91 |
| 01046000 | Austin Stream At Bingham, Me | 2360 | 3790 | 4940 | 6640 | 8110 | 9760 | 14400 | 1932-1969 | 4860 | 90 |
| 01046800 | South Branch Carrabassett River At Bigelow, Me | 1120 | 1550 | 1820 | 2150 | 2390 | 2630 | 3150 | 1963-1973 | 1620 | 14.2 |
| 01048100 | Pelton Brook Near Anson, Me | 755 | 1220 | 1610 | 2180 | 2670 | 3230 | 4830 | 1964-1973 | 2080 | 14.1 |
| 01049100 | Hall Brook At Thorndike, Me | 193 | 390 | 589 | 949 | 1320 | 1800 | 3500 | 1963-1973 | 933 | 5.23 |
| 01049300 | North Branch Tanning Brook Near Manchester, Maine | 73.2 | 108 | 135 | 173 | 205 | 241 | 339 | 1963-1973 | 74 | 0.93 |
| 01050900 | Four Ponds Brook Near Houghton, Me | 96.6 | 169 | 229 | 322 | 404 | 497 | 768 | 1963-1973 | 349 | 3.41 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01054200 | Wild River At Gilead, Maine | 8830 | 14000 | 17400 | 21700 | 24700 | 27700 | 34300 | 1959-2003 | 7510 | 69.6 |
| 01054300 | Ellis River At South Andover, Maine | 4220 | 5960 | 7080 | 8480 | 9490 | 10500 | 12800 | 1963-2003 | 5420 | 130 |
| 01055000 | Swift River Near Roxbury, Maine | 6180 | 9870 | 12500 | 16000 | 18700 | 21500 | 28200 | 1930-2003 | 9120 | 96.9 |
| 01055300 | Bog Brook Near Buckfield, Me | 182 | 246 | 288 | 341 | 380 | 419 | 511 | 1963-1973 | 166 | 10.5 |
| 01057000 | Little Androscoggin River Near South Paris, Maine | 2170 | 3390 | 4300 | 5560 | 6570 | 7660 | 10500 | 1914-2003 | 9340 | 73.5 |
| 01062700 | Patte Brook Near Bethel, Me | 219 | 401 | 557 | 800 | 1020 | 1270 | 2000 | 1964-1973 | 664 | 5.35 |
| 01064300 | Ellis River Near Jackson, Nh | 1250 | 2030 | 2590 | 3330 | 3900 | 4480 | 5910 | 1964-2003 | 99 | 10.9 |
| 01064380 | E Br Saco R @ Town Hall Rd, Nr Lower Bartlett, Nh | 2070 | 3130 | 3930 | 5070 | 6000 | 7000 | 9680 | 1966-1976 | 4610 | 32 |
| 01064400 | Lucy Brook Near North Conway, Nh | 571 | 1050 | 1430 | 1960 | 2390 | 2850 | 4030 | 1964-1991 | 571 | 4.68 |
| 01064500 | Saco River Near Conway, NH | 17000 | 26200 | 32700 | 41200 | 47700 | 54400 | 70700 | 1904-2003 | 33900 | 385 |
| 01064800 | Cold Brook At South Tamworth, Nh | 416 | 1030 | 1720 | 3100 | 4610 | 6670 | 14600 | 1963-1973 | 507 | 5.41 |
| 01066100 | Pease Brook Near Cornish, Me | 153 | 260 | 353 | 502 | 637 | 797 | 1290 | 1965-1996 | 486 | 4.62 |
| 01072850 | Mohawk Brook Near Center Strafford, Nh | 274 | 638 | 1030 | 1780 | 2580 | 3630 | 7530 | 1965-1977 | 351 | 7.34 |
| 01074500 | East Branch Pemigewasset River Near Lincoln, Nh | 6050 | 9120 | 11600 | 15100 | 18200 | 21500 | 31000 | 1929-1972 | 11800 | 104 |
| 01075000 | Pemigewasset River At Woodstock, Nh | 11800 | 19100 | 24700 | 32600 | 39100 | 46000 | 64400 | 1940-2003 | 16900 | 193 |
| 01075500 | Baker River At Wentworth, Nh | 2890 | 4780 | 6460 | 9170 | 11700 | 14700 | 24100 | 1940-1951 | 3740 | 58.8 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01075800 | Stevens Brook Near Wentworth, Nh | 203 | 393 | 573 | 878 | 1170 | 1540 | 2740 | 1964-1998 | 270 | 2.94 |
| 01076000 | Baker River Near Rumney, Nh | 5170 | 8730 | 11800 | 16500 | 20900 | 25900 | 41000 | 1927-2003 | 12600 | 143 |
| 01085800 | West Branch Warner River Near Bradford, Nh | 351 | 562 | 711 | 907 | 1060 | 1210 | 1580 | 1963-2003 | 351 | 5.75 |
| 01093800 | Stony Brook Tributary Near Temple, Nh | 188 | 308 | 407 | 556 | 686 | 833 | 1250 | 1963-2004 | 343 | 3.6 |
| 01094400 | North Nashua River At Fitchburg, Ma | 1690 | 2360 | 2800 | 3370 | 3790 | 4220 | 5240 | 1973-2004 | 2830 | 64.2 |
| 01095800 | Easter Brook Near North Leominster, Ma | 36.3 | 57.7 | 74.9 | 100 | 122 | 147 | 217 | 1964-1973 | 85 | 0.92 |
| 01100100 | Richardson Brook Near Lowell, Ma | 105 | 170 | 221 | 296 | 360 | 431 | 629 | 1962-1983 | 424 | 4.22 |
| 01100800 | Cobbler Brook Near Merrimac, Ma | 57.6 | 80.8 | 97.5 | 120 | 138 | 158 | 207 | 1962-1983 | 117 | 0.77 |
| 01104900 | Mill Brook At Westwood, Ma | 30.5 | 50.1 | 66.6 | 91.7 | 114 | 139 | 214 | 1964-1974 | 96 | 1.52 |
| 01105550 | Plantingfield Brook At Norwood, Ma | 132 | 166 | 188 | 215 | 235 | 256 | 304 | 1963-1974 | 185 | 1.52 |
| 01109100 | Taunton River Tributary Near Fall River, Ma | 45.2 | 65.1 | 79.2 | 98 | 113 | 128 | 166 | 1964-1983 | 108 | 0.23 |
| 01119255 | Delphi Bk Nr Staffordville, Ct. | 86.3 | 176 | 263 | 411 | 555 | 732 | 1310 | 1964-1976 | 310 | 2.59 |
| 01119360 | Conat Bk At W Willington, Ct. | 57.9 | 97.3 | 130 | 179 | 221 | 270 | 408 | 1964-1983 | 150 | 2.4 |
| 01119450 | Eagleville Bk At Storrs, Ct. | 83.8 | 108 | 124 | 143 | 157 | 171 | 203 | 1953-1969 | 123 | 0.36 |
| 01119600 | Ash Bk Nr N Coventry, Ct. | 150 | 194 | 225 | 266 | 297 | 329 | 410 | 1960-1970 | 260 | 2.79 |
| 01120500 | Safford Bk Nr Woodstock Valley, Ct. | 334 | 516 | 662 | 877 | 1060 | 1270 | 1850 | 1951-1981 | 445 | 4.15 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01121000 | Mount Hope River Near Warrenville, Ct. | 1010 | 1650 | 2230 | 3140 | 3990 | 5000 | 8150 | 1938-2003 | 2640 | 28.6 |
| 01121300 | Fenton R At East Willington, Ct. | 343 | 560 | 727 | 963 | 1160 | 1370 | 1920 | 1964-1976 | 750 | 11.4 |
| 01122680 | Merrick Bk Nr Scotland, Ct. | 267 | 462 | 632 | 900 | 1140 | 1430 | 2300 | 1960-1984 | 1020 | 5.21 |
| 01123160 | Wales Brook Tributary Near Wales, Ma | 27 | 40.2 | 50.2 | 64 | 75.4 | 87.6 | 120 | 1964-1983 | 63 | 0.73 |
| 01124050 | Tufts Branch At Dudley, Ma | 57.8 | 92.3 | 119 | 159 | 191 | 228 | 327 | 1963-1983 | 128 | 1.1 |
| 01124750 | Browns Brook Near Webster, Ma | 14.9 | 33.3 | 53.3 | 91.7 | 133 | 189 | 401 | 1963-1977 | 53 | 0.49 |
| 01125300 | English Neighborhood Bk At N Woodstock, Ct. | 188 | 406 | 620 | 988 | 1350 | 1790 | 3230 | 1962-1984 | 1200 | 4.66 |
| 01125650 | Wappoquia Bk Nr Pomfret,Ct. | 239 | 400 | 543 | 771 | 983 | 1230 | 2020 | 1964-1984 | 850 | 4.21 |
| 01125900 | Cady Bk At East Putnam, Ct. | 304 | 538 | 729 | 1010 | 1250 | 1520 | 2260 | 1964-1984 | 950 | 8.29 |
| 01126600 | Blackwell Bk Nr Brooklyn, Ct. | 504 | 916 | 1270 | 1830 | 2320 | 2900 | 4600 | 1962-1976 | 840 | 17 |
| 01127700 | Trading Cove Bk Nr Thamesville, Ct. | 356 | 580 | 764 | 1040 | 1280 | 1550 | 2330 | 1961-1974 | 940 | 8.46 |
| 01127760 | Hunts Bk At Old Norwich Rd At Quaker Hill, Ct | 240 | 390 | 516 | 709 | 881 | 1080 | 1670 | 1964-1976 | 650 | 11.5 |
| 01127880 | Big Brook Near Pittsburg, Nh | 265 | 341 | 389 | 445 | 485 | 524 | 610 | 1964-1984 | 300 | 6.36 |
| 01129400 | Black Brook At Averill, Vt | 30.6 | 40.7 | 47.8 | 57.3 | 64.7 | 72.4 | 91.7 | 1964-1978 | 54 | 0.882 |
| 01129440 | Mohawk River Near Colebrook Nh | 2110 | 3150 | 3910 | 4950 | 5790 | 6670 | 8960 | 1987-2003 | 2450 | 36.7 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01129700 | Paul Stream Tributary Near Brunswick Springs, Vt | 50 | 73.8 | 92 | 118 | 139 | 162 | 225 | 1966-2003 | 126 | 1.481 |
| 01133000 | East Branch Passumpsic River Near East Haven, Vt | 1360 | 1970 | 2440 | 3090 | 3640 | 4220 | 5810 | 1927-2003 | 2310 | 51.329 |
| 01133200 | Quimby Brook Near Lyndonville, Vt | 79.7 | 130 | 172 | 237 | 295 | 361 | 557 | 1964-2003 | 290 | 2.151 |
| 01133300 | Cold Hill Brook Near Lyndon, Vt | 55.6 | 93.2 | 125 | 173 | 215 | 263 | 405 | 1964-1977 | 195 | 1.639 |
| 01134500 | Moose River At Victory, Vt | 2090 | 2770 | 3240 | 3860 | 4340 | 4840 | 6080 | 1947-2003 | 4100 | 75.166 |
| 01134800 | Kirby Brook At Concord, Vt | 387 | 623 | 819 | 1120 | 1390 | 1700 | 2620 | 1964-2004 | 400 | 8.126 |
| 01135150 | Pope Brook (Site W-3) Near North Danville, Vt | 152 | 190 | 215 | 246 | 268 | 291 | 345 | 1991-2003 | 90 | 3.269 |
| 01135300 | Sleepers River (Site W-5) Near St. Johnsbury, Vt | 1820 | 2920 | 3850 | 5320 | 6640 | 8180 | 12900 | 1990-2003 | 1380 | 42.504 |
| 01135700 | Joes Brook Tributary Near East Barnet, Vt | 33.7 | 53.6 | 69.9 | 94.2 | 115 | 139 | 208 | 1964-2003 | 103 | 0.7 |
| 01137500 | Ammonoosuc River At Bethlehem Junction, Nh | 4380 | 6330 | 7740 | 9670 | 11200 | 12800 | 17000 | 1940-2003 | 6300 | 87.6 |
| 01138800 | Keenan Brook At Groton, Vt | 94.3 | 173 | 239 | 339 | 426 | 523 | 797 | 1964-1973 | 275 | 4.723 |
| 01139700 | Waits River Tributary Near West Topsham, Vt | 45.2 | 70.1 | 87.7 | 111 | 128 | 147 | 191 | 1964-2003 | 94 | 1.211 |
| 01139800 | East Orange Branch At East Orange, Vt | 252 | 386 | 484 | 620 | 728 | 842 | 1140 | 1959-2003 | 260 | 8.79 |
| 01140000 | South Branch Waits River Near Bradford, Vt | 965 | 1410 | 1740 | 2190 | 2550 | 2930 | 3920 | 1940-1951 | 1350 | 43.817 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01140100 | South Branch Waits R Tr Near Bradford Center, Vt | 5.4 | 7.3 | 8.5 | 10.2 | 11.5 | 12.8 | 16 | 1964-1974 | 9 | 0.211 |
| 01140800 | West Br Ompompanoosuc R Tr At South Strafford, Vt | 78 | 104 | 124 | 151 | 173 | 197 | 261 | 1964-1977 | 168 | 1.349 |
| 01141500 | Ompompanoosuc River At Union Village, Vt | 2550 | 3540 | 4210 | 5090 | 5760 | 6450 | 8130 | 1927-2003 | 3320 | 130.729 |
| 01141800 | Mink Brook Near Etna, Nh | 215 | 366 | 486 | 662 | 810 | 973 | 1420 | 1963-1998 | 261 | 4.6 |
| 01142400 | Third Branch White River Tributary At Randolph, Vt | 47.2 | 85.6 | 123 | 187 | 251 | 332 | 611 | 1964-2004 | 130 | 0.827 |
| 01142500 | Ayers Brook At Randolph, Vt | 725 | 1100 | 1400 | 1850 | 2250 | 2700 | 3990 | 1927-2003 | 1550 | 30.466 |
| 01145000 | Mascoma River At West Canaan, Nh | 1600 | 2230 | 2640 | 3140 | 3500 | 3860 | 4670 | 1938-2004 | 3190 | 80.5 |
| 01150800 | Kent Brook Near Killington, Vt | 214 | 370 | 497 | 685 | 846 | 1030 | 1530 | 1964-2004 | 300 | 3.261 |
| 01150900 | Ottauquechee River Near West Bridgewater, Vt | 1010 | 1380 | 1630 | 1970 | 2230 | 2500 | 3170 | 1985-2004 | 1460 | 23.25 |
| 01151200 | Ottauquechee River Tributary Near Quechee, Vt | 16.6 | 27.4 | 37 | 52.6 | 67.3 | 85 | 141 | 1964-2004 | 93 | 0.77 |
| 01153300 | Middle Branch Williams River Tr At Chester, Vt | 137 | 195 | 238 | 297 | 344 | 394 | 524 | 1964-2003 | 367 | 3.182 |
| 01153500 | Williams River At Brockways Mills, Vt | 4010 | 5900 | 7300 | 9230 | 10800 | 12400 | 16800 | 1938-1984 | 5340 | 102.292 |
| 01153550 | Williams River Near Rockingham Vt | 6200 | 8340 | 9730 | 11500 | 12700 | 14000 | 17000 | 1987-2003 | 6670 | 111.913 |
| 01154000 | Saxtons River At Saxtons River, Vt | 2680 | 4060 | 5110 | 6590 | 7790 | 9090 | 12500 | 1936-2003 | 3350 | 72.085 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01155200 | Sackets Brook Near Putney, Vt | 284 | 522 | 725 | 1040 | 1310 | 1620 | 2530 | 1964-1973 | 268 | 10.147 |
| 01155300 | Flood Brook Near Londonderry, Vt | 516 | 890 | 1210 | 1690 | 2120 | 2620 | 4070 | 1964-1973 | 596 | 9.285 |
| 01155350 | Trib To West River Trib @ Rt 30, Nr Jamaica, Vt | 56.6 | 98.8 | 136 | 196 | 252 | 317 | 522 | 1964-2003 | 320 | 0.926 |
| 01156300 | Whetstone Brook Tributary Near Marlboro, Vt | 122 | 185 | 231 | 292 | 341 | 392 | 519 | 1963-2004 | 253 | 1.076 |
| 01156450 | Connecticut River Tributary Near Vernon, Vt | 53.4 | 82.5 | 108 | 149 | 187 | 233 | 376 | 1964-2003 | 128 | 1.103 |
| 01158500 | Otter Brook Near Keene, Nh | 1140 | 2010 | 2780 | 4020 | 5170 | 6550 | 10900 | 1924-1957 | 4040 | 42.3 |
| 01160000 | S Br Ashuelot River At Webb, Nr Marlborough, Nh | 954 | 1680 | 2350 | 3460 | 4520 | 5820 | 10000 | 1920-1978 | 3070 | 36 |
| 01161300 | Millers Brook At Northfield, Ma | 108 | 194 | 276 | 419 | 560 | 740 | 1360 | 1964-1983 | 680 | 2.3 |
| 01165000 | East Branch Tully River Near Athol, Ma | 743 | 1300 | 1840 | 2780 | 3710 | 4880 | 8940 | 1917-1990 | 3650 | 50.5 |
| 01167800 | Beaver Brook At Wilmington, Vt | 432 | 742 | 1010 | 1430 | 1820 | 2270 | 3640 | 1963-1977 | 593 | 6.361 |
| 01169000 | North River At Shattuckville, Ma | 4750 | 7710 | 10100 | 13600 | 16700 | 20100 | 29600 | 1940-2004 | 8740 | 89 |
| 01169900 | South River Near Conway, Ma | 1820 | 2950 | 3920 | 5460 | 6850 | 8490 | 13500 | 1966-2004 | 1570 | 24.1 |
| 01170100 | Green River Near Colrain, Ma | 2490 | 3450 | 4120 | 5020 | 5730 | 6470 | 8330 | 1968-2004 | 2420 | 41.4 |
| 01170200 | Allen Brook Near Shelburne Falls, Ma | 24.7 | 46.3 | 64.9 | 93.5 | 119 | 148 | 232 | 1964-1973 | 89 | 0.72 |
| 01170900 | Mill River Near South Deerfield, Ma | 139 | 197 | 240 | 299 | 347 | 399 | 534 | 1963-1974 | 300 | 6.42 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01171200 | Scarboro Brook At Dwight, Ma | 72 | 102 | 124 | 154 | 179 | 206 | 277 | 1963-1973 | 148 | 2.9 |
| 01171500 | Mill River At Northampton, Ma | 2220 | 3290 | 4030 | 4980 | 5700 | 6430 | 8170 | 1938-2004 | 3870 | 52.6 |
| 01171910 | Broad Brook Near Holyoke, Ma | 70.9 | 111 | 148 | 208 | 266 | 335 | 561 | 1964-1983 | 393 | 2.27 |
| 01173040 | Pleasant Brook Near Barre, Ma | 37.6 | 61.2 | 81.6 | 114 | 143 | 178 | 283 | 1965-1973 | 123 | 1.22 |
| 01173260 | Moose Brook Near Barre, Ma | 79.2 | 138 | 191 | 277 | 358 | 456 | 765 | 1963-1973 | 128 | 4.63 |
| 01173330 | Fish Brook Near Gilbertville, Ma | 39.7 | 65.1 | 86.4 | 119 | 148 | 181 | 278 | 1964-1973 | 104 | 1.2 |
| 01173900 | Middle Branch Swift River At North New Salem, Ma | 95.1 | 152 | 202 | 281 | 353 | 438 | 700 | 1964-1973 | 320 | 4.77 |
| 01174000 | Hop Brook Near New Salem, Ma | 151 | 217 | 261 | 317 | 359 | 401 | 501 | 1948-1982 | 175 | 3.39 |
| 01174600 | Cadwell Creek Near Pelham, Ma | 33.1 | 45.8 | 54.6 | 66.3 | 75.2 | 84.5 | 107 | 1962-1994 | 37 | 0.6 |
| 01174900 | Cadwell Creek Near Belchertown, Ma | 118 | 177 | 220 | 276 | 321 | 367 | 484 | 1962-1996 | 181 | 2.55 |
| 01175600 | Caruth Brook Near Paxton, Ma | 95.6 | 143 | 178 | 225 | 264 | 304 | 410 | 1965-1983 | 203 | 2.27 |
| 01176450 | Roaring Brook Near Belchertown, Ma | 94.6 | 151 | 192 | 249 | 295 | 344 | 468 | 1963-1974 | 185 | 2.74 |
| 01178230 | Mill Brook At Plainfield, Ma | 181 | 303 | 397 | 529 | 637 | 752 | 1050 | 1964-1983 | 470 | 4.45 |
| 01180000 | Sykes Brook At Knightville, Ma | 57.9 | 120 | 181 | 291 | 400 | 540 | 1020 | 1946-1973 | 159 | 1.73 |
| 01180500 | Middle B Westfield River At Goss Heights, Ma | 2800 | 4950 | 7020 | 10600 | 14100 | 18600 | 34000 | 1911-1989 | 6240 | 52.7 |
| 01180800 | Walker Brook Near Becket Center, Ma | 156 | 276 | 380 | 540 | 684 | 849 | 1340 | 1962-1977 | 165 | 2.94 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area (mi$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01181000 | West Branch Westfield River At Huntington, Ma | 5100 | 8830 | 12000 | 16900 | 21200 | 26200 | 40800 | 1936-2004 | 10500 | 94 |
| 01183100 | Dickinson Brook Tributary At Granville, Ma | 53.2 | 119 | 182 | 291 | 396 | 523 | 930 | 1964-1983 | 208 | 0.7 |
| 01184300 | Gillette Bk At Somers, Ct. | 116 | 197 | 263 | 364 | 453 | 553 | 842 | 1960-1984 | 375 | 3.64 |
| 01184900 | Haley Pond Outlet Near Otis, Ma | 11.4 | 20 | 26.9 | 37.1 | 45.7 | 55.1 | 81 | 1964-1973 | 30 | 0.26 |
| 01187300 | Hubbard River Nr. West Hartland, Ct. | 960 | 1820 | 2590 | 3820 | 4930 | 6240 | 10200 | 1938-2003 | 10500 | 19.9 |
| 01187400 | Valley Bk Nr West Hartland, Ct. | 271 | 610 | 1010 | 1840 | 2810 | 4220 | 10300 | 1941-1972 | 5400 | 7.03 |
| 01187850 | Clear Bk Nr Collinsville, Ct. | 13.5 | 25 | 35.2 | 51.6 | 66.7 | 84.4 | 138 | 1927-1973 | 34 | 0.59 |
| 01188000 | Burlington Brook Near Burlington, Ct. | 271 | 472 | 631 | 860 | 1050 | 1260 | 1810 | 1932-2003 | 673 | 4.1 |
| 01189000 | Pequabuck R At Forestville, Ct. | 1570 | 2720 | 3760 | 5440 | 7000 | 8890 | 14800 | 1938-2003 | 6500 | 45.8 |
| 01189390 | E.Br.Salmon Bk At Granby,Ct. | 779 | 1420 | 1970 | 2810 | 3550 | 4390 | 6820 | 1964-1976 | 1100 | 39.5 |
| 01189500 | Salmon Bk Near Granby, Ct. | 2090 | 5090 | 8890 | 17300 | 27700 | 43600 | 118000 | 1947-1963 | 18400 | 67.4 |
| 01192600 | South Branch Salmon Bk At Buckingham, Ct. | 22.5 | 44.3 | 65.9 | 104 | 142 | 191 | 358 | 1936-1981 | 30 | 0.94 |
| 01192800 | Parmalee Bk Nr Durham, Ct. | 215 | 329 | 413 | 528 | 620 | 716 | 963 | 1960-1983 | 517 | 2.79 |
| 01193120 | Ponset Bk Nr Higganum, Ct | 239 | 424 | 588 | 854 | 1100 | 1390 | 2310 | 1962-1982 | 1700 | 5.72 |
| 01193800 | Hemlock Valley Bk At Hadlyme, Ct. | 120 | 189 | 240 | 311 | 369 | 430 | 589 | 1960-1976 | 87 | 2.62 |
| 01194000 | Eightmile R At North Plain, Ct. | 821 | 1330 | 1750 | 2360 | 2900 | 3490 | 5180 | 1938-1984 | 1480 | 20.1 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01195000 | Menunketesuck R Nr Clinton, Ct. | 408 | 631 | 812 | 1080 | 1320 | 1590 | 2350 | 1938-1982 | 573 | 11.2 |
| 01196600 | Willow Bk Nr Cheshire, Ct. | 267 | 476 | 673 | 1010 | 1340 | 1750 | 3130 | 1960-1983 | 3000 | 9.34 |
| 01196990 | Windsor Brook Tributary At Windsor, Ma | 24.4 | 35.9 | 45 | 58.1 | 69.2 | 81.5 | 116 | 1963-1973 | 52 | 0.3 |
| 01197050 | Churchill Brook At Pittsfield, Ma | 32.2 | 59.9 | 85.3 | 127 | 167 | 215 | 369 | 1964-1973 | 139 | 1.16 |
| 01197155 | Housatonic River Tributary No. 2 At Lee, Ma | 35.9 | 65.4 | 90.7 | 130 | 165 | 206 | 324 | 1965-1973 | 88 | 0.73 |
| 01197300 | Marsh Brook At Lenox, Ma | 80.3 | 109 | 129 | 155 | 175 | 197 | 250 | 1963-1973 | 70 | 2.12 |
| 01198000 | Green River Near Great Barrington, Ma | 1270 | 2010 | 2670 | 3720 | 4690 | 5860 | 9540 | 1952-1996 | 2700 | 51 |
| 01198500 | Blackberry R At Canaan, Ct. | 1970 | 4190 | 6550 | 11000 | 15700 | 22100 | 45900 | 1948-1981 | 6220 | 45.9 |
| 01199150 | Furnace Bk At Cornwall Bridge,Ct. | 305 | 576 | 831 | 1260 | 1670 | 2170 | 3810 | 1945-1976 | 4060 | 13.3 |
| 01199200 | Guinea Bk At West Woods Rd At Ellsworth, Ct | 95.8 | 154 | 200 | 266 | 321 | 382 | 547 | 1960-1981 | 143 | 3.5 |
| 01201190 | West Aspetuck R At Sand Rd Nr New Milford, Ct | 353 | 617 | 848 | 1220 | 1550 | 1950 | 3160 | 1963-1972 | 845 | 23.8 |
| 01201890 | Pond Bk Nr Hawleyville, Ct. | 418 | 778 | 1110 | 1650 | 2170 | 2790 | 4760 | 1963-1976 | 1400 | 11.9 |
| 01202700 | Butternut Bk Nr Litchfield, Ct. | 229 | 406 | 554 | 781 | 980 | 1210 | 1860 | 1960-1984 | 860 | 2.42 |
| 01203100 | Jacks Bk Nr Roxbury Falls, Ct | 537 | 928 | 1240 | 1690 | 2070 | 2480 | 3600 | 1961-1984 | 1600 | 7.9 |
| 01203600 | Nonewaug River At Minortown, Ct. | 1330 | 2520 | 3560 | 5190 | 6670 | 8380 | 13500 | 1955-2003 | 1210 | 17.7 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area (mi$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01203700 | Wood Ck Nr Bethlehem, Ct. | 185 | 305 | 411 | 580 | 735 | 919 | 1490 | 1962-1984 | 700 | 3.39 |
| 01204800 | Copper Mill Bk Nr Monroe, Ct. | 147 | 213 | 259 | 318 | 363 | 408 | 517 | 1959-1976 | 121 | 2.45 |
| 01206400 | Leadmine Bk Nr Harwington,Ct. | 1080 | 1950 | 2780 | 4190 | 5550 | 7240 | 12900 | 1931-1984 | 657 | 19.6 |
| 01206500 | Leadmine Bk Nr Thomaston, Ct. | 1600 | 3170 | 4780 | 7700 | 10700 | 14700 | 28900 | 1931-1959 | 3660 | 24.3 |
| 01208100 | Hancock Bk Nr Terryville, Ct. | 116 | 175 | 218 | 276 | 322 | 370 | 489 | 1960-1981 | 300 | 1.18 |
| 01208400 | Hop Bk Nr Middlebury,Ct. | 414 | 723 | 994 | 1430 | 1820 | 2290 | 3710 | 1955-2003 | 1700 | 9.43 |
| 01208700 | Little R At Oxford, Ct. | 233 | 367 | 467 | 607 | 721 | 843 | 1160 | 1960-1984 | 1350 | 4.54 |
| 01208950 | Sasco Brook Near Southport, Ct. | 256 | 475 | 694 | 1090 | 1490 | 2020 | 3900 | 1960-2003 | 785 | 7.38 |
| 01209770 | Fivemile R Nr Norwalk,Ct. | 565 | 870 | 1100 | 1420 | 1690 | 1970 | 2730 | 1955-1984 | 2750 | 8.96 |
| 01211700 | E Br Byram R At Round Hill, Ct. | 98.9 | 169 | 227 | 316 | 395 | 484 | 745 | 1960-1975 | 245 | 1.69 |
| 01328900 | Tanner Brook Near Sunderland, Vt | 30.8 | 44.6 | 55.6 | 72 | 86 | 102 | 147 | 1964-2003 | 84 | 2.336 |
| 01329000 | Batten Kill At Arlington, Vt | 3220 | 4520 | 5490 | 6860 | 7980 | 9190 | 12400 | 1929-1984 | 7280 | 149.793 |
| 01331400 | Dry Brook Near Adams, Ma | 479 | 695 | 844 | 1040 | 1190 | 1340 | 1720 | 1962-1973 | 290 | 7.67 |
| 01332000 | North Branch Hoosic River At North Adams, Ma | 2370 | 3780 | 4930 | 6670 | 8190 | 9910 | 14900 | 1927-1990 | 4200 | 40.9 |
| 01333800 | South Stream Near Bennington, Vt | 76.4 | 102 | 121 | 148 | 170 | 194 | 259 | 1963-1973 | 166 | 7.714 |
| 01333900 | Paran Creek Near South Shaftsbury, Vt | 76.5 | 119 | 149 | 189 | 219 | 250 | 325 | 1964-2004 | 193 | 2.375 |
| 01334000 | Walloomsac River Near North Bennington, Vt | 3380 | 4940 | 6040 | 7510 | 8650 | 9830 | 12800 | 1932-2004 | 6350 | 115.542 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area (mi$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 04279400 | Poultney River Tributary At East Poultney, Vt | 57.7 | 77.4 | 89.5 | 104 | 114 | 124 | 145 | 1964-2004 | 98 | 1.144 |
| 04280200 | Mettawee River Tributary No. 2 At East Ruppert, Vt | 70.8 | 105 | 131 | 166 | 193 | 223 | 299 | 1963-1974 | 130 | 1.661 |
| 04280300 | Mettawee River Tributary Near Pawlet, Vt | 72 | 143 | 205 | 305 | 395 | 499 | 807 | 1963-1973 | 70 | 2.09 |
| 04280350 | Mettawee River Near Pawlet, Vt | 2110 | 3500 | 4600 | 6230 | 7610 | 9150 | 13400 | 1985-2003 | 2860 | 70.483 |
| 04280900 | Moon Brook At Rutland, Vt | 72.7 | 107 | 133 | 167 | 194 | 223 | 296 | 1964-1977 | 153 | 1.841 |
| 04282000 | Otter Creek At Center Rutland, Vt | 5390 | 7420 | 8740 | 10400 | 11600 | 12800 | 15500 | 1929-2003 | 10100 | 308.026 |
| 04282200 | Neshobe River At Brandon, Vt | 668 | 765 | 820 | 881 | 922 | 959 | 1040 | 1968-1977 | 800 | 17.857 |
| 04282300 | Brandy Brook At Bread Loaf, Vt | 114 | 191 | 256 | 353 | 438 | 534 | 810 | 1963-2004 | 546 | 1.879 |
| 04282525 | New Haven River @ Brooksville, Nr Middlebury, Vt | 4720 | 8030 | 10900 | 15300 | 19300 | 23900 | 37900 | 1990-2003 | 6880 | 116.086 |
| 04282550 | Beaver Brook At Cornwall, Vt | 59.4 | 66.5 | 70.7 | 75.7 | 79.1 | 82.4 | 89.7 | 1964-1973 | 73 | 1.059 |
| 04282600 | Little Otter Creek Tributary Near Bristol, Vt | 33.8 | 57 | 76.9 | 108 | 137 | 171 | 272 | 1964-1978<br>1999-2004 | 168 | 1.521 |
| 04282700 | Lewis Creek Tributary At Starksboro, Vt | 234 | 439 | 626 | 934 | 1220 | 1570 | 2670 | 1963-2003 | 310 | 5.344 |
| 04282750 | Lewis Creek Tributary No. 2 Near Rockville, Vt | 41.3 | 58.9 | 71.4 | 88.1 | 101 | 115 | 150 | 1964-1977 | 95 | 1.226 |
| 04282850 | Winooski River Tributary No 2 Near Cabot, Vt | 19.5 | 33.2 | 44.1 | 59.9 | 73.3 | 88 | 128 | 1964-1973 | 52 | 0.577 |

| USGS stream-gaging station No. | Gaging Station Name | 2-year | 5-year | 10-year | 25-year | 50-year | 100-year | 500-year | Period of Record | Flood of Record (cfs) | Drainage Area ($mi^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 04283470 | Stevens Branch Tributary At South Barre, Vt | 23.7 | 37.5 | 48 | 63.1 | 75.5 | 89 | 125 | 1964-1974 | 62 | 0.494 |
| 04287000 | Dog River At Northfield Falls, Vt | 3180 | 4990 | 6300 | 8050 | 9420 | 10800 | 14400 | 1935-2003 | 4390 | 76.619 |
| 04287300 | Sunny Brook Near Montpelier, Vt | 146 | 251 | 331 | 442 | 531 | 624 | 864 | 1964-2003 | 128 | 2.383 |
| 04288400 | Bryant Brook At Waterbury Center, Vt | 143 | 199 | 236 | 281 | 314 | 347 | 422 | 1964-2003 | 302 | 2.632 |
| 04290700 | Bailey Brook At East Hardwick, Vt | 91.6 | 134 | 168 | 216 | 257 | 302 | 427 | 1964-2003 | 285 | 2.549 |
| 04292100 | Stony Brook Near Eden, Vt | 288 | 437 | 551 | 713 | 847 | 993 | 1390 | 1964-2003 | 320 | 4.238 |
| 04292150 | Gihon River Tributary Near Johnson, Vt | 45 | 61.7 | 74.2 | 91.6 | 106 | 121 | 162 | 1964-1974 | 112 | 0.465 |
| 04292200 | Lamoille River Tributary At Jeffersonville, Vt | 33 | 42.1 | 48 | 55.3 | 60.6 | 65.8 | 78 | 1964-1974 | 48 | 0.581 |
| 04293400 | Whittaker Brook At Richford, Vt | 64.6 | 105 | 137 | 184 | 224 | 269 | 391 | 1963-2004 | 216 | 0.878 |
| 04293800 | Missisquoi River Tributary At Sheldon Junction, Vt | 61.7 | 86.1 | 102 | 121 | 136 | 150 | 182 | 1963-2002 | 122 | 1.727 |
| 04295900 | Ware Brook Near Coventry, Vt | 118 | 143 | 159 | 178 | 193 | 207 | 240 | 1963-1974 | 171 | 2.839 |
| 04296150 | Lord Brook Near Evansville, Vt | 209 | 297 | 356 | 432 | 489 | 548 | 687 | 1964-2003 | 425 | 4.608 |
| 04296200 | Brownington Branch Near Evansville, Vt | 122 | 186 | 235 | 305 | 362 | 424 | 592 | 1964-2003 | 97 | 2.213 |
| 04296300 | Pherrins River Tributary Near Island Pond, Vt | 44 | 65.1 | 82.1 | 108 | 130 | 155 | 227 | 1964-2004 | 140 | 1.02 |

**Table A.2.** Drainage areas and mean annual precipitation for gaging stations used in regression equations.

| State | Station | Name | Drainage Area (mi2) | Mean Annual Precip (in) |
|---|---|---|---|---|
| VT | 1129400 | Black Brook At Averill, Vt | 0.88 | 44.3 |
| VT | 1129700 | Paul Stream Tributary Near Brunswick Springs, Vt | 1.48 | 40.4 |
| VT | 1133000 | East Branch Passumpsic River Near East Haven, Vt | 51.3 | 44.7 |
| VT | 1133200 | Quimby Brook Near Lyndonville, Vt | 2.15 | 39.1 |
| VT | 1133300 | Cold Hill Brook Near Lyndon, Vt | 1.64 | 40.5 |
| VT | 1134800 | Kirby Brook At Concord, Vt | 8.13 | 41.8 |
| VT | 1135150 | Pope Brook (Site W-3) Near North Danville, Vt | 3.27 | 44.0 |
| VT | 1135300 | Sleepers River (Site W-5) Near St. Johnsbury, Vt | 42.5 | 41.9 |
| VT | 1135700 | Joes Brook Tributary Near East Barnet, Vt | 0.70 | 37.6 |
| VT | 1138800 | Keenan Brook At Groton, Vt | 4.72 | 42.2 |
| VT | 1139700 | Waits River Tributary Near West Topsham, Vt | 1.21 | 43.4 |
| VT | 1139800 | East Orange Branch At East Orange, Vt | 8.79 | 41.7 |
| VT | 1140000 | South Branch Waits River Near Bradford, Vt | 43.8 | 39.8 |
| VT | 1140100 | South Branch Waits R Tr Near Bradford Center, Vt | 0.21 | 37.8 |
| VT | 1140800 | West Br Ompompanoosuc R Tr At South Strafford, Vt | 1.35 | 40.5 |
| VT | 1142400 | Third Branch White River Tributary At Randolph, Vt | 0.83 | 39.6 |
| VT | 1142500 | Ayers Brook At Randolph, Vt | 30.5 | 40.6 |
| VT | 1150800 | Kent Brook Near Killington, Vt | 3.26 | 55.0 |
| VT | 1150900 | Ottauquechee River Near West Bridgewater, Vt | 23.3 | 52.6 |
| VT | 1151200 | Ottauquechee River Tributary Near Quechee, Vt | 0.77 | 38.8 |
| VT | 1153300 | Middle Branch Williams River Tr At Chester, Vt | 3.18 | 43.0 |
| VT | 1153500 | Williams River At Brockways Mills, Vt | 102 | 44.7 |
| VT | 1153550 | Williams River Near Rockingham Vt | 112 | 44.4 |
| VT | 1154000 | Saxtons River At Saxtons River, Vt | 72.1 | 45.7 |
| VT | 1155200 | Sackets Brook Near Putney, Vt | 10.2 | 43.3 |
| VT | 1155300 | Flood Brook Near Londonderry, Vt | 9.29 | 51.2 |
| VT | 1155350 | Trib To West River Trib @ Rt 30, Nr Jamaica, Vt | 0.93 | 47.3 |
| VT | 1156300 | Whetstone Brook Tributary Near Marlboro, Vt | 1.08 | 50.3 |
| VT | 1156450 | Connecticut River Tributary Near Vernon, Vt | 1.10 | 44.7 |
| VT | 1167800 | Beaver Brook At Wilmington, Vt | 6.36 | 53.0 |
| VT | 1333900 | Paran Creek Near South Shaftsbury, Vt | 2.38 | 46.6 |
| VT | 4279400 | Poultney River Tributary At East Poultney, Vt | 1.14 | 38.0 |
| VT | 4280200 | Mettawee River Tributary No. 2 At East Ruppert, Vt | 1.66 | 54.4 |
| VT | 4280300 | Mettawee River Tributary Near Pawlet, Vt | 2.09 | 45.8 |
| VT | 4280350 | Mettawee River Near Pawlet, Vt | 70.5 | 48.2 |
| VT | 4280900 | Moon Brook At Rutland, Vt | 1.84 | 44.4 |
| VT | 4282300 | Brandy Brook At Bread Loaf, Vt | 1.88 | 48.2 |
| VT | 4282525 | New Haven River @ Brooksville, Nr Middlebury, Vt | 116 | 44.2 |
| VT | 4282550 | Beaver Brook At Cornwall, Vt | 1.06 | 35.3 |
| VT | 4282600 | Little Otter Creek Tributary Near Bristol, Vt | 1.52 | 36.7 |
| VT | 4282700 | Lewis Creek Tributary At Starksboro, Vt | 5.34 | 45.1 |
| VT | 4282750 | Lewis Creek Tributary No. 2 Near Rockville, Vt | 1.23 | 39.1 |
| VT | 4282850 | Winooski River Tributary No 2 Near Cabot, Vt | 0.58 | 44.9 |

| State | Station | Name | Drainage Area (mi2) | Mean Annual Precip (in) |
|---|---|---|---|---|
| VT | 4283470 | Stevens Branch Tributary At South Barre, Vt | 0.49 | 35.3 |
| VT | 4287000 | Dog River At Northfield Falls, Vt | 76.6 | 41.3 |
| VT | 4287300 | Sunny Brook Near Montpelier, Vt | 2.38 | 39.8 |
| VT | 4288400 | Bryant Brook At Waterbury Center, Vt | 2.63 | 45.9 |
| VT | 4290700 | Bailey Brook At East Hardwick, Vt | 2.55 | 42.8 |
| VT | 4292100 | Stony Brook Near Eden, Vt | 4.24 | 48.5 |
| VT | 4292150 | Gihon River Tributary Near Johnson, Vt | 0.47 | 42.4 |
| VT | 4292200 | Lamoille River Tributary At Jeffersonville, Vt | 0.58 | 41.6 |
| VT | 4293400 | Whittaker Brook At Richford, Vt | 0.88 | 48.4 |
| VT | 4293800 | Missisquoi River Tributary At Sheldon Junction, Vt | 1.73 | 43.8 |
| VT | 4295900 | Ware Brook Near Coventry, Vt | 2.84 | 42.7 |
| VT | 4296150 | Lord Brook Near Evansville, Vt | 4.61 | 43.3 |
| VT | 4296200 | Brownington Branch Near Evansville, Vt | 2.21 | 44.4 |
| VT | 4296300 | Pherrins River Tributary Near Island Pond, Vt | 1.02 | 42.7 |
| NH | 1064300 | Ellis River Near Jackson, Nh | 10.9 | 73.5 |
| NH | 1064380 | E Br Saco R @ Town Hall Rd, Nr Lower Bartlett, Nh | 32.0 | 54.4 |
| NH | 1072850 | Mohawk Brook Near Center Strafford, Nh | 7.34 | 47.4 |
| NH | 1074500 | East Branch Pemigewasset River Near Lincoln, Nh | 104 | 61.8 |
| NH | 1075500 | Baker River At Wentworth, Nh | 58.8 | 45.4 |
| NH | 1085800 | West Branch Warner River Near Bradford, Nh | 5.75 | 45.4 |
| NH | 1093800 | Stony Brook Tributary Near Temple, Nh | 3.60 | 48.1 |
| NH | 1127880 | Big Brook Near Pittsburg, Nh | 6.36 | 48.8 |
| NH | 1129440 | Mohawk River Near Colebrook Nh | 36.7 | 47.2 |
| NH | 1141800 | Mink Brook Near Etna, Nh | 4.60 | 40.5 |
| NH | 1158500 | Otter Brook Near Keene, Nh | 42.3 | 43.9 |
| NH | 1160000 | S Br Ashuelot River At Webb, Nr Marlborough, Nh | 36.0 | 43.6 |
| ME | 1014700 | Factory Brook Near Madawaska, Me | 5.83 | 38.0 |
| ME | 1017300 | Nichols Brook Near Caribou, Me | 3.94 | 38.5 |
| ME | 1017900 | Marley Brook Near Ludlow, Me | 1.47 | 37.8 |
| ME | 1024200 | Garland Brook Near Mariaville, Me | 9.79 | 42.8 |
| ME | 1026800 | Frost Pond Brook Near Sedgwick, Me | 5.68 | 44.2 |
| ME | 1034900 | Coffin Brook Near Lee, Me | 2.21 | 39.5 |
| ME | 1037430 | Goose River At Rockport, Me | 8.32 | 44.5 |
| ME | 1041900 | Mountain Brook Near Lake Parlin, Me | 3.91 | 43.0 |
| ME | 1046000 | Austin Stream At Bingham, Me | 90.0 | 42.8 |
| ME | 1046800 | South Branch Carrabassett River At Bigelow, Me | 14.2 | 52.5 |
| ME | 1048100 | Pelton Brook Near Anson, Me | 14.1 | 39.0 |
| ME | 1049100 | Hall Brook At Thorndike, Me | 5.23 | 41.5 |
| ME | 1049300 | North Branch Tanning Brook Near Manchester, Maine | 0.93 | 41.0 |
| ME | 1050900 | Four Ponds Brook Near Houghton, Me | 3.41 | 46.0 |
| ME | 1054300 | Ellis River At South Andover, Maine | 130 | 44.2 |
| ME | 1055300 | Bog Brook Near Buckfield, Me | 10.5 | 41.5 |
| ME | 1057000 | Little Androscoggin River Near South Paris, Maine | 73.5 | 43.1 |
| ME | 1062700 | Patte Brook Near Bethel, Me | 5.35 | 43.0 |
| ME | 1066100 | Pease Brook Near Cornish, Me | 4.62 | 44.0 |

| State | Station | Name | Drainage Area (mi2) | Mean Annual Precip (in) |
|---|---|---|---|---|
| MA | 1094400 | North Nashua River At Fitchburg, Ma | 64.2 | 43.0 |
| MA | 1095800 | Easter Brook Near North Leominster, Ma | 0.92 | 42.0 |
| MA | 1100100 | Richardson Brook Near Lowell, Ma | 4.22 | 40.0 |
| MA | 1100800 | Cobbler Brook Near Merrimac, Ma | 0.77 | 40.0 |
| MA | 1104900 | Mill Brook At Westwood, Ma | 1.52 | 43.0 |
| MA | 1123160 | Wales Brook Tributary Near Wales, Ma | 0.73 | 46.0 |
| MA | 1124050 | Tufts Branch At Dudley, Ma | 1.10 | 42.0 |
| MA | 1124750 | Browns Brook Near Webster, Ma | 0.49 | 42.0 |
| MA | 1161300 | Millers Brook At Northfield, Ma | 2.30 | 44.0 |
| MA | 1165000 | East Branch Tully River Near Athol, Ma | 50.5 | 42.2 |
| MA | 1169900 | South River Near Conway, Ma | 24.1 | 47.0 |
| MA | 1170100 | Green River Near Colrain, Ma | 41.4 | 46.0 |
| MA | 1170200 | Allen Brook Near Shelburne Falls, Ma | 0.72 | 45.0 |
| MA | 1170900 | Mill River Near South Deerfield, Ma | 6.42 | 45.0 |
| MA | 1171200 | Scarboro Brook At Dwight, Ma | 2.90 | 44.0 |
| MA | 1171910 | Broad Brook Near Holyoke, Ma | 2.27 | 46.0 |
| MA | 1173040 | Pleasant Brook Near Barre, Ma | 1.22 | 44.0 |
| MA | 1173260 | Moose Brook Near Barre, Ma | 4.63 | 43.0 |
| MA | 1173330 | Fish Brook Near Gilbertville, Ma | 1.20 | 43.0 |
| MA | 1174000 | Hop Brook Near New Salem, Ma | 3.39 | 44.5 |
| MA | 1174600 | Cadwell Creek Near Pelham, Ma | 0.60 | 45.0 |
| MA | 1174900 | Cadwell Creek Near Belchertown, Ma | 2.55 | 45.0 |
| MA | 1175600 | Caruth Brook Near Paxton, Ma | 2.27 | 44.0 |
| MA | 1176450 | Roaring Brook Near Belchertown, Ma | 2.74 | 46.0 |
| MA | 1178230 | Mill Brook At Plainfield, Ma | 4.45 | 48.0 |
| MA | 1180000 | Sykes Brook At Knightville, Ma | 1.73 | 44.0 |
| MA | 1180800 | Walker Brook Near Becket Center, Ma | 2.94 | 47.0 |
| MA | 1184900 | Haley Pond Outlet Near Otis, Ma | 0.26 | 50.0 |
| MA | 1196990 | Windsor Brook Tributary At Windsor, Ma | 0.30 | 47.0 |
| MA | 1197050 | Churchill Brook At Pittsfield, Ma | 1.16 | 46.0 |
| MA | 1197155 | Housatonic River Tributary No. 2 At Lee, Ma | 0.73 | 46.0 |
| MA | 1197300 | Marsh Brook At Lenox, Ma | 2.12 | 46.0 |
| MA | 1198000 | Green River Near Great Barrington, Ma | 51.0 | 44.2 |
| MA | 1331400 | Dry Brook Near Adams, Ma | 7.67 | 48.0 |
| CT | 1119255 | Delphi Bk Nr Staffordville, Ct. | 2.59 | 45.0 |
| CT | 1119360 | Conat Bk At W Willington, Ct. | 2.40 | 43.0 |
| CT | 1119450 | Eagleville Bk At Storrs, Ct. | 0.36 | 43.0 |
| CT | 1119600 | Ash Bk Nr N Coventry, Ct. | 2.79 | 43.0 |
| CT | 1120500 | Safford Bk Nr Woodstock Valley, Ct. | 4.15 | 44.0 |
| CT | 1121000 | Mount Hope River Near Warrenville, Ct. | 28.6 | 43.5 |
| CT | 1121300 | Fenton R At East Willington, Ct. | 11.4 | 43.5 |
| CT | 1122680 | Merrick Bk Nr Scotland, Ct. | 5.21 | 43.0 |
| CT | 1125300 | English Neighborhood Bk At N Woodstock, Ct. | 4.66 | 45.0 |
| CT | 1125650 | Wappoquia Bk Nr Pomfret,Ct. | 4.21 | 44.0 |
| CT | 1125900 | Cady Bk At East Putnam, Ct. | 8.29 | 44.0 |

| State | Station | Name | Drainage Area (mi2) | Mean Annual Precip (in) |
|---|---|---|---|---|
| CT | 1126600 | Blackwell Bk Nr Brooklyn, Ct. | 17.0 | 43.0 |
| CT | 1127700 | Trading Cove Bk Nr Thamesville, Ct. | 8.46 | 45.5 |
| CT | 1127760 | Hunts Bk At Old Norwich Rd At Quaker Hill, Ct | 11.5 | 47.0 |
| CT | 1184300 | Gillette Bk At Somers, Ct. | 3.64 | 43.5 |
| CT | 1188000 | Burlington Brook Near Burlington, Ct. | 4.10 | 48.0 |
| CT | 1189000 | Pequabuck R At Forestville, Ct. | 45.8 | 47.0 |
| CT | 1189390 | E.Br.Salmon Bk At Granby,Ct. | 39.5 | 44.0 |
| CT | 1192600 | South Branch Salmon Bk At Buckingham, Ct. | 0.94 | 43.5 |
| CT | 1192800 | Parmalee Bk Nr Durham, Ct. | 2.79 | 45.5 |
| CT | 1193120 | Ponset Bk Nr Higganum, Ct | 5.72 | 47.0 |
| CT | 1193800 | Hemlock Valley Bk At Hadlyme, Ct. | 2.62 | 47.0 |
| CT | 1194000 | Eightmile R At North Plain, Ct. | 20.1 | 47.0 |
| CT | 1195000 | Menunketesuck R Nr Clinton, Ct. | 11.2 | 45.0 |
| CT | 1196600 | Willow Bk Nr Cheshire, Ct. | 9.34 | 46.0 |
| CT | 1199150 | Furnace Bk At Cornwall Bridge,Ct. | 13.3 | 42.5 |
| CT | 1199200 | Guinea Bk At West Woods Rd At Ellsworth, Ct | 3.50 | 42.0 |
| CT | 1201190 | West Aspetuck R At Sand Rd Nr New Milford, Ct | 23.8 | 43.0 |
| CT | 1201890 | Pond Bk Nr Hawleyville, Ct. | 11.9 | 45.0 |
| CT | 1202700 | Butternut Bk Nr Litchfield, Ct. | 2.42 | 44.0 |
| CT | 1203100 | Jacks Bk Nr Roxbury Falls, Ct | 7.90 | 44.5 |
| CT | 1203600 | Nonewaug River At Minortown, Ct. | 17.7 | 44.5 |
| CT | 1203700 | Wood Ck Nr Bethlehem, Ct. | 3.39 | 44.0 |
| CT | 1204800 | Copper Mill Bk Nr Monroe, Ct. | 2.45 | 47.0 |
| CT | 1208100 | Hancock Bk Nr Terryville, Ct. | 1.18 | 47.0 |
| CT | 1208400 | Hop Bk Nr Middlebury,Ct. | 9.43 | 46.0 |
| CT | 1208700 | Little R At Oxford, Ct. | 4.54 | 47.0 |
| CT | 1208950 | Sasco Brook Near Southport, Ct. | 7.38 | 45.0 |
| CT | 1209770 | Fivemile R Nr Norwalk,Ct. | 8.96 | 46.5 |
| CT | 1211700 | E Br Byram R At Round Hill, Ct. | 1.69 | 46.5 |