

Estimating the Magnitude of Peak Flows for Streams in Maine for Selected Recurrence Intervals

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U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 99-4008



Prepared in cooperation with the

MAINE DEPARTMENT OF TRANSPORTATION

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by Glenn Hodgkins

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Augusta, Maine
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U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONTENTS

| | |
|---|----|
| Abstract..... | 1 |
| PART 1: PURPOSE AND USE OF THIS REPORT..... | 1 |
| Introduction | 1 |
| Choosing the appropriate section of this report to obtain estimated peak flows | 2 |
| PART 2: ESTIMATING THE MAGNITUDE OF PEAK FLOWS | 4 |
| Section 1: Estimates of peak flows and maximum recorded flows at USGS streamflow-gaging stations | 4 |
| Data used for the estimates | 4 |
| Development of the estimates..... | 4 |
| Presentation of the estimates | 6 |
| Limitations and accuracy of the estimates..... | 6 |
| Section 2: Estimating peak flows for ungaged, unregulated streams in rural drainage basins..... | 18 |
| Data used for the technique | 18 |
| Development of the technique..... | 19 |
| Application of the technique..... | 22 |
| Limitations and accuracy of the technique..... | 24 |
| Advanced accuracy analysis | 25 |
| Comparison of estimated peak flows for ungaged, unregulated streams in rural drainage basins computed using Maine Department of Transportation and USGS techniques | 27 |
| Section 3: Estimating peak flows for ungaged, unregulated streams in rural drainage basins— Simplified technique..... | 29 |
| Application of the simplified technique..... | 29 |
| Limitations and accuracy of the simplified technique | 30 |
| Section 4: Estimating peak flows for ungaged sites on gaged, unregulated streams in rural drainage basins | 30 |
| Application of the technique..... | 31 |
| Limitations of the technique | 32 |
| Section 5: Estimating peak flows for ungaged, unregulated streams in urbanized drainage basins..... | 32 |
| Application of the technique..... | 32 |
| Limitations and accuracy of the technique..... | 36 |
| Section 6: Estimating peak flows for ungaged sites on regulated streams | 37 |
| PART 3: SUPPLEMENTAL INFORMATION | 38 |
| References cited..... | 38 |
| Appendix—Detailed descriptions of gaging-station locations | 39 |

FIGURES

| | |
|---|----|
| 1. Flowchart for choosing the appropriate means of obtaining estimated peak flows in Maine | 3 |
| 2. Map of U.S. Geological Survey streamflow-gaging stations used to estimate the magnitude of peak flows for streams in Maine..... | 7 |
| 3. Graph of two-dimensional range of explanatory variables for the full regression equations..... | 25 |
| 4. Map of National Weather Service 2-hour, 2-year rainfall for Maine | 34 |
| 5. Schematic of typical drainage-basin shapes and subdivision into basin thirds | 35 |

TABLES

| | |
|--|----|
| 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations | 8 |
| 2. Drainage areas and percentage of basin wetlands for 70 gaging stations used in regression equations..... | 20 |
| 3. Full regression equations and their accuracy for estimating peak flows for ungaged, unregulated streams in rural drainage basins in Maine..... | 23 |
| 4. Estimated model error variance and average sampling error variance for the full regression equations | 26 |
| 5. $(\mathbf{X}^T \mathbf{A}^{-1} \mathbf{X})^{-1}$ matrices for the n-year full regression equations..... | 27 |
| 6. Accuracy comparison of Maine Department of Transportation and USGS techniques to estimate 50-year peak flows for ungaged, unregulated streams in rural drainage basins using weighted-average flows as true flows | 28 |
| 7. Accuracy comparison of Maine Department of Transportation and USGS techniques to estimate 50-year peak flows for ungaged, unregulated streams in rural drainage basins using gaging-station flows as true flows | 28 |
| 8. Simplified regression equations and their accuracy for estimating peak flows for ungaged, unregulated streams in rural drainage basins in Maine..... | 29 |
| 9. Urban regression equations and their accuracy for estimating peak flows | 33 |
| 10. Ranges of explanatory variables used in the urban regression equations | 37 |

CONVERSION FACTORS AND UNIT ABBREVIATIONS

| Multiply | By | To obtain |
|---|---------|--|
| meter (m) | 3.281 | foot |
| kilometer (km) | 0.6215 | mile |
| square kilometer (km ²) | 0.3861 | square mile |
| cubic meter (m ³) | 35.31 | cubic foot |
| cubic meter per second (m ³ /s) | 35.31 | cubic foot per second |
| cubic meter per square kilometer (m ³ /km ²) | 91.45 | cubic foot per square mile (ft ³ /mi ²) |
| inch (in) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile (mi ²) | 2.590 | square kilometer |
| cubic foot per second (ft ³ /s) | 0.02832 | cubic meter per second |

Estimating the Magnitude of Peak Flows for Streams in Maine for Selected Recurrence Intervals

by Glenn Hodgkins

ABSTRACT

This report gives estimates of, and presents techniques for estimating, the magnitude of peak flows for streams in Maine for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. A flowchart in this report guides the user to the appropriate estimates and (or) estimating techniques for a site on a specific stream.

Section 1, "Estimates of peak flows and maximum recorded flows at USGS streamflow-gaging stations," contains peak-flow estimates and the maximum recorded flows at 98 U.S. Geological Survey (USGS) streamflow-gaging stations. In the development of the peak-flow estimates at gaging stations, a new generalized skew coefficient was calculated for Maine. This single statewide value of 0.029 (with a standard error of prediction of 0.297) is more accurate for Maine than the national skew isoline map in Bulletin 17B of the Interagency Advisory Committee on Water Data.

Two techniques are presented to estimate the peak flows for ungaged, unregulated streams in rural drainage basins. These two techniques were developed using generalized least squares regression procedures at 70 USGS gaging stations in Maine and eastern New Hampshire. Section 2, "Estimating peak flows for ungaged, unregulated streams in rural drainage basins," uses the final explanatory variables of drainage area and basin wetlands. The average standard error of prediction for the 100-year peak flow regression equation in section 2 was 48.6 percent to -32.7 percent. Drainage area was the only explanatory variable used in section 3, "Estimating peak flows for ungaged,

unregulated streams in rural drainage basins—Simplified technique." The average standard error of prediction for the 100-year peak flow regression equation in section 3 was 80.3 percent to -44.5 percent.

Section 4 of the report describes techniques for estimating peak flows for ungaged sites on gaged, unregulated streams in rural drainage basins. Section 5, "Estimating peak flows for ungaged, unregulated streams in urbanized drainage basins," describes regression equations for use when a drainage basin is urbanized. These urban regression equations come from a previous USGS nationwide study. As stated in section 6, because peak flows on regulated streams are dependent on variable human actions, estimating peak flows at ungaged sites on regulated streams is beyond the scope of this report.

PART 1: PURPOSE AND USE OF THIS REPORT

INTRODUCTION

Estimates of the magnitude of peak streamflows (such as the 50-year-recurrence-interval peak flow) are necessary to safely and economically design bridges, culverts, and other structures that are in or near streams. These estimates are also needed by Federal, State, regional, and local officials for effective floodplain management. This report, prepared by the U.S. Geological Survey (USGS) in cooperation with the Maine Department of Transportation (MDOT), will help MDOT and many others better estimate the magnitude of peak flows for streams in Maine.

This report gives estimates of, and presents techniques for estimating, the magnitude of peak flows for streams in Maine for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. Peak flows and the maximum recorded flows are listed for USGS streamflow-gaging stations with 10 years or more of recorded flows. Two techniques are presented for estimating the peak flows for ungaged, unregulated streams in rural drainage basins. Techniques also are described for estimating peak flows at ungaged sites on gaged streams (for unregulated sites in rural drainage basins) and for estimating peak flows on ungaged, unregulated streams in urbanized drainage basins. A technique for estimating peak flows for ungaged sites on regulated streams is beyond the scope of this report, although a possible approach is mentioned and cautions about inappropriate approaches are given.

Many peak-flow studies have been published for Maine and New England since the 1940's, including Morrill (1975) and Benson (1962). The estimates and estimating techniques in this report should provide more accurate estimates of peak flows for Maine than previous reports because of the use of additional data and more rigorous statistical procedures.

The following USGS employees provided significant help analyzing the data, reviewing the data, and (or) preparing the final report: William P. Bartlett Jr., Robert W. Dudley, Laura E. Flight, Gloria L. Morrill, and Joseph P. Nielsen. Gary D. Tasker wrote the computer program that is included in this report and provided very helpful guidance on many complex technical issues.

This report would not be possible without nearly 100 years of peak-flow data collection, often under hazardous conditions, by USGS hydrologic technicians and hydrologists. This historical data collection was funded primarily by the USGS and the State of Maine.

CHOOSING THE APPROPRIATE SECTION OF THIS REPORT TO OBTAIN ESTIMATED PEAK FLOWS

Peak flows in this report refer to peak flows of a specified recurrence interval. The recurrence interval is the *average* period of time between peak flows that are equal to or greater than a specified peak flow. For example, the 50-year peak flow is the flow that would be equaled or exceeded, on long-term average, once in 50 years. This does not imply, however, that flooding will happen at regular intervals. Two 50-year peak flows could occur in the same year. In contrast, a 50-year peak flow might not occur in 100 years.

The reciprocal of the recurrence interval is called the annual exceedance probability; that is, the probability that a given peak flow will be equaled or exceeded in any given year. For example, the annual exceedance probability of the 50-year peak flow would be 0.02. In other words, there is a 2 percent chance that the 50-year peak flow will be equaled or exceeded in any given year.

To obtain estimated peak flows for streams in Maine, information on the site (site refers to a location on a stream) of interest is needed, including whether the site is at or near (and on the same stream as) a U.S. Geological Survey (USGS) streamflow-gaging station and whether the site drains an urbanized or regulated drainage basin. The different peak-flow estimates and estimating techniques in this report are appropriate to various combinations of these site characteristics.

The flowchart in figure 1 should be used to choose the appropriate method of obtaining estimated peak flows. The boxes in the right column of the flowchart show the appropriate section of the report for obtaining the peak flows. The "Limitations and accuracy" statements in each section should be read before applying that section. Although the discussions on limitations are intended to be comprehensive, it is possible that other specific limitations will arise in the application of these sections. Figure 1 does not show an option for ungaged sites on gaged, unregulated streams in urbanized drainage basins because no current (1998) or historical urbanized streamflow gages exist in Maine.

The following definitions apply to figure 1:

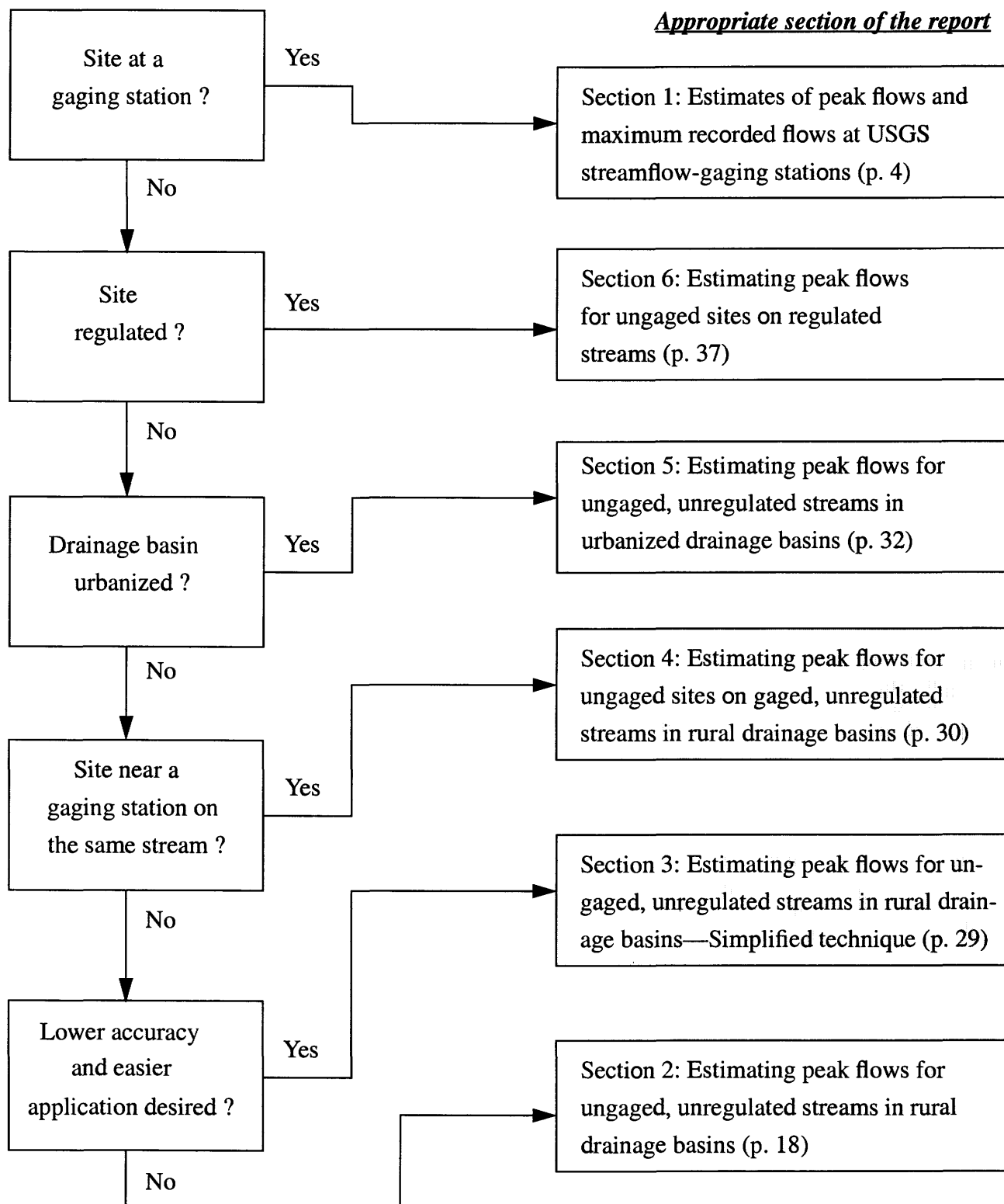
Site at a gaging station—the drainage area of the study site is within 3 percent of the drainage area of a USGS streamflow-gaging station and on the same stream (see figure 2 for a map of the gaging stations and the appendix for detailed descriptions of the gaging station locations);

Regulated—the drainage basin above the site contains more than 49,200 cubic meters of usable reservoir storage per square kilometer (Benson, 1962) (usable reservoir storage is the volume of water normally available for release from a reservoir, between the minimum and maximum controllable elevations);

Urbanized—more than 15 percent of the drainage-basin area above the site is covered by some type of commercial, industrial, or residential development;

Site near a gaging station—the drainage area of the site is between 50 and 200 percent of the drainage area of a USGS gaging station (excluding the plus or minus 3 percent considered "at a gaging station") and on the same stream.

Figure 1. Flowchart for choosing the appropriate means of obtaining estimated peak flows in Maine



PART 2: ESTIMATING THE MAGNITUDE OF PEAK FLOWS

Section 1: Estimates of peak flows and maximum recorded flows at USGS streamflow-gaging stations

The 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows for streamflow-gaging stations discussed in this section were calculated using the guidelines (Bulletin 17B) of the Interagency Advisory Committee on Water Data (1982). The calculations involved fitting the Pearson Type III probability distribution to the logarithms (base 10) of the observed annual peak flows at a gaging station. This required computation of the mean, standard deviation, and skew of the logarithms of the annual peak-flow data. The peak flow for any selected recurrence interval was determined from the fitted curve.

Data used for the estimates

The USGS has been collecting and publishing streamflow data for gaging stations in Maine since 1901. The data currently are published by the USGS in the annual report series titled “Water Resources Data—Maine.” The data from 99 Maine stations, 6 New Hampshire stations, and 1 New Brunswick station (106 total stations) that have at least 10 years of recorded annual peak flows were considered for use in this section of the report. Annual peak flows available at streamflow-gaging stations through September 30, 1996 were used, except for six stations: Presumpscot River at Westbrook, Maine (USGS gaging station number 01064118); Diamond River near Wentworth Location, New Hampshire (01052500); Wild River at Gilead, Maine (01054200); Big Black River near Depot Mountain, Maine (01010070); Dennys River at Dennysville, Maine (01021200); and Oyster River near Durham, New Hampshire (01073000). More recent data were used at these stations because of large peak flows that occurred after September 30, 1996. The peak flows from the Oyster River are not reported in this section because they are not relevant by themselves for estimating peak flows in Maine.

The peak flows from several gaging stations are not reported for various reasons. The data at two stations were combined into one station if the drainage area for a station was less than 10 percent different from the drainage area of another station and if doing

so appeared reasonable on the basis of the data. A drainage-area correction (Morrill, 1975) was applied when combining the stations if the drainage areas differed by 3 to 10 percent. Drainage area corrections were not applied to stations for which the drainage areas differed by less than 3 percent. The following stations were combined: Mattawamkeag River at Mattawamkeag (01031000) combined into Mattawamkeag River near Mattawamkeag (01030500); Kenduskeag Stream near Bangor (01037000) combined into Kenduskeag Stream near Kenduskeag (01036500); Kennebec River at North Sidney (01049265) combined into Kennebec River near Waterville (01049205); and Saco River at Salmon Falls (01067500) combined into Saco River at West Buxton (01067000).

The peak flows for St. John River above Fish River at Fort Kent (01012500) and St. John River at Van Buren (01015000) are not reported because the annual peak flows at these stations appear to have been collected during an unrepresentative short period when compared to other St. John River stations. Similarly, peak flows for Penobscot River at Eddington (01036390) are not reported because the annual peak flows at this station appear to come from an unrepresentative short period when compared to those at Penobscot River at West Enfield (01034500). The peak flows for St. Croix River near Baileyville (01020000) are not reported because the peak flows at St. Croix River at Baring (01021000) appeared more reasonable. The logarithms of the annual peak flows at Baring appeared to fit a Pearson type III distribution better than those at Baileyville.

Development of the estimates

The guidelines (Bulletin 17B) of the Interagency Advisory Committee on Water Data (1982) require that the peak-flow data used for statistical analysis at a gaging station be a reliable and representative sample of random, homogeneous events. The annual peak flows at gaging stations in this report are assumed to be random, reliable, and independent of each other.

The peak flows in a drainage basin will not be homogeneous if the hydrologic conditions in the basin change significantly over time because of urbanization or other human activities. A two-sided Mann-Kendall trend test (Helsel and Hirsch, 1992) was performed on the annual peak flows at most gaging stations to test for changes in drainage basins over time. To produce accurate results for the significance of a trend, this test

requires that the data have no correlation over time (serial correlation). Annual peak-flow data can exhibit some serial correlation. This correlation can cause the Mann-Kendall trend test to indicate a significant trend when there is none, especially at gaging stations with less than 30 years of peak-flow data (G.D. Tasker, U.S. Geological Survey, written commun., 1997). For this reason, some judgement is necessary to determine whether the results of the Mann-Kendall trend test are significant. The Mann-Kendall test was not performed at stations with 10 to 15 years of peak-flow data because trends cannot be distinguished from serial correlation at stations with this length of data. No gaging stations in this study were determined to have a significant trend in their annual peak-flow data. The annual peak flows at all stations were also plotted to look for large changes in the distribution of peak flows over time, especially at gaging stations whose basins are regulated.

In the Bulletin 17B analyses, the sample of annual peak flows from a gaging station is assumed to be representative of future peak flows. Therefore, use of all peak flows from a gaging station is not always appropriate. There are several regulated gaging stations in Maine where significant regulation was added (sometimes in addition to significant regulation already in place) during the period for which annual peak flows are available. The older, less regulated annual peak flows were not used in the Bulletin 17B analyses if the drainage basin regulation, at the time of the older peaks, differed by more than 49,200 m³ of usable storage per square kilometer (Benson, 1962) from the regulation at the time of newer peaks. In addition, older peaks were not used if the annual peak-flow data at a station indicated that the regulation of peak flows had changed significantly over time.

Bulletin 17B guidelines were followed for the treatment of high and low outliers, for the conditional probability adjustment, for the adjustment for historical information, and for weighting the station skew coefficient with a generalized skew coefficient. In some cases, multiple low outliers that were near, but not below, the Bulletin 17B low outlier threshold were censored (dropped from the data set) if doing so improved the fit between the logs of the observed annual peaks and the Pearson Type III distribution. Most of the historical information used in this study came from Thomson and others (1964). The station skew was not weighted with the generalized skew if the annual peak flows at a gaging station were significantly affected by

regulation. A station was considered significantly regulated if its drainage basin had more than 49,200 m³ of usable storage per square kilometer (Benson, 1962). The annual peak flows from the gaging stations in this study did not show obvious evidence of being caused by multiple generating mechanisms. The procedures used to handle this situation were therefore not used. Expected probability adjustments were not made. These adjustments are explained in Bulletin 17B.

A generalized skew coefficient was developed for Maine. This new skew coefficient is 0.029, with a mean square error of prediction of 0.088 (or a standard error of prediction of 0.297). To compute this skew coefficient, the station skews from 44 gaging stations (37 in Maine, 6 in New Hampshire, and 1 in New Brunswick) were computed using the procedures in Bulletin 17B. None of these stations are significantly affected by regulation, diversions, or urbanization. At least 25 years of annual peak-flow data were available for all stations, except for five stations that were included to increase the representation of small-drainage-area stations. The 44 stations had an average of 53 years of annual peak-flow data. The five small-drainage-area stations had an average of 18 years of annual peak-flow data. The computed station skews were adjusted for bias (Tasker and Stedinger, 1986).

Four methods were tested to find the most accurate generalized skew for Maine. The first method was to compute an arithmetic mean of the 44 station skews. The second method was to calculate a weighted mean for the 44 station skews. The weight was the number of annual peak flows at a station divided by the average number of annual peak flows for the 44 stations. In the third method, a state skew isoline map was created by plotting the station skews on a map at the centroid of their drainage basins. In the fourth method, an attempt was made to develop a multiple regression equation with station skew as the response variable and drainage basin characteristics (such as drainage area and stream slope) as the explanatory variables. No significant multiple regression models were found. For the first three methods, the mean square error of prediction was computed using the predicted and observed values of station skew for the 44 stations in this analysis. The weighted mean skew had the smallest mean square error and was therefore considered the most accurate generalized skew.

The accuracy of the new Maine generalized skew (the weighted mean skew) was compared to the accuracy of the Bulletin 17B generalized skew (the

national skew isoline map). The national skew isoline map was used to predict the station skews for the 44 stations used in the previous skew analyses. The mean square error of prediction was then computed. The Bulletin 17B generalized skew had a much larger mean square error of prediction (0.188) than the new Maine generalized skew (0.088).

Recorded peak flows at individual gaging stations, especially those with short periods of records, may not be representative of peak flows from longer periods of record. Because of this, peak flows for given recurrence intervals at each gaging station were combined with the regression-equation peak flows at that station to compute the best estimate of peak flows for that station. If two independent estimates are weighted inversely proportional to their variances, the variance of the weighted average is less than the variance of either estimate (Interagency Advisory Committee on Water Data, 1982). In other words, the weighted average will produce the most accurate estimates (number of years of record is inversely proportional to variance and thus the weighting in equation 1 becomes direct with years of record). The weighted-average peak flow (Q_w) was calculated using the following equation:

$$Q_w = ((Q_g)(n) + (Q_r)(e)) / (n + e), \quad (1)$$

where

Q_g is the gaging-station peak flow for a given recurrence interval, calculated by the methods described in this section,

n is the number of annual peak flows at a gaging station,

Q_r is the regression-equation peak flow calculated by the methods in section 2, "Estimating peak flows for ungaged, unregulated streams in rural drainage basins", and

e is the average equivalent years of record for the appropriate regression equations. Equivalent years of record are listed and defined in section 2.

Presentation of the estimates

The peak flows for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years at USGS streamflow-gaging stations with 10 years or more of record (with the exceptions noted in "Data used for the estimates") are listed in table 1. Three different peak flows are given (where appropriate) for unregulated stations: the gaging-station estimate (G), the regression-equation

estimate (R), and a weighted average (W) of these two estimates. As discussed in "Development of the estimates", the weighted average is the most accurate peak-flow estimate for each gaging station. For regulated stations, the regression-equation estimate cannot be weighted with the gaging-station estimate because the regression equations do not apply to regulated stations. Regression estimates were not computed for stations that include Canadian drainage. Also included in table 1 are the USGS gaging-station number and name, the magnitude and date of the highest peak flow known at the gaging station, the period of known peak flows (the period includes recorded peak flows at the gaging station and relevant historical information at or near the gaging station), the regulated or unregulated status of the station, and the drainage-basin area for the gaging station. Detailed location descriptions for the gaging stations are in the Appendix. Station locations are shown in figure 2.

Limitations and accuracy of the estimates

The recorded annual peak flows used to compute the peak flows for given recurrence intervals at gaging stations in this section are assumed to be representative of recorded and unrecorded peaks. Generally, more years of data at a station lead to more accurate estimates of peak flows. The estimated peak flows at gaging stations will not be reliable if the drainage basin of a station becomes significantly more regulated or urbanized than it was during the period used to calculate the peak flows. In addition, if the flow management at a regulated station (a station with more than 49,200 m³ of usable storage per square kilometer) changes, the estimated peak flows presented in this section may not apply, depending on the magnitude of the changes. The actual peak flows at stations were analyzed to identify significant changes in flow management. Subtle or recent changes in flow management may have gone undetected.

If an extreme flood did not occur at a regulated station during the period of streamflow-data collection for that station, the estimated peak flows may seriously underestimate the true peak flows. This underestimation could occur because a very large inflow to a reservoir may cause outflows to be regulated differently than at any time in the past.

The estimated peak flows in this section do not consider the possibility of dam failures on peak flows. The peak flows on streams with dams that store large quantities of water could be significantly greater than the given peak flows if a dam failure occurs.



Figure 2. U.S. Geological Survey streamflow-gaging stations used to estimate the magnitude of peak flows for streams in Maine.

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regression (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regulation ^c | Drainage area (km ²) |
|----------------------------|--|---|---|----------------------|----------------------|----------------------|----------------------|-----------------------|-------------------------|-------------------------|--------------------------|---|-------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01010000 | St. John River at Ninemile Bridge, Maine | G | 686 | 895 | 1,030 | 1,180 | 1,290 | 1,400 | 1,640 | 5-1-1974 | 1,260 | 1948-96 | u | 3,470 |
| 01010070 | Big Black River nr Depot Mountain, Maine | G | 121 | 173 | 209 | 255 | 290 | 325 | 409 | 4-1-1987 | 246 | 1983-97 | u | 443 |
| 01010500 | St. John River at Dickey, Maine | G | 1,410 | 1,880 | 2,180 | 2,550 | 2,820 | 3,080 | 3,690 | 4-29-1979 | 2,600 | 1943-96 | u | 6,940 |
| 01011000 | Allagash River nr Allagash, Maine | G R W | 418 563 422 | 574 781 582 | 677 928 689 | 806 1,120 825 | 902 1,260 926 | 997 1,400 1,030 | 1,220 1,740 1,270 | 4-18-1983 | 1,040 | 1931-96 | u | 3,180 |
| 01011500 | St. Francis River at outlet of Glasier Lake, nr Connors, New Brunswick, Canada | G | 201 | 272 | 319 | 378 | 421 | 464 | 567 | 4-30-1979 | 425 | 1951-96 | u | 1,360 |
| 01013500 | Fish River nr Fort Kent, Maine | G R W | 232 290 233 | 294 394 297 | 332 462 338 | 377 549 386 | 409 615 422 | 439 679 456 | 508 834 535 | 4-30-1973 | 447 | 1903-08, 1929-96 | u | 2,660 |
| 01014000 | St. John River below Fish River, at Fort Kent, Maine | G | 2,310 | 2,950 | 3,350 | 3,830 | 4,180 | 4,510 | 5,270 | 4-30-1979 | 4,280 | 1897-1996 | u | 14,700 |
| 01014700 | Factory Brook nr Madawaska, Maine | G R W | 4.50 9.09 5.15 | 6.14 15.1 7.78 | 7.23 19.7 10.1 | 8.62 26.3 13.4 | 9.66 31.6 16.3 | 10.7 37.2 19.4 | 13.2 51.8 27.4 | 5-2-1974 | 7.96 | 1963-74 | u | 15.2 |
| 01015700 | Houlton Brook nr Oxbow, Maine | G R W | 3.46 2.76 3.36 | 4.76 4.19 4.66 | 5.64 5.22 5.54 | 6.75 6.59 6.71 | 7.59 7.69 7.62 | 8.43 8.81 8.56 | 10.4 11.6 10.8 | 4-29-1973 | 6.68 | 1963-74 | u | 14.1 |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued

[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regres-sion (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regula-tion ^c | Drainage area (km ²) |
|----------------------------|---|--|---|----------------------|-----------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|--------------------------|---|--------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01015800 | Aroostook River nr Masardis, Maine | G R W | 373 324 371 | 500 443 497 | 581 522 577 | 680 622 674 | 752 698 746 | 822 773 816 | 982 954 978 | 4-19-1983 | 654 | 1957-96 | u | 2,310 |
| 01016500 | Machias River nr Ashland, Maine | G R W | 175 191 176 | 248 276 250 | 298 335 301 | 365 411 370 | 416 470 423 | 468 530 477 | 597 675 610 | 6-29-1954 | 470 | 1951-83 | u | 852 |
| 01017000 | Aroostook River at Washburn, Maine | G R W | 662 617 661 | 877 839 876 | 1,020 985 1,010 | 1,180 1,170 1,180 | 1,310 1,310 1,310 | 1,430 1,450 1,430 | 1,710 1,780 1,710 | 4-19-1983 | 1,230 | 1930-96 | u | 4,280 |
| 01017300 | Nichols Brook nr Caribou, Maine | G R W | 2.98 4.44 3.19 | 4.79 7.23 5.24 | 6.14 9.34 6.86 | 8.00 12.3 9.17 | 9.49 14.7 11.1 | 11.1 17.2 13.1 | 15.1 23.6 18.2 | 10-3-1970 | 7.96 | 1963-74 | u | 10.3 |
| 01017900 | Marley Brook nr Ludlow, Maine | G R W | 2.40 3.16 2.47 | 4.03 5.51 4.21 | 5.30 7.38 5.62 | 7.14 10.1 7.69 | 8.65 12.3 9.42 | 10.3 14.8 11.3 | 14.7 21.2 16.4 | 7-5-1973 | 9.49 | 1964-82 | u | 3.81 |
| 01018000 | Meduxnekeag River nr Houlton, Maine | G R W | 94.7 65.2 93.5 | 135 91.6 133 | 163 110 159 | 198 133 192 | 225 150 217 | 252 168 242 | 317 211 303 | 4-3-1976 | 188 | 1940-82 | u | 453 |
| 01018500 | St. Croix River at Vanceboro, Maine | G | 91.6 | 149 | 185 | 228 | 257 | 284 | 340 | 6-3-1984 | 191 | 1928-96 | r | 1,070 |
| 01019000 | Grand Lake Stream at Grand Lake Stream, Maine | G | 40.2 | 54.2 | 62.2 | 71.1 | 76.9 | 82.2 | 92.8 | 6-12-1952 | 80.4 | 1928-96 | r | 588 |
| 01021000 | St. Croix River at Baring, Maine | G | 331 | 449 | 524 | 614 | 679 | 742 | 884 | 5-1-1923 | 683 ^d | 1881-1996 | r | 3,560 |
| 01021200 | Dennys River at Dennyville, Maine | G | 41.2 | 57.7 | 69.9 | 87.0 | 101 | 116 | 155 | 4-30-1973 | 111 | 1955-98 | r | 241 |
| 01021300 | Wiggins Brook nr West Lubec, Maine | G R W | 7.59 4.24 7.07 | 11.6 6.71 10.6 | 14.5 8.55 13.1 | 18.5 11.1 16.3 | 21.6 13.1 18.8 | 25.0 15.2 21.6 | 33.6 20.6 28.5 | 12-12-1967 | 22.1 | 1964-74 | u | 13.0 |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued

[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regres-sion (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regula-tion ^c | Drainage area (km ²) |
|----------------------------|--|--|---|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-------------------------|--------------------------|---|--------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01021500 | Machias River at Whitneyville, Maine | G R W | 170 168 170 | 229 233 229 | 270 276 270 | 322 331 323 | 362 373 363 | 403 414 404 | 504 514 505 | 5-29-1961 | 419 | 1905-21, 1929-77 | u | 1,190 |
| 01021600 | Middle River nr Machias, Maine | G R W | 5.71 6.12 5.77 | 7.35 9.51 7.78 | 8.39 12.0 9.27 | 9.66 15.4 11.3 | 10.6 18.1 13.0 | 11.5 20.9 14.8 | 13.5 27.9 19.1 | 4-2-1970 | 8.55 | 1964-74 | u | 21.4 |
| 01022000 | East Machias River nr East Machias, Maine | G R W | 58.0 61.5 58.2 | 73.3 83.1 74.0 | 82.8 97.3 84.1 | 94.4 115 96.8 | 103 129 106 | 111 142 115 | 129 174 137 | 12-15-1950 | 104 | 1926-58 | u | 648 |
| 01022260 | Pleasant River nr Epping, Maine | G R W | 24.2 15.2 22.9 | 30.1 21.0 28.4 | 33.7 24.9 31.7 | 38.0 29.8 35.8 | 41.0 33.6 38.8 | 43.9 37.4 41.8 | 50.4 46.5 49.0 | 5-13-1989 | 35.1 | 1980-91 | u | 157 |
| 01022500 | Narraguagus River at Cherryfield, Maine | G R W | 116 95.5 115 | 162 135 161 | 194 162 192 | 234 196 231 | 265 223 261 | 297 250 292 | 373 314 366 | 5-28-1961 | 295 | 1947-96 | u | 588 |
| 01022700 | Forbes Pond Brook nr Prospect Harbor, Maine | G R W | 6.04 4.91 5.87 | 9.20 7.42 8.85 | 11.4 9.23 10.9 | 14.4 11.6 13.6 | 16.8 13.6 15.8 | 19.1 15.5 17.8 | 25.0 20.4 23.2 | 4-2-1970 | 11.4 | 1964-74 | u | 23.7 |
| 01023000 | West Branch Union River at Amherst, Maine | G R W | 49.9 52.6 50.0 | 67.9 73.7 68.1 | 80.1 88.0 80.5 | 95.7 106 96.4 | 108 120 109 | 120 135 121 | 149 169 151 | 3-25-1979 | 120 | 1908-10, 1911-19, 1929-79 | u | 386 |
| 01024200 | Garland Brook nr Mariaville, Maine | G R W | 12.1 10.3 11.9 | 19.9 16.4 19.5 | 26.2 21.0 25.4 | 35.3 27.3 33.8 | 42.9 32.4 40.7 | 51.3 37.7 48.2 | 74.2 51.2 68.2 | 12-27-1969 | 34.8 | 1964-82 | u | 25.4 |
| 01026800 | Frost Pond Brook nr Sedgwick, Maine | G R W | 4.83 3.58 4.64 | 7.13 5.61 6.83 | 8.72 7.12 8.33 | 10.8 9.16 10.3 | 12.4 10.8 11.9 | 14.0 12.5 13.5 | 17.9 16.8 17.5 | 2-4-1970 | 9.91 | 1964-74 | u | 12.5 |
| 01028000 | West Branch Penobscot River nr Medway, Maine | G | 269 | 419 | 543 | 732 | 900 | 1,090 | 1,660 | 6-16-1917 | 733 | 1916-39 | r | 5,480 |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued

[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regression (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regulation ^c | Drainage area (km ²) |
|----------------------------|--|---|---|----------------------|-----------------------|-----------------------|-----------------------|-------------------------|-------------------------|-------------------------|--------------------------|---|-------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01029500 | East Branch Penobscot River at Grindstone, Maine | G | 385 | 535 | 632 | 754 | 844 | 933 | 1,140 | 4-30-1923 | 1,050 | 1902-82, 1987 | r | 2,810 |
| 01030000 | Penobscot River nr Mattawamkeag, Maine | G | 752 | 1,060 | 1,270 | 1,540 | 1,740 | 1,950 | 2,440 | 4-29-1973 | 1,870 | 1940-96 | r | 8,690 |
| 01030300 | Trout Brook nr Danforth, Maine | G R W | 4.13 3.14 3.98 | 6.81 4.95 6.44 | 8.86 6.28 8.24 | 11.7 8.10 10.6 | 14.1 9.56 12.6 | 16.6 11.1 14.7 | 23.2 14.9 20.0 | 4-25-1970 | 10.0 | 1963-73 | u | 10.8 |
| 01030400 | Gulliver Brook nr Monarda, Maine | G R W | 6.67 5.40 6.49 | 9.63 8.08 9.34 | 11.7 9.99 11.3 | 14.5 12.5 14.0 | 16.7 14.5 16.0 | 18.9 16.6 18.1 | 24.5 21.7 23.5 | 7-5-1973 | 15.9 | 1963-74 | u | 28.5 |
| 01030500 | Mattawamkeag River nr Mattawamkeag, Maine | G R W | 462 353 460 | 609 465 605 | 705 537 699 | 824 626 816 | 912 694 901 | 999 759 986 | 1,200 915 1,190 | 5-1-1923 | 1,320 ^d | 1902-96 | u | 3,670 |
| 01031500 | Piscataquis River nr Dover-Foxcroft, Maine | G R W | 233 161 232 | 351 232 348 | 436 281 431 | 553 344 544 | 645 393 633 | 742 442 726 | 989 562 962 | 4-1-1987 | 1,060 | 1857-1996 | u | 772 |
| 01031600 | Morrison Brook nr Sebec Corners, Maine | G R W | 2.96 4.25 3.12 | 5.44 6.83 5.66 | 7.56 8.77 7.80 | 10.8 11.4 11.0 | 13.7 13.6 13.7 | 17.1 15.9 16.7 | 26.8 21.6 25.1 | 11-3-1966 | 16.3 | 1964-77 | u | 11.3 |
| 01033000 | Sebec River at Sebec, Maine | G | 105 | 150 | 183 | 231 | 269 | 311 | 423 | 3-20-1936 | 405 ^e | 1924-93 | r | 844 |
| 01033500 | Pleasant River nr Milo, Maine | G R W | 234 178 232 | 376 256 371 | 485 310 476 | 643 380 626 | 775 434 750 | 919 488 884 | 1,310 621 1,240 | 11-4-1966 | 810 | 1920-96 | u | 837 |
| 01034000 | Piscataquis River at Medford, Maine | G R W | 601 439 597 | 890 600 880 | 1,100 707 1,080 | 1,380 842 1,350 | 1,610 944 1,560 | 1,840 1,050 1,780 | 2,450 1,290 2,340 | 4-1-1987 | 2,410 | 1847-1996 | u | 3,010 |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued

[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regression (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | | Highest peak flow known | | | Regulation ^c | Drainage area (km ²) |
|----------------------------|---|---|---|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------|--------------------------|---|---|-------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | | |
| 01034500 | Penobscot River at West Enfield, Maine | G | 1,740 | 2,400 | 2,830 | 3,380 | 3,790 | 4,200 | 5,160 | 5-1-1923 | 4,330 | 1854-1996 | r | 17,300 | |
| 01034900 | Coffin Brook nr Lee, Maine | G R W | 1.94 1.80 1.92 | 2.91 2.90 2.91 | 3.61 3.72 3.63 | 4.52 4.85 4.61 | 5.23 5.77 5.39 | 5.97 6.73 6.22 | 7.77 9.19 8.29 | 12-27-1969 | 4.05 | 1963-74 | u | 5.49 | |
| 01035000 | Passadumkeag River at Lowell, Maine | G R W | 57.9 74.3 58.4 | 77.7 100 78.5 | 91.1 117 92.3 | 108 139 110 | 122 155 124 | 135 171 138 | 168 209 172 | 5-2-1923 | 161 | 1915-79 | u | 769 | |
| 01036500 | Kenduskeag Stream nr Kenduskeag, Maine | G R W | 98.0 89.6 97.7 | 134 128 134 | 156 155 156 | 183 190 184 | 203 217 204 | 222 244 224 | 264 310 269 | 4-1-1987 ^f | 210 | 1908-19, 1941-79, 1987 | u | 479 | |
| 01037200 | Shaw Brook ^g nr Northern Maine Junction, Maine | G R W | 5.50 4.53 5.36 | 9.28 7.57 8.97 | 12.3 9.92 11.8 | 16.6 13.2 15.7 | 20.2 16.0 18.9 | 24.2 18.8 22.4 | 34.8 26.3 31.7 | 12-27-1969 | 16.9 | 1963-74 | u | 7.95 | |
| 01037430 | Goose River at Rockport, Maine | G R W | 11.0 9.69 10.8 | 15.8 15.7 15.8 | 19.0 20.1 19.3 | 23.1 26.4 24.0 | 26.1 31.4 27.7 | 29.2 36.7 31.7 | 36.3 50.2 41.4 | 3-23-1972 | 17.7 | 1963-74 | u | 21.4 | |
| 01038000 | Sheepscot River at North Whitefield, Maine | G R W | 57.3 66.1 57.6 | 86.3 94.7 86.6 | 108 114 108 | 139 140 139 | 165 160 165 | 192 180 191 | 266 228 262 | 4-1-1987 | 208 | 1938-96 | u | 376 | |
| 01041000 | Kennebec River at Moosehead, Maine | G | 227 | 321 | 384 | 462 | 520 | 578 | 714 | 5-3-1974, 9-25-1981 | 473 | 1918-82 | r | 1,270 | |
| 01041900 | Mountain Brook nr Lake Parlin, Maine | G R W | 6.32 6.54 6.35 | 10.8 10.9 10.8 | 14.3 14.4 14.3 | 19.5 19.2 19.4 | 24.0 23.1 23.7 | 28.9 27.4 28.4 | 42.5 38.3 40.9 | 7-5-1973 | 26.0 | 1963-74 | u | 10.6 | |
| 01042500 | Kennebec River at The Forks, Maine | G | 351 | 465 | 549 | 665 | 760 | 860 | 1,130 | 6-1-1984 | 858 | 1902-96 | r | 4,120 | |
| 01043500 | Dead River nr Dead River, Maine | G | 214 | 284 | 332 | 394 | 442 | 491 | 610 | 9-12-1954 | 510 | 1939-96 | r | 1,340 | |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued
[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regression (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regulation ^c | Drainage area (km ²) |
|----------------------------|---|---|---|---------|----------|----------|----------|-----------|-----------|-------------------------|--------------------------|---|-------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01045000 | Dead River at The Forks, Maine | G | 294 | 404 | 470 | 547 | 601 | 651 | 758 | 3-20-1936 | 813 | 1903-07, 1911-79 | r | 2,250 |
| 01046000 | Austin Stream at Bingham, Maine | G | 68.0 | 108 | 139 | 182 | 218 | 256 | 359 | 11-3-1966 | 234 | 1931-69 | u | 233 |
| | | R | 64.5 | 96.5 | 119 | 150 | 173 | 198 | 258 | | | | | |
| | | W | 67.8 | 107 | 137 | 179 | 213 | 249 | 344 | | | | | |
| 01046500 | Kennebec River at Bingham, Maine | G | 710 | 1,040 | 1,250 | 1,510 | 1,690 | 1,880 | 2,290 | 6-1-1984 | 1,850 | 1907-10, 1930-96 | r | 2,720 |
| 01046800 | South Branch Carrabassett River at Bigelow, Maine | G | 31.7 | 43.9 | 51.8 | 61.6 | 68.8 | 75.9 | 92.3 | 11-6-1969 | 45.9 | 1963-74 | u | 36.5 |
| | | R | 20.1 | 32.7 | 42.3 | 55.6 | 66.3 | 77.7 | 107 | | | | | |
| | | W | 30.0 | 41.8 | 49.6 | 60.0 | 68.0 | 76.5 | 97.6 | | | | | |
| 01047000 | Carrabassett River nr North Anson, Maine | G | 343 | 533 | 674 | 867 | 1,020 | 1,180 | 1,600 | 4-1-1987 | 1,440 | 1925-96 | u | 914 |
| | | R | 218 | 317 | 385 | 474 | 542 | 612 | 782 | | | | | |
| | | W | 340 | 526 | 662 | 845 | 992 | 1,140 | 1,540 | | | | | |
| 01048000 | Sandy River nr Mercer, Maine | G | 395 | 591 | 726 | 900 | 1,030 | 1,160 | 1,480 | 4-1-1987 | 1,450 | 1776-1996 | u | 1,340 |
| | | R | 300 | 431 | 520 | 637 | 725 | 816 | 1,040 | | | | | |
| | | W | 392 | 585 | 716 | 883 | 1,010 | 1,140 | 1,440 | | | | | |
| 01048100 | Pelton Brook nr Anson, Maine | G | 21.9 | 35.0 | 44.9 | 58.8 | 70.0 | 82.1 | 114 | 12-21-1973 | 58.9 | 1964-74 | u | 38.6 |
| | | R | 17.9 | 28.8 | 37.0 | 48.2 | 57.2 | 66.7 | 90.9 | | | | | |
| | | W | 21.3 | 33.8 | 43.0 | 55.7 | 65.9 | 76.7 | 105 | | | | | |
| 01048500 | Kennebec River at Waterville, Maine | G | 1,390 | 1,910 | 2,300 | 2,830 | 3,270 | 3,740 | 5,000 | 12-16-1901 | 4,450 | 1892-1986 | r | 11,000 |
| 01049000 | Sebasticook River nr Pittsfield, Maine | G | 184 | 249 | 291 | 344 | 383 | 423 | 514 | 4-3-1987 | 498 | 1928-96 | u | 1,480 |
| | | R | 201 | 276 | 327 | 390 | 438 | 486 | 601 | | | | | |
| | | W | 184 | 250 | 293 | 347 | 387 | 428 | 522 | | | | | |
| 01049100 | Hall Brook at Thorndike, Maine | G | 5.78 | 11.3 | 16.3 | 24.2 | 31.4 | 39.9 | 65.2 | 12-27-1969 | 26.4 | 1963-74 | u | 13.3 |
| | | R | 7.59 | 12.6 | 16.4 | 21.8 | 26.2 | 30.9 | 43.0 | | | | | |
| | | W | 6.04 | 11.5 | 16.3 | 23.6 | 29.8 | 37.0 | 57.0 | | | | | |
| 01049130 | Johnson Brook at South Albion, Maine | G | 2.07 | 3.30 | 4.23 | 5.54 | 6.60 | 7.74 | 10.7 | 4-1-1987 | 5.04 | 1980-91 | u | 7.56 |
| | | R | 2.68 | 4.30 | 5.52 | 7.21 | 8.58 | 10.0 | 13.7 | | | | | |
| | | W | 2.16 | 3.48 | 4.52 | 6.00 | 7.20 | 8.49 | 11.8 | | | | | |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued

[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regres-sion (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regula-tion ^c | Drainage area (km ²) |
|----------------------------|--|--|---|---------|----------|----------|----------|-----------|-----------|-------------------------|--------------------------|---|--------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01049205 | Kennebec River nr Waterville, Maine | G | 1,700 | 2,620 | 3,200 | 3,890 | 4,370 | 4,820 | 5,770 | 4-2-1987 | 6,340 ^d | 1761-1996 | r | 13,400 |
| 01049300 | North Branch Tanning Brook nr Manchester, Maine | G | 2.12 | 3.08 | 3.77 | 4.69 | 5.42 | 6.18 | 8.09 | 12-17-1973 | 5.52 | 1963-83 | u | 2.41 |
| | | R | 1.57 | 2.70 | 3.59 | 4.87 | 5.92 | 7.07 | 10.1 | | | | | |
| | | W | 2.07 | 3.04 | 3.74 | 4.72 | 5.52 | 6.37 | 8.57 | | | | | |
| 01049373 | Mill Stream at Winthrop, Maine | G | 8.26 | 14.4 | 19.5 | 27.0 | 33.6 | 40.9 | 61.4 | 4-2-1987 | 37.7 | 1977-92 | u | 84.7 |
| | | R | 16.7 | 24.7 | 30.4 | 37.9 | 43.7 | 49.7 | 64.3 | | | | | |
| | | W | 9.18 | 15.9 | 21.4 | 29.3 | 36.0 | 43.2 | 62.3 | | | | | |
| 01049500 | Cobbosseecontee Stream at Gardiner, Maine | G | 64.7 | 88.0 | 101 | 116 | 126 | 135 | 154 | 3-21-1936 | 142 | 1890-1964, 1976-96 | r | 562 |
| 01049550 | Togus Stream at Togus, Maine | G | 12.0 | 17.9 | 22.2 | 28.1 | 32.7 | 37.6 | 49.9 | 4-1-1987 | 28.6 | 1981-95 | u | 61.4 |
| | | R | 9.55 | 13.9 | 17.0 | 20.9 | 24.1 | 27.2 | 34.9 | | | | | |
| | | W | 11.7 | 17.3 | 21.2 | 26.5 | 30.5 | 34.7 | 45.2 | | | | | |
| 01049700 | Gardiner Pond Brook at Dresden Mills, Maine | G | 4.01 | 6.12 | 7.68 | 9.86 | 11.6 | 13.5 | 18.4 | 12-17-1973 | 12.9 | 1964-74 | u | 20.7 |
| | | R | 4.43 | 6.73 | 8.39 | 10.6 | 12.4 | 14.2 | 18.7 | | | | | |
| | | W | 4.08 | 6.24 | 7.85 | 10.1 | 11.9 | 13.7 | 18.5 | | | | | |
| 01050900 | Four Ponds Brook nr Houghton, Maine | G | 2.80 | 4.81 | 6.42 | 8.74 | 10.7 | 12.8 | 18.6 | 7-30-1969 | 9.88 | 1963-74 | u | 10.7 |
| | | R | 2.24 | 3.43 | 4.29 | 5.45 | 6.38 | 7.34 | 9.73 | | | | | |
| | | W | 2.72 | 4.56 | 5.94 | 7.84 | 9.39 | 11.0 | 15.3 | | | | | |
| 01052500 | Diamond River nr Wentworth Location, New Hampshire | G | 135 | 173 | 199 | 233 | 258 | 284 | 348 | 3-31-1998 | 360 | 1941-98 | u | 394 |
| | | R | 138 | 210 | 261 | 330 | 383 | 438 | 576 | | | | | |
| | | W | 135 | 175 | 202 | 240 | 268 | 297 | 371 | | | | | |
| 01053500 | Androscoggin River at Errol, New Hampshire | G | 198 | 279 | 330 | 392 | 436 | 479 | 572 | 5-22-1969 | 467 | 1905-96 | r | 2,710 |
| 01054000 | Androscoggin River nr Gorham, New Hampshire | G | 305 | 401 | 458 | 525 | 570 | 613 | 704 | 4-30-1923 | 620 ^d | 1912-96 | r | 3,520 |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued

[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regres-sion (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regula-tion ^c | Drainage area (km ²) |
|----------------------------|---|--|---|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-------------------------|--------------------------|---|--------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01054200 | Wild River at Gilead, Maine | G R W | 242 84.1 234 | 374 132 358 | 464 167 438 | 589 216 548 | 685 253 632 | 782 293 715 | 1030 394 929 | 10-24-1959 | 801 | 1959, 1964-98 | u | 180 |
| 01054300 | Ellis River at South Andover, Maine | G R W | 99.8 95.5 99.4 | 130 142 131 | 149 176 153 | 171 220 180 | 188 254 201 | 203 290 222 | 239 377 274 | 12-29-1969 | 159 | 1963-82 | u | 337 |
| 01054500 | Androscoggin River at Rumford, Maine | G | 748 | 1,010 | 1,190 | 1,390 | 1,550 | 1,700 | 2,040 | 3-20-1936 | 2,100 | 1870-1996 | r | 5,360 |
| 01055000 | Swift River nr Roxbury, Maine | G R W | 167 96.8 165 | 270 149 266 | 347 187 340 | 452 238 440 | 536 277 519 | 624 319 601 | 848 423 811 | 10-24-1959 | 476 | 1929-96 | u | 251 |
| 01055300 | Bog Brook nr Buckfield, Maine | G R W | 5.18 7.52 5.51 | 6.98 11.6 7.83 | 8.14 14.6 9.60 | 9.57 18.7 12.1 | 10.6 21.9 14.0 | 11.7 25.3 16.2 | 14.0 33.7 21.3 | 2-11-1970 | 8.18 | 1963-74 | u | 26.9 |
| 01055500 | Nezinscot River at Turner Center, Maine | G R W | 93.5 94.5 93.5 | 143 137 143 | 181 167 180 | 234 206 232 | 278 236 275 | 325 267 320 | 450 341 439 | 3-27-1953 | 394 | 1914-96 | u | 438 |
| 01057000 | Little Androscoggin River nr South Paris, Maine | G R W | 60.7 58.0 60.6 | 96.3 87.9 96.0 | 122 109 121 | 156 138 155 | 183 160 182 | 211 183 209 | 280 241 277 | 4-1-1987 | 265 | 1897-1996 | u | 190 |
| 01058500 | Little Androscoggin River nr Auburn, Maine | G R W | 110 164 112 | 156 233 160 | 189 281 195 | 236 343 245 | 275 390 287 | 316 438 330 | 424 554 441 | 3-28-1953 | 467 | 1936-83 | u | 850 |
| 01059000 | Androscoggin River nr Auburn, Maine | G | 1,090 | 1,430 | 1,650 | 1,910 | 2,100 | 2,280 | 2,690 | 3-20-1936 | 3,820 | 1814-1996 | r | 8,450 |
| 01059800 | Collyer Brook nr Gray, Maine | G R W | 16.6 11.8 16.2 | 24.6 18.4 23.8 | 30.0 23.2 29.0 | 37.0 29.9 35.7 | 42.3 35.1 40.8 | 47.6 40.6 46.0 | 60.3 54.4 58.8 | 12-27-1969 | 34.6 | 1964-82, 1996 | u | 35.7 |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued
[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regres-sion (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regula-tion ^c | Drainage area (km ²) |
|----------------------------|---|--|---|----------------------|----------------------|-----------------------|-----------------------|-----------------------|-------------------------|-------------------------|--------------------------|---|--------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01060000 | Royal River at Yarmouth, Maine | G R W | 107 88.7 106 | 158 131 157 | 194 160 192 | 242 199 238 | 280 229 275 | 318 259 312 | 414 335 404 | 3-13-1977 | 326 | 1949-96 | u | 365 |
| 01062700 | Patte Brook nr Bethel, Maine | G R W | 6.35 7.31 6.50 | 11.4 12.0 11.5 | 15.6 15.5 15.6 | 21.7 20.5 21.4 | 26.8 24.5 26.1 | 32.5 28.8 31.2 | 48.1 39.7 44.8 | 7-1-1973 | 18.8 | 1964-74 | u | 14.6 |
| 01064000 | Presumpscot River at Outlet of Sebago Lake, Maine | G | 36.2 ^h | 59.2 ^h | 78.9 ^h | 110 ^h | 138 ^h | 172 ^h | 273 ^h | 4-7-1902 | 198 ⁱ | 1886-1996 | r | 1,140 |
| 01064118 | Presumpscot River at Westbrook, Maine | G | 150 | 222 | 280 | 368 | 446 | 534 | 792 | 10-22-1996 | 660 | 1895-1996 | r | 1,500 |
| 01064200 | Mill Brook nr Old Orchard Beach, Maine | G R W | 2.57 3.65 2.74 | 4.00 6.21 4.44 | 5.03 8.21 5.80 | 6.41 11.1 7.77 | 7.48 13.4 9.39 | 8.60 15.9 11.2 | 11.4 22.5 15.7 | 4-2-1973 | 5.89 | 1964-74 | u | 5.57 |
| 01064500 | Saco River nr Conway, New Hampshire | G R W | 462 329 459 | 723 490 715 | 913 603 900 | 1,170 754 1,150 | 1,370 870 1,340 | 1,580 989 1,540 | 2,110 1,280 2,040 | 3-27-1953 | 1,340 | 1903-09, 1929-96 | u | 997 |
| 01065000 | Ossipee River at Effingham Falls, New Hampshire | G R W | 100 175 103 | 135 251 141 | 160 303 169 | 192 370 206 | 216 422 235 | 242 474 265 | 304 602 339 | 3-28-1953 | 331 | 1937-96 | u | 855 |
| 01065500 | Ossipee River at Cornish, Maine | G R W | 127 235 129 | 180 335 185 | 218 403 225 | 268 492 279 | 306 559 320 | 347 627 365 | 446 793 472 | 3-21-1936 | 487 | 1916-96 | u | 1,170 |
| 01066000 | Saco River at Cornish, Maine | G R W | 378 618 383 | 519 860 529 | 610 1,020 626 | 721 1,230 746 | 801 1,390 834 | 880 1,550 922 | 1,060 1,930 1,120 | 3-21-1936 | 1,320 | 1786-1996 | u | 3,350 |
| 01066100 | Pease Brook nr Cornish, Maine | G R W | 4.51 6.52 4.82 | 7.49 10.8 8.14 | 9.83 14.0 10.8 | 13.2 18.6 14.8 | 16.0 22.2 18.0 | 19.1 26.2 21.6 | 27.4 36.3 30.9 | 4-23-1969 | 13.8 | 1964-74, 1996 | u | 12.4 |

Table 1. Estimated peak flows and maximum recorded flows for selected U.S. Geological Survey streamflow-gaging stations—Continued

[m³/s, cubic meters per second; km², square kilometers; u, unregulated; r, regulated; nr, near]

| USGS gaging station number | Gaging station name | Gaging station (G), Regres-sion (R), Weighted (W) ^a | Peak flow (m ³ /s) for given recurrence interval | | | | | | | Highest peak flow known | | | Regula-tion ^c | Drainage area (km ²) |
|----------------------------|--|--|---|----------------------|----------------------|----------------------|----------------------|-----------------------|-------------------------|-------------------------|--------------------------|---|--------------------------|----------------------------------|
| | | | 2 years | 5 years | 10 years | 25 years | 50 years | 100 years | 500 years | Date | Flow (m ³ /s) | Period of known peak flows ^b | | |
| 01066500 | Little Ossipee River nr South Limington, Maine | G R W | 57.5 87.8 58.7 | 88.9 127 91.0 | 112 154 115 | 145 189 149 | 172 217 176 | 200 244 205 | 275 312 280 | 3-19-1936 | 242 ^d | 1936-96 | u | 435 |
| 01067000 | Saco River at West Buxton, Maine | G R W | 398 694 412 | 529 957 555 | 621 1,130 661 | 744 1,360 804 | 840 1,520 916 | 940 1,690 1,030 | 1,190 2,090 1,320 | 3-22-1936 | 1,650 | 1786-1996 | u | 4,070 |
| 01069500 | Mousam River nr West Kennebunk, Maine | G | 39.8 | 57.3 | 70.0 | 87.5 | 102 | 116 | 155 | 3-20-1983 | 114 | 1939-84, 1996 | r | 256 |
| 01069700 | Branch Brook nr Kennebunk, Maine | G R W | 7.18 8.71 7.42 | 12.6 13.6 12.8 | 16.9 17.3 17.0 | 23.2 22.3 22.9 | 28.4 26.2 27.7 | 34.2 30.3 32.9 | 50.0 40.8 46.4 | 10-22-1996 | 28.9 | 1964-74, 1996 | u | 26.7 |
| 01072100 | Salmon Falls River at Milton, New Hampshire | G | 37.4 | 57.0 | 71.6 | 92.0 | 109 | 126 | 172 | 4-6-1984 | 113 | 1955-96 | r | 280 |
| 01072500 | Salmon Falls River nr South Lebanon, Maine | G | 48.8 | 73.3 | 93.3 | 124 | 150 | 180 | 269 | 3-19-1936 | 155 | 1929-76 | r | 363 |

^aGaging station (G) refers to gaging-station peak flow. Regression (R) refers to regression-equation peak flow. Weighted (W) refers to weighted-average peak flow (the weighted average of the gaging-station peak flow and the regression-equation peak flow).

^bPeriod of known peak flows includes relevant historical information (information outside of the period of systematic data collection at or near a streamflow-gaging station).

^cRegulated (r) indicates that the drainage basin upstream of a streamflow-gaging station has more than 49,200 cubic meters of usable storage per square kilometer (Benson, 1962). Usable storage is the volume of water normally available for release from a reservoir, between the minimum and maximum controllable elevations. Unregulated (u) indicates that the drainage basin upstream of a gaging station has less than 49,200 cubic meters of usable storage per square kilometer.

^dPeak flow is an estimate.

^ePeak flow was affected by a dam break. The peak flow, removing the effects of the dam break, is estimated to be 326 m³/s.

^fDay of occurrence is not exact.

^gGaging station formerly published under the name Cold Brook near Northern Maine Junction, Maine.

^hPeak flows for given recurrence intervals at this site were computed using daily-mean peak flows rather than (instantaneous) peak flows. Peak flows are equal to or greater than daily-mean peak flows.

ⁱPeak flow is a daily-mean peak flow.

Section 2: Estimating peak flows for ungaged, unregulated streams in rural drainage basins

Peak flows for ungaged drainage basins for selected recurrence intervals are generally estimated by rainfall-runoff procedures or by regression-based procedures. Newton and Herrin (1982) analyzed several procedures of both types. The rainfall-runoff models that they analyzed, including the Natural Resources Conservation Service TR-20 and TR-55 models, the U.S. Army Corps of Engineers HEC-1 model, and the rational method, were not calibrated to at-site flow data. Newton and Herrin concluded that certain regression-based methods (specifically, the USGS state regression equations and index flood methods) are the most accurate and reproducible procedures for estimating peak flows for given recurrence intervals.

Regression equations are used in this section of the report to compute peak-flow estimates for ungaged, unregulated streams in rural drainage basins in Maine. The response (dependent) variables used in developing the regression equations were the peak flows computed at USGS gaging stations and the explanatory (independent) variables were drainage basin characteristics such as drainage area and stream slope.

Data used for the technique

Regression equations are used to estimate a response variable (in this case, a peak flow for a given recurrence interval) for an ungaged drainage basin by measuring explanatory variables (such as drainage area). Explanatory variables should make hydrologic sense, explain a significant amount of the variability of the response variable, and be reasonably easy to measure. A set of explanatory variables that were qualitatively judged to best meet these criteria was selected for testing.

The values of 14 explanatory variables were determined for gaged, unregulated streams in rural drainage basins in Maine and New Hampshire. These 14 explanatory variables were: *drainage area*, the area of a drainage basin; *main-channel length*, the length of the main channel from the gaging station to the basin divide; *main-channel slope*, the slope of the main channel between points that are 85 percent and 10 percent of the main-channel length from the gaging station; *elevation*, the mean basin elevation; *forest cover*, the percentage of a basin covered by forests; *snow*, the average water content of the snow in a basin on March

1; *lake area*, the areal percentage of lakes, ponds, and reservoirs in a basin; *basin wetlands*, the areal percentage of all types of wetlands (which includes lakes, ponds, reservoirs, and rivers) in a basin; *upper third wetlands*, the areal percentage of all types of wetlands in the upper third of a basin; *middle third wetlands*, the areal percentage of all types of wetlands in the middle third of a basin; *lower third wetlands*, the areal percentage of all types of wetlands in the lower third of a basin; *mean annual precipitation*, the mean annual precipitation in a basin; *24-hour, 2-year rain*, the maximum 24-hour rainfall having a recurrence interval of 2 years; and *24-hour, 100-year rain*, the maximum 24-hour rainfall having a recurrence interval of 100 years.

The peak flows for 72 unregulated streamflow-gaging stations in Maine, New Hampshire, and New Brunswick were reported in table 1 (page 8). The peak flows from all of these stations were considered for use as response variables in the regression equations. Peak flows for six additional stations in New Hampshire are not reported in table 1 (individually they are not useful for estimating peak flows in Maine) but were considered for use in the equations: Ellis River near Jackson, N.H. (station number 01064300); East Branch Saco River near Lower Bartlett, N.H. (01064380); Lucy Brook near North Conway, N.H. (01064400); Cold Brook at South Tamworth, N.H. (01064800); Mohawk Brook near Center Strafford, N.H. (01072850); and Oyster River near Durham, N.H. (01073000).

Some of the 78 unregulated streamflow-gaging stations were not used in the final regression analysis. When examining the results of preliminary regressions, three of the six New Hampshire stations listed in the previous paragraph (Ellis River, Lucy Brook, and Cold Brook) were noted as having extremely steep stream slopes (75.2 m/km to 102 m/km). In addition, the regression residual values were large (the regression equations significantly underpredicted peak flows at all three stations). The steepest gaged stream in Maine is Mountain Brook near Lake Parlin with a slope of 49.1 m/km. It is unknown whether Maine sites with slopes similar to the three New Hampshire stations would have similar residual values. Because of this, and because including these stations would change the regression equations, the three New Hampshire stations were dropped from the Maine regression equation analyses.

Five gaging stations in northern Maine were not used in the regression analyses because part of their drainage basins are in Canada. An important explana-

tory variable in this study, basin wetlands, was determined from U.S. Fish and Wildlife Service National Wetland Inventory Maps (scale 1:24,000). The Canadian Wildlife Service has produced Wetland Inventory Maps at a different scale (1:50,000). Because it is not known if these two sets of maps are comparable, the five stations with Canadian drainage area were not used in the regression analysis: St. John River at Ninemile Bridge, Maine (01010000); Big Black River near Depot Mountain, Maine (01010070); St. John River at Dickey, Maine (01010500); St. Francis River near Connors, New Brunswick (01011500); and St. John River below Fish River at Ft. Kent, Maine (01014000). Seventy unregulated, gaged basins were used in the final Maine regression analyses.

Development of the technique

Ordinary least squares (OLS) regression techniques (Helsel and Hirsch, 1992) were used to select the explanatory variables that would appear in the final regression equations. Linear relations between the explanatory and response variables are necessary in OLS regression. For this reason, variables must often be transformed. For example, the relation between drainage areas and peak flows is typically not linear, however, the relation between the logarithms of drainage areas and the logarithms of peak flows often is linear. Homoscedasticity (a constant variance in the response variable over the range of the explanatory variables) and normality also are important in OLS regression. Linearity, homoscedasticity, and normality in the relation between explanatory variables and response variables were examined with component-plus-residual plots (Cook and Weisburg, 1994).

OLS regression of all possible subsets was used to determine the best combination of explanatory variables to use in the final regression equations. Initially, the 14 explanatory variables or transformations of these variables were used with the response variables (the base-10 logarithms of the n -year peak flows; $n = 2, 5, 10, 25, 50, 100, 500$) from 53 gaged drainage basins. These 53 stations were used because most of the explanatory variables at these stations were computed in a previous study (Morrill, 1975). The best combination of the variables was chosen on the basis of Mallows's C_p statistic, the PRESS statistic, the amount of variability in the response variables explained by the explanatory variables, the statistical significance of the explanatory variables, and the difficulty of calculating the explanatory variables. Basin wetlands and the base-10 logarithms of drainage area were chosen as the final

variables from all possible combinations of the 14 explanatory variables. Both of these variables were highly significant (the p -values from the T -statistics for both variables were less than 0.00005).

OLS regression of all possible subsets was then used for the full 70 gaging stations for the following explanatory variables: drainage area, basin wetlands, upper third wetlands, middle third wetlands, lower third wetlands, and slope. On the basis of the results from the 53-station regressions, it was not considered useful to compute additional values for the rest of the explanatory variables. Basin wetlands and the base-10 logarithms of drainage area were again the best choice as final explanatory variables. Both variables were still highly significant (p -values were still less than 0.00005). The values of drainage area and percentage of basin wetlands for the 70 stations are listed in table 2.

Regression diagnostic tools were used to test the adequacy of the OLS regressions at the 70 gaging stations (response variables were the base-10 logarithms of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year peak flows; explanatory variables were percentage of basin wetlands and the base-10 logarithms of drainage area). Multicollinearity of the explanatory variables was measured by the variance inflation factor (VIF). The influence of individual stations on the regressions was measured by Cook's D statistic. There were no problems with multicollinearity or high influence points.

Different types of residual plots were analyzed. The regression residuals were plotted against predicted values to look for linearity, homoscedasticity, normality, and the presence of outliers. Normal probability plots of the residuals also were analyzed. Residuals were plotted against the explanatory variables to look for biases in the explanatory variables over their range. All regression diagnostics indicated that the use of percentage of basin wetlands and the base-10 logarithms of drainage area as explanatory variables resulted in a very good regression model.

The regression residuals (for the 2-year and 100-year peak flows) were plotted at the centroid of their respective drainage basins to look for geographical biases and to determine whether Maine should be divided into more than one hydrologic region. Separate regression equations would have been computed for each region if more than one hydrologic region was called for. No distinct pattern, however, was seen in the mapped residuals.

Table 2. Drainage areas and percentage of basin wetlands for 70 gaging stations used in regression equations

| USGS gaging-station number | Gaging-station name | Drainage area (square kilometers) | Areal percentage of wetlands in drainage basin |
|-----------------------------------|---|--|---|
| 01011000 | Allagash River near Allagash, Maine | 3,180 | 9.4 |
| 01013500 | Fish River near Fort Kent, Maine | 2,260 | 15.5 |
| 01014700 | Factory Brook near Madawaska, Maine | 15.2 | 2.8 |
| 01015700 | Houlton Brook near Oxbow, Maine | 14.1 | 21.2 |
| 01015800 | Aroostook River near Masardis, Maine | 2,310 | 14.0 |
| 01016500 | Machias River near Ashland, Maine | 852 | 8.8 |
| 01017000 | Aroostook River at Washburn, Maine | 4,280 | 12.0 |
| 01017300 | Nichols Brook near Caribou, Maine | 10.3 | 9.1 |
| 01017900 | Marley Brook near Ludlow, Maine | 3.81 | 0.9 |
| 01018000 | Meduxnekeag River near Houlton, Maine | 453 | 17.6 |
| 01021300 | Wiggins Brook near West Lubec, Maine | 13.0 | 13.1 |
| 01021500 | Machias River at Whitneyville, Maine | 1,190 | 15.5 |
| 01021600 | Middle River near Machias, Maine | 21.4 | 14.0 |
| 01022000 | East Machias River near East Machias, Maine | 648 | 23.5 |
| 01022260 | Pleasant River near Epping, Maine | 157 | 26.7 |
| 01022500 | Narraguagus River at Cherryfield, Maine | 588 | 15.0 |
| 01022700 | Forbes Pond Brook near Prospect Harbor, Maine | 23.7 | 19.0 |
| 01023000 | West Branch Union River at Amherst, Maine | 386 | 18.9 |
| 01024200 | Garland Brook near Mariaville, Maine | 25.4 | 7.9 |
| 01026800 | Frost Pond Brook near Sedgwick, Maine | 12.5 | 15.3 |
| 01030300 | Trout Brook near Danforth, Maine | 10.8 | 15.4 |
| 01030400 | Gulliver Brook near Monarda, Maine | 28.5 | 20.0 |
| 01030500 | Mattawamkeag River near Mattawamkeag, Maine | 3,670 | 19.0 |
| 01031500 | Piscataquis River near Dover-Foxcroft, Maine | 772 | 10.2 |
| 01031600 | Morrison Brook near Sebec Corners, Maine | 11.3 | 11.1 |
| 01033500 | Pleasant River near Milo, Maine | 837 | 9.7 |
| 01034000 | Piscataquis River at Medford, Maine | 3,010 | 12.7 |

77

Table 2. Drainage areas and percentage of basin wetlands for 70 gaging stations used in regression equations—Continued

| USGS gaging-station number | Gaging-station name | Drainage area (square kilometers) | Areal percentage of wetlands in drainage basin |
|----------------------------|---|-----------------------------------|--|
| 01034900 | Coffin Brook near Lee, Maine | 5.49 | 15.1 |
| 01035000 | Passadumkeag River at Lowell, Maine | 769 | 22.8 |
| 01036500 | Kenduskeag Stream near Kenduskeag, Maine | 479 | 13.2 |
| 01037200 | Shaw Brook ^a near Northern Maine Junction, Maine | 7.95 | 5.2 |
| 01037430 | Goose River at Rockport, Maine | 21.4 | 6.5 |
| 01038000 | Sheepscot River at North Whitefield, Maine | 376 | 14.8 |
| 01041900 | Mountain Brook near Lake Parlin, Maine | 10.6 | 3.2 |
| 01046000 | Austin Stream at Bingham, Maine | 233 | 8.6 |
| 01046800 | South Branch Carrabassett River at Bigelow, Maine | 36.5 | 2.0 |
| 01047000 | Carrabassett River near North Anson, Maine | 914 | 7.6 |
| 01048000 | Sandy River near Mercer, Maine | 1,340 | 7.7 |
| 01048100 | Pelton Brook near Anson, Maine | 38.6 | 4.6 |
| 01049000 | Sebasticook River near Pittsfield, Maine | 1,480 | 15.6 |
| 01049100 | Hall Brook at Thorndike, Maine | 13.3 | 3.9 |
| 01049130 | Johnson Brook at South Albion, Maine | 7.56 | 13.1 |
| 01049300 | North Branch Tanning Brook near Manchester, Maine | 2.41 | 6.0 |
| 01049373 | Mill Stream near Winthrop, Maine | 84.7 | 16.6 |
| 01049550 | Togus Stream at Togus, Maine | 61.4 | 21.3 |
| 01049700 | Gardiner Pond Brook at Dresden Mills, Maine | 20.7 | 18.8 |
| 01050900 | Four Ponds Brook near Houghton, Maine | 10.7 | 20.8 |
| 01052500 | Diamond River near Wentworth Location, New Hampshire | 394 | 3.4 |
| 01054200 | Wild River at Gilead, Maine | 180 | 0.7 |
| 01054300 | Ellis River at South Andover, Maine | 337 | 7.3 |
| 01055000 | Swift River near Roxbury, Maine | 251 | 3.0 |
| 01055300 | Bog Brook near Buckfield, Maine | 26.9 | 13.8 |
| 01055500 | Nezinscot River at Turner Center, Maine | 438 | 11.1 |
| 01057000 | Little Androscoggin River near South Paris, Maine | 190 | 7.5 |
| 01058500 | Little Androscoggin River near Auburn, Maine | 850 | 11.3 |
| 01059800 | Collyer Brook near Gray, Maine | 35.7 | 10.4 |

Table 2. Drainage areas and percentage of basin wetlands for 70 gaging stations used in regression equations—Continued

| USGS gaging-station number | Gaging-station name | Drainage area (square kilometers) | Areal percentage of wetlands in drainage basin |
|----------------------------|---|-----------------------------------|--|
| 01060000 | Royal River at Yarmouth, Maine | 365 | 9.6 |
| 01062700 | Patte Brook near Bethel, Maine | 14.6 | 5.8 |
| 01064200 | Mill Brook near Old Orchard Beach, Maine | 5.57 | 3.8 |
| 01064380 | East Branch Saco River near Lower Bartlett, New Hampshire | 82.8 | 0.7 |
| 01064500 | Saco River near Conway, New Hampshire | 997 | 2.1 |
| 01065000 | Ossipee River at Effingham Falls, New Hampshire | 855 | 10.3 |
| 01065500 | Ossipee River at Cornish, Maine | 1,170 | 9.8 |
| 01066000 | Saco River at Cornish, Maine | 3,350 | 8.6 |
| 01066100 | Pease Brook near Cornish, Maine | 12.4 | 5.4 |
| 01066500 | Little Ossipee River near South Limington, Maine | 435 | 12.2 |
| 01067000 | Saco River at West Buxton, Maine | 4,070 | 9.4 |
| 01069700 | Branch Brook near Kennebunk, Maine | 26.7 | 11.3 |
| 01072850 | Mohawk Brook near Center Strafford, New Hampshire | 23.0 | 8.3 |
| 01073000 | Oyster River near Durham, New Hampshire | 31.3 | 10.8 |

^aStation formerly published as Cold Brook near Northern Maine Junction, Maine

Generalized least squares (GLS) regression techniques (Stedinger and Tasker, 1985; Tasker and Stedinger, 1989) were used to compute the final coefficients and the measures of accuracy for the regression equations, using the computer program GLSNET (G.D. Tasker, K.M. Flynn, A.M. Lumb, and W.O. Thomas Jr., U.S. Geological Survey, written commun., 1995). Stedinger and Tasker found that GLS regression equations are more accurate (and provide a better estimate of the accuracy of the equations) than OLS regression equations when streamflow records at gaging stations are of different and widely varying lengths and when concurrent flows at different stations are correlated. GLS regression techniques give less weight to streamflow-gaging stations that have shorter periods of record than other stations. Less weight is also given to those stations whose concurrent peak flows are correlated with other stations.

Application of the technique

Peak-flow regression equations for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years are presented in table 3. The variables used in the equations are described in the text that follows the table. These regression equations are referred to as the “full” regression equations. The average standard error of prediction, the PRESS statistic, and the average equivalent years of record are discussed in “Limitations and accuracy of the technique” at the end of this 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, determining the basin wetland variable by making field delineations) will result in peak-flow estimates of unknown accuracy.

Table 3. Full regression equations and their accuracy for estimating peak flows for ungaged, unregulated streams in rural drainage basins in Maine

[Q is peak flow, in cubic meters per second; A is drainage area, in square kilometers; W is percentage of basin wetlands]

| Peak-flow regression equation for given recurrence interval (recurrence intervals from 2 to 500 years) | Average standard error of prediction (percent) | (PRESS/n) ^{1/2} (percent) | Average equivalent years of record |
|--|--|------------------------------------|------------------------------------|
| $Q_2 = 1.075 (A)^{0.848} 10^{-0.0266(W)}$ | 40.6 to -28.9 | 42.2 to -29.7 | 1.82 |
| $Q_5 = 1.952 (A)^{0.820} 10^{-0.0288(W)}$ | 41.9 to -29.5 | 43.5 to -30.3 | 2.47 |
| $Q_{10} = 2.674 (A)^{0.806} 10^{-0.0300(W)}$ | 42.9 to -30.0 | 45.2 to -31.1 | 3.20 |
| $Q_{25} = 3.740 (A)^{0.790} 10^{-0.0312(W)}$ | 45.2 to -31.1 | 48.3 to -32.5 | 4.14 |
| $Q_{50} = 4.637 (A)^{0.780} 10^{-0.0320(W)}$ | 46.9 to -31.9 | 51.0 to -33.8 | 4.78 |
| $Q_{100} = 5.629 (A)^{0.771} 10^{-0.0326(W)}$ | 48.6 to -32.7 | 53.5 to -34.8 | 5.37 |
| $Q_{500} = 8.283 (A)^{0.754} 10^{-0.0340(W)}$ | 53.5 to -34.8 | 60.0 to -37.5 | 6.41 |

Definitions of equation variables in table 3:

Q_n - Peak flow - The calculated peak flow, in cubic meters per second, for recurrence interval n (n equals 2, 5, 10, 25, 50, 100, or 500 years).

A - Drainage area - The contributing area, in square kilometers, of a drainage basin. The term “contributing” means that flow from an area could contribute flow to a study site on a stream. This definition is intended to exclude only closed subbasins (subbasins with no outlet) of a drainage basin. Noncontributing drainage area in Maine of any significant size is rare. Contributing drainage area, as defined for this report, does include parts of drainage-basin area that may not contribute significant flow to a peak flow because of the timing of peak flows from different parts of a basin.

All units of drainage area, except square kilometers, will result in incorrect estimates of peak flows. If inch-pound units are desired for the estimated peak flows, the conversion should be made to the peak flows after applying the equation(s).

The drainage area can be computed from a number of sources. A series of drainage area reports that list drainage areas at selected points on most streams in Maine have been published by the USGS (Cowing and Caracappa, 1978; Cowing and McNelly, 1978; Fontaine, 1979a, 1979b, 1980, 1981, 1982a, 1982b; Fontaine, Herrick, and Norman, 1982). Drainage areas can also be computed by digitizing the area of a drainage basin, after delineating the drainage-basin boundaries on topographic maps. Drainage areas can be computed from geographic information system (GIS) coverages. However, these coverages currently (1998) are not

available in an easily usable form. The drainage areas for the 70 streamflow-gaging stations used in the development of the Maine regression equations (table 2) were calculated using the first two methods in this paragraph. The values of drainage area measured by all three methods are expected to be very similar.

W - Basin Wetlands - The areal percentage of all types of wetlands in a basin (which includes lakes, ponds, reservoirs, and rivers). The areal percentage should be computed with National Wetland Inventory Maps because these maps were used in the development of the regression equations. The National Wetland Inventory Maps are produced by the U.S. Fish and Wildlife Service at a scale of 1:24,000. The types of wetlands on the maps (palustrine, lacustrine, and so forth) are not relevant to this study. If a drainage area of interest contains Canadian land, Wetland Inventory Maps are available from the Canadian Wildlife Service at a scale of 1:50,000. It is not known if the Canadian wetland maps are comparable to United States wetland maps, however, these maps are the Canadian product that is most likely to be similar to the United States wetland maps. One known difference between the Canadian and American maps is that the Canadian maps do not include all lake, pond, reservoir, and river areas in their wetland categories. The calculation of the basin wetlands variable for sites that have Canadian drainage area should include the area of these bodies of water plus the Canadian wetland area. The accuracy of the regression equations (table 3) may not be applicable to sites with Canadian drainage area.

To compute the basin wetlands variable, the drainage-basin boundaries must be delineated. After this, the percentage of all wetlands in the basin (total surface area of wetlands divided by the drainage area, multiplied by 100) is computed. The area of wetlands can be computed from GIS coverages. Currently (1998), coverages do not exist for all drainage basins in Maine. The total area of wetlands in a basin also can be digitized. This is tedious, however, for basins with a large percentage of wetlands. In either method, the total surface area of wetlands is divided by the drainage area (and multiplied by 100) to compute the areal percentage of wetlands in a basin. Grid sampling can also be used to compute the percentage of wetlands in a basin. In this method, after delineating the drainage-basin boundaries, a grid of evenly spaced points is placed over the National Wetland Inventory maps. The total number of points that fall within the drainage-basin boundaries are counted. The total number of points that fall in a wetland (within the drainage-basin boundaries) are then counted. The number of wetland points divided by the number of points in the drainage basin (multiplied by 100) is the percentage of wetlands in the basin. Based on experience, for the grid-sampling method to be accurate, at least 400 points in the basin must be sampled. In addition, the percentage of wetlands in the basin must be at least 4 percent. The percentage of basin wetlands for the 70 streamflow-gaging stations used in the development of the Maine regression equations are listed in table 2. These basin wetland values were computed by all of the methods described except for GIS coverages. The GIS coverages of the National Wetland Inventory Maps are expected to be very similar to the paper copies.

A fortran computer program is included on a disk in the back of this report that calculates peak flows using the regression equations in table 3. The program runs on all 80386, 80486, and Pentium based PC's compatible with MS DOS and Microsoft Windows. To run the program from DOS, type ME in the directory with the program. To run the program from Windows, double click the left mouse button with the cursor on the file ME.EXE. The program will prompt the user for the drainage area and basin wetlands of each site.

Limitations and accuracy of the technique

These regression equations are not applicable to regulated or urbanized drainage basins. "Regulated" and "urbanized" are defined and the appropriate methodologies for these conditions are described in "Choosing the appropriate section of this report to obtain estimated peak flows" in Part 1 of this report.

If the explanatory variables (drainage area and basin wetlands) used in the regression equations in this section are outside the two-dimensional range of the values used to develop the equations (the gray area in figure 3), the accuracy of predictions of peak flows from the equations will be reduced. The magnitude of this reduction in accuracy is unknown and potentially large. The potential for large reductions in the accuracy of the regression equations increases as the distance from the gray area in figure 3 increases.

The regression equations in this section may seriously underestimate the peak flows for sites that have very steep slopes (slopes, as defined in "Data used for the technique", of greater than 50 m/km). As explained in "Data used for the technique", preliminary regression equations significantly underpredicted the peak flows for three very steep-sloped New Hampshire basins.

The average standard error of prediction (ASEP) is a measure of how well the regression equations will estimate peak flows when they are applied to ungaged drainage basins. The ASEP is the square root of the average variance of prediction at a group of sites that have the same basin characteristics as the gaging stations used in development of the regression equations. The standard error of prediction varies from site to site, depending on the values of the explanatory variables (drainage area and basin wetlands) for each site. The standard error of prediction will be smaller for sites that have explanatory variables near the mean of their range; however, the error associated with the different values of the explanatory variables is a small part of the total standard error of prediction. For this reason, the ASEP can be used as an approximate standard error of prediction for individual sites. If a standard error of prediction for an individual site is desired, it can be calculated as explained in "Advanced accuracy analysis", which immediately follows this discussion. The probability that the true value of a peak flow at a study site is between the positive-percent ASEP and the negative-percent ASEP is approximately 68 percent. For example, there is a 68 percent probability that the true 50-year peak flow at an ungaged site is between +46.9 percent and -31.9 percent (table 3) of the computed peak flow.

Another overall measure of how well regression equations will estimate flood peaks when applied to ungaged basins is the PRESS statistic. The PRESS statistic is a validation-type statistic. To compute the PRESS statistic, one gaging station is removed from the stations used to develop the regression equation, then the value of the one left out is predicted. The dif-

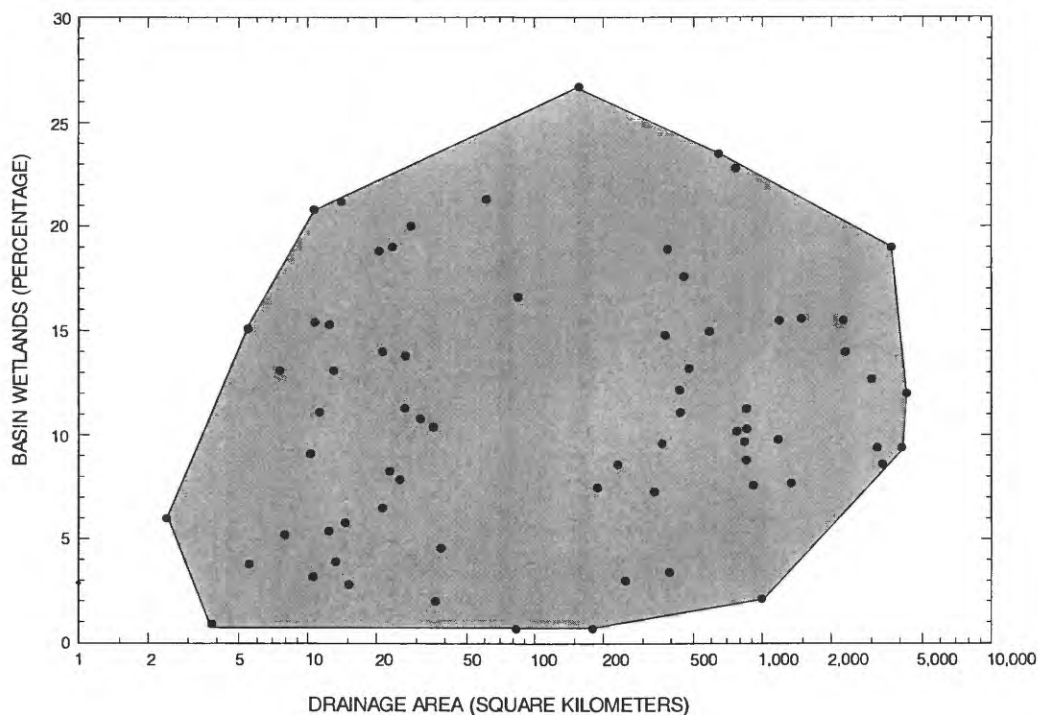


Figure 3. Two-dimensional range of explanatory variables for the full regression equations.

ference between the predicted value from the regression equation and the observed peak flow at that station is computed. The gaging station left out is then changed and the above process repeated until every station has been left out once. The prediction errors are then squared and summed. $PRESS/n$ is analogous to the average variance of prediction, and the square root of $PRESS/n$ is analogous to the average standard error of prediction. Values of the square root of $PRESS/n$ close to the values of the average standard error of prediction provide some measure of validation of the regression equations.

The average equivalent years of record is a third measure of the overall accuracy of the regression equations. This measure represents the average number of years of gaging-station data needed to achieve results with accuracy equal to the regression equations. The average equivalent years of record is a function of the accuracy of the regression equations, the recurrence interval, and the average variance and skew of the annual peak flows at gaging stations (Hardison, 1971).

Advanced accuracy analysis

The standard error of prediction at individual sites (a more accurate standard error of prediction than the average standard error of prediction (ASEP) discussed in the previous section) can be calculated using the following methods. The fortran computer program included in this report computes the standard error of

prediction for any study site as well as the 50-, 67-, 90- and 95-percent prediction intervals. As an example, we are 90 percent confident that the true peak flow at a study site lies within the 90-percent prediction interval.

In generalized least squares regression, the average variance of prediction is divided into two parts: the model error variance and the sampling error variance. The average standard error of prediction is the square root of the average variance of prediction. The estimated model error variance and average sampling error variance from the regression equations in this section of the report are given in table 4. The model error variance is a measure of the error resulting from an incomplete model if the true values of the estimated peak flows at gaging stations were known at all streams in Maine (rather than the sample values that were used). In other words, the explanatory variables of drainage area and basin wetlands in the regression model would not explain all of the variation in the peak flows from the complete population. The true model error variance cannot be reduced by additional data collection, although the estimated model error variance may change if additional data are obtained. The average sampling error variance for the regression equations is a measure of the error due to sampling only a subset of the total population of streams in Maine (space-sampling error) and sampling only a subset of the total years of data at gaging stations (time-sampling error).

Table 4. Estimated model error variance and average sampling error variance for the full regression equations

| Q_n - Peak flow for recurrence interval n ($n = 2, 5, 10, 25, 50, 100, 500$ years) | Estimated model error variance (base-10 logs) | Average sampling error variance (base-10 logs) |
|--|---|--|
| Q_2 | 0.0206 | 0.0017 |
| Q_5 | 0.0211 | 0.0019 |
| Q_{10} | 0.0220 | 0.0021 |
| Q_{25} | 0.0236 | 0.0025 |
| Q_{50} | 0.0250 | 0.0028 |
| Q_{100} | 0.0265 | 0.0031 |
| Q_{500} | 0.0308 | 0.0039 |

The sampling error can be reduced by collecting more data at existing gaging stations, collecting data at new gaging stations, or some combination of both.

The standard error of prediction at an individual study site can be calculated using matrix algebra. The general regression model can be represented in matrix form (ignoring errors) by

$$\mathbf{Y} = \mathbf{XB}, \quad (2)$$

where

\mathbf{Y} is the 70-by-1 column vector of the logarithms (base-10) of gaging-station peak flows at the 70 stations used in the development of each regression equation in this section of the report;

\mathbf{X} is the 70-by-3 vector containing a column of ones, a column of the logarithms of the drainage areas for each of the 70 stations, and a column of the percentage of basin wetlands for each station; and

\mathbf{B} is the 3-by-1 column vector of regression coefficients.

The sampling error variance at a site (SE_S^2) is defined by

$$SE_S^2 = \mathbf{x}_0 (\mathbf{X}^T \Lambda^{-1} \mathbf{X})^{-1} \mathbf{x}_0^T, \quad (3)$$

where

\mathbf{x}_0 is the row vector for the study site, containing a one, the logarithm of the drainage area for the study site, and the percentage of basin wetlands for the site;

T is the matrix algebra symbol for “transpose”; and

the $(\mathbf{X}^T \Lambda^{-1} \mathbf{X})^{-1}$ matrix for the n -year ($n = 2, 5, 10, 25, 50, 100, 500$) regression equations in this section (table 5) was computed by GLSNET, a computer program for generalized least squares regression.

The standard error of prediction (SE_P) for a study site is then calculated as

$$SE_P = (SE_M^2 + SE_S^2)^{1/2}, \quad (4)$$

where

SE_M^2 is the estimated model error variance (table 4) and

SE_S^2 is calculated in equation 3.

The prediction interval for a study site can then be computed as

$$(1/V)Q_n < \Theta_n < (V)Q_n, \quad (5)$$

where

$\log(\text{base-10}) V = (t_{(\alpha/2, 67)} SE_P)$ for the regression equations in this section (the value of 67 is the degrees of freedom for the t -distribution for these regression equations, and α is the probability of a Type 1 error),

Q_n is the computed peak flow (from the appropriate regression equation) for recurrence interval n ($n = 2, 5, 10, 25, 50, 100, 500$ years) at the ungaged study site, and

Θ_n is the true peak flow for recurrence interval n . We are 100(1- α) percent confident that the true value lies in the prediction interval.

Table 5. $(X^T \Lambda^{-1} X)^{-1}$ matrices for the n-year ($n = 2, 5, 10, 25, 50, 100, 500$) full regression equations

[Numbers are in scientific notation]

| $(X^T \Lambda^{-1} X)^{-1}$ matrix |
|---------------------------------------|
| 2-year recurrence interval |
| 0.58123E-02 -0.15009E-02 -0.10490E-03 |
| -0.15009E-02 0.60524E-03 -0.44046E-05 |
| -0.10490E-03 -0.44046E-05 0.94475E-05 |
| 5-year recurrence interval |
| 0.65716E-02 -0.16938E-02 -0.11312E-03 |
| -0.16938E-02 0.66864E-03 -0.43865E-05 |
| -0.11312E-03 -0.43865E-05 0.10050E-04 |
| 10-year recurrence interval |
| 0.74881E-02 -0.19256E-02 -0.12376E-03 |
| -0.19256E-02 0.74673E-03 -0.45182E-05 |
| -0.12376E-03 -0.45182E-05 0.10878E-04 |
| 25-year recurrence interval |
| 0.88850E-02 -0.22793E-02 -0.14074E-03 |
| -0.22793E-02 0.86835E-03 -0.48668E-05 |
| -0.14074E-03 -0.48668E-05 0.12244E-04 |
| 50-year recurrence interval |
| 0.10014E-01 -0.25652E-02 -0.15473E-03 |
| -0.25652E-02 0.96761E-03 -0.52042E-05 |
| -0.15473E-03 -0.52042E-05 0.13387E-04 |
| 100-year recurrence interval |
| 0.11175E-01 -0.28591E-02 -0.16918E-03 |
| -0.28591E-02 0.10700E-02 -0.55727E-05 |
| -0.16918E-03 -0.55727E-05 0.14574E-04 |
| 500-year recurrence interval |
| 0.14051E-01 -0.35887E-02 -0.20624E-03 |
| -0.35887E-02 0.13277E-02 -0.66561E-05 |
| -0.20624E-03 -0.66561E-05 0.17670E-04 |

Comparison of estimated peak flows for ungaged, unregulated streams in rural drainage basins computed using Maine Department of Transportation and USGS techniques

The 50-year peak flows estimated from six different methods were compared to the weighted-average 50-year peak flows and the gaging-station 50-year peak flows (table 1) for 53 gaging stations in Maine. Four of these estimating methods are described in "A guide for the hydrologic and hydraulic analysis of bridge drainage structures" (Maine Department of Transportation (MDOT), Design Division, Bridge Section, written commun., 1995). The four methods in the

MDOT guide are "Potter's series," "Benson's method," "USGS method," and "FHWA method." The fifth method is the full 50-year regression equation (table 3) from this report and the sixth method is the simplified 50-year regression equation (table 8) from this report. The "USGS method" uses Morrill's (1975) regression equations. The "FHWA method" is the average of FHWA methods A and B.

After the 50-year peak flows were computed by these six methods, the logarithms (base 10) of the flows were calculated. The logs of the weighted-average 50-year peak flows (considered the best estimate of true flows) and the gaging-station 50-year peak flows (another estimate of true flows) were subtracted from the logs of the flows from the method estimates. These differences were the basis for the rest of the comparison discussed here. By computing the difference of the logs of the peak flows, the ratio of the estimated flows to the true flows are calculated rather than the arithmetic difference. If this had not been done, the difference between the estimated and true flows for small watersheds would have looked insignificant when compared to the difference calculated for large watersheds. For example, if the true 50-year peak flow was 10,000 m³/s and the estimated 50-year flow was 11,000 m³/s, the absolute difference between the two would be 1,000 m³/s. For a true flow of 100 m³/s and an estimated flow of 200 m³/s, the absolute difference would be 100 m³/s. This difference appears much smaller than the 1,000 m³/s difference; however, 200 m³/s is twice as large as 100 m³/s, whereas 11,000 m³/s is only 1.1 times as large as 10,000 m³/s. Also, by using the logarithms of the flows, an estimated flow that is half of the true flow will show the same difference as one that is twice the true flow. For example, with a true flow of 100 m³/s and an estimated flow of 200 m³/s, the logarithm of the estimated flow minus the logarithm of the true flow is 0.3. For a true flow of 100 m³/s and an estimated flow of 50 m³/s, the difference of the logarithms is -0.3.

The root mean square error (RMSE) was used as an overall measure of accuracy for the six estimating methods. A lower RMSE indicates a better overall accuracy. The RMSE is computed as the square root of the mean of the squared differences between the logs of the true and estimated flows. For Benson's method and Potter's series, it was not possible to calculate the estimated 50-year peak flows for several of the 53 stations used in this comparison. The input data for these two methods were outside the range of data that could be

used for the methods. For this reason, the number of stations used to calculate the overall accuracy of Benson's method was 44, and the number for Potter's series was 33. The RMSE is converted to percentage errors using formulas from Riggs (1968). Approximately 68 percent of the estimated flows for each method are within the given percentages of the true flows. The RMSE values in table 6 were computed using the weighted-average peak flow at each station (table 1) as the true peak flow.

Because the weighted-average peak flows are weighted with peak flows estimated from the full 50-year regression equation (table 3), the computed

RMSE is a biased measure of error for the full regression equation. For this reason, the overall accuracy of the estimation methods also was computed using the gaging-station peak flows as the true flows, even though the weighted-average peak flows are considered the best estimate of the true flows. The RMSE values in table 7 were computed using the gaging-station peak flows (table 1) as estimates of the true flows to calculate each RMSE.

Based on the RMSE values in tables 6 and 7, the full regression equation from this report is the most accurate method of computing the 50-year peak flow in Maine.

Table 6. Accuracy comparison of Maine Department of Transportation and USGS techniques to estimate 50-year peak flows for ungaged, unregulated streams in rural drainage basins using weighted-average flows as true flows [RMSE, root mean square error; USGS, U.S. Geological Survey; FHWA, Federal Highway Administration]

| Method | RMSE (log units) | RMSE (percentage) |
|--|---------------------|----------------------|
| Potter's series | 0.355 | 126.6 to -55.9 |
| Benson's method | 0.257 | 80.9 to -44.7 |
| USGS method | 0.166 | 46.6 to -31.8 |
| FHWA method | 0.170 | 47.9 to -32.4 |
| Full regression equation (table 3) | 0.133 | 35.7 to -26.3 |
| Simplified regression equation (table 8) | 0.247 | 76.5 to -43.3 |

Table 7. Accuracy comparison of Maine Department of Transportation and USGS techniques to estimate 50-year peak flows for ungaged, unregulated streams in rural drainage basins using gaging-station flows as true flows [RMSE, root mean square error; USGS, U.S. Geological Survey; FHWA, Federal Highway Administration]

| Method | RMSE (log units) | RMSE (percentage) |
|--|---------------------|----------------------|
| Potter's series | 0.375 | 137.2 to -57.8 |
| Benson's method | 0.282 | 91.6 to -47.8 |
| USGS method | 0.191 | 55.2 to -35.6 |
| FHWA method | 0.190 | 55.0 to -35.5 |
| Full regression equation (table 3) | 0.167 | 47.0 to -32.0 |
| Simplified regression equation (table 8) | 0.261 | 82.3 to -45.2 |

Section 3: Estimating peak flows for ungaged, unregulated streams in rural drainage basins—Simplified technique

The regression equations for the simplified technique were developed using drainage area as the only explanatory variable. Use of this single explanatory variable results in regression equations that are much less accurate than the full regression equations in section 2, “Estimating peak flows for ungaged, unregulated streams in rural drainage basins”, but the technique takes less time to apply.

Application of the simplified technique

The simplified peak-flow regression equations for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years are presented in table 8. The average standard error of prediction, the PRESS statistic, and the average equivalent years of record are discussed in “Limitations and accuracy of the technique” at the end of this section.

Definitions of equation variables in table 8:

Q_n - Peak flow - The calculated peak flow, in cubic meters per second, for recurrence interval n (n equals 2, 5, 10, 25, 50, 100, and 500 years).

A - Drainage area - The contributing area, in square kilometers, of a drainage basin. The term “contributing” means that flow from an area could contribute flow to a study site on a stream. This definition is intended to exclude only closed subbasins (subbasins

with no outlet) of a drainage basin. Noncontributing drainage area in Maine of any significant size is rare. Contributing drainage area, as defined for this report, does include parts of drainage-basin area that may not contribute significant flow to a peak flow because of the timing of peak flows from different parts of a basin.

All units of drainage area, except square kilometers, will result in incorrect estimates of peak flows. If inch-pound units are desired for the estimated peak flows, the conversion should be made to the peak flows after applying the equation(s).

The drainage area can be computed from a number of sources. A series of drainage area reports that list drainage areas at selected points on most streams in Maine have been published by the USGS (Cowing and Caracappa, 1978; Cowing and McNelly, 1978; Fontaine, 1979a, 1979b, 1980, 1981, 1982a, 1982b; Fontaine, Herrick, and Norman, 1982). Drainage areas can also be computed by digitizing the area of a drainage basin, after delineating the drainage-basin boundaries on topographic maps. Drainage areas can be computed from geographic information system (GIS) coverages. However, these coverages currently (1998) are not available in an easily usable form. The drainage areas for the 70 streamflow-gaging stations used in the development of the Maine regression equations are located in table 2. These drainage areas were calculated using the first two methods in this paragraph. The values of drainage area measured by all three methods are expected to be very similar.

Table 8. Simplified regression equations and their accuracy for estimating peak flows for ungaged, unregulated streams in rural drainage basins in Maine

[Q is peak flow, in cubic meters per second; A is drainage area, in square kilometers]

| Peak-flow regression equation for given recurrence interval (recurrence intervals from 2 to 500 years) | Average standard error of prediction (percent) | (PRESS/ n) ^{1/2} (percent) | Average equivalent years of record |
|--|--|--|------------------------------------|
| $Q_2 = 0.601 (A)^{0.825}$ | 65.2 to -39.5 | 65.6 to -39.6 | 0.85 |
| $Q_5 = 1.028 (A)^{0.797}$ | 69.0 to -40.8 | 70.6 to -41.4 | 1.08 |
| $Q_{10} = 1.363 (A)^{0.783}$ | 71.8 to -41.8 | 73.8 to -42.5 | 1.39 |
| $Q_{25} = 1.844 (A)^{0.767}$ | 75.4 to -43.0 | 78.6 to -44.0 | 1.81 |
| $Q_{50} = 2.244 (A)^{0.757}$ | 77.8 to -43.8 | 82.0 to -45.0 | 2.13 |
| $Q_{100} = 2.680 (A)^{0.748}$ | 80.3 to -44.5 | 85.4 to -46.0 | 2.42 |
| $Q_{500} = 3.836 (A)^{0.729}$ | 86.2 to -46.3 | 93.6 to -48.4 | 3.04 |

Limitations and accuracy of the simplified technique

The regression equations for the simplified technique are significantly less accurate than those developed in section 2, “Estimating peak flows for ungaged, unregulated streams in rural drainage basins” (see the measures of accuracy in table 3 and table 8). The latter regression equations are referred to as the “full regression equations.”

The regression equations in this section of the report are not applicable to regulated or urbanized drainage basins. “Choosing the appropriate section of this report to obtain estimated peak flows” in Part 1 of this report defines “regulated” and “urbanized” and indicates the appropriate techniques for such basins.

The accuracy of the equations will be reduced if the explanatory variable (drainage area) used in the simplified regression equations is outside the range of the values used to develop the equations (2.41 km^2 to $4,280 \text{ km}^2$). The magnitude of this reduction in accuracy is unknown and potentially large. The potential for large reductions in the accuracy of the regression equations increases as the distance outside the range increases.

The regression equations in the simplified technique may seriously underestimate the peak flows for sites that have very steep slopes (slopes, as defined in “Data used for the technique” of section 2, of greater than 50 m/km). As explained in section 2, preliminary regression equations significantly underpredicted the peak flows for three very steep-sloped basins in New Hampshire.

The average standard error of prediction (ASEP) is a measure of how well the regression equations will estimate peak flows when they are applied to ungaged drainage basins. The ASEP is the square root of the average variance of prediction at a group of sites that have the same basin characteristics as the gaged stations used in development of the regression equations. The standard error of prediction varies from site to site, depending on the value of the explanatory variable (drainage area) for each site. The standard error of prediction will be smaller for sites that have a drainage area near the mean of its range; however, the error associated with the different values of the explanatory variable is a small part of the total standard error of prediction. For this reason, the ASEP can be used as an approximate standard error of prediction for individual sites. The probability that the true value of a peak flow at a site is between the positive-percent ASEP and the

negative-percent ASEP is approximately 68 percent. For example, there is a 68 percent probability that the true 50-year peak flow at an ungaged site is between +77.8 percent and -43.8 percent (table 8) of the computed peak flow. In comparison, there is a 68 percent probability that the true 50-year peak flow from the full regression equations will be between +46.9 percent and -31.9 percent (table 3, page 23) of the computed peak flow.

Another overall measure of how well regression equations will estimate flood peaks when applied to ungaged basins is the PRESS statistic. The PRESS statistic is a validation-type statistic. To compute the PRESS statistic, one gaging station is removed from the stations used to develop the regression equation, then the value of the one left out is predicted. The difference between the predicted value from the regression equation and the observed peak flow at that station is computed. The gaging station left out is then changed and the above process repeated until every station has been left out once. The prediction errors are then squared and summed. PRESS/n is analogous to the average variance of prediction, and the square root of PRESS/n is analogous to the average standard error of prediction. Values of the square root of PRESS/n close to the values of the average standard error of prediction provide some measure of validation of the regression equations.

The average equivalent years of record is a third measure of the overall accuracy of the regression equations. This measure represents the average number of years of gaging-station data needed to achieve results with accuracy equal to the regression equations. The average equivalent years of record is a function of the accuracy of the regression equations, the recurrence interval, and the average variance and skew of the annual peak flows at gaging stations (Hardison, 1971).

Section 4: Estimating peak flows for ungaged sites on gaged, unregulated streams in rural drainage basins

If an ungaged site is relatively near (see “Limitations of the technique” later in this section for details) a USGS streamflow-gaging station and on the same stream, a weighted peak flow is calculated. The weights are determined by how far (in terms of drainage area) the ungaged site is from the gaging station.

Application of the technique

Equation 6 provides the means for calculating a final weighted peak flow at an ungaged site on a gaged stream by weighting the peak flow from the gaging station with the peak flow from the regression equation. A different approach is given (equation 10) for sites (1) whose explanatory variables (drainage area and percentage of basin wetlands) are outside the two-dimensional range of the variables used in the development of the regression equations (fig. 3, page 25); or (2) sites that drain Canadian land. Yet another approach (equation 11) is provided for ungaged sites located between two gaging stations.

$$Q_{uf} = Q_r(W_r) + Q_u(1 - W_r), \quad (6)$$

where

Q_{uf} is the final weighted peak flow for a given recurrence interval (for example, the 50-year peak flow) for an ungaged site on a gaged stream, and

Q_r is the regression estimate of the peak flow, at the ungaged site, for a given recurrence interval (for example, the 50-year peak flow) from table 3 in section 2, "Estimating peak flows for ungaged, unregulated streams in rural drainage basins",

W_r is a weighting factor:

For $A_u > A_g$, $W_r = (A_u / A_g) - 1$, and (7)

For $A_u < A_g$, $W_r = (A_g / A_u) - 1$, (8)

where

A_u is the drainage-basin area of the ungaged site, and

A_g is the drainage-basin area of the gaging station.

Q_u is the peak flow from the gaging station with a drainage area adjustment:

$$Q_u = Q_w (A_u / A_g)^b, \quad (9)$$

where

Q_w is the weighted-average peak flow for a given recurrence interval (such as the 50-year peak flow) for the gaging station from table 1 in section 1, "Estimates of peak flows and maximum recorded flows at USGS streamflow-gaging stations" (or from future reports), and

b is the coefficient of the simplified (drainage area only) regression equation for the appropriate recurrence interval:

$b = 0.825$ for a recurrence interval of 2 years,

$b = 0.797$ for a recurrence interval of 5 years,

$b = 0.783$ for a recurrence interval of 10 years,

$b = 0.767$ for a recurrence interval of 25 years,

$b = 0.757$ for a recurrence interval of 50 years,

$b = 0.748$ for a recurrence interval of 100 years, and

$b = 0.729$ for a recurrence interval of 500 years.

If the explanatory variables (drainage area and percentage of basin wetlands) are (1) outside the 2-dimensional range of the variables used for the regression equations (fig. 3, page 25); or (2) if the ungaged site has Canadian drainage, then

$$Q_{uf} = Q_w (A_u / A_g)^b, \quad (10)$$

where

Q_{uf} is the final weighted peak flow for a given recurrence interval (for example, the 50-year peak flow) for an ungaged site on a gaged stream, and

Q_w is the weighted-average peak flow for a given recurrence interval (such as the 50-year peak flow) for the gaging station from table 1 in section 1, "Estimates of peak flows and maximum recorded flows at USGS streamflow-gaging stations" (or from future reports). If the weighted-average peak flow is not available, the gaging-station peak flow should be used.

A_u , A_g , and b were defined in equations 7, 8, and 9.

If the ungaged site is located between two gaging stations, then

$$Q_{uff} = (Q_{uf1}(A_{g2} - A_u) + Q_{uf2}(A_u - A_{g1})) / (A_{g2} - A_{g1}), \quad (11)$$

where

Q_{uff} is the final weighted flow for an ungaged site between gaging stations 1 and 2,

Q_{uf1} is computed in equation 6 or 10 (as appropriate) for the upstream gaging station,

A_{g2} is the drainage-basin area of the downstream gaging station,

A_u is the drainage-basin area of the ungaged site,

Q_{uf2} is computed in equation 6 or 10 (as appropriate) for the downstream gaging station, and

A_{g1} is the drainage-basin area of the upstream gaging station.

Limitations of the technique

Equations 6 through 11 are applicable to ungaged sites on gaged, unregulated streams in rural drainage basins that are between 50 and 200 percent of the drainage area of the gaging station(s), except for sites that are plus or minus 3 percent of the drainage area. For ungaged sites within 3 percent of the gaging-station drainage area, the weighted-average peak-flow estimates (table 1, page 8) should be used. If the difference in drainage areas is less than 3 percent and the weighted-average peak-flow estimate is not available for a station, the gaging-station peak-flow estimate from table 1 should be used.

This method is not applicable to urbanized drainage basins or to regulated streams (see "Choosing the appropriate section of this report to obtain estimated peak flows" in Part 1 of this report for definitions of these terms); neither is it applicable if the area between the ungaged site and the gaging station(s) is urbanized or contains regulation (using the same definitions of urbanized and regulated just referred to, but using drainage-area difference instead of drainage area in these definitions).

There may be other situations where the techniques in this section are not applicable. One known example is the Saco River between Conway, New Hampshire, and Cornish, Maine. As shown in table 1, the estimated peak flows are larger at Conway than at Cornish even though the drainage area at Cornish is more than 3 times the drainage area at Conway. The calculation of Q_U in equation 9 would obviously give unreasonable results in this situation. It is unknown how close (in terms of drainage area) a site would have to be to the gaging stations at Conway or at Cornish for the calculation of Q_U to be reasonable. The large amount of natural storage in the Saco River valley between Conway and Cornish may be the cause of this unusual situation.

Section 5: Estimating peak flows for ungaged, unregulated streams in urbanized drainage basins

Sauer and others (1983) computed regression equations that consider the effects of urbanization on a drainage basin. Data from 269 gaging stations in 31 states (56 cities) were considered for use in computing these equations. Although no stations from Maine were used, tests by Sauer and others indicated that the equations are not geographically biased.

Sauer and others presented seven-variable and three-variable regression equations in their report.

Although the three-variable equations are easier to apply, a later study using new data (Sauer, 1985) showed the three-variable equations to be biased in some areas of the country (mainly in some southeastern states). For this reason, the seven-variable regression equations are presented here. Data from 199 gaging stations across the United States were used to compute the seven-variable equations.

Application of the technique

The seven-variable regression equations are presented in table 9. Explanations of the variables used in table 9 are presented below. These regression equations are referred to as the "urban" regression equations. The average standard error of estimate and the average standard error of prediction are discussed in "Limitations and accuracy of the technique" at the end of this section.

These regression equations are statistical models and 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, using maps other than the 1961 National Weather Service (NWS) maps to compute the 2-hour, 2-year rainfall) will result in peak-flow estimates of unknown accuracy. It is necessary to use inch-pound units for these equations.

Definitions of equation variables in table 9:

UQ_n - The peak flow, in cubic feet per second, for the urban drainage basin for recurrence interval n ; that is, UQ_2 = 2-year urban peak flow, UQ_5 = 5-year urban peak flow, and so forth.

A - The contributing drainage area, in square miles (not square kilometers). In urban areas, drainage systems sometimes cross topographic divides. Such drainage-area changes should be accounted for when computing A . This may require field inspections.

SL - The main channel slope, in feet per mile, measured from points that are 10 percent and 85 percent of the main-channel length upstream from the study site. The main channel, where two channels join, is the one that drains the largest area. The main-channel length is measured as the distance from the study site to the basin divide. For sites where SL is greater than 70 ft/mi, 70 ft/mi is used in the equations.

R_2 - The rainfall, in inches, for the 2-hour 2-year occurrence. Determined from NWS maps (1961). The Maine section of the appropriate NWS map is reproduced as figure 4.

Table 9. Urban regression equations and their accuracy for estimating peak flows
[Q is peak flow in cubic feet per second, dash indicates not available]

| Peak-flow regression equation for given recurrence interval (recurrence intervals from 2 to 500 years) | Average standard error of estimate (percent) | Average standard error of prediction (percent) |
|---|--|--|
| $UQ_2 = 2.35 (A)^{0.41} (SL)^{0.17} (R_2+3)^{2.04} (ST+8)^{-0.65} (13 - BDF)^{-0.32} (IA)^{0.15} (RQ_2)^{0.47}$ | 46 to -31 | 54 to -35 |
| $UQ_5 = 2.70 (A)^{0.35} (SL)^{0.16} (R_2+3)^{1.86} (ST+8)^{-0.59} (13 - BDF)^{-0.31} (IA)^{0.11} (RQ_5)^{0.54}$ | 44 to -31 | - |
| $UQ_{10} = 2.99 (A)^{0.32} (SL)^{0.15} (R_2+3)^{1.75} (ST+8)^{-0.57} (13 - BDF)^{-0.30} (IA)^{0.09} (RQ_{10})^{0.58}$ | 45 to -31 | 55 to -35 |
| $UQ_{25} = 2.78 (A)^{0.31} (SL)^{0.15} (R_2+3)^{1.76} (ST+8)^{-0.55} (13 - BDF)^{-0.29} (IA)^{0.07} (RQ_{25})^{0.60}$ | 48 to -32 | - |
| $UQ_{50} = 2.67 (A)^{0.29} (SL)^{0.15} (R_2+3)^{1.74} (ST+8)^{-0.53} (13 - BDF)^{-0.28} (IA)^{0.06} (RQ_{50})^{0.62}$ | 50 to -34 | - |
| $UQ_{100} = 2.50 (A)^{0.29} (SL)^{0.15} (R_2+3)^{1.76} (ST+8)^{-0.52} (13 - BDF)^{-0.28} (IA)^{0.06} (RQ_{100})^{0.63}$ | 54 to -35 | 66 to -40 |
| $UQ_{500} = 2.27 (A)^{0.29} (SL)^{0.16} (R_2+3)^{1.86} (ST+8)^{-0.54} (13 - BDF)^{-0.27} (IA)^{0.05} (RQ_{500})^{0.63}$ | 61 to -38 | - |

ST - Drainage basin wetlands, the areal percentage of the drainage basin occupied by lakes, reservoirs, and wetlands. In-channel storage of a temporary nature caused by detention ponds, roadway embankments, or other structures is not included in the computation of ST. This variable should be computed from USGS topographic maps (not U.S. Fish and Wildlife Service National Wetland Inventory maps or by other methods).

IA - The percentage of the drainage basin occupied by impervious surfaces, such as houses, buildings, streets, and parking lots. This variable should be computed from the best available maps or aerial photographs. Field inspections to supplement the maps are useful.

RQ_n - The peak flow, in cubic feet per second, for an equivalent rural drainage basin for recurrence interval n. For Maine, the equations in table 3 in section 2, "Estimating peak flows for ungaged, unregulated streams in rural drainage basins" should be used to calculate RQ_n. Note that the peak flow must be converted from metric to inch-pound units before entering this variable into the urban regression equations.

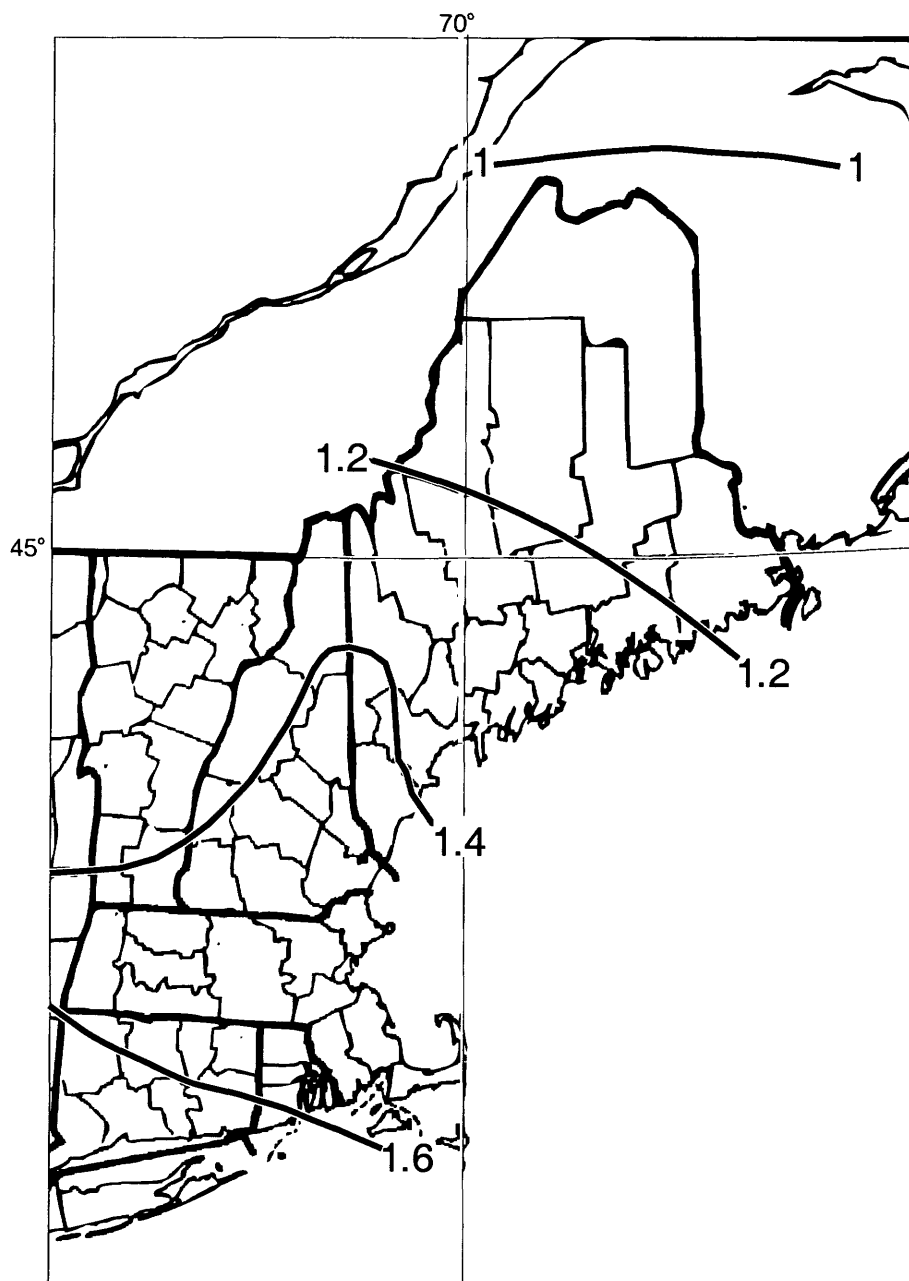
BDF - The basin development factor, an index of the prevalence of the drainage aspects of (a) storm sewers, (b) channel modifications, (c) impervious channel linings, and (d) curb-and-gutter streets. The range of BDF is 0 to 12. A value of zero for BDF indicates that the above drainage aspects are not prevalent, but it does not necessarily mean the basin is nonurbanized. A value of 12 indicates full development of the drainage aspects throughout the basin.

BDF can be easily determined from drainage maps and field inspections of the drainage basin. After

the basin has been delineated on a topographic map, the basin is divided into upper, middle, and lower thirds on the same map. Each third contains approximately one-third of the drainage area and drains the upper, middle, or lower reaches of the basin. Because travel time is considered when drawing the lines separating the basin into thirds, distances along main streams and tributaries can be marked to help locate the boundaries of the basin thirds. This drawing of the boundaries means that not all thirds of the basin have equal travel distances but that within each third, the travel distances of two or more streams are about equal. Because precise definition of the lines dividing the basin into thirds is not considered necessary, the lines can generally be drawn on the drainage map by eye, without precise measurements. Figure 5 shows schematics of three typical basin shapes and their division into thirds. Complex basin shapes and drainage patterns are sometimes encountered; they require more judgment in subdividing.

Within each drainage-basin third, four aspects of the drainage system are evaluated, and each is assigned a code as follows:

1. *Channel modifications* - If channel modifications such as straightening, enlarging, deepening, and clearing are prevalent for the main drainage channels and principal tributaries (those that drain directly into the main channel) in a basin third, then a code of 1 is assigned. Any or all of these modifications would qualify for a code of 1. To be considered prevalent, at least 50 percent of the main drainage channels and principal tributaries must be modified to some degree over natural conditions. If channel modifications are not prevalent, then a code of zero is assigned.



Base from U.S. Department of
Commerce, National Weather Service

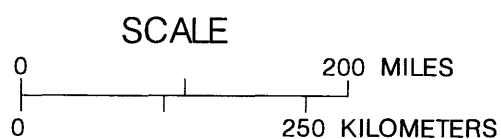


Figure 4. National Weather Service 2-hour, 2-year rainfall for Maine.

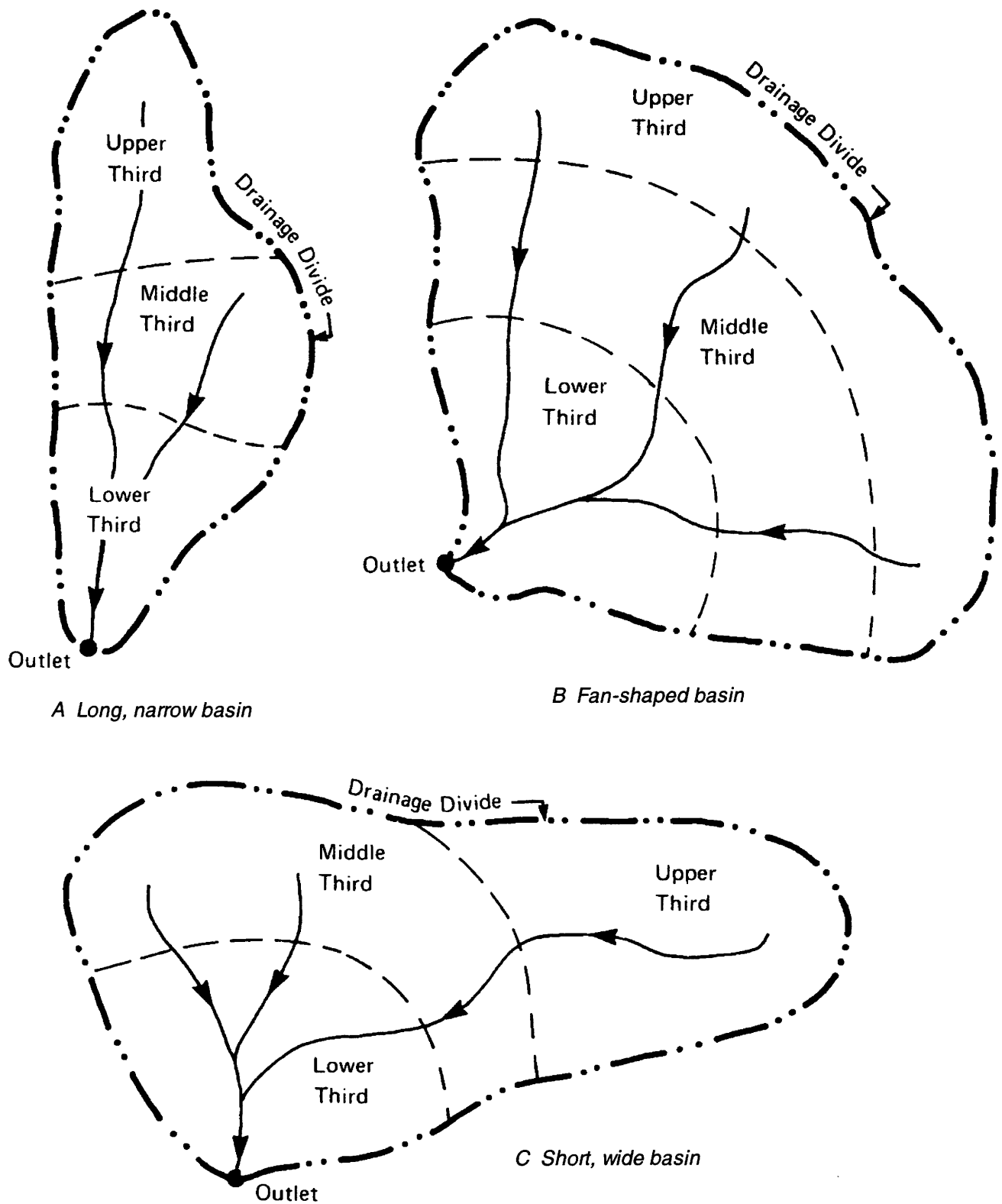


Figure 5. Typical drainage-basin shapes and subdivision into basin thirds (from Sauer and others, 1983).

2. *Channel linings* - If more than 50 percent of the length of the main drainage channel and principal tributaries in each basin third has been lined with an impervious material, such as concrete, then a code of 1 is assigned to this aspect. If less than 50 percent of these channels are lined, then a code of zero is assigned. The presence of channel linings would obviously indicate the presence of channel modifications as well. Therefore, this is an added factor that indicates a more highly developed drainage system.

3. *Storm drains (storm sewers)* - Storm drains are defined as enclosed drainage structures (usually pipes), frequently used on the secondary tributaries (those that drain directly into the principal tributaries) where the drainage is received directly from streets or parking lots. Many of these drains empty into open channels; however, in some basins they empty into channels enclosed as box or pipe culverts. When more than 50 percent of the secondary tributaries within a subarea (third) consist of storm drains, then a code of 1 is assigned to this aspect; if less than 50 percent of the secondary tributaries consist of storm drains, then a code of zero is assigned. It should be noted that if 50 percent or more of the main drainage channels and principal tributaries are enclosed, then the aspects of channel modifications and channel linings would also be assigned a code of 1.

4. *Curb-and-gutter streets* - If more than 50 percent of a subarea (third) is urbanized (covered by residential, commercial, and (or) industrial development) and if more than 50 percent of the streets and highways in the subarea are constructed with curbs and gutters, then a code of 1 is assigned to this aspect. Otherwise, it receives a code of zero. Drainage from curb-and-gutter streets frequently empties into storm drains.

The above guidelines for determining the various drainage-system codes are not intended to be precise measurements. A certain amount of subjectivity will necessarily be involved. Field checking should be performed to obtain the best estimate. BDF is the sum of the assigned codes; four drainage aspects to which codes are assigned in each of the 3 basin thirds. The maximum value for a fully developed drainage system would be 12. In contrast, if the drainage system were totally undeveloped, then a BDF of zero would result. Such a condition does not necessarily mean that the basin is unaffected by urbanization. In fact, a basin could be partially urbanized, have some impervious area, and have some modification of secondary tributaries and still have an assigned BDF of zero.

The BDF is a fairly easy index to estimate for an existing urban basin. The 50-percent guideline will usually not be difficult to evaluate because many urban

areas tend to use the same design criteria and therefore have similar drainage aspects throughout. Also, the BDF is convenient for projecting the effects of future development. Obviously, full development and maximum urban effects on peaks would occur when BDF equals 12.

Limitations and accuracy of the technique

The computed urban peak flow (UQ_n) should be compared to the equivalent rural peak flow (RQ_n) to make sure that the urban peak-flow estimate is reasonable. This is especially true if the drainage-basin wetlands variable (ST) from the urban equations (which is calculated using USGS topographic maps) differs by more than 50 percent from the basin wetlands variable (W) from the rural equations (page 23, calculated using U.S. Fish and Wildlife National Wetland Inventory Maps).

The urbanization of a drainage basin generally causes peak flows to increase for those basins that do not have significant in-channel or detention storage. The increase in peak flows is usually most dramatic for lower recurrence interval flows (which occur frequently) and less pronounced for higher recurrence interval flows (Sauer and others, 1983).

The location of urbanization in a drainage basin may have an effect on peak flows that is not accounted for in the urban regression equations. For example, if the lower part of a basin is urbanized and the upper part is not, rapid removal of floodwaters from the lower part may occur before the upper part can contribute significant runoff. This pattern of urbanization could potentially decrease peak flows from a drainage basin (Sauer and others, 1983).

At gaging stations that were used to compute the urban regression equations, at least 15 percent of their drainage area was covered with some type of commercial, industrial, or residential development. For this reason, the urban equations may not be applicable to basins containing less than 15 percent developed land.

The ranges of the explanatory variables used in the urban regression equations are listed in table 10, and the standard errors for the equations are given in table 9. If values outside the ranges of the explanatory variables are used, then the standard errors may be considerably higher than the listed standard errors.

As discussed by Sauer and others, the drainage basin wetlands variable (ST) does not include in-channel storage of a temporary nature (resulting from detention ponds, roadway embankments, or other structures). This type of storage tends to reduce peak

Table 10. Ranges of explanatory variables used in the urban regression equations

[From Sauer and others, 1983]

| Variable | Minimum | Maximum | Units |
|----------------|---------|-----------------|---------------|
| A | 0.2 | 100 | Square miles |
| SL | 3.0 | 70 ^a | Feet per mile |
| R ₂ | 0.2 | 2.8 | Inches |
| ST | 0 | 11 | Percent |
| BDF | 0 | 12 | None |
| IA | 3 | 50 | Percent |

^aMaximum value of slope for use in urban equations is 70 feet per mile, although numerous drainage basins used in this study had SL values as high as 500 feet per mile.

flows. Reservoir- and channel-routing techniques are recommended to determine the effect that temporary in-channel storage has on peak flows in an urbanized basin.

The average standard error of estimate is, by definition, one standard deviation on each side of the regression equation and contains about 68 percent of the data within this range. The average standard error of estimate is a measure of how well the regression equations estimated the response variable (UQ_n) at the stations used to develop the equations. The average standard error of prediction is a measure of how well the regression equations will estimate peak flows when they are applied to ungaged drainage basins. The average standard errors of prediction (ASEP's) in table 9 were computed by Sauer and others using a validation method (split sampling) unlike the ASEP's computed earlier in this report. The ASEP's in table 9 are comparable to $(PRESS/n)^{1/2}$ in tables 3 and 8.

There is a 68 percent probability that the true value of a peak flow at a site (a site where a peak flow is being estimated) will be within the average standard error of prediction range. The standard errors in table 9 are based on 199 gaging stations nationwide, none of which are in Maine. Standard errors for Maine are assumed to be similar to those in table 9 but could be larger or smaller.

Section 6: Estimating peak flows for ungaged sites on regulated streams

Techniques for estimating peak flows for regulated streams are beyond the scope of this report because peak flows on regulated streams are dependent on variable human actions. A potential procedure for estimating peak flows for ungaged sites on regulated streams would be to route peak inflows through the regulated reservoir(s), taking into account regulation practices. The applicable method of this report could be used to estimate the magnitude of the peak inflows.

Equation 6 in section 4, "Estimating peak flows for ungaged sites on gaged, unregulated streams in rural drainage basins" is not applicable to regulated streams because there are no regulated regression equations to use in the weighting scheme of this method. Also, equations 9 and 10 in section 4, are not, in general, considered reliable for regulated streams. Several reaches of streams in Maine show these equations to be unreliable for regulated streams: Kennebec River between The Forks and Waterville; Androscoggin River between Gorham, New Hampshire, and Rumford, Maine; and Presumpscot River between the outlet of Sebago Lake and Westbrook.

PART 3: SUPPLEMENTAL INFORMATION

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Appendix—Detailed descriptions of gaging-station locations

[lat, latitude; long, longitude; km, kilometers; m, meters; right and left bank are referenced facing downstream]

| USGS gaging-station number | Gaging station name | Station location |
|----------------------------------|--|--|
| 01010000 | St. John River at Ninemile Bridge, Maine | Lat 46°42'00", long 69°42'59", Aroostook County, on right bank in T12 R15, 0.2 km downstream from Ninemile Brook, and 0.6 km downstream from Ninemile Bridge, and 17.7 km northwest of Clayton Lake Post Office. |
| 01010070 | Big Black River near Depot Mountain, Maine | Lat 46°53'38", long 69°45'08", Aroostook County, on left bank at the Six Mile Landing Road Bridge, 6.4 km northeast of Depot Mountain, 43.1 km upstream from mouth. |
| 01010500 | St. John River at Dickey, Maine | Lat 47°06'44", long 69°05'25", Aroostook County, on right bank 150 m downstream of highway bridge at Dickey, 0.6 km downstream from Little Black River, and 4.5 km upstream from Allagash River. |
| 01011000 | Allagash River near Allagash, Maine | Lat 47°04'14", long 69°04'51", Aroostook County, on left bank 4.8 km upstream from mouth and village of Allagash. |
| 01011500 | St. Francis River at outlet of Glasier Lake, near Connors, New Brunswick, Canada | Lat 47°12'25", long 68°57'25", Madawaska County, on left bank at outlet of Glasier Lake, 6.4 km upstream from mouth, and 10.5 km west of Connors. |
| 01013500 | Fish River near Fort Kent, Maine | Lat 47°14'14", long 68°34'56", Aroostook County, on right bank 90 m upstream from highway bridge at Fort Kent Mills, 3.0 km upstream from mouth, and 3.0 km south of Fort Kent. |
| 01014000 | St. John River below Fish River, at Fort Kent, Maine | Lat 47°15'27", long 68°35'35", Aroostook County, on right bank at Fort Kent and 0.3 km downstream from Fish River. |
| 01014700 | Factory Brook near Madawaska, Maine | Lat 47°21'09", long 68°17'55", Aroostook County, 4 m upstream from culvert in U.S. Highway 1, 0.8 km upstream from mouth and 1.8 km east of Madawaska. |
| 01015700 | Houlton Brook near Oxbow, Maine | Lat 46°26'18", long 68°24'21", Aroostook County, at culvert in road west from State Highway 11 to Oxbow, 3.1 km upstream from mouth, and 6.9 km northeast of Oxbow. |
| 01015800 | Aroostook River near Masardis, Maine | Lat 46°31'21", long 68°22'23", Aroostook County, on left bank, 55 m upstream from highway bridge, and 2.9 km downstream from St. Croix Stream and Masardis. |
| 01016500 | Machias River near Ashland, Maine | Lat 46°37'42", long 68°26'07", Aroostook County, on right bank 30 m upstream from highway bridge, 1.3 km upstream from mouth, and 2.4 km west of Ashland. |
| 01017000 | Aroostook River at Washburn, Maine | Lat 46°46'36", long 68°09'29", Aroostook County, on right bank, 15 m upstream from Bangor and Aroostook Railroad bridge, 0.2 km downstream from Salmon Brook, and 1.6 km south of railroad station at Washburn. |
| 01017300 | Nichols Brook near Caribou, Maine | Lat 46°51'31", long 67°56'18", Aroostook County, at culvert in road north from Grimes Mills to State Highway 223, 90 m upstream from mouth and 5.6 km east of Caribou. |
| 01017900 | Marley Brook near Ludlow, Maine | Lat 46°08'42", long 68°03'42", Aroostook County, on left bank at upstream entrance of culvert under U.S. Route 2, 0.7 km upstream from mouth, and 1.8 km west of Ludlow. |
| 01018000 | Meduxnekeag River near Houlton, Maine | Lat 46°06'17", long 67°52'00", Aroostook County, on right bank 0.5 km downstream from South Branch, and 3.2 km upstream from Houlton. |

Appendix—Detailed descriptions of gaging-station locations—Continued

[lat, latitude; long, longitude; km, kilometers; m, meters; right and left bank are referenced facing downstream]

| USGS gaging-station number | Gaging station name | Station location |
|----------------------------------|---|---|
| 01018500 | St. Croix River at Vanceboro, Maine | Lat 45°34'08", long 67°25'47", Washington County, on right bank at international highway bridge in Vanceboro, and 120 m downstream from outlet of Spednik Lake. |
| 01019000 | Grand Lake Stream at Grand Lake Stream, Maine | Lat 45°10'23", long 67°46'06", Washington County, on left bank at Big Falls, 0.8 km southeast of village of Grand Lake Stream, and 1.3 km downstream from outlet dam of Grand Lake. |
| 01021000 | St. Croix River at Baring, Maine | Lat 45°08'12", long 67°19'05", Washington County, on right bank at site of destroyed international highway bridge at Baring. |
| 01021200 | Dennys River at Dennysville, Maine | Lat 44°54'03", long 67°14'56", Washington County, on right bank 305 m upstream from railroad bridge, 1.4 km upstream from Cathance Stream, and 1.6 km west of Dennysville. |
| 01021300 | Wiggins Brook near West Lubec, Maine | Lat 44°45'26", long 67°05'23", Washington County, 3 m upstream from culvert in State Highway 191, 7.1 km southwest of West Lubec. |
| 01021500 | Machias River at Whitneyville, Maine | Lat 44°43'23", long 67°31'15", Washington County, on right bank 245 m downstream from highway bridge on U.S. Route 1A at Whitneyville. |
| 01021600 | Middle River near Machias, Maine | Lat 44°44'14", long 67°29'35", Washington County, 12 m upstream from highway bridge in connecting road between State Highway 192 and U.S. Highway 1A, 3.5 km northwest of Machias and 5.5 km upstream from mouth. |
| 01022000 | East Machias River near East Machias, Maine | Lat 44°46'05", long 67°24'30", Washington County, just downstream from outlet of Hadley Lake and 5.0 km upstream from East Machias. |
| 01022260 | Pleasant River near Epping, Maine | Lat 44°41'52", long 67°47'16", Washington County, on right bank at Saco Falls, 30 m upstream from East Base Road bridge in Columbia, 1.0 km upstream from North Branch Pleasant River, and 2.6 km northeast of the village of Epping. |
| 01022500 | Narraguagus River at Cherryfield, Maine | Lat 44°36'29", long 67°56'10", Washington county, on left bank 245 m upstream from railroad bridge at Cherryfield, and 1.1 km downstream from West Branch of Narraguagus River. |
| 01022700 | Forbes Pond Brook near Prospect Harbor, Maine | Lat 44°24'33", long 68°01'37", Hancock County, on abutment of highway bridge in State Highway 186, 30 m upstream from mouth and in the village of Prospect Harbor. |
| 01023000 | West Branch Union River at Amherst, Maine | Lat 44°50'25", long 68°22'22", Hancock County on right bank 60 m upstream from site of old tannery dam, 1.0 km upstream from Indian Camp Brook, and 1.1 km northwest of Amherst. |
| 01024200 | Garland Brook near Mariaville, Maine | Lat 44°43'17", long 68°24'40", Hancock County, on left bank 6.7 m upstream from State Highway 181, 1.9 km upstream from mouth, and 2.4 km north of Mariaville. |
| 01026800 | Frost Pond Brook near Sedgwick, Maine | Lat 44°22'12", long 68°39'29", Hancock County, at culvert in State Highway 15 between Grays Corner and Black Corner, 215 m upstream from mouth, and 8 km northeast of Sedgwick. |

Appendix—Detailed descriptions of gaging-station locations—Continued

[lat, latitude; long, longitude; km, kilometers; m, meters; right and left bank are referenced facing downstream]

| USGS gaging-station number | Gaging station name | Station location |
|----------------------------------|--|--|
| 01028000 | West Branch Penobscot River near Medway, Maine | Lat 45°36'25", long 68°32'25", Penobscot County, on left bank just above Nichatou Rapids at Nichatou Island, 0.8 km upstream from confluence of East and West Branches, and 0.8 km west of Medway. |
| 01029500 | East Branch Penobscot River at Grindstone, Maine | Lat 45°43'49", long 68°35'22", Penobscot County, on left bank 150 m downstream from Bangor and Aroostook Railroad bridge, 0.8 km south of Grindstone, and 15.3 km upstream from confluence with West Branch Penobscot River. |
| 01030000 | Penobscot River near Mattawamkeag, Maine | Lat 45°34'00", long 68°24'10", Penobscot County, on left bank 550 m downstream from Mattaseunk Dam and powerhouse, 2.0 km upstream from Mattaseunk Brook, and 7.2 km upstream from Mattawamkeag. |
| 01030300 | Trout Brook near Danforth, Maine | Lat 45°41'43", long 67°54'07", Washington County, at culvert in road between Bancroft and Danforth, 2.1 km upstream from mouth and 5.0 km northeast of Danforth. |
| 01030400 | Gulliver Brook near Monarda, Maine | Lat 45°44'23", long 68°18'30", Aroostook County, at culvert in U.S. Highway 2, 0.8 km upstream from mouth and 6.6 km south of Monarda. |
| 01030500 | Mattawamkeag River near Mattawamkeag, Maine | Lat 45°30'03", long 68°18'22", Penobscot County, on left bank 1.0 km downstream of Gordon Falls, 1.0 km upstream from Mattakeunk Stream, 5.8 km upstream from Mattawamkeag, and 6.4 km upstream from mouth. |
| 01031500 | Piscataquis River near Dover-Foxcroft, Maine | Lat 45°10'31", long 69°18'55", Piscataquis County, on left bank 9 m downstream from Lows Bridge, 1.6 km upstream from Black Stream, and 7.6 km upstream from Dover-Foxcroft. |
| 01031600 | Morrison Brook near Sebec Corners, Maine | Lat 45°14'17", long 69°03'06", Piscataquis County, on left bank 18 m upstream from culvert in State Highway 16, 3.9 km east of Sebec Corners, and 6.1 km upstream from mouth. |
| 01033000 | Sebec River at Sebec, Maine | Lat 45°16'12", long 69°06'44", Piscataquis County, on right bank, 305 m downstream from highway bridge and dam at outlet of Sebec Lake at Sebec. |
| 01033500 | Pleasant River near Milo, Maine | Lat 45°16'58", long 69°00'13", Piscataquis County, on left bank 4.0 km northeast of Milo on Pleasant River Road, and 12.7 km upstream from mouth. |
| 01034000 | Piscataquis River at Medford, Maine | Lat 45°15'40", long 68°52'07", Piscataquis County, on left bank 3.2 km southwest of Medford and 5.3 km downstream from Pleasant River. |
| 01034500 | Penobscot River at West Enfield, Maine | Lat 45°14'12", long 68°38'56", Penobscot County, on left bank 9 m downstream from highway bridge, 305 m downstream from Piscataquis River, and at West Enfield. |
| 01034900 | Coffin Brook near Lee, Maine | Lat 45°20'18", long 68°21'42", Penobscot County, 4 m upstream from culvert on Lee Back Road, and 6.0 km southwest of Lee. |
| 01035000 | Passadumkeag River at Lowell, Maine | Lat 45°11'04", long 68°28'29", Penobscot County, on right bank at Lowell, 0.8 km downstream from dam and highway bridge on Fogg Brook Road, and 18.0 km upstream from mouth. |

Appendix—Detailed descriptions of gaging-station locations—Continued

[lat, latitude; long, longitude; km, kilometers; m, meters; right and left bank are referenced facing downstream]

| USGS gaging-station number | Gaging station name | Station location |
|----------------------------------|---|--|
| 01036500 | Kenduskeag Stream near Kenduskeag, Maine | Lat 44°53'48", long 68°53'04", Penobscot County, on right bank 90 m upstream from highway bridge on State Route 15, 2.9 km downstream from Black Stream, and 4.7 km south of Kenduskeag. |
| 01037200 | Shaw Brook ^a near Northern Maine Junction, Maine | Lat 44°46'39", long 68°50'59", Penobscot County, 8 m upstream from culvert in U.S. Highway 95, 1.8 km upstream from mouth, and 1.9 km southwest of Northern Maine Junction. |
| 01037430 | Goose River at Rockport, Maine | Lat 44°11'21", long 69°04'49", Knox County, 2 m upstream from culvert in U.S. Highway 1, 0.6 km upstream from mouth, and 0.6 km northeast of Rockport. |
| 01038000 | Sheepscot River at North Whitefield, Maine | Lat 44°13'23", long 69°35'38", Lincoln County, on left bank 15 m upstream from highway bridge on State Route 126 at North Whitefield, at mouth of Finn Brook, and 0.5 km east of North Whitefield village. |
| 01041000 | Kennebec River at Moosehead, Maine | Lat 45°35'08", long 69°43'05", Somerset County, on right bank 215 m downstream from dam at East Outlet of Moosehead Lake, and 0.3 km northwest of Moosehead. |
| 01041900 | Mountain Brook near Lake Parlin, Maine | Lat 45°28'12", long 70°03'54", Somerset County, at culvert in U.S. Highway 201, 2.9 km upstream from mouth and 6.1 km southeast of Lake Parlin. |
| 01042500 | Kennebec River at The Forks, Maine | Lat 45°20'45", long 69°57'48", Somerset County, on right bank at The Forks, 0.6 km upstream from highway bridge, and 1.1 km upstream from Dead River. |
| 01043500 | Dead River near Dead River, Maine | Lat 45°13'48", long 70°11'58", Somerset County, on right bank at foot of Long Falls, in T3 R4, 0.5 km upstream from Black Brook, and 0.8 km downstream from Flagstaff Lake Dam. |
| 01045000 | Dead River at The Forks, Maine | Lat 45°20'59", long 69°59'26", Somerset County, on left bank 2.4 km northwest of The Forks, and 2.9 km upstream from mouth. |
| 01046000 | Austin Stream at Bingham, Maine | Lat 45°03'55", long 69°52'55", Somerset County, at Bingham, and 1.2 km upstream from mouth. |
| 01046500 | Kennebec River at Bingham, Maine | Lat 45°03'06", long 69°53'12", Somerset County, on right bank at Bingham, 15 m downstream from highway bridge, 0.6 km downstream from Austin Stream, and 2.6 km downstream from Wyman Dam. |
| 01046800 | South Branch Carrabassett River at Bigelow, Maine | Lat 45°04'45", long 70°19'03", Franklin County, at bridge in State Highway 27, and 915 m southeast of Bigelow. |
| 01047000 | Carrabassett River near North Anson, Maine | Lat 44°52'09", long 69°57'20", Somerset County, on left bank 5.5 km upstream from Mill Stream and North Anson. |
| 01048000 | Sandy River near Mercer, Maine | Lat 44°42'26", long 69°56'21", Somerset County, on right bank 1.4 km upstream from Bog Stream, 3.4 km north of Mercer, and 13.8 km upstream from mouth. |
| 01048100 | Pelton Brook near Anson, Maine | Lat 44°45'58", long 69°54'32", Somerset County, on wingwall of abandoned highway bridge just downstream from State Highway 43, 1.1 km upstream from mouth, and 3.9 km southwest of Anson. |

Appendix—Detailed descriptions of gaging-station locations—Continued

[lat, latitude; long, longitude; km, kilometers; m, meters; right and left bank are referenced facing downstream]

| USGS gaging-station number | Gaging station name | Station location |
|----------------------------------|--|---|
| 01048500 | Kennebec River at Waterville, Maine | Lat 44°33'45", long 69°37'10", Kennebec County, at dam and mill of Hollingworth and Whitney Co. at Winslow, 3.2 km above Sebec River, and 5.6 km above Messalonskee Stream. |
| 01049000 | Sebec River near Pittsfield, Maine | Lat 44°43'00", long 69°24'56", Somerset County, on right bank 2.7 km upstream from Twentyfive Mile Stream, and 8.0 km south of Pittsfield. |
| 01049100 | Hall Brook at Thorndike, Maine | Lat 44°34'52", long 69°16'50", Waldo County, at culvert in State Highway 139, 0.3 km northwest of Thorndike, and 0.5 km upstream from mouth. |
| 01049130 | Johnson Brook at South Albion, Maine | Lat 44°29'53", long 69°29'12", Kennebec County, on right bank approximately 1.3 km downstream from Dutton Pond, and approximately 0.8 km southwest of Albion. |
| 01049205 | Kennebec River near Waterville, Maine | Lat 44°31'38", long 69°39'09", Kennebec County, on right bank at Waterville Sewage Treatment Plant, 2.1 km downstream from Sebec River, and 0.6 km upstream from Messalonskee Stream. |
| 01049300 | North Branch Tanning Brook near Manchester, Maine | Lat 44°21'00", long 69°51'07", Kennebec County, on right bank 8.5 m upstream from culvert under Prescott Road, 0.3 km north of the intersection with Puddle Dock Road, 550 m upstream from mouth, and 2.9 km north of Manchester. |
| 01049373 | Mill Stream at Winthrop, Maine | Lat 44°18'24", long 69°58'18", Kennebec County, on right bank 150 m downstream from bridge on Main Street, at Winthrop. |
| 01049500 | Cobosseecontee Stream at Gardiner, Maine | Lat 44°13'42", long 69°46'42", Kennebec County, on left bank 90 m upstream from Winter Street bridge in Gardiner, 0.6 km upstream from mouth, and 1.3 km downstream from Gardiner Water District Dam. |
| 01049550 | Togus Stream at Togus, Maine | Lat 44°15'57", long 69°41'55", Kennebec County, on right bank 30 m downstream from mouth of Chase Meadow Stream and 185 m downstream from State Route 226 bridge, and 2.4 km northeast of Chelsea. |
| 01049700 | Gardiner Pond Brook at Dresden Mills, Maine | Lat 44°06'29", long 69°43'21", Lincoln County, 5 m upstream from culvert in town road from Dresden Mills to Head Tide, 185 m upstream from mouth, and in northeast section of village of Dresden Mills. |
| 01050900 | Four Ponds Brook near Houghton, Maine | Lat 44°49'55", long 70°42'08", Franklin County, 8 m upstream from culvert in State Highway 17, 1.5 km upstream from mouth, and 10.9 km north of Houghton. |
| 01052500 | Diamond River near Wentworth Location, New Hampshire | Lat 44°52'40", long 71°03'25", Coos County, on left bank, 1.6 km upstream from mouth, and 2.6 km north of Wentworth Location. |
| 01053500 | Androscoggin River at Errol, New Hampshire | Lat 44°46'57", long 71°07'46", Coos County, on right bank 0.6 km downstream from Errol Dam, 0.6 km northeast of Errol, and 1.0 km upstream from Clear Stream. |
| 01054000 | Androscoggin River near Gorham, New Hampshire | Lat 44°26'10", long 71°11'27", on right bank at Pulsifer Rips, 3.5 km downstream from Dead River, and 6.4 km upstream from Gorham. |

Appendix—Detailed descriptions of gaging-station locations—Continued

[lat, latitude; long, longitude; km, kilometers; m, meters; right and left bank are referenced facing downstream]

| USGS gaging-station number | Gaging station name | Station location |
|----------------------------------|---|---|
| 01054200 | Wild River at Gilead, Maine | Lat 44°23'27", long 70°58'47", Oxford County, on right bank 61 m upstream from highway bridge on U.S. Route 2, 600 m upstream from mouth, and 0.6 km west of Gilead. |
| 01054300 | Ellis River at South Andover, Maine | Lat 44°35'37", long 70°44'01", Oxford County, on left bank 30 m upstream from covered bridge at South Andover. |
| 01054500 | Androscoggin River at Rumford, Maine | Lat 44°33'04", long 70°32'38", Oxford County, on right bank below lower power plant of Rumford Falls Power Co. in Rumford, and 300 m upstream from Swift River. |
| 01055000 | Swift River near Roxbury, Maine | Lat 44°38'32", long 70°35'17", Oxford County, on left bank 0.3 km downstream from Philbrick Brook 3.4 km downstream from Roxbury, and 11.6 km upstream from mouth. |
| 01055300 | Bog Brook near Buckfield, Maine | Lat 44°15'57", long 70°18'58", Oxford County, 5 m upstream from culvert in State Highway 117, 275 m upstream from mouth, and 5.0 km southeast of Buckfield. |
| 01055500 | Nezinscot River at Turner Center, Maine | Lat 44°16'10", long 70°13'49", Androscoggin County, on left bank 150 m upstream from State Highway 117 bridge at Turner Center, and 5.8 km upstream from mouth. |
| 01057000 | Little Androscoggin River near South Paris, Maine | Lat 44°18'12", long 70°32'22", Oxford County, on island 15 m upstream from Snow Falls, and 9.6 km upstream from South Paris. |
| 01058500 | Little Androscoggin River near Auburn, Maine | Lat 44°03'49", long 70°16'28", Androscoggin County, on right bank 30 m upstream from highway bridge at Littlefields, 5.0 km southwest of Auburn, and 7.4 km upstream from mouth. |
| 01059000 | Androscoggin River near Auburn, Maine | Lat 44°04'20", long 70°12'31", Androscoggin County, on right bank 2.4 km downstream from Little Androscoggin River, and 3.4 km downstream from North Bridge between Auburn and Lewiston. |
| 01059800 | Collyer Brook near Gray, Maine | Lat 43°55'03", long 70°19'02", Cumberland County, 15 m downstream from U.S. Highway 202, 3.9 km northeast of Gray, and 5.5 km upstream from mouth. |
| 01060000 | Royal River at Yarmouth, Maine | Lat 43°47'57", long 70°10'45", Cumberland County, on right bank 45 m upstream from East Main Street bridge in Yarmouth. |
| 01062700 | Patte Brook near Bethel, Maine | Lat 44°20'41", long 70°47'32", Oxford County, 5 m upstream from culvert in town road between State Highway 5 and West Bethel, 550 m upstream from mouth, and 7.2 km south of Bethel. |
| 01064000 | Presumpscot River at Outlet of Sebago Lake, Maine | Lat 43°49'03", long 70°27'01", Cumberland County, at dam of hydroelectric plant at Eel Weir Falls 1.6 km downstream from lake outlet. |
| 01064118 | Presumpscot River at Westbrook, Maine | Lat 43°41'13", long 70°20'49", Cumberland County, on right bank 0.6 km downstream from Cumberland Street Bridge in Westbrook, at S.D. Warren Co. owned bridge. |
| 01064200 | Mill Brook near Old Orchard Beach, Maine | Lat 43°32'40", long 70°23'31", York County, on abutment of dismantled bridge, 23 m upstream from culvert in Portland Avenue, 2.8 km upstream from mouth, and 3.0 km northwest of Old Orchard Beach. |

Appendix—Detailed descriptions of gaging-station locations—Continued

[lat, latitude; long, longitude; km, kilometers; m, meters; right and left bank are referenced facing downstream]

| USGS gaging-station number | Gaging station name | Station location |
|----------------------------------|--|--|
| 01064500 | Saco River near Conway, New Hampshire | Lat 43°59'27", long 71°05'29", Carroll County, on left bank at Odell Falls, 2.9 km downstream from Swift River and Conway. |
| 01065000 | Ossipee River at Effingham Falls, New Hampshire | Lat 43°47'44", long 71°03'36", Carroll County, on left bank 0.5 km upstream from bridge on State Highway 153 at Effingham Falls, 0.5 km downstream from outlet of Ossipee Lake, and 6.4 km northwest of Effingham. |
| 01065500 | Ossipee River at Cornish, Maine | Lat 43°48'26", long 70°47'55", Oxford County, on left bank 30 m downstream from highway bridge in Cornish, and 2.1 km upstream from mouth. |
| 01066000 | Saco River at Cornish, Maine | Lat 43°48'29", long 70°46'53", Cumberland County, on left bank 90 m upstream from State Highway 117 bridge at Cornish, and 0.6 km downstream from Ossipee River. |
| 01066100 | Pease Brook near Cornish, Maine | Lat 43°47'19", long 70°45'58", York County, 2 m upstream from culvert in State Highway 25, 365 m upstream from mouth, and 3.0 km southeast of Cornish. |
| 01066500 | Little Ossipee River near South Limington, Maine | Lat 43°41'22", long 70°40'15", York County, on right bank, 8 m upstream from highway bridge, 3.0 km southeast of South Limington, and 9.3 km upstream from mouth. |
| 01067000 | Saco River at West Buxton, Maine | Lat 43°40'00", long 70°36'05", York County, at hydroelectric plant of Central Maine Power Co. at West Buxton, and 9.6 km downstream from Little Ossipee River. |
| 01069500 | Mousam River near West Kennebunk, Maine | Lat 43°25'04", long 70°39'32", York County, on right bank 30 m upstream from highway bridge, 2.3 km downstream from Middle Branch, and 6.4 km west of West Kennebunk. |
| 01069700 | Branch Brook near Kennebunk, Maine | Lat 43°22'44", long 70°34'56", York County, on wingwall of culvert in State Highway 9A, 3.4 km west of Kennebunk, and 5.3 km upstream from mouth. |
| 01072100 | Salmon Falls River at Milton, New Hampshire | Lat 43°24'50", long 70°59'15", Strafford County, on right bank just downstream from Milton Pond, at Milton. |
| 01072500 | Salmon Falls River near South Lebanon, Maine | Lat 43°19'40", long 70°55'40", York County, on left bank at Stair Falls, 2.4 km southeast of South Lebanon, and 4.0 km upstream from Little River. |

^aStation formerly published as Cold Brook near Northern Maine Junction, Maine