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

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Prepared in cooperation with the
MAINE DEPARTMENT OF TRANSPORTATION

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by Glenn Hodgkins

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Augusta, Maine

1999

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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

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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 flood-plain 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:

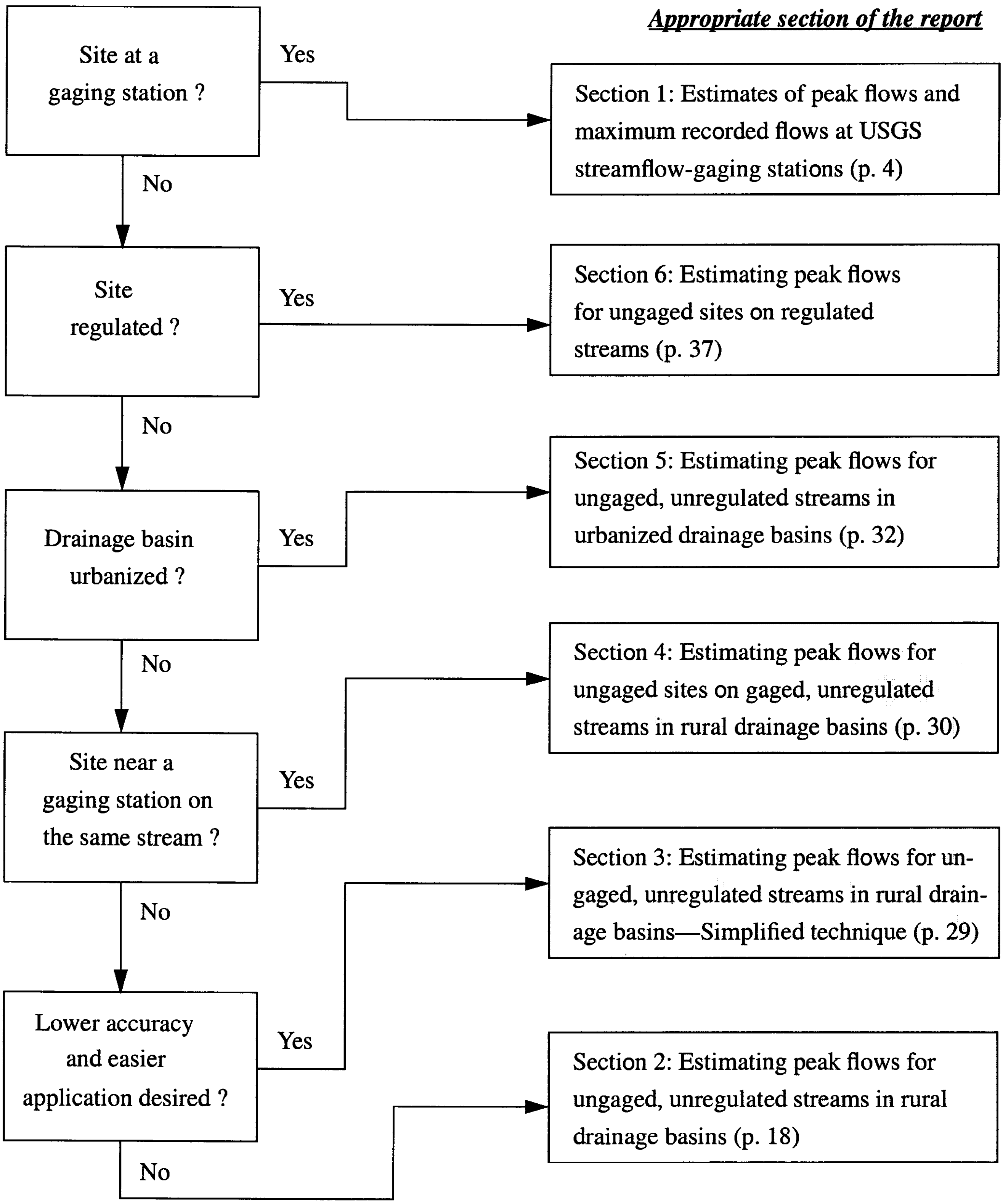
Site at a gaging station—the drainage area of the study site is within 3 percent of the drainage area of a USGS streamflow-gaging station and on the same stream (see figure 2 for a map of the gaging stations and the appendix for detailed descriptions of the gaging station locations);

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 m^3 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 m^3 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:

$$Q_W = ((Q_g)(n) + (Q_r)(e)) / (n + e), \qquad (1)$$

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 m^3 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

[m^3/s, cubic meters per second; km^2, 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: 2 years	5 years	10 years	25 years	50 years	100 years	500 years	Highest peak flow known: Date	Flow (m^3/s)	Period of known peak flows[b]	Regulation[c]	Drainage area (km^2)
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	418	574	677	806	902	997	1,220	4-18-1983	1,040	1931-96	u	3,180
		R	563	781	928	1,120	1,260	1,400	1,740					
		W	422	582	689	825	926	1,030	1,270					
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	232	294	332	377	409	439	508	4-30-1973	447	1903-08, 1929-96	u	2,660
		R	290	394	462	549	615	679	834					
		W	233	297	338	386	422	456	535					
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	4.50	6.14	7.23	8.62	9.66	10.7	13.2	5-2-1974	7.96	1963-74	u	15.2
		R	9.09	15.1	19.7	26.3	31.6	37.2	51.8					
		W	5.15	7.78	10.1	13.4	16.3	19.4	27.4					
01015700	Houlton Brook nr Oxbow, Maine	G	3.46	4.76	5.64	6.75	7.59	8.43	10.4	4-29-1973	6.68	1963-74	u	14.1
		R	2.76	4.19	5.22	6.59	7.69	8.81	11.6					
		W	3.36	4.66	5.54	6.71	7.62	8.56	10.8					

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

[m^3/s, cubic meters per second; km^2, 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: 2 years	5 years	10 years	25 years	50 years	100 years	500 years	Highest peak flow known: Date	Flow (m^3/s)	Period of known peak flows[b]	Regulation[c]	Drainage area (km^2)
01015800	Aroostook River nr Masardis, Maine	G	373	500	581	680	752	822	982	4-19-1983	654	1957-96	u	2,310
		R	324	443	522	622	698	773	954					
		W	371	497	577	674	746	816	978					
01016500	Machias River nr Ashland, Maine	G	175	248	298	365	416	468	597	6-29-1954	470	1951-83	u	852
		R	191	276	335	411	470	530	675					
		W	176	250	301	370	423	477	610					
01017000	Aroostook River at Washburn, Maine	G	662	877	1,020	1,180	1,310	1,430	1,710	4-19-1983	1,230	1930-96	u	4,280
		R	617	839	985	1,170	1,310	1,450	1,780					
		W	661	876	1,010	1,180	1,310	1,430	1,710					
01017300	Nichols Brook nr Caribou, Maine	G	2.98	4.79	6.14	8.00	9.49	11.1	15.1	10-3-1970	7.96	1963-74	u	10.3
		R	4.44	7.23	9.34	12.3	14.7	17.2	23.6					
		W	3.19	5.24	6.86	9.17	11.1	13.1	18.2					
01017900	Marley Brook nr Ludlow, Maine	G	2.40	4.03	5.30	7.14	8.65	10.3	14.7	7-5-1973	9.49	1964-82	u	3.81
		R	3.16	5.51	7.38	10.1	12.3	14.8	21.2					
		W	2.47	4.21	5.62	7.69	9.42	11.3	16.4					
01018000	Meduxnekeag River nr Houlton, Maine	G	94.7	135	163	198	225	252	317	4-3-1976	188	1940-82	u	453
		R	65.2	91.6	110	133	150	168	211					
		W	93.5	133	159	192	217	242	303					
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 Dennysville, 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	7.59	11.6	14.5	18.5	21.6	25.0	33.6	12-12-1967	22.1	1964-74	u	13.0
		R	4.24	6.71	8.55	11.1	13.1	15.2	20.6					
		W	7.07	10.6	13.1	16.3	18.8	21.6	28.5					

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 (m³/s) for given recurrence interval: 2 years	5 years	10 years	25 years	50 years	100 years	500 years	Highest peak flow known: Date	Flow (m³/s)	Period of known peak flows[b]	Regulation[c]	Drainage area (km²)
01021500	Machias River at Whitneyville, Maine	G	170	229	270	322	362	403	504	5-29-1961	419	1905-21, 1929-77	u	1,190
		R	168	233	276	331	373	414	514					
		W	170	229	270	323	363	404	505					
01021600	Middle River nr Machias, Maine	G	5.71	7.35	8.39	9.66	10.6	11.5	13.5	4-2-1970	8.55	1964-74	u	21.4
		R	6.12	9.51	12.0	15.4	18.1	20.9	27.9					
		W	5.77	7.78	9.27	11.3	13.0	14.8	19.1					
01022000	East Machias River nr East Machias, Maine	G	58.0	73.3	82.8	94.4	103	111	129	12-15-1950	104	1926-58	u	648
		R	61.5	83.1	97.3	115	129	142	174					
		W	58.2	74.0	84.1	96.8	106	115	137					
01022260	Pleasant River nr Epping, Maine	G	24.2	30.1	33.7	38.0	41.0	43.9	50.4	5-13-1989	35.1	1980-91	u	157
		R	15.2	21.0	24.9	29.8	33.6	37.4	46.5					
		W	22.9	28.4	31.7	35.8	38.8	41.8	49.0					
01022500	Narraguagus River at Cherryfield, Maine	G	116	162	194	234	265	297	373	5-28-1961	295	1947-96	u	588
		R	95.5	135	162	196	223	250	314					
		W	115	161	192	231	261	292	366					
01022700	Forbes Pond Brook nr Prospect Harbor, Maine	G	6.04	9.20	11.4	14.4	16.8	19.1	25.0	4-2-1970	11.4	1964-74	u	23.7
		R	4.91	7.42	9.23	11.6	13.6	15.5	20.4					
		W	5.87	8.85	10.9	13.6	15.8	17.8	23.2					
01023000	West Branch Union River at Amherst, Maine	G	49.9	67.9	80.1	95.7	108	120	149	3-25-1979	120	1908-10, 1911-19, 1929-79	u	386
		R	52.6	73.7	88.0	106	120	135	169					
		W	50.0	68.1	80.5	96.4	109	121	151					
01024200	Garland Brook nr Mariaville, Maine	G	12.1	19.9	26.2	35.3	42.9	51.3	74.2	12-27-1969	34.8	1964-82	u	25.4
		R	10.3	16.4	21.0	27.3	32.4	37.7	51.2					
		W	11.9	19.5	25.4	33.8	40.7	48.2	68.2					
01026800	Frost Pond Brook nr Sedgwick, Maine	G	4.83	7.13	8.72	10.8	12.4	14.0	17.9	2-4-1970	9.91	1964-74	u	12.5
		R	3.58	5.61	7.12	9.16	10.8	12.5	16.8					
		W	4.64	6.83	8.33	10.3	11.9	13.5	17.5					
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

[m^3/s, cubic meters per second; km^2, 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: 2 years	5 years	10 years	25 years	50 years	100 years	500 years	Highest peak flow known: Date	Flow (m^3/s)	Period of known peak flows[b]	Regulation[c]	Drainage area (km^2)
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	4.13	6.81	8.86	11.7	14.1	16.6	23.2	4-25-1970	10.0	1963-73	u	10.8
		R	3.14	4.95	6.28	8.10	9.56	11.1	14.9					
		W	3.98	6.44	8.24	10.6	12.6	14.7	20.0					
01030400	Gulliver Brook nr Monarda, Maine	G	6.67	9.63	11.7	14.5	16.7	18.9	24.5	7-5-1973	15.9	1963-74	u	28.5
		R	5.40	8.08	9.99	12.5	14.5	16.6	21.7					
		W	6.49	9.34	11.3	14.0	16.0	18.1	23.5					
01030500	Mattawamkeag River nr Mattawamkeag, Maine	G	462	609	705	824	912	999	1,200	5-1-1923	1,320[d]	1902-96	u	3,670
		R	353	465	537	626	694	759	915					
		W	460	605	699	816	901	986	1,190					
01031500	Piscataquis River nr Dover-Foxcroft, Maine	G	233	351	436	553	645	742	989	4-1-1987	1,060	1857-1996	u	772
		R	161	232	281	344	393	442	562					
		W	232	348	431	544	633	726	962					
01031600	Morrison Brook nr Sebec Corners, Maine	G	2.96	5.44	7.56	10.8	13.7	17.1	26.8	11-3-1966	16.3	1964-77	u	11.3
		R	4.25	6.83	8.77	11.4	13.6	15.9	21.6					
		W	3.12	5.66	7.80	11.0	13.7	16.7	25.1					
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	234	376	485	643	775	919	1,310	11-4-1966	810	1920-96	u	837
		R	178	256	310	380	434	488	621					
		W	232	371	476	626	750	884	1,240					
01034000	Piscataquis River at Medford, Maine	G	601	890	1,100	1,380	1,610	1,840	2,450	4-1-1987	2,410	1847-1996	u	3,010
		R	439	600	707	842	944	1,050	1,290					
		W	597	880	1,080	1,350	1,560	1,780	2,340					

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

[m^3/s, cubic meters per second; km^2, 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	1.94	2.91	3.61	4.52	5.23	5.97	7.77	12-27-1969	4.05	1963-74	u	5.49
		R	1.80	2.90	3.72	4.85	5.77	6.73	9.19					
		W	1.92	2.91	3.63	4.61	5.39	6.22	8.29					
01035000	Passadumkeag River at Lowell, Maine	G	57.9	77.7	91.1	108	122	135	168	5-2-1923	161	1915-79	u	769
		R	74.3	100	117	139	155	171	209					
		W	58.4	78.5	92.3	110	124	138	172					
01036500	Kenduskeag Stream nr Kenduskeag, Maine	G	98.0	134	156	183	203	222	264	4-1-1987[f]	210	1908-19, 1941-79, 1987	u	479
		R	89.6	128	155	190	217	244	310					
		W	97.7	134	156	184	204	224	269					
01037200	Shaw Brook[g] nr Northern Maine Junction, Maine	G	5.50	9.28	12.3	16.6	20.2	24.2	34.8	12-27-1969	16.9	1963-74	u	7.95
		R	4.53	7.57	9.92	13.2	16.0	18.8	26.3					
		W	5.36	8.97	11.8	15.7	18.9	22.4	31.7					
01037430	Goose River at Rockport, Maine	G	11.0	15.8	19.0	23.1	26.1	29.2	36.3	3-23-1972	17.7	1963-74	u	21.4
		R	9.69	15.7	20.1	26.4	31.4	36.7	50.2					
		W	10.8	15.8	19.3	24.0	27.7	31.7	41.4					
01038000	Sheepscot River at North Whitefield, Maine	G	57.3	86.3	108	139	165	192	266	4-1-1987	208	1938-96	u	376
		R	66.1	94.7	114	140	160	180	228					
		W	57.6	86.6	108	139	165	191	262					
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	6.32	10.8	14.3	19.5	24.0	28.9	42.5	7-5-1973	26.0	1963-74	u	10.6
		R	6.54	10.9	14.4	19.2	23.1	27.4	38.3					
		W	6.35	10.8	14.3	19.4	23.7	28.4	40.9					
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

[m^3/s, cubic meters per second; km^2, 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

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USGS gaging station number	Gaging station name	Gaging station (G), Regression (R), Weighted (W)[a]	Peak flow (m^3/s) for given recurrence interval: 2 years	5 years	10 years	25 years	50 years	100 years	500 years	Highest peak flow known: Date	Flow (m^3/s)	Period of known peak flows[b]	Regulation[c]	Drainage area (km^2)
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

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

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

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

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

[m^3/s, cubic meters per second; km^2, 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]		
01066500	Little Ossipee River nr South Limington, Maine	G	57.5	88.9	112	145	172	200	275	3-19-1936	242[d]	1936-96	u	435
		R	87.8	127	154	189	217	244	312					
		W	58.7	91.0	115	149	176	205	280					
01067000	Saco River at West Buxton, Maine	G	398	529	621	744	840	940	1,190	3-22-1936	1,650	1786-1996	u	4,070
		R	694	957	1,130	1,360	1,520	1,690	2,090					
		W	412	555	661	804	916	1,030	1,320					
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	7.18	12.6	16.9	23.2	28.4	34.2	50.0	10-22-1996	28.9	1964-74, 1996	u	26.7
		R	8.71	13.6	17.3	22.3	26.2	30.3	40.8					
		W	7.42	12.8	17.0	22.9	27.7	32.9	46.4					
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

[a]Gaging 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).

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

[c]Regulated (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.

[d]Peak flow is an estimate.

[e]Peak flow was affected by a dam break. The peak flow, removing the effects of the dam break, is estimated to be 326 m^3/s.

[f]Day of occurrence is not exact.

[g]Gaging station formerly published under the name Cold Brook near Northern Maine Junction, Maine.

[h]Peak 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.

[i]Peak 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 explanatory 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. Homoscedasicity (a constant variance in the response variable over the range of the explanatory variables) and normality also are important in OLS regression. Linearity, homoscedasicity, 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 Mallow's Cp 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, homoscedasicity, 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

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

[a]Station 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-

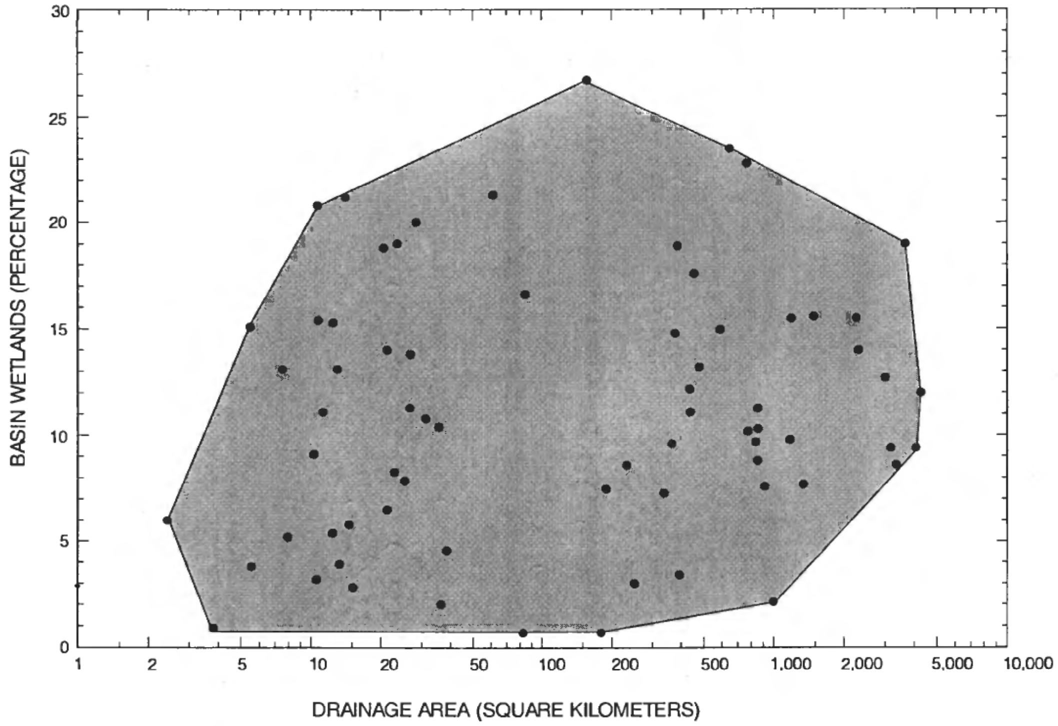

Figure 3. Two-dimensional range of explanatory variables for the full regression equations.

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 by 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

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

where

- **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;
- **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
- **B** is the 3-by-1 column vector of regression coefficients.

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

$$SE_S^2 = x_0\,(\mathbf{X}^T\,\Lambda^{-1}\,\mathbf{X})^{-1}\,x_0^T, \qquad (3)$$

where

- 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

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

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 than be computed as

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

where

- log (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 m^3/s and the estimated 50-year flow was 11,000 m^3/s, the absolute difference between the two would be 1,000 m^3/s. For a true flow of 100 m^3/s and an estimated flow of 200 m^3/s, the absolute difference would be 100 m^3/s. This difference appears much smaller than the 1,000 m^3/s difference; however, 200 m^3/s is twice as large as 100 m^3/s, whereas 11,000 m^3/s is only 1.1 times as large as 10,000 m^3/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 m^3/s and an estimated flow of 200 m^3/s, the logarithm of the estimated flow minus the logarithm of the true flow is 0.3. For a true flow of 100 m^3/s and an estimated flow of 50 m^3/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 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.

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

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:

$$Q_u = Q_w (A_u / A_g)^b, \tag{9}$$

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

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

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

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

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.

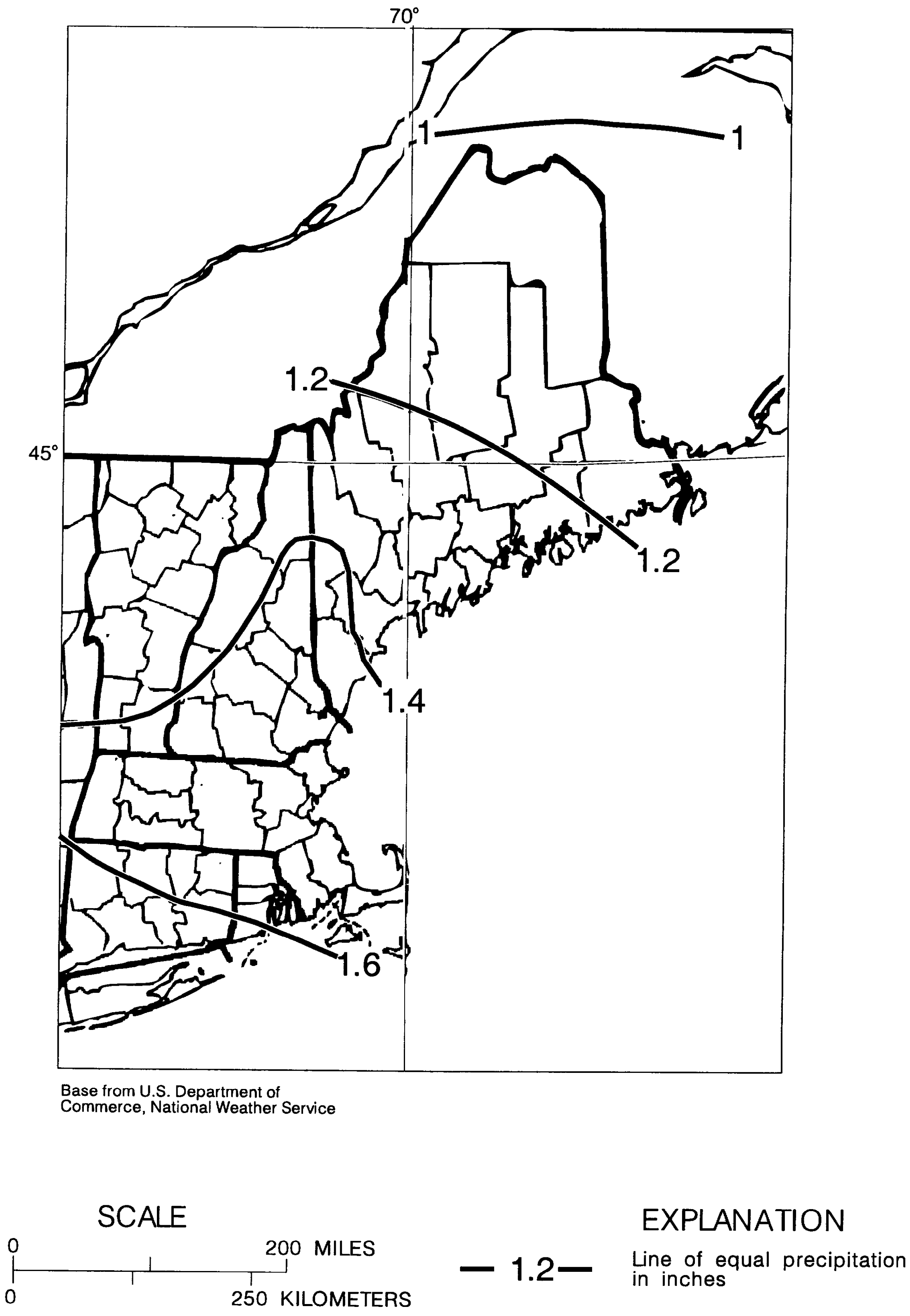

Figure 4. National Weather Service 2-hour, 2-year rainfall for Maine.

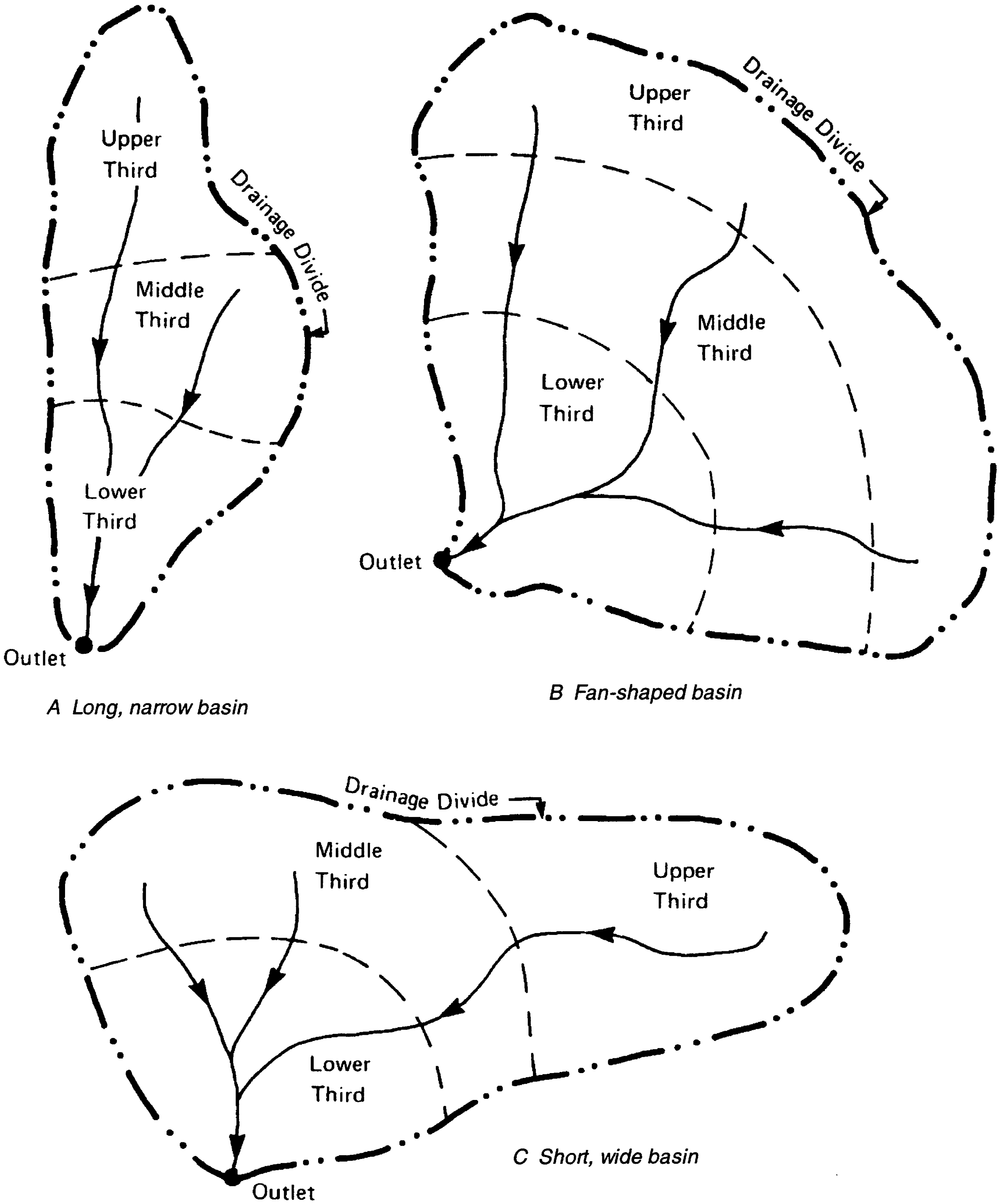

Figure 5. Typical drainage-basin shapes and subdivision into basin thirds (from Sauer and others, 1983).

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

[a]Maximum 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

REFERENCES CITED

Benson, M.A., 1962, Factors influencing the occurrence of floods in a humid region of diverse terrain: U.S. Geological Survey Water-Supply Paper 1580—B, 64 p.

Cook, R.D., and Weisburg, S., 1994, An introduction to regression graphics: New York, John Wiley and Sons, 253 p.

Cowing, D.J., and Caracappa, D., 1978, Drainage areas of surface water bodies of the Saco River basin in southwestern Maine: U.S. Geological Survey Open-File Report, 25 p.

Cowing, D.J., and McNelly, J.L., 1978, Drainage areas of surface water bodies of the Royal and Presumpscot River basins in southwestern Maine: U.S. Geological Survey Open-File Report, 23 p.

Fontaine, R.A., 1979a, Drainage areas of surface water bodies of the Androscoggin River basin in southwestern Maine: U.S. Geological Survey Open-File Report, 42 p.

———1979b, Drainage areas of surface water bodies of southern Maine coastal river basins: U.S. Geological Survey Open-File Report, 23 p.

———1980, Drainage areas of surface water bodies of the Kennebec River basin in southwestern Maine: U.S. Geological Survey Open-File Report, 83 p.

———1981, Drainage areas of surface water bodies of the Penobscot River basin in central Maine: U.S. Geological Survey Open-File Report, 92 p.

———1982a, Drainage areas of surface-water bodies of eastern Maine coastal river basins: U.S. Geological Survey Open-File Report, 54 p.

———1982b, Drainage areas of surface water bodies of central Maine coastal river basins: U.S. Geological Survey Open File Report, 27 p.

Fontaine, R.A., Herrick, E., and Norman, N., 1982, Drainage areas of surface-water bodies of the St. John River basin in northern Maine: U.S. Geological Survey Open-File Report, 70 p.

Hardison, C.H., 1971, Prediction error of regression estimates of streamflow characteristics at ungaged sites: U.S. Geological Survey Professional Paper 750—C, p. 228-236.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elsevier, 522 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency—Bulletin 17B of the Hydrology Subcommittee: U.S. Geological Survey, Office of Water-Data Coordination, 183 p.

Morrill, R.A., 1975, A technique for estimating the magnitude and frequency of floods in Maine: U.S. Geological Survey Open-File Report 75-292, 44 p.

National Weather Service, 1961, Rainfall frequency atlas of the United States: U.S. Department of Commerce Technical Paper 40, 61 p.

Newton, D.W. and Herrin, J.C., 1982, Assessment of commonly used methods of estimating flood frequency: Transportation Research Record 896, p. 10-30.

Riggs, H.C., 1968, Some statistical tools in hydrology: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chapter A1, 39 p.

Sauer, V.B., Thomas, W.O. Jr., Stricker, V.A., and Wilson, K.V., 1983, Flood characteristics of urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2207, 63 p.

Sauer, V.B., 1985, New studies of urban flood frequency in the southeastern United States: Proceedings 1985 International Symposium on Urban Hydrology, Hydraulic Infrastructures, and Water-Quality Control, University of Kentucky, July 23-25, 1985, Lexington, Ky., p. 195-201.

Stedinger, J.R. and Tasker, G.D., 1985, Regional hydrologic analysis 1. Ordinary, weighted, and generalized least squares compared: Water Resources Research, v. 21, no. 9, p. 1421-1432.

Tasker, G.D. and Stedinger, J.R., 1986, Regional skew with weighted LS regression: Journal of Water Resources Planning and Management, v. 112, no. 2, p. 225-237.

———1989, An operational GLS model for hydrologic regression: Journal of Hydrology, v. 111, p. 361-375.

Thomson, M.T., Gannon, W.B., Thomas, M.P., Hayes, G.S., and others, 1964, Historical floods in New England: U.S. Geological Survey Water-Supply Paper 1779-M, 105 p.

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 Sebasticook River, and 5.6 km above Messalonskee Stream.
01049000	Sebasticook 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 Sebasticook 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	Cobbosseecontee 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.

[a]Station formerly published as Cold Brook near Northern Maine Junction, Maine