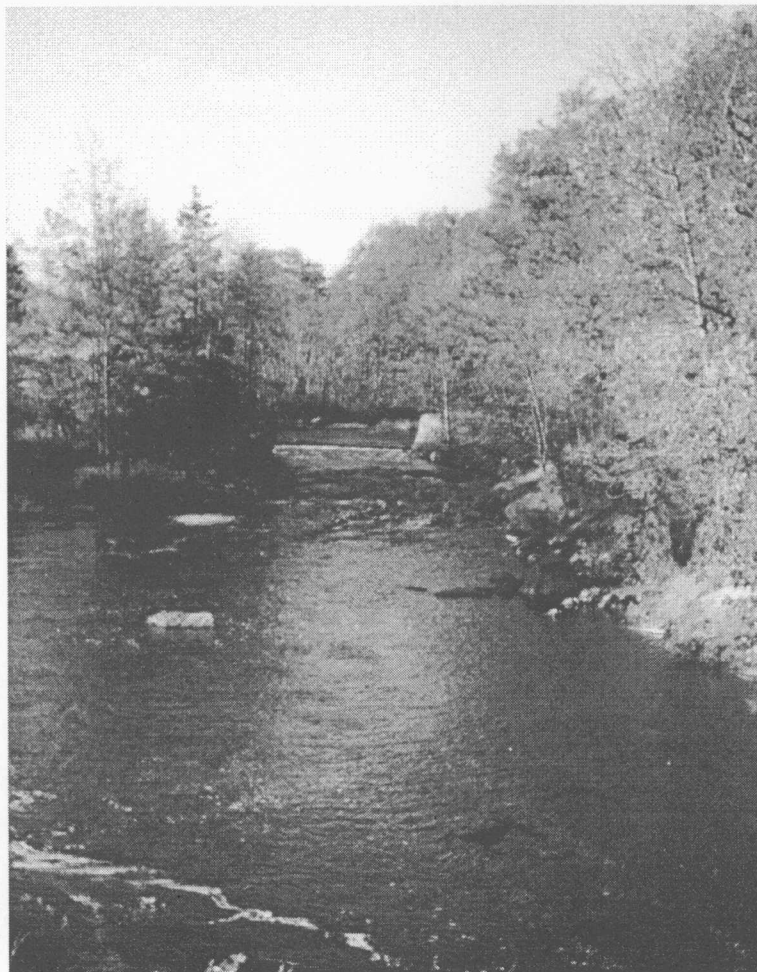


U.S. DEPARTMENT OF THE INTERIOR  
U.S. GEOLOGICAL SURVEY

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# Record Extension and Streamflow Statistics for the Pleasant River, Maine

Water-Resources Investigations Report 99-4078



Prepared in cooperation with the  
MAINE STATE PLANNING OFFICE

**Cover Photograph.** Pleasant River near Epping, Maine at site of streamgaging station. (Photograph by W. Nichols)

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By Joseph P. Nielsen

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Augusta, Maine  
1999

U.S. DEPARTMENT OF THE INTERIOR  
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY  
Charles G. Groat, Director

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## CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi <sup>2</sup> )	2.59	square kilometer



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## ABSTRACT

Historical streamflow data for the Pleasant River are limited to 11 years (from 1980 to 1991) at the U.S. Geological Survey streamgaging station near Epping. Analysis of these data in conjunction with flow data from other nearby stations indicates that the 11 years of record for the Pleasant River may not be representative of longer-term conditions in the basin. A correlation between the historical streamflows from the Pleasant River station and at the nearby station on the Narraguagus River at Cherryfield provides a means of extending the record at the Pleasant River station, increasing the period of record on the Pleasant River from 11 to 51 years. When used to calculate new streamflow-duration statistics, the extended record shows significant differences from the original 11 years of record, particularly during the summer months. The August median streamflow, an important statistical measure for fisheries habitat, changed from 50 cubic feet per second prior to the record extension, to 35 cubic feet per second after the record extension.

## INTRODUCTION

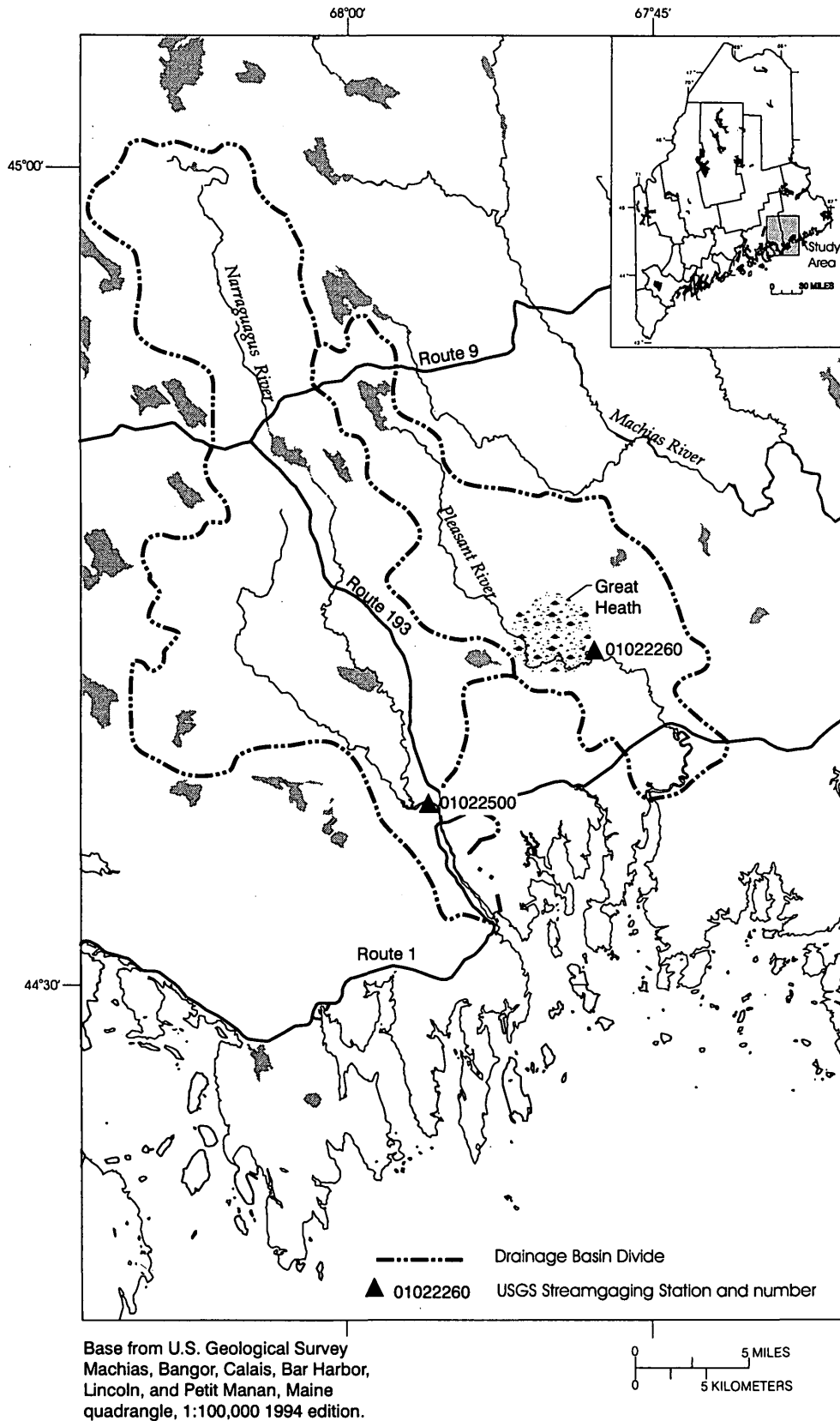
In 1997, the State of Maine developed a conservation plan for Atlantic salmon in seven rivers in Maine (Maine Atlantic Salmon Task Force, 1997). As part of its implementation, the plan called for the development of total water use management plans for each of the river basins to balance the needs of agriculture with those of salmon. These plans, once developed, will set limits on water withdrawals from the river basins, one of which is the Pleasant River basin in eastern Maine. Until the plan for the Pleasant River basin is completed, interim limits, which are subject to annual review, are being used.

The only source of long-term hydrologic data in the Pleasant River basin on which to base withdrawal limits is a discontinued U.S. Geological Survey (USGS) streamgaging station on the Pleasant River near Epping (station 01022260), which was operated from August 1980 through September 1991. Analysis of the data for this station in conjunction with data for other nearby stations, however, suggests that the 11 years of record at the station is not representative of longer-term hydrologic conditions in the basin, and that summer discharges in particular may be biased high (M. Loiselle, Maine Geological Survey, written comm., 1998). If this is the case, water-resources managers risk making poor decisions in balancing the needs of salmon and agriculture.

This report describes a study done by the USGS, in cooperation with the Maine State Planning Office, to analyze the streamflow record at the Pleasant River station. The analysis included (1) an assessment of possible bias in the historical streamflow record, (2) extension of the record to a longer period to reduce any bias, and (3) estimation of streamflow statistics from the extended streamflow record for the station.

## PHYSICAL SETTING

The Pleasant River basin is in eastern Maine along the coast of the Atlantic Ocean (fig. 1). Draining an area of 126 mi<sup>2</sup>, the river flows predominately from north to south beginning at the top of Pleasant Mountain (elevation 1,374 ft) in Devereaux Township. The center of the basin is dominated by the Great Heath, a large raised bog with an area of approximately 7 mi<sup>2</sup>. The basin is bounded to the east by the Machias River basin and to the West by the Narraguagus River basin. Largely unsettled, the basin is made up primarily of forest, blueberry barrens, and heath. The average



**Figure 1.** Study area and location of streamgaging stations used in the analysis.



annual temperature is 42°F and ranges from an average of 18° F in January to 64°F in July (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1996). The average annual precipitation is 49 in. and is fairly evenly distributed throughout the year.

Flow in the Pleasant River, as measured by the discontinued USGS streamgaging station near Epping immediately below the Great Heath, shows a seasonal distribution common in Maine (fig. 2). High flows typically occur in early spring and late fall, and low flows generally occur in the summer, and to a lesser extent, in mid-winter.

## ANALYSIS OF EXISTING DATA

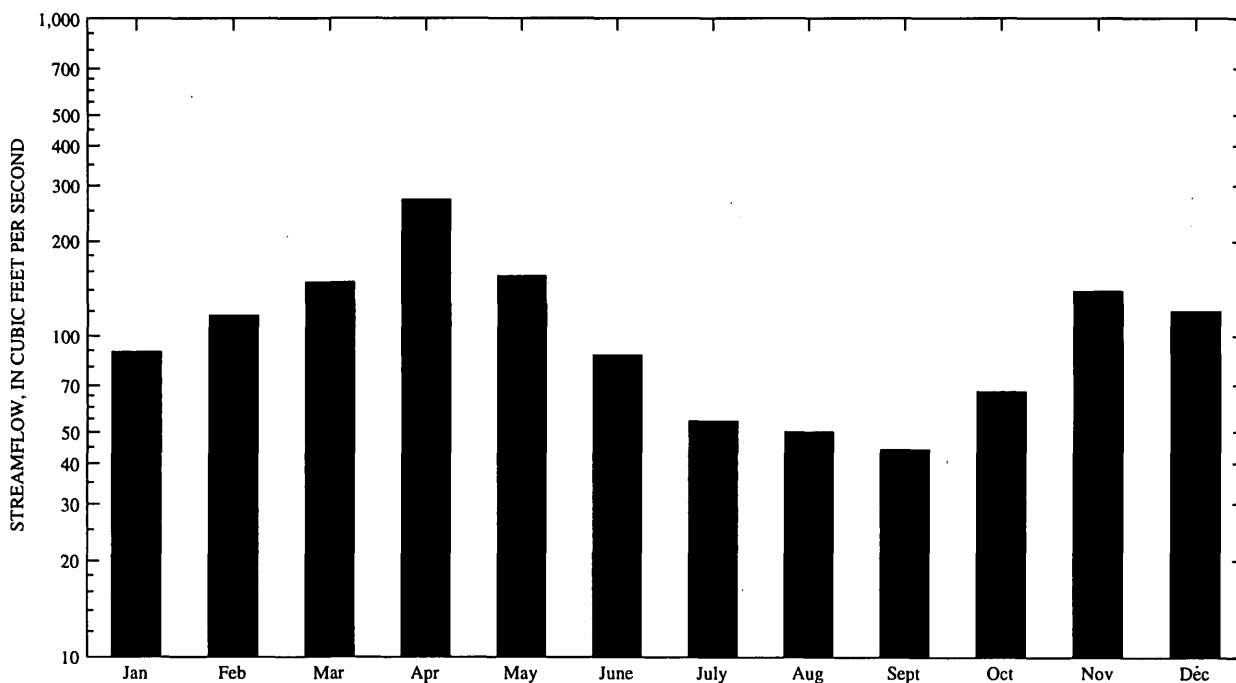
To determine if the existing 11 years of data at the Pleasant River station are representative of longer-term historical conditions, the flow data from this station were analyzed in conjunction with data from the station on the Narraguagus River at Cherryfield (station 01022500). This latter station was chosen for the analysis because (1) the Narraguagus River basin adjoins the Pleasant River basin, (2) the period of record at the

Narraguagus River station is coincident with the entire period of record at the Pleasant River station, and (3) the Narraguagus River station has a much longer period of record (51 years).

In the analysis, monthly median streamflows at the Narraguagus River station for the years of data corresponding to the period of record at the Pleasant River station (1980-91) were tested against the monthly median streamflows for the years not coincident with the period of record at the Pleasant River station (1948-79 and 1992-98). Using the rank-sum test at a significance level of 10% (Helsel and Hirsch, 1992), the months of January, August, and September have significantly different median values.

As a second step, pairs of boxplots of daily mean streamflow at the Narraguagus River station were developed for each month in order to compare the distribution of streamflow for the entire period of record with the distribution for the period of record coincident with the period of record at the Pleasant River station (fig. 3). The months of January, August, and September again stand out as showing considerable difference between the two periods.

Both analyses indicate bias in certain months when using flow data from the period of record of the



**Figure 2.** Median streamflows for the Pleasant River near Epping, Maine using the historical period of record, 1980-91.

Pleasant River station. The bias shown in August is particularly significant because the August median flow is used by the U.S. Fish and Wildlife Service (USFWS) (1981) as the recommended minimum streamflow for summertime maintenance of habitat for biota. Overestimation of the August median flow, as is indicated by the statistical tests, might lead to more strict limits on water withdrawal than that intended by the USFWS policy.

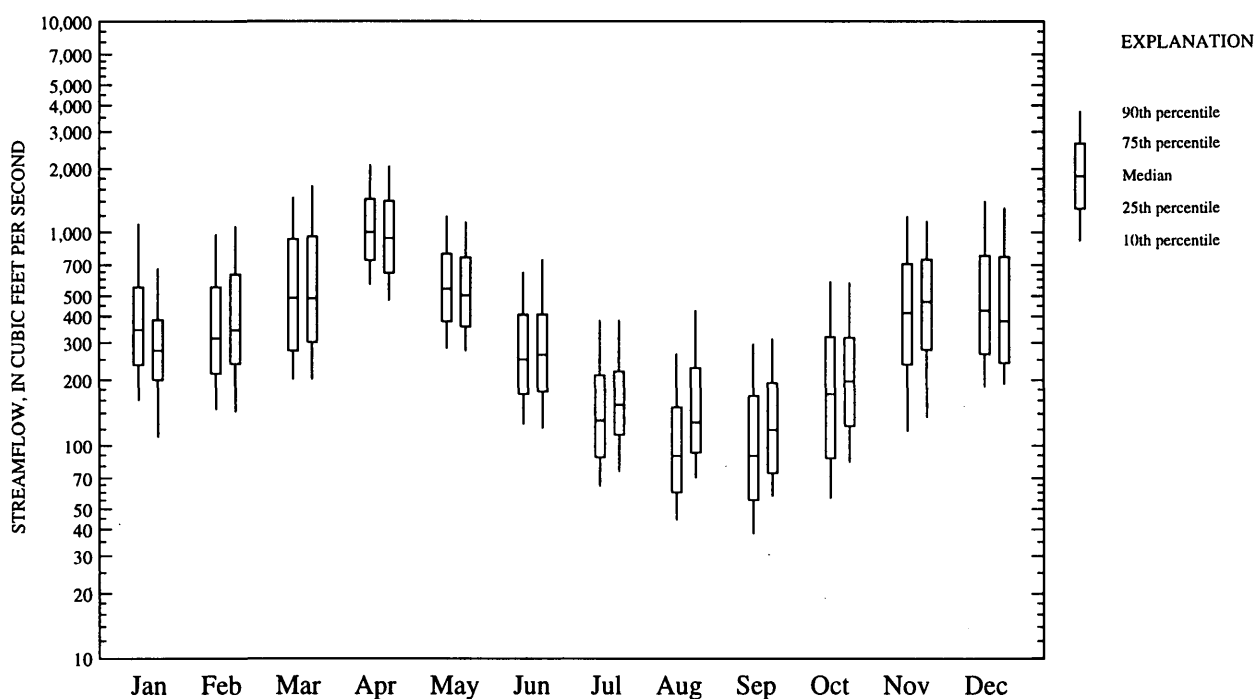
## STREAMFLOW RECORD EXTENSION

Record extension is a technique of extending the historical record at a streamgaging station through a correlation between that station and a longer-term index station. The correlation is used to estimate streamflow at the short-term station from the known streamflow at the index station. The record-extension technique is commonly used to improve statistical measures of streamflow at the short-term station by reducing error and/or bias, or as part of a larger study of many stations for which a common reference period of analysis is desired (Ries, 1994). Several methods of

streamflow record extension have been proposed or used in the past, including graphical-correlation (Searcy, 1959) and linear regression (Hirsch, 1982). The method used in this study is known as MOVE.1 (Maintenance Of Variance-Extension, type 1) or the Line of Organic Correlation (Helsel and Hirsch, 1992). It was first used as a means of record extension by Hirsch (1982). The MOVE.1 technique produces streamflow estimates at the short-term station with a statistical distribution similar to that expected if the streamflow had actually been measured (Helsel and Hirsch, 1992, p. 277) and will thus correctly estimate the probability of extreme high or low streamflow. Simple linear regression, by comparison, will always underestimate the occurrence of extreme events.

## Record Extension Technique

The MOVE.1 technique assumes that a linear relation exists between the concurrent flows at the short and long-term stations. Because streamflow data are highly skewed, a log transformation is commonly done in order to linearize the data. Once linearity is con-



**Figure 3.** Distribution of daily mean streamflow for the Narraguagus River at Cherryfield, Maine. [The first box of each pair is for the period of record March 1948 to September 1998. The second box is for the period August 1980 to September 1991.]

firmed, the means ( $\bar{Y}$  and  $\bar{X}$ ) and standard deviations ( $S_y$  and  $S_x$ ) of the logs of the concurrent streamflow data are calculated. The MOVE.1 equation is then written as follows:

$$\hat{Y}_i = \bar{Y} + \frac{S_y}{S_x}(X_i - \bar{X}). \quad (1)$$

Estimates of discharge for the short-term site are computed by entering known logarithms of the discharge at the long-term site ( $X_i$ ) into the equation and then exponentiating the estimates ( $\hat{Y}_i$ ) from logarithms back into original units.

## Application of Record Extension

Application of the MOVE.1 record extension technique involves choosing the most appropriate long-term index station, computing the necessary terms in the MOVE.1 equation, and calculating the record extended streamflow estimates. The application of this technique to the Pleasant River is described in the following sections.

### Index Station Selection

The long-term index station used in the record extension must satisfy several criteria, including that it be unregulated, have a portion of its period of record coincident with that at the short-term station, and have a substantially longer period of record than the short term station. In addition, the concurrent daily streamflows for the short and long-term stations must plot linearly in log space and be highly correlated. The only station meeting these criteria in eastern Maine is the Narraguagus River at Cherryfield (table 1), primarily because the Narraguagus River station is the only available station with over two years of overlapping record with the Pleasant River station.

The period of record at the Narraguagus River station completely contains the 11 years of record at the Pleasant River station, but in addition includes another 40 years of record from both prior to the start of, and after the discontinuation of, the Pleasant River station. The Narraguagus River drains the watershed immediately west of the Pleasant River basin and has similar watershed characteristics. Due to the presence of the Great Heath, however, the percentage of the basin in

wetlands is substantially higher in the Pleasant River basin (26.7%), than in the Narraguagus (15.0%) (Hodgkins, 1999).

A graph of concurrent daily mean discharge in log space for the Pleasant and Narraguagus Rivers (fig. 4), and the computed correlation coefficient of 0.97, confirm that a linear relation exists between streamflow at the two stations. A minimum correlation coefficient required for the MOVE.1 technique has not been developed; however, similar correlation studies have used values ranging from 0.70 (Stedinger and Thomas, 1985) to 0.80 (Ries, 1994).

It is possible, however, that although a strong correlation exists between the two stations for the entire period of concurrent record, correlations might be weaker for individual months. If so, this could cause considerable error in the estimates of streamflow for those months. As a check of this, plots also were developed for each month individually and correlation coefficients were found to be between 0.90 and 0.98. These high correlation coefficients indicate that differences in watershed characteristics between the two basins, including drainage area and percentage of basin wetlands, are either explained by the MOVE.1 equation or are not a dominant factor in the relation of streamflow at the two sites.

**Table 1.** Unregulated streamgaging stations in eastern Maine with more than 10 years of record

USGS station number	Station name	Period of record	Drainage area in square miles
01021500	Machias River at Whitneyville	1906-09 1910-21 1929-77	458
01022000	East Machias River near East Machias	1927-58	251
01022260	Pleasant River near Epping	1980-91	60.6
01022500	Narraguagus River at Cherryfield	1948-98	227
01023000	West Branch Union River near Amhearth	1910-19 1929-79	148
01024200	Garland Brook near Mariaville	1964-82	9.79

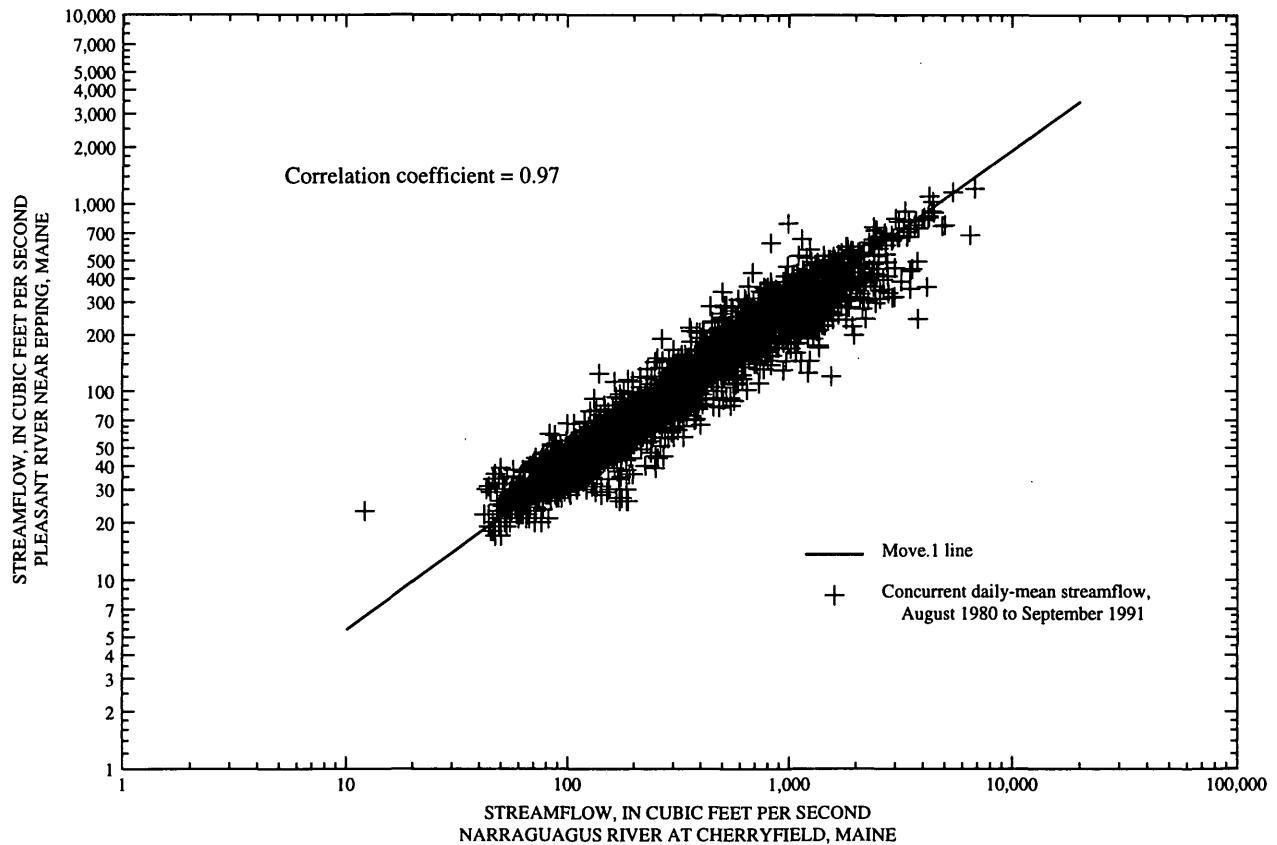


Figure 4. Correlation of daily mean streamflow between Pleasant and Narraguagus Rivers.

### Generation of Extended Record

Once the Narraguagus River station was chosen as the most appropriate long-term index station, the means and standard deviations of the logarithms of the concurrent daily mean streamflows for the Narraguagus and Pleasant River stations were computed. These were then used to develop the final MOVE.1 equation:

$$\hat{Y}_i = 2.010 + \frac{0.3389}{0.3985}(X_i - 2.498), \quad (2)$$

which simplifies to:

$$\hat{Y}_i = 0.8504X_i - (0.1144), \quad (3)$$

where

- $X_i$  are the logarithms of the daily mean streamflow on the Narraguagus River, and
- $\hat{Y}_i$  are the logarithms of the estimated daily mean streamflow on the Pleasant River.

To compute estimates of streamflows at the Pleasant River station, all of the historical daily mean streamflow from the Narraguagus River station were used in the MOVE.1 equation except those for which data already existed on the Pleasant River. The estimates from the equation were then exponentiated to obtain the final extended-record estimates in original units for the Pleasant River. These estimates were then added to the historical record from the Pleasant River to obtain the final streamflows used in the computation of streamflow statistics.

### EXTENDED-RECORD STREAMFLOW STATISTICS

Median streamflows for the Pleasant River are shown in table 2 for all days and by month for the period of historical record and the period of record extension. The months of January, August, and September, which were the months found to have significant bias in the historical record, show the largest percentage change in median streamflow as a result of

the record extension. The months of March through June show the smallest percentage change in median streamflow.

Monthly flow-duration curves for the historical and extended periods of record, and flow-duration statistics for the extended record are shown in the graphs and tables in figures 5-16 at the back of this report. Similar curves for the entire record for both periods of analysis, and statistics for the entire record for the extended period are shown in figure 17. The duration curves for the entire record show that streamflows below 70 cubic feet per second, which occurred primarily during the months of July through October, were underrepresented in the historical period. Several months show very little change between the percentiles calculated from data for the historical record and those calculated on the basis of the extended record.

**Table 2.** Median streamflows for historical and record-extended periods for the Pleasant River near Epping

Period	Median streamflow in cubic feet per second		Percent difference
	Historical period, August 1980 to Sep- tember 1991	Record- extended period, March 1948 to Sep- tember 1998	
January	89	110	+23.6
February	116	104	-10.3
March	148	149	+0.7
April	270	276	+2.2
May	155	162	+4.5
June	87	84	-3.4
July	54	48	-11.1
August	50	35	-30.0
September	44	35	-20.5
October	67	60	-10.4
November	139	126	-9.4
December	120	133	-10.8
Entire record	96	99	+3.1

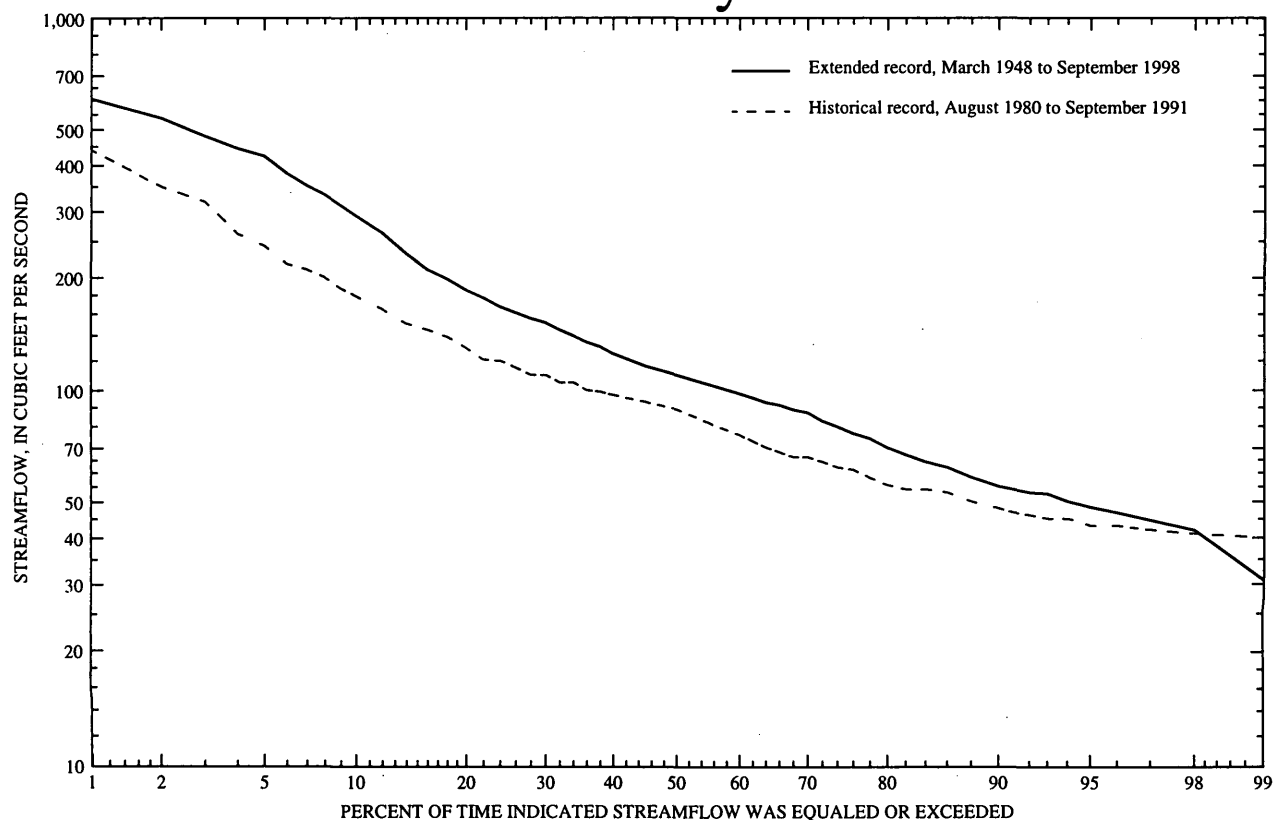
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## Figures 5-17: Flow-Duration Curves and Statistics

# January

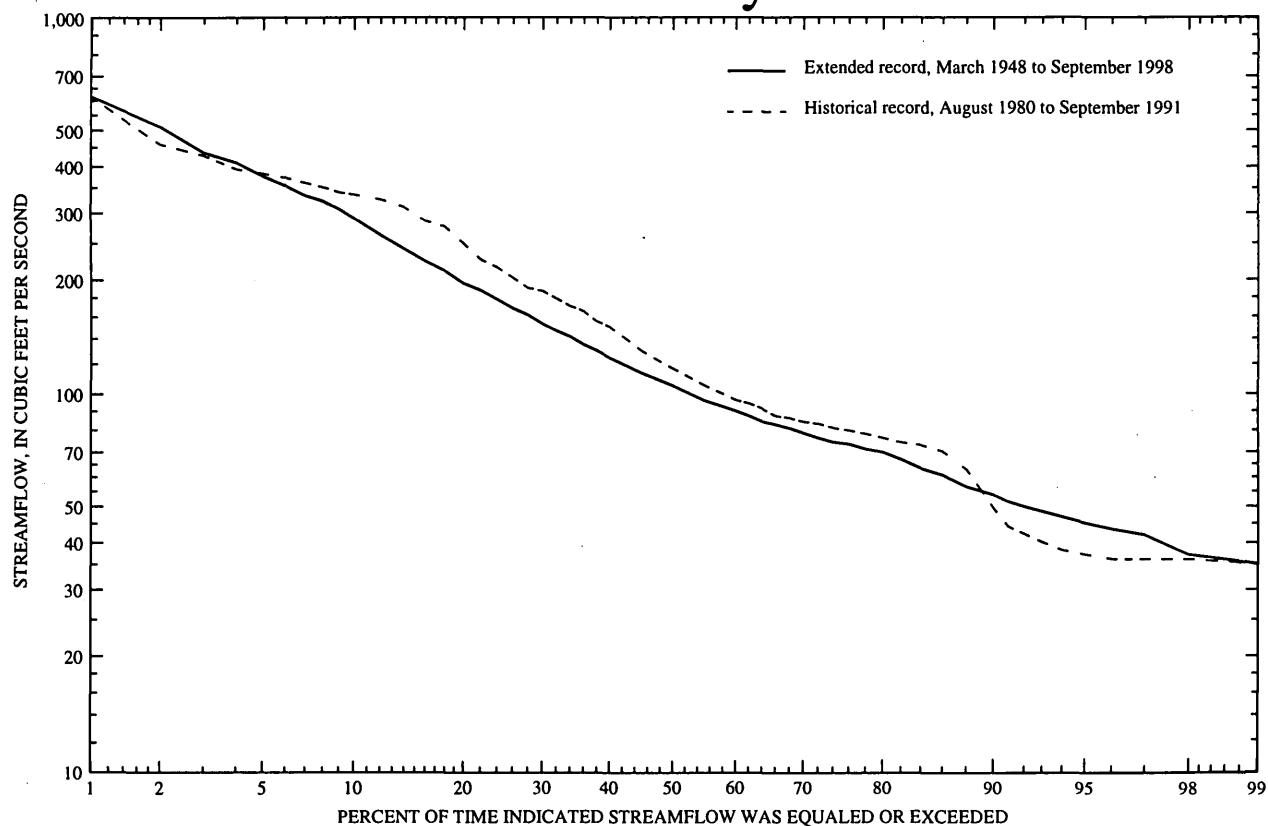


Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	605	55	104
5	423	60	98
10	292	65	93
15	220	70	87
20	185	75	78
25	163	80	70
30	152	85	64
35	137	90	55
40	125	95	48
45	116	99	31
50	110		

**Figure 5.** Flow-duration curves for January for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.



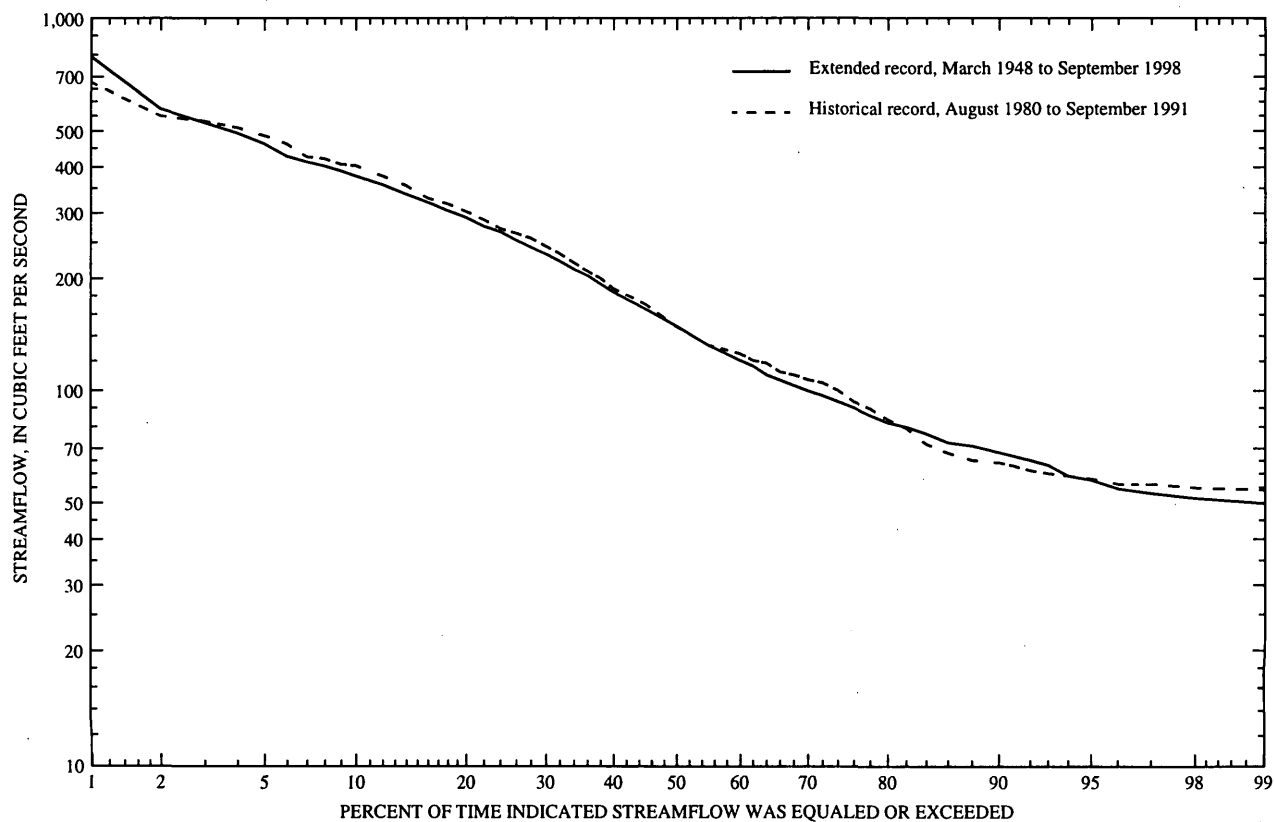
# February



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	617	55	96
5	376	60	90
10	290	65	84
15	231	70	78
20	195	75	74
25	173	80	70
30	153	85	61
35	139	90	54
40	124	95	45
45	113	99	35
50	105		

**Figure 6.** Flow-duration curves for February for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

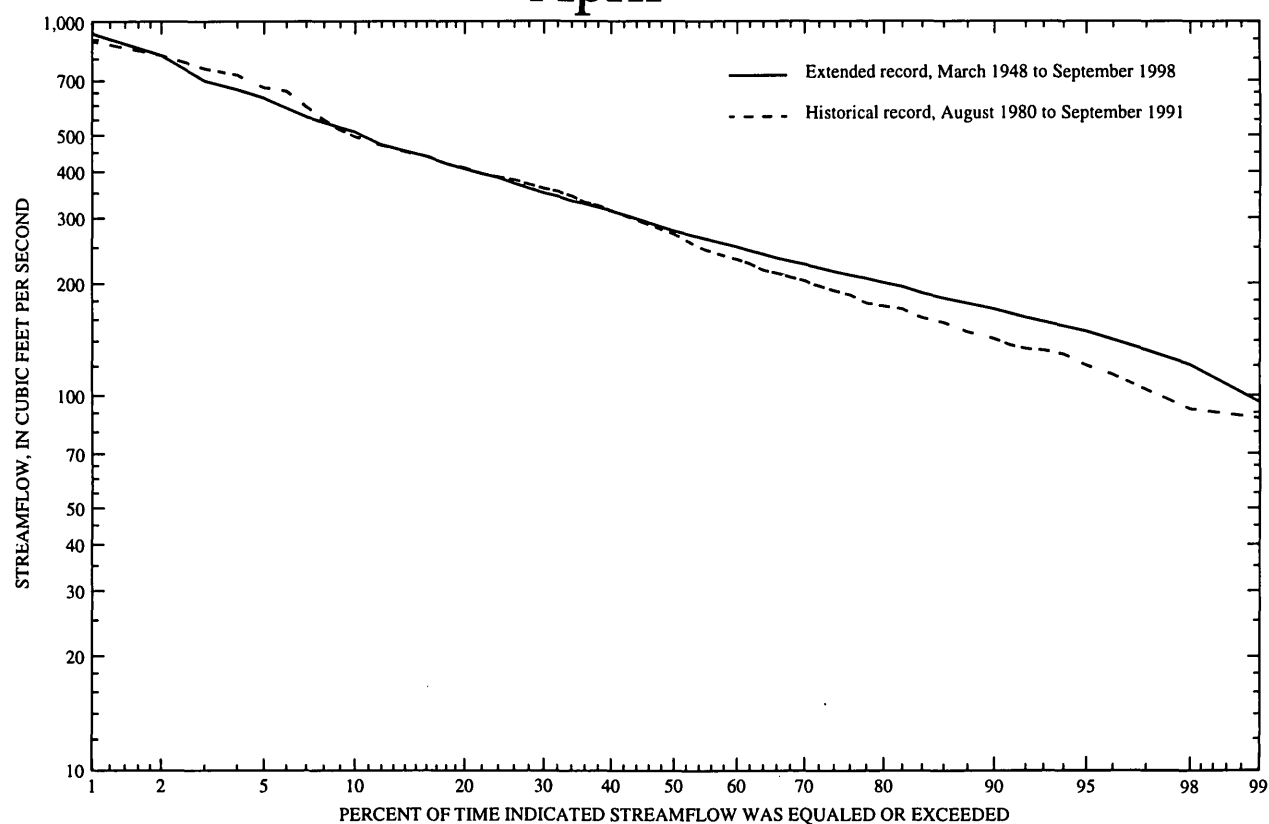
# March



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	788	55	132
5	461	60	120
10	377	65	109
15	330	70	100
20	291	75	92
25	259	80	82
30	232	85	75
35	208	90	68
40	183	95	58
45	165	99	50
50	149		

**Figure 7.** Flow-duration curves for March for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

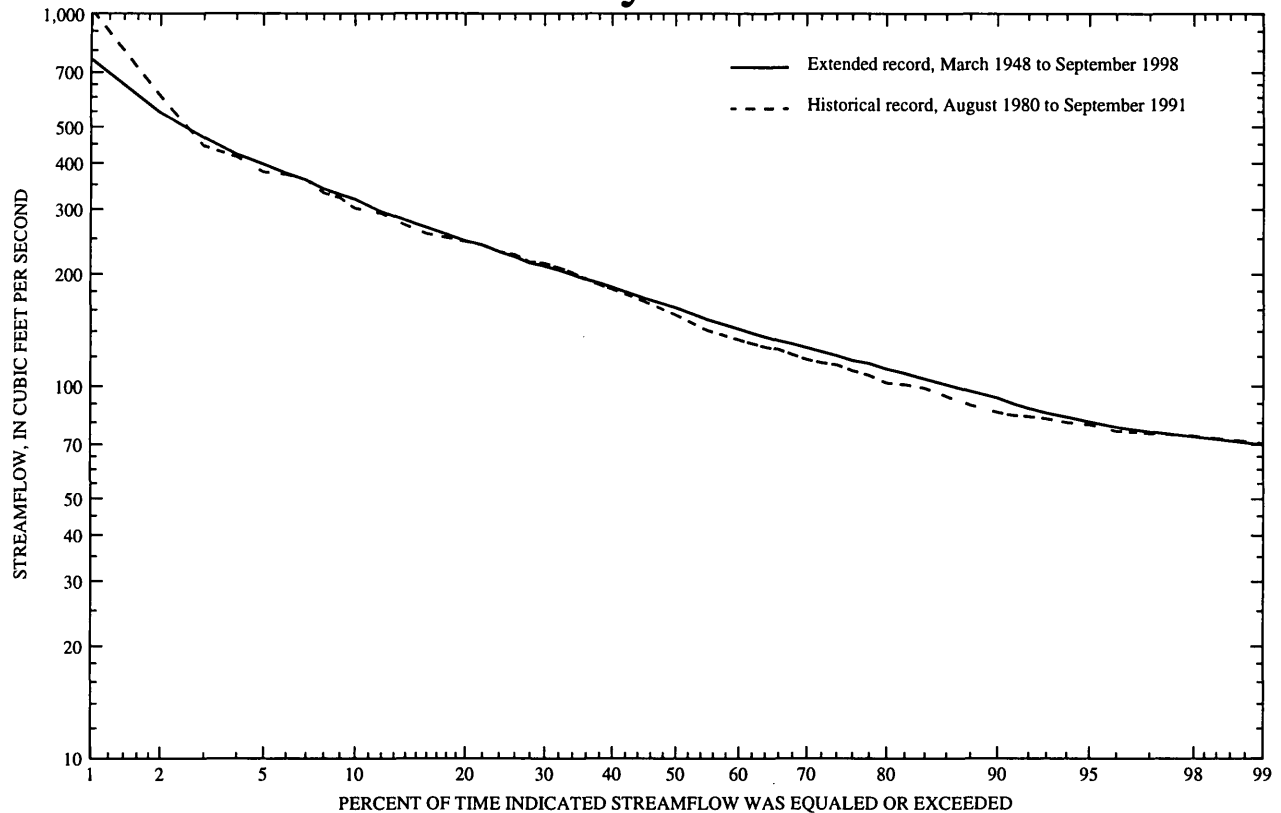
# April



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	933	55	262
5	627	60	250
10	509	65	236
15	443	70	224
20	405	75	212
25	379	80	200
30	348	85	184
35	331	90	170
40	312	95	148
45	294	99	96
50	276		

**Figure 8.** Flow-duration curves for April for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

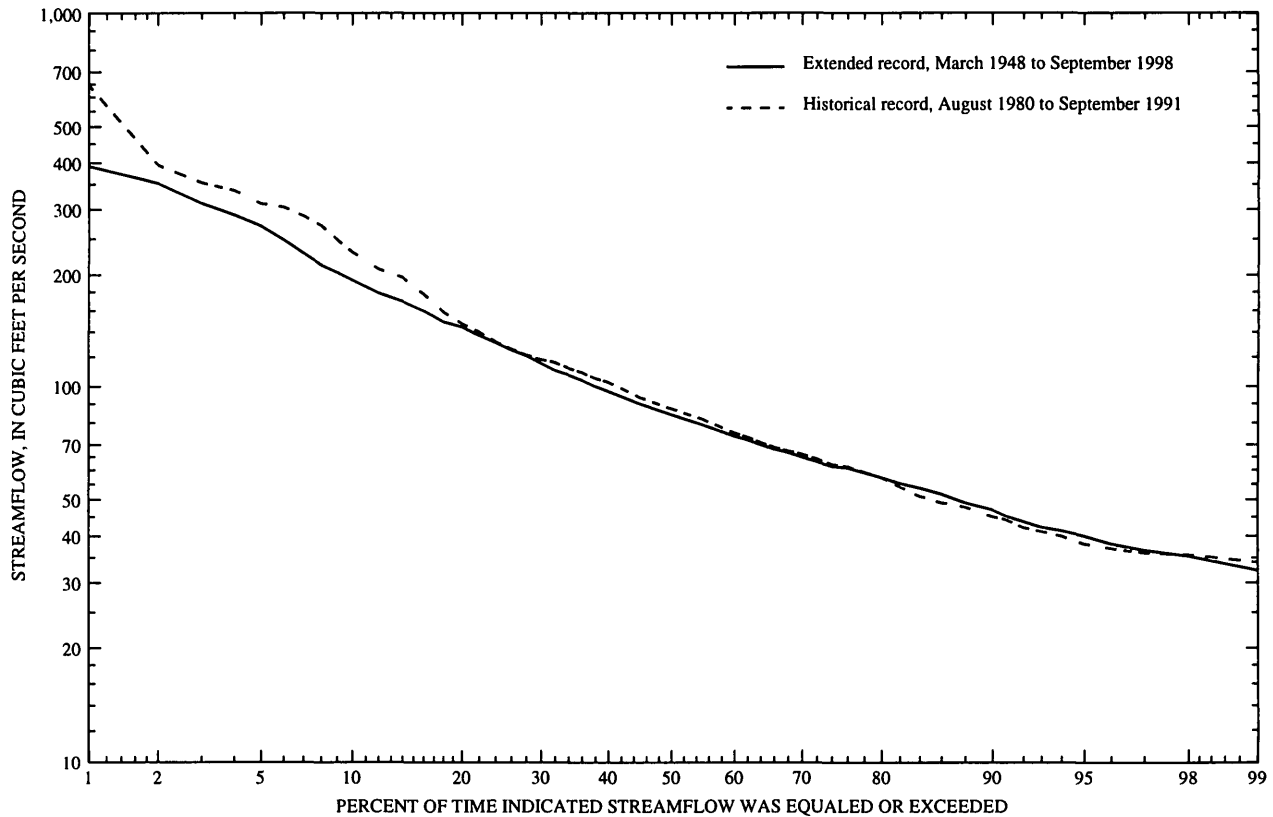
# May



Percent of time Indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time Indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	758	55	151
5	396	60	142
10	319	65	134
15	271	70	127
20	246	75	119
25	226	80	111
30	210	85	103
35	197	90	93
40	184	95	80
45	172	99	70
50	162		

**Figure 9.** Flow-duration curves for May for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

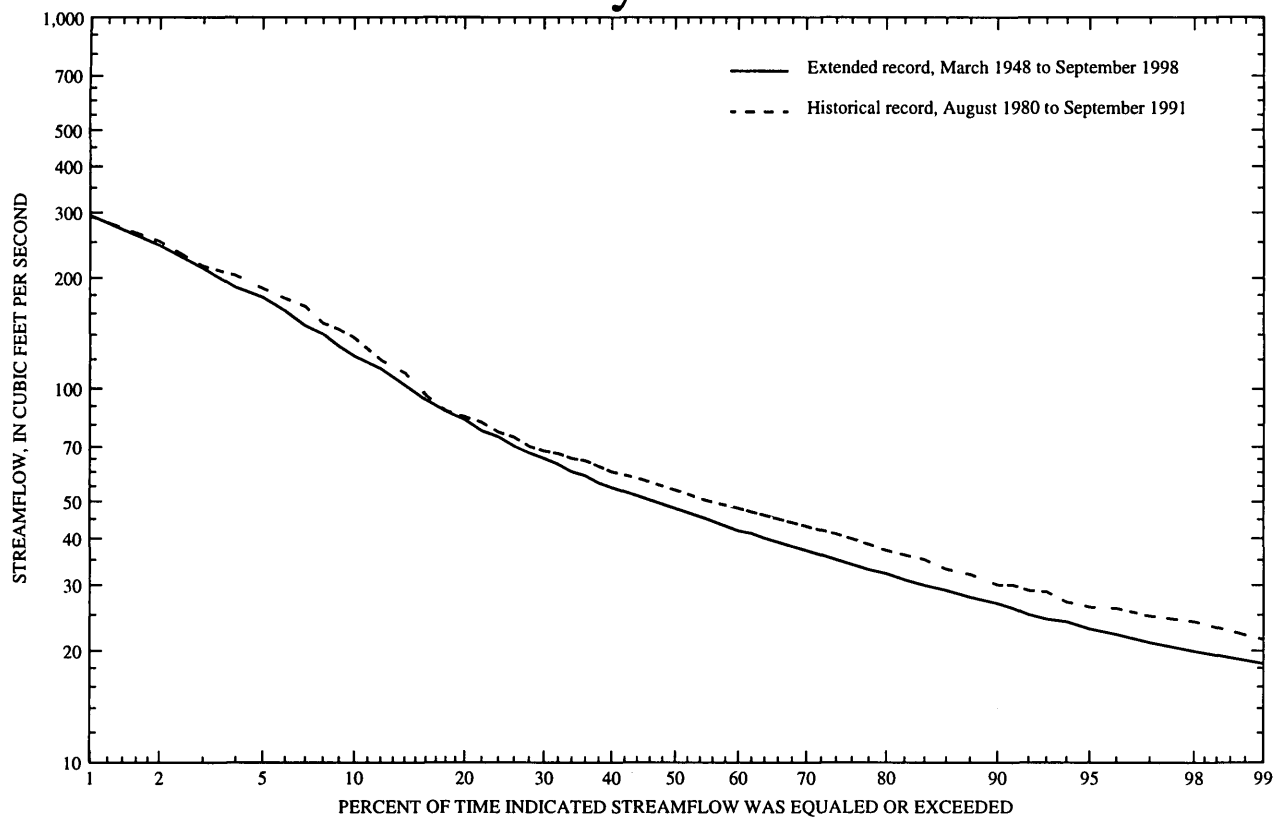
# June



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	391	55	79
5	270	60	74
10	194	65	69
15	163	70	65
20	144	75	61
25	127	80	57
30	115	85	53
35	106	90	47
40	97	95	40
45	90	99	32
50	84		

**Figure 10.** Flow-duration curves for June for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

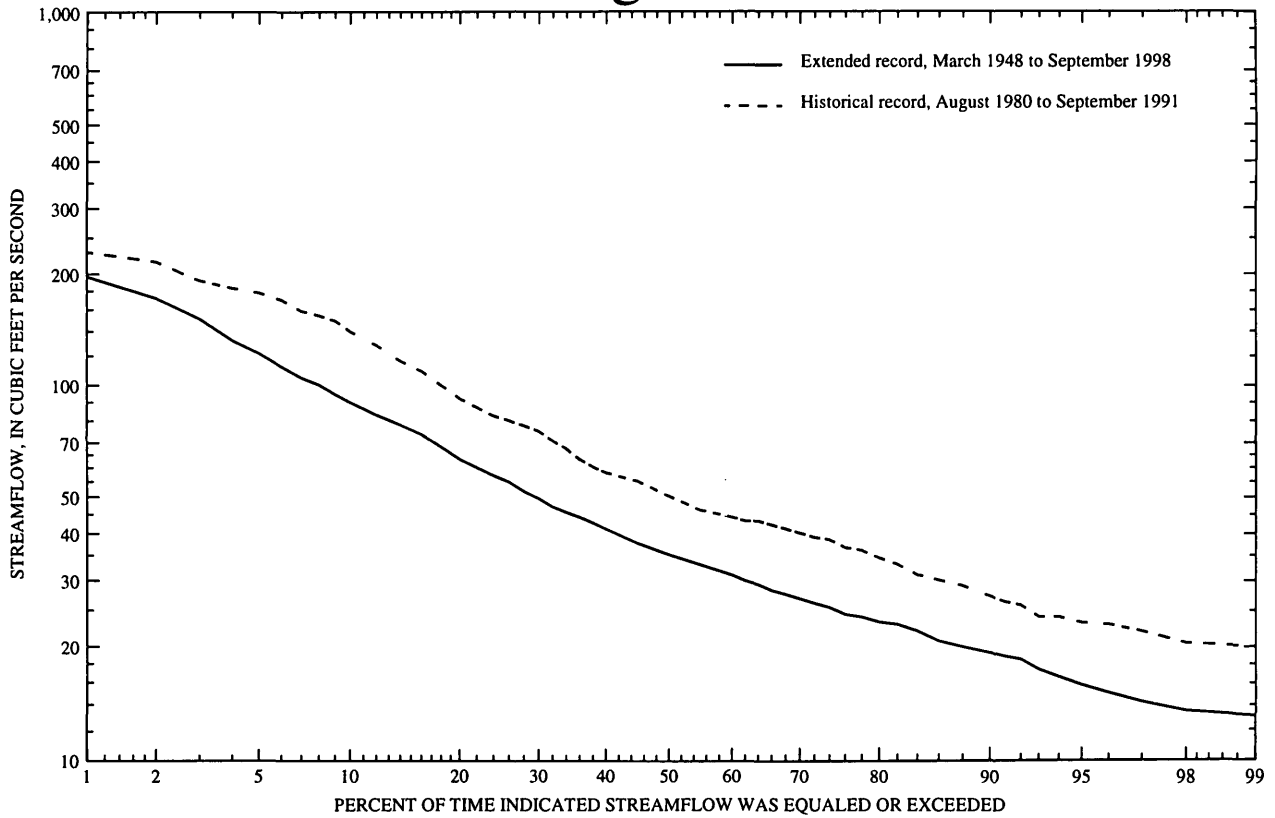
# July



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	294	55	45
5	177	60	42
10	122	65	39
15	99	70	37
20	83	75	35
25	72	80	32
30	65	85	29
35	59	90	27
40	54	95	23
45	51	99	18
50	48		

**Figure 11.** Flow-duration curves for July for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

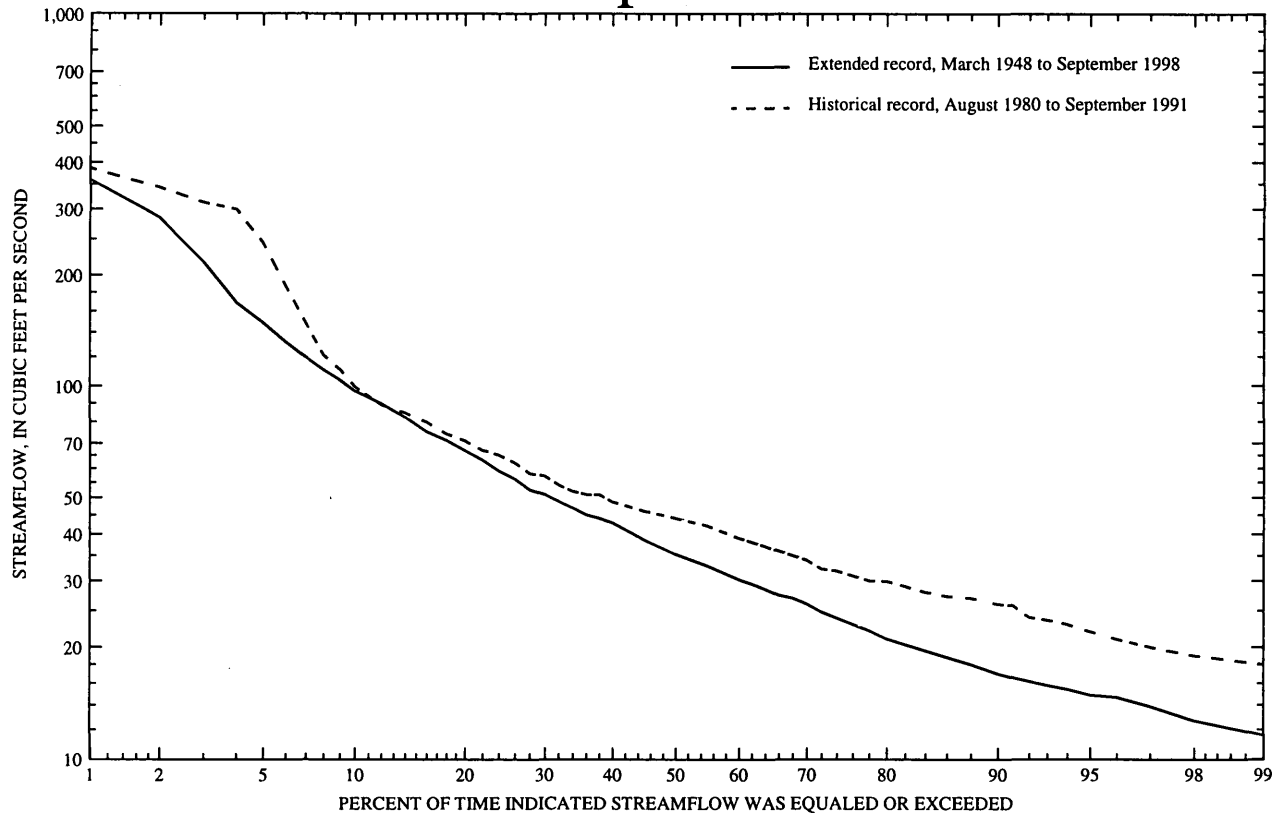
# August



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	196	55	33
5	122	60	31
10	90	65	28
15	76	70	27
20	63	75	25
25	56	80	23
30	49	85	21
35	45	90	19
40	41	95	16
45	38	99	13
50	35		

**Figure 12.** Flow-duration curves for August for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

# September

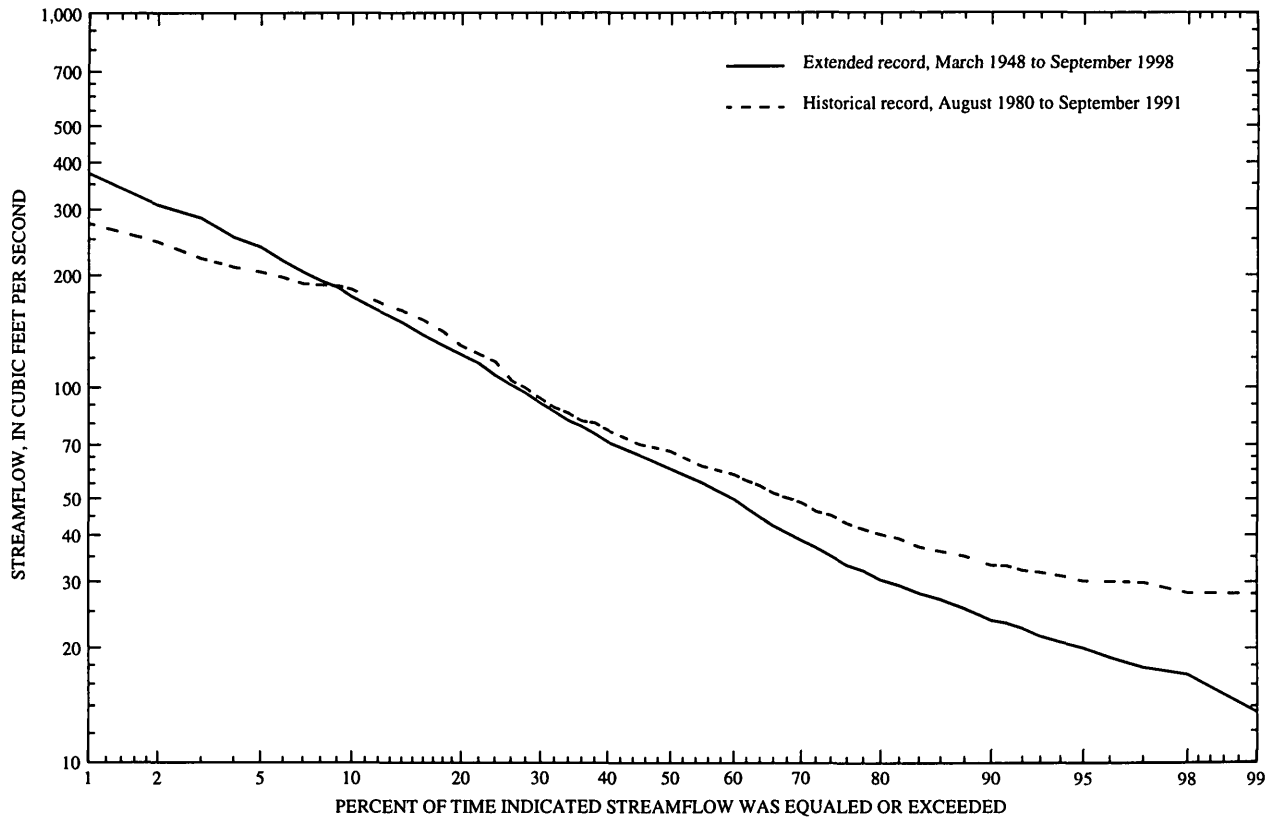


Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	358	55	33
5	149	60	30
10	97	65	28
15	79	70	26
20	67	75	23
25	58	80	21
30	51	85	19
35	46	90	17
40	43	95	15
45	39	99	12
50	35		

**Figure 13.** Flow-duration curves for September for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.



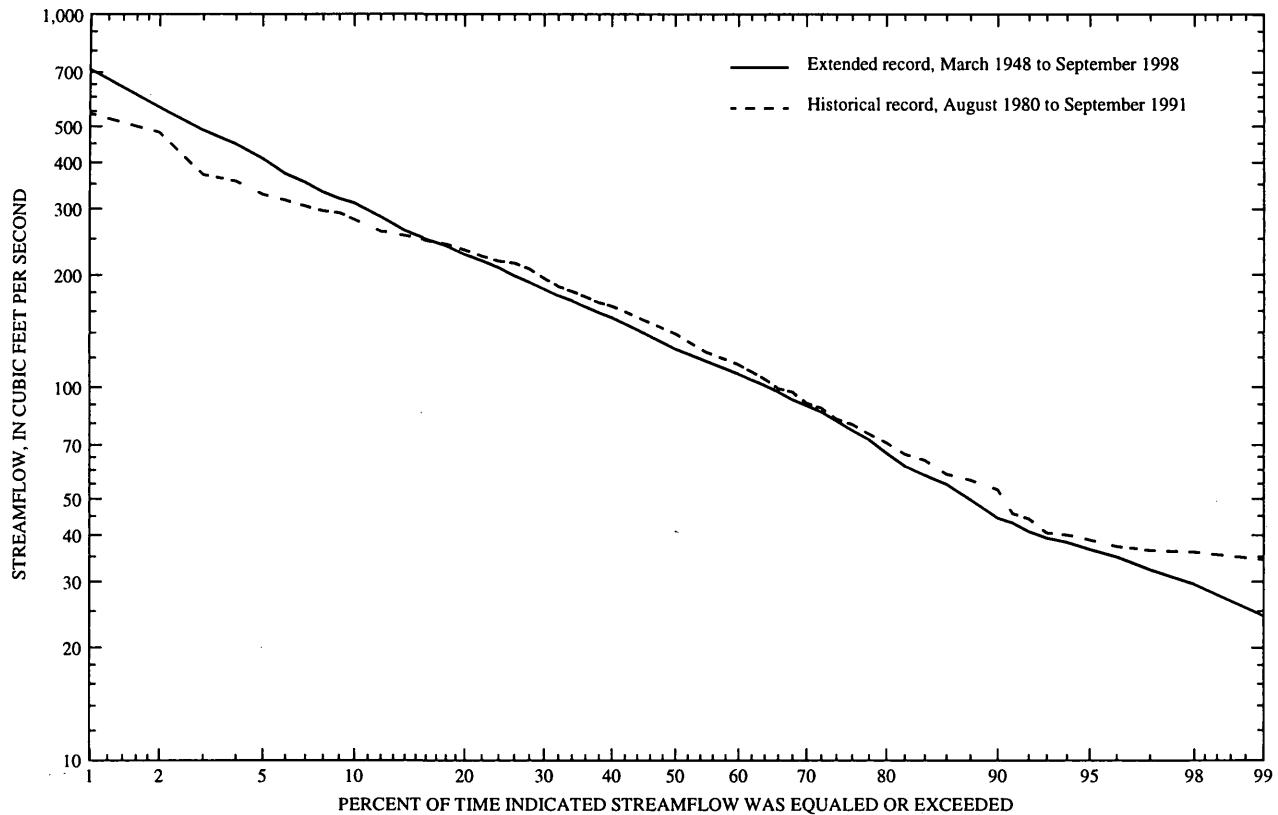
# October



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	374	55	55
5	238	60	50
10	175	65	43
15	145	70	39
20	122	75	34
25	104	80	30
30	90	85	27
35	80	90	24
40	71	95	20
45	65	99	13
50	60		

**Figure 14.** Flow-duration curves for October for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

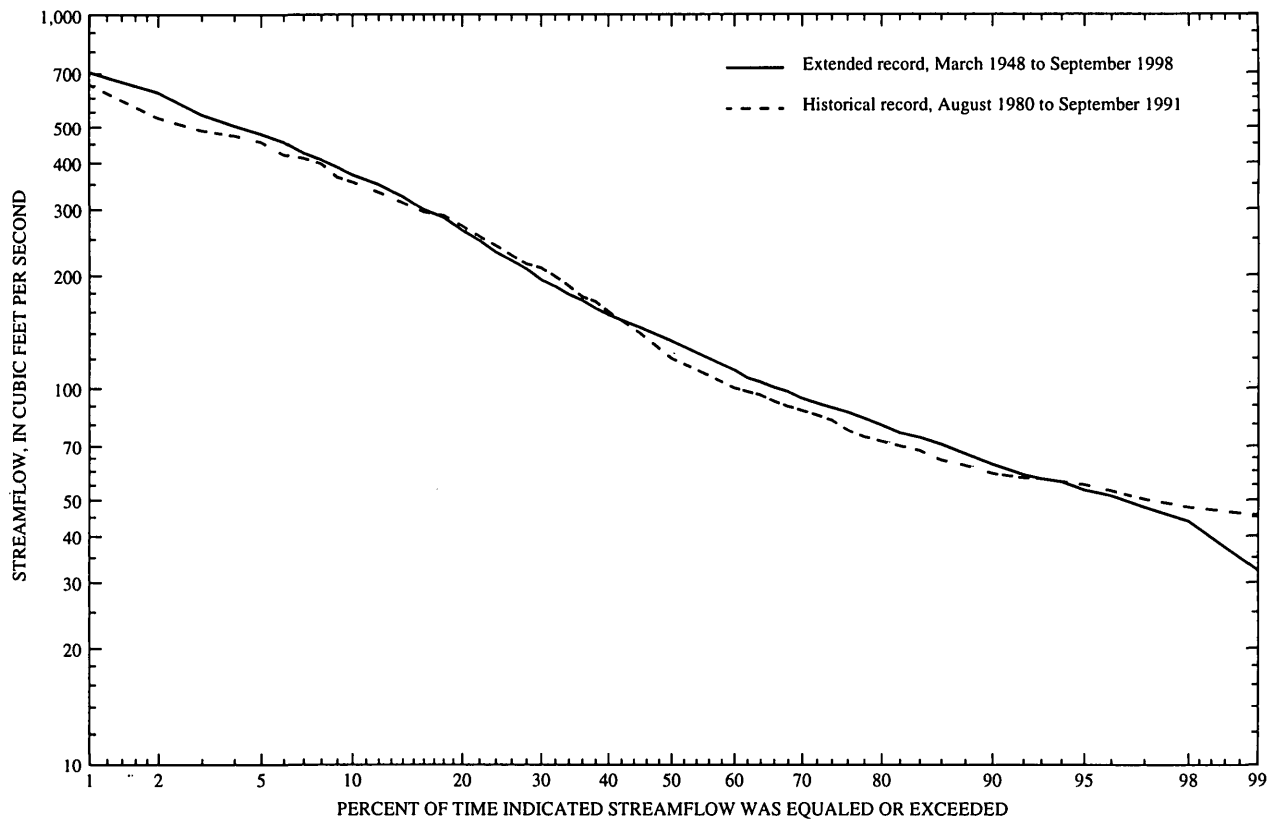
# November



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	711	55	117
5	410	60	109
10	310	65	99
15	253	70	89
20	227	75	80
25	205	80	67
30	183	85	57
35	168	90	44
40	153	95	37
45	140	99	24
50	126		

**Figure 15.** Flow-duration curves for November for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

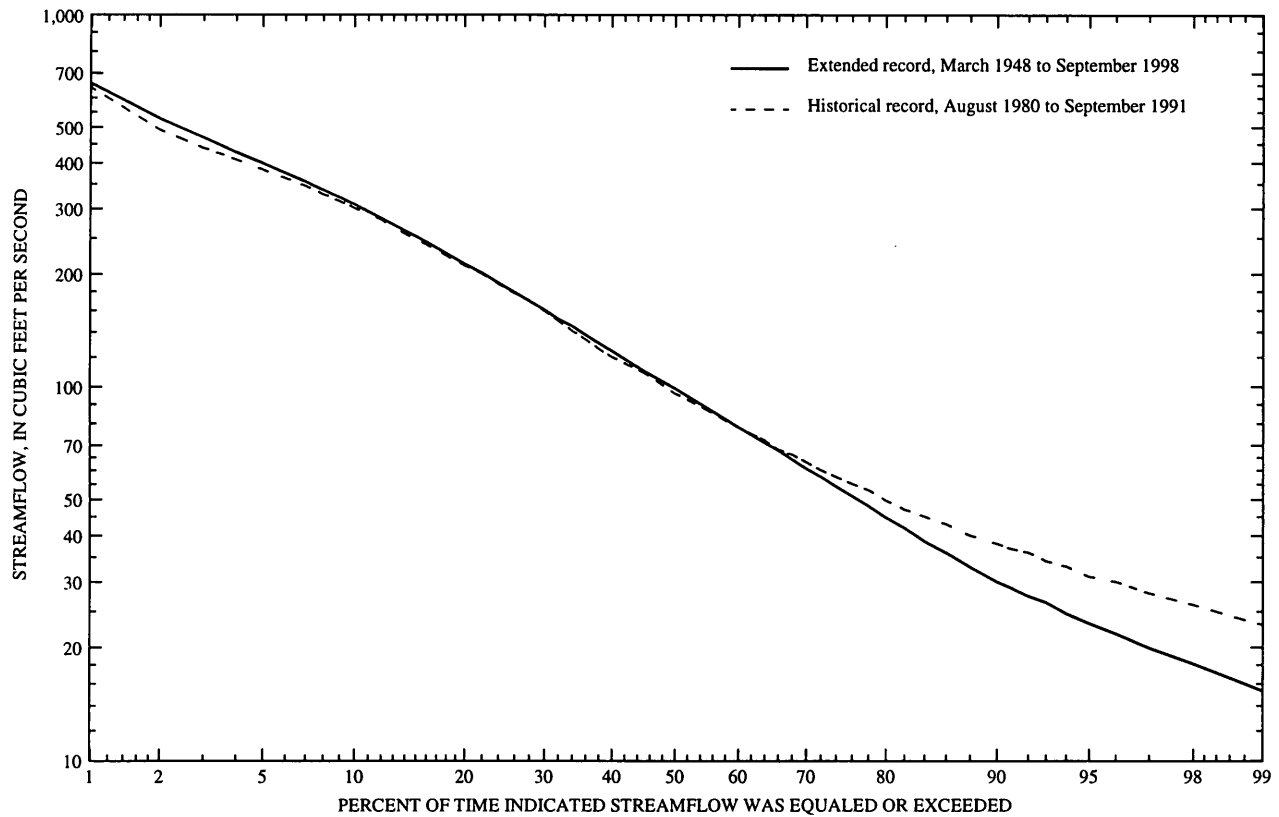
# December



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	703	55	122
5	478	60	112
10	371	65	102
15	310	70	94
20	263	75	87
25	223	80	80
30	194	85	72
35	175	90	62
40	157	95	53
45	145	99	32
50	134		

**Figure 16.** Flow-duration curves for December for extended and historical period of record (top), and flow-duration statistics for January based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

# Entire Record



Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second	Percent of time indicated streamflow was equaled or exceeded	Streamflow, in cubic feet per second
1	656	55	88
5	399	60	78
10	308	65	70
15	252	70	61
20	213	75	53
25	184	80	45
30	160	85	37
35	141	90	30
40	125	95	23
45	110	99	15
50	99		

**Figure 17.** Flow-duration curves for extended and historical period of record (top), and flow-duration statistics based on extended period of record, March 1948 through September 1998 (bottom), for Pleasant River near Epping, Maine.

