Factors Influencing the Occurrence of Floods in a Humid Region of Diverse Terrain

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1580-B

FACTORS INFLUENCING FLOODS IN A HUMID REGION OF DIVERSE TERRAIN—Geological Survey Water-Supply Paper 1580-B

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By MANUEL A. BENSON

FLOOD HYDROLOGY

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A study of the relation of annual peak discharges to many hydrologic factors in New England

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FACTORS INFLUENCING THE OCCURRENCE OF FLOODS IN A HUMID REGION OF DIVERSE TERRAIN

By Manuel A. Benson

ABSTRACT

This report describes relations between flood peaks and hydrologic factors in a humid region with limited climatic variation but a diversity of terrain. Statistical multiple-regression techniques have been applied to hydrologic data on New England. Many topographic and climatic factors have been evaluated, and their relations to flood peaks have been examined.

Many of the factors that influence flood peaks are interrelated, and part of the investigation consisted of determining the most efficient factor in each of several groups of highly interrelated variables. Drainage area size was found to be the most important factor. Main-channel slope was found to be next in importance, and a simple yet efficient index of main-channel slope was developed. The surface area of lakes and ponds was found to be a factor significantly influencing peak discharges. Of several indices tested the intensity of rainfall for a given duration and frequency was found to be most highly related to the magnitude of peaks. The increase in peaks caused by snowmelt and frozen ground was found to be related to an index of winter temperature—the average number of degrees below freezing in January.

After the above-mentioned topographic and climatic characteristics had been taken into account, there remained deviations in peak discharges that showed an evident relation to orographic patterns. An orographic factor was mapped as defined by the peak discharges of record. Multiple-regression equations were developed that related, with acceptable accuracy, peak discharges of 1.2-to 300-year recurrence intervals to 6 hydrologic variables; 3 of the variables were topographic, 2 climatic, and 1 orographic. The remaining unexplained variations in flood-peak occurrence are believed attributable to the chance variation in storms.

INTRODUCTION

The techniques for predicting or reproducing a hydrograph for a specific flood period are fairly well standardized and acceptably reliable for many purposes. However, there is much to be learned about the definition of generalized flood-frequency relations. The "T-year flood" is a statistical concept, used for purposes of engineering planning and design and for studying geomorphological relations of stream pattern and formation. What is required is an adequate explanation of the variation in flood frequencies and magnitudes from place to place with the physical characteristics and the climatic characteristics to be found within any drainage basin.

In order to study the relation of hydrologic characteristics to the frequency of floods, some procedure must first be adopted for treating flood data so as to determine the frequencies of floods. Therefore, as a preliminary to this investigation, a study of alternative methods of flood-frequency analysis has been made, the results of which are presented in Benson (1962).

Benson (1962) presents a brief history of methods of flood-frequency analysis, proceeding from simple flood formulas to statistical methods of flood-frequency analysis on a regional basis. Currently used techniques are described and evaluated. Also, the significance and predictive values of flood-frequency relations are discussed.

The studies described in Benson (1962) led to the adoption of some of the procedures used in the investigations described here. Among other things, the decision was made to use graphically drawn flood-frequency curves at individual gaging sites, from which to determine the floods of various recurrence intervals. Also, it was decided that independent studies would be made at the various recurrence intervals, in an attempt to relate hydrologic factors to the floods of those levels.

This report describes the study of the relation of hydrologic characteristics to flood peaks within a humid region of the United States. On the basis of various criteria, New England was chosen as the study region. The mass of hydrologic data on New England provided an unprecedented opportunity to study the relations between flood peaks and their causative factors. The objective was to examine the relation of flood peaks with all hydrologic characteristics, both topographic and climatic, that might be expected to influence the magnitude of the peaks and to determine the relative effects of such characteristics.

Another phase of the overall study is the relation of hydrologic characteristics to flood peaks within semiarid and arid regions. This phase has not yet been completed.

This study has been made as part of the project on areal flood frequency. The project leader was M. A. Benson. The cooperation of the following in furnishing data is acknowledged: G. S. Hayes, C. E. Knox, and B. L. Bigwood (now retired), district engineers in Augusta, Maine, Boston, Mass., and Hartford, Conn., respectively. M. T. Thomson conducted the search for historical data which made it possible to define the return periods of major floods. D. R. Dawdy, J. Davidian, and M. W. Busby, engineers, contributed original ideas as well as their labors to the progress of the work.

CHOICE OF STUDY REGION

The general objective of this study and other related studies to follow is to find methods of explaining the variations in flood magnitudes and frequencies throughout the range of terrain and climatic conditions in the United States so that flood-frequency relations may be predicated for any location on any stream. In general, the physical characteristics of an area are more tangible and more easily evaluated than the climatic conditions. It was decided that the first attack on this problem should be made not on a nationwide basis but within a region of relatively homogeneous climate. This would to some extent negate the extreme variations possible from climatic differences and enable a better analysis of the effects of topographic factors. It was also necessary that the study region chosen should have adequate base data on flood peaks, topography, and climate. As the New England area met these needs and, in addition, provided a considerable range in topographic variables, it was chosen as the region to be studied. Findings for New England are thought to be representative of other humid areas.

PREVIOUS FLOOD STUDIES IN NEW ENGLAND

New England is a densely populated, highly industrialized area. Many industries use water for power and for other purposes in the manufacturing process. Because industries and residences are located close to streams and, in fact, encroach at many places on the flood plains, major floods exact a large toll in lives and property damage. For this reason people in New England have shown an intense interest in the field of flood analysis. Many engineers in New England pioneered in the development of hydrograph analysis and flood formulas.

The Boston Society of Civil Engineers, through its Committee on Floods, published two famous reports in its journal—those of September 1930 and January 1942. In the 1930 report, recommendations were made for computing design floods at individual sites based on previous flood experience at each site. The conclusion was reached that

> * * * the flood situation at any point on any stream presents a problem of its own. No general formula can be of universal application. It is only by special study of all the data, and the conditions for the point under consideration, and comparison with floods on similar streams that the best results can be obtained.

The 1942 report elaborated on the methods of using unit hydrographs to improve the prediction of floods. The committee also investigated the frequency curves obtained by applying various theoretical probability distributions to the data. It concluded that results ranged widely between the various methods and that none of them was a reliable basis for prediction beyond the period of record.

Kinnison and Colby (1945) made a study of the relation of flood peaks to drainage-basin characteristics in Massachusetts. In many respects the general methods used were similar to those of the present study. Separate formulas were derived for minor, major, and rare flood peaks.

The New England-New York Interagency Committee (1955) tabulated flood-frequency data for 196 stream-gaging stations in New England. The methods used followed the practices of the Corps of Engineers. For each station, the mean and standard deviation of the logarithms of annual flood peaks were computed. The skew coefficients were computed for 20 of the principal long-record stations. The results were not generalized so as to furnish flood-frequency information for ungaged sites directly. The recommendation was, "Where necessary, flood-frequency curves for ungaged areas may be derived by interpolation of data, or selection of a nearby station for correlation." The stations for which the flood-frequency parameters were tabulated are affected in widely varying degrees by artificial regulation.

Bigwood and Thomas (1955) and Bigwood (1957) developed a flood-flow formula for Connecticut. The index-flood method (Dalrymple, 1960) was used to develop flood-frequency relations of general application within Connecticut.

DATA AVAILABLE IN NEW ENGLAND

Records of streamflow and precipitation in New England are as numerous and as long as those of any other region of the United States. Historical flood data of New England are probably more numerous than those of any other region. New England is completely mapped topographically. In addition, a great deal of work had already been done in compiling topographic characteristics of New England drainage basins. Various precipitation data for New England have already been published in special reports of the U.S. Weather Bureau, including a recent report covering precipitation intensity-frequency relations. Thus data on peak flow and those needed for defining hydrologic characteristics were deemed adequate for the use of multiple-correlation techniques that were planned.

PEAK-DISCHARGE DATA

Records of stage and discharge are being collected at many gaging sites in New England. The Geological Survey currently operates most of the stream-gaging stations. The earliest records were maintained by private or municipal organizations in connection with water-power or municipal water supplies, and many streamflow records are still being collected by such agencies. In 1955, 10 or more years of record were available at 254 sites. Of these records, 51 percent are between 10 and 25 years in length, 41 percent between 26 and 50 years, 5 percent between 51 and 60 years, and 3 percent between 61 and 100 years.

In addition to the records of peak discharge collected at gaging stations, a considerable amount of information is available to extend the background of flood experience. At times of extraordinary floods, peak discharges have been computed or estimated at many sites by interested parties. Some peak flows were measured directly, others were determined by computing the flows through slope-area reaches or over the numerous dams found in New England, or by other methods.

Information on peak discharge and other hydrologic information on the most notable floods in New England have been published in special flood reports (Grover, 1937; Kinnison, 1929: Kinnison and others, 1938; Paulsen, 1940; Stackpole, 1946; U.S. Geol. Survey, 1947, 1952, and 1956).

Records of annual peak discharges for all gaging stations currently or previously operated, through 1950, are published in the Geological Survey series, "Compilation of records of surface waters of the United States through September 1950," (U.S. Geol. Survey, 1954, 1958, 1960). Data for subsequent years are available in the annual series of Water-Supply Papers. Information on New England is contained in parts 1-A, 1-B, and 4 in the above-mentioned series.

HISTORICAL FLOOD DATA

A large amount of historical data on floods could be obtained in New England because it was settled long ago and because the residents kept records of events of interest. Large floods which kill people or livestock and which destroy crops or manmade structures are likely to be recorded in many ways. Personal diaries, church records, mill records, newspapers, and town histories frequently contain accounts of outstanding floods. Such references are most useful when information is given comparing the current flood heights with past events or relating the elevation of the peak stage to the level of some structure or feature of the landscape. Sometimes, information is retained only in memory and may be passed on from generation to generation. In such form it is most vulnerable to human error, but if confirmed by more than one source, it may prove to be reliable and is often invaluable.

Previous studies of historical flood data on New England had been limited in extent. An extensive study was made during the summer of 1957 as part of this investigation. The study involved a search of recorded material as well as field reconnaissance and interviews with hundreds of residents (usually the oldest) along the riverbanks. Details and results of this investigation are described by M. T. Thomson (written communication, 1959).

The importance of such an investigation for extending flood knowledge, and hence the period of time on which the frequencies of floods are determined, cannot be overemphasized. Insofar as flood frequencies are concerned, the historical flood data may be more important than data collected during 50 years of a recent period of gaging-station operation. The time base may be increased manyfold, and in this study it was increased from 50 to 200 or even 300 years.

TOPOGRAPHIC DATA

New England is completely mapped on topographic quadrangle sheets, at scales of 1:62,500, 1:31,680, or 1:24,000. Maps with those scales show sufficient detail to permit detection and measurement of topographic characteristics ordinarily considered as related to flood peaks. A large number of such variables for many drainage basins within New England and elsewhere have been abstracted and compiled by Langbein and others (1947). Other variables have been computed during the course of this study. Details of all the topographic variables investigated are discussed later under "Topographic characteristics."

METEOROLOGIC DATA

The U.S. Weather Bureau has prepared special reports summarizing several generalized precipitation factors in New England. Data on station precipitation for 1-, 2-, 3-, 6-, 12-, and 24-hour periods are published for many stations in New England (U.S. Weather Bureau, 1954).

A U.S. Weather Bureau report (1952) presents a "Generalized Estimate of Maximum Possible Precipitation Over New England and New York." Knox and Nordenson (1955) show detailed maps of mean annual precipitation and runoff by means of contours. Mean annual precipitation by drainage basins was furnished by Mr. T. J. Nordenson of the U.S. Weather Bureau for use in this study. Messrs. W. T. Wilson and D. M. Hershfield provided advance information from the U.S. Weather Bureau (1959). The Weather Bureau also supplied figures for average monthly rainfall for all New England precipitation stations. Details of all the precipitation indices investigated are discussed in the section "Meteorologic characteristics."

DATA USED IN ANALYSIS

PEAK-DISCHARGE DATA

SELECTION OF GAGING-STATION RECORDS

A listing of all the sites where streamflow records have been collected in New England is found in the indexes of surface-water records for parts 1 and 4, tabulated by Knox (1956a and 1956b). It was decided that 10 years of record of the annual peak discharge was the minimum which would be used in the analysis. A listing was therefore made of all the gaging stations in New England shown in the indexes as having 10 years or more of published record; some, however, may have lacked information on one or more annual peaks. There were 254 such station records.

The next consideration was the amount of regulation affecting the annual flood peaks. Most streams in New England are affected to some degree by artificial regulation for power or for industrial or municipal uses. Much of this regulation, however, affects only daily flows or low flows. Even where regulation is possible at the stages of the annual peak floods, the amount of such regulation might be negligible, or within acceptable limits. Because adjustment to natural flow is unfeasible for all stations used in this study, it was necessary to eliminate all records excessively affected by regulation. In order to avoid subjective or uncertain decisions, a study was made to develop a criterion for selecting or rejecting the records on the basis of regulation effect.

A tabulation was made of the amount of usable storage above each gaging station being considered for use in the analysis. This information was obtained from recent publications of the Geological Survey and from the following State publications:

1. Connecticut Geological Survey Bulletin 44, 1928.
2. Maine Water Storage Commission, 4th Annual Report—Gazeteer, 1913.
3. Massachusetts State Senate Report 289, Water Resources of Massachusetts, 1918.
4. Report of Massachusetts State Department of Public Health, 1922.

The effect of regulation on flood peaks was estimated on the basis of published flood-routing studies, flood reports of the Geological Survey, and "308 reports" and reservoir regulation manuals of the Corps of Engineers. An attempt was made to define the degree of regulation in terms of various measures of storage and drainage area. It was concluded that only a rough criterion could be established from the data at hand unless a long and comprehensive study were undertaken. By using data on New England as well as data on other parts of the country, it was concluded that a usable storage of less than 4.5 million cubic feet (103 acre-feet) per square mile would in general affect peak discharges by less than 10 percent. This was set as the limiting value for acceptance of peak discharge data. An independent choice of usable records was made by the Survey's district engineers in New England on the basis of their personal knowledge and judgment. It is interesting to note that choices made by the two methods produced nearly identical results.

From the list of 254 records previously mentioned, deletions were made for the following reasons:

1. Ten annual peak discharges not available, or annual daily maximums available rather than momentary maximums.
2. Less than 25 percent difference between drainage areas of adjacent stations on the same stream. Only the longest record was used in this case. If two stations differed in size of area by less than 10 percent and had some nonoverlapping record, they were combined by the ratio shown by overlapping record or by a drainage-area ratio.
3. More than 4.5 million cubic feet of usable storage per square mile. If record had been obtained for at least 10 years prior to the construction of reservoirs which caused the criterion to be exceeded, the record prior to that time was used.
4. Some special indication of excess diversion or regulation, even though not exceeding the usable storage criterion. Such a situation may arise where the gage is directly below a large reservoir. Only five station records were deleted for this reason.
5. Stage-discharge relation of doubtful accuracy at upper end. Only one station record was deleted for this reason.

After deletion or combining of records, 164 station records remained for use in the analysis. The drainage areas for the stations ranged from 1.64 square miles to 9,661 square miles. No further changes were made in the group selected for study. The locations of the selected stations are shown on the map of plate 1; their names are listed in table 1.

DETERMINATION OF T-YEAR FLOODS

The annual peak discharges were listed for all 164 station records selected as being suitable for flood-frequency analysis. These represent the momentary peak discharges for each water year. The water year starts on October 1 and ends on September 30 of the following year.

The peaks for each station were listed in order of magnitude, and probabilities for each peak were computed by the formula

$$P=\frac{m}{n+1},$$

where n represents the number of years of record and m is the rank starting with the highest as 1. For historical floods or floods within a recent period of record whose rank was known relative to long periods of time, the longer period of time was used as n in the above formula. The computed probability represents the chance of an annual peak of that magnitude or higher occurring within any year. The magnitude of each peak in cubic feet per second was plotted against its probability on logarithmic probability paper. A frequency curve was drawn graphically through each set of points to average the trend of the plotted points. Each curve was extended only as high as it could be drawn with confidence on the basis of the plotted points, aided in some cases by comparison with curves for nearby stations. No curves were extended beyond the data at the individual gaging stations except where historical data may have been based on information at adjoining stations. For example, at some stations the highest floods are known to have recurrence intervals far greater than the period of record, yet local information is lacking to extend the recurrence intervals. Where such information is available for the same floods at nearby sites, that information was used to improve the plotting positions.

Values of the peak discharge were selected from each frequency curve at probabilities of 0.833, 0.429, 0.200, 0.100, 0.040, 0.020, 0.010, 0.005, and 0.0033. These discharges (shown in table 1, upper line for each station) represent, respectively, the flood peaks having recurrence intervals of 1.2, 2.33, 5, 10, 25, 50, 100, 200, and 300 years. The following numbers of peaks of each size of flood were then available for further study, and they represented the dependent variables which were to be correlated with pertinent hydrologic factors.

Recurrence interval (years)	*Number of annual peaks*
1.2	164
2.33	164
5	164
10	164
25	154
50	116
100	100
200	68
300	22

TABLE 1.—*T-year peak discharges by station, in cubic feet per second*

[The upper numbers are values of Q_T from individual station frequency curves. The lower numbers are values of Q_T computed using regression equations]

Inventory No.[1]	No. on pl. 1[2]	Station	$Q_{1.2}$	$Q_{2.33}$	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{300}
1A0110	2	Allagash River near Allagash, Maine	10,800 9,470	15,500 13,800	18,500 17,400	20,400 20,800	22,100 21,900	23,000 21,900	23,900 28,400	--- ---	--- ---
1A0135	6	Fish River near Fort Kent, Maine	6,400 5,040	8,500 7,200	9,900 9,000	10,600 10,800	11,500 12,800	12,000 14,000	--- ---	--- ---	--- ---
1A0140	7	St. John River below Fish River at Fort Kent, Maine	62,000 52,500	85,000 75,200	100,000 93,400	108,000 110,000	115,000 122,000	120,000 126,000	--- ---	--- ---	--- ---
1A0150	9	St. John River at Van Buren, Maine	90,000 74,400	105,000 105,000	120,000 129,000	134,000 151,000	153,000 166,000	--- ---	--- ---	--- ---	--- ---
1A0170	12	Aroostook River at Washburn, Maine	16,300 13,900	24,800 19,800	31,000 25,000	36,000 29,500	43,000 34,700	47,500 39,600	--- ---	--- ---	--- ---
1A0180	14	Meduxnekeag River near Houlton, Maine	2,200 2,370	3,800 3,800	4,800 5,220	5,420 6,690	6,200 8,860	6,600 10,800	--- ---	--- ---	--- ---
1A0230	22	West Branch Union River at Amherst, Maine	1,220 1,140	1,760 1,780	2,320 2,390	2,930 2,990	3,880 4,360	4,660 5,820	--- ---	--- ---	--- ---
1A0305	33	Mattawamkeag River near Mattawamkeag, Maine	12,300 10,000	18,000 14,500	22,300 18,300	26,000 21,700	30,000 29,400	33,200 33,900	--- ---	--- ---	--- ---
1A0315	35	Piscataquis River near Dover-Foxcroft, Maine	5,030 3,930	8,750 6,440	12,000 8,890	14,800 11,500	18,300 17,100	20,200 21,700	22,000 29,000	23,000 36,500	--- ---
1A0335	39	Pleasant River near Milo, Maine	5,000 4,100	8,250 6,820	12,500 9,620	18,000 12,500	23,000 19,200	25,300 24,300	--- ---	--- ---	--- ---
1A0365	45	Kenduskeag Stream near Kenduskeag, Maine	2,280 2,530	3,560 3,910	4,600 5,170	5,500 6,400	6,600 8,920	--- ---	--- ---	--- ---	--- ---
1A0380	48	Sheepscot River at North Whitefield, Maine	1,240 1,240	1,900 2,000	2,740 2,740	3,950 3,500	5,600 4,790	6,500 5,860	7,200 7,660	--- ---	--- ---
1A0450	61	Dead River at The Forks, Maine	11,600 7,680	16,500 12,500	20,000 16,100	23,000 19,500	26,200 23,000	29,000 26,400	--- ---	--- ---	--- ---
1A0460	63	Austin Stream at Bingham, Maine	1,520 1,570	2,800 2,750	4,050 4,010	4,900 5,330	5,800 8,060	6,200 10,300	6,600 13,000	--- ---	--- ---

1A0470	65	Carrabassett River near North Anson, Maine	7,000 6,670	14,100 11,100	19,900 15,700	23,300 20,500	27,200 26,700	29,900 31,000	32,000 36,000		
1A0480	67	Sandy River near Mercer, Maine	8,200 6,410	14,200 9,860	19,100 13,200	23,100 16,300	28,100 21,100	31,900 25,200	35,300 31,200	39,000 38,200	
1A0525	76	Diamond River near Wentworth Location, N.H.	3,530 3,360	5,250 5,590	6,600 7,860	7,700 10,100	9,000 13,200				
1A0550	82	Swift River near Roxbury, Maine	3,400 2,600	6,600 3,460	9,300 6,500	11,500 8,580	14,000 11,800	15,800 14,800			
1A0555	83	Nezinscot River at Turner Center, Maine	2,050 1,670	3,400 2,560	4,730 3,360	6,100 4,120	8,250 5,190	10,200 6,670	13,000 8,500		
1A0570	86	Little Androscoggin River near South Paris, Maine	1,360 1,770	2,600 2,960	3,700 4,210	4,600 5,540	5,800 7,630	6,600 10,000	7,400 11,600	8,200 13,200	
1A0645	100	Saco River near Conway, N.H.	10,000 7,940	16,800 13,200	22,900 18,500	27,900 23,600	34,400 34,100	39,500 43,000	44,900 48,300		
1A0650	101	Ossipee River at Effingham Falls, N.H.	2,530 3,510	3,600 5,900	4,960 8,270	6,300 10,700	8,400 14,200	10,100 15,500			
1A0655	102	Ossipee River at Cornish, Maine	3,130 4,010	4,650 6,460	6,200 8,540	7,800 11,000	10,300 14,500	12,800 16,600	15,300 20,700	18,400 23,600	
1A0660	103	Saco River at Cornish, Maine	9,800 [illegible]	14,100 16,400	18,000 21,400	21,400 26,100	27,100 33,900	33,000 38,800	40,000 47,600	50,000 56,800	
1A0665	104	Little Ossipee River near South Limington, Maine	1,100 1,340	1,700 2,150	3,500 2,890	5,000 3,680	6,400 5,000	7,350 6,120	8,100 7,870	8,850 9,130	
1A0730	117	Oyster River near Durham, N.H.	192 127	322 216	440 310	540 409					
1A0735	118	Lamprey River near Newmarket, N.H.	1,230 1,600	2,150 2,530	3,080 3,390	3,950 4,290	5,200 4,900				
1A0745	120	East Branch Pemigewasset River near Lincoln, N.H.	4,120 3,100	6,900 5,390	10,100 7,950	13,300 10,600	18,200 14,400				
1A0750	121	Pemigewasset River at Woodstock, N.H.	7,400 4,970	14,100 8,490	18,900 12,300	21,300 16,100	23,500 21,000				
1A0755	122	Baker River at Wentworth, N.H.	1,800 2,070	3,050 3,770	4,900 5,700	7,650 7,730					

See footnotes at end of table.

TABLE 1.—*T-year peak discharges by station, in cubic feet per second*—Continued

Inventory No.[1]	No. on pl. 1[2]	Station	$Q_{1.2}$	$Q_{2.33}$	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{300}
1A0760	123	Baker River near Rumney, N.H.	3,620 3,620	6,600 6,350	13,100 9,360	18,900 12,500	23,900 16,700	26,200 19,400	------ ------	------ ------	------ ------
1A0765	124	Pemigewasset River at Plymouth, N.H.	15,500 12,600	22,500 20,500	27,400 28,300	34,000 36,200	45,200 46,100	53,000 54,100	60,000 59,400	68,000 67,300	------ ------
1A0780	127	Smith River near Bristol, N.H.	1,250 1,170	1,900 1,910	2,620 2,680	3,920 3,440	5,700 4,420	6,900 5,430	8,000 6,500	------ ------	------ ------
1A0820	135	Contoocook River at Peterboro, N.H.	810 757	1,390 1,300	1,880 1,860	2,300 2,450	------ ------	------ ------	------ ------	------ ------	------ ------
1A0830	137	Nubanusit Brook near Peterboro, N.H.	495 442	760 776	970 1,130	1,200 1,520	1,690 2,320	2,240 2,870	3,050 3,060	4,150 4,240	------ ------
1A0840	139	North Branch Contoocook River near Antrim, N.H.	570 548	1,010 926	1,500 1,330	1,980 1,740	2,680 2,480	3,290 3,080	3,960 4,080	4,700 4,700	5,200 5,780
1A0845	140	Beards Brook near Hillsboro, N.H.	890 928	1,360 1,660	1,800 2,470	2,200 3,330	------ ------	------ ------	------ ------	------ ------	------ ------
1A0850	141	Contoocook River near Henniker, N.H.	2,500 3,160	5,100 5,050	7,700 6,810	10,000 8,500	13,400 12,000	16,100 14,500	19,100 18,900	21,500 22,600	------ ------
1A0860	143	Warner River at Davisville, N.H.	1,220 1,850	2,220 3,130	3,220 4,350	4,110 5,710	5,400 8,180	------ ------	------ ------	------ ------	------ ------
1A0870	145	Blackwater River near Webster, N.H.	1,500 1,650	2,500 1,720	3,530 3,760	4,520 4,860	6,000 6,380	7,300 7,600	8,800 9,260	10,500 10,600	------ ------
1A0880	146	Contoocook River at Penacook, N.H.	5,200 7,880	10,500 12,100	15,800 15,800	20,600 19,400	27,500 25,500	33,000 31,100	39,200 38,400	46,000 46,500	------ ------
1A0895	148	Suncook River at North Chichester, N.H.	1,460 1,400	2,600 2,280	4,000 3,150	5,600 4,030	8,200 5,220	10,500 6,000	13,300 7,390	------ ------	------ ------
1A0910	150	South Branch Piscataquog River near Goffstown, N.H.	1,180 1,530	2,300 2,560	3,140 3,570	3,700 4,630	4,300 6,520	------ ------	------ ------	------ ------	------ ------
1A0915	151	Piscataquog River near Goffstown, N.H.	1,870 2,670	3,900 4,380	6,050 6,050	8,200 7,740	11,500 10,800	14,300 13,900	17,500 16,400	21,000 18,800	------ ------
1A0940	156	Souhegan River at Merrimack, N.H.	2,300 2,680	3,610 4,460	5,000 6,100	7,100 7,890	11,100 11,300	13,800 15,200	16,000 18,000	18,100 20,300	------ ------

1A0945	157	North Nashua River near Leominster, Mass	1,010 1,120	2,410 1,940	5,300 2,800	9,300 3,720	14,500 5,580	---- ----	---- ----	---- ----	---- ----
1A0970	162	Assabet River at Maynard, Mass	650 756	1,040 1,170	1,450 1,560	1,850 1,910	2,500 2,580	3,100 3,520	3,800 4,690	4,520 5,580	---- ----
1A1010	169	Parker River at Byfield, Mass	139 122	220 195	288 262	342 335	415 451	---- ----	---- ----	---- ----	---- ----
1A1015	170	Ipswich River at South Middleton, Mass	240 276	375 426	487 560	580 691	695 915	---- ----	---- ----	---- ----	---- ----
1A1020	171	Ipswich River near Ipswich, Mass	650 602	1,070 884	1,440 1,120	1,750 1,340	2,150 1,650	2,460 2,200	2,800 2,860	---- ----	---- ----
1A1035	174	Charles River at Charles River Village, Mass	730 1,030	1,280 1,540	1,800 2,000	2,300 2,420	3,010 3,340	3,700 4,630	4,410 6,120	5,300 6,980	5,900 5,130
1A1050	177	Neponset River at Norwood, Mass	190 250	305 430	410 612	510 810	---- ----	---- ----	---- ----	---- ----	---- ----
1A1060	178	Adamsville Brook at Adamsville, R.I	95 80.5	143 143	190 202	231 269	300 353	---- ----	---- ----	---- ----	---- ----
1A1090	181	Wading River near Norton, Mass	315 342	500 550	660 742	800 941	1,000 1,280	1,130 1,850	1,300 2,280	---- ----	---- ----
1A1115	186	Branch River at Forestdale, R.I	900 744	1,550 1,260	2,100 1,760	2,600 2,300	3,250 3,460	3,750 4,520	4,300 5,660	4,800 5,870	5,100 7,290
1A1125	187	Blackstone River at Woonsocket, R.I	3,050 2,680	5,800 4,260	8,300 5,680	10,500 7,090	13,600 10,600	16,100 13,900	19,000 17,800	21,700 19,400	23,500 23,000
1A1145	189	Woonasquatucket River at Centerdale, R.I	268 214	465 381	640 542	790 718	990 1,060	---- ----	---- ----	---- ----	---- ----
1A1160	191	South Branch Pawtuxet River at Washington, R.I	423 368	660 611,	840 840	1,000 1,090	1,190 1,490	1,350 1,930	1,520 2,300	1,700 2,210	1,810 2,110
1A1170	193	Potowomut River near East Greenwich, R.I	230 245	310 404	371 618	418 820	472 1,120	---- ----	---- ----	---- ----	---- ----
1A1175	194	Pawcatuck River at Wood River Junction, R.I	485 376	605 587	750 758	910 938	---- ----	---- ----	---- ----	---- ----	---- ----
1A1180	195	Wood River at Hope Valley, R.I	500 495	777 836	1,050 1,140	1,310 1,490	1,700 2,070	---- ----	---- ----	---- ----	---- ----
1A1185	196	Pawcatuck River at Westerly, R.I	1,510 1,130	2,050 1,680	2,630 2,120	3,210 2,570	4,100 3,280	---- ----	---- ----	---- ----	---- ----

See footnotes at end of table.

TABLE 1.—*T-year peak discharges by station, in cubic feet per second*—Continued

Inventory No.[1]	No. on pl. 1[2]	Station	$Q_{1.2}$	$Q_{2.33}$	Q_{5}	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{300}
1A1195	198	Willimantic River near South Coventry, Conn	1, 100 1, 620	2, 250 2, 390	3, 850 3, 970	5, 800 5, 470	9, 300 8, 090	12, 800 10, 300	17, 100 13, 800	23, 000 17, 700	---------- ----------
1A1200	199	Hop River near Columbia, Conn	1, 160 853	2, 000 1, 550	2, 700 2, 090	3, 300 2, 840	4, 100 4, 100	4, 700 5, 340	5, 400 6, 840	6, 000 8, 000	6, 500 8, 030
1A1210	200	Mount Hope River near Warrenville, Conn	510 680	980 1, 270	1, 550 2, 040	2, 400 3, 000	4, 400 4, 780	6, 900 6, 330	---------- ----------	---------- ----------	---------- ----------
1A1220	201	Natchaug River at Willimantic, Conn	2, 020 2, 560	3, 700 4, 460	5, 500 6, 550	7, 600 9, 160	11, 500 13, 100	15, 500 14, 500	21, 100 19, 700	28, 500 24, 600	34, 100 27, 900
1A1225	202	Shetucket River near Willimantic, Conn	4, 350 5, 000	7, 000 8, 140	9, 600 11, 400	12, 500 15, 200	18, 700 22, 300	25, 500 27, 700	34, 600 36, 800	46, 500 48, 500	56, 000 51, 900
1A1235	203	Quinebaug River at Westville, Mass	550 965	900 1, 580	1, 350 2, 250	1, 970 3, 030	3, 420 4, 560	5, 400 6, 210	8, 900 8, 990	16, 000 12, 500	---------- ----------
1A1240	204	Quinebaug River at Quinebaug, Conn	1, 260 1, 880	2, 020 3, 115	3, 000 4, 480	4, 830 6, 120	9, 400 9, 310	15, 900 12, 300	26, 100 17, 000	43, 100 22, 900	---------- ----------
1A1245	205	Little River at Buffumville, Mass	220 339	405 623	635 948	1, 020 1, 340	1, 960 2, 180	3, 060 2, 910	4, 700 3, 850	6, 900 4, 340	8, 800 7, 460
1A1255	207	Quinebaug River at Putnam, Conn	2, 260 3, 230	4, 550 5, 290	6, 800 7, 390	9, 100 9, 890	13, 300 14, 900	17, 600 19, 300	23, 200 26, 400	30, 800 33, 800	36, 300 43, 200
1A1265	209	Moosup River at Moosup, Conn	910 771	1, 460 1, 280	2, 000 1, 750	2, 500 2, 270	3, 210 3, 090	3, 850 4, 010	4, 550 4, 790	5, 300 4, 950	---------- ----------
1A1270	210	Quinebaug River at Jewett City, Conn	4, 950 6, 430	8, 400 10, 400	11, 300 14, 100	14, 100 18, 600	18, 700 25, 300	23, 000 29, 500	28, 200 36, 600	34, 600 44, 400	39, 000 48, 200
1A1275	211	Yantic River at Yantic, Conn	1, 530 1, 140	2, 410 2, 030	3, 100 3, 070	3, 710 4, 370	5, 100 6, 070	6, 750 7, 110	8, 800 8, 630	11, 500 9, 910	13, 600 11, 200
1A1300	216	Upper Ammonoosuc River near Groveton, N.H	3, 700 3, 560	5, 900 5, 730	7, 600 7, 840	9, 000 9, 890	10, 800 12, 400	---------- ----------	---------- ----------	---------- ----------	---------- ----------
1A1315	219	Connecticut River near Dalton, N.H	17, 800 15, 200	26, 200 22, 600	34, 000 28, 600	38, 000 33, 600	42, 500 41, 300	44, 900 48, 800	46, 500 57, 400	48, 000 67, 600	---------- ----------
1A1330	221	Passumpsic River near East Haven, Vt	1, 000 788	1, 610 1, 330	1, 950 1, 840	2, 100 2, 330	2, 220 3, 040	---------- ----------	---------- ----------	---------- ----------	---------- ----------

1A1350	224	Moose River at St. Johnsbury, Vt.	2,000 1,650	3,140 2,660	4,050 3,490	4,820 4,190	5,800 5,090	-- --	-- --	-- --	-- --
1A1355	225	Passumpsic River at Passumpsic, Vt.	5,400 4,860	7,600 7,380	9,400 9,310	11,000 10,800	13,000 12,900	-- --	-- --	-- --	-- --
1A1375	228	Ammonoosuc River at Bethlehem Junction, N.H.	2,820 2,390	4,650 4,080	7,100 5,920	9,500 7,790	12,800 11,400	-- --	-- --	-- --	-- --
1A1380	229	Ammonoosuc River near Bath, N.H.	7,500 6,820	13,000 10,800	18,600 14,400	23,500 17,800	30,500 22,400	-- --	-- --	-- --	-- --
1A1390	231	Wells River at Wells River, Vt.	1,150 1,200	1,650 2,040	2,020 2,810	2,320 3,460	-- --	-- --	-- --	-- --	-- --
1A1395	232	Connecticut River at South Newbury, Vt.	25,500 25,800	34,000 37,400	41,500 45,600	49,000 52,700	59,000 62,800	67,000 72,800	76,000 85,400	86,000 97,700	-- --
1A1400	233	South Branch Waits River near Bradford, Vt.	580 690	1,020 1,160	1,500 1,560	1,950 1,890	2,630 2,310	-- --	-- --	-- --	-- --
1A1415	236	Ompompanoosuc River at Union Village, Vt.	1,500 1,550	2,700 2,550	3,800 3,420	4,800 4,170	-- --	-- --	-- --	-- --	-- --
1A1420	237	White River near Bethel, Vt.	6,300 6,430	11,200 10,400	16,100 14,600	21,000 19,600	28,000 23,700	-- --	-- --	-- --	-- --
1A1425	238	Ayers Brook at Randolph, Vt.	420 646	940 1,110	1,590 1,560	2,290 2,010	3,430 2,520	-- --	-- --	-- --	-- --
1A1440	241	White River at West Hartford, Vt.	12,800 12,600	20,400 18,900	28,000 25,200	35,000 31,300	49,300 36,300	66,000 42,000	90,000 47,600	122,000 60,700	-- --
1A1445	242	Connecticut River at White River Junction, Vt.	37,500 37,500	52,500 52,500	66,000 63,500	78,000 72,900	95,000 81,900	107,000 94,700	121,000 108,000	136,000 128,000	-- --
1A1450	243	Mascoma River at West Canaan, N.H.	1,110 1,220	1,830 2,100	2,470 3,050	3,000 4,060	3,740 5,500	4,300 6,420	4,900 7,660	-- --	-- --
1A1515	247	Ottauquechee River at North Hartland, Vt.	5,100 5,000	8,000 8,160	12,100 11,500	16,500 15,100	21,100 18,500	24,600 21,400	27,600 24,600	30,600 30,300	-- --
1A1525	249	Sugar River at West Claremont, N.H.	3,300 2,970	5,300 4,950	7,500 6,940	9,400 9,040	11,600 11,800	13,000 13,100	14,200 16,300	-- --	-- --
1A1530	250	Black River at North Springfield, Vt.	3,800 3,580	6,000 5,940	9,000 8,650	12,000 11,600	15,900 15,100	-- --	-- --	-- --	-- --
1A1535	251	Williams River at Brockway Mills, Vt.	2,550 2,770	4,400 4,680	6,500 6,778	8,000 8,890	9,700 11,400	-- --	-- --	-- --	-- --

See footnotes at end of table.

TABLE 1.—*T-year peak discharges by station, in cubic feet per second*—Continued

Inventory No.[1]	No. on pl. 1[2]	Station	$Q_{1.2}$	$Q_{2.33}$	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{300}
1A1540	252	Saxtons River at Saxtons River, Vt	1,790 1,990	2,660 3,450	4,160 5,010	5,200 5,980	6,100 9,240	---------- ----------	---------- ----------	---------- ----------	---------- ----------
1A1545	253	Connecticut River at North Walpole, N.H	53,900 48,100	66,000 67,400	80,000 81,600	94,000 93,100	112,000 111,000	130,000 130,000	145,000 153,000	162,000 188,000	----------
1A1550	254	Cold River at Drewsville, N.H	1,180 1,480	2,210 2,510	3,200 3,600	4,150 4,770	---------- ----------	---------- ----------	---------- ----------	---------- ----------	---------- ----------
1A1560	256	West River at Newfane, Vt	9,000 8,180	13,000 13,400	21,700 19,400	31,100 26,100	41,100 35,400	47,100 42,800	52,500 50,500	---------- ----------	---------- ----------
1A1565	257	Connecticut River at Vernon, Vt	65,000 55,100	80,000 76,200	94,000 92,200	106,000 106,000	121,000 124,000	136,000 142,000	150,000 169,000	166,000 210,000	---------- ----------
1A1570	258	Ashuelot River near Gilsum, Vt	1,110 896	1,710 1,500	2,560 2,210	3,410 2,940	4,100 3,940	4,450 4,590	4,720 5,560	5,000 6,100	---------- ----------
1A1585	261	Otter Brook near Keene, N.H	660 635	1,300 1,120	1,900 1,670	2,900 2,250	4,550 3,070	5,500 3,690	6,200 4,430	---------- ----------	---------- ----------
1A1600	264	South Branch Ashuelot River at Webb near Marlboro, N.H	550 640	1,010 1,170	1,590 1,770	2,260 2,400	3,500 3,300	4,700 3,980	6,200 4,590	---------- ----------	---------- ----------
1A1620	267	Millers River near Winchendon, Mass	740 673	1,170 1,120	1,510 1,570	1,900 2,060	3,140 2,850	4,900 3,550	7,500 4,630	---------- ----------	---------- ----------
1A1625	268	Priest Brook near Winchendon, Mass	215 229	425 390	625 558	870 744	1,350 1,060	1,920 1,410	2,710 1,780	---------- ----------	---------- ----------
1A1650	273	East Branch Tully River near Athol, Mass	470 681	830 1,060	1,200 1,740	1,630 2,330	2,500 3,420	3,360 4,310	4,510 5,250	---------- ----------	---------- ----------
1A1655	274	Moss Brook at Wendell Depot, Mass	156 179	290 319	430 467	620 633	960 889	1,300 1,160	1,700 1,440	---------- ----------	---------- ----------
1A1665	276	Millers River at Erving, Mass	3,160 3,550	4,700 5,730	5,900 7,760	8,000 9,760	14,100 13,100	22,000 15,500	35,000 18,600	---------- ----------	---------- ----------
1A1690	282	North River at Shattuckville, Mass	2,450 2,010	4,150 3,490	5,900 5,040	7,550 6,740	9,900 9,340	---------- ----------	---------- ----------	---------- ----------	---------- ----------
1A1705	284	Connecticut River at Montague City, Mass	66,000 56,400	96,000 78,700	117,000 94,400	135,000 108,000	156,000 129,000	172,000 152,000	190,000 186,000	203,000 207,000	214,000 156,000

1A1715	285	Mill River at Northampton, Mass.	1,470 936	2,270 1,680	2,930 2,480	3,600 3,050	4,660 5,070	5,600 6,750	6,600 7,770	---------- ----------	---------- ----------
1A1735	289	Ware River at Gibbs Crossing, Mass.	1,460 2,000	2,370 3,200	2,840 4,300	4,000 5,480	9,200 7,930	17,100 10,600	31,000 13,400	---------- ----------	---------- ----------
1A1745	291	East Branch Swift River near Hardwick, Mass.	390 488	690 852	1,200 1,220	2,000 1,630	3,900 2,480	6,300 3,280	---------- ----------	---------- ----------	---------- ----------
1A1755	293	Swift River at West Ware, Mass.	1,220 1,630	1,900 2,570	2,300 3,380	2,730 4,200	4,000 5,720	5,700 7,600	8,200 9,540	---------- ----------	---------- ----------
1A1760	294	Quaboag River at West Brimfield, Mass.	910 1,150	1,200 1,850	1,520 2,490	2,050 3,200	4,440 4,780	8,000 6,500	14,800 9,140	---------- ----------	---------- ----------
1A1770	295	Chicopee River at Indian Orchard, Mass.	4,400 6,380	6,400 10,200	7,600 13,300	10,200 16,700	18,300 24,400	28,500 32,000	43,500 53,700	---------- ----------	---------- ----------
1A1795	300	Westfield River at Knightville, Mass.	4,000 4,040	7,100 6,960	9,700 10,200	15,400 14,000	31,000 20,400	---------- ----------	---------- ----------	---------- ----------	---------- ----------
1A1800	301	Sykes Brook at Knightville, Mass.	35.5 53.0	68.5 102	150 172	300 263	540 462	760 717	---------- ----------	---------- ----------	---------- ----------
1A1805	302	Middle Branch Westfield River at Goss Heights, Mass.	1,780 2,000	3,200 3,600	5,000 5,620	8,200 8,120	13,200 12,300	17,600 16,600	22,000 20,000	---------- ----------	---------- ----------
1A1810	303	West Branch Westfield River at Huntington, Mass.	[illegible]100 2,[illegible]	5,200 3,970	7,900 6,080	11,100 8,540	17,000 13,100	22,200 16,900	29,000 21,000	---------- ----------	---------- ----------
1A1835	307	Westfield River near Westfield, Mass.	9,200 9,290	15,500 15,700	23,000 22,300	31,500 30,300	45,300 47,200	56,000 62,200	66,000 76,800	76,000 100,000	---------- ----------
1A1840	308	Connecticut River at Thompsonville, Conn.	79,000 78,200	115,000 108,000	145,000 129,000	169,000 148,000	198,000 192,000	219,000 238,000	239,000 292,000	260,000 382,000	270,000 314,000
1A1845	309	Scantic River at Broad Brook, Conn.	580 921	1,080 1,460	1,540 1,900	2,000 2,350	3,260 33,30	5,000 4,900	7,700 5,880	11,900 6,160	---------- ----------
1A1870	313	West Branch Farmington River at Riverton, Conn.	4,150 3,460	7,200 6,050	9,900 9,000	12,100 12,600	17,500 21,100	26,000 27,700	42,500 36,600	70,000 46,700	---------- ----------
1A1880	315	Burlington Brook near Burlington, Conn.	165 132	325 252	480 414	630 624	870 1,040	1,090 1,560	1,340 2,000	1,640 2,560	---------- ----------
1A1890	317	Pequabuck River at Forestville, Conn.	860 935	1,520 1,750	2,460 2,730	3,500 4,020	5,200 6,500	6,850 8,460	8,800 10,700	11,100 13,200	---------- ----------
1A1905	320	South Branch Park River at Hartford, Conn.	720 686	1,500 1,220	2,350 1,900	3,110 3,000	4,200 4,330	5,000 5,820	5,790 7,720	6,500 9,850	6,900 12,100

See footnotes at end of table.

TABLE 1.—*T-year peak discharges by station, in cubic feet per second*—Continued

Inventory No.[1]	No. on pl. 1[2]	Station	$Q_{1.2}$	$Q_{2.33}$	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{300}
1A1910	321	North Branch Park River at Hartford, Conn	730	1,250	1,900	2,700	4,100	5,400	6,900	8,600	9,800
			372	641	960	1,350	2,140	3,100	4,390	6,060	5,660
1A1915	322	Park River at Hartford, Conn	1,420	2,360	3,700	5,200	7,600	9,600	11,900	14,500	16,100
			1,210	2,060	3,250	4,560	7,170	9,600	12,500	15,900	18,900
1A1925	324	Hockanum River near East Hartford, Conn	490	1,080	1,710	2,320	3,200	3,950	4,790	5,650	6,200
			584	982	1,360	1,720	2,560	3,460	4,200	4,060	4,770
1A1935	325	Salmon River near East Hampton, Conn	1,580	2,950	4,200	5,300	6,800	8,000	9,300	10,600	11,600
			1,460	2,540	3,750	5,200	6,940	8,250	9,400	10,100	10,400
1A1940	327	Eightmile River at North Plain, Conn	425	750	1,020	1,310	1,700	2,050	2,420		
			278	536	850	1,220	1,770	2,090	2,420		
1A1945	326	East Branch Eightmile River near North Lyme, Conn	445	650	800	1,150	1,850	2,550	3,470		
			377	692	1,070	1,530	2,070	2,600	2,940		
1A1950	328	Menunketesuck River near Clinton, Conn	212	500	810	1,160	1,880				
			140	269	426	640	862				
1A1965	331	Quinnipiac River at Wallingford, Conn	1,100	1,800	2,370	2,850	3,500	4,000	4,480	5,000	5,300
			1,060	1,710	2,420	3,280	4,490	5,640	7,340	9,090	6,710
1A1970	332	East Branch Housatonic River at Coltsville, Mass	1,200	2,060	2,810	3,460	4,300	4,970	5,600	6,300	
			857	1,490	2,180	2,930	4,260	5,400	6,440	7,080	
1A1975	333	Housatonic River at Great Barrington, Mass	2,730	4,450	5,900	7,100	8,600	9,800	11,000	12,200	
			2,480	4,010	5,420	6,890	9,060	10,900	13,100	14,000	
1A1990	335	Housatonic River at Falls Village, Conn	4,400	6,700	8,600	10,500	13,800	17,000	20,600	25,000	
			4,840	7,440	9,560	11,800	16,800	22,700	28,200	33,300	
1A2000	337	Tenmile River near Gaylordsville, Conn	1,570	3,020	5,180	7,600	10,700	12,900	15,000	17,000	
			2,090	3,320	4,470	5,630	8,170	11,200	13,800	15,600	
1A2005	338	Housatonic River at Gaylordsville, Conn	7,400	12,200	16,600	20,500	27,100	33,700	43,000	55,000	
			6,920	10,600	13,500	16,400	22,400	28,600	34,400	37,400	
1A2015	340	Still River near Lanesville, Conn	610	1,080	1,910	3,200	5,100	6,500	7,800	9,100	9,800
			772	1,330	1,970	2,770	4,110	5,330	7,090	8,750	9,160
1A2030	343	Shepaug River near Roxbury, Conn	2,010	3,460	5,000	8,200	14,500	21,900	32,000	46,500	
			2,310	4,070	6,180	8,820	14,400	18,600	24,400	31,600	

1A2040	344	Pomperaug River at Southbury, Conn	1,860 1,580	3,000 2,890	4,750 4,400	7,000 6,420	11,000 10,100	15,000 13,400	20,000 16,300	26,000 19,500	30,000 24,800
1A2055	347	Housatonic River at Stevenson, Conn	10,600 14,000	20,600 21,500	30,000 28,300	38,600 35,700	50,500 50,000	60,000 60,600	70,000 75,300	---------- ----------	---------- ----------
1A2060	348	Naugatuck River near Thomaston, Conn	2,020 1,500	3,610 2,710	6,000 4,290	9,000 6,380	15,000 10,600	21,000 13,900	29,000 19,500	39,100 27,700	---------- ----------
1A2065	349	Leadmine Brook near Thomaston, Conn	840 792	1,850 1,490	4,000 2,450	5,600 3,760	7,400 6,380	8,500 8,860	9,600 12,000	10,600 17,400	---------- ----------
1A2085	353	Naugatuck River near Beacon Falls, Conn	4,900 4,800	9,400 8,250	14,600 12,600	21,000 17,900	34,800 29,200	50,000 37,900	70,000 53,400	100,000 81,300	---------- ----------
1B3290	50	Batten Kill at Arlington, Vt	2,570 5,360	3,700 9,250	4,650 14,100	6,300 19,700	10,200 26,200	---------- ----------	---------- ----------	---------- ----------	---------- ----------
1B3315	54	Hoosic River at Adams, Mass	830 526	1,320 868	1,810 1,240	2,270 1,670	3,000 2,270	3,620 2,900	4,400 3,930	5,300 5,000	---------- ----------
1B3320	55	North Branch Hoosic River at North Adams, Mass	1,500 1,460	2,460 2,650	3,300 4,180	4,150 6,100	5,500 8,870	6,800 10,800	8,500 13,100	11,000 17,200	---------- ----------
1B3325	56	Hoosic River near Williamstown, Mass	2,960 2,300	4,500 3,810	6,000 5,550	9,500 7,540	17,400 10,100	---------- ----------	---------- ----------	---------- ----------	---------- ----------
1B3340	58	Walloomsac River near North Bennington, Vt	2,260 2,300	3,600 3,750	5,300 5,360	7,200 7,200	---------- ----------	---------- ----------	---------- ----------	---------- ----------	---------- ----------
4-2800	397	Poultney River below Fair Haven, Vt	2,750 2,700	4,860 4,590	7,000 6,660	9,000 9,000	12,500 16,700	---------- ----------	---------- ----------	---------- ----------	---------- ----------
4-2820	399	Otter Creek at Center Rutland, Vt	3,720 4,540	6,200 6,970	8,200 9,540	10,000 12,500	12,100 15,300	13,900 18,300	---------- ----------	---------- ----------	---------- ----------
4-2825	400	Otter Creek at Middlebury, Vt	3,500 8,340	4,850 12,400	6,000 16,700	7,200 21,200	9,000 25,700	10,800 30,000	12,800 38,800	---------- ----------	---------- ----------
4-2865	407	Dog River at Northfield, Vt	1,190 1,420	2,100 2,470	3,000 3,570	3,800 4,750	5,000 6,250	6,100 8,140	7,400 8,920	---------- ----------	---------- ----------
4-2870	408	Dog River at Northfield Falls, Vt	1,850 1,890	3,620 3,180	5,500 4,550	7,300 5,940	10,000 7,810	---------- ----------	---------- ----------	---------- ----------	---------- ----------
4-2880	409	Mad River near Moretown, Vt	3,930 3,270	6,200 5,390	8,300 7,480	10,300 9,620	13,700 12,300	16,800 14,600	20,300 17,500	25,000 20,700	---------- ----------
4-2905	413	Winooski River near Essex Junction, Vt	15,200 12,500	23,100 18,500	30,000 23,800	38,000 28,600	54,000 33,300	71,000 38,600	94,000 45,600	126,000 56,000	---------- ----------

See footnotes at end of table.

TABLE 1.—*T-year peak discharges by station, in cubic feet per second*—Continued

Inventory No.[1]	No. on pl. 1[2]	Station	$Q_{1.2}$	$Q_{2.33}$	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{300}
4-2910	414	Green River at Garfield, Vt	301 218	450 395	600 600	750 824	990 1,100	1,220 1,220	1,580 1,600	2,100 1,760	---------- ----------
4-2920	416	Lamoille River at Johnson, Vt	5,700 4,100	7,900 6,580	9,600 8,970	11,100 11,300	13,200 13,800	---------- ----------	---------- ----------	---------- ----------	---------- ----------
4-2925	417	Lamoille River at East Georgia, Vt	10,300 8,730	14,100 13,300	17,100 17,400	19,700 21,400	23,000 25,000	---------- ----------	---------- ----------	---------- ----------	---------- ----------
4-2930	418	Missisquoi River near North Troy, Vt	3,410 2,530	4,500 3,980	5,400 5,400	6,400 6,810	8,000 7,840	---------- ----------	---------- ----------	---------- ----------	---------- ----------
4-2935	419	Missisquoi River near Richford, Vt	7,700 6,700	10,000 10,000	11,900 13,100	14,100 15,800	19,100 17,700	25,000 20,800	34,000 24,100	47,500 30,400	---------- ----------
4-2965	421	Clyde River at Newport, Vt	1,100 1,200	1,700 1,910	2,220 2,640	2,700 3,380	3,350 4,190	3,950 4,700	---------- ----------	---------- ----------	---------- ----------

[1] U.S. Geol. Survey gaging-station inventory number. The part numbers, 1A, 1B, or 4, are shown at the left.

[2] Numbers for stations in parts 1A, 1B, and 4 are those used respectively in Water-Supply Papers 1301, 1302, and 1307, "Compilation of records of surface waters of the United States through September 1950."

HYDROLOGIC CHARACTERISTICS

Floods are caused ordinarily by runoff from rainfall or snowmelt and less frequently by dam failures, ice gorges, or high tides. The probabilities of the latter types are, with rare exceptions, too small and erratic to be considered in this type of study. What we are concerned with are the regularly occurring year-to-year floods caused by rainfall or snowmelt, although a few of the other types may be included.

After precipitation in some form reaches the ground surface, its rate of runoff will be influenced by many factors. Meteorologic factors such as temperature, dewpoint, winds, radiation, or other elements affecting snowmelt or evaporation affect the amount of runoff. Once the runoff has started, however, its pattern is controlled by the topographic characteristics of the drainage basin. This is especially true if the precipitation is in the form of rain. These characteristics may be either surface or underground features. Most topographic features are relatively stable, such as the size of the drainage area or the amount of land slopes; others are variable, such as kind of ground cover or state of cultivation.

The problem is, first to choose those factors which may be expected to be causally related to flood peaks, to break them down into their simplest components, to evaluate them, and to choose factors having the least interdependence. This part requires a knowledge of hydrologic and hydraulic principles. Finally, statistical methods are applied to finding those factors that are most significant and to developing the relations between flood peaks and their causes. The hydrologic factors are, in statistical terms, the independent variables that are to be associated with the flood peaks, which are the dependent variables.

A set of independent variables which are actually independent of each other would be preferable. In flood hydrology this is not possible. Actually, there are very few which are mainly independent. The most important factor is, intuitively, the size of drainage area (its importance is later demonstrated). The larger the area, the larger is the volume of rain that may fall on it and in general the the larger the peak discharge. Once drainage-area size has been selected as a variable, most other factors that may be chosen have some degree of interdependence. The general magnitude of rainfall is virtually independent, being a climatic factor; yet rainfall intensities vary with size of the drainage area and rainfall distribution varies with directional or orographic characteristics of the basin. Soil, cover, and channel slopes may be affected by the amount of rainfall generally available. Thus it is seen that topographic and meteorologic variables are not independent of each other. Topographic factors may be highly interrelated. Land slopes, channel slopes, stream densities, and altitudes are interrelated and each is related to drainage area. Cover has some relation to both slope and altitude.

TOPOGRAPHIC CHARACTERISTICS

The choice of topographic characteristics to be used in the analysis must first be made by considering which factors may be expected to be influential in determining the size of flood peaks. The size of the basin, as previously discussed, is very important, and experience has shown that it merits first consideration. When water falls on a basin it first flows mainly by an overland route to small channels; thence it flows to larger and larger streams through a complex drainage pattern to the principal stream on which the gaging point is located. The land slopes, tributary slopes, and main-channel slopes are all important factors in determing the velocity of this flow. The ground cover and the nature of the channel bed materials are retarding influences, representing the "roughness" or friction coefficients in hydraulic formulas, and should be considered if possible. Some of the water travels by subsurface or underground routes; hence the type of soil and geology may need to be considered. The drainage pattern influences the timing of the flood peak and should therefore be evaluated, possibly as a lag factor or as a basin shape factor. The stream density and length of the main channel also influence the timing. Altitude or orientation of the basin with respect to storm pattern may influence the amount or the timing of rainfall and thus merit consideration. The amount of storage in lakes, ponds, reservoirs, swamps, or within river channels or flood plains may reduce the peaks of floods.

Not all these topographic characteristics may need to be used in the final flood-frequency relations. Because of their interdependence, only one of many related factors may be sufficient. Many of these factors have not yet been successfully evaluated—for example, geologic influences have not yet been reduced to simple numerical indices. Data may be lacking by which other factors thought to be effective, such as soil depths or land treatment, can be appraised. There is considerable latitude in the method of defining some variables, and simplicity is a highly desirable feature of any method. Many of the complex topographic factors which hydrologists have used are little justified in view of the current lack of knowledge of the relation between flood peaks and even the simplest variables.

DRAINAGE AREA

The gross drainage areas in square miles were used as shown in the latest Survey publications. In New England there are no natural closed basins or areas that are noncontributing during peak flows, so far as is known. The criterion for excess storage had eliminated those basins in which a large proportion of the drainage area might have been noncontributing because of artificial storage.

The drainage area, as expected, was found to be very significant statistically and was the most important of the variables affecting peak discharge.

SLOPE FACTORS

Various factors representing slope were investigated. The "principal channel slope" as defined by Langbein (1947) was considered. This is the mean slope of all channels draining at least 10 percent of the total drainage area; thus it may include parts of the principal tributary streams. In addition, the main-channel slope and average channel slope as defined by Bigwood and Thomas (1955) were studied. Average land slope, as listed by Langbein, was another variable compared in the study.

Langbein's "tributary channel slope" was also studied. The tributary channel slope comprises the mean slope of all channels draining less than 10 percent of the total drainage area. This may vary considerably depending on the number of such headwater tributaries considered. Langbein (1947, p. 139, fig. 50) illustrates the variation in this index.

It was found early in the investigation that, next to the drainage area, some index representing the slope of the basin was the most important variable. Several such indices were tested—the two measures of the main-channel slope previously mentioned, the tributary channel slope, and the average land slope. Each is highly correlated with the others. It was found that residual errors from the relation between the mean annual flood and drainage area size, when correlated with each of four slope indices, had correlation coefficients ranging from 0.71 to 0.78. Tributary channel slope showed the highest correlation coefficient, average land slope the lowest, and main-channel slope was between the two. However, the differences between the correlation coefficients were not statistically significant.

At this point the decision was made to use some index of the main-channel slope, following drainage area, in the relation with peak discharges, and to test other factors later for any residual signficance. The main-channel slope was chosen over the tributary-channel slope and the average land slope because of the ease of computing it compared to either of the other two. As demonstrated by Langbein, the tributary-channel slopes have limiting values which are not reached without a considerable amount of labor. Actually, the values listed by Langbein for New England basins and used in the comparison are not the limiting values; hence their reliability is not known.

There has been no unique or universally accepted way of evaluating channel slope. Some hydrologists have used the total drop from the head of the longest watercourse to the gaging point. Others have used weighing methods that evaluate the slope all along the main channel. Some have used parts of the main channel, such as the lower three-quarters. Still others have in some manner combined the slopes of tributary streams with the main channel. Part of the difficulty is that methods of defining the main channel or of differentiating the tributary streams are rather arbitrary.

Langbein's "principal channel slope" was found to be the most significant index of main-channel slope of several investigated because it accounted for more of the residual error than the others did. Its computation involves the determination of the points on the larger streams at which 10 percent of the total area is drained. This is a laborious task, however, particularly in a regional study that may require computations for hundreds of stations. It was therefore considered desirable to find a simpler and possibly better channel-slope factor. It was also considered desirable to separate the effects of tributary streams from those of the main stream. It was therefore decided (a) to use only the main channel in a variable expressing channel slope, leaving the tributary slopes for separate consideration, (b) to define the main channel, above each stream junction, as the channel draining the largest area, and (c) to make an exhaustive study to find a way of expressing the main-channel slope that is most closely related to peak discharge.

Topographic maps were used to draw channel profiles for 170 stations in New England. (This number was later changed to 164 after a criterion for allowable regulated storage was developed.) At the upstream end, each profile was extended to the drainage divide beyond the end of the stream shown on the topographic map. Distances were measured from the gaging point to each contour crossing (except where these were very dense), and channel profiles were plotted from these figures.

It was considered that the uppermost part of the stream, in the steep headwaters, might affect the slope out of proportion to the volume of water furnished by the headwater area. At the downstream end the slope might not be indicative of that affecting the size of peak discharges because of the flatter slope. It was therefore postulated that the part of the main channel whose slope would best correlate with peak discharge would be the one excluding the extreme headwater reach and possibly some of the extreme downstream reach.

The total distance along the main channel between the gage and the divide was measured. Stream-bed elevations were determined at points that subdivided the downstream 0.7 of the channel into 7 parts of equal length and the upstream 0.3 into 6 equal parts. The object was to compute the slopes between all possible combinations of the points so selected. There were 91 such combinations. Two additional slope factors were computed. These were the constants in the regression equation relating the logarithm of the rise to the logarithm of the distance from the gage, equivalent to drawing a straight line through the channel profile plotted to a logarithmic scale. These two factors represent an integrated slope for the entire main channel, rather than merely the slope between two points.

To determine the optimum slope factor, multiple-correlation analyses were to be made with the 1.2-, 2.33-, 5-, 10-, 25-, and 50-year floods as dependent variables and drainage area and each of the 93 slope factors as the independent variables. (At the time this work was being done, historical data had not yet been collected which if available would have permitted extension of some curves up to 300 years.) The best slope factor is defined as the one yielding the minimum standard error. The data were prepared for solution by an automatic computer. The programming covered computation of all the slopes, the logarithmic slope factors, the standard errors with drainage areas alone, and the standard errors and correlation coefficients with drainage area and each of the 93 slope factors.

Results of the solutions by automatic computer are shown in figures 1 and 2. These figures show contours representing equal values of the standard error. On figure 1, for example, the standard error using the slope between points 0.5 and 0.4 of the total distance above the gage is 0.193 log units. Figure 1 shows all the standard errors on which the contours are based, whereas figure 2 shows only the contours. Note the similar patterns shown by the contours for each size of flood and the minimum in the upper left of each figure. A weighing process reveals that the slope between points 85 and 10 percent above the gage would satisfactorily give the minimum standard error for all floods, with little accuracy lost for any particular size of flood. Standard errors using the two logarithmic slope factors were higher for all floods than those using the 85 to 10 percent slope. Results of the slope investigation have been reported previously in somewhat more detail by Benson (1959).

Results obtained from using the "85–10" slope factor are practically equivalent to those obtained from using the principal-channel slope in the original graphical analysis. This is gratifying because the "85–10" slope is far simpler to compute. The 85 to 10 percent main-channel slope was found to be a significant variable and generally second only to drainage area in its effect on peak discharge.

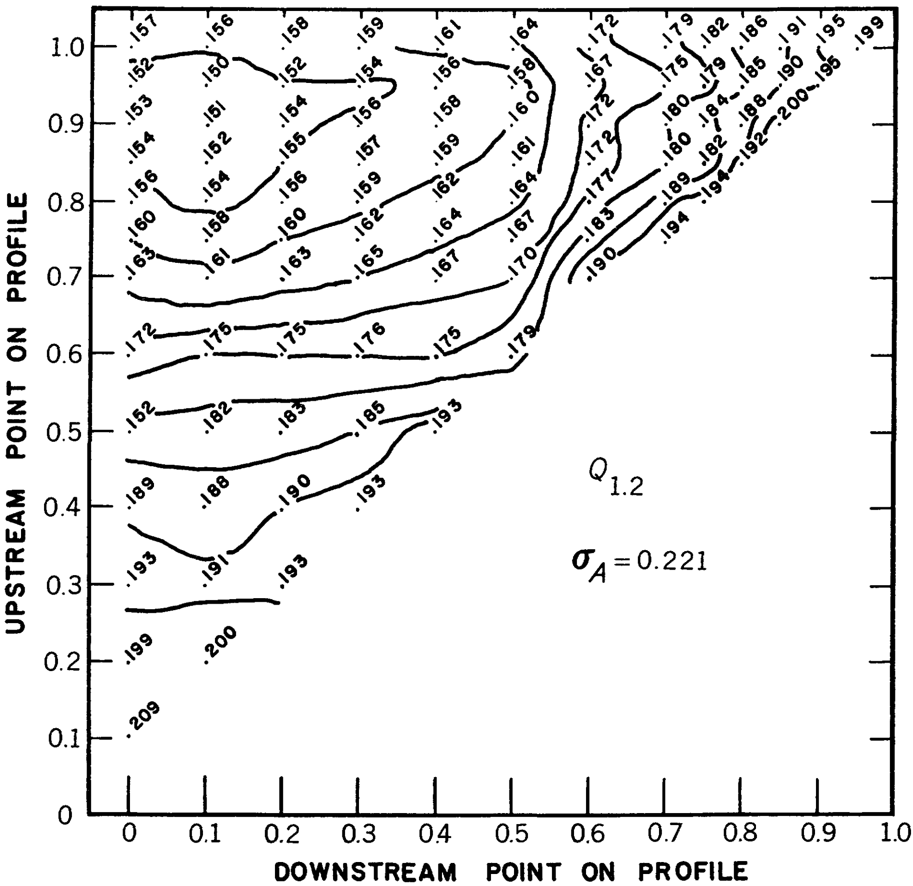

FIGURE 1.—Variation of standard error with slope factor for $Q_{1.2}$; contoured values represent the standard error in log units.

PROFILE CURVATURE

It was considered that, in addition to the slope of the main channel, the vertical curvature of the main-channel profile might have a significant effect on flood-peak magnitude. Most streams have profiles that are steep in the headwaters and become increasingly flatter in a downstream direction, but some exhibit almost straight-line profiles, and others become steeper as they progress downstream. The degree of curvature for all the stations analyzed was expressed by two indices that were devised in this study.

These indices were used to represent the curvature between the two points used to compute main-channel slope; that is, at 85 and 10 percent of the total distance above the gage. In the first index the rise between the 10 percent point and a point halfway (in distance)

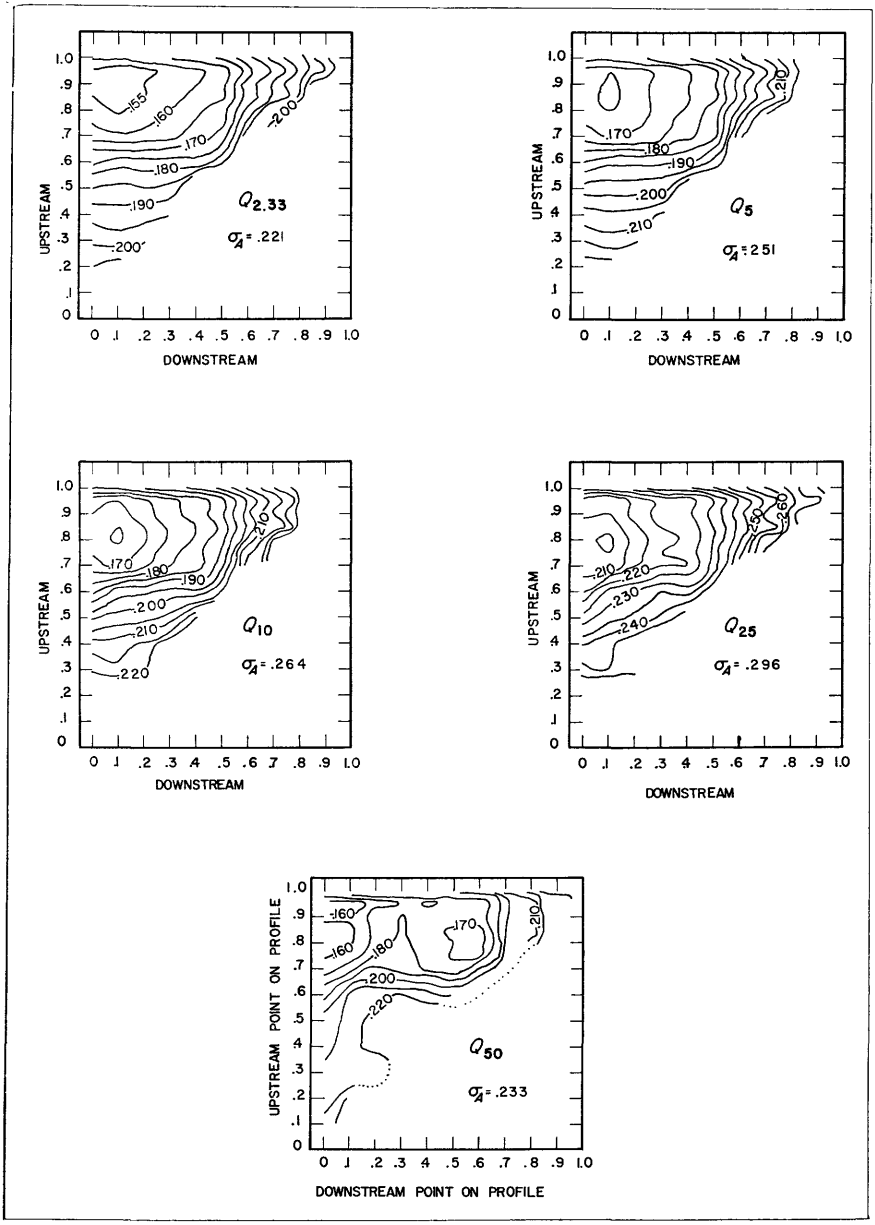

FIGURE 2.—Variation of standard error with slope factor for $Q_{2.33}$ to Q_{50}; contoured values represent the standard error in log units.

between the 10 and 85 percent points was divided by the total rise between the 10 and 85 percent points. This is a height ratio, h:H, which is a measurement of the curvature. The other index was based on length. If another intermediate point is chosen, one at which one-half the rise between the 10 and 85 percent points has occurred, then the ratio of the downstream distance to the total distance is a length ratio, $\frac{l}{L_{.75}}$, and is a measure of the profile curvature.

Neither index of profile curvature had any significant effect on peak discharge, when tested after making allowance for main-channel slope.

SHAPE FACTOR

Shape factors of various types were studied. Among those already proposed or available were the length of the main channel (L) as used previously in computing the main-channel slope and Σal as listed by Langbein (1947). The latter is the summation of the areas of many small subdivisions of the drainage basin, each multiplied by its stream distance to the gaging point. The index $\Sigma al:A$ was also used, where A is the drainage area, as a measure of effective length of water travel in a basin. Other factors studied were L^2/A, which is the same as L/w, the length-to-width ratio of the basin, and L/A, which is equal to $1/w$. An attempt was made to introduce L as an exponent of A. Finally, a subjective index was devised to express the effect of basin length and drainage pattern. Six categories were established, in which the characteristics ranged from a long and narrow basin with only 1 principal channel and no large tributaries to a short, compact fan-shaped basin with 2 or more major channels coming together near the gage.

None of these indices of basin shape or drainage pattern were significantly related to peak discharge, if tested after the effect of the drainage area and main-channel slope had been taken into account. Probably this is because shape had to a large extent already been included in the area and slope terms. The slope factor made use of length of channel, which is a measure of shape when used together with the size of drainage area.

STORAGE AREA

The criteria for selecting the station records to be used excluded those basins having an excessive amount of usable storage; that is, storage subject to regulation. However, some artificial and much natural storage remains that may effectively reduce the peak flow. Such storage may be in lakes, ponds, reservoirs, swamps, or in the stream channels and overflow plains. Storage areas previously compiled by Langbein (1947) were used to study their effect on flood peaks.

Langbein gives surface areas of (a) lakes and reservoirs and (b) swamps, for many New England streams In the course of this study it was found that the areas of swamps as delineated on older and on recent topographic maps varied considerably. The recent maps commonly showed a twofold or threefold increase over the swamp areas compiled by Langbein. Because of lack of reliable information on size of swamp areas and because the size could vary as conditions change, it was considered desirable to avoid the use of swamp areas if this were feasible. Fortunately, it was found that correlations based on storage area of lakes and reservoirs alone were better, though not significantly so, than correlations based on the total storage figures which included swamp areas as well.

Because the more recent maps are better than those available when Langbein (1947) compiled his data, the surface areas of lakes and reservoirs were recomputed for all stations used in this analysis. These areas were expressed as percentages of the total drainage area in each basin. It was found that the addition of 0.5 percent to the value for storage area brought about a straight-line power relation similar to other factors used in the relation with peak discharges. The addition of 0.5 percent also insures that where there is no storage area, the discharge will not thereby appear to be equal to zero (the form of the relation being multiplicative). The 0.5 percent of drainage area may represent the average effect of channel storage.

Where station records were used only to the time when construction of reservoirs caused the amount of regulatable storage to be excessive, the percentage of storage area used was that existing before the reservoirs were constructed.

The evaluation of channel storage is an old and a difficult hydrologic problem which has not yet been solved. No doubt its effect is evaluated indirectly, at least in part, by related factors such as channel slope. Potter (1957) has added to lake and swamp areas the area within flood plains that exceed one-quarter of a mile in width. An adjustment of this kind was attempted during this study, but it was found that only small amounts of area were added by this rule, and no improvement in the correlations resulted.

The surface area of lakes and reservoirs, expressed as a percentage of the total drainage area, and increased by 0.5 percent, has been found to be a significant variable in relation to peak discharge.

ALTITUDE

Altitude is a factor which is not in itself a direct cause of variation in flood peaks. Yet many factors that are not easily evaluated may vary with altitude. Some of these are: precipitation (its depth and distribution and the percentage occurring as snow) vegetation, soil type and depth, geology, and factors affecting snowmelt, such as evaporation, temperature, and radiation. Because of these other related elements, altitude might be expected to show some relation to variations in flood peaks.

Langbein (1947) gives the maximum, mean, and minimum altitudes for New England basins. Both the mean altitude and the difference between the mean altitude and the gage altitude, as computed from Langbein's figures, were considered in this study.

Two additional indices were computed which involved the distribution of altitude within the basin. The altitude corresponding to the mean altitude of the basin was located on each main-channel profile. The distance from the head of the stream to this point, divided by the total main-channel length, was considered an index of the distribution of altitude. A similar index was computed with the point located at the average of the maximum and minimum altitudes.

No index of altitude was found to have any significant relation to the size of flood peaks, after channel slope had been taken into account.

STREAM DENSITY

The density of a stream system is expressed in miles of stream length per square mile. All streams are measured down to the smallest shown on topographic maps. Like swamp area, the length of small streams shown on the map may vary with conditions at the time of the survey, with the mapping standards and with the judgment of the cartographer preparing the map. The true stream density may vary from place to place with amount of rainfall, land slope, cover, geology, and soils.

Stream density did not show any significant relation to peak discharge, once channel slope and storage area had been accounted for.

SOILS, COVER, LAND USE, URBANIZATION

Data were sought on depths of the soil mantle, but they were either not available for most parts of New England or were much too generalized. Some research on very small mountainous drainage areas outside of New England has shown peak discharge to be highly related to soil depths. However, it is not expected that a high degree of correlation with soil depths exists for the sizes of drainage areas used in this study. Furthermore, because soil depth is related to slope and size of drainage area, perhaps its effect has to some extent been included.

Only the latest topographic maps differentiate between wooded and nonwooded areas. The percentage of wooded area could be evaluated for only a small proportion of gaged basins within New England. It is believed that for the range of basin sizes involved in this study the percentage of wooded area would not have a wide range and its effect, if any, would not be apparent.

Land use varies with time in both its character and its areal extent. If complete data on land use were available and were compiled for the sizes of drainage areas used in this study, the best that could be hoped for would be some rough index of its effect, such as the proportion of the total drainage area farmed or the proportions farmed in such a way as to increase or decrease peak flow. Data for the evaluation of such an index and its variation during the period of record are not readily available. In any case, a comprehensive study for all of New England on the effect of land use on flood peaks was beyond the scope of this investigation. The prospect of finding significance in the relation of land use to annual peak discharges for the sizes of drainage areas used in this study was not believed to be great, on the basis of any evidence known.

There is reason to believe that the effect of urbanization is to increase peak discharges, perhaps by a considerable amount. Numerical evaluation of the degree of urbanization has not yet been properly investigated. Too few gaged basins exist within wholly or partly urbanized areas, and during the periods of gaged discharges there has been continual variation in the degree of urbanization. Bigwood and Thomas (1955) presented some coefficients taking urbanization into account in their floodflow formula for Connecticut. However, until such time as a well-planned program of data collection is made for this purpose and the effect of urbanization analyzed with sufficient data, the problem must be considered unsolved.

METEOROLOGIC CHARACTERISTICS

RAINFALL

During the period of known flood peaks, the topographic basin characteristics have remained fixed or relatively fixed. However, a meteorological factor such as rainfall, which is the direct antecedent of most flood peaks, has varied from year to year, from hour to hour during any storm, and from place to place. How then can we render this fluctuation into meaningful figures that will disclose their relation to flood peaks?

One way of expressing a variable is by an average. The mean annual rainfall is a factor that describes the general climate—humid, semiarid, or arid—and thus may have a general relation to flood peaks. The mean annual rainfall for each drainage basin, as determined from contours of annual rainfall, was used as a variable.

The mean annual runoff (weighted for each basin) was tested as a variable. It was considered as an index of that part of the precipitation which actually reaches the main stream. Thus the index takes into account many losses and diversions occurring between rainfall and runoff.

About 70 percent of the annual peak discharges in New England occur during March, April, and May. The average rainfall during this 3-month period might therefore be expected to show better correlation with peak discharges than annual rainfall. This 3-month average was computed for each basin and tested as a variable.

Because annual peak discharges are caused by individual storms, it would be expected that rainfall representative of shorter periods of time than a year or 3 months might better correlate with peak discharges. In the early part of this study published data for the maximum 24-hour precipitation were used as the basis of another precipitation variable.

During the course of this study the U.S. Weather Bureau completed work on part 4 of Technical Paper 29, defining the "Rainfall intensity-frequency regime" for the Northeastern United States. This material was made available for use prior to publication. The maps and diagrams allow the determination of rainfall intensities for durations from 20 minutes to 24 hours and for recurrence intervals from 1 year to 100 years, on all sizes of drainage areas. From this material it is possible to determine, for example, the 18-hour 25-year rainfall to be expected on a drainage area of 250 square miles. Rainfall data of this type seemed to offer the best promise of correlation with peak discharges.

The study first showed that for flood peaks ranging from 1.2 to 100 years in recurrence interval the correlation of intensities for 24-hour periods with peak discharges was as good as or better than that for 1-hour or 6-hour durations. It was also found that best results were obtained when rainfall intensities were used having the same recurrence intervals as the peak discharges. For example, the 100-year peak discharges correlated best with the 100-year 24-hour precipitation.

The mean annual and 3-month precipitations showed an equal degree of correlation with peak discharges. However, the 24-hour rainfall intensities for recurrence intervals corresponding to the discharge showed even better correlation and proved to be statistically significant variables, at the 5-percent level or better. The values for 200- and 300-year intensities were obtained by extrapolation beyond 100 years. This was done (rather than using 100-yr values for 100-yrs and more) in order that the resulting equations for peak discharge would follow a pattern consistent with those for lesser floods.

For many parts of the country, up-to-date intensity-frequency data for rainfall are not available. In lieu of this, other precipitation indices may be used, such as mean annual precipitation or mean precipitation during the months when annual peak discharges most commonly occur. In arid and semiarid regions, the mean number of thunderstorm days may be a useful index.

SNOWFALL AND TEMPERATURE

Throughout Maine and in the northern parts of New Hampshire and Vermont, almost all annual peak discharges occur during the 3-month period March to May. The annual peaks here are characteristically caused by spring rains augmented by snowmelt. Confirmation of the effect of snowmelt on runoff was obtained by examining the average ratio of runoff to precipitation during the March to May period. These ratios were computed for all 164 records used, and the contours of figure 3 were based on these ratios. The effect of snowmelt on runoff is evident because the ratio is more than 1.0 throughout northern New England. There seems no reason to doubt that, in a similar manner, peak discharges also are progressively increased by snowmelt the farther north the basin is located.

The water equivalent of accumulated snow at the time of the spring floods therefore appears to be an important factor influencing peak discharge. Unfortunately, outside of Maine only scattered data are available on the accumulated water equivalent of snow in these areas, and long-time averages for the whole of New England cannot now be mapped. It might be expected that winter temperatures would have a very close relation to snow accumulation, and this was found to be so. Figure 4 (U.S. Dept. of Agriculture, 1941) is a map of mean January temperature in New England. This map shows a pattern of regional variation similar to that of the 3-month runoff-precipitation ratio. The temperature contours do not show the detailed variations which probably exist in the mountain areas; however, this map has been used as the best representation available of temperature differences.

Either the 3-month runoff-rainfall ratio or the January temperature can be used as an index of the combined effect of accumulated snow and frozen ground conditions. January temperature was defined in more detail and was therefore used. Temperature correlated best with peak discharges when the actual mean January temperatures were subtracted from 32°. The resulting figures, in absolute values, represent the number of degrees Fahrenheit below the freezing point. January temperatures, represented this way, proved to be a significant variable related to peak discharge.

ANALYTICAL PROCEDURES

The correlation of peak floods of various recurrence interval with hydrologic factors was first studied using graphical methods. This study was made to explore first the many possible variables that might be used and to attempt improvement by varying the form of some of them.

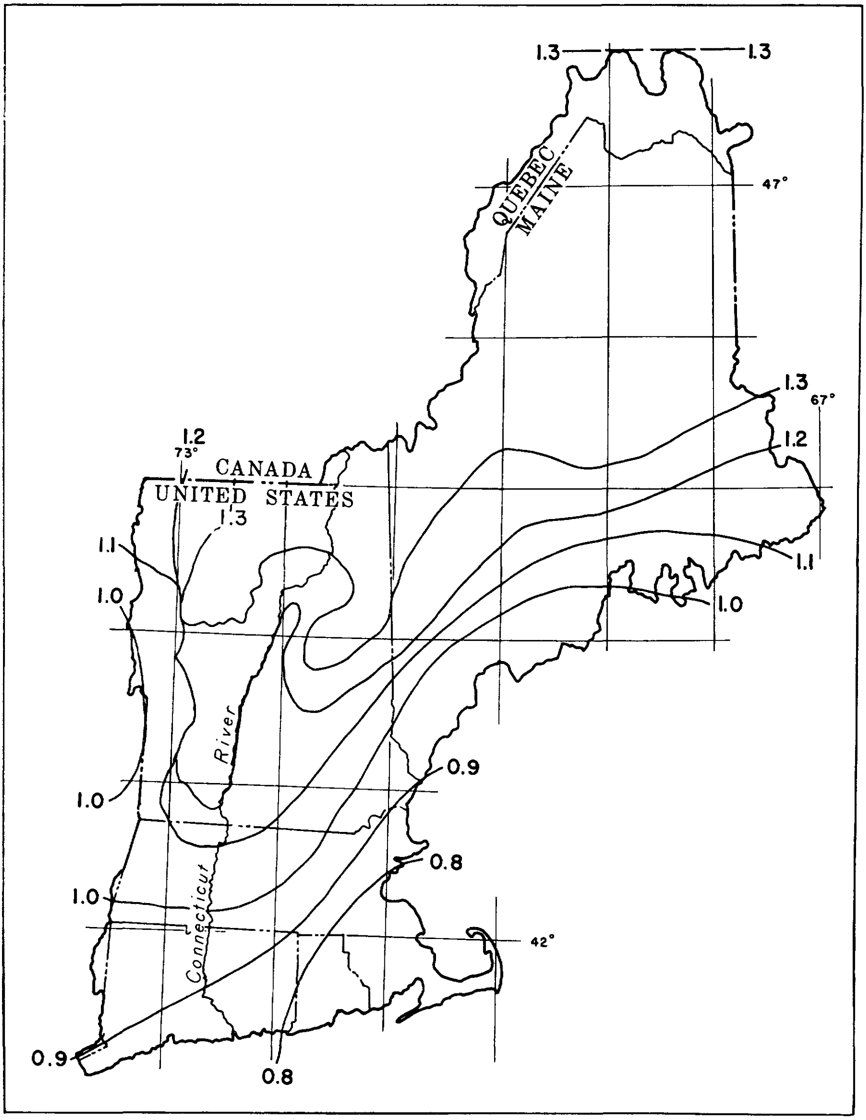

FIGURE 3.—Map of New England, showing the ratio of runoff to precipitation for the 3-month period, March through May.

Relations between peak discharges and hydrologic characteristics were first plotted using both rectangular and logarithmic coordinates. It was found that straight-line relations resulted when logarithmic plotting was used and curved lines resulted when rectangular plotting was used. This confirmed previous experience in which discharge has generally been found to vary as a power function of hydrologic characteristics. Logarithmic plotting was then adhered to throughout the

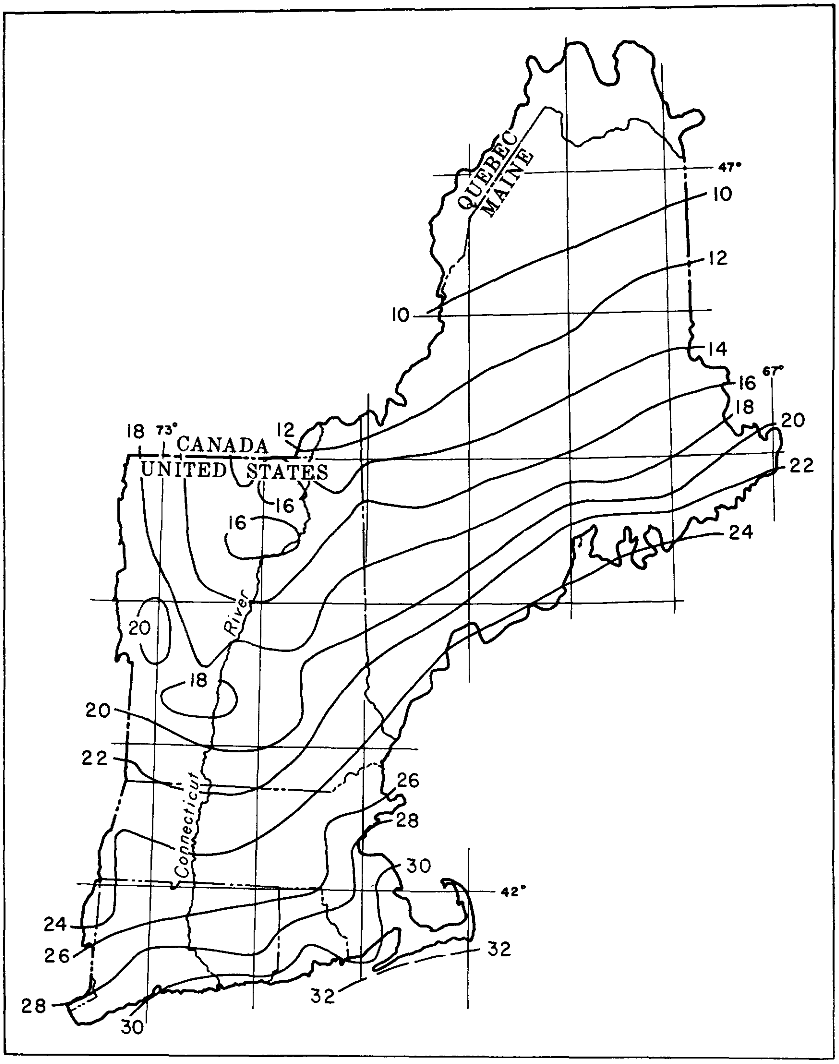

FIGURE 4.—Map of New England, showing average January temperature, in degrees Fahrenheit.

rest of the study and appeared to give the correct form for all the relations. Finally, the logarithms of all the variables retained in the multiple-correlation equations (including those for the T-year peaks) were found to be normally distributed. This was a validation of the logarithmic transformations used and of the multiple-correlation methods in general.

Q_T, the T-year flood, was plotted against the size of the drainage area. An average curve was drawn through the plotted points and the departures from this curve (also known as deviations, residuals, or residual errors) were determined for each station. These departures were then tested against other variables either by plotting or by rank-correlation methods (Wallis and Roberts, 1956, p. 603, 604) to determine the variable having the most effect after drainage area. From the relation of the first set of departures with this variable, a second set of departures was selected and further comparative studies were made. The process continued until all the variables showing statistical significance were separated out.

Graphical methods have their limitations, particularly where many variables are involved and where their effects may be small. After 3 or 4 variables have been incorporated into the relation, the residual departures may contain large accumulated errors that are due to small errors in drawing the individual curves of relation. These residual errors are no longer useful for studying further variables. At such a point, multiple-correlation computations provide exact formulations of the relations with the variables already selected, and the the computed residuals are then suitable for further study.

Such a stage was reached in this study after significant correlation had been established between flood peaks and the following variables:

1. Drainage-area size in square miles, designated *A*.
2. Main-channel slope, in feet per mile, between the 0.85 and 0.10 points, designated *S*.
3. Percentage of drainage area in lakes and ponds (increased by 0.5 percent), designated *St*.
4. Rainfall intensity, in inches per 24 hours, with recurrence interval corresponding to that of the peak discharge—designated as *I*.

No other variables could be found by graphical means which would improve the correlations appreciably. Multiple-correlation computations were then carried out, resulting in standard errors which ranged from 34 to 52 percent as the recurrence interval varied from 1.2 to 300 years. Residual departures for computed peaks at all nine recurrence intervals were averaged at each station, and the averages were plotted on a map of New England, figure 5.

If all the important factors influencing annual peak discharge had already been included in the multiple correlation, the residual errors in the computed peaks for individual stations would be expected to show a random pattern. Instead, a general pattern emerged of high residuals in the north diminishing to lower values in the south.

This pattern strongly suggested some factor or factors that could not vary appreciably with individual basins but could vary regionally; most probably those factors would be climatological in nature. The high residuals in the north meant that peak discharges experienced were higher than computed, and the lower residuals in the south meant that discharges experienced were lower than those computed.

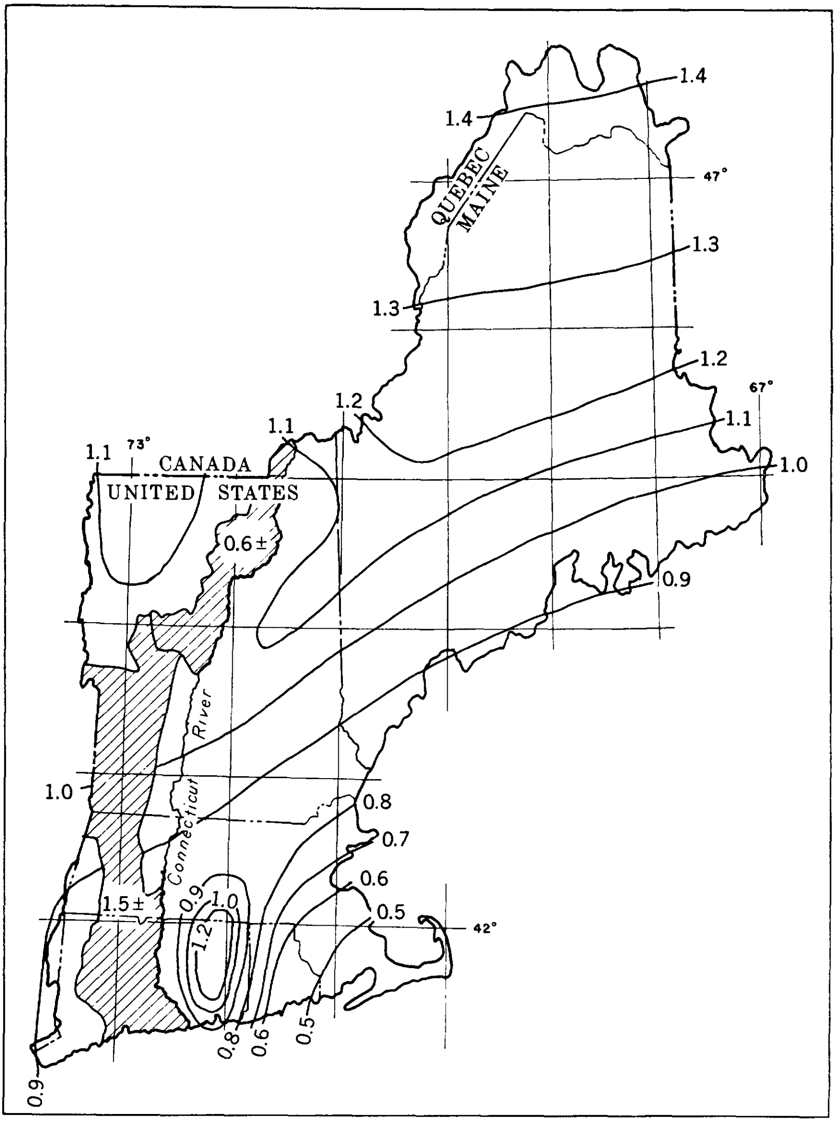

FIGURE 5.—Map of New England, showing residual error of discharges computed by using *A*, *S*, *St*, and *I*; contoured values represent the ratio of actual to computed discharges.

The north-to-south variation from high to low values is inverse to the pattern of winter temperatures. This pattern of residuals is consistent with the hypothesis that annual peak discharges in this region (known to occur mostly between March and May) are augmented by the melting of accumulated snow and by the frozen condition of the ground.

To test this hypothesis, the ratio of runoff to rainfall in the 3-month period March to May was computed and mapped. (See fig. 3.) Runoff is normally expected to be less than rainfall, because of the many losses between the two. The variation from about 1.3 in the north to 0.8 in the south clearly shows the effect of snowmelt and frozen ground on runoff. Only the melting of accumulated snow could account for values greater than 1.0. The runoff-rainfall ratio defines in general a pattern similar to that of winter temperature. It would seem that the maximum water equivalent of the accumulated snowfall would be a logical variable to incorporate into the multiple correlation. In the absence of sufficient data on average conditions of the accumulated water equivalent of snow, some other index must be used, such as the average January temperature or the 3-month runoff-rainfall ratio.

As discussed previously January temperature was selected as the index, and the variable used was the number of degrees below freezing, obtained by subtracting the actual mean January temperature from 32.

After temperature was incorporated into the multiple correlation, the resulting residual errors were again mapped. The general north-to-south variation was found to have disappeared, but residual errors indicating geographic patterns were found, extending along and about the Connecticut River. A study of these patterns (shown by contours on pl. 1) showed definite indications that these residual errors were directly related to the effects of orography on precipitation and temperature in relation to the prevailing direction of storm winds.

For example, consider the depression in the pattern of residuals shown in the upper part of the Connecticut River Basin. On a topographic map this is seen to be an area flanked on the east by the White Mountains, which in this locality form the highest range of peaks in New England. The direction of the heavier storm winds is from the east or southeast, as described in "Climate and Man" (U.S. Dept. of Agriculture, 1941, p. 996)—"The most active precipitation-producing storms are those in which the moist southeast or east winds flow over the uplands and the air mass is forced aloft over cold resident air to condensation levels." The White Mountains here evidently act as a barrier to the easterly winds and cause a "rain shadow" of lessened precipitation on their leeward side. A cross section of ground altitudes along lat 44° 15′ is shown in figure 6. Below this is plotted the variation in the orographic factor.

To the south, around lat 43° 15′, the White Mountains at the east side of the Connecticut Valley are not as high as the Green Mountain ridge to their west. The upper slopes of the Green Mountains intercept heavier precipitation, which is reflected in the peak discharges from those streams which head in the upper slopes of the west ridge; namely, the White, Ottauquechee, Black, and West Rivers.

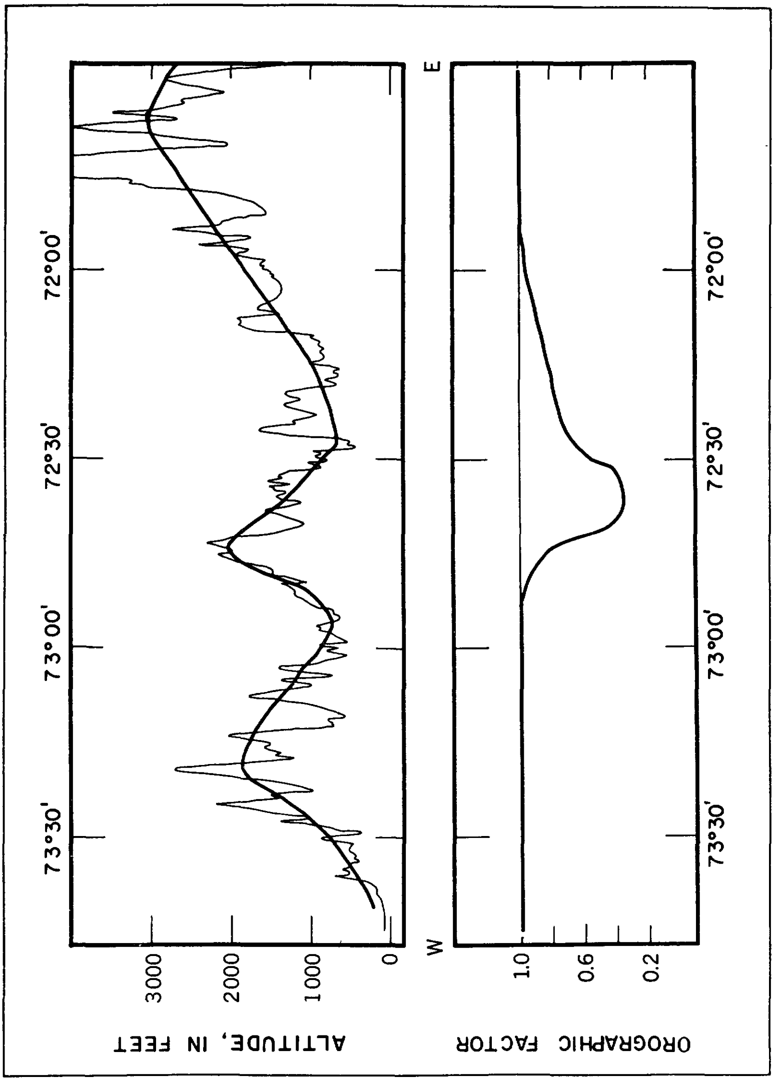

FIGURE 6.—Ground altitudes and orographic factor along lat 44° 15'.

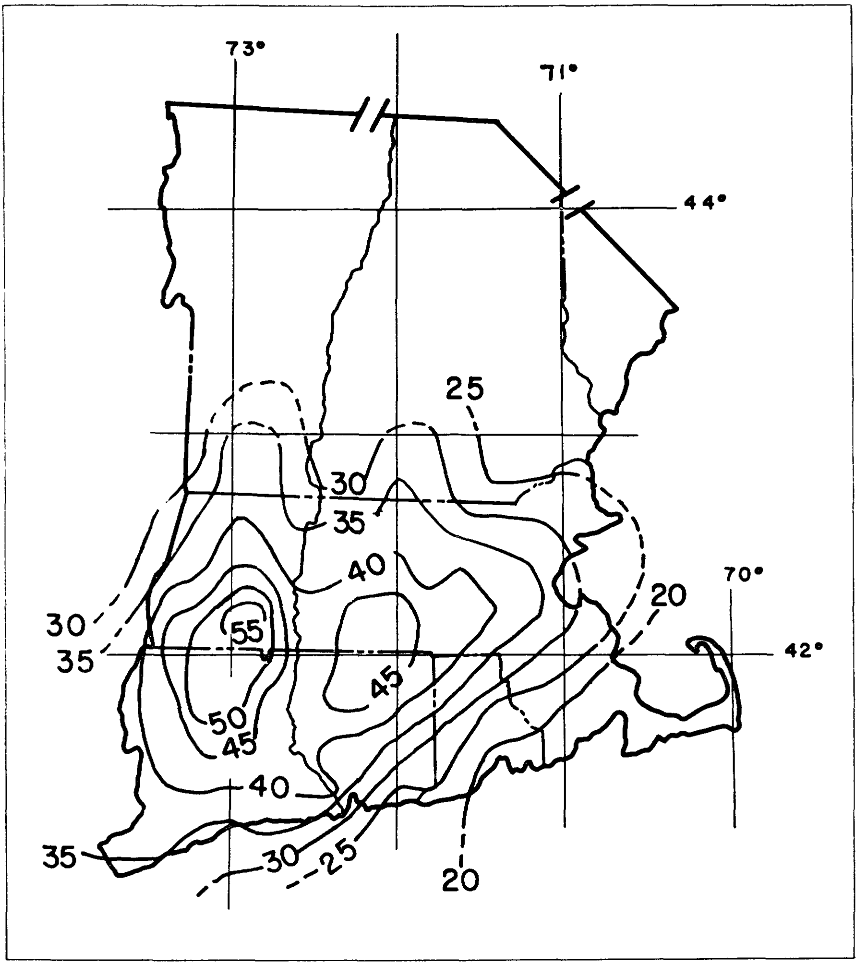

FIGURE 7.—Map of southern New England, showing combined precipitation in inches in six major storms—November 1927, March 1936, July 1938, September 1938, December 1948, and August 1955.

The southwest part of New England receives the heaviest storm precipitation. This is evident from the map of figure 7, which shows the combined volume of precipitation within six major storms of recent times (November 1927, March 1936, July 1938, September 1938, December 1948, and August 1955). The effects of orography can be discerned in this southwest corner of New England; for example, consider the section along 42° 15′ latitude, figure 8. The upward slopes in Rhode Island intercept the first of the heavy rain coming from the east and southeast. The east side of the Connecticut Valley is on the downslope and has low residual values. The rising west slopes of the Connecticut Valley show increasing values of the residuals, and there is a decrease toward the Housatonic basin.

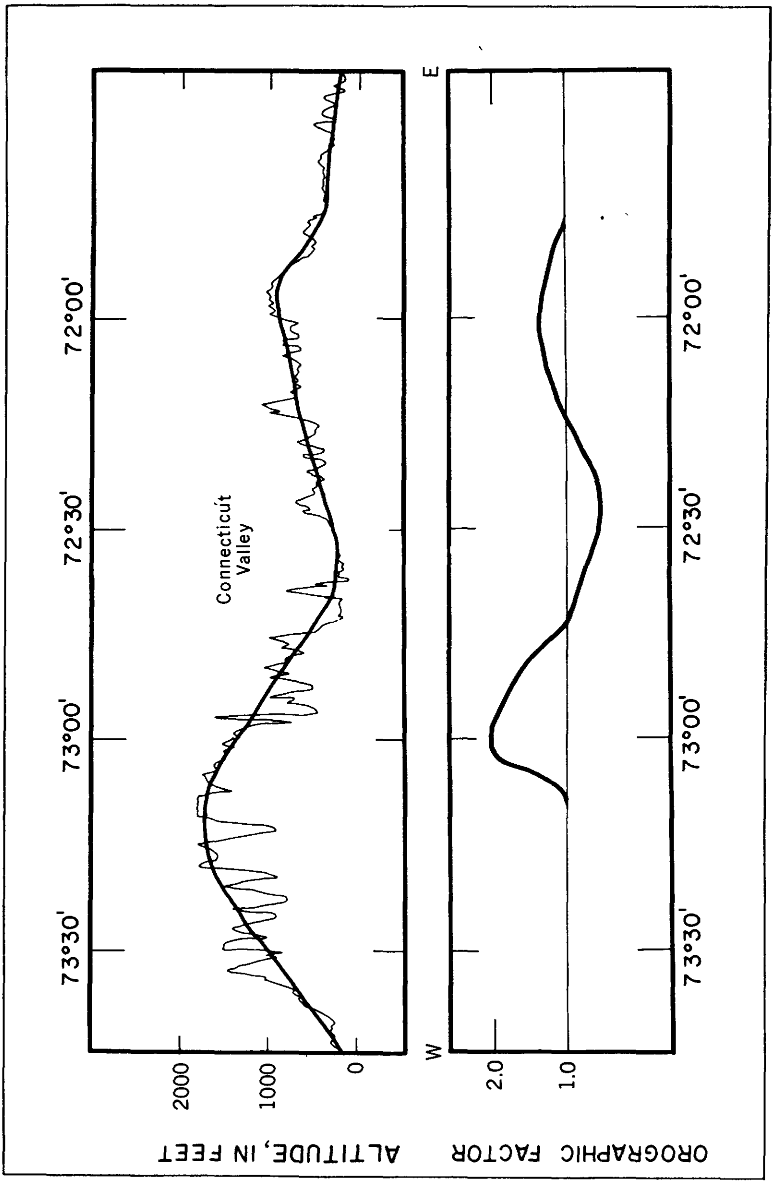

FIGURE 8.—Ground altitudes and orographic factor along lat 42° 15'.

It would be desirable to use precipitation, temperature, or other variables to define these variations. Some of the available precipitation indices—such as mean annual precipitation, mean annual runoff, intensity-frequency values, maximum 24-hour precipitation experienced—show some high and low values corresponding roughly to the high and low areas defined by the residuals. Yet none of these are adequate to account fully for the uniform pattern shown by the residual errors. Possibly this is because there are too few precipitation and temperature records in mountainous terrain, where the orographic effect is pronounced. Perhaps the precipitation and temperature indices now used are inadequate to represent the full effect of those variables. Possibly also there are other variables, unexpressed or unknown, that are related to the orography, and are responsible for the remaining error. Streamflow records, on which the residual errors are based, represent the integrated effect of the precipitation and other variables over entire basins. Because of the consistency of the pattern of residuals with orography, it is considered that these residuals may be used as the basis for an orographic factor, to be used as an additional independent variable. This use of residual errors represents maximum utilization of the information furnished by the discharge records.

The mapped orographic factor (pl. 1) is based on the averaged values of residuals from flood peaks of as many as nine different recurrence intervals at each station. The contours have been drawn only where a pattern is defined by groups of stations and have not been drawn around departures at individual stations which are not part of a pattern. The contours were drawn giving consideration to the fact that the residuals define the effect on the entire drainage basin rather than at the gaging-station site.

Such definition of an orographic factor is not merely a correlation of errors with themselves. The pattern of residuals outside of the contoured area shown in plate 1 is random throughout New England. Within the area the pattern is systematic and can be related to a characteristic (orographic effect) which cannot readily be evaluated independently because of its complexity and because of lack of detailed definition by known hydrologic variables. The residual errors furnish a practical expedient for evaluating this characteristic.

Correlations were made using the six independent variables of area, *A;* slope, *S;* storage, *St;* intensity, *I;* temperature, *t;* and orography, *O.* The values of these six independent variables are listed in table 2. Intensity, *I,* was deleted from the formulas for 1.2 to 10 years for reasons subsequently discussed. The resulting correlations had standard errors between 24 and 33 percent, which were considered satisfactory.

TABLE 2.—*Independent variables by station*

A: Drainage area, in square miles.
S: Main-channel slope, in feet per mile, between 2 points, 0.1 and 0.85 of the total main-channel length above gaging point.
St: Percentage of surface storage area, plus 0.5 percent, in lakes and ponds.
I_{T-24}: T-year 24-hour rainfall intensity, in inches.
t: Average degrees Fahrenheit below freezing in January.
O: Orographic factor.

Part	No. on pl. 1	*A*	*S*	*St*	$I_{1.2-24}$	$I_{2.33-24}$	I_{5-24}	I_{10-24}	I_{25-24}	I_{50-24}	I_{100-24}	I_{200-24}	I_{300-24}	*t*	*O*
1A	2	1,250	4.34	4.27	1.3	1.7	2.1	2.3	2.8	3.1	3.5	-----	-----	23	1.0
	6	871	2.80	6.69	1.7	2.1	2.6	2.9	3.5	3.9	-----	-----	-----	23	1.0
	7	5,690	5.32	2.80	1.5	1.9	2.3	2.7	3.1	3.5	-----	-----	-----	23	1.0
	9	8,270	4.65	2.75	1.5	1.9	2.3	2.7	3.1	-----	-----	-----	-----	23	1.0
	12	1,620	4.14	2.55	1.7	2.1	2.7	3.0	3.6	4.1	-----	-----	-----	22	1.0
	14	175	19.88	2.09	1.9	2.4	3.1	3.6	4.2	4.8	-----	-----	-----	19	1.0
	22	148	8.19	4.09	2.5	3.2	4.0	4.6	5.4	6.1	-----	-----	-----	15	1.0
	33	1,400	4.11	3.36	2.0	2.7	3.4	4.0	4.8	5.0	-----	-----	-----	17	1.0
	35	297	25.41	2.68	2.3	2.9	3.8	4.3	5.2	5.9	6.7	7.3	-----	18	1.0
	39	322	32.73	3.97	2.2	2.9	3.8	4.5	5.3	6.1	-----	-----	-----	18	1.0
	45	178	11.86	.69	2.2	2.8	3.7	4.3	5.2	-----	-----	-----	-----	14	1.0
	48	148	14.49	3.77	2.1	2.7	3.4	3.9	4.7	5.3	6.0	-----	-----	11	1.0
	61	872	6.94	2.39	1.7	2.1	2.7	3.0	3.6	4.1	-----	-----	-----	19	1.0
	63	91.1	58.70	2.45	2.3	2.9	3.7	4.2	5.0	5.7	6.4	-----	-----	18	1.0
	65	354	46.00	1.39	1.9	2.4	3.0	3.4	4.0	4.5	5.1	-----	-----	17	1.0
	67	514	13.70	1.58	2.1	2.6	3.2	3.6	4.2	4.7	5.3	5.7	-----	16	1.0
	76	153	42.60	.80	1.8	2.3	2.9	3.3	4.0	-----	-----	-----	-----	18	1.0
	82	95.8	80.70	.70	2.2	2.7	3.3	3.8	4.3	4.9	-----	-----	-----	17	1.0
	83	171	7.61	1.45	2.2	2.7	3.3	3.8	4.3	4.9	5.5	-----	-----	13	1.0
	86	76.2	50.60	.58	2.4	2.9	3.6	4.1	4.7	5.3	5.9	6.4	-----	14	1.0
	100	386	50.30	.83	2.8	3.3	3.9	4.4	5.0	5.6	6.2	-----	-----	13	1.0
	101	330	29.40	4.35	2.4	2.8	3.3	3.7	4.2	4.6	-----	-----	-----	13	1.0
	102	453	14.90	4.01	2.5	2.9	3.4	3.8	4.3	4.8	5.3	5.7	-----	13	1.0
	103	1,298	9.06	3.14	2.5	2.9	3.4	3.8	4.3	4.8	5.3	5.7	-----	13	1.0
	104	161	12.00	3.18	2.6	3.1	3.7	4.2	4.8	5.3	5.9	6.4	-----	11	1.0
	117	12.1	21.50	1.82	2.4	2.9	3.6	4.1	-----	-----	-----	-----	-----	9	1.0
	118	183	12.10	2.16	2.3	2.8	3.5	3.9	4.6	-----	-----	-----	-----	9	1.0
	120	104	108.80	.59	2.2	2.7	3.3	3.8	4.3	-----	-----	-----	-----	15	1.0
	121	193	80.70	.73	2.2	2.6	3.1	3.5	4.0	-----	-----	-----	-----	15	1.0
	122	58.8	187.00	.57	2.2	2.6	3.1	3.5	-----	-----	-----	-----	-----	15	1.0
	123	143	107.10	1.00	2.2	2.6	3.1	3.5	4.0	4.5	-----	-----	-----	15	1.0
	124	622	42.00	.88	2.2	2.6	3.1	3.5	4.0	4.5	5.0	5.4	-----	15	1.0
	127	85.8	22.60	1.36	2.2	2.7	3.2	3.6	4.2	4.7	5.2	-----	-----	13	1.0
	135	68.1	33.90	3.30	2.5	3.2	3.9	4.5	-----	-----	-----	-----	-----	11	1.0

TABLE 2.—*Independent variables by station*—Continued

Part	No. on pl. 1	A	S	St	$I_{1.2-24}$	$I_{2.33-24}$	I_{5-24}	I_{10-24}	I_{25-24}	I_{50-24}	I_{100-24}	I_{200-24}	I_{300-24}	t	O
1A	137	46.9	37.30	6.26	2.5	3.2	3.9	4.5	5.3	6.0	6.8	7.4		11	1.0
	139	54.8	24.40	4.08	2.5	3.0	3.7	4.2	4.8	5.4	6.1	6.6	6.9	13	1.0
	140	55.4	78.30	2.41	2.5	3.0	3.7	4.2						13	1.0
	141	368	13.60	3.71	2.3	2.9	3.6	4.2	4.9	5.5	6.2	6.8		12	1.0
	143	146	31.80	2.51	2.3	2.9	3.6	4.2	4.9					13	1.0
	145	129	24.50	2.09	2.2	2.7	3.2	3.6	4.2	4.7	5.2	5.6		14	1.0
	146	766	10.50	1.75	2.3	2.8	3.4	3.9	4.5	5.1	5.7	6.2		13	1.0
	148	157	16.35	3.00	2.1	2.6	3.2	3.6	4.2	4.7	5.3			10	1.0
	150	104	30.60	1.16	2.4	3.0	3.8	4.3	5.1					11	1.0
	151	202	26.60	1.50	2.4	3.0	3.7	4.2	4.9	5.6	6.2	6.8		11	1.0
	156	171	31.20	.87	2.5	3.2	4.0	4.6	5.4	6.1	6.9	7.5		10	1.0
	157	107	40.70	3.80	2.5	3.2	4.0	4.6	5.4					9	1.0
	162	116	5.86	2.27	2.2	2.9	3.8	4.4	5.3	6.1	6.9	7.6		8	1.0
	169	21.6	6.23	3.19	2.5	3.2	3.9	4.5	5.3					7	1.0
	170	43.4	5.10	1.49	2.5	3.2	4.0	4.6	5.4					6	1.0
	171	124	2.50	1.86	2.3	2.9	3.6	4.2	4.9	5.5	6.2			6	1.0
	174	184	4.47	2.16	2.4	3.2	4.1	4.8	5.8	6.6	7.5	8.2	8.7	6	1.0
	177	35.2	23.80	3.88	2.5	3.3	4.2	4.9						5	1.0
	178	8.6	32.20	.62	2.8	3.4	4.2	4.8	5.5					2	1.0
	181	42.4	10.70	1.11	2.5	3.2	4.2	4.8	5.7	6.5	7.4			5	1.0
	186	93.3	23.60	3.34	2.7	3.5	4.4	5.0	5.9	6.7	7.6	8.3	8.7	6	1.0
	187	416	11.50	3.51	2.6	3.4	4.4	5.1	6.1	7.0	8.0	8.8	9.2	6	1.0
	189	38.3	26.90	5.12	2.8	3.6	4.5	5.1	6.1					3	1.0
	191	63.8	13.80	3.46	2.8	3.4	4.2	4.8	5.5	6.2	6.9	7.5	7.8	4	1.0
	193	23.0	41.80	.89	2.8	3.4	4.2	4.8	5.5					3	1.0
	194	100	4.41	3.26	2.9	3.5	4.3	4.8						3	1.0
	195	72.4	16.20	2.61	2.9	3.5	4.3	4.8	5.6					4	1.05
	196	295	2.71	2.55	2.9	3.5	4.2	4.8	5.5					3	1.1
	198	121	16.00	2.08	2.4	3.2	4.0	4.7	5.6	6.3	7.2	7.8		6	1.85
	199	76.2	17.00	2.15	2.6	3.2	4.1	4.7	5.5	6.3	7.1	7.7	8.1	5	1.6
	200	29.1	72.70	1.74	2.6	3.4	4.3	5.0	5.9	6.8				6	2.0
	201	169	23.40	2.02	2.5	3.2	3.9	4.4	5.2	5.8	6.6	7.2	7.5	5	2.0
	202	401	11.40	1.99	2.4	3.2	4.0	4.7	5.6	6.3	7.2	7.8	8.3	6	1.85
	203	93.8	89.8	2.92	2.4	3.2	4.2	4.9	5.9	6.8	7.8	8.6		7	1.75
	204	157	14.20	2.61	2.4	3.2	4.2	4.9	5.9	6.8	7.8	8.6		7	1.7
	205	27.7	56.80	4.44	2.4	3.3	4.3	5.1	6.1	7.1	8.1	8.9	9.4	7	1.3

207	331	13.00	3.49	2.4	3.2	4.2	4.9	5.9	6.8	7.8	8.6	9.1	7	1.5
209	83.5	15.10	1.49	2.9	3.4	4.1	4.6	5.3	5.9	6.6	7.1	----	5	1.15
210	711	10.30	2.99	2.6	3.1	3.8	4.3	5.0	5.6	6.3	6.8	7.2	6	1.5
211	88.6	25.10	2.69	2.7	3.2	3.9	4.4	5.0	5.6	6.2	6.7	7.0	4	2.0
216	232	28.60	1.22	1.8	2.3	2.9	3.3	3.9	----	----	----	----	16	.9
219	1,514	10.50	1.40	1.8	2.3	2.9	3.4	4.0	4.5	5.1	5.6	----	16	.8
221	53.8	60.50	1.19	1.9	2.4	3.0	3.5	4.1	----	----	----	----	16	.65
224	126	40.40	.75	1.8	2.3	2.9	3.3	3.9	----	----	----	----	16	.55
225	436	21.50	.72	1.8	2.3	2.9	3.3	3.9	----	----	----	----	16	.55
228	87.6	72.00	.51	2.5	3.2	3.9	4.4	5.2	----	----	----	----	15	1.0
229	395	28.70	.71	1.9	2.4	3.0	3.4	4.0	----	----	----	----	16	.85
231	98.4	89.80	1.65	1.9	2.3	2.8	3.2	----	----	----	----	----	16	.5
232	2,825	8.15	1.30	1.8	2.3	2.9	3.3	3.9	4.4	5.0	5.4	----	16	.75
233	42.7	95.70	.50	2.0	2.4	2.9	3.3	3.8	----	----	----	----	16	.45
236	130	52.60	1.24	2.0	2.4	2.8	3.2	----	----	----	----	----	15	.55
237	241	19.90	.50	2.0	2.4	2.8	3.2	3.7	----	----	----	----	13	1.65
238	30.5	80.40	.50	2.1	2.5	3.1	3.4	4.0	----	----	----	----	15	.7
241	690	13.10	.58	2.0	2.4	2.8	3.1	3.6	4.0	4.4	4.8	----	15	1.15
242	4,092	5.95	1.15	1.9	2.3	2.8	3.1	3.6	4.1	4.6	5.0	----	16	.8
243	80.5	50.20	2.36	2.2	2.7	3.2	3.6	4.2	4.7	5.2	----	----	14	1.0
247	221	27.10	0.68	2.0	2.4	2.8	3.2	3.7	4.1	4.6	4.9	----	14	1.3
249	269	27.40	4.17	2.2	2.6	3.1	3.5	4.0	4.5	5.0	----	----	15	1.0
250	158	27.90	1.13	2.2	2.6	3.1	3.5	4.0	----	----	----	----	15	1.5
251	103	56.50	0.50	2.3	2.7	3.2	3.5	4.0	----	----	----	----	14	1.1
252	72.2	87.40	0.56	2.4	2.9	3.5	3.9	4.5	----	----	----	----	14	1.0
253	5,493	4.60	1.29	2.1	2.5	3.1	3.4	4.0	4.5	5.0	5.4	----	15	.9
254	82.7	49.00	1.36	2.2	2.7	3.2	3.7	----	----	----	----	----	14	1.0
256	308	31.70	0.78	2.3	2.8	3.4	3.8	4.4	4.9	5.4	----	----	14	1.55
257	6,266	4.10	1.24	2.1	2.5	3.0	3.4	3.9	4.4	4.9	5.3	----	14	.95
258	71.1	38.50	3.06	2.2	2.7	3.2	3.6	4.2	4.7	5.2	5.6	----	13	1.0
261	42.3	64.00	2.53	2.2	2.7	3.3	3.8	4.3	4.9	5.5	----	----	12	1.0
264	36.0	100.00	1.97	2.2	2.7	3.3	3.8	4.3	4.9	5.5	----	----	11	1.0
267	83.0	19.60	4.99	2.3	2.9	3.6	4.2	4.9	5.5	6.2	----	----	10	1.0
268	19.4	27.20	1.84	2.4	3.0	3.8	4.3	5.1	5.7	6.4	----	----	10	1.0
273	50.4	51.90	2.31	2.4	3.0	3.8	4.3	5.1	5.7	6.4	----	----	10	1.0
274	12.3	48.10	1.56	2.5	3.0	3.7	4.2	4.8	5.4	6.1	----	----	10	1.0
276	375	17.70	2.83	2.3	2.8	3.4	3.9	4.5	5.1	5.7	----	----	10	1.0
282	88.4	65.60	0.67	2.6	3.1	3.7	4.2	4.8	----	----	----	----	10	1.1
284	7,865	3.80	1.30	2.1	2.6	3.2	3.7	4.3	4.9	5.5	6.0	6.3	9	.95
285	52.8	94.80	1.31	2.6	3.2	4.1	4.7	5.5	6.3	7.1	----	----	9	.95

TABLE 2.—*Independent variables by station*—Continued

Part	No. on pl. 1	A	S	St	$I_{1.2-24}$	$I_{2.33-24}$	I_{5-24}	I_{10-24}	I_{25-24}	I_{50-24}	I_{100-24}	I_{200-24}	I_{300-24}	t	O
1A	289	199	15.50	1.71	2.4	3.2	4.0	4.7	5.6	6.3	7.2	----	----	9	1.0
	291	43.7	38.20	2.83	2.5	3.2	4.1	4.8	5.7	6.4	----	----	----	9	1.0
	293	188	11.80	1.60	2.3	2.9	3.8	4.3	5.2	5.9	6.7	----	----	9	.9
	294	151	8.62	3.27	2.4	3.2	4.2	4.9	5.9	6.8	7.8	----	----	8	1.2
	295	688	14.79	1.94	2.4	3.2	4.1	4.8	5.8	6.6	7.5	----	----	8	1.0
	300	162	41.70	0.77	2.5	3.2	3.9	4.4	5.2	----	----	----	----	9	1.6
	301	1.64	118.00	0.93	2.8	3.7	4.9	5.7	6.9	8.0	----	----	----	8	1.8
	302	52.6	79.00	0.51	2.6	3.2	4.1	4.7	5.5	6.3	7.1	----	----	8	1.95
	303	93.7	54.90	1.02	2.4	3.2	4.0	4.7	5.6	6.3	7.2	----	----	8	1.65
	307	497	28.80	1.14	2.6	3.4	4.4	5.1	6.1	7.0	8.0	8.8	----	7	1.65
	308	9,661	3.56	1.34	2.2	2.8	3.6	4.1	4.9	5.5	6.2	6.8	7.1	12	1.0
	309	98.4	15.10	0.85	2.4	3.2	4.2	4.9	5.9	6.8	7.8	----	----	7	.8
	313	216	38.90	2.76	2.6	3.5	4.6	5.4	6.5	7.5	8.6	----	----	7	1.7
	315	4.12	87.70	0.67	2.8	3.7	4.8	5.5	6.6	7.6	8.6	----	----	6	2.0
	317	45.2	61.20	1.74	2.8	3.6	4.5	5.3	6.2	7.1	8.0	----	----	5	2.0
	320	40.6	33.30	1.90	2.8	3.6	4.6	5.3	6.3	7.2	8.2	9.0	9.4	5	2.0
	321	25.3	14.90	1.61	2.7	3.6	4.7	5.4	6.5	7.5	8.5	9.3	9.8	6	2.0
	322	74.0	27.00	1.69	2.7	3.5	4.5	5.2	6.2	7.1	8.1	8.8	9.3	5	2.0
	324	74.5	28.50	2.35	2.5	3.3	4.3	5.0	6.0	6.8	7.8	8.6	9.0	6	.8
	325	105	29.70	1.51	2.6	3.1	3.7	4.2	4.8	5.4	6.0	6.5	6.8	4	1.65
	326	22.0	38.00	1.05	2.8	3.3	3.9	4.4	5.0	5.6	6.2	----	----	3	2.0
	327	18.6	55.40	2.33	2.8	3.3	3.9	4.4	5.0	5.6	6.2	----	----	3	2.0
	328	11.6	47.00	2.48	2.8	3.3	3.9	4.4	5.0	----	----	----	----	2	2.0
	331	109	6.80	1.94	2.9	3.4	4.1	4.6	5.3	5.9	6.6	7.1	7.4	4	2.0
	332	57.1	47.70	1.71	2.4	3.0	3.8	4.3	5.1	5.7	6.4	7.0	----	9	1.1
	333	280	16.50	2.44	2.3	2.8	3.5	4.0	4.6	5.2	5.9	6.4	----	8	1.0
	335	263	8.28	2.04	2.6	3.4	4.2	4.9	5.8	6.6	7.4	8.1	----	8	1.0
	337	204	15.00	1.36	2.6	3.4	4.2	4.9	5.8	6 6	7.4	8.1	----	8	1.0
	338	994	7.65	1.84	2.6	3.2	4.1	4.7	5.5	6.2	7.0	7.6	----	6	1.0
	340	68.5	15.30	2.57	2.7	3.5	4.4	5.0	5.9	6.7	7.6	8.3	8.7	4	2.0
	343	133	34.00	2.29	2.9	3.7	4.6	5.3	6.3	7.2	8.1	8.8	----	6	2.0
	344	75.3	48.00	1.15	2.9	3.7	4.6	5.3	6.3	6.2	8.1	8.8	9.3	4	2.1
	347	1,545	8.26	2.33	2.8	3.3	4.1	4.6	5.3	6.0	6.7	----	----	7	1.35
	348	71.9	35.30	2.41	2.8	3.7	4.7	5.5	6.5	7.4	8.4	9.2	----	6	2.55
	349	24.0	64.20	1.17	2.9	3.8	4.8	5.6	6.6	7.6	8.6	9.4	----	6	2.8
	353	246	20.70	2.23	2.8	3.6	4.6	5.3	6.3	7.2	8.2	9.0	----	7	2.55
1B	50	152	62.70	0.63	2.5	2.9	3.4	3.8	4.3	----	----	----	----	12	1.7
	54	46.3	12.60	2.38	2.5	3.0	3.7	4.2	4.8	5.4	6.1	6.6	----	9	1.45
	55	39.0	77.40	0.72	2.5	3.0	3.6	4.1	4.7	5.2	5.8	6.2	----	10	2.0
	56	132	19.20	1.37	2.4	2.9	3.5	3.9	4.5	----	----	----	----	9	1.7

	58	111	12.50	0.77	2.4	2.9	3.4	3.9	----------	----------	----------	----------	----------	11	1.85
4----------	397	187	35.20	3.40	2.2	2.6	3.1	3.4	3.9	----------	----------	----------	----------	13	1.25
	399	307	6.96	1.28	2.2	2.6	3.1	3.5	4.0	4.5	----------	----------	----------	13	1.65
	400	628	5.33	1.26	2.2	2.6	3.1	3.5	4.0	4.5	5.0	----------	----------	13	1.55
	407	52	97.40	0.52	2.0	2.5	3.1	3.6	4.2	4.8	5.4	----------	----------	15	.9
	408	76.1	61.70	0.53	2.0	2.5	3.1	3.6	4.2	----------	----------	----------	----------	15	.95
	409	139	41.60	0.50	1.9	2.4	3.0	3.5	4.1	4.6	5.2	5.7	----------	15	1.0
	413	1,044	9.54	1.14	1.8	2.2	2.7	3.1	3.6	4.1	4.6	5.0	----------	16	.95
	414	18	59.00	6.50	1.9	2.3	2.9	3.2	3.8	4.2	4.8	5.2	----------	16	1.0
	416	310	23.00	1.85	1.8	2.2	2.7	3.1	3.6	----------	----------	----------	----------	16	.95
	417	686	11.60	1.22	1.8	2.2	2.7	3.1	3.6	----------	----------	----------	----------	16	1.0
	418	131	19.10	0.51	1.7	2.1	2.6	2.9	3.5	----------	----------	----------	----------	17	1.0
	419	479	10.00	0.84	1.7	2.1	2.6	2.9	3.3	3.8	4.2	4.6	----------	17	1.0
	421	142	14.20	5.43	1.7	2.2	2.8	3.2	3.7	4.2	----------	----------	----------	17	.95

Discharges and residual errors were computed by means of the regression equations for all flood levels at all stations. The residuals were tested against all variables that had been eliminated in earlier stages of the work, as well as against a joint function of the two most important variables—area and slope. No significant relation with these variables remained. As a final step, the residual errors were plotted on maps and were found to be randomly distributed. Residuals for small-area stations showed the same random pattern and were scattered on both sides of 1.0. The results were then accepted as being satisfactory.

RESULTS

The final results were obtained by standard mathematical multiple-correlation computations and are expressed in the following equation:

$$Q_T = aA^b S^c St^d I^e t^f O^g$$

or its equivalent:

$$\log Q_T = a' + b \log A + c \log S + d \log St + e \log I + f \log t + g \log O$$

where Q_T=T-year annual peak discharge, in cubic feet per second
A=drainage area, in square miles
S=main-channel slope, in feet per mile
St=percent of surface storage area plus 0.5 percent
I=T-year 24-hour rainfall intensity, in inches
t=average January degrees below freezing, in degrees Fahrenheit
O=orographic factor
$a,'a,b,c,d,e,,f,g$=regression coefficients, where a=antilogarithm of a'.

A summary of the results (table 3) shows the values of the regression coefficients, the multiple-correlation coefficients, and the standard errors for 9 values of T, for several independent variables from 1 to 6, listed generally in order of decreasing importance. Also shown is the change in the standard error as each variable is added.

Simplification of the coefficients is discussed later and simplified values are shown in table 4.

DISCUSSION OF RESULTS

VARIABLES IN FINAL EQUATION

The variables that appear in the final equation are not the only ones that affect flood peaks. However, they represent the most efficient combination found for explaining peak flow with the smallest number of simple basic variables. For example, it would have been possible to use average land slope or stream density in place of main-channel slope. Either of these would have showed significant correlation with flood peaks. Yet, the standard error would have been larger if either had been used instead of main-channel slope. Similarly with rainfall intensity—if mean annual precipitation or other rainfall variables had been used instead, the correlations would have been significant, but standard errors would have been larger.

GRAPH OF REGRESSION COEFFICIENTS

Figure 9 is a graph of the regression coefficients showing their variation with recurrence interval. These coefficients are the values when 5 independent variables (excluding rainfall intensity, *I*) are used for recurrence intervals from 1.2 to 10 years and when 6 independent variables are used for intervals of more than 10 years. The *a* coefficient changes abruptly between 10 and 25 years because of the change in the number of variables at that point. In general, other coefficients vary uniformly with time. Sharp changes at the 300-year level may be attributed to the small number of stations (22) defining the relation there. The variation among the coefficients is not consistent with time; that is, one may increase as another decreases. For this reason, a single general formula incorporating recurrence interval, *T*, as an additional variable cannot be used.

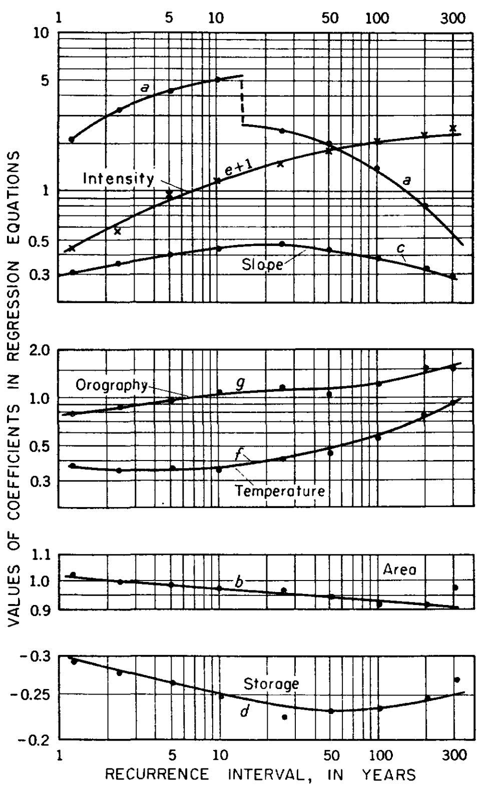

Figure 9.—Variation of regression coefficients with recurrence interval.

Table 3.—*Summary of regression equations*

T: Recurrence interval, in years.
n: Number of stations used to define regression equation.
R: Coefficient of multiple correlation.
S.E.: Standard error, in percent, except figures marked with asterisk.
ΔS.E.: Improvement in standard error, in percent, caused by addition of variable shown in parentheses.

[$Q_T = aA^bS^cSt^dI^et^fO^g$. Simplified values of coefficients recommended for use, are shown on table 4]

T (years)	*n*	Independent variables included	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*R*	*S.E.* (percent)	Δ*S.E.* (percent)
											*186.0	
		A	21.779	0.8957						0.928	53.7	132.3(A)
		A, S	1.8770	1.0895	0.4770					.962	38.7	15.0(S)
		A, S, St	3.6956	1.0546	.3647	−0.3067				.971	33.8	4.9(St)
		A, S, St, O	2.5991	1.0952	.3896	−.3103			0.5531	.979	28.6	5.2(O)
		†*A, S, St, O, t*	2.1556	1.0119	.3014	−.2978		0.3694	.7947	.985	24.8	3.8(t)
1.2	164	*A, S, St, O, t, I*	4.1473	1.0114	.3226	−.2893	−0.5536	.2532	.8308	.985	24.4	0.4(I)
											*176.1	
		A	44.382	.8538						.917	55.9	120.2(A)
		A, S	3.1111	1.0639	.5172					.960	38.6	17.3(S)
		A, S, St	5.8559	1.0314	.4123	−.2864				.968	34.3	4.3(St)
		A, S, St, O	3.9529	1.0766	.4402	−.2904			.6232	.979	27.6	6.7(O)
		†*A, S, St, O, t*	3.3163	.9984	.3573	−.2786		.3469	.8453	.984	24.4	3.2(t)
2.33	164	*A, S, St, O, t, I*	6.1703	.9963	.3713	−.2673	−.4330	.2562	.8787	.984	24.2	0.2(I)
											*169.6	
		A	74.54	.8174						.899	60.1	109.5(A)
		A, S	4.376	1.0415	.5517					.951	41.4	18.7(S)
		A, S, O	2.749	1.0944	.5857				.7216	.967	34.0	7.4(O)
		A, S, O, St	5.044	1.0635	.4846	−.2768			.7280	.975	29.5	4.5(St)
		†*A, S, O, St, t*	4.211	.9831	.3995	−.2646		.3564	.9562	.981	26.1	3.4(t)
5	164	*A, S, O, St, t, I*	4.491	.9827	.4004	−.2634	−.0379	.3484	.9591	.981	26.2	−0.1(I)
											*164.4	
		A	113.06	.7858						.883	63.6	100.8(A)
		A, S	5.9808	1.0182	.5720					.942	44.4	19.2(S)
		A, S, O	3.4623	1.0804	.6119				.8482	.965	34.5	9.9(O)
		A, S, O, St	6.1854	1.0508	.5153	−.2645			.8543	.972	30.4	4.1(St)
		†*A, S, O, St, t*	5.1680	.9707	.4306	−.2524		.3549	1.0815	.978	27.2	3.2(t)
10	164	*A, S, O, St, t, I*	3.6365	.9726	.4255	−.2592	.1915	.3963	1.0668	.978	27.2	0.0(I)

											*157.2	
		A	196.87	.7405						.869	65.2	92.0(A)
		A, S	8.7933	.9875	.6044					.935	45.4	19.8(S)
		A, S, O	4.9837	1.0560	.6320				.9428	.964	34.0	11.4(O)
		A, S, O, St	7.9508	1.0332	.5514	−.2136			.9657	.969	31.4	2.6(St)
		A, S, O, St, t	6.7908	.9653	.4790	−.2090		.3041	1.1758	.973	29.2	2.2(t)
25	154	†A, S, O, St, t, I	2.4102	.9720	.4678	−.2274	.5114	.4148	1.1421	.975	28.6	0.6(I)
											*145.4	
		A	342.32	.6764						.875	59.9	85.5(A)
		A, S	17.892	.9197	.5704					.931	44.6	15.3(S)
		A, S, O	9.7302	1.0006	.5727				.9894	.962	33.0	11.6(O)
		A, S, O, St	17.115	.9675	.4978	−.2520			.9288	.969	29.9	3.1(St)
		A, S, O, St, t	13.433	.9354	.4602	−.2554		.2165	1.1089	.971	29.0	.9(t)
50	116	†A, S, O, St, t, I	1.8401	.9458	.4349	−.2757	.8773	.4504	1.0866	.975	26.8	2.2(I)
											*134.6	
		A	395.75	.6922						.862	62.8	71.8(A)
		A, S	25.504	.9095	.5438					.910	50.6	11.2(S)
		A, S, O	13.937	.9922	.5332				1.0627	.950	37.7	12.9(O)
		A, S, O, t	10.964	.9480	.4667			.2837	1.2930	.952	36.8	.9(t)
		A, S, O, t, I	1.1194	.9524	.4409		.9507	.4409	1.2730	.958	34.6	2.2(I)
100	100	†A, S, O, t, I, St	1.4203	.9226	.3823	−.2308	1.0685	.5632	1.2129	.965	32.2	2.4(St)
											*151.1	
		A	558.53	.6695						.851	67.9	83.2(A)
		A, S	31.753	.8906	.5864					.888	59.1	8.8(S)
		A, S, O	13.592	1.0181	.5381				1.3073	.947	40.5	18.6(O)
		A, S, O, t	9.533	.9430	.4052			.4735	1.6752	.955	37.7	2.8(t)
		A, S, O, t, I	.6760	.9596	.3875		1.0342	.7725	1.6387	.961	35.3	2.4(I)
200	68	†A, S, O, t, I, St	.8075	.9240	.3262	−.2451	1.2189	.7702	1.5601	.967	32.8	2.5(St)
											*156.2	
		A	521.95	.6671						.844	72.5	83.7(A)
		A, S	16.100	.9451	.7497					.898	60.0	12.5(S)
		A, S, O	8.922	1.0138	.6749				1.2413	.951	42.6	17.4(O)
		A, S, O, t	2.7913	.9316	.6251			.8933	1.6680	.967	35.4	7.2(t)
		A, S, O, t, I	.0661	1.0070	.6226		1.6331	.8596	1.6657	.978	29.5	5.9(I)
300	22	†A, S, O, t, I, St	.1053	.9689	.6269	−.2680	1.5863	.9079	1.5258	.981	28.8	0.7(St)

*Standard deviation, in percent, of original peak discharges of recurrence interval *T*.
†Variables used for computed discharges of table 1.

TABLE 4.—*Summary of simplified regression coefficients*

[$Q_T{}^* = a\,A^b\,S^c\,St^d\,I^e\,t^f\,O^g$†]

Recurrence interval in years	Regression coefficients							Standard error (percent)
	a	*b*	*c*	*d*	*e*	*f*	*g*	
1.2	2.14	1.0	0.3	−0.3	0	0.4	0.8	24.9
2.33	2.60	1.0	.4	−.3	0	.4	.8	23.2
5	3.54	1.0	.4	−.3	0	.4	1.0	26.6
10	4.52	1.0	.4	−.3	0	.4	1.1	28.4
25	2.08	1.0	.5	−.3	.5	.4	1.1	29.3
50	2.26	.9	.4	−.3	.9	.5	1.1	27.2
100	1.38	.9	.4	−.3	1.1	.6	1.2	32.6
200	1.01	.9	.3	−.3	1.2	.8	1.5	33.0
300	.681	.9	.3	−.3	1.3	.9	1.6	37.2

*Q_T—T-year annual peak discharge, in cubic feet per second.
†For meaning of symbols *A*, *S*, *St*, *I*, *t*, and *O*, see headnotes to table 2.

CONSISTENCY OF EQUATIONS

The uniformity in the variation of the individual regression coefficients gives reason for confidence in the consistency of the peak discharges at any station, computed over the entire range of recurrence interval. However, the number of stations used in the analysis, of necessity, decreased progressively as the recurrence interval increased above 10 years. The range in each of the variables was somewhat different at each level above 10 years. For these reasons the formulas are not entirely consistent. It had been considered that there was more to be gained by use of all possible data at each level than by a drastic decrease to obtain an equal number at all levels.

Peak discharges were computed, by means of the formulas, for all stations used in the report. These discharges are shown in table 1 as the lower line for each station. The flood magnitudes at any station, when plotted on a frequency graph, usually line up so as to define a smooth curve. Occasionally they plot somewhat erratically, particularly at the upper end. Similar erratic plotting may be expected to occur occasionally when the equations are used for ungaged sites. A smooth curve averaging all the points would be the best representation of the magnitude-frequency relation.

COEFFICIENT, *b*, FOR DRAINAGE AREA

The coefficient, *b*, for area has a value of 0.85 at 2.33 years when only area, *A*, is considered in relation to Q_T. This corresponds closely to values found in many statewide frequency studies in which the mean annual flood was related to drainage area. Based on unit-hydrograph theory and assuming uniform climatic effect, a value about 0.75 might be expected. According to Johnstone and Cross (1949, p. 213), "If two drainage basins of different area are 'hydraulically similar' in all respects, then (mathematically) the vertical dimensions (discharges) are in the same ratio as the three-fourths power of the areas." When main-channel slope is added as a variable, the *b* coefficient immediately changes to a value close to 1.0, and in general approaches it even more closely as more variables are added. Apparently after other important factors have been accounted for, flood peaks of all sizes will vary almost directly with the size of drainage area. (The final *b* coefficients range between 1.01 and 0.92.) It is possible that if more variables were included, the coefficient would have a value of 1.0 throughout. At present it varies consistently with recurrence interval.

It has been stated previously that drainage area is the most important variable related to flood peaks. This is now apparent from the difference between the original standard deviations of the flood peaks at each level and the standard errors of the correlations with drainage area alone. The percentage reduction in the "error" ranges from 72 to 132 percent. This is larger by far than the effect of any other variable.

COEFFICIENT, *c*, FOR MAIN-CHANNEL SLOPE

The coefficient, *c*, for main-channel slope ranges between 0.30 and 0.47 with all factors considered. If slope were entirely a hydraulic factor, discharge would vary as the 0.5 power of the slope (as in the Manning, Chezy, and other hydraulic formulas). The coefficient increases progressively with recurrence interval up to 25 years and then decreases (disregarding the 300-yr value). The effect of slope (in percentage reduction of the standard error) varies in the same way. Second to area, slope is the most important of all the variables up to a recurrence interval of 50 years. It produces an average reduction of 15 percent in the standard error.

COEFFICIENT, *d*, FOR STORAGE

The coefficient, *d*, for storage is negative, as would be expected, because storage causes a reduction in flood peaks. The coefficient is fairly consistent throughout, with an average value of −0.26 (with all significant variables considered). The decrease in standard error by the use of storage as a variable ranges between 4.9 and 2.2 percent where it is significant (5-percent level or better). The percentage improvement is progressively smaller as the recurrence interval increases. Storage has been found to be an important factor in other parts of the country (Minnesota, Florida, Wisconsin) where it has higher values than in New England.

COEFFICIENT, *e*, FOR RAINFALL INTENSITY

The coefficient, *e*, for the rainfall-intensity factor was found to have negative values for the 1.2-, 2.33-, and 5-year floods and positive values for less frequent floods. The negative values are not reasonable because peak discharge should vary directly with rainfall intensity. The negative coefficient is statistically significant at the 5-percent level for the 1.2-year peak but is not significant for the 2.33- or 5-year peak. At 10 years the coefficient is positive but not significant. The apparent percentage improvement in the standard error by using intensity at the 1.2-year level is only 0.4 percent, so that in spite of its seeming significance it has been deleted there and also at the 2.33-, 5-, and 10-year levels. The reduction in standard error by the use of intensity above 10 years ranges to as much as 2.4 percent (excluding the 300-yr peak).

Offhand it seems hardly worthwhile to include a factor that improves the standard error by a maximum of only 2.4 percent. However, if I is omitted the residual errors at individual stations are no longer random geographically but show patterns of high and low values, with regional errors as much as 20 percent. In addition, I shows a high degree of significance (usually at the 1-percent level) wherever the coefficient is positive, in spite of the low improvement percentagewise.

Because rainfall is obviously the primary cause of flood peaks, it is strange that rainfall intensity does not seem to be among the most important of the hydrologic variables influencing peak discharges. But consider the consequence if rainfall averages and intensities were wholly uniform over New England. Under these conditions no rainfall index would appear directly as a variable in the regression equations defining peak discharges. Its highly important effect would, however, be reflected in the value of the a constant of the regression equation, which is a measure of the general level of magnitude of flood peaks. All other things being equal, the a in an equation for an arid region would be lower than the a for a humid region. The intensity factor, I, in the regression equation expresses the effect of the differences in intensity within New England rather than the general effect of intensity on peak discharge.

COEFFICIENT, f, FOR TEMPERATURE

The coefficient, f, for temperature (degrees below freezing) is positive throughout, as would be expected, and its value ranges from 0.35 to 0.77 (all significant variables considered). The reduction in standard error ranges from 0.9 to 3.8 percent (disregarding 300-yr results). As with the rainfall intensity variable, I, the chief value of the temperature variable is that it accounts for geographical variation. If temperature is omitted, the pattern of residual errors is no longer random, even though the standard error is only slightly higher than when temperature is included. This pattern can be seen in figure 5, which depicts the regional errors prior to the use of temperature.

It is evident that regional errors as large as 50 percent of the true values are present if temperature is not used.

COEFFICIENT, *g*, FOR OROGRAPHIC FACTOR

The coefficient, g, for the orographic factor, O, ranges from 0.79 to 1.56 (all significant variables considered). The coefficient increases with recurrence interval, as does the percent reduction in standard error due to O, the orographic factor. The percentage improvement due to O ranges from 5.2 to 18.6 percent. For recurrence intervals up to 50 years, main-channel slope, S, remains the most important variable next to drainage area. Above 50 years, O produces more reduction in the standard error than does S (slope).

DEFINITION OF OROGRAPHIC FACTOR

The orographic factor, as any other mapped factor, must be defined by the data at hand. In addition to the residuals, which represent the integrated effect shown by peak discharge records, topography might be used if its effect were known. Some stations in other parts of New England, such as the east slopes of the White Mountain Range in the northern sector, seem to show isolated orographic effect. However, individual stations have not been used to define contours of orographic effect. In mapping a factor such as this, a serious question arises as to the degree of smoothing which should be done. The local differences may be due entirely to chance variation in storm experience or they may represent the effect of physical conditions that will persist. Statistically, the answer is indeterminate because of insufficient data, and individual judgment can therefore be the only guide. The goal is the establishment of relations that will be the best representation of future events. It would be possible to decrease the apparent standard error appreciably by using geographical contours that follow the local differences in more detail. The same effect would be produced by using rainfall factors such as intensity, based on local experience rather than generalized mapped results. In either case the resulting relations would be a better fit with the past but probably a poorer representation of the future.

STANDARD ERROR OF RESULTS

The standard error of estimate, here referred to as standard error, represents the spread in a set of data derived from past experience. It may also be taken to represent the expected spread (for a specified confidence level) in a similar set of data to be collected in the future, provided that both past and future sets can be expected to be homogeneous samples. There is some question as to whether annual peak discharges are wholly random events. (See section on "Relation of period of record to flood-frequency findings.") If they are not, though the relative effects of the independent variables may be well defined, the general level of the flood peaks may not be as reliable as is indicated by the computed standard errors. Even though the sample is a random one, the interdependence of flood-peak data (see Benson, 1962) may diminish considerably the predictive value of flood-frequency relations.

Subject to the considerations in the preceding paragraph, the final computed standard errors range from 24.4 to 32.8 percent, from the low to the high recurrence intervals. Because of the interdependence of peak-discharge data these are a measure of the expected dispersion of peaks of the given magnitudes, without relation to the recurrence intervals assigned to them. If the distribution of flood peaks were normal, 68 percent or about two-thirds of the predictions would be expected to lie within these limits. Because the distribution of flood peaks is not entirely normal, these figures are only approximate. The percentages given are actually the averages of the plus and minus percentages computed from the standard errors in log units. (One log unit equals one log cycle, and a decimal part of a log unit is that same decimal part of the linear distance representing one log cycle.) Thus, an average standard error of 24.4 percent represents a deviation of 27.3 percent on the plus side and 21.5 percent on the minus side.

Possibly there are significant variables not yet evaluated, such as cover, channel geometry, bed roughness, soils, and geology which might reduce the standard errors.

Another reason for the remaining error may lie in the inexactness or error in the values of the variables used. Some of the error lies undoubtedly in the peak-flow data, because the fixing of exact values for individual T-year flood peaks is subject to some variation. (We must assume that the average values based on our experience represent the true population values.) However, most of the residual error is believed due to the chance variability of storm occurrence. Even if 300 years of annual peak discharges were completly defined, there still would be considerable local variation in flood experience. Examination of maps showing individual values of precipitation variables of all kinds shows erratic local variation, much of which is due not to local characteristics of terrain but to the randomness of this phenomenon. This results in a scattering of data that cannot be explained by other variables but must be averaged, with resulting residual errors in the individual values. The same type of scattering will happen in the future as in the past, so that averaged values for predicted peak discharges are the best that can be hoped for.

In summary, it is believed that, considering the many factors affecting peak discharge that have been tested, the nost important of them have been recognized. Further variables may or may not improve the average relations by small amounts. Most of the residual error is believed due to the inescapable random variation in storm occurrence. It is still possible that some factor not included, which has an extreme condition within a basin, may influence the peak discharges within that basin inordinately.

LIMITS OF APPLICATION OF FORMULAS

Multiple-correlation equations such as developed in this paper have limitations based on the data from which they were derived. For example, as derived they define unregulated discharges. They are applicable only to basins having less than 4.5 million cubic feet (103 acre-feet) of usable storage per square mile and would not apply in any case to a location just below a reservoir of any size, even though the unit storage were less than that specified.

The equations apply, of course, only in New England. The range in the recurrence intervals of the peak discharges used as the dependent variables is from 1.2 to 300 years. Within Maine, no peak discharges were available for recurrence intervals of more than 200 years and only 4 stations were defined for intervals of more than 100 years. Use of the formulas to compute the rare floods in Maine would mean assuming that the same general relations exist there as in the remainder of New England. The 300-year flood has been defined for only 22 stations throughout New England, so that the equation defining it would be necessarily less reliable than equations for lesser floods. For this reason, the modified formula (see table 4) is considered a better representation of relations for the 300-year flood.

The drainage areas ranged between 1.64 and 9,661 square miles. The upper end of the possible range in this variable is well defined for New England. At the lower end, only 13 stations with less than 25 square miles, including 3 with less than 10 square miles, were available. None of these small-area stations were located in Maine. Residual errors for areas less than 25 square miles are randomly distributed, which is an indication that the same basic relations exist within the lower part of the range sampled. Yet the formulas are poorly defined below 10 square miles.

The range of main-channel slopes sampled was between 2.50 and 187 feet per mile. The range in the storage factor was from 0.50 (no storage) to 6.69 (6.19+0.50) percent. The values of mean January temperature covered the complete range of those found in New England.

STUDY OF SIMILAR RELATIONS IN OTHER REGIONS

Are the relations found for New England to be expected in other regions? This cannot be predicted, and only future studies using comparable methods will reveal the generality and usefulness of the relations elsewhere. New England is to some extent representative of the humid regions of the United States, which consists of the eastern half (roughly east of the 101st meridian) and the coastal parts of Washington, Oregon, and northern California. If a wide-scale study is made to define flood-frequency relations anywhere in the humid region, the basic approach used in this study would seem to be useful, at least as the initial procedure. If this is inadequate, modifications may be made as necessary because of conditions differing from those in the New England area.

The principal features of such a study would be:

1. Definition of peak discharges for individual stations only as high as defined by the length of record plus any historical information.
2. Use of multiple-correlation methods defining the peak discharges at various levels.
3. Use of the main-channel slope factor as defined during the course of this investigation.
4. Use of the storage factor as defined in this study.
5. Use of either separate meteorological variables or a composite geographical factor.

The type of analysis does not preclude the use of physiographic and meteorologic factors other than those used or recognized in this study.

In the semiarid or arid regions, the same basic approach may be useful and at least merits a trial. Such regions may be found deficient in peak discharge data, in precipitation data, and in physiographic data because of the lack of maps. These deficiencies may be a deterrent in developing satisfactory flood-frequency relations.

RELATION OF PERIOD OF RECORD TO FLOOD-FREQUENCY FINDINGS

In New England, considerable uncertainty as to both flood-frequency methods and predictions of future flood occurrence has been engendered because of the apparently extreme high flood experience there during the past 30 or 40 years. Flood-frequency characteristics based on 53 years of recent streamflow records differ considerably from characteristics based on data incorporating the historical flood experience of the past 300 years with the recent records. Discharge-frequency curves for the short period are steeper than those for the long period. The same tendency has been found for frequencies of maximum annual 1-day and 2-day precipitation as for discharge frequencies, based on the longest precipitation records in New England. Engineering design based only on the recent period would have to consider higher flood peaks and would be much costlier.

It is very pertinent, therefore, to ask whether or not the recent period of high flood activity represents a tendency that may be expected to persist in the future. A positive answer to this effect has not been given by climatologists or meteorologists.

The other alternative to be considered is that floods, like other natural phenomena that have been studied (as evidenced by tree rings and glacial geology) show both long-term and short-term variations in time. Large-scale climatic factors may now be in a stage of rapid change. Yet, even the tossing of a coin will result in apparent trends and persistence within short segments of a long series. The 300-year historical period in New England contains all the known experience of floods there and comprises periods of low as well as high flood activity. If we look at the overall picture, the recent period appears to be only one of a succession of high-flood periods within the 300-year span, even though it may be the highest of these. Both statistical logic and hydrologic experience indicate that different 50-year periods may vary widely from the long-time average occurrences. In the absence of any definite proof that the recent period of high floods represents a climatic shift that will continue in the near future, it seems advisable to conclude that flood-frequency relations based on the sum total of flood experience represent the most efficient use of the available information and are the best augury for future events.

SIMPLIFICATION OF RESULTS

The regression coefficients (b through g) in the flood formulas are shown to four figures to the right of the decimal point in table 3, although such precision is not warranted. This table permits examination of the trends as the recurrence interval changes or as variables are added or deleted. Statistical tests show that the general trends in the values of each coefficient are not random but are significant at the 5 percent level or less for all variables except storage, *St*. However, simplified values that vary consistently as indicated by the curves of figure 9 would represent the relations more realistically. Such values are shown in table 4 for the relations that include all the variables. The a coefficients were recomputed using the simplified coefficients of the independent variables and the average values of each of the variables including Q; the resulting equations could then be considered as balanced.

The values of the coefficients in table 4 are only slightly different from those in table 3 except at 300 years, where the formula is based on only 22 items. The originally computed coefficients and the standard error for 300 years were somewhat inconsistent with trends shown at shorter recurrence intervals. The standard errors of the simplified formulas are virtually unchanged from the original standard error of table 3 except at 300 years, where there is an 8 percent increase. However, the revised formula for 300 years is preferable to the original because the simplified coefficients and the resulting standard error are consistent with those for the other formulas.

COMPUTATION OF INDEPENDENT VARIABLES

The previous descriptions of the topographic and climatic variables that were investigated for their effect on flood peaks did not describe the exact methods of determining the variables. As the reader may be interested in the details of these procedures, the following summary is presented of methods used in this study to obtain the values of the factors that were found to influence flood frequency in New England:

1. The drainage areas in square miles above the gaging station sites were already available in published Survey reports. The most recent of such figures were used.
2. Within each basin, the main channel was outlined on a topographic map. Upstream from each junction point, the main channel was chosen as the stream that drains the most area. The main channel was continued to the ridge beyond the upstream end of the blue line on the map by drawing the flow lines indicated by contours. The total length was measured by using dividers set to one-tenth of a mile, the points 85 and 10 percent of the total length above the gaging station were located, and the elevations at these points were determined. The main-channel slope was computed as the difference in elevation in feet divided by the length in miles between the two points.
3. The surface area (sq mi) in lakes and ponds was measured. This was done by planimetering or more simply and just as accurately by using a transparent grid with squares equal to 0.04 or 0.01 square mile (depending on the size of ponds). The grid was laid over the water area on the map and the squares and part squares (estimated in tenths) were counted. More simply, if the area was large enough (at least 30 squares) the number of grid intersections within the area was counted. The area in all such ponds was summed and expressed as a percentage of the total drainage area. This percentage was then increased by 0.5 percent to obtain the storage index, *St*, that was used.
4. The T-year 24-hour rainfall intensity, in inches, was computed by using U.S. Weather Bureau Technical Paper 29, part 4 (1959). The 2-year and 100-year values were first obtained from the maps supplied in that publication (figs. 2–4 and 2–7) and the T-year point rainfall intensity then either interpolated or extrapolated from the diagram provided for that purpose (fig. 1–2). Adjustment was then made by means of a further graph (fig. 1–3)

from point rainfall intensity to that for the drainage area above the design site. A different value was determined for each recurrence interval for which the peak discharge was computed.

5. The average January temperature, in degrees Fahrenheit, for the drainage basin was obtained from figure 4. The value chosen was the average over the basin rather than that at the design site. This temperature was then subtracted from 32 to obtain the number of degrees below freezing (with a minimum value of 1), which is the temperature index, *t*, that was used.
6. The orographic factor, *O*, was obtained from the map of plate 1. The value was chosen as the average over the basin rather than that at the design site.

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