GEOLOGICAL SURVEY CIRCULAR 365

A FLOOD-FLOW FORMULA FOR CONNECTICUT

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By B. L. Bigwood and M. P. Thomas

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Washington, D C., 1955

Free on application to the Geological Survey, Washington 25, D. C.

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PREFACE

Recognizing that a flood-magnitude-and-frequency relation for Connecticut streams, based on actual flood events recorded at gaging stations on typical streams within the State or closely bordering territory, would in all likelihood provide reliable estimates of flood probabilities for ungaged sites on State streams, the State Board of Supervision of Dams and the State Highway Department, in cooperation with the United States Geological Survey, have sponsored the study described in this report. The investigation is especially needed in connection with regulative functions of the Board of Supervision of Dams and for purposes of hydraulic design in the State Highway Department. The derived flood-flow formula also might be expected to answer design needs of private engineers and consultants throughout the State and, as well, those outside the State who might have interest in Connecticut hydraulic projects.

A formula was envisioned which would incorporate drainage-basin characteristics that could readily be scaled from standard topographic maps. A highly desired attribute of the formula would be simplicity in form and application. Involved analysis, resulting in a profusion of terms having but little weight in final results, was to be avoided. In brief, a formula of few and simple terms, giving results of reasonable practical accuracy, was the goal. These desired general requirements influenced the derivation of the formula set forth in this study.

The U. S. Geological Survey has planned a nationwide flood-frequency study, which is to be issued separately for sections of the country corresponding to the parts in the annual surface water series of the water-supply papers. The first one to be published will be that for part 1A, comprising virtually all New England, including Connecticut. This first volume is now in preparation but will not be forthcoming immediately; because of the nature of statistical studies, it may lead to a different form of analysis than is developed here.

Cooperating State agencies, namely, the State Board of Supervision of Dams under the chairmanship of Mr. Richard Martin, succeeded by Mr. William S. Wise; and the State Highway Department, Mr. William J. Cox, Commissioner, succeeded by Dr. G. Albert Hill, rendered most valuable assistance. Acknowledgments are due also to individual members and staff personnel of the Board of Supervision of Dams and to the engineering staff of the State Highway Department for helpful cooperation.

The basic flood discharge records and some other hydrologic data used in this study have been collected and compiled largely under the continuing surface-water investigational programs maintained--in Connecticut, in cooperation with the State Water Commission, the Hartford Department of Public Works (succeeding the Hartford Flood Investigation & Improvement Commission), the New Britain Board of Water Commissioners, and other agencies; in New York, in cooperation with the Westchester County Department of Public Works; and in Massachusetts in cooperation with the State Department of Public Works.

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ABSTRACT

A study of the frequency and magnitude of floods within the Connecticut area is contained in this report. Annual flood discharges for 44 stream-gaging stations whose records range in length from 10 to 40 years are presented and a regional flood-frequency relationship developed based upon the ratios of all floods to the mean annual flood at each of these locations. Definition of this curve for floods of larger recurrence intervals is based upon historical studies of extraordinary floods which have occurred within the area. For ungaged areas, the mean annual flood value may be determined by use of a flood-flow formula based upon the topographic characteristics of drainage area and basin slope. The development of this formula also is included.

INTRODUCTION

Problems relating to flood flows in river channels have been the concern of man ever since he chose to settle in river valleys where rich soil was available for agriculture, where grades for highways and railroads were moderate, and where abundant water was available. Through the years he has learned to his dismay that rivers are not always friendly. At times they overflow their banks in uncontrolled fury and ruthlessly destroy everything before them. In order to control flood flows properly and to design and locate structures, such as dams, bridges, culverts, highways, railroads, residential and industrial buildings, water-supply and sewage-disposal works, and other facilities, it becomes necessary to evaluate the magnitude and probable frequency of recurrence of floods. Where loss of life or great property damage is involved if the structure be overtopped or destroyed, the "design flood" must be of such magnitude that it may never be exceeded. In general, however, it is adequate and economical to design for a flood which may be expected to occur on an average of from once in 10 to once in 100 years, depending upon the type of structure involved.

Before 1900, engineers attempted to evaluate the flood-producing potentialities of rivers by devising the flood-flow formulas which abound in our engineering literature. Most of these are general in character, based on data collected over relatively short periods of time, and apply largely to single stream or localized areas. These formulas usually involve only the use of the drainage area and coefficients, the values of which vary within a wide range. The final value of discharge obtained was largely a matter of judgment in selecting the coefficient in the formula, and for that selection there was little or no basis. The results obtained usually were in the form of maximum values, base data being so meager that anything but a very rough approximation of frequency was impossible.

Enveloping curves of maximum known discharge per square mile were also commonly used in the design of hydraulic structures. These curves likewise ignored the element of frequency and the effect of the physical characteristics of the drainage basin other than the drainage area, which have an important bearing upon the problem.

In 1913, the late Weston E. Fuller introduced the concept of a magnitude-frequency relationship based upon statistical methods applied to floods in the United States, following a line of reasoning that was introduced into studies of riverflow about the same time by the late Allen Hazen. From that time on, as streamflow records have become more extensive and reliable, the concept of maximum flood values for hydraulic design based on limited experience has been superseded by magnitude-frequency relationships computed on the basis of methods involving the use of rainfall-runoff relationships or physical characteristics of the drainage basins.

It has long been recognized that equal amounts of rainfall of similar intensities would produce widely varied peak discharge rates in this region. In 1944 the Geological Survey (Kinnison and Colby, 1945) completed a study to relate the magnitude of flood peaks of various frequencies on Massachusetts streams to certain significant drainage-basin characteristics. Short discharge records necessitated the use of rainfall-runoff studies through unit-hydrograph relationships for flood frequencies greater than 15 years. The resulting formulas are free of coefficients or estimated terms and are designed to give the peak discharge for minor (15-year), major (100-year), rare (1,000-year), or maximum floods on any stream in or near the Massachusetts area.

In Connecticut, also, there has developed a pressing need for a flood-flow formula for hydraulic design, particularly for streams having drainage areas under 100 square miles. Previous reliance on outmoded formulas has resulted in a wide divergence of results. It was, therefore, conceived that by means of an analysis of existing streamflow records alone, a formula might be developed to serve as a basis for estimating expected flood flows on any stream in the Connecticut area. This formula, it was recognized, should not necessarily give results of minute theoretical exactness but rather of reasonable practical accuracy to serve as a guide in hydraulic design, particularly on ungaged streams where no observational data exist for evaluating flood flows. Some desirable requirements were (1) that the formula be simple in form and application so that even the inexperienced might be encouraged in its use, (2) that the physical characteristics used be readily determinable from standard topographic maps, and (3) that the results exhibit a standard error no higher than about 20 percent. A further desired requirement--that acceptable results might be obtained for drainage areas under 5 square miles--could not be expected inasmuch as the base data provided only 3 of 44 gaging-station records for streams under 10 square miles and none under 4 square miles. This basic lack of acceptable streamflow records for sites having drainage areas of less than 10 square miles points up the urgent need for programming additional hydrologic investigations on small streams. At the other extreme, the formula would not be expected to apply to streams draining more than about 1,500 square miles.

METHOD OF ANALYSIS

Derivation of a flood-magnitude-frequency formula for the Connecticut area, incorporating the desirable features mentioned, presented two separate and distinct phases: the development of a state-wide magnitude-frequency relation, and the evaluation of the effects that the important physical characteristics of each drainage basin individually might have in modifying this relation. Methods employed in the analytical attack on these phases in the development of the overall formula are outlined below.

FLOOD MAGNITUDE AND FREQUENCY RELATION

In analyzing flood frequency on a regional basis two aspects are presented: geographic sampling and time sampling. For the first, records for a large number of gage sites is required to sample a wide diversity of terrain. For the second, a large number of years of record is required, not necessarily at one station.

Experience has shown that within fairly wide regions, flood-frequency curves for all streams will be essentially the same, if floods are expressed in dimensionless terms. This is accomplished by expressing each flood as a ratio to an index flood at each station, called the mean annual flood.

The degree of similarity of such individual curves may be tested by a statistical "homogeneity" test. All the curves within a region thus demonstrated as being homogeneous may then be combined to obtain a basic flood-frequency curve for the region. The State of Connecticut was found to be homogeneous in this respect and a single curve for the region was found possible. The method of combining increases the reliability of the basic relationship for the available period of record; it does not increase the period of time.

To increase the flood experience in respect to time, it might be thought that the station-year method of analysis could be applied profitably to flood-frequency studies as it has to rainfall-intensity frequencies. By this method, for example, 5 station records of 20 years each would be combined to obtain a 100-year record, thereby increasing the accuracy of flood prediction by reducing the sampling errors. Such a method requires that flood-frequency characteristics be comparable, and that the data be entirely independent. Although the former holds true in Connecticut, the latter does not. For this reason, it was not considered possible to combine Connecticut records using the station-year method.

There remained only the possibility of extending time experience through study of historical records. It is known, for example, that no flood equal to or in excess of the 1936 flood peak has been observed within the past 320 years of recorded history on the Connecticut River. Historical studies from Connecticut sources indicate that this is probably also true with regard to the 1938 hurricane flood on some of the streams in eastern Connecticut. Although historical data on floods are admittedly meager, nevertheless major floods are usually recognized and often related to one another and perhaps to others within the period of record, so that by use of such data it is possible to improve the frequency plotting of extreme floods.

There are two types of flood data which may be considered in flood-frequency analysis, the annual-flood series and the partial-duration series (called floods above a base). An annual flood is defined as the highest momentary peak discharge in a water year. Only the greatest flood in each year is used. An objection most frequently met with regarding the use of the annual-flood series is the very fact that only one flood in each year is employed. Infrequently, other floods in a given year, which the method omits, may outrank many annual floods.

This objection is met in the partial-duration series, by listing all floods above a selected base regardless of the number within any given period. The base is generally selected as equal to the lowest annual flood so that at least one flood in each year is included. However, this may result in listing an excessive number of floods in some years. Therefore, in a long record, the base may be raised so that on the average only three or four floods a year are included. An objection to the use of the partial-duration series is that the floods listed may not be fully independent events, that is, one flood sets the stage for the next.

There is an important distinction in meaning between recurrence intervals by the annual-flood-series method and by the partial-duration-series method. In the annual-flood series the recurrence interval is the average interval in which a flood of given size will recur as an annual maximum. In the partial-duration series, the recurrence interval is the average interval between floods of a given size regardless of their relationship to the year or any other period of time. This distinction remains, even though for large floods the recurrence intervals are closely the same by both methods. From statistical principles there is a definite relationship between results by the two methods, and the following table shows comparative values of recurrence intervals:

Recurrence Intervals in Years

Annual floods	Partial-duration series
1.16	0.5
1.58	1.0
2.00	1.45
2.54	2.0
5.52	5.0
10.5	10
20.5	20
50.5	50
100.5	100

The two methods give essentially identical results for intervals greater than about 10 years. As most designs are based on floods of rarer frequency than this, it is apparent that, from a practical standpoint, either method is satisfactory, and the simplicity of the annual-flood-series method makes it more attractive. For this study the annual-flood-series method was used.

Since 1928 when the State-Federal cooperative stream-gaging program was inaugurated in Connecticut, the U. S. Geological Survey has maintained an increasing number of stream gaging stations within the State, nearly all of them equipped with automatic water-stage recorders. Currently, 37 of these station records are of adequate length for use in a flood-flow analysis. Only one station in Connecticut, Burlington Brook near Burlington, has a drainage area of less than 5 square miles. However, two records in the State of New York, Beaver Swamp Brook at Harrison and Blind Brook at Rye, having respectively 4.7 and 9.2 square miles of drainage area in close proximity to the southwest corner of Connecticut, could be used in the flood study. Five other stations in Massachusetts, located on tributaries of streams that flow into Connecticut, also could be used. In all, a total of 44 streamflow records were available covering a range in size of drainage area from 1,545 down to 4.1 square miles. Seven of these records began previous to 1929. Figure 1 shows the location of the gage sites throughout Connecticut and contiguous areas. The numbers refer to the stations listed in table 1.

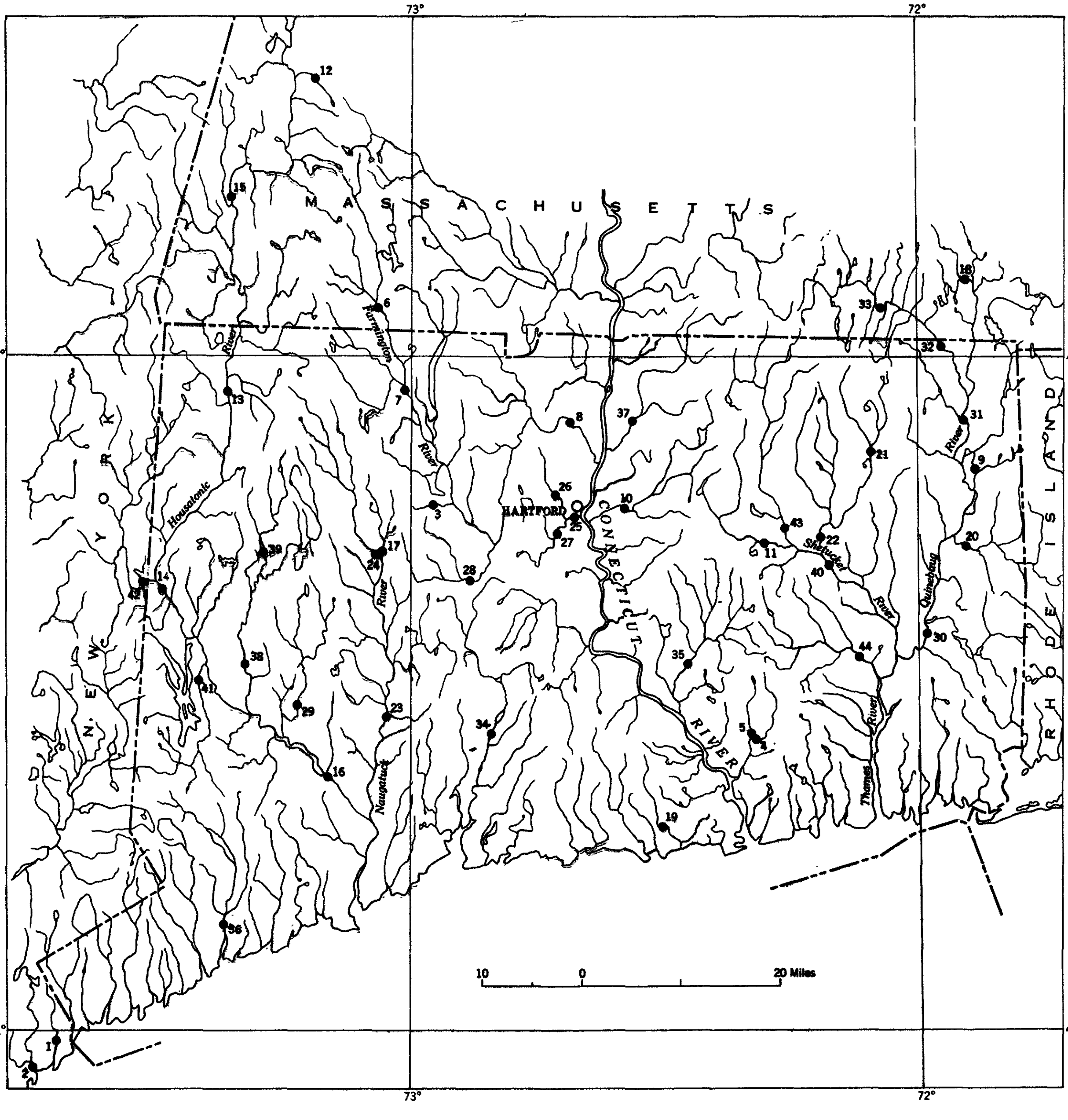

Figure 1. --Map of Connecticut showing location of gaging stations used.

Table 1.--Index of gaging stations used in Connecticut flood-frequency report

Index no.	Gaging station
1	Beaver Swamp Brook at Harrison, N. Y.
2	Blind Brook at Rye, N. Y.
3	Burlington Brook near Burlington, Conn.
4	East Branch Eightmile River near North Lyme, Conn.
5	West Branch Eightmile River at North Plain, Conn.
6	West Branch Farmington River near New Boston, Mass.
7	West Branch Farmington River at Riverton, Conn.
8	Farmington River at Rainbow (Tariffville), Conn.
9	Five Mile River at Killingly, Conn.
10	Hockanum River near East Hartford, Conn.
11	Hop River near Columbia, Conn.
12	East Branch Housatonic River at Coltsville, Mass.
13	Housatonic River at Falls Village, Conn.
14	Housatonic River at Gaylordsville, Conn.
15	Housatonic River near Great Barrington, Mass.
16	Housatonic River at Stevenson, Conn.
17	Leadmine Brook near Thomaston, Conn.
18	Little River at Buffumville, Mass.
19	Menunketesuck River near Clinton, Conn.
20	Moosup River at Moosup, Conn.
21	Mount Hope River near Warrenville, Conn.
22	Natchaug River at Willimantic, Conn.
23	Naugatuck River near Naugatuck, Conn.
24	Naugatuck River near Thomaston, Conn.
25	Park River at Hartford, Conn.
26	North Branch Park River at Hartford, Conn.
27	South Branch Park River at Hartford, Conn.
28	Pequabuck River at Forestville, Conn.
29	Pomperaug River at Southbury, Conn.
30	Quinebaug River at Jewett City, Conn.
31	Quinebaug River at Putnam, Conn.
32	Quinebaug River at Quinebaug, Conn.
33	Quinebaug River at Westville, Mass.
34	Quinnipiac River at Wallingford, Conn.
35	Salmon River near East Hampton, Conn.
36	Saugatuck River near Westport, Conn.
37	Scantic River near Broad Brook, Conn.
38	Shepaug River near Roxbury, Conn.
39	Shepaug River at Woodville, Conn.
40	Shetucket River near Willimantic, Conn.
41	Still River near Lanesville, Conn.
42	Tenmile River near Gaylordsville, Conn.
43	Willimantic River near South Coventry, Conn
44	Yantic River at Yantic, Conn.

Annual flood discharges were tabulated from the streamflow records for these 44 gage sites. For all stations in Connecticut, these values were revised if necessary in accordance with the latest rating information, and some that were known to be affected by regulation or breaching of dams upstream were adjusted as nearly as possible to natural flow. The final results are shown in tables 2 and 3. Examination of these tables, or figure 2, shows a very slow rate of increase in the establishment of usable station records from 1 station in 1901 to 8 by 1928, followed by a more rapid and steady accumulation to 44 stations by 1944.

Mean annual flood values for each station were based on either an 18 year (1936-53) or a 25-year (1929-53) record, depending upon the comparative lengths of station records. The annual flood values given in tables 2 and 3, were arranged in order of magnitude from highest to lowest for each station, assigning order numbers and computing corresponding recurrence intervals from the ratio $\frac{N+1}{M}$, where N is the total number of events, and M is the number of an event in order of magnitude. For a few years in some series for which no records were available, estimated order numbers were assigned to the missing events, based upon records for nearby

Table 2.--Annual peak discharges, before 1929, in cubic feet per second

Water year	Station no.								
	6	8	10	13	14	15	23	30	40
1901	--	--	--	--	17,700	--	--	--	--
1902	--	--	--	--	31,000	--	--	--	--
1903	--	--	--	--	12,300	--	--	--	--
1904	--	--	--	--	12,900	--	--	--	--
1905	--	--	--	--	13,700	--	--	--	--
1906	--	--	--	--	10,400	--	--	--	--
1907	--	--	--	--	6,690	--	--	--	--
1908	--	--	--	--	16,900	--	--	--	--
1909	--	--	--	--	11,500	--	--	--	--
1910	--	--	--	--	13,200	--	--	--	--
1911	--	--	--	--	8,530	--	--	--	--
1912	--	--	--	--	12,100	--	--	--	--
1913	--	8,100	--	--	13,200	--	--	--	--
1914	3,090	9,300	--	8,830	14,900	5,070	--	--	--
1915	2,420	13,500	--	--	--	4,110	--	--	--
1916	1,900	6,700	--	6,960	--	5,300	--	--	--
1917	1,660	7,100	--	6,000	--	4,200	--	--	--
1918	1,010	4,900	--	4,220	--	2,670	--	--	--
1919	2,360	10,500	--	4,320	--	2,490	--	7,350	--
1920	2,280	6,900	1,860	7,950	--	4,450	8,470	12,100	11,000
1921	2,350	7,200	623	5,490	--	4,800	6,290	5,950	8,900
1922	1,960	5,500	--	5,230	--	3,900	14,200	11,600	--
1923	1,580	7,400	--	5,570	--	4,650	6,490	7,480	--
1924	3,390	21,000	--	8,390	16,000	4,900	21,900	9,800	--
1925	1,830	6,900	--	7,410	--	4,350	--	6,820	--
1926	1,530	4,200	--	4,210	--	3,370	--	5,770	--
1927	1,620	4,300	--	5,500	--	3,860	--	3,050	--
1928	6,490	24,500	--	11,700	21,000	7,910	26,000	12,500	--

streams, in order to rank the observed flood events over the base periods of 18 and 25 years. After plotting the annual flood discharges for each station against the corresponding computed recurrence intervals on Powell-Gumbel type frequency charts and drawing a curve to average the data, the mean annual flood was taken therefrom as the flood of a 2.33-year recurrence interval. The results are given in table 4. Although experience has demonstrated that the mean of the annual-flood series for one station may not usually be compared with the mean for another station for a different period of record, it was found by a study of the longer records that the mean annual floods for the 18-, 25-, or 40-year periods used in the analysis lie within a range of about 8 percent and further adjustments were not made.

The mean annual flood values thus determined can be said, therefore, to be analytically comparable in time. Dimensionless flood ratios were obtained by dividing each annual flood value for each station by its corresponding mean annual flood value. The dimensionless ratios for floods of the same rank may be averaged for any number of stations within a homogeneous region to produce an average frequency curve.

An 18-year composite frequency curve was then constructed for all 44 stations, an 18-year and 25-year curve for 29 of these stations, and a 25-year and 40-year curve for the 7 stations with records exceeding 25 years. A composite frequency curve was then developed representing a 40-year record (1914-53) for 44 stations by adjusting the 18-year frequency curve in successive steps by the relationship between the 18-and 25-year frequency curves for 29 stations and the 25-and 40-year frequency curves for 7 stations.

In order to obtain additional flood data beyond the 40-year periods as previously discussed, recourse was had to historical flood accounts in newspaper files and town histories. Although the information secured was relatively meager and largely descriptive, it did serve to improve the relative plotting positions of the extraordinary floods of record in eastern and western Connecticut.

Jahns in 1947 (p. 132) states:

"From a combination of historic records of meteorologic and hydrologic conditions in the Connecticut River drainage basin, together with evidence furnished by the great flood deposits and materials associated with them, the conclusion seems valid that no flood as great as or greater than that of March 1936 has visited the lower reaches of the Connecticut since civilization began in the valley, and probably not for an additional period of several hundreds of years prior to that time."

Table 3. --Annual peak discharges, 1929 to 1953, in cubic feet per second

Index no.	Water year												
	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941
1	--	--	--	--	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--	--	--	--	--
3	--	--	--	101	395	434	346	533	288	676	243	293	189
4	--	--	--	--	--	--	--	--	--	2,950	560	670	790
5	--	--	--	--	--	--	--	--	--	1,810	495	705	645
6	2,160	920	1,310	1,840	3,640	2,080	2,750	9,830	2,990	18,500	2,250	2,310	1,450
7	--	1,990	3,130	5,040	9,720	6,180	6,600	19,900	7,330	37,100	5,070	6,240	4,500
8	7,220	3,250	5,640	4,860	7,610	7,390	6,800	26,900	6,990	29,900	6,190	9,000	4,900
9	--	--	--	--	--	--	--	--	--	2,480	552	552	480
10	1,190	321	350	410	500	1,920	810	1,810	710	5,160	1,320	1,330	1,600
11	--	--	--	--	1,970	1,700	1,500	3,640	1,720	6,450	1,600	2,330	2,880
12	--	--	--	--	--	--	--	6,000	1,930	6,400	3,390	1,380	832
13	6,850	2,890	4,320	5,290	8,160	5,400	4,560	14,500	5,520	19,900	7,790	9,360	2,590
14	9,100	4,000	7,300	7,900	10,800	13,000	7,500	26,000	8,200	37,000	10,300	15,000	5,370
15	4,740	1,820	2,520	2,940	6,380	2,590	3,690	8,990	2,960	11,520	5,180	4,290	1,400
16	12,700	5,530	12,700	11,900	21,700	26,400	14,700	55,000	13,600	59,500	17.100	25,100	30,500
17	--	--	750	925	1,880	3,080	1,880	2,680	1,000	3,050	1,740	1,500	880
18	--	--	--	--	--	--	--	--	--	-	--	516	168
19	--	--	--	--	--	--	--	--	--	--	--	--	--
20	--	--	--	--	1,460	1,520	2,470	4,080	1,460	4,100	795	1,290	1,490
21	--	--	--	--		--	--	--	--	--	--	--	950
22	--	--	2,520	2,680	3,270	4,150	4,560	12,900	4,050	27,200	2,530	4,900	4,790
23	5,730	2,480	3,420	3,970	8,470	10,500	7,820	23,300	6,490	25,300	8,800	9,590	11,900
24	--	--	1,910	2,620	3,800	5,000	4,450	6,590	3,050	10,100	3,100	4,010	2,160
25	--	--	--	--	--	--	--	5,400	1,620	5,650	1,830	3,490	2,960
26	--	--	--	--	--	--	--	2,800	900	3,000	1,100	1,460	950
27	--	--	--	--	--	--	--	2,380	635	3,600	950	2,430	2,330
28	--	--	--	--	--	--	--	--	--	3,800	--	--	--
29	--	--	--	--	2,980	5,300	1,570	5,990	2,200	7,420	2,000	3,660	5,960
30	6,750	3,030	5,450	6,160	7,090	9,800	13,100	29,200	8,520	25,000	5,770	9,400	7,150
31	--	1,180	3,930	2,320	3,830	6,830	5,600	17,100	4,350	20,900	2,940	5,710	2,560
32	--	--	--	1,200	1,800	2,310	2,140	10,500	2,100	14,100	1,700	2,550	1,280
33	--	--	--	--	--	--	--	--	--	--	--	1,450	559
34	--	--	818	1,280	1,270	1,810	1,100	3,240	1,080	5,230	1,690	2,680	2,320
35	2,810	940	1,770	2,330	1,840	2,560	3,030	6,250	2,640	12,400	1,900	3,470	4,120
36	--	--	--	--	1,230	3,100	788	5,310	1,420	4,420	1,330	3,400	3,830
37	1,190	378	613	664	877	1,670	1,290	1,820	733	5,130	1,110	1,290	1,110
38	--	--	2,720	1,210	3,650	4,150	3,950	7,480	2,420	10,500	2,920	3,190	3,190
39	--	--	--	--	--	--	--	4,070	1,500	6,000	1,280	1,500	1,150
40	6,110	3,710	5,140	5,620	7,000	9,720	8,600	23,900	7,140	52,200	4,980	9,240	10,000
41	--	--	--	605	950	730	476	3,930	710	4,410	770	1,730	3,800
42	--	980	1,980	2,050	3,090	4,000	1,580	10,200	2,080	12,500	2,630	5,280	2,370
43	--	--	--	1,160	1,260	4,420	2,220	7,880	1,660	15,500	2,100	3,400	2,660
44	--	--	2,320	2,400	2,560	2,500	3,100	6,300	2,600	13,500	1,240	2,500	3,570

He also states (p. 64, 65):

"The 1936 flood, although of extraordinary magnitude, was relatively most serious along the main river The hurricane flood (of September 1938), though of short duration as a great flood along the Connecticut, was of record-breaking intensity on many tributary streams, particularly those draining the central upland area of Massachusetts."

In most places in the Connecticut area the 1938 flood exceeded in magnitude the flood of 1936 and it seems reasonable to assume. then, that the 1938 flood was the greatest flood of historical time in part of the Connecticut area, with a reourrence interval in excess of 300 years.

There is an apparent tendency toward independence of flood events in eastern and western Connecticut; therefore, in assembling information from historical and other sources, each half of the State was considered separately. It was assumed that, though the flood descriptions were usually very local in coverage, floods of such magnitudes were probably general over at least

Table 3.--Annual peak discharges, 1929 to 1953, in cubic feet per second--Continued

Index no.	Water year											
	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953
1	--	--	140	88	137	93	96	112	30	130	141	140
2	--	--	1,330	614	834	409	502	534	119	964	770	1,240
3	268	144	242	442	374	205	256	591	131	287	191	335
4	630	750	525	578	542	250	595	542	490	610	730	690
5	615	880	585	555	425	326	580	455	335	550	650	650
6	2,500	1,810	2,610	2,450	1,500	1,850	3,180	11,700	1,270	10,100	4,060	3,240
7	7,520	4,750	5,900	6,960	3,990	4,910	7,710	22,000	2,530	17,400	7,140	6,780
8	7,200	5,100	5,460	5,660	5,900	5,420	11,200	25,200	3,840	9,900	10,100	9,680
9	534	686	512	435	353	336	795	254	339	483	502	582
10	620	1,060	1,020	960	427	300	880	351	700	1,000	940	1,150
11	1,660	2,180	2,580	1,480	815	785	1,700	960	900	1,940	1,860	2,180
12	1,450	1,720	1,280	1,970	1,190	1,730	1,970	5,700	1,070	3,280	2,080	1,630
13	4,720	4,960	4,000	6,100	5,570	5,840	10,100	23,900	3,790	7,270	7,170	7,790
14	8,590	7,890	7,210	8,830	7,890	10,800	16,500	32,300	5,630	11,600	12,400	13,800
15	2.830	3,000	2,550	3,570	3,450	4,090	5,420	12,200	2.670	4,290	3 790	3,970
16	14,100	16,800	11,800	13,600	10,800	14,700	26 000	51,800	9,450	21,000	22,700	25,300
17	1,480	1,000	1,040	2,120	840	1,180	920	2,700	840	1,440	900	1,770
18	502	264	337	331	334	255	448	181	208	520	356	518
19	390	720	400	510	330	184	870	510	151	340	370	770
20	1,320	2,150	1,020	975	825	680	1,660	582	720	1,320	1,350	1,470
21	814	814	950	767	469	486	767	444	646	1,170	915	890
22	4,470	3,880	3,150	2,930	1,610	1,710	4,100	1,720	1,780	3,090	3,020	3,330
23	10,100	7,640	5,840	11,500	4,880	7,140	6,700	28,500	6,100	11,300	7,880	15,200
24	3,900	2,610	2,020	4,450	1,770	2,380	2,700	10,200	1,470	5,000	3,200	6,150
25	1,680	2,630	1,220	1,910	1,420	1,060	1,870	2,100	1,400	2,880	2,160	2,970
26	850	1,380	560	1,500	755	545	1,160	1,010	900	1,750	1,260	1,660
27	800	1,800	1,250	890	795	615	1,110	1,190	625	1,600	1,380	2,220
28	1,340	1,190	1,280	1,980	730	805	1,090	3,260	1,060	1,970	1,170	1,340
29	2,230	2,340	2,340	3,340	1,520	2,060	1,960	5,600	2,920	3,160	2,500	3,400
30	8,800	8,660	6,250	6,010	4,870	4,130	9,460	3,950	4,250	8,900	8,080	10,200
31	4,430	3,130	2,950	2,790	2,490	2,130	5,290	1,820	1,780	5,180	3,570	5,180
32	2,070	1,340	1,420	1,560	1,490	1,080	2,370	1,020	955	2,940	1,990	2,240
33	820	740	748	546	712	625	1,500	497	569	1,000	827	1,220
34	1,370	2,170	2,580	1,180	1,180	770	1,690	2,960	648	1,680	2,270	2,020
35	2,440	3,470	2,860	2,320	1,380	1,240	2,480	1,590	1,050	3,080	4,390	2,800
36	1,150	1,790	1,860	1,120	1,930	1,240	2,000	1,360	441	3,220	2,350	4,710
37	611	1,370	920	945	550	475	1,580	500	610	1,040	995	1,520
38	2,830	3,470	2,090	2,330	1,360	2,330	3,100	7,010	1,970	3,980	5,080	4,530
39	2,050	880	1,100	1,300	753	1,470	1,500	5,160	1,000	1,430	2,400	1,900
40	8,160	8,610	6 590	6,030	3,670	3,670	7,570	3,850	3,740	7,010	6,080	7,430
41	730	850	850	1,110	660	825	1,100	1,110	528	1,080	1,730	1,420
42	1,600	2,640	2,640	1,950	1,210	4,410	3,310	6,360	1,410	2,630	3,450	5,390
43	1,880	2,040	2,120	1,510	910	1,010	2,240	1,070	838	2,240	1,800	2,300
44	2,430	3,050	1,720	1,670	1,560	785	1,790	1,520	1,710	2,500	2,830	2,280

the half of the State in which they were reported. Results of the search through town histories, newspaper files, and the like could not be considered completely satisfactory, but such information is deemed essential to a comprehensive flood-flow analysis. Its use involved the exercise of a considerable amount of judgment, but it has served as a valuable guide to final conclusions.

In western Connecticut the search was more rewarding, particularly in the central part around Waterbury. The earliest flood of significance which was recorded in the accounts consulted occurred in February 1691. From the historical information listed in this study, it seems probable that this flood had not been exceeded between 1634 and 1691 because the period is less than the normal life span of some of the hardier inhabitants. This flood therefore, considered in relation to a period of 320 years (1634-1953), was doubtless higher than the 1938 flood in the western part of the State and probably the highest in the 320-year record. It was, therefore, given an order number of 1 with other floods following it in descending order in accordance with the numbering system which

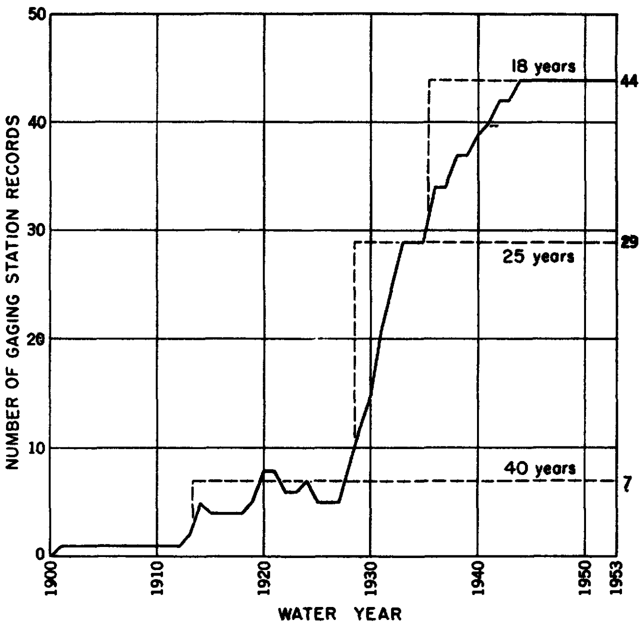

Figure 2. --Chronological record of gaging stations.

appears below. The floods of November 13, 1853, and April 30, 1854, both within the climatic year 1854, seem to be very closely of the same magnitude and were given places 2a and 2b in the annual-flood series. Many more flood events were recorded but are not mentioned here inasmuch as all appeared to be of lesser magnitude than the November 1927 flood.

The historical information obtained in western Connecticut resulted in the following list of floods which are arranged in an approximate order of magnitude, although the relative positions of any but the recorded floods of 1927, 1936, 1938, and 1949 are important only as they affect the relative position in magnitude of the recorded floods. Descriptive material used in deciding the order number of these floods is also given.

1. February 1691. Bronson (1858, p. 111) states: "In February 1691, happened the Great Flood, so called. Owing to rains and the sudden melting of the snows, the river left its banks and covered the meadows, rising to a height never known before or since." Also, Anderson (1896, v. 1, p. 229) prints an "Extract from collections of Rev'd. Mr. Prince, at Boston, anno. 1872." as follows: "In February 1691, There was a remarkable Flood in this town. The meadows were all under water and the ground so soft and the stream so rapid that it tore away a great part of the meadows and almost ruined them. The frost came out very quick and the rain fell apace, which made the ground uncommonly soft. The town did not recover from the damage it received by this deluge for many years. Some of the inhabitants were grately discouraged, and many drew off, and the town was almost ruined."

2a. November 13, 1853. Bronson (1858, p. 112) states that this flood was the largest "seen by oldest person living." Cothern (1854, v. 1, p. 798) calls this "by far the largest and most destructive freshet that the town has suffered since its first settlement--3 feet higher than was known by the 'oldest inhabitant' and 3 feet higher than 'the old Indian marks'." Campbell, Sharpe and Bassett (1902, p. 14) state that in the Naugatuck River at Seymour, Conn., "the water rose 18 feet 11 inches. The south part of the railroad bridge was carried away with the abutment. The bridges at Beacon Falls, Pinebridge, and Ansonia were carried away."

2b. April 30, 1854. Sharpe (1879, p. 84) states that "Water rose 8 or 10 inches higher than in the November freshet. Great damage was done throughout the valley. Derby Avenue was washed out from Broad Street to Pine Street to a depth of three feet. The water at Derby was 19 feet 8½ inches above the low water mark." Campbell, Sharpe and Bassett (1902, p. 14) state: "Apr. 30, 1854, there was a rise of water 19 ft. 5 in. and Derby Avenue was washed out to a depth of three feet or more and boats were used in the avenue." Bronson (1858, p. 112) states that this flood was 18 inches lower than that of Nov. 13, 1853, at Waterbury. "At Derby, owing to a greater freshet in the Housatonic, the water was highest in April." The Hartford Courant, Tuesday, May 2, 1854, states: "At Simsbury, the Farmington River rose very rapidly and at its greatest height on Sunday evening was about one foot higher than in the flood of 1801. In New Hartford, a saw mill and the west end of Merrills Bridge were carried away. The Naugatuck was higher at Seymour than at any previous freshet." The Hartford Courant, Wednesday, May 3, 1854: at Ansonia, Conn., "The water has never been known to be as high. It is from 12 to 15 inches higher than on the 13th of November last." The Hartford Courant, Saturday, May 6, 1854: At Gaylord's Bridge on the Housatonic River "the water is said to have been some 6 feet higher than at any point previously known, by the oldest inhabitant." A U. S. Geological Survey observer, G. H. Monroe, of Gaylordsville, Conn., in his notebook for 1902 states: "Highest water mark known. Height of water between piers 21 feet 3 inches. Got the measure Aug. 16, 1902." If this is correct, runoff in the Housatonic River here was about 50 cubic feet per second per square mile. In The History of the Old Town of Derby (Orcutt, 1880, p. 343) is found a flood height of 19 feet 8½ inches in the Housatonic River at Derby (then Birmingham), the highest during the period 1853 to 1879, according to John Whitlock, the observer.

3. January 22, 1891. On the 50th anniversary of this flood a Derby newspaper published the following: "Just 50 years ago *** water poured 12 feet over crest of Derby dam *** the largest flood ever to reach these towns on the lower banks of the Housatonic. At 5 p. m. Jan. 22 the gate tender reported 12 feet of water on the crest of the dam. Capstones started going off at 10-11 p. m. and eastern half of the dam was torn down to its foundations. Probably the greatest flood the two towns ever did or ever will witness."

4. March 1801. Perley (1891, p. 159), says this storm began March 18 and continued as a 4-day rain to produce the greatest flood ever known on the Farmington River. "No other freshet has equalled it." Bronson (1858, p. 112), calls it the "most recent of the great floods, previous to the two last" (Nov. 13, 1853, and Apr. 30, 1854).

5. September 21, 1938. From Geological Survey Water-Supply Paper 867: Upper dam of Farmington River at Collinsville (p. 553), 10.5 feet over 342.5-foot crest; Derby dam on Housatonic River (p. 554), "7.6 feet

Table 4. --Characteristics of streams

Index no.	Mean annual flood (cfs)	Drainage area (sq mi)	Non-contributing area (sq mi)	Effective drainage area (sq mi)	Main channel slope (ft/mi)	Tributary channel slope (ft/mi)	Average channel slope (ft/mi)	Effective area x Average slope (4) x (7)	Basin coefficient C_B	Computed mean (8) x (9)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	140	4.71	0	4.71	12.8	17.4	15.1	71.1	2.0	142
2	1,150	9.20	0	9.20	38.4	85.3	61.8	569	2.0	1,140
3	300	4.1	0	4.1	67.3	143.3	105.3	432	.85	367
4	650	22.0	0	22.0	34.5	49.5	42.0	924	.85	785
5	600	18.6	2.5	16.1	45.8	67.5	56.6	911	.85	774
6	2,400	92.0	17	75.0	48.7	87.7	68.2	5,120	.85	4,350
7	7,500	216	29	187	37.4	65.4	51.4	9,610	.85	8,170
8	8,000	584	129	455	12.6	46.2	34.4	15,400	.55	8,470
9	550	58.2	26.5	31.7	15.7	46.2	31.0	983	.55	541
10	1,000	745	17	57.5	15.1	55.0	35.0	2,010	.55	1,110
11	1,850	76.2	7.5	68.7	15.4	62.2	38.8	2,670	.85	2,270
12	2,000	57.1	4	53.1	47.9	68.7	58.3	3,100	.55	1,700
13	7,000	632	53	579	8.0	29.8	18.9	10,900	.55	6,000
14	11,000	994	69	925	9.3	18.8	14.0	13,000	.85	11,000
15	4,000	280	35	245	12.7	36.7	24.7	6,050	.55	3,330
16	20,000	1,545	160	1,385	8.5	26.4	17.5	24,200	.85	20,600
17	1,400	24.0	.8	23.2	57.5	87.0	72.2	1,680	.85	1,430
18	400	27.7	9.5	18.2	36.8	45.7	41.2	750	.55	412
19	500	11.6	0	11.6	44.2	67.2	55.7	646	.85	549
20	1,400	83.5	1.5	82.0	17.3	29.6	23.4	1,920	.85	1,630
21	1,000	29.1	0	29.1	51.2	43.5	47.8	1,400	.85	1,190
22	3,500	169	4	165	16.9	27.0	22.0	3,630	.85	3,090
23	9,000	246	10	236	17.6	57.4	37.5	8,850	.85	7,520
24	3,600	71.9	3	68.9	28.4	73.3	50.8	3,500	.85	2,980
25	2,400	74.0	10	64.0	9.4	17.4	13.4	858	3.0	2,570
26	1,250	25.3	1	24.3	14.6	16.4	15.5	377	3.0	1,130
27	1,450	40.6	9	31.6	14.6	18.4	16.5	521	3.0	1,560
28	1,700	45.2	10	35.2	54.1	54.6	54.4	1,920	.85	1,630
29	2,850	75.3	2	73.3	23.6	57.1	40.4	2,960	.85	2,520
30	8,000	711	96	615	7.8	21.4	14.6	8,980	.85	7,630
31	4,000	331	57	274	14.1	25.8	20.0	5,480	.85	4,660
32	1,900	157	19	138	16.1	34.4	25.2	3,480	.55	1,914
33	850	93.8	17	76.8	9.4	34.4	21.9	1,680	.55	924
34	1,800	109	7	102	7.4	33.0	20.2	2,060	.85	1,750
35	2,800	105	7	98	16.3	41.3	28.8	2,820	.85	2,400
36	1,800	77.5	33	44.5	27.4	36.8	32.1	2,060	.85	1,750
37	1,100	98.4	0	98.4	14.1	22.0	18.0	1,770	.55	974
38	3,400	133	0	133	28.4	35.6	32.0	4,260	.85	3,620
39	1,600	38.0	0	38.0	33.6	42.5	38.0	1,950	.85	1,660
40	7,200	401	18	383	14.4	13.9	14.2	8,210	.85	6,980
41	1,000	68.5	10	58.5	15.7	25.2	20.4	1,190	.85	1,010
42	3,000	204	27	177	11.0	34.2	22.6	4,000	.85	3,400
43	2,100	121	6	115	15.9	35.7	25.8	2,970	.85	2,520
44	2,500	88.6	5	83.6	22.2	23.8	23.0	2,460	.85	2,090

over top of about 0.5 foot of flashboards on 675-foot spillway." Average peak runoff from 20 Geological Survey gages used in this analysis, 102 csm (cubic feet per second per square mile); Housatonic River at Falls Village, Conn., 34.4 csm; Housatonic River near Barrington, Mass., 47.0 csm; Naugatuck River near Naugatuck, Conn., 107 csm.

6. January 8, 1874. From Geological Survey Water-Supply Paper 798, p. 458: Derby dam, 7.8 feet over 636- or 637-foot spillway. Orcutt (1880, p. 343) lists a flood height of 17 feet 4½ inches in the Housatonic River at Derby (the Birmingham), determined by John Whitlock. Campbell, Sharpe, and Bassett, (1902, p. 15) state that water rose 17 feet 6 inches at Seymour on the Naugatuck River.

7. October 4, 1869. Known as "The Pumpkin Flood." Campbell, Sharpe, and Bassett (1902, p. 15) say that the water rose 15 feet 9 inches at Seymour on the Naugatuck River. Orcutt (1880, p. 343) lists a flood height of 16 feet in the Housatonic River at Derby (then Birmingham), determined by John Whitlock. Sharpe (1879, p. 102) states: "The Naugatuck rose to the highest point reached in 15 years" (since 1854). From Geological Survey Water-Supply Paper 798, p. 457: Upper dam on Farmington River at Collinsville, Conn., 10 feet over 329.6-foot crest. Porter (1880, p. 72) states: "In the great storm of Oct. 3 and 4, 1869, the water poured over the Collinsville dam 10 feet deep. This storm was a most remarkable one and caused widespread damage in New England. It appeared to be central 2 or 3 miles east of New Hartford, where a downfall of 12.35 inches was recorded. The amount was above 8 inches for the entire Farmington River Basin." Also, "While (Derby) dam was in process of construction, and indeed nearly complete, a violent storm which swept over this part of the country caused a heavy freshet in the Housatonic; water poured 13 feet deep over the partially finished dam, undermined and destroyed 160 feet of its length and scoured out an immense cavity 20 feet deep on the river bed immediately below." (Probably 13-foot depth was over partly finished portion since height of river at Birmingham did not indicate such an extraordinary stage over the actual spillway). Hartford Courant, Friday, October 8, 1869, says of the Farmington River at Collinsville, "At 4 p.m. Monday, the water had reached a higher point than at any time since the great ice flood of 1857."

8. January 1, 1949. Average runoff from 20 Geological Survey gages, 72.9 csm; Housatonic River at Falls Village, Conn., 41.3 csm; Housatonic River near Great Barrington, Mass., 49.8 csm; and Naugatuck River at Naugatuck, Conn., 120.8 csm.

9. March 12, 1936. From Geological Survey Water-Supply Paper 798, p. 457: Upper dam of Farmington River at Collinsville 9.0 feet over 342.5-foot crest. Derby dam on Housatonic River, 7.4 feet over 675-foot spillway (natural peak). Average peak runoff from 20 Geological Survey gages, 79.1 csm; Housatonic River at Falls Village, Conn., 25.0 csm; Housatonic River near Great Barrington, Mass., 36.7 csm; and Naugatuck River at Naugatuck, Conn. 98.7 csm.

10. January 1770. Perley (1891, p. 78), relates that this storm began January 7, 1770, "the greatest freshet perhaps that ever occurred in New England." Ice was present. Farmington River high. At Simsbury, iron works of Richard Smith were carried away.

11. November 1927. From Geological Survey Water-Supply Paper 798, p. 457, 458: Upper dam of Farmington River at Collinsville, 9.0 feet over 342.5-foot crest; Derby dam on Housatonic River, 5.4 feet over 675-foot spillway; Housatonic River at Falls Village, Conn., 20.2 csm; Housatonic River near Great Barrington, Mass., 32.3 csm; and Naugatuck River at Naugatuck, Conn., 131 csm.

In computing recurrence intervals for the recorded floods, a period of 320 years (1634 to 1953) was used for the September 1938 flood, for it was considered extraordinary enough so that none probably equaled or exceeded it during the period 1634 to 1691. For the other floods of November 1927, March 1936, and January 1949, the base period of 262 years from 1691 to 1953 was used, for it is possible any one of these floods might have been exceeded before 1691. The following table gives the original plotting positions for these 4 floods based upon 41 years of record and the new plotting positions based upon historical data (order of magnitude in parenthesis):

Flood of		Ratio to mean annual flood	Recurrence interval	
			41 years	Historical
November	1927	2.188	10.5 (4)	23.9 (11)
March	1936	2.440	14.0 (3)	29.2 (9)
September	1938	3.106	42.0 (1)	64.0 (5)
January	1949	2.593	21.0 (2)	32.9 (8)

In eastern Connecticut historic flood information was not so complete, but the following list of floods arranged in approximate order of magnitude was used to position the two outstanding floods of March 1936 and September 1938. The floods of November 1927 and January 1949 were not outstanding floods in eastern Connecticut.

1. September 21, 1938. From Water-Supply Paper 867, p. 553: Greenville Dam, on the Shetucket River at Norwich, 14.5 feet over 401-foot crest.

2. February 7, 1807. Caulkins (1874, p. 353) states that "The Shetucket River rose 18 or 20 feet.*** For many years no such inundation had been known." Many bridges were lost. Perley (1891, p. 176), confirms the fact that the Shetucket River rose from 18 to 20 feet and also infers that this flood was greater than that of 1801 on the Shetucket River.

3. March 26, 1876. From Water-Supply Paper 798, p. 553: Greenville Dam on the Shetucket River at Norwich, 12 to 14 feet over a 326-foot crest (approximately equivalent to 11.5 feet over a 1938 crest length of 401 feet, assuming same crest coefficients). Porter (1880, p. 20), states that "The Shetucket River rose to such a height as to run 10 feet deep over the Taftville Dam, and 12 to 14 feet deep over that at Greenville. *** Through the preceding week heavy rains had filled all the reservoirs and during Saturday night (March 25) drenching showers carried the streams out of their beds. The storm was general and disastrous in Connecticut, Rhode Island and Massachusetts; it was stated that in the vicinity of Providence 4.06 inches of rain fell during Saturday and Saturday night making 7.66 inches in six days. The losses by this freshet were estimated to amount to several hundred thousand dollars in eastern Connecticut."

4. March 19, 1936. From Water-Supply Paper 798, p. 451: Greenville Dam on Shetucket River at Norwich, 11. 1 feet over crest partly due to dam failures upstream (approximately equivalent to 10. 5 feet over 401-foot crest, adjusted to natural flow).

The 1938 flood was considered the greatest in eastern Connecticut in the historic period of 320 years (1634 to 1953) and probably was not exceeded for many years before 1634. Its recurrence interval was therefore taken as 321 years instead of 36. 0 years as indicated by the 35-year period of record. The 1936 flood was considered the fourth-ranking flood in a period of 216 years, 1737 to 1953, as no adequate accounts of flood events before 1737 were found; its recurrence interval was, therefore, taken as 54. 3 years instead of 18. 0 years as indicated by its second place in the 35-year period of record.

The new plotting positions obtained for outstanding floods of record in eastern and western Connecticut by analysis of the foregoing historical data define very well the position of the frequency curve above a recurrence interval of 6 years, and they were used in drawing the final frequency curve which is shown on figure 3. Its position seemingly cannot be further improved on basis of currently available information. It is possible, however, that as time progresses and added information becomes available, a flatter curve may be indicated, and the recurrence interval of the 1938 flood, in eastern Connecticut at least, here taken as 321 years, may be found too low. Until such time, the curve used in this report may give ratios to mean annual floods too high for frequencies greater than perhaps once in 10 years, but such results are doubtless on the safer side in dealing with the vagaries of future flood events.

INFLUENCE OF TOPOGRAPHIC CHARACTERISTICS

Mean annual flood discharge at any given site on a stream results from the integrated influences of innumerable meteorologic, topographic, and geologic factors upon the precipitation which falls on the drainage basin above it. It is impractical, if not impossible, to evaluate them all in a study of this kind, and the problem resolved itself into finding the major factors of correlation and resolving them into as simple a relationship as possible that would give results of an acceptable accuracy. Simplicity of relationship was emphasized and striven for from beginning to end of this study.

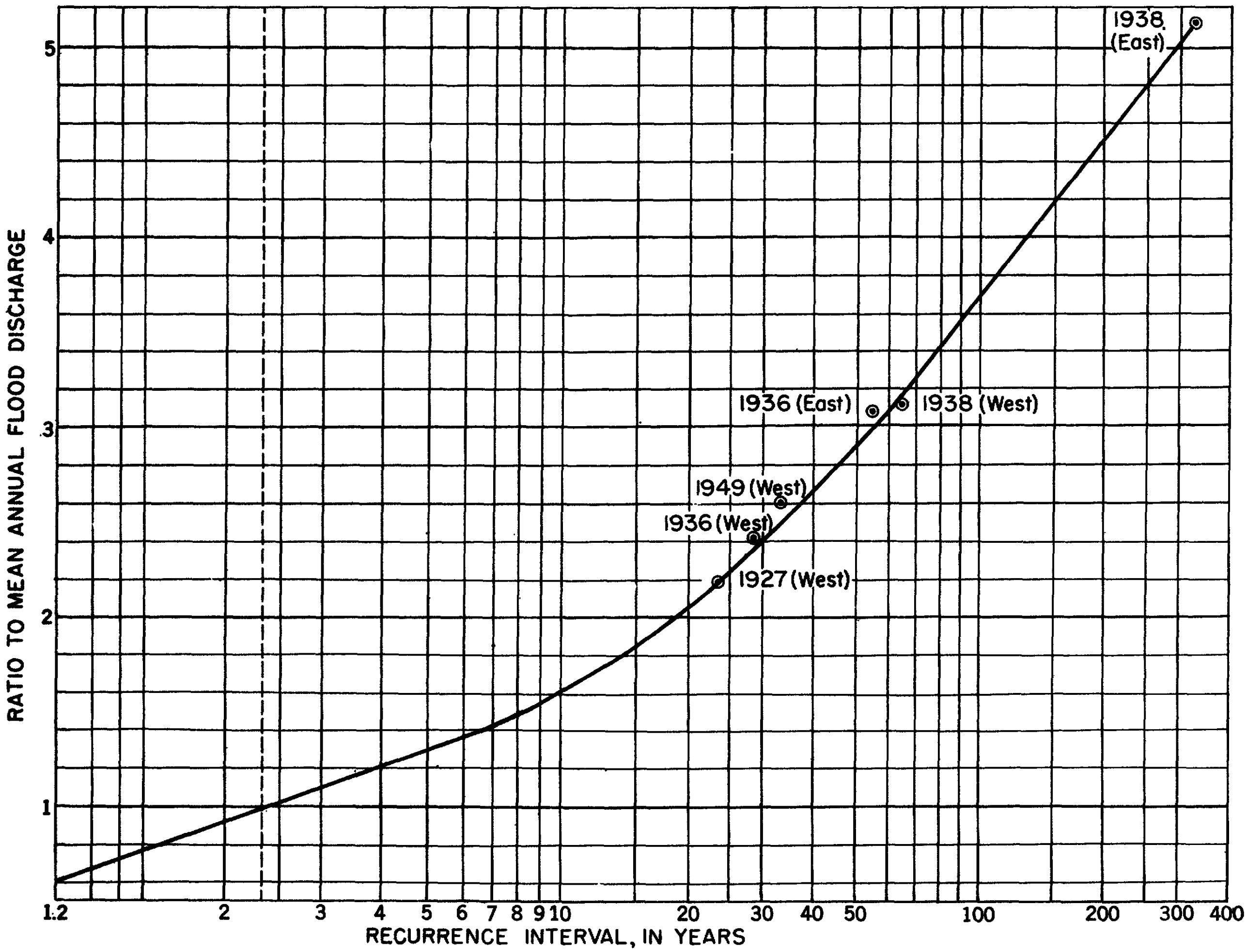

Figure 3. --Flood magnitude and frequency curve, ratios to mean annual flood.

Meteorological factors, such as evaporation and transpiration, are probably relatively uniform in a homogeneous area such as Connecticut. Their effects in causing variations in mean annual flood flows were, therefore, considered negligible. Geological factors, too, are probably relatively uniform, as the eastern and western Highlands are similar in that both are made up of old eroded metamorphic rock overlain by debris. Most of the streams in the State on which records are available rise in these Highlands. There are probably some contrasting effects from the geology of the Central Lowland upon the mean annual floods of streams flowing through that area, but for this study it seems probable that geologic factors cause relatively small variations, if any, in the mean annual flood discharge in the Connecticut area.

Factors classified under the term topographic do not exhibit the uniformity of metorologic or geologic factors. They may be grouped under such headings as (1) surface area--land, water, swamp, (2) altitude--maximum, minimum, mean, or median, (3) slope--of land, of main stream channel, of tributary stream channels, (4) shape of basin--length, width, form factor (length divided by width), and (5) surface cover--wooded, grassed, cultivated. Of these factors, investigation indicated that the effect of variations of altitude within the Connecticut area was negligible, and the types of vegetative cover averaged so closely similar on all basins that their effects could be neglected. The remaining factors of area, slope, and shape of the basin received concentrated study. Basin shape was found insignificant.

For years it has been recognized by hydrologists and engineers that one of the major factors of correlation in a flood-flow formula is the drainage area of the basin above the point of measurement. The form of the relation is generally $Q = CA^n$, where Q is the peak discharge in cubic feet per second, C is a constant, and A is the drainage area in square miles. The exponent, n, varies from 0.5 to 0.8. Correlation of mean annual flood with drainage area (data in table 4) for the Connecticut area resulted in the formula $Q = 55A^{0.8}$ for the average curve based on the data in this report. That the area factor was not the sole factor in the problem, however, was indicated by the fact that the plotted data scattered about the curve in an enveloping band ranging about 50 percent low and 125 percent high of the mean curve, disregarding one point outside the band. As a much closer correlation was necessary other factors were investigated, among them average fall, total fall and length of longest watercourse, and length and width of basin. Also investigated were slope factors, such as the total and average slope of longest watercourse; shape factors, such as length and width, stream density, form factor of basin; and the relation between the drainage area at the average basin altitude and the total drainage area. The use of none of these various factors seemed to improve the relationship already established between mean annual flood and drainage area.

Further study of the relationship between mean annual discharge and drainage area (fig. 4) disclosed that plotted data for some groups of stations along the main stems of the larger streams, such as the Housatonic, Quinebaug, and Shetucket Rivers, seemed to define two separate straight-line relationships of the form $Q \propto KA^{1.0}$. These relationships are indicated in figure 4 by dashed lines connecting the plotted positions for the 3 lower stations at Falls Village (13), Gaylordsville (14), and Stevenson (16) on the Housatonic River; the 4 stations at Westville (33), Quinebaug (32), Putnam (31), and Jewett City (30) on the Quinebaug River; and the stations on the Willimantic River near South Coventry (43) and Shetucket River near Willimantic (40). Assuming this relationship between mean annual discharge and drainage area to be true, it remained to discover the major basin characteristics represented by the factor K. It became evident that this factor was a function of slopes of channels in the basin; therefore, various slope factors were tried, such as total slope of main channel, average slope of main channel, and finally the weighted slope of the main channel obtained by dividing the difference between the average altitude of the main channel and the altitude at outlet (point of study) by half the length of the same watercourse. This slope value is weighted in favor of the slope of the lower reaches of the stream channel. Correlation of the products of drainage area and this weighted main-channel slope, S_M, with the mean annual flood showed a considerable improvement, with the values for the station groupings on each major stream still plotting as simple relationships, $Q \propto S_M$, with exponents of unity. Then, some further improvement was discovered by modifying the main channel slope factor, S_M, by averaging it with the average slopes similarly determined for major tributaries, defined as those draining 10 percent or more of the total effective drainage area. In the absence of these major tributaries to the main channel, its uppermost reach above a point where 10 percent of the total effective watershed area is drained should be considered as a tributary. Slope factors for each station are shown in table 4.

Using the data shown in table 4, the final correlation, Q vs AS_{avg}, for the 44 gaging station locations (fig. 5), resulted in what may be analyzed as 3 lineal groupings of plotted data, the major one applying to most streams in the area, characterized by watersheds largely rural with a general similarity of physical features, designed "normal" for the State. Of the two other groupings, one applies to streams, otherwise normal, but having abnormal amounts of channel storage, and the second includes streams draining urban residential areas. Two stations, 1 and 2, are intermediate in position between the normal and the urban-residential curves and probably represent "suburban" conditions. The primary expression for mean annual discharge, that for streams of so-called normal characteristics, applicable to a large percentage of streams in the State, took the form $Q = 0.85AS$, in which the coefficient may reduce to 0.55 in places of unusual channel storage capacity. For streams draining urban residential watersheds a multiplier of 3.0 is indicated. Estimated mean annual floods for all stations by use of this formula are shown in table 4. The standard errors of estimate were found to be 13.2 percent for the 29 stations on streams having basins with normal characteristics, and 13.1 percent for the 10 stations on streams affected by an excess of channel storage. Values of the mean annual flood plotted within about 20 percent of their respective curves of relationship. Therefore, the maximum error to be expected from use of these formulas for rural conditions is about 20 percent, providing that the extent of channel storage is properly evaluated. The standard error, which includes 68 percent of all cases, is about 13 percent. In those places where the degree of urbanization must be estimated, unknown and possibly larger errors may be involved.

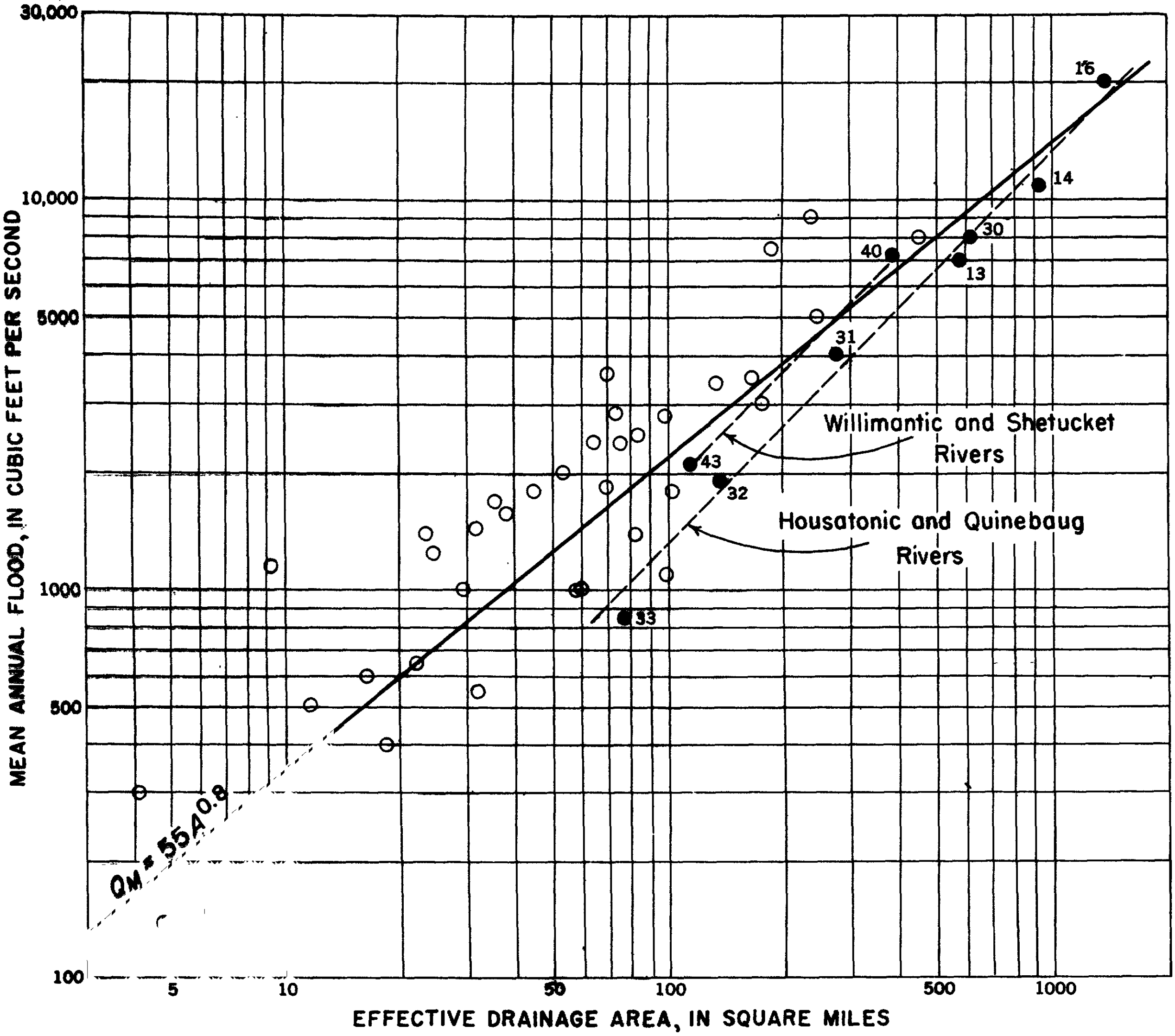

Figure 4. --Relation of mean annual flood to drainage area.

In using these curves, it must be remembered that the "normal" curve is that best defined by the bulk of the data, and the condition which will be represented by most design locations. Other curves should be considered as guides for the engineer in extending the relationships to conditions of abnormal slope or of urbanization, rather than as defining specific conditions.

Caution should be exercised in applying the formula to streams draining areas of less than 10 square miles, and particularly those of less than 5 square miles. The curves of figure 5 are not adequately defined for a product of drainage area times channel slope of less than 300. Application of the formula to streams of greater drainage area than 1,500 square miles also should be made with caution. The formula is not intended to apply to the Connecticut River within Connecticut, the drainage area of which is around 10,000 square miles. These limitations obviously must be established because of the inadequacy of data beyond these extremes.

SUMMARY OF PROCEDURE

The step-by-step procedure in the application of this flood-frequency formula is as follows:

1 On topographic maps, outline and measure (with a planimeter or by other means) the drainage area above the selected outlet point or point of study on the stream.

2. Outline and measure the portions of the drainage area not contributing to flood volumes. Such portions of the drainage area include the watersheds of ponds and reservoirs on headwater streams having a relatively large surface area with respect to the drainage area and of other ponds and reservoirs elsewhere of a size that would impound a considerable proportion of the flood volume, and thus delay the runoff from those parts of the basin to the extent that their contribution to the flood crest at the outlet is unimportant.

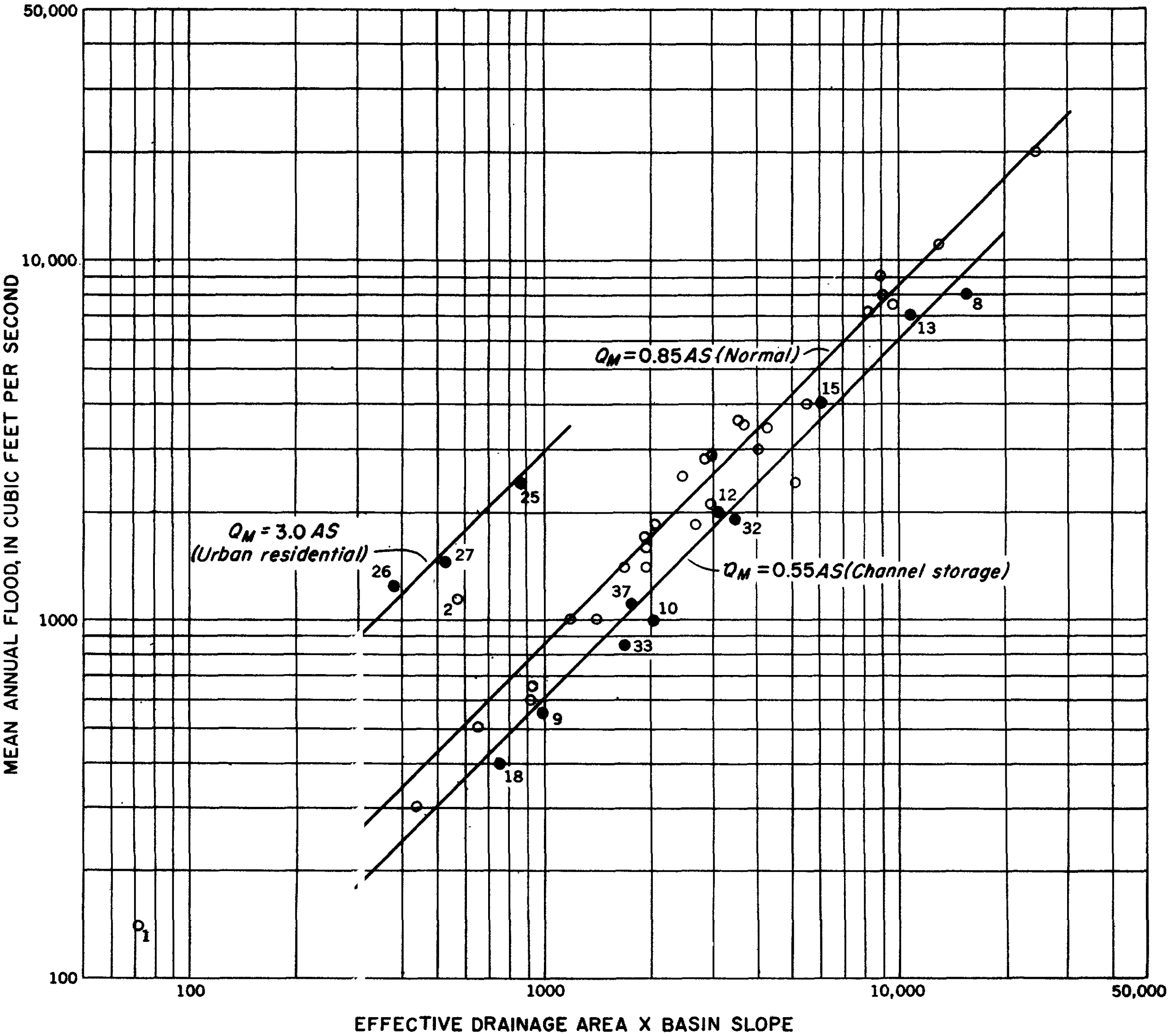

Figure 5. --Relation of mean annual flood to product of drainage area and basin slope.

3. Note whether the watershed comprises two or more tributaries of comparable basin size that have confluence closely upstream from the outlet point. If so, each tributary basin must be treated separately and their respective peak flows added to determine peak flow at the outlet.

4. Determine the effective drainage area above the outlet point as the total drainage area less the combined areas of the noncontributing portions.

5. Select the main channel, usually the longest continuous water-course, and determine the mean altitude along its profile by graphical or arithmetical means. Subtract from this value the altitude of channel at the outlet point and divide the result by one-half the length of the channel in miles. This is the so-called slope of main channel, expressed in feet per mile. Source of a stream may be defined as the upstream beginning of its main channel as shown on a standard topographic map.

6. Select all tributary streams which drain more than about 10 percent of the effective drainage area at the outlet. Determine the slope of each tributary (main stem only) by the method outlined for the main channel in paragraph 5 above. Average the slopes for all such tributaries. This value is the so-called tributary-channel slope. If there are no tributaries draining more than about 10 percent of the total effective drainage area, the slope of the uppermost reach of the main watercourse that drains 10 percent of the total effective drainage area should be used.

7. Determine the basin channel slope as the average of the main channel slope and the tributary channel slope. This is the slope (S) in the derived formula for mean annual flood.

8. From personal knowledge or from an inspection of the effective drainage area on topographic maps, classify the basin as normal, suburban, or urban residential

and decide whether or not the stream course in flood may contain abnormal channel storage. Abnormal channel storage is usually evidenced by a meandering stream course and flat stream profile in the middle or lower reaches of the river. Urban residential classification includes watersheds of intensive residential and street development, whereas suburban areas show substantially less development of similar type.

9. Compute the mean annual flood from the formula $Q_M = 0.85AS$, if the basin has normal characteristics. If there is an abnormal amount of channel storage, a coefficient approaching 0.55 must be selected. For streams in semisuburban areas, the basin coefficient might range between 1.0 and 1.5, for suburban areas from 1.5 to 2.5, and for urban residential areas from 2.5 to 3.0, the upper limit of definition by the base data employed herein.

10. Select the recurrence interval desired from consideration of the type of structure, its economic life, or whether its destruction might result in undue damage or loss of life.

11. Apply the selected recurrence interval to the frequency curve (fig. 3) to determine the ratio to mean annual flood corresponding to the selected recurrence interval.

12. Compute the design flood rate as the product of the mean annual flood value and the ratio to the mean for the selected frequency.

In essence, of course, the several procedural steps given above amount to the determination of the factors in the complete flood-flow formula:

$$Q = R(C_B AS)$$

in which R is the design ratio from the frequency curve, and $C_B AS$ is the mean annual flood based on the watershed characteristics.

EXAMPLE OF APPLICATION OF FORMULA

As an example of the application of the method outlined above, an analysis is presented for the existing gage site on Leadmine Brook near Thomaston, Conn. From observation and reference to the topographic map, this basin appears as one of normal type, the stream draining rural farmland and wooded areas and having a channel rather rough and steep, with no abnormal amount of channel storage along its course.

An outline of the basin above the gage on the topographic map (fig. 6), encloses the entire drainage area, which was found to be 24.0 square miles. Inspection indicated that the drainage areas above the outlets of two ponds in the headwaters probably were not effective in contributing to peak flows at the gage site, as their surface areas are large in proportion to their drainage areas, and flood runoff from these areas would be considerably delayed by storage in the ponds. The total noncontributing drainage area was 0.8 square mile, leaving a total effective basin area of 23.2 square miles. Although the adjustment here involved is only about 3½ percent, and virtually negligible, it is possible to find reductions in other watersheds of much greater proportion. Inspection of the map shows that the stream above the gage site comprises a single main stem with 2 major (10 percent) tributaries, and further subdivision of the area is unnecessary for computation purposes.

Plots on figure 6 of the profile of the main stem and the two tributaries that drain more than 10 percent of the effective drainage area indicate that, for the main stem, the slope factor is 57.5 feet per mile, whereas, for the two tributaries, the values are 81.0 and 93.0 feet per mile, respectively, or an average of 87.0 feet per mile. Computing basin channel slope as the average of the main channel slope of 57.5 feet per mile and the average tributary slope of 87.0 feet per mile results in a value of 72.2 feet per mile for substitution in the formula.

From the topographic map it is evident that the basin above the gage site is entirely rural, and that, since the main stem has no abnormally flat reaches or ponds along its course, the stream may be classified as of normal type with a formula coefficient of 0.85.

The mean annual flood for this gage site is then computed as the product of the basin coefficient (0.85), the basin channel slope (72.2 ft per mile), and the effective drainage area (23.2 sq mi), or 1,430 cfs which, in this case, is within 2 percent of the observed median annual flood of 1,400 cfs for this site.

For selected recurrence intervals of 15, 50, and 100 years, factors of 1.85, 2.9, and 3.7, respectively, are found from the flood-frequency curve (fig. 3). These factors, multiplied by the computed mean annual flood of 1,430 cfs, result in peak flood flows expected to recur once every 15, 50, or 100 years, namely, 2,600, 4,200, and 5,300 cfs, respectively.

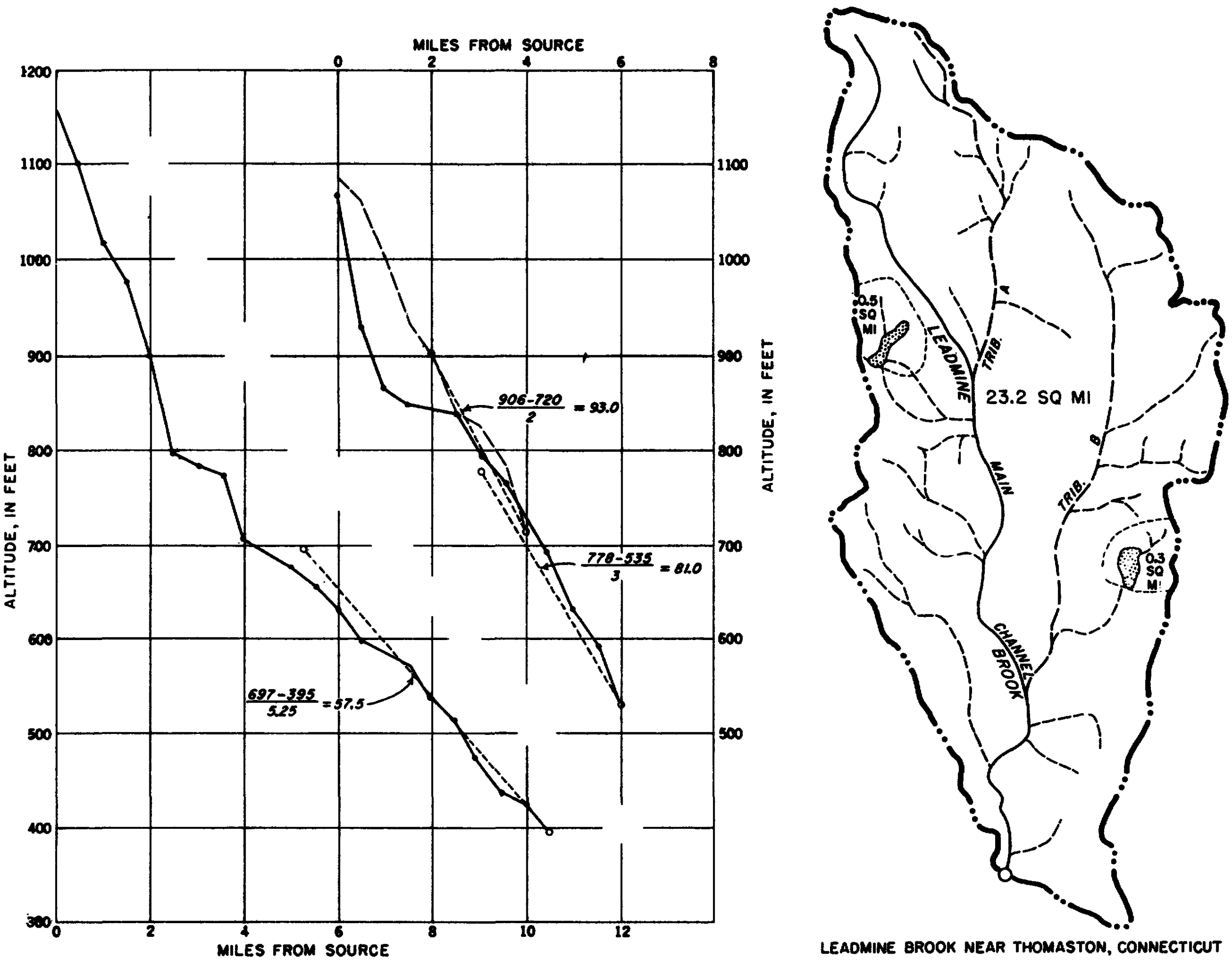

Figure 6. --Topographic characteristics of a typical stream.

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