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Uniform Flood-Frequency Estimating Methods for Federal Agencies

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Abstract. Large-scale planning for improved flood-plain management and expanding water-resources development has made it increasingly important that a consistent approach be adopted for estimating flood frequencies, a major analytical component in studies required in flood-plain management and, in a larger sense, in river-basin management. A Federal interagency group has studied the most commonly used methods of flood-frequency analysis and has compared the results of applying these methods to a selected group of long-record representative sites in different parts of the country. Based on these comparisons and on other considerations, it is recommended that all government agencies adopt a uniform procedure for flood-frequency analysis at sites where records are available. The log-Pearson Type III distribution has been selected as the base method, with provisions for departures from the base method where justified. Continuing study leading toward improvement or revision of methods is recommended. (Key words: Floods; rivers; statistics)

NOTATION

The following symbols are used in this paper:

g = skew coefficient;
K = Pearson Type III coordinates;
M = mean of the logarithms of flood magnitudes;
m = order number, starting with 1 as the highest, of a series of floods arranged in order of magnitude;
n = total number of items in a record of annual floods;
Q = computed flood flow for a selected recurrence interval or per cent chance;
Q_D = data value of flood at selected recurrence interval, interpolated between adjacent observed peak annual floods;
S = standard deviation of the logarithms of flood magnitudes;
X = logarithm of a flood magnitude;
Y = arithmetic magnitude of an annual flood event.

INTRODUCTION

Stream discharges and flood flows have long been measured and used by engineers in the design of hydraulic structures and flood-protection works and in planning for flood plain use. A flood-frequency analysis is the basis for the engineering design of many projects and the economic analysis of flood-control projects.

Methods of flood-frequency analysis, which started about 1914, have developed along divergent lines, with resulting nonuniformity in methods of analysis and, hence, in results. The present state of the art is such that no general agreement has been reached as to preferable techniques, and no standards have been established for design purposes, as has been done in other branches of engineering.

Government agencies have been active in the development of frequency analysis, and many agencies have developed flow-frequency information for their own use or for use by other agencies or the public. However, the methods used have been different, and situations have arisen where conflicting values for the same situation have been furnished to the public, thus causing confusion and questioning of such results.

There are many programs of national scope involving large expenditures of public funds that depend on flood-frequency analysis. Among these are: the large national highway program that includes bridge and drainage design, the flood-protection program, and a pending program of flood insurance on a national scale. It is in the public interest that a sound method of flood-frequency analysis be used and that a consistent approach be adopted so that costs and benefits may be assessed on a uniform basis.

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These circumstances were recognized by a Task Force on Federal Flood Control Policy which, in August 1966, transmitted a report to the President entitled 'A Uniform National Program for Managing Flood Losses.' This report was subsequently submitted to the Congress [*House Doc. 465,* 1966]. In the report the following statements are included relating to flood-frequency methods:

> Techniques for determining and reporting the frequency of floods used by the several Federal agencies are not now in consistent form. This results in misunderstanding and confusion of interpretation by State and local authorities who use the published information. Inasmuch as wider, discerning use of flood information is essential to mitigation of flood losses, the techniques for reporting flood frequencies should be resolved.

Recommendation 2 of the report [*House Doc. 465,* 1966] states: 'A uniform technique of determining flood frequency should be developed by a panel of the Water Resources Council.' The Water Resources Council is a Federal agency established in 1965 under the Water Resources Planning Act [*Public Law 89-90,* 1965]. Its members are officers of the President's Cabinet. In addition to a headquarters staff, the Council has policy, planning, state grants, and technical committees composed of representatives from Federal agencies. In Recommendation 2, the Task Force specified further:

> . . . The panel should be directed to examine methods of frequency analyses with regard to their sufficiency for applying various techniques of flood damage abatement. After this review the panel should present a set of techniques for frequency analyses that are based on the best of known hydrological and statistical procedures . . . Its report should describe those procedures among the suitable methods which, in its judgment, should be standardized in Federal practice. . . .

The Water Resources Council implemented these recommendations through its Hydrology Committee, which established a Work Group on Flow-Frequency Methods. Various agencies in the Hydrology Committee designated their representatives to the Work Group (see Acknowledgments). The Work Group obtained the services of two professional statisticians as consultants: Joan R. Rosenblatt of the National Bureau of Standards and Geoffrey S. Watson of The Johns Hopkins University.

INVESTIGATIONS

The Work Group decided that several methods of flood-frequency analysis in common use among Federal agencies and elsewhere would be applied to a group of 10 long-term records of annual flood peaks at selected locations in the continental United States. These stations represent different climatic regions and hydrologic conditions and have a large range and a good distribution of drainage area size. Only long-record stations were considered, because their underlying flood distributions are less apt to be obscured by erratic chance variations. At each station selected, the annual flood peaks were essentially unaffected by artificial regulation. Each record was scanned to see that it did not contain any single outstandingly high flood event. This was done to avoid, in the test set, the controversial question of the treatment of so-called 'outliers.' It was not intended that this question be ignored, but it is one of several related problems that will be the subject of future study by the Work Group. Gaps in the records were not filled in. The objective was to examine the general applicability of each of the methods of flood-frequency analysis and to postpone consideration of other problems involved in data handling. Table 1 lists the ten test stations, their U. S. Geological Survey inventory numbers, drainage areas, and the number of years of peak flood record through 1965.

The flood data for these stations were submitted to those agencies that had digital computer programs or standardized procedures for computing flood-frequency relations and that volunteered to apply the methods to the data (these were not necessarily methods used by the agencies in their operations.)

The following six methods were applied to the flood series: (1) 2-parameter gamma distribution; (2) Gumbel distribution; (3) log-Gumbel distribution; (4) log-normal distribution; (5) log-Pearson Type III distribution; (6) Hazen method. These methods are not entirely different. For example, the log-normal distribution is a special case of the log-Pearson Type III distribution, for conditions where the skew coefficients of the logarithms of the flood magnitudes are zero. The 2-parameter gamma

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U. S. Geol. Su Inventory No
1–1805
2–2185
5–3310
6–3340
6–8005
7–2165
8–1500
10–3275
11–0980
12–4570

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TABLE 1. Ten Test Stations

U. S. Geol. Surv. Inventory No.	Location	Drainage area (sq. mi.)	Years of record (through 1965)
1–1805	Middle Br. Westfield River at Goss Heights, Mass.	52.6	55
2–2185	Oconee River near Greensboro, Ga.	1,090	62
5–3310	Mississippi River at St. Paul, Minn.	36,800	97
6–3340	Little Missouri River near Alzada, Wyo.	904	49
6–8005	Elkhorn River at Waterloo, Nebr.	6,900	44
7–2165	Mora River near Golondrinas, N. Mex.	267	40
8–1500	Llano River near Junction, Texas	1,874	51
10–3275	Humboldt River at Comus, Nev.	12,100	50
11–0980	Arroyo Seco near Pasadena, Calif.	16.4	51
12–4570	Wenatchee River at Plain, Wash.	591	53

distribution is a special case of the Pearson Type III distribution (also known as the 3-parameter gamma), in which one of the three parameters has a value of zero. The Hazen method is an early version of log-normal curve-fitting in combination with empirically derived coefficients for fitting skewed distributions. The original Hazen procedures permitted arbitrary adjustments to arrive at close fit to the data.

All of these methods and the procedures for applying them to the data are described in several textbooks and have been summarized in a recent publication [*Interagency Comm., Bull. 13,* 1966].

Another method in common use but not considered in the testing procedure is the graphical method of curve fitting. By any criterion of goodness of fit which has as its basis the closeness of the curve to the data points, the graphical curve would in most instances appear more suitable than a fitted mathematical curve. Yet this has little meaning, because the question may always be asked, 'Which of the many possible graphical curves is to be used?' A curve may be drawn that passes through every data point, thus apparently fitting the data perfectly. Yet no one would accept this as representing the true frequency relation or the pattern to be expected in the future. Operationally, the graphical method is not actually inferior to other methods, because the range of uncertainty caused by sampling variation is always large.

The graphical curve may be varied subjectively over a range of possible positions; this range is small at the lower end of the flood range but may be large at the upper end. Graphical fitting involves the risk of bias on the part of the curve fitter, which may vary with every individual and every situation. Such bias is difficult to evaluate or eliminate. The faith of the curve fitter in his own judgment is frequently not shared by others. In the case of a mathematical fitting procedure, any particular method can be tested and eliminated if there is inherent bias in fitting flood data, either in general or within a particular region.

Objectivity is particularly important in programs of national scope, where uniformity, soundness, and lack of bias in analytical methods are essential for the efficient use of national resources. It is for this reason that another technique than the graphical method was sought. If methods of data-fitting are available that are objective, fit the data closely, produce unbiased results, and in addition can utilize automatic computation, it would be advantageous to use them.

In applying the six different methods of flood-frequency analysis, five of the six were fitted by programs of more than one agency. In all, 14 sets of computations were made, one for the Hazen method, two for the 2-parameter gamma, Gumbel, and log-Gumbel distributions, three sets (by two agencies) for the log-Pearson Type III distribution, and four for the log-normal distribution. Results of the fitting for the 14 separate computations are shown in Table 2.

Each of the agencies that computed one or

TABLE 2. Computed Flood Discharges (cfs) for Selected Recurrence Intervals, by All Methods

Method	Comp. No.	Recurrence Interval (years)					
		2	5	10	25	50	100
		Station No. 1-1805					
2-Parameter Gamma	1	3,214	5,599	7,206	9,211	10,671	12,099
	2	3,040	5,400	7,100	9,180	10,680	12,100
Gumbel	1	3,231	6,583	8,802	11,606	13,686	15,751
	2	3,208	6,261	8,282	10,835	12,730	14,610
Log-Gumbel	1	2,653	5,055	7,746	13,282	19,814	29,473
	2	2,642	4,751	7,007	11,449	16,480	23,657
Log Normal	1	2,946	5,154	6,904	9,428	11,530	13,813
	2	2,947	5,153	6,902	9,424	11,525	13,812
	3	3,000	5,200	7,100	9,700	12,000	14,600
	4	2,690	5,510	8,080	12,070	15,650	19,720
Hazen	1	2,530	4,890	7,480	12,200	16,980	22,990
Log Pearson Type III	1	2,770	5,020	7,110	10,600	13,900	18,100
	2	2,790	5,050	7,110	10,700	14,000	18,100
	3	2,790	5,050	7,120	11,200	15,000	20,000
		Station No. 2-2185					
2-Parameter Gamma	1	13,755	22,484	28,208	35,249	40,328	45,261
	2	13,800	22,500	28,500	35,300	40,800	45,700
Gumbel	1	13,855	24,476	31,508	40,393	46,985	53,528
	2	13,788	23,535	29,988	38,142	44,192	50,196
Log Gumbel	1	11,675	21,090	31,197	51,161	73,843	106,293
	2	11,632	20,020	28,683	45,180	63,290	88,438
Log Normal	1	12,866	21,577	28,271	37,705	45,415	53,670
	2	12,866	21,581	28,282	37,732	45,455	53,746
	3	12,800	21,700	28,600	38,500	47,000	56,500
	4	12,600	22,290	30,030	41,230	50,570	60,680
Hazen	1	12,180	21,260	29,410	42,030	53,220	65,920
Log Pearson Type III	1	12,500	21,300	28,600	39,400	48,800	60,400
	2	12,600	21,500	28,500	39,200	48,500	59,400
	3	12,600	21,500	29,000	40,500	51,000	63,000
		Station No. 5-3310					
2-Parameter Gamma	1	36,578	59,207	73,989	92,125	105,187	117,861
	2	35,800	58,400	73,400	91,600	104,800	118,100
Gumbel	1	37,046	61,868	78,303	99,068	114,473	129,764
	2	36,939	60,259	75,699	95,207	109,681	124,046
Log Gumbel	1	31,039	55,917	82,565	135,095	194,664	279,742
	2	30,948	53,816	77,625	123,320	173,840	244,440
Log Normal	1	34,313	58,113	76,532	102,634	124,060	147,077
	2	34,311	58,095	76,520	102,640	124,080	147,170
	3	34,800	59,000	77,500	104,000	127,000	152,000
	4	34,550	57,910	76,240	101,560	122,660	144,930
Hazen	1	34,170	57,390	75,860	102,460	124,580	148,520

All Methods

	100
71	12,099
30	12,100
36	15,751
30	14,610
14	29,473
30	23,657
30	13,813
25	13,812
00	14,600
50	19,720
80	22,990
00	18,100
00	18,100
00	20,000
28	45,261
00	45,700
85	53,528
92	50,196
43	106,293
90	88,438
15	53,670
55	53,746
00	56,500
70	60,680
220	65,920
300	60,400
500	59,400
000	63,000
187	117,861
800	118,100
473	129,764
681	124,040
664	279,742
840	244,440
060	147,077
080	147,170
000	152,000
660	144,930
580	148,520

TABLE 2 (*continued*)

Method	Comp. No.	Recurrence Interval (years) 2	5	10	25	50	100
Log Pearson Type III	1	35,000	58,400	75,300	98,200	115,000	132,000
	2	34,900	58,000	74,800	98,000	115,000	132,000
	3	34,900	58,000	76,000	100,000	117,000	135,000
Station No. 6-3340							
2-Parameter Gamma	1	1,968	3,327	4,232	5,353	6,166	6,959
	2	1,960	3,310	4,260	5,390	6,180	6,970
Gumbel	1	2,057	3,401	4,291	5,416	6,250	7,079
	2	2,034	3,321	4,173	5,250	6,049	6,841
Log Gumbel	1	1,623	3,337	5,377	9,826	15,367	23,954
	2	1,614	3,098	4,771	8,233	12,341	18,443
Log Normal	1	1,822	3,388	4,686	6,620	8,277	10,113
	2	1,822	3,390	4,691	6,632	8,281	10,141
	3	1,830	3,400	4,750	6,900	8,700	11,000
	4	1,940	3,170	4,100	5,380	6,440	7,540
Hazen	1	2,130	3,380	4,120	5,000	5,620	6,210
Log Pearson Type III	1	2,010	3,420	4,290	5,200	5,860	6,420
	2	2,010	3,400	4,250	5,200	5,850	6,410
	3	2,010	3,420	4,300	5,330	6,000	6,650
Station No. 6-8005							
2-Parameter Gamma	1	11,823	22,397	29,772	39,140	46,049	52,853
	2	12,200	23,300	31,000	40,400	46,700	52,800
Gumbel	1	12,068	28,316	39,073	52,665	62,749	72,757
	2	11,930	26,500	36,142	48,328	57,370	66,344
Log Gumbel	1	9,334	19,806	32,593	61,158	97,548	155,057
	2	9,274	18,210	28,466	50,059	76,096	115,310
Log Normal	1	10,513	19,993	27,972	40,013	50,424	62,509
	2	10,514	19,956	27,972	40,021	50,439	62,109
	3	10,600	20,000	28,400	41,500	53,000	67,000
	4	9,020	21,360	33,720	54,700	74,910	99,110
Hazen	1	8,790	16,990	28,250	53,090	83,470	128,740
Log Pearson Type III	1	9,780	19,400	28,900	45,800	62,900	84,800
	2	9,890	19,400	28,900	45,000	62,000	84,800
	3	9,890	20,000	30,000	48,000	68,000	97,000
Station No. 7-2165							
2-Parameter Gamma	1	1,038	2,295	3,227	4,449	5,368	6,284
	2	1,320	2,410	3,250	4,440	5,380	6,300
Gumbel	1	1,085	3,346	4,843	6,735	8,138	9,531
	2	1,065	3,077	4,409	6,092	7,341	8,580
Log Gumbel	1	746	1,867	3,425	7,374	13,024	22,906
	2	741	1,674	2,872	5,683	9,427	15,581
Log Normal	1	861	1,874	2,813	4,337	5,736	7,373

TABLE 2 (*continued*)

Method	Comp. No.	Recurrence Interval (years)					
		2	5	10	25	50	100
	2	862	1,874	2,812	4,336	5,735	7,375
	3	870	1,880	2,850	4,500	6,100	8,100
	4	620	1,950	3,660	6,920	10,560	15,410
Hazen	1	660	1,440	2,600	6,310	11,570	20,110
Log Pearson Type III	1	771	1,780	2,940	5,310	7,980	11,900
	2	778	1,780	2,960	5,300	8,000	11,700
	3	778	1,810	3,100	5,700	8,900	13,800
		Station No. 8-1500					
2-Parameter Gamma	1	17,637	60,060	97,237	149,658	190,844	232,920
	2	28,000	62,400	95,300	148,000	189,000	231,000
Gumbel	1	27,624	82,755	119,257	165,376	199,590	233,551
	2	27,206	77,177	110,264	152,069	183,090	213,870
Log Gumbel	1	8,590	47,992	149,921	632,261	1,839,032	5,307,051
	2	8,481	40,319	113,190	417,130	1,097,800	2,868,500
Log Normal	1	11,330	50,047	108,769	248,799	424,625	686,137
	2	11,332	50,010	108,680	248,610	424,280	686,260
	3	11,300	48,500	110,000	265,000	480,000	830,000
	4	16,140	49,960	92,270	172,930	261,820	378,630
Hazen	1	16,250	55,140	97,540	174,440	252,140	349,420
Log Pearson Type III	1	12,200	50,700	103,000	226,000	327,000	485,000
	2	12,200	52,000	101,000	207,000	325,000	485,000
	3	12,200	54,000	108,000	225,000	370,000	570,000
		Station No. 10-3275					
2-Parameter Gamma	1	1,052	1,935	2,543	3,311	3,875	4,429
	2	1,020	1,880	2,490	3,300	3,910	4,400
Gumbel	1	1,108	2,164	2,863	3,746	4,401	5,052
	2	1,100	2,056	2,689	3,488	4,081	4,670
Log Gumbel	1	835	1,819	3,046	5,844	9,475	15,307
	2	830	1,680	2,679	4,832	7,483	11,552
Log Normal	1	946	1,852	2,630	3,823	4,868	6,047
	2	946	1,852	2,631	3,824	4,870	6,048
	3	940	1,880	2,670	4,000	5,200	6,600
	4	950	1,860	2,650	3,850	4,900	6,080
Hazen	1	940	1,850	2,640	3,850	4,910	6,100
Log Pearson Type III	1	957	1,860	2,610	3,900	4,710	5,820
	2	953	1,850	2,600	3,750	4,750	5,820
	3	953	1,850	2,660	3,900	5,000	6,300
		Station No. 11-980					
2-Parameter Gamma	1	612	1,679	2,539	3,710	4,611	5,522
	2	750	1,700	2,480	3,600	4,580	5,480
Gumbel	1	770	2,345	3,387	4,705	5,682	6,652
	2	1,290	2,188	3,135	4,332	5,219	6,101

TABLE 2 (*continued*)

Method	Comp. No.	Recurrence Interval (years) 2	5	10	25	50	100
Log Gumbel	1	366	1,361	3,246	4,735	21,987	49,359
	2	363	1,192	2,620	7,087	14,828	30,856
Log Normal	1	452	1,405	2,541	4,778	7,185	10,362
	2	453	1,405	2,541	4,778	7,185	10,361
	3	445	1,400	2,600	5,100	8,000	12,000
	4	440	1,390	2,600	4,910	7,490	10,910
Hazen	1	440	1,480	2,670	4,950	7,330	10,380
Log Pearson Type III	1	472	1,420	2,460	4,270	6,200	8,440
	2	471	1,420	2,430	4,300	6,200	8,480
	3	471	1,420	2,500	4,550	6,700	9,400
Station No. 12-4570							
2-Parameter Gamma	1	11,576	14,904	16,869	19,141	20,708	22,185
	2	11,600	14,650	16,980	19,250	20,800	22,180
Gumbel	1	11,372	14,979	17,368	20,386	22,625	24,848
	2	11,346	14,624	16,794	19,536	21,570	23,589
Log Gumbel	1	10,829	14,792	18,185	23,606	28,648	34,716
	2	10,804	14,352	17,321	21,968	26,203	31,215
Log Normal	1	11,389	14,919	17,180	19,968	22,006	24,012
	2	11,389	14,927	17,194	19,993	22,038	24,056
	3	11,500	15,000	17,100	20,000	22,200	24,700
	4	11,420	14,800	16,760	19,600	21,530	23,420
Hazen	1	11,570	14,940	16,950	19,300	20,960	22,560
Log Pearson Type III	1	11,600	15,000	16,900	19,000	20,500	21,900
	2	11,600	15,000	16,800	19,000	20,400	21,800
	3	11,600	15,000	17,000	19,300	21,000	22,300

more flood-frequency relations used exactly the same set of flood data at each station. None of the items of data was changed or deleted, nor were any gaps in data filled in. At each station, the differences in computed results are therefore due wholly to the basic methods used and to alternate procedures within the basic methods.

Table 2 shows large differences in results obtained by the different methods, particularly at the larger recurrence intervals. This was in part what might have been anticipated. However, Table 2 reveals unanticipated differences of considerable magnitude where, nominally, the same method is being applied.

The within-method differences were not due to errors in computer programs or in application of the basic principles involved in the separate methods but resulted from differences in the statistical treatment of small samples. For example, there are alternate tabular values for the statistical distributions (either tables of probabilities or of the so-called '*K*' values) that vary, depending on whether or not the length of the record is taken into account, that is, depending on whether the results are to represent the distribution during the period of record or the underlying distribution. Another cause for differences is the alternate treatment where a logarithmic transformation is used. It is possible either to convert the flood data immediately and to operate on the logarithms or to operate on the original data and then to compute flood magnitudes based on theoretical relations between natural and logarithmic data. Results obtained by these two procedures are not the same.

These within-method differences are statistical considerations in the treatment of the data. The statistical consultants assisting the Work Group were of the opinion that the state of the art of frequency analysis is such that a specific set of procedures cannot be selected as correct or superior within each method at the present time.

As for the large differences in results by different methods, the consultants did not find these surprising in view of the wide confidence limits existing at the upper ends of the frequency relations. In effect, the widely varying results at the higher recurrence intervals are all within the range of uncertainty existing there. The consultants urged that confidence limits should always be computed for flood-frequency computations, instead of only the single-value estimates; however, methods for doing this are not yet fully developed.

The primary objective of mathematically defining a flood-frequency curve is to find a relation that conforms well to the data yet represents an orderly variation of probability rather than the erratic chance variations usually found in a set of flood data. It would be eminently satisfactory if the fitted distribution in addition were one with such properties that it could be expected on rational grounds to fit a series of flood events. Although attempts have been made to rationalize the use of one or another statistical distribution on the basis of inherent properties, each of these rationalizations involves some assumptions that can be questioned. The primary consideration, therefore, in selection of a method for fitting, is that there be general conformance to the data.

A way was sought to compare the general conformance of each of the tested methods to the original data. To be acceptable the method had to be objective. The comparison would have to be made at several levels of flood magnitudes, because some methods might fit better at low levels than at high levels and vice versa.

The following method of testing was used. For each method, comparisons were made between the computed discharges and 'data values,' at recurrence intervals of 2, 5, 10, 25, 50, and 100 years (probabilities, respectively, of 0.50, 0.20, 0.10, 0.04, 0.02, and 0.01). The data values were obtained by interpolating between the two adjacent floods of record that bracketed the specified probability. This was done graphically as illustrated in Figure 1 (corresponding data shown in Table 3). The flood data are listed in order of magnitude, and the expected probability for each item was computed as $m/(n + 1)$, where m is the order number starting with one as the highest, and n is the total number of items. One can work either with the probabilities or with the recurrence interval, which is the reciprocal of the probability, or $(n + 1)/m$. The flood magnitudes were plotted on extreme values logarithmic graph paper to a recurrence-interval scale, and the flood values at the specified recurrence intervals were based on straight-line interpolations (Figure 1). The example in Table 3 shows the six highest ranked floods for station number 1-1805 and the interpolated values. Table 4 shows the data values for all ten stations as selected by this procedure.

It was found that the type of graph paper on which the data values were selected did not significantly influence the data values. This was because at the higher recurrence intervals (10 years and above), both the extreme-values and the normal probability scales have graduations that vary almost logarithmically; below this the plotted points are closely spaced, so that interpolated distances are small. This means that essentially the same data values would have been selected had the procedure been carried out on log-probability graph paper; trial has shown this to be true.

The values computed by all methods, as listed in Table 2, were compared with the data values of Table 4 by computing the departure, in per cent, of the computed value from the data value at each recurrence interval. The deviation at each point was computed as 100 $(Q - Q_D)/Q_D$, where Q is the computed value from Table 2 and Q_D the data value from Table 4 for corresponding recurrence intervals.

Table 5 lists the deviations at each station, tabulated separately by method. At the bottom of each column the deviations are totaled for all 10 stations and then averaged.

DISCUSSION OF RESULTS

The average deviations for each method as shown in Table 5 were an important considera-

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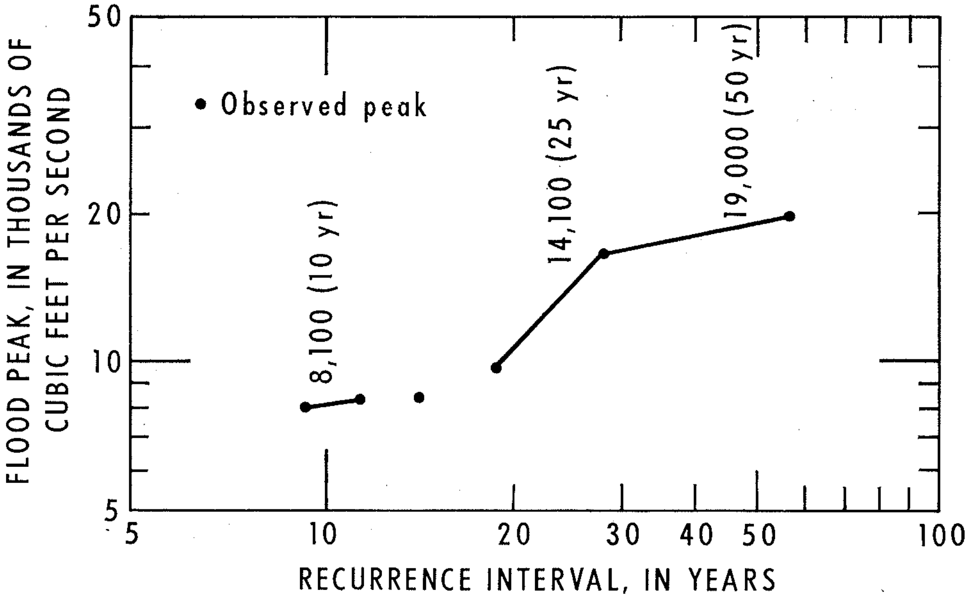

Fig. 1. Data values of floods by interpolation: Station 1–1805, Middle Branch Westfield River at Goss Heights, Massachusetts.

TABLE 3. Example of Interpolation of Floods between Adjacent Values (Station 1-1805)

Water Year	Observed Floods, cfs	Order No.	Recurrence Interval, yr	*Interpolated Values, cfs
1938	19,900	1	56.0	
...			(50)	19,000
1955	16,500	2	28.0	
...			(25)	14,100
1949	9,600	3	18.7	
1936	8,400	4	14.0	
1951	8,320	5	11.2	
...			(10)	8,100
1933	8,020	6	9.33	

* Magnitude at selected recurrence interval from straight line drawn between two adjacent ranked floods of record, from Figure 1.

TABLE 4. Flood Magnitudes as Interpolated between Adjacent Observations

Station	Recurrence Interval (yrs) 2	5	10	25	50	100
1–1805	2,600	4,200	8,100	14,100	19,000	...*
2–2185	13,300	19,500	29,000	43,300	58,500	...*
5–3310	37,000	56,600	73,000	93,000	126,000	172,000
6–3340	2,000	3,690	4,250	4,550	6,000	...*
6–8005	9,000	18,800	26,500	55,000	...*	...*
7–2165	670	1,950	2,270	7,900	...*	...*
8–1500	12,200	70,000	104,000	155,000	305,000	...*
10–3275	1,030	1,730	3,060	3,850	5,800	...*
11–980	570	1,390	2,600	5,800	8,400	...*
12–4570	11,400	15,000	16,900	19,400	21,400	...*

* Record too short to define flood magnitudes by interpolation.

TABLE 5. Deviations (in per cent) of Computed Values from Values Interpolated between Adjacent Observations

2-PARAMETER GAMMA

Station No.	Computation No. 1					Computation No. 2				
	Recurrence Interval (yr)					Recurrence Interval (yr)				
	2	5	10	25	50	2	5	10	25	50
1–1805	24	33	−11	−35	−44	17	29	−12	−35	−44
2–2185	3	15	−3	−19	−31	4	15	−2	−20	−30
5–3310	−1	5	1	−1	−16	−5	3	0	1	−17
6–3340	−2	−10	0	18	3	−2	−10	0	19	3
6–8005	31	19	12	−29	...	36	24	17	−27	...
7–2165	55	18	42	−44	...	97	24	43	−44	...
8–1500	45	−14	−6	−3	−37	130	−11	−8	−4	−38
10–3275	2	12	−17	−14	−33	−1	9	−19	−14	−33
11–0980	7	21	−2	−36	−45	32	22	−5	−38	−45
12–4570	2	−1	0	−1	−3	2	−2	0	−1	−3
Total	+166	+98	+16	−164	−206	+320	+103	+14	−163	−207
Average	+16.6	+9.8	+1.6	−16.4	−25.8	+32.0	+10.3	+1.4	−16.3	−25.9

GUMBEL

Station No.	Computation No. 1					Computation No. 2				
1–1805	24	57	9	−18	−28	23	49	2	−23	−33
2–2185	4	26	9	−7	−20	4	21	3	−12	−24
5–3310	0	9	7	7	−9	0	7	4	2	−13
6–3340	3	−8	1	19	4	2	−10	−2	15	1
6–8005	34	51	47	−4	...	33	41	36	−12	...
7–2165	62	72	113	−15	...	59	58	94	−23	...
8–1500	126	18	15	7	−35	123	10	6	−2	−40
10–3275	8	25	−6	−3	−24	7	19	−12	−9	−30
11–0980	35	69	30	−19	−32	126	57	21	−25	−38
12–4570	0	0	3	5	6	0	−2	−1	1	1
Total	+296	+319	+228	−28	−138	+377	+250	+151	−88	−176
Average	+29.6	+31.9	+22.8	−2.8	−17.2	+37.7	+25.0	+15.1	−8.8	−22.0

LOG GUMBEL

Station No.	Computation No. 1					Computation No. 2				
1–1805	2	20	−4	−6	4	2	13	−14	−19	−13
2–2185	−12	8	7	18	26	−13	3	−1	4	8
5–3310	−16	−1	13	45	54	−16	−5	6	33	38
6–3340	−19	−10	27	116	156	−19	−16	12	81	106
6–8005	4	5	23	11	...	3	−3	7	−9	...
7–2165	11	−4	51	−7	...	11	−14	27	−28	...
8–1500	−30	−31	44	318	503	−30	−42	9	169	260
10–3275	−19	5	0	52	63	−19	−3	−12	25	29
11–0980	−36	−2	25	68	162	−36	−14	1	22	76
12–4570	−5	−1	8	22	34	−5	−4	2	13	22
Total	−120	−11	+194	+637	+1002	−122	−85	+37	+291	+526
Average	−12.0	−1.1	+19.4	+63.7	+125.0	−12.2	−8.5	+3.7	+29.1	+65.8

LOG NORMAL

Station No.	Computations Nos. 1 and 2					Computation No. 3				
	Recurrence Interval (yr)					Recurrence Interval (yr)				
	2	5	10	25	50	2	5	10	25	50
1–1805	13	23	−15	−33	−39	15	24	−12	−31	−37
2–2185	−3	10	−3	−13	−22	−4	11	−1	−11	−20
5–3310	−7	3	5	10	−1	−6	4	6	12	1
6–3340	−9	−8	10	46	38	−8	−8	12	52	45
6–8005	17	6	6	−27	...	18	6	7	−24	...
7–2165	29	−4	24	−45	...	30	−4	26	−43	...
8–1500	−7	−28	5	60	39	−7	−31	6	71	57
10–3275	−8	7	−14	−1	−16	−9	9	−13	4	−10
11–0980	−21	1	−2	−18	−14	−22	1	0	−12	−5
12–4570	0	−1	2	3	3	1	0	1	3	4
Total	+4	+9	+18	−18	−12	+8	+12	+32	+21	+35
Average	+0.4	+0.9	+1.8	−1.8	−1.5	+0.8	+1.2	+3.2	+2.1	+4.4

TABLE 5 *(continued)*

Computation No. 4*

1–1805	3	31	0	−14	−18
2–2185	−5	14	4	−5	−14
5–3310	−7	2	4	+9	−3
6–3340	−3	−14	−3	18	7
6–8005	0	14	27	−1	. . .
7–2165	−7	0	61	−12	. . .
8–1500	32	−29	−11	12	−14
10–3275	−8	8	−13	0	−16
11–0980	−23	0	0	−15	−11
12–4570	0	−1	−1	1	1
Total	−18	+25	+68	−7	−68
Average	−1.8	+2.5	+6.8	−0.7	−8.5

HAZEN

Computation No. 1

1–1805	−3	16	−8	−13	−11
2–2185	−8	9	1	−3	−9
5–3310	−8	1	4	+10	−1
6–3340	6	−8	−3	10	−6
6–8005	−2	−10	7	−3	. . .
7–2165	−1	−26	15	−20	. . .
8–1500	33	−21	−6	11	−17
10–3275	−9	7	−14	0	−15
11–0980	−23	6	3	−15	−13
12–4570	2	0	0	0	−2
Total	−13	−26	−1	−21	−74
Average	−1.3	−2.6	−0.1	−2.1	−9.2

LOG PEARSON TYPE III

Station No.	Computation No. 1					Computation No. 2				
	Recurrence Interval (yr)					Recurrence Interval (yr)				
	2	5	10	25	50	2	5	10	25	50
1–1805	7	20	−12	−25	−27	7	20	−12	−24	−26
2–2185	−6	9	−1	−9	−17	−5	10	−2	−9	−17
5–3310	−5	3	3	6	−9	−6	2	2	5	−9
6–3340	1	−7	1	14	−2	1	−8	0	14	−2
6–8005	9	3	9	−17	. . .	10	3	9	−18	. . .
7–2165	15	−9	30	−33	. . .	16	−9	30	−33	. . .
8–1500	0	−28	−1	46	7	0	−26	−3	34	7
10–3275	−7	8	−15	1	−19	−7	7	−15	−3	−18
11–0980	−17	2	−5	−26	−26	−17	2	−7	−26	−26
12–4570	2	0	0	−2	−4	2	0	−1	−2	−5
Total	−1	+1	+9	−45	−97	+1	+1	+1	−62	−96
Average	−0.1	+0.1	+0.9	−4.5	−12.1	+0.1	+0.1	+0.1	−6.2	−12.0

Computation No. 3*

1–1805	7	20	−12	−21	−21
2–2185	−5	10	0	−6	−13
5–3310	−6	2	4	8	−7
6–3340	0	−7	1	17	0
6–8005	10	6	13	−13	. . .
7–2165	16	−7	37	−28	. . .
8–1500	0	−23	4	45	21
10–3275	−7	7	−13	1	−14
11–0980	−17	2	−4	−22	−20
12–4570	2	0	1	−1	−2
Total	0	+10	+31	−20	−56
Average	0.0	+1.0	+3.1	−2.0	−7.0

*Adjusted for expected probability.

tion in deciding between methods. A method that succeeds in fitting the data well would have small average deviations varying randomly around zero throughout the range of recurrence intervals.

The tabulated deviations for the gamma, Gumbel, and log-Gumbel distributions are large at both the low and high ends of the frequency range. The signs of the departures are consistent among the 10 stations. The averages in each case display a consistent variation in the magnitudes of the departures, which reverse in direction from one end of the range to the other. There appear, therefore, to be consistent tendencies, or biases, in the results as obtained by these three methods, as judged from this group of stations.

The log-normal, log-Pearson Type III, and Hazen methods show relatively smaller deviations than the first three methods discussed. There appears to be a small, though consistent, negative bias at the upper end of the frequency range for both the Hazen and the log-Pearson Type III methods. The average deviations for the 50-year flood for log-Pearson Type III computations 1 and 2 are significantly different from zero at the 0.05 level; for other floods the averages do not differ significantly from zero. Such a tendency may be due to the nature of flood events in a relatively short record, as there is more opportunity for large departures at the upper end than at the lower end of the range.

The data values were interpolated between data points whose probability was computed by the formula for expected probability $m/(n + 1)$. This formula requires no prior assumption of a distribution and appears suitable as a way of comparing the computed values with the data. However, to examine the possible effect of plotting position on the results, the procedures were repeated using the Hazen plotting position for probability $(2m - 1)/2n$. The departures were computed only for the 25- and 50-year values, because differences between the two formulas are very small at the lower recurrence intervals. The departures computed on this basis then showed the following characteristics:

1. The same biases as found before for the 2-parameter gamma and Gumbel distributions, although the biases are somewhat reduced at the higher recurrence intervals;
2. For the log-Gumbel distribution, an increase in bias at the higher recurrence intervals;
3. For the log-normal and Hazen methods and for the log-Pearson Type III adjusted for 'expected probability,' mostly positive departures, averaging about +10%, at both 25 and 50 years;
4. For the log-Pearson Type III distribution, unadjusted (computation Nos. 1 and 2), the departures averaged less than +5% for both the 25- and 50-year frequencies.

SELECTION OF METHOD

The statistical consultants had indicated that no unique procedures could be specified as correct for any one method of flood-frequency analysis. No single method of testing the computed results against the original data was acceptable to all those on the Work Group, and the statistical consultants could not offer a mathematically rigorous method. It appeared, consequently, that if a choice could not be made solely on statistical grounds, a choice on administrative grounds, for which compelling reasons existed, was justified. This administrative choice was largely governed by the relative values of the results and the tests of conformance that were made.

Results of analyses by the 2-parameter gamma, Gumbel, and log-Gumbel methods, as tested, showed departures from the data that exhibited trends or biases. Each of these methods resulted in generally high or low values among all the values computed by different methods.

For the log-normal, Pearson Type III, and Hazen methods, average departures (as shown on Table 5) are small, and the bias, if real, is small. The results of these three methods represented, in general, a middle position among the values computed. Based both on departures from the data and on the relative values among all those computed, the latter three appear to be preferable. The Work Group might have recommended all three methods if good reasons had been found for continuing the use of all of them. However, no valid hydrologic or statistical reasons were found to indicate that under one set of circumstances or for some special purpose one method, because of its properties, was better suited than the others. Actually, all three have statistical properties that are interrelated. In the interest of uniformity, one base method is preferable to three.

There are several reasons why, of these three, the log-Pearson Type III method was selected:

1. It is now in common use among some Federal agencies, detailed procedures for applying it have been published, and computer programs are available.
2. The log-Pearson Type III and the Hazen methods include the skew coefficient as a variable and therefore are more flexible than the log-normal, which has a skew of zero of the logarithms. Both the Pearson Type III and the Hazen methods are capable of fitting frequency relations that may, for hydrologic reasons, be highly skewed.
3. The log-Pearson Type III and Hazen methods include the log-normal as a special case when the skew of the logarithms is zero, so that the log-normal can be considered as a part of either of these.
4. The Hazen method in its original form achieves close fit to the data by means of empirical adjustments. Even though such adjustments are not used, the Pearson Type III is preferable because its application is based on rigorous mathematical analysis, whereas the Hazen table of skew factors was derived by empirical and graphical methods.

The analysis of flood-frequency relations for 10 records is admittedly a small sample on which to base general conclusions. However, it may be pointed out that, in a statistical sense, this was not a sample, but a case study. A truly random sample representative of all possible conditions might have required hundreds or thousands of records. A sample this size would probably be self-defeating, because it would have to contain mostly short records in which the sampling variation tends to obscure the basic form of the distribution.

The stations were selected to represent widely different hydrologic conditions over the entire United States. They were also chosen for a wide range in drainage-basin size. In addition, they represent long-term flood records, and therefore the effect of sampling variation should be small. The experience of preparing data for the 10 stations, analyzing them by the six methods, and comparing them, indicated that the costs entailed in preparing a much larger sample would have been excessive and would have delayed any decisions for a long time. The tendencies shown by the results of analyzing this wide-ranging sample were remarkably consistent, and it is believed that the analysis of a larger sample would not have changed the results or conclusions reached.

RECOMMENDATIONS

The Work Group realized that its task would not be adequately fulfilled simply by choosing one among several alternative methods of frequency analysis. Its investigations brought out very forcibly that the range of uncertainty in flood analysis, regardless of the method used, is still quite large, that there is still a need for continued research and development to solve the many unresolved questions, and that it would be unwise either to rigidly specify any one method or to restrict in any way the future development of flood-frequency analysis. Taking into consideration the demonstrated need for the utmost possible uniformity, and the state of the art, the Work Group made the following recommendations, all of which it considered highly desirable:

1. That the log-Pearson Type III distribution (with the log-normal as a special case) be adopted as a base method for analyzing flood-flow frequencies.
2. That in such cases where investigation showed that other distributions or techniques would be better suited, these techniques should be used, but justification for the departure from the base method should be documented.
3. That the choice of a base method should not be considered as final and should not freeze hydrologic practice into any set pattern, either now or in the future. That in view of the increasing importance of frequency analysis in water-resources development, studies should be continued for the purpose of resolving uncertainties, improving methods of analysis, and reviewing all work in this field. That when considered desirable, new techniques or methods should be recommended.

The Work Group's report to the Hydrology Committee on its findings and recommendations was accepted by the Committee, which then, in turn, presented the same recommendations to the Water Resources Council. These recommendations were accepted by the Council, and a report [*Water Resources Council,* 1967] was then issued that formalized the recommendations to government agencies. The report describes the application of the log-Pearson Type III method to a set of data and includes the required tables. The method of application and the tables (Tables 6*a* and 6*b*) are included in Appendix 2 of this paper.

FURTHER CONSIDERATIONS

It must be realized that at present, and perhaps for a long time in the future, it may not be possible to set down rules that will lead in all cases to exactly the same answer for everyone who is analyzing a set of flood data, even though the same base method is being used to analyze the data. This is because judgment still has a legitimate place in data use and interpretation, prior to analysis. Such questions arise as whether or not to fill in missing periods of record and how to handle 'outliers' or rare events occurring in a short period of record. The intensity of effort put into the total study may affect the results, such as when historical information is incorporated into the rest of the data. The inclusion or omission of such information will affect the results, yet one investigator may have the resources required to make the necessary search for this information and another may not.

It must also be recognized that the adoption of a base method for fitting the flood data at a specific site is only a first step in attaining uniformity. It has been realized for some time that usually better estimates of frequency can be made by combining all the data over a wide region and generalizing the frequency information than by using only the data at the individual site. The best methods for such generalization still remain to be decided. Even given a base method of fitting data and a uniform method of regionalization, differences in results are still possible because of the somewhat intangible problem of the size of the region over which the generalization is carried out.

Many of the uncertainties can be resolved by further study. The question of filling in missing records or treating outliers should be solvable by proper statistical studies. Technical statistical questions such as adjustments for length of record or expected probability should be amenable to study.

Another question involved is whether to compute the statistical parameters (mean, standard deviation, and skew) by the method of moments, as is now done in use of the log-Pearson Type III, or by the method of maximum likelihood. The latter method, now used in application of the 2-parameter gamma distribution, is claimed by many statisticians to be superior to the method of moments. The applicability of maximum-likelihood parameters for the log-Pearson Type III distribution to the sample sizes ordinarily found in flood series needs to be investigated. The efficiency of approximate methods necessary when automatic computers cannot be used must also be investigated. In any case, any major modifications, such as use of maximum-likelihood estimates, would have to meet the test of conforming to the data satisfactorily.

CONCLUSIONS

1. Present methods of flood-frequency analysis produce widely varying results, particularly at the higher recurrence intervals.
2. Present procedures may lead to large differences in results, even where nominally the method is the same.
3. There are no rigorous statistical criteria on which to base a choice of method.
4. The present state of the art of frequency analysis does not warrant the specification of best procedures for any one method.
5. Test of the methods based on 10 long-term records representing different hydrologic conditions in various parts of the country has shown that some of the methods result in consistent departures from the data for recurrence intervals of 50 years or less.
6. Of the methods that showed good conformance with the data, the log-Pearson Type III, containing the log-normal as a special case, was recommended as a base method.
7. A further recommendation allowed for use of other methods if study showed this to be justified.
8. Recommendations were made for continuing study of flood-frequency analysis and improvement or revision of methods when these were desirable.

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Acknowledgments. The Work Group that conducted the studies leading to the final recommendations for uniformity was made up of the following members:

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As Chairman of the Work Group on Flow-Frequency Methods, I have described here the investigations performed by the group as a whole that led ultimately to the recommendations that were made. I am grateful to the members of the group for their review of this report. Publication is authorized by the Water Resources Council.

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APPENDIX 1. LOG-PEARSON TYPE III METHOD

The Pearson Type III method was originally presented for use in flood-frequency studies by *H. A. Foster* [1924]. As used by Foster, the method required the use of the natural data in computations of the mean, standard deviation, and skew coefficient of the distribution. The current practice, and the recommendation of the Hydrology Committee, is first to transform the natural data to their logarithms and then to compute the statistical parameters. Because of this transformation the method is now called the log-Pearson Type III method.

The events considered here are flood flows in the annual series, but any series of independent events in which there is one extreme event per time interval may be used. Definitions of hydrological and statistical terms used here may be found in the Glossary of Bulletin 13 (3). In the work, the physical units used for Y (such as cfs or cfs-days) are also those for Q. In the equations shown for standard deviation or for skew, the first equation in each case is preferable for use in automatic computation. For calculation by desk calculator or by tables, the second equation may be preferable. When automatic computation is not being used, 4-place logarithms may be used to simplify computations. The outline of work is as follows:

1. Transform the list of n annual flood magnitude Y_1 $Y_2, \ldots, Y_n$ to a list of corresponding logarithmic magnitudes $X_1, X_2, \ldots, X_n$.

TABLE 6*a*. *K* Value for Positive Skew Coefficients

Skew Coefficient (g)	Recurrence Interval in Years 1.0101	1.0526	1.1111	1.2500	2	5	10	25	50	100	200
	Percent Chance 99	95	90	80	50	20	10	4	2	1	0.5
3.0	-0.667	-0.665	-0.660	-0.636	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	-0.690	-0.688	-0.681	-0.651	-0.390	0.440	1.195	2.277	3.134	4.013	4.909
2.8	-0.714	-0.711	-0.702	-0.666	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	-0.740	-0.736	-0.724	-0.681	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.762	-0.747	-0.696	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.790	-0.771	-0.711	-0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	-0.832	-0.819	-0.795	-0.725	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	-0.867	-0.850	-0.819	-0.739	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.882	-0.844	-0.752	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	-0.946	-0.914	-0.869	-0.765	-0.319	0.592	1.294	2.230	2.942	3.656	4.372
2.0	-0.990	-0.949	-0.895	-0.777	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.984	-0.920	-0.788	-0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	-1.087	-1.020	-0.945	-0.799	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.140	-1.056	-0.970	-0.808	-0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-1.093	-0.994	-0.817	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	-1.256	-1.131	-1.018	-0.825	-0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	-1.318	-1.168	-1.041	-0.832	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-1.206	-1.064	-0.838	-0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-1.243	-1.086	-0.844	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	-1.518	-1.280	-1.107	-0.848	-0.180	0.745	1.341	2.066	2.585	3.087	3.575
1.0	-1.588	-1.317	-1.128	-0.852	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
.9	-1.660	-1.353	-1.147	-0.854	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
.8	-1.733	-1.388	-1.166	-0.856	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
.7	-1.806	-1.423	-1.183	-0.857	-0.116	0.790	1.333	1.967	2.407	2.824	3.223
.6	-1.880	-1.458	-1.200	-0.857	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
.5	-1.955	-1.491	-1.216	-0.856	-0.083	0.808	1.323	1.910	2.311	2.686	3.041
.4	-2.029	-1.524	-1.231	-0.855	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
.3	-2.104	-1.555	-1.245	-0.853	-0.050	0.824	1.309	1.849	2.211	2.544	2.856
.2	-2.178	-1.586	-1.258	-0.850	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
.1	-2.252	-1.616	-1.270	-0.846	-0.017	0.836	1.292	1.785	2.107	2.400	2.670
0	-2.326	-1.645	-1.282	-0.842	0	0.842	1.282	1.751	2.054	2.326	2.576

TABLE 6*b*. *K* Value for Negative Skew Coefficients

Skew Coefficient	Recurrence Interval in Years 1.0101	1.0526	1.1111	1.2500	2	5	10	25	50	100	200

.6	-1.880	-1.458	-1.200	-0.857	-0.099	0.800	1.328	1.939	2.311	2.686	3.041
.5	-1.955	-1.491	-1.216	-0.856	-0.083	0.808	1.323	1.910	2.261	2.615	2.949
.4	-2.029	-1.524	-1.231	-0.855	-0.066	0.816	1.317	1.880	2.211	2.544	2.856
.3	-2.104	-1.555	-1.245	-0.853	-0.050	0.824	1.309	1.849	2.159	2.472	2.763
.2	-2.178	-1.586	-1.258	-0.850	-0.033	0.830	1.301	1.818	2.107	2.400	2.670
.1	-2.252	-1.616	-1.270	-0.846	-0.017	0.836	1.292	1.785	2.054	2.326	2.576
0	-2.326	-1.645	-1.282	-0.842	0	0.842	1.282	1.751	2.054	2.326	2.576

TABLE 6b. *K* Value for Negative Skew Coefficients

Recurrence Interval in Years

Skew Coefficient (g)	1.0101	1.0526	1.1111	1.2500	2	5	10	25	50	100	200
Percent Chance	99	95	90	80	50	20	10	4	2	1	0.5
0	-2.326	-1.645	-1.282	-0.842	0	0.842	1.282	1.751	2.054	2.326	2.576
- .1	-2.400	-1.673	-1.292	-0.836	0.017	0.846	1.270	1.716	2.000	2.252	2.482
- .2	-2.472	-1.700	-1.301	-0.830	0.033	0.850	1.258	1.680	1.945	2.178	2.388
- .3	-2.544	-1.726	-1.309	-0.824	0.050	0.853	1.245	1.643	1.890	2.104	2.294
- .4	-2.615	-1.750	-1.317	-0.816	0.066	0.855	1.231	1.606	1.834	2.029	2.201
- .5	-2.686	-1.774	-1.323	-0.808	0.083	0.856	1.216	1.567	1.777	1.955	2.108
- .6	-2.755	-1.797	-1.328	-0.800	0.099	0.857	1.200	1.528	1.720	1.880	2.016
- .7	-2.824	-1.819	-1.333	-0.790	0.116	0.857	1.183	1.488	1.663	1.806	1.926
- .8	-2.891	-1.839	-1.336	-0.780	0.132	0.856	1.166	1.448	1.606	1.733	1.837
- .9	-2.957	-1.858	-1.339	-0.769	0.148	0.854	1.147	1.407	1.549	1.660	1.749
-1.0	-3.022	-1.877	-1.340	-0.758	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	-1.894	-1.341	-0.745	0.180	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	-1.910	-1.340	-0.732	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	-1.925	-1.339	-0.719	0.210	0.838	1.064	1.240	1.324	1.383	1.424
-1.4	-3.271	-1.938	-1.337	-0.705	0.225	0.832	1.041	1.198	1.270	1.318	1.351
-1.5	-3.330	-1.951	-1.333	-0.690	0.240	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.388	-1.962	-1.329	-0.675	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	-1.972	-1.324	-0.660	0.268	0.808	0.970	1.075	1.116	1.140	1.155
-1.8	-3.499	-1.981	-1.318	-0.643	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	-1.989	-1.310	-0.627	0.294	0.788	0.920	0.996	1.023	1.037	1.044
-2.0	-3.605	-1.996	-1.302	-0.609	0.307	0.777	0.895	0.959	0.980	0.990	0.995
-2.1	-3.656	-2.001	-1.294	-0.592	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	-2.006	-1.284	-0.574	0.330	0.752	0.844	0.888	0.900	0.905	0.907
-2.3	-3.753	-2.009	-1.274	-0.555	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	-3.800	-2.011	-1.262	-0.537	0.351	0.725	0.795	0.823	0.830	0.832	0.833
-2.5	-3.845	-2.012	-1.250	-0.518	0.360	0.711	0.771	0.793	0.798	0.799	0.800
-2.6	-3.889	-2.013	-1.238	-0.499	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	-2.012	-1.224	-0.479	0.376	0.681	0.724	0.738	0.740	0.740	0.741
-2.8	-3.973	-2.010	-1.210	-0.460	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	-2.007	-1.195	-0.440	0.390	0.651	0.681	0.683	0.689	0.690	0.690
-3.0	-4.051	-2.003	-1.180	-0.420	0.396	0.636	0.660	0.666	0.666	0.667	0.667

2. Compute the mean of the logarithms

$$M = \Sigma X/n$$

3. Compute the standard deviation of the logarithms

$$S = \sqrt{\frac{\Sigma(X - M)^2}{n - 1}}, \quad \text{or}$$

$$\sqrt{\frac{\Sigma X^2 - (\Sigma X)^2/n}{n - 1}}$$

4. Compute the coefficient of skewness

$$g = \frac{n\Sigma(X - M)^3}{(n - 1)(n - 2)S^3}, \quad \text{or}$$

$$\frac{n^2\Sigma X^3 - 3n\Sigma X\Sigma X^2 + 2(\Sigma X)^3}{n(n - 1)(n - 2)S^3}$$

5. Compute the logarithms of discharges at selected recurrence intervals or per cent chance

$$\log Q = M + KS$$

Take K from Table 6a or 6b for the computed value of g and the selected recurrence interval or per cent chance. Log Q is the logarithm of a flood discharge having the same recurrence interval or per cent chance.

6. Find the antilog of log Q to get the flood discharge Q. The frequency line can be shown by plotting each Q versus its respective per cent chance on log-normal probability paper and drawing a continuous line through the plotted points.

Tables 6a and 6b were made from larger and more complete tables prepared by H. Leon Harter, Mathematical Statistician, Wright-Patterson Air Force Base, and the U. S. Soil Conservation Service. Copies of those tables are available, free of charge, from the Central Technical Unit, Soil Conservation Service, 269 Federal Center Building, Hyattsville, Md. 20782.

Federal agencies such as the Bureau of Reclamation, Corps of Engineers, Geological Survey, Soil Conservation Service, Tennessee Valley Authority, and others have prepared computer programs for the log-Pearson Type III method. These programs are in various computer languages and for various types of computers. Inquiries regarding these programs may be addressed to those agencies.