UNITED STATES

A UNIFORM TECHNIQUE
FOR DETERMINING FLOOD FLOW FREQUENCIES

DECEMBER 1967

WATER RESOURCES COUNCIL
WASHINGTON, D. C.

THE WATER RESOURCES COUNCIL

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WATER RESOURCES COUNCIL

HYDROLOGY COMMITTEE

A UNIFORM TECHNIQUE FOR DETERMINING FLOOD FLOW FREQUENCIES

DECEMBER 1967

BULLETIN NO. 15

Published by

Water Resources Council, 1025 Vermont Avenue, N.W.
Washington, D.C. 20005

FOREWORD

Within the federalism that is a distinguishing characteristic of the governmental structure of the United States, the responsibility for managing the water and related land resources of the Nation's river basins is shared among Federal, State, and local governments, and private enterprise.

In response to the practical problems that confront them, Federal agencies are continually developing technical methods to improve the performance of their assigned responsibilities. Where agencies have different but related assignments, methodological differences in making the same types of technical determinations tend to develop. The determination of flood flow frequency is one of the technical methods that has experienced separate agency evolution over the years, and consequent differences in technique.

With the growing need for improved flood plain management, desirability of a basic, uniform method of establishing flood frequencies for general use throughout the Nation is manifest. A consistent approach to estimation of the average annual value of flood losses--a major analytical component in determination of the best measure, or best combination of measures, in flood plain management--is dependent upon equable analysis of flood frequencies whether determined by Federal, State, local government or private engineers.

With this need in mind, the uniform technique for determining flood flow frequencies set forth in this bulletin was adopted by the Council's Hydrology Committee. It is hoped that this base method will commend itself for use by State, local government and private engineers, and that it will be looked upon as a desirable first step in the development through further study, research, and experience of a more precise and complete technique. The Water Resources Council has adopted the uniform technique set forth in the bulletin for use in all Federal planning involving water and related land resources. It has done this, however, with the understanding that efforts directed toward finding methodological improvements will be continued and adopted when deemed appropriate.

All who are interested in improving determinations of flood flow frequencies are encouraged to submit comments, criticisms, and proposals to the Water Resources Council for consideration by its Hydrology Committee.

Stewart L. Udall
Chairman, Water Resources Council

December 1967

TOWARD A UNIFORM TECHNIQUE FOR DETERMINING FLOOD FLOW FREQUENCIES

In a letter of September 10, 1966, the Executive Director informed the Hydrology Committee that the Council had assigned it responsibility for developing a uniform technique for the determination of flood flow frequencies. The Hydrology Committee of the Council consists of technical staff members of the Federal departments represented in the Council and of the Tennessee Valley Authority. The Committee devotes its efforts to technical matters in hydrology and has published many hydrologic bulletins that are nationally used..

The Council's assignment was made in conformance with Recommendation 2 of the report by the Task Force on Federal Flood Control Policy, "A Unified National Program for Managing Flood Losses."1/ Recommendation 2 called for the establishment of a panel to examine methods of frequency analysis and to provide a set of techniques based on the best known hydrological and statistical procedures.

In a letter of October 20, 1967, the Chairman of the Hydrology Committee submitted the Committee's report to the Council. The letter and report contained (i) a resume of the Committee's activities in this field, (ii) recommendations regarding a technique of flood flow frequency analysis for gaged areas, (iii) an outline of the recommended base method of analysis, (iv) appropriate tables of constants for use with the base method, and (v) a discussion of further and immediate problems requiring the Committee's attention in this field. The Committee's letter and report were based on the report of the Work Group on Flood Flow Frequency Analysis, an ad hoc work group established by the Committee. Two professional statisticians were employed as technical advisors to the group. The group's main findings were that of six methods tested, three fitted the data well and showed no bias. The recommended base method is one of these three.

In its meeting of October 25, 1967, the Water Resources Council accepted the Committee's report and recommendations and agreed that they should be published.

1/ House Document No. 465, 89th Congress, 2nd Session.

Recommendations

The recommendations of the Hydrology Committee are:

"1. The Hydrology Committee agreed that the state of the art with respect to flood flow frequency methods, as with most other hydrologic techniques, has not advanced to the point where complete standardization is feasible or appropriate. For that reason, the Committee recommends that a base method be adopted with provisions for using other methods where adequate justification is presented.

"2. On the basis of current use by Federal agencies, availability of detailed instructions and computer programs, and flexibility in application, the log-Pearson Type III distribution (with the log-normal as a special case) is recommended for adoption as a base method for flow frequencies. In those cases where information exists which indicates some other type of distribution or technique should be employed, such use should be acceptable provided appropriate justification is given. A concise summary of the log-Pearson Type III method is presented in Bulletin No. 13, April 1966, "Methods of Flow Frequency Analysis," prepared under the auspices of the Subcommittee on Hydrology, Inter-Agency Committee on Water Resources.1/

"3. In view of the importance of flood flow frequency estimates in the expanding field of water resources development and related programs for managing flood losses, continuing efforts by the Hydrology Committee are needed to encourage and coordinate efforts of the member agencies in improving existing techniques and procedures in this field. In this connection, the Committee will establish appropriate ad hoc work groups when required for specific tasks; major emphasis, however, will be directed toward bringing such matters to the attention of the full Committee. Some immediate problems requiring attention are outlined in Attachment 4."2/

1/ Now the Hydrology Committee, Water Resources Council.

2/ The material in Attachment 4 is given later in this pamphlet under the title "Additional Considerations in Flood Flow Frequency Analysis.

THE BASE METHOD

The Pearson Type III method, as originally presented by H. A. Foster (Ref. 1) in 1924, is described in Bulletin 13 (Ref. 2) in Foster's own words. 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 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.

Outline of the Method

The following symbols are used in the outline submitted by the Work Group on Flood Flow Frequency Analysis, which based its work on the presentation in Bulletin 13:

- Y = arithmetic magnitude of an annual flood event
- X = logarithmic magnitude of Y
- N = number of events in the record being used
- M = mean of the X's
- x = X - M
- S = standard deviation of the X's
- g = skew coefficient
- K = Pearson Type III coordinates expressed in number of standard deviations from the mean for various recurrence intervals or percent chance
- Q = computed flood flow for a selected recurrence interval or percent chance

The events considered here are flood flows in the annual series. (Definitions of hydrological and statistical terms used here are found in the Glossary of Bulletin 13). In the work, the physical units used for Y (such as cfs) are also those for Q.

The outline of work is as follows:

1. Transform the list of N annual flood magnitudes Y_1, Y_2, ... , Y_N to a list of corresponding logarithmic magnitudes X_1, X_2, ... , X_N.

2. Compute the mean of the logarithms:

$$M = \frac{\Sigma X}{N}$$

3. Compute the standard deviation of the logarithms:

$$S = \sqrt{\frac{\Sigma x^2}{N-1}}$$

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

4. Compute the coefficient of skewness:

$$g = \frac{N \Sigma x^3}{(N-1)(N-2)S^3}$$

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

5. Compute the logarithms of discharges at selected recurrence intervals or percent chance:

$$\log Q = M + K S$$

Take K from Table 1 or Table 2 for the computed value of g and the selected recurrence interval or percent chance. Log Q is the logarithm of a flood discharge having the same recurrence interval or percent chance.

6. Find the antilog of log Q to get the flood discharge Q.1/

Tables of K Values

Tables 1 and 2 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.

Computer Program Sources

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 should be addressed to those agencies.

References

(1) "Theoretical Frequency Curves," by H. A. Foster: American Society of Civil Engineers, Transactions, v. 87, p. 142-203: 1924.

(2) "Methods of Flow Frequency Analysis," by the Subcommittee on Hydrology, Inter-Agency Committee on Water Resources: Notes on Hydrologic Activities, Bulletin 13, April 1966. For sale by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Price 35 cents.

1/ The frequency line can be shown by plotting each Q versus its respective percent chance on lognormal probability paper and drawing a continuous line through the plotted points.

Table 1 -- K values for positive skew coefficients

Skew Coefficient (g)	1.0101	1.0526	1.1111	1.2500	2	5	10	25	50	100	200
	Recurrence Interval in Years										
	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 2.--K values for negative skew coefficients

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

ADDITIONAL CONSIDERATIONS IN FLOW-FREQUENCY ANALYSIS

There are important considerations in flow-frequency analysis beyond the type of distribution that may be used to fit the data. Some of these considerations are discussed below.

A short record of flood flows may contain large sampling errors because of chance geographical or temporal variations in rainfall during the period of record. Therefore a short record may be a poor indicator of the basic long-time distribution of floods at the site.

Flood flow frequencies often need to be determined for sites where there are no streamflow data. It is possible to examine the individual flood records within the region as a unit and to develop generalized relationships that apply anywhere in the region including ungaged sites. This approach often overcomes many of the uncertainties due to sampling error at individual sites. Several methods of regionalization have been developed to date; a study of such methods, and recommendations for their use, should be part of the continuing program of the Committee.

Another problem is the treatment of a record that contains one or more events of rare frequency--the so-called outlier problem. By using historical information at the site or at nearby sites it is often possible to assign a realistic recurrence interval to each outlier. This information is incorporated into the set of data to define the overall distribution. An alternative is to compute the frequency distribution omitting the rare events, plot the frequency line, and then to adjust the line to conform to the historical information. Where no historical information is available, an obviously very rare event may be excluded from the computations. The specific treatment that is used to handle outliers should become a matter of record.

Where streamflow data are lacking at the site or where a regional analysis is not justified, the use of hydrologic methods, such as rainfall-runoff relationships and unit hydrograph studies, may be the only feasible approach.

In the flood series for some streams in arid regions, it is not unusual for one or more of the flood values to be zero. This poses a difficulty when using a logarithmic transformation because the logarithm of zero is minus infinity. One way around the difficulty is to add a small constant to all the items of data. A second is to determine the frequency relation from only non-zero items and afterwards to adjust the relation to the full period of record. This method does not retain the zeros. A third method is to consider a two-step or conditional probability. If Z is the percentage of zero items, the frequency relation is based on the nonzero items, and defines the probability in 100 - Z percent of all years; Z percent of future years are considered as having expected values of zero. Or, for any one year, the expected probability of a zero flood is Z/100, and the expected probability of any other size of flood, given that the flood is not zero, is that furnished by the developed frequency relation. This may be thought of as a separation into two frequency relations, both solvable, which are then recombined.

The skew coefficient has greater variability between samples than the mean and standard deviation, and it is therefore a less reliable estimator of a population statistic for a particular site. Use of a regionalized skew coefficient to replace that coefficient computed from the station data has been recommended at times. The standard error of estimate of a sample skew coefficient Sg, taken from a normal population having zero skew, is given by

$$Sg = \sqrt{\frac{6N(N - 1)}{(N - 2)(N + 1)(N + 3)}}$$

where N is the number of years of record. For a selected confidence level, this can be used to test whether or not a skew coefficient computed at a site is significantly different from zero. If a regional average skew coefficient is considered appropriate, the average of the Sg's, divided by $\sqrt{n}$, where n is the equivalent number of independent stations, should be used to test whether the regional value is significantly different from zero.

In the use of the log-normal and log-Pearson Type III distributions, an adjustment for length of record, referred to as "expected probability," has been applied to the probabilities. On the basis of comparative studies, it appears that the average fit of the log-Pearson is slightly improved by the use of this adjustment. However, the adjustment has been developed theoretically only for a normal (and log-normal) distribution, and its use for a log-Pearson Type III distribution is arbitrary. Simulation (Monte Carlo) techniques could be used to develop similar correction factors for the log-Pearson Type III distribution.

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