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	Engineering and Design HYDROLOGIC FREQUENCY ESTIMATES	
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DEPARTMENT OF ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

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Regulation
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Engineering and Design
HYDROLOGIC FREQUENCY ESTIMATES

1. Purpose

This regulation defines the scope of analysis, reporting, and coordination requirements for determining frequency estimates of hydrologic variables.

2. Applicability

This regulation applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works engineering and design responsibilities.

3. References

- a. EP 1110-2-7, Hydrologic Risks.
- b. EP 1110-2-8, Explaining Flood Risk.
- c. EM 1110-2-1415, Hydrologic Frequency Analysis.
- d. Beard, Leo R. 1962 (Jan). "Statistical Methods in Hydrology," U.S. Army Engineer District, Sacramento, 1325 J Street, Sacramento, CA 95814-2922.
- e. Hydrology Subcommittee of the Interagency Advisory Committee on Water Data, Bulletin 17B 1982 (Mar), *Guidelines for Determining Flood Flow Frequency*, U.S. Department of Interior, Geological Survey, Office of Water Data Coordination, Reston, VA 22092.

4. Objective and Scope

a. This regulation deals principally with the development of flow-frequency estimates. Frequency estimates constitute a major factor in the economic evaluation of water resource projects and in the establishment of certain project design, operation criteria, floodplain management, and local land use regulations. It is important that the frequency estimates be structured to meet study goals and objectives. Flood frequency analyses should be designed to be consistent with the quantity, type, and quality of data for other study inputs, e.g., economic impact assessment. It is also important that the effect of estimation errors be systematically evaluated.

b. The information contained in this regulation is general and applies to all hydrologic frequency analyses. The publications referenced in paragraph 3 present methods that are usually applicable to hydrologic variables. The methods should be applied unless there are special situations where the methods are shown not to be applicable or more complex analyses are required. If more detailed procedures are necessary to provide a complete solution, thorough documentation of the procedures, assumptions, and application is required in the presentation of the results.

c. The development of hydrologic frequency estimates requires the application of proper procedures and the correct interpretation of the results. Therefore, the judgment of a professional, trained and experienced in hydrologic analysis, is essential to the appropriate development and application of hydrologic frequency estimates.

This regulation supersedes ER 1110-2-1450, dated 10 October 1962.

5. Terminology

EM 1110-2-1415 and Bulletin 17B (Hydrology Subcommittee of the Interagency Advisory Committee on Water Data 1982) contain extensive glossaries of hydrologic frequency terms. The following paragraphs prescribe specific terminology relating to flood frequency estimates that is to be used in Corps of Engineers reports and presentations.

a. Flood frequency. Technical reports should label flood frequency curves as "Percent Chance Exceedance." References to the frequency of a specific event should use the phrase "[x] percent chance exceedance flood." If the phrase is used several times in the text, it may be shortened to "[x] percent flood." Information for public dissemination may use the short term with the full definition provided as a footnote: "The [x] percent flood has one chance in [100/x] of being exceeded in any given year." Highly technical reports such as research papers may have need to use the term "exceedance probability." Use of the terms "[x]-year flood," "recurrence interval," "exceedance interval," and "return period" are not acceptable in Corps reports.

b. Partial-duration frequency. The frequency scale for partial-duration curves should be labeled "Number of Events per Hundred Years."

c. Low-flow frequency. Low-flow data are usually arrayed from the smallest to the largest. Therefore, the frequency scale is labeled "Percent Chance Nonexceedance."

d. Lake-level frequency. Annual maximum or minimum lake levels are often not independent events as the level one year may depend on what the level was the previous year. Therefore, a true frequency curve cannot be computed from the annual values. When the annual events are not independent, the appropriate label is "Percent of Years Level is Exceeded" for annual maximums and "Percent of Years Level Not Exceeded" for annual minimums.

6. Technical Guidelines

EM 1110-2-1415 provides detailed computational procedures and guidelines on computing frequency estimates for several hydrologic variables. These procedures should be generally followed unless it is determined that they are not applicable to the situation

under study. The computation of flood frequency estimates for unregulated riverine situations will follow the procedures in Bulletin 17B (Hydrology Subcommittee of the Interagency Advisory Committee on Water Data 1982). The guidance on flood frequency analysis in the manual clarifies and expands on the guidance in Bulletin 17B. Therefore, no conflicts should exist.

7. Study Procedures

a. General. The study procedures outlined herein are applicable to flood flow frequency analysis, and many of the same techniques can be applied to other hydrologic variables. The study guidelines are briefly described in the next paragraphs and are shown in Figure 1.

b. Selection of series type. There are two types of frequency arrays, the annual series and the partial-duration series, sometimes called the peaks-over-threshold (POT) series. The selected series type should be established early in the study in coordination with the planner and/or economist with consideration given to the economic consequences in the specific study.

(1) Annual series. The annual series is derived by selecting the largest (or smallest for a minimum series) event out of each year. The "year" may be a calendar year, water year, climatic year, or some other type of year depending on the hydrologic variable. The annual series is used when only one damaging event per year is possible. Flood flow frequency curves will be computed in accordance with Bulletin 17B. Frequency curves of other hydrologic variables may be derived by analytical procedures when a theoretical distribution is found to provide good results at several locations. If poor results are evident, a graphical fit to the data should be made. It may also be necessary to select an appropriate transformation for the data in an attempt to linearize the cumulative frequency curve.

(2) Partial-duration series. The partial-duration series consists of all of the independent events above (or below for a minimum series) a given base value. This series is used when more than one damaging event per year is possible. Application of the partial-duration frequency curve to economic analyses requires that the events be economically independent

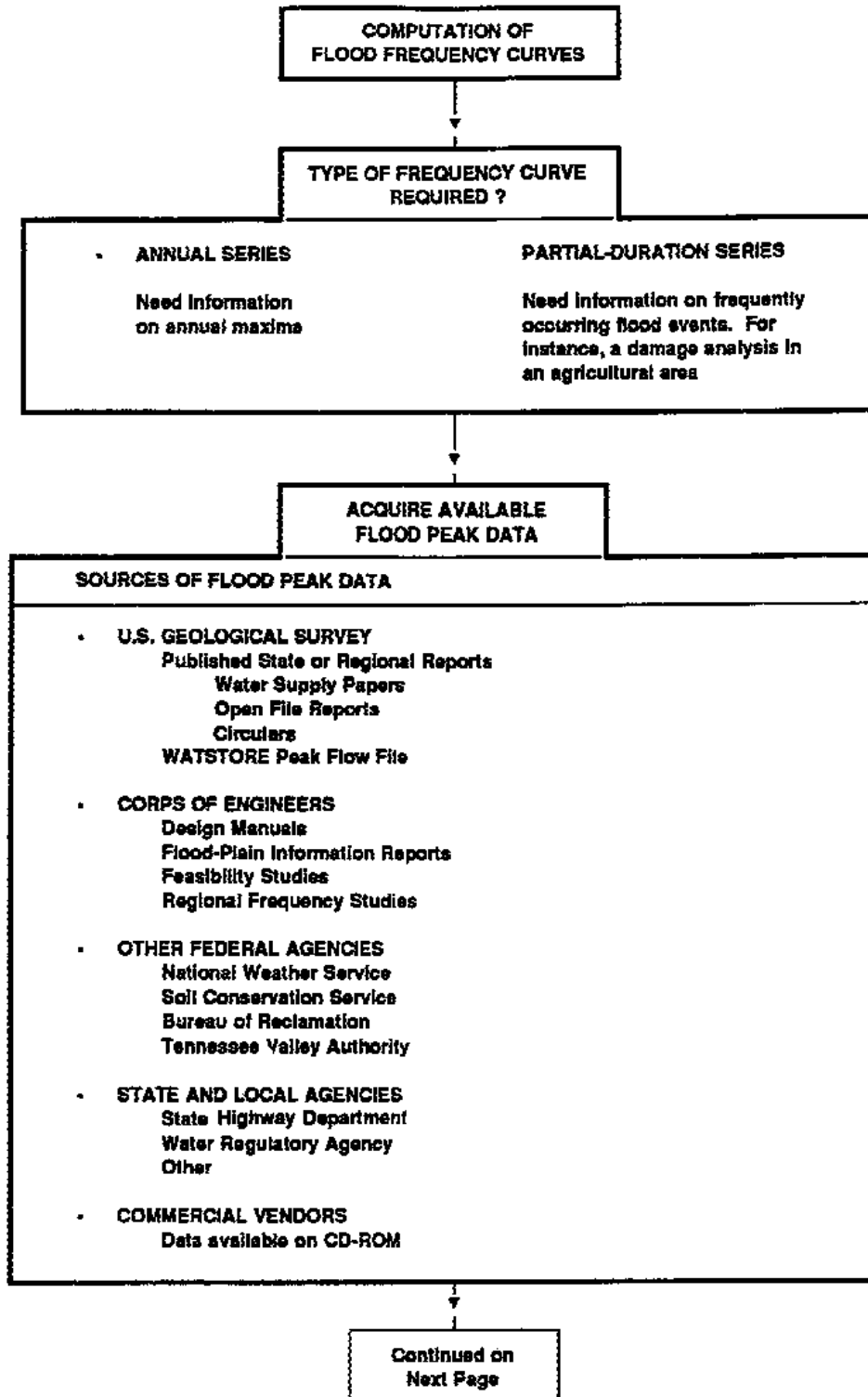


Figure 1. Flood frequency analysis flowchart (Continued)

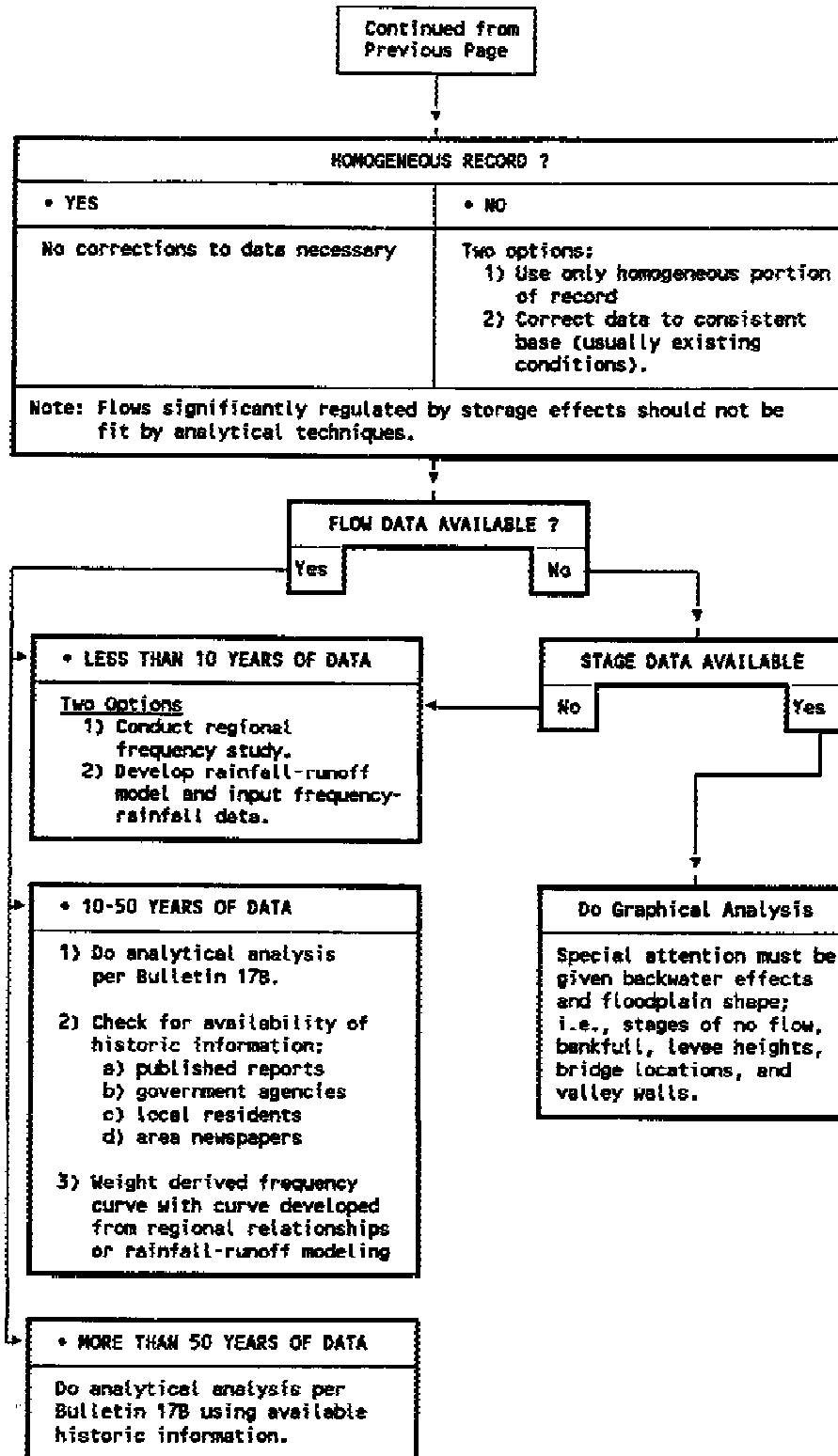


Figure 1. (Concluded)

as well as hydrologically independent. Also, the economic consequences must be indexed to the independent events and *not* represent the total annual consequences indexed to the annual maximum value. In other words, develop a separate partial-duration curve based on the recovery time for each flood damage category. The partial-duration curve should be determined by a graphical fit to the data. The Langbein adjustment to the annual series should not be routinely used to obtain the partial-duration series. Use of a log scale for the “Number of Events per Hundred Years” axis will tend to linearize the plot.

c. Acquisition of data. Some of the sources of hydrologic data are shown in Figure 1. It is important to check the data for accuracy, even though acquired through electronic media.

d. Homogeneity of data. The hydrologic data used in a frequency analysis should be homogeneous. Data are considered homogeneous when each event in the record has occurred under the same set of conditions. If there have been significant changes, then the record should be adjusted through other analyses to a uniform set of conditions. An example of a non-homogeneous streamflow record would be a record obtained at a site while there was increasing upstream storage regulation or urbanization. Frequency curves representing future conditions may be required if there are projects under construction, or construction is imminent, or significant urbanization is expected to occur in the basin.

e. Frequency analysis. Frequency curves can be determined by graphical and analytical computational procedures. Every set of frequency data should be plotted graphically, even though the frequency curve is derived analytically. The nonlinearity of some frequency data may preclude the application of analytical techniques, e.g., regulated annual peaks immediately below a large flood control reservoir.

(1) Graphical frequency analysis. The median or “Beard” plotting positions are recommended, but Weibull plotting positions may be used. The approximating equation for the median plotting position (Equation 2-2b of EM 1110-2-1415) is applicable to annual series. Plotting positions for events more frequent than once a year (partial-duration series) should be obtained using Equation 1a in Beard (1962). The expected probability adjustment (see paragraph 9) is *not* made to graphically derived frequency curves.

(2) Analytical frequency analysis. The analytical procedures described in Bulletin 17B will be followed when computing frequency curves of annual peak flow data. When using Bulletin 17B procedures on other hydrologic variables, statistical tests and/or graphical fitting should be applied to determine if the assumed transformation and theoretical distribution provide reasonable results.

(3) With- and without-project analyses. Flow frequency analyses supporting economic impact assessments for flood damage reduction studies will reflect appropriate without-project and with-project watershed conditions, e.g., storage and urbanization.

8. Expected-Probability Adjustment

Flow frequency curves are used in Corps flood damage reduction studies to estimate the expected annual damage and damage reduction benefits of project alternatives. This is accomplished in the “frequency-based” method by integrating the flow-frequency curve with stage-flow rating and stage-damage curves. Corps policy is that frequency curves used in such analyses be adjusted to reflect expected probability. The expected probability frequency curve is obtained by applying an adjustment to the median frequency curve. The adjustment ensures that the asymmetry of the sampling uncertainty is reflected in the curve and, thus, the resulting expected annual damage and benefits are accurate. In risk-based analysis applications, the asymmetry of the sampling uncertainty in the procedure used to derive the expected damage is explicitly incorporated as part of the procedure used to derive the expected damage. Thus, the frequency curves used in risk-based analysis should be the median (or computed) curves and not the expected probability curves. For flood damage analysis that is performed using traditional frequency-based methods, the frequency curve used must continue to be the expected probability curve. Frequency information in text, tables, and graphs will be clearly noted as being derived from the “median” frequency curve or the “expected-probability” curve, as appropriate.

9. Risk

Every opportunity should be taken to describe flood risk when describing a flood hazard. In a hydrologic context, risk is the probability that one or more events

will exceed a specified value, that has an estimated “true” percent chance exceedance, during a specified number of years. Note that this narrow definition includes a time specification. Risk evaluation enables a probabilistic statement to be made about the chances of a particular location being flooded within a specified number of consecutive years. For example, assume that a community would like a levee to be designed to a height equal to the 1 percent chance flood level. The community’s perception about the risk of flooding may change when it is understood that there is a 26 percent chance that the levee will be overtopped over the span of a 30-year mortgage.

10. Uncertainty

Uncertainty refers to the fact that the true statistics of the total population of occurrences of a particular phenomena, e.g. annual peak stream flow, are not known. Only the statistics of the observed sample data are known. Those statistics usually change as the sample size changes. Confidence limits specify the probability that the true or population frequency curve lies within the stated limits. Confidence limits will be computed for all frequency curves. For frequency curves and other measures computed from regional statistics, standard errors of estimate and sensitivity analysis will be used to estimate confidence limits and evaluate the potential variation in the frequency estimates and consequent impact on a project.

11. Presentation of Results

a. General. The hydrologic frequency information presented in reports will provide: a complete record of the basic data, along with data source(s); any data corrections, censoring, or adjustments; assumptions; analysis methods; reasons for nonstandard procedures; and the final results. The included information should allow a reviewer to follow the complete analysis and provide an independent judgment on the analysis procedures and any decisions that were made. Maximum use will be made of tables, graphs, and maps to convey information. The primary function of text is to document the decision process, any nonstandard procedures, additional study recommendations, and a summary of the results.

b. List of recommended information. Below is a list of information needed in reports to convey

hydrologic frequency estimates. All of the items may not be necessary for every study, and there may be additional items that will be required for the complete documentation of some studies. The amount of information to be presented for a particular item will govern whether it is included along with the text or is put in an appendix, either attached or separate. Major items included in hydrologic frequency analysis documents, if applicable, are:

- (1) Map showing gage locations.
- (2) List of gage names, locations, tributary drainage area, period-of-record, and other pertinent information.
- (3) List of basic data with sources.
- (4) Description of watershed conditions, such as urbanization, storage, flow obstructions, etc., upstream of the gage.
- (5) Description of data corrections, censoring, and/or adjustments.
- (6) Description of analysis procedures, including justification of homogeneity.
- (7) Justification for and details of nonstandard procedures.
- (8) Arrayed data with plotting positions.
- (9) Computed statistics if analytical analysis.
- (10) Probability plot showing data, computed curve, expected probability curve (if appropriate), and confidence limits (usually 5 percent and 95 percent).
- (11) Regional correlation studies showing
 - Basin characteristics.
 - Regression analysis results.
 - Adopted equations and/or maps.
 - Regional statistics estimated at gaged and selected ungaged locations.
- (12) Explanation of differences between Corps results and other agencies’ frequency estimates, if any.

12. Coordination

Coordination with appropriate in-house Corps personnel, Corps headquarters, and other Federal, state, and local agencies is important in the development of accurate and uniform flood frequency estimates.

a. In-house. The most important coordination during frequency studies is that which takes place, or should take place, within the individual office. This is particularly true within field offices where hydrologic frequency analyses are conducted by more than one element of the office. Recurring coordination between those making the estimates and those using the estimates should take place during the study process.

b. Intragency. Adequate coordination and discussion of hydrologic frequency analysis procedures between Corps offices can usually be accomplished by informal contacts. More formal written exchanges will be required when issues are complex or a

permanent record is required. Requests to higher authorities for the review of hydrologic frequency analysis procedures and/or final estimates will follow established procedures through the chain-of-command.

c. Interagency. The division offices have the basic responsibility for coordination at the field level. Field offices should be encouraged to establish routine channels of communication with the active Federal, state, and local water resource agencies in their area. Resolution of differences in frequency estimates between agencies should be accomplished at the field level where possible. Higher authorities should be regularly informed of differences through informal communications. However, the division, or higher, offices may be requested to assist in resolving major differences when the estimates have major fiscal impacts. Finally, flood insurance studies conducted by districts for the Federal Emergency Management Agency (FEMA) should be conducted using FEMA procedures for flood frequency analysis.

FOR THE COMMANDER:



ROBERT L. VANANTWERP
Colonel, Corps of Engineers
Chief of Staff