Chapter 17
Development of Frequency-Based Estimates

17-1. Introduction

Frequency-based estimates of flood discharge are a fundamental requirement for flood-risk investigations and flood-damage analysis. The development of such estimates is a challenging task that requires sound interpretation of regional historical flood-related data and appropriate application of various analytical techniques. This chapter deals with issues such as choice of methodology, use of hypothetical storms in frequency determinations, transfer of frequency-based information from gauged to ungauged sites, development of future-condition frequency estimates, and adjustment of peak discharges to represent stationary conditions.

17-2. Choice of Methodology

a. Choice of methodology for frequency curve development will depend on the purpose of a study and characteristics of available data. Possible methods include the following:

(1) Statistical analysis of observed streamflow data.

(2) Regional frequency analysis.

(3) Event-type precipitation-runoff analysis with hypothetical storms.

(4) Period-of-record precipitation-runoff analysis.

b. Key questions related to study purpose are as follows:

(1) Will effects of future land-use changes or project alternatives be evaluated?

(2) Is period-of-record type information required because of the nature of the study?

(3) What are accuracy and reliability requirements?

c. The answer to the first question is a primary determinant for choice of methodology. If it is necessary to model future land-use changes and/or the effects of projects, application of a precipitation-runoff simulation model is generally essential. The answer to the second question will determine whether the simulation model should have capability for period-of-record analysis. For example, analysis of pond stage on the interior (landward) side of a levee often requires such analysis to reflect the coincident effects of exterior (main river) stage and interior runoff. If modeling of future land-use changes and/or projects is not required, choice of methodology will depend on availability of data and accuracy and reliability requirements. Key questions related to available data are as follows:

(1) Are long-term historical discharge records available for the location(s) of interest?

(2) Are long-term historical discharge records available for nearby sites?

(3) Are short-term discharge records available for the location(s) of interest?

(4) Are (applicable) regional-frequency relationships available for the location(s) of interest?

d. "Long-term" as used here refers to a length of record sufficient to enable development of statistically based frequency estimates of reasonable reliability. Long-term data is extremely valuable and generally provides the most reliable basis for frequency determinations. If land-use conditions have changed during the period of collecting the long-term data, or if there are reservoirs (with significant capacity to store flood runoff) upstream of the location(s) of interest, the period-of-record peak discharges must generally be adjusted to represent a stationary, storage-free condition. The making of such adjustments can require substantial analysis and application of simulation.

e. If long-record data are not available for the location(s) of interest, it may be possible to transfer (and adjust) discharge data or frequency-based information from nearby, similar locations. Such transfer can be difficult, and reliability of results is affected by the transfer process. However, use of such data can be of substantial value and can result in frequency estimates that are significantly more reliable than could be produced without such data.

f. "Short-term" as used here implies that discharge records are insufficient to enable development of statistically based frequency estimates of reasonable reliability. Short-term data can, however, be adequate to enable the calibration of a precipitation-runoff simulation model.

Hence, the availability of such data is very significant when a simulation approach is required.

g. When land-use changes and/or project conditions are not a factor, it may be possible to employ regional-frequency relations. Previously determined relations should be applied carefully; their applicability should be verified, and independent variables should be evaluated properly.

h. In many cases, frequency estimates should be developed by several independent techniques. Different segments of the adopted frequency curve may be derived from different sources depending on the basis for, and reliability of, the individual estimates. All the means at one's disposal should be used to verify resulting estimates. For example, it may be reasonable to expect that the standard project flood would have a magnitude within a certain range of exceedance frequency. The range can be used as a rough check for the upper end of a derived frequency curve. Historical accounts of flooding should be used, if possible, to verify estimates. Peak discharge envelope curves may also be useful.

17-3. Hypothetical Storm Frequency

a. The magnitude and spatial and temporal characteristics of every natural storm is unique. Hence, it is only possible to determine probabilities for average storm depths over specific areas and for specific durations. Although generalized rainfall criteria such as that provided in NOAA publications associate recurrence intervals with rainfall depths, the recurrence interval (or exceedance frequency) of a hypothetical storm developed from such depths is indeterminate. To label a storm as a "100-year" or "25-year" storm can therefore, be misleading.

b. What is generally of primary interest is the exceedance frequency of streamflow peaks and volumes. Attempts are, therefore, made to devise hypothetical storms that can be associated with the generation of streamflow peaks and/or volumes of specified exceedance frequency. However, the runoff generated by a particular storm will be a function of the state of the watershed when the storm occurs. A major storm occurring on a very dry watershed can result in moderate runoff, and a moderate storm on a saturated watershed can result in substantial runoff. Streamflow peaks or volumes of a specified frequency can be caused by an infinite number of combinations of storms and watershed states.

c. Paragraph 13-4 addresses the development of a *balanced* hypothetical storm. With such a storm, the average depth of rainfall for a duration equal to the time of concentration for a watershed will have a 'known' exceedance frequency, as will the average depth for any other duration. However, the triangular temporal distribution of rainfall will generally not be representative of natural storms. For watersheds with substantial natural storage, the streamflow at the outlet may be relatively insensitive to the temporal distribution, whereas for a watershed with a short response time, the resulting streamflow may be quite sensitive. Methods have been developed (Huff 1967, Pilgrim and Cordery 1975) that base the time distribution of a hypothetical storm on distributions observed in historical storms.

d. Associated with application of a hypothetical storm is selection of a storm duration. When a balanced hypothetical storm is used, the duration is generally chosen to equal or exceed the time of concentration for a watershed. The infiltration rate that pertains during the period of peak storm intensities will depend on how dry the watershed is initially and on how much infiltration occurs during the early part of the storm. If a storm duration substantially longer than the time of concentration is used, the infiltration rate during the period of peak storm intensities may be unreasonably low because of the large volume of infiltration that occurs initially. Sensitivity analysis can be useful to determine the effects of storm duration.

e. Another issue is the spatial distribution of hypothetical-storm rainfall. A common assumption is that the distribution is uniform. Such an assumption is consistent with use of a nondistributed model for an elemental basin (i.e., one which is not subdivided). However, for a large, subdivided basin, such an assumption may not be reasonable, especially if orographic or other effects tend to result in substantial deviations from a uniform distribution. Analysis of storm patterns for historical events can provide insight as to the variability of the spatial distribution and whether or not there is a tendency for relatively greater concentrations of rainfall in some subbasins and less in others. It may be appropriate to distribute hypothetical-storm rainfall in accordance with a representative pattern based on such analysis.

f. Also, with large basins, it may be unreasonable to assume that the temporal distribution of rainfall is the same for all subbasins. Such an assumption implies that storm movement and other phenomena affecting the timing of rainfall are not important. Analysis of historical precipitation data can provide a basis for evaluating temporal characteristics of large storms over the basin.

17-4. Transfer of Frequency Information with Hypothetical Events

a. A situation commonly occurs where there are one or more gauged locations with long-term streamflow records in the vicinity of ungauged locations for which discharge-frequency estimates are required. When this is the case, it may be possible to develop discharge-frequency estimates for an ungauged location by transferring frequency-based information from a gauged location using simulation of runoff from hypothetical storms. A prerequisite for this approach is that storm-occurrence characteristics for the gauged and ungauged basin be essentially the same; that is, there should be about equal likelihood that a storm of a given magnitude could occur over either basin. The procedure is as follows:

(1) Let Basin A be a gauged basin for which there is a sufficient length of record to enable development of a discharge frequency relation by statistical procedures. Develop and calibrate an event-type precipitation-runoff model for Basin A.

(2) Let Basin B be the basin for which a discharge frequency relation is required. There may be no stream-flow data for the basin, or there may be a limited amount of stream-flow data which may be adequate to enable calibration of a precipitation-runoff model. In any case, develop (and if possible, calibrate) a precipitation-runoff model for the basin.

(3) Apply a set of hypothetical storms to Basin A. These may correspond to the various recurrence intervals associated with NOAA criteria, or they may simply be proportions of a single hypothetical storm. If storms of specific recurrence intervals are used, adjust loss rates, if possible, so that an x percent-chance storm produces an x percent-chance peak discharge as defined by the statistically derived frequency curve. If this is not possible, or if loss rates so determined are not reasonable, use reasonable loss rates and determine the percent-chance exceedances of the resulting peak discharges for Basin A from the statistically derived frequency curve.

(4) Apply the storm and antecedent moisture condition combinations used for Basin A in the Basin B model. Associate resulting peak discharges for Basin B with the exceedance frequencies of the events as established for Basin A.

b. An advantage of using storms with defined exceedance frequencies rather than proportioned storms and adjusting loss rates as required to produce peak discharges of the same frequencies is that the loss rates so derived can be checked for consistency. Typically, loss rates decrease with decreasing storm frequency. However, it is often not possible to reconcile storms, loss rates, and the ’known’ frequency curve in a reasonable fashion, in which case the storm and antecedent moisture condition combinations are treated simply as index events without regard to assigning predetermined exceedance frequencies to them.

17-5. Development of Future-Condition Frequency Estimates

a. The development of frequency estimates for future conditions based on estimates for existing conditions can be accomplished using an approach similar to that for transferring frequency information from a gauged to an ungauged location. A procedure is as follows:

(1) Develop an existing-condition frequency curve by whatever means is appropriate considering study requirements and data availability.

(2) Develop and calibrate (if possible) an event-type rainfall-runoff simulation model to represent existing conditions.

(3) Apply a set of hypothetical storms with the existing-condition model and associate exceedance frequencies of the storm and antecedent moisture condition combinations with the exceedance frequencies of the resulting peak discharges from the existing-condition frequency curve.

(4) Adjust the existing-condition simulation model to represent future conditions. This may involve, for example, changes to values for percent imperviousness, unit hydrograph or kinematic wave parameters, and routing parameters. Chapter 18 is concerned with techniques for modeling watershed changes.

(5) Apply the same storm and antecedent moisture combinations used for existing conditions to simulate corresponding future-condition peak discharges. Assign exceedance frequencies determined for the events for existing conditions to the future-condition peak discharges.

b. If the future condition is to include new storage elements such as detention reservoirs, such elements must be added to the future-condition model. The modeling of storage elements involves additional considerations, however, because as antecedent storage conditions can be very significant. A period-of-record analysis may be the most viable approach in this case. Chapter 18 provides further discussion on this topic.

17-6. Adjustment of Peak Discharges to Represent Stationary Conditions

a. A common problem in statistical analysis of annual peak discharges is that watershed changes have occurred during the period of record so that the annual values reflect nonstationary conditions. If the changes are primarily due to the construction of storage reservoirs, it is possible to adjust hydrographs at a downstream gauge to natural conditions by routing reservoir *holdouts* (increments of stored water) to the gauge and adding the routed discharge to the observed discharge. A statistical analysis of the adjusted peaks could then be performed to produce a natural-condition frequency curve.

b. If watershed changes are due to effects of urbanization such as land use and channel modifications, it is generally much more difficult to make adjustments to stationary conditions. An approach for adjusting peak discharges to existing conditions is as follows:

(1) Develop and calibrate a rainfall-runoff model for existing basin conditions and for conditions at several other points in time during the period of record. In the example illustrated in Figure 17-1, rainfall-runoff models were developed to represent existing basin conditions (for the year 1975, in this example), and conditions in the years 1960, 1950, and 1940.

(2) Develop an x percent-chance hypothetical storm for the basin using generalized rainfall criteria. The recurrence interval is arbitrary as it is not assumed in this approach that runoff frequency is equal to rainfall frequency. The purpose of adopting a specific magnitude is to establish a base storm to which ratios can be applied for subsequent steps in the analysis.

(3) Apply several ratios to the hypothetical storm developed in step (2) so that the resulting calculated peak discharges at the gauge cover the range desired for frequency analysis. Input the storms to the rainfall-runoff models for each of the basin conditions and determine peak discharges at the gauged location.

(4) Plot curves representing peak discharge versus storm ratio for each basin condition, as illustrated in Figure 17-1.

(5) Use the curves developed in the previous step to adjust the observed annual peak discharges. For example, an annual peak discharge for 1963 would be used to enter the family of storm-ratio curves to interpolate a storm ratio consistent with that peak. This storm ratio can then be used to intersect the base-condition (for example, existing condition) curve to determine the adjusted peak discharge. The adjustment method is applied for each of the annual peaks of record.

(6) A statistical analysis of the adjusted peak discharges can then be performed.

c. The above approach can also be extended to apply to a future condition. For example, a basin model could be developed to represent year 2020 conditions, and a corresponding storm-ratio curve developed. The observed annual peak discharges could then be adjusted as in step (5) above to year 2020 conditions.

Year	Observed Peak Q cfs	Peak Q Adjusted to Exist Cond. cfs
1947	9,000	13,200
1948	8,200	12,800
1949	3,880	6,200
1950	6,150	9,100
1951	3,400	5,700
1952	3,340	5,590
1953	1,460	2,700
1954	3,900	6,400
1955	2,290	3,600
1956	5,160	8,000
1957	3,870	6,000
1958	2,000	3,700
1959	2,610	4,680
1960	2,940	3,990
1961	2,160	2,920
1962	3,850	5,320
1963	2,250	3,000
1964	1,360	1,790
1965	4,420	6,130
1966	2,790	3,800
1967	6,420	8,640
1968	7,080	9,500
1969	4,600	5,940
1970	2,810	2,810
1971	3,470	3,470
1972	2,700	2,700
1973	4,390	4,390
1974	3,810	3,810
1975	5,560	5,560

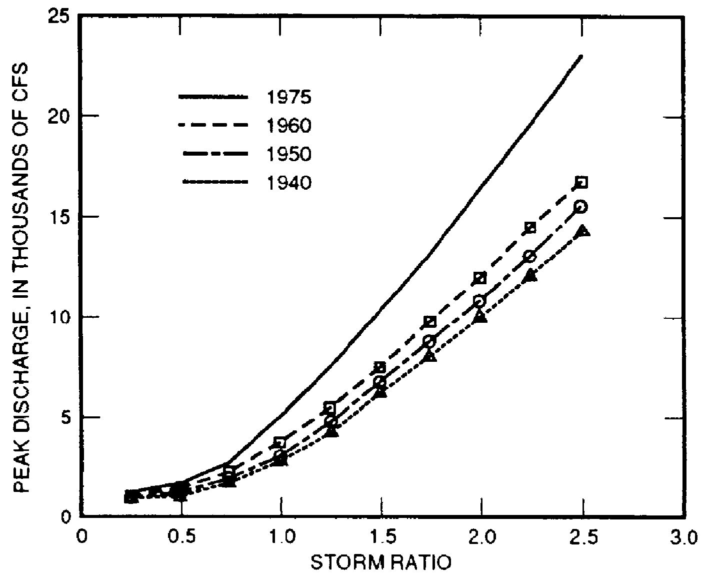

Figure 17-1. Conversion of nonstationary to stationary peak discharges