Chapter 2
Introduction to Flood-Runoff Analysis

2-1. General

This chapter describes products of flood-runoff analysis and relates them to the various types of investigations associated with the Corps of Engineers Civil Works activities. Flood-runoff analysis as described in this manual can be regarded as an engineering application of the science of flood hydrology. Aspects of flood hydrology are briefly described as a precursor to detailed treatment in Part II, *Hydrologic Analysis*. The type, amount, and quality of hydrologic and meteorologic data available for a flood-runoff analysis affect the choice of methodology and reliability of results. Consequences of data availability are discussed. Finally, broad approaches to flood-runoff analysis are presented. The approaches are a framework for a detailed discussion of methods in Part III, *Methods for Flood-Runoff Analysis*.

2-2. Applications of Flood-Runoff Analysis

a. Products of flood-runoff analysis. Products can be categorized with respect to the type of variable (e.g., stage, discharge, volume) and the measure of the variable.

(1) Measure might be simply the magnitude associated with a particular point in time (as in flow forecasting), magnitude associated with a nonfrequency based design flood (e.g., standard project or probable maximum), magnitude associated with duration (e.g., value that is exceeded, or not exceeded, X-% of the time), or magnitude associated with a particular exceedance or nonexceedance frequency. Exceedance frequency measures are particularly common for flood prediction and are the basis for flood risk evaluations (e.g., delineation of the "1-% chance" floodplain for flood insurance purposes), as well as flood damage analysis for project design. In other words, the end product of many flood-runoff analyses is a set of discharge or stage exceedance frequency relations, perhaps for both existing and alternative future conditions, for locations of interest in a watershed. The development of probabilistic estimates of flood runoff is dealt with in Chapter 12, "Frequency Analysis of Streamflow Data," and Chapter 17, "Development of Frequency-Based Estimates."

(2) Generally, water elevation at a location in a river or on a floodplain is of more direct interest for flood analysis than magnitude of discharge. Water elevation is determined with a hydraulic analysis, which is oftentimes performed subsequent to a hydrologic analysis. However, the hydraulic characteristics of floodwave movement are an important aspect of hydrologic analysis, and there are situations where it is best to incorporate detailed hydraulic analysis directly in the determination of discharge. Chapter 9, "Streamflow and Reservoir Routing," deals with hydraulic aspects of hydrologic analysis, including techniques with which water elevations can be determined.

b. Types of investigation requiring flood-runoff analysis. Types of investigation include flood risk evaluation of floodplains, flood damage evaluation for project planning, design of hydraulic structures for flood control, and flood-runoff forecasting for project operations.

(1) The evaluation of flood risk for floodplains, such as is required for flood insurance studies, requires discharge-exceedance frequency estimates for locations along a stream. Discharges for selected exceedance frequencies are then used in the hydraulic determination of water surface profiles from which maps of inundated areas can be prepared. Hence, the primary product of flood-runoff analysis for these investigations is a set of discharge-exceedance frequency relations for current land use conditions.

(2) Flood damage evaluations for project planning generally require the development of both discharge-exceedance frequency relations and stage-discharge relations for index locations associated with "damage" reaches of a stream. These relations must be developed for existing conditions as well as future conditions with and without proposed projects. The development of such relations is among the most challenging of applications in flood-runoff analysis. Chapter 18, "Evaluating Change," is particularly pertinent to such studies.

(3) Design of hydraulic structures for floods such as the standard project or probable maximum generally requires estimation of the peak stage, discharge, or runoff volume associated with such events. In the case of a large dam, the spillway capacity and height of dam are generally based on routing the spillway design flood (i.e., the probable maximum flood) through the reservoir. Because such events are beyond experience, judgment is required in establishing parameters for the analysis. Chapter 13, "Analysis of Storm Events," deals with aspects of such analyses.

(4) Real-time estimates of flood runoff are used in making operational decisions for reservoirs, reservoir systems, and other hydraulic structures. Precipitation, stage, and other data are transmitted by telemetry systems

to water control centers, where the data are processed and forecasts are made. Although flow forecasting is not dealt with explicitly in this manual, pertinent sections are Part II on hydrologic analysis and Part III sections dealing with precipitation-runoff modeling. Other types of investigation for which flood-runoff analysis may be required include those involving the evaluation of applications for permits to encroach on water bodies and studies involving the design of flood warning systems. In both cases, simplified techniques may be appropriate, some of which are described in Chapter 11, "Simplified Techniques."

2-3. Nature of Flood Hydrology

a. The hydrologic system.

(1) A significant aspect of flood hydrology is the estimation of the magnitude of streamflow at various locations in a watershed resulting from a given precipitation input, as illustrated schematically in Figure 2-1.

(2) The hydrologic system embodies all of the physical processes that are involved in the conversion of precipitation to streamflow, as well as physical characteristics of the watershed and atmosphere that influence runoff generation. The use of computer models to simulate the hydrologic system is of major significance in the performance of many flood-runoff analyses. A fundamental problem in simulating hydrologic systems is to employ the appropriate level of detail to represent those components of the system that have a significant influence on the phenomena being modeled. An associated problem is to acquire and interpret information on watershed characteristics, etc. to enable appropriate representation of the system. Part II, Hydrologic Analysis, is largely devoted to techniques for representing various components of the hydrologic system.

b. Physical processes. The hydrologic cycle comprises all of the physical processes that affect the movement of water in its various forms, from its occurrence as precipitation near the earth's surface to it's discharge to the ocean. Such processes include interception, water storage in depressions, water storage in lakes and reservoirs, snow accumulation and melt, infiltration through the earth's surface, percolation to various depths in the subsurface, the storage of water in the subsurface, the lateral movement of water in both unsaturated and saturated portions of the subsurface, evaporation from water bodies and moist soil, transpiration from vegetation, overland flow, and streamflow. The processes are complex and can be defined with varying degrees of sophistication. Some processes are more significant than others for particular types of analysis. For example, if an analysis of runoff from a historical storm with an event-type simulation model were being performed, it would be appropriate to exclude evapotranspiration during the storm event from the analysis. On the other hand, if a continuous (moisture accounting) simulation model were being used for a period-of-record analysis, appropriate representation of evapotranspiration would be very significant.

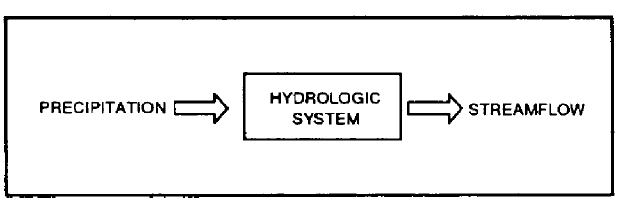

Figure 2-1. Hydrologic system

c. Storm characteristics.

(1) In Figure 2-1, precipitation is viewed as an input to a hydrologic system. The precipitation might be associated with a historical storm, a design storm, or may result from a stochastic generation procedure. Generally, precipitation is averaged spatially (i.e., "lumped") over a subbasin, or perhaps over a geometric "element," if a "distributed" model is being used. Likewise, precipitation intensity is averaged over a time interval. Thus, the precipitation input to the hydrologic system is commonly represented by hyetographs of spatially and temporally averaged precipitation. The development of such hyetographs is addressed in Chapter 4, "Rainfall Analysis."

(2) Each storm type (e.g., convective, frontal, orographic) has predominant characteristics regarding the spatial extent and variability, intensity, and duration of precipitation. Precipitation fields associated with storms, especially the convective type, exhibit substantial spatial and temporal variability. The sampling of such fields with gauge networks of typical density results in precipitation estimates that may be highly uncertain. Indeed, the gauge measurements themselves may exhibit significant uncertainty, primarily due to wind effects. As indicated in Chapter 4, advances in use of radar-based rainfall data may offer a significant improvement in capabilities for defining the spatial and temporal variations of rainfall.

d. Watershed characteristics. A key aspect of simulating a hydrologic system is representation of the physical properties of the system. Watersheds are heterogenous with respect to topography, geology, soils, land use, vegetation, drainage density, river characteristics, etc. In most applications, the properties are lumped on a subbasin basis and represented by simple indices. The representation of physical properties is dealt with in chapters in Part II that treat components of the hydrologic system.

e. Scale considerations. The techniques that are most appropriate for a simulation model are a function of the scale of the phenomena being modeled.

(1) For example, for small upland basins, a physically based model should recognize a variety of storm-runoff production mechanisms, including overland flow caused by rainfall exceeding infiltration capacity over the entire basin, overland flow caused by rainfall exceeding infiltration capacity over a portion of the basin (partial area overland flow), overland flow caused by a high water table near the stream system, and subsurface stormflow. Even with capabilities to simulate these processes, such models may not perform satisfactorily because of the lack of information regarding spatial variability of rainfall and of subsurface hydraulic properties.

(2) At a larger scale (i.e., larger basins), the processes that are dominant at a smaller scale tend to average out such that different approaches to modeling are appropriate. Emphasis is given to use of the unit hydrograph and (macro scale) kinematic wave methods in this manual. However, application of these methods requires the determination of rainfall excess and the estimation of subsurface contributions to runoff, both of which are the source of substantial uncertainty. Also, at the larger scale, flood wave movement through the stream network becomes a dominant factor affecting the magnitude and timing of flood runoff. Hence, significant attention must be given to streamflow routing. The primary focus in this manual is on basins that are from one to thousands of square miles in size, and for which it is generally necessary to divide the basin into multiple subbasins and perform streamflow routing to obtain total flow at the outlets of downstream subbasins.

2-4. Data Considerations

a. Types and sources of data for flood-runoff analysis. Data may be categorized as that related to physical attributes of a basin, and data pertaining to the historical movement of water (in its various states) through the hydrologic cycle.

(1) Physical attributes include area, surficial geometric characteristics (area, shape, slope, etc.), soil type, land use, vegetative cover, subsurface characteristics (location, size and geometry of subsurface features, hydraulic conductivities, etc.), and stream channel characteristics (shape, slope, roughness, etc.). Some of these attributes are static, while others may change seasonally or over longer time periods. Generally for flood studies, resources are not expended in acquiring subsurface information, as such information can be very costly to acquire, and use of such information is limited.

(2) Data related to water movement include precipitation, snow depth and other snow-related information, storage of water in surface water bodies, infiltration, soil moisture, movement of water in both unsaturated and saturated portions of the subsurface, evaporation, transpiration, and streamflow (or flow in conduits or other drainage devices). In addition, meteorologic data such as air temperature, solar radiation and wind may be used with energy relations to define water movement. Although a number of these data types might be used in a particular analysis, many flood-runoff studies rely primarily on historical precipitation and streamflow data.

b. Significance of data availability. Because of the complex nature of hydrologic processes, storm characteristics and basin characteristics, the type and amount of data available can have a major influence on the choice of methodology for performing an analysis and on the reliability of results. Part III, *Methods for Flood-Runoff Analysis*, describes the data requirements for various methods. Streamflow data, in particular, is extremely valuable. A relatively long record of streamflow data can be used to make estimates of flood-runoff probabilities that are far more reliable than could be made by any method without such data. Even a short record of streamflow data is valuable because it can be used in the calibration of precipitation-runoff simulation models.

2-5. Approaches to Flood-Runoff Analysis

In this section, general approaches to flood-runoff analysis are described. For each approach, there may be several methods of analysis. These are described in detail in Part III. Selection of methods is discussed in Chapter 3, "Study Formulation and Reporting."

a. Approaches. Methods of flood-runoff analysis are categorized under four approaches, as follows:

(1) Simplified methods.

(2) Frequency analysis of streamflow data.

(3) Precipitation-runoff analysis of storm events.

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

(a) Simplified methods may involve use of formulas, previously derived regression equations, envelope curves, etc. as a basis for making hydrologic estimates. The methods may be especially useful for preliminary estimates of the expected magnitude of a variable, or for providing an independent check on estimates developed by other means.

(b) Where adequate streamflow data are available, frequency analysis of such data can be performed to develop exceedance frequency relationships. General aspects of such analyses are described in Chapter 12; details are provided in EM 1110-2-1415, Hydrologic Frequency Analysis.

(c) For situations where historical streamflow data is nonexistent or inadequate for required estimates, a precipitation-runoff simulation model is commonly used for flood-runoff analysis. Generally, such a model *must* be used if it is intended to evaluate flood runoff effects of structural projects or historic or future land use changes. The third approach listed above involves use of a simulation model that is designed for analyzing single storm events. Such models do not perform a continuous water balance and, therefore, must be provided input that describes the state of a basin (in terms of base flow and some measure of wetness) at the beginning of the simulation. Design storms are used with such models to develop exceedance frequency estimates, or design-flood estimates, of hydrologic variables of interest. Care must be exercised in assigning exceedance frequencies to simulated values because the runoff from a storm of specific exceedance frequency does not necessarily have the same exceedance frequency. Chapter 17, "Development of Frequency-Based Estimates," deals with this issue. It is also possible to use an "event" type model to both analyze each of the largest precipitation events of record and develop exceedance frequency estimates by statistical analysis of the results. This type of discrete event period-of-record analysis requires screening of precipitation data for the largest events and the establishment of initial conditions at the beginning of each event, as discussed in Chapter 13, "Analysis of Storm Events."

(d) The fourth approach is to use a precipitation-runoff simulation model with period-of-record precipitation as an input and to simulate period-of-record sequences of the variables of interest. If exceedance frequency relations are desired, they can be developed by conventional statistical analysis of the period-of-record outputs. Such a model maintains a continuous moisture balance; therefore, the state of the basin at the beginning of each storm event is implicitly determined. The use of such models is conceptually attractive. However, the model requirements in terms of data and the number of parameters that must be calibrated are substantial. Aspects of continuous moisture accounting are described in Chapter 8, "Subsurface Runoff Analysis," and Chapter 14, "Period-of-Record Analysis."

b. Factors affecting choice of approach. The choice of approach for a flood-runoff analysis should take into account required "products" of the analysis, data availability, reliability of results, and resource requirements. With regard to data availability, a key factor is the availability of streamflow data adequate for frequency analysis, if frequency estimates are required. Though not always the case, improved reliability is generally achieved with the use of more sophisticated and comprehensive methods of analysis. There is significant uncertainty associated with virtually *all* hydrologic estimates. It is often advisable to produce estimates by two or more independent methods and to perform a sensitivity analysis to gain information regarding reliability of results. Finally, financial and human resources available for a study can be a controlling factor in choice of methodology. These issues are discussed in Chapter 3, "Study Formulation and Reporting."