Methods for Delineating Flood-Prone Areas in the Great Basin of Nevada and Adjacent States

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Prepared in cooperation with the U.S. Bureau of Land Management

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By D.E. BURKHAM

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Conversion Factors and Abbreviations

English units of measure used in this report may be converted to International System (metric) units by using the following factors:

Multiply	By	To obtain
inches (in.)	25.40	millimeters (mm)
feet (ft)	0.3048	meters (m)
feet per second (ft/s)	0.3048	meters per second (m/s)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
miles (mi)	1.609	kilometers (km)

Altitude Datum

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), which is derived from a general adjustment of the first-order leveling networks of both the United States and Canada.

Methods for Delineating Flood-Prone Areas in the Great Basin of Nevada and Adjacent States

By D.E. Burkham

Abstract

The Great Basin is a region of about 210,000 mi^2 having no surface drainage to the ocean; it includes most of Nevada and parts of Utah, California, Oregon, Idaho, and Wyoming. The area is characterized by many parallel mountain ranges and valleys trending north-south. Stream channels usually are well defined and steep within the mountains, but on reaching the alluvial fan at the canyon mouth, they may diverge into numerous distributary channels, be discontinuous near the apex of the fan, or be deeply entrenched in the alluvial deposits. Larger rivers normally have well-defined channels to or across the valley floors, but all terminate at lakes or playas.

Major floods occur in most parts of the Great Basin and result from snowmelt, frontal-storm rainfall, and localized convective rainfall. Snowmelt floods typically occur during April–June. Floods resulting from frontal rain and frontal rain on snow generally occur during November–March. Floods resulting from convective-type rainfall during localized thunderstorms occur most commonly during the summer months.

Methods for delineating flood-prone areas are grouped into five general categories: Detailed, historical, analytical, physiographic, and reconnaissance. The detailed and historical methods are comprehensive methods; the analytical and physiographic are intermediate; and the reconnaissance method is only approximate. Other than the reconnaissance method, each method requires determination of a *T*-year discharge (the peak rate of flow during a flood with long-term average recurrence interval of *T* years) and *T*-year profile and the development of a flood-boundary map. The procedure is different, however, for each method. Appraisal of the applicability of each method included consideration of its technical soundness, limitations and uncertainties, ease of use, and costs in time and money.

Of the five methods, the detailed method is probably the most accurate, though most expensive. It is applicable to hydraulic and topographic conditions found in many parts of the Great Basin.

The historical method is also applicable over a wide range of conditions and is less expensive than the detailed method. However, it requires more historical flood data than are usually available, and experience and judgement are needed to obtain meaningful results.

The analytical method is also less expensive than the detailed method and can be used over a wide range of conditions in which the *T*-year discharge can be determined directly. Experience, good judgement, and thorough knowledge of hydraulic principles are required to obtain adequate results, and the method has limited application in other than rigid-channel situations.

The physiographic method is applicable to rigid-boundary channels and is less accurate than the detailed method.

The reconnaissance method is relatively imprecise, but it may be the most rational method to use on alluvial fans or valley floors with discontinuous channels.

In general, a comprehensive method is most suitable for use with rigid-bank streams in urban areas; only an approximate method seems justified in undeveloped areas.

INTRODUCTION

General Problem

The U.S. Bureau of Land Management (BLM), in response to directives from the U.S. Congress, is inventorying the natural resources of the public lands administered by them. As part of the inventory, the BLM plans to delineate areas having flood-related hazards. Specifically, they will evaluate areas having a 1-percent or greater chance of flooding in any one year. The BLM has asked the U.S. Geological Survey for assistance in appraising and selecting methods for the delineation of such areas in the Great Basin.

Purpose and Scope

The study undertaken by the Geological Survey has the following main objectives:

1. Appraise several possible methods for delineating flood-prone areas on BLM lands in the Great Basin.
2. Suggest which methods are most suitable for mountainous areas, alluvial fans, valley floors, and playas.
3. Provide guidelines, mainly by example, for the use of each suggested method.

The flood-prone areas considered in these three objectives are those having a 1-percent or greater chance of flooding in any one year. Information required for the study includes general descriptions and discussions of the types of hazard that exist in such flood-prone areas in each of the four physiographic settings listed as part of the second objective. The hazards include inundation by water and debris, damage from high-velocity water and debris, and erosion.

Results reported herein relate primarily to objectives 1 and 2. They include a general description of the physiography and hydrologic setting of the Great Basin; a general discussion of flood problems; and a general classification of methods that have been used in flood mapping, including a discussion of the basic assumptions, limitations, applicability, and accuracy of each procedure. A significant part of the discussions in this report was taken directly from other published reports.

CHARACTERISTICS OF THE GREAT BASIN

Physiography

The Great Basin, a region having no surface drainage to the ocean, encompasses about 210,000 mi^2 and includes most of Nevada and parts of Utah, California, Oregon, Idaho, and Wyoming (fig. 1). The basin extends from the United States-Mexico border in southern California north-northwestward for about 850 mi into southeastern Oregon, and from near Lake Tahoe in northeastern California eastward for about 560 mi into southwestern Wyoming (fig. 2). Prominent peripheral features are the Wasatch Range and High Plateaus to the east, the Columbia Plateau to the north, the Sierra Nevada to the west, and minor ranges to the south (Butler and others, 1966, p. 2–4).

Most of the Great Basin is in the Basin and Range physiographic province as described by Fenneman (1931). As is typical for that province, the interior land of the Great Basin is characterized by many mountain ranges that trend north-south and are paralleled by valleys underlain by alluvial and lacustrine sedimentary deposits. The mountain ranges commonly are 50 to 75 mi long, 5 to 15 mi wide, and reach altitudes of 2,000 to more than 10,000 ft above sea level.

Drainage basins within the interior of the Great Basin generally have moderately to steeply sloping mountains along most of their boundaries, although some drainage boundaries are barely above the adjacent valley floors (Lamke and Moore, 1965). The steepness of the mountain slopes depends on the character of the bedrock and the age and magnitude of the structural deformation that formed the mountain. The land surface of the mountains varies from almost bare rock to high mountain slopes covered with conifers. Alluvial fans have formed aprons at the base of the mountains; each fan may be several miles in width. The fan deposits consist of erosional debris from the mountains, usually with the coarser material near the mountains. The fan surface may be free of vegetation, have a cover of desert brush, or support meadow grass.

An alluvial fan from one mountain range may extend outward to coalesce with one from an adjacent range (Lamke and Moore, 1965). Generally, this results in the development of a nearly flat area, where water may stand at intervals (playa lake) and where fine-grained deposits accumulate.

Stream channels within the mountains in the Great Basin usually are well defined and of high gradient. Some of the streams are in steep-walled gorges; most of them, however, have narrow flood plains and moderately sloping banks. Most larger rivers in the Great Basin head in the mountains. These include the Bear, Ogden, Weber, Jordan, Provo, and Sevier in Utah; the Humboldt, Reese, and Quinn in Nevada; and the Carson, Truckee, and Walker in California and Nevada.

Many of the mountain streams diverge into numerous distributary channels upon reaching the alluvial fan at the canyon mouth. Some others are discontinuous near the apex of the fan or have become deeply entrenched in the alluvial deposits. Larger rivers, such as those previously mentioned, normally have well-defined channels to or across the valley floors; however, each one terminates at a lake or playa. The density of well-defined channels in most of the valleys is very low.

Extensive arid areas, including Death Valley and the Great Salt Lake and Mojave Deserts, occupy parts of the Great Basin.

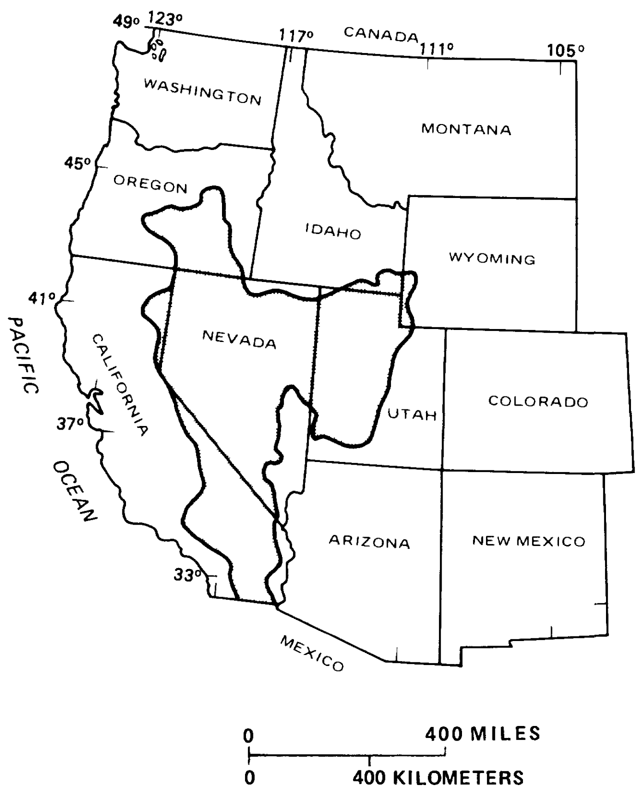

Figure 1. Location and extent of study area (shaded).

Hydrologic Setting

As a whole, the Great Basin is one of the most arid regions in the United States, having an overall average annual precipitation of about 9 in. However, the annual average differs greatly from place to place. It ranges from 1.5 to 4 in. in the low altitudes of the southern part of the basin, from 4 to 6 in. in west-central Nevada and western Utah, and from 25 to 50 in. over the Sierra Nevada and the highest mountains in the northeastern part of the basin (Houghton, 1969).

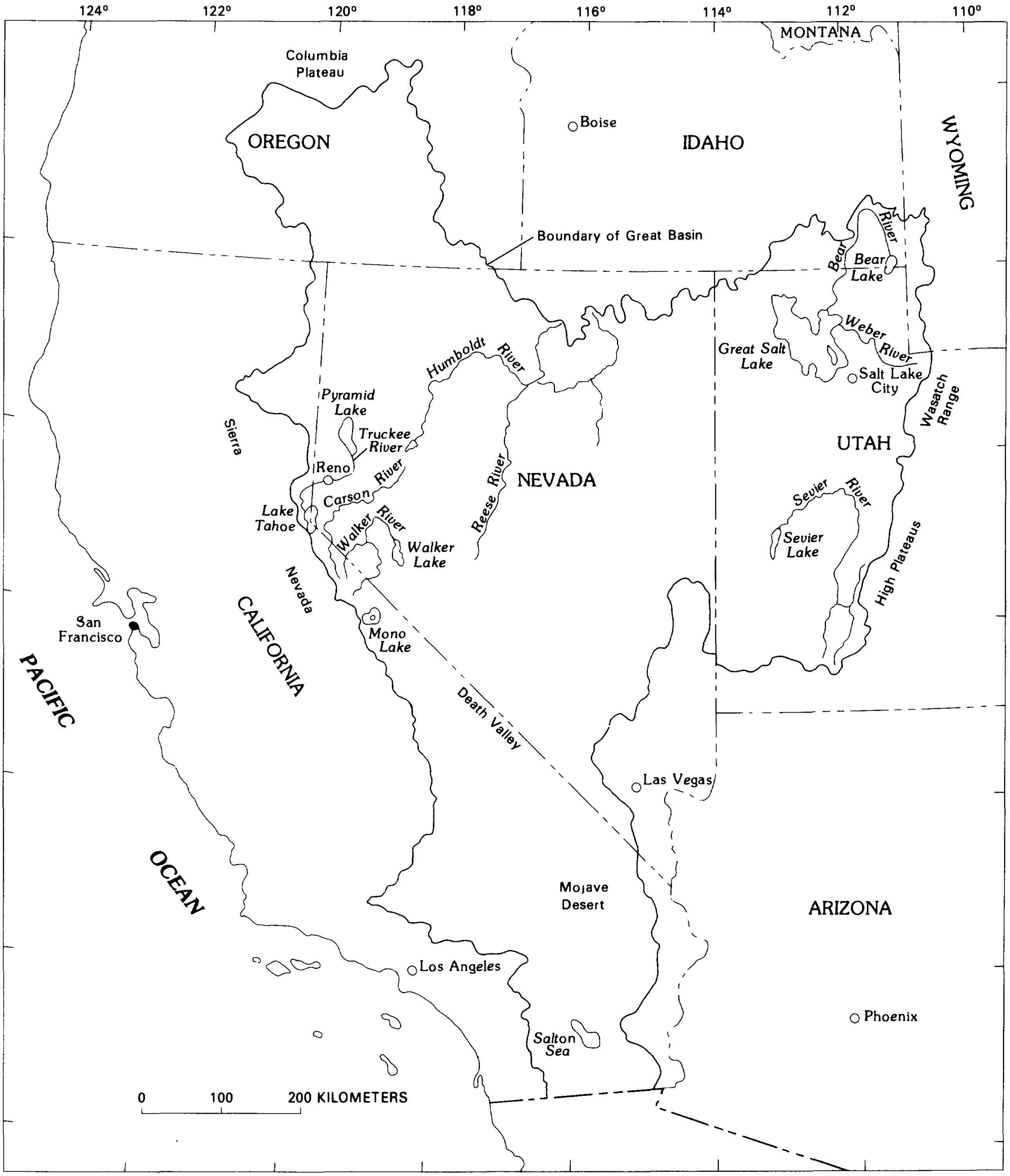

Figure 2. Selected major drainage and geographic features in the Great Basin of Nevada and adjacent sites.

The temporal variability of annual precipitation also is great. If we assume that the Great Basin is typical of regions in the Basin and Range physiographic province, the coefficient of variation for annual precipitation would range from 0.2 to 0.5 in. (McDonald, 1956; Burkham, 1970). The predominant form of precipitation in the Sierra Nevada and the highest mountains of the northeastern Great Basin is snow. In the remaining part of the Great Basin, the predominant form of precipitation is rain.

Moisture in the basin comes mainly from two sources—the Pacific Ocean and the Gulf of California (Houghton, 1969). The first provides most of the moisture for precipitation during October–June. The second provides moisture during July–September; in some years the Gulf of Mexico may also provide moisture during the summer period.

The great variability of precipitation in space and time in the Great Basin is due to (1) the relative importance of the two oceanic sources; (2) the frequency, position, and nature of the various triggering mechanisms; and (3) the circulation pattern of air movement (Houghton, 1969). The types of triggering mechanisms include convection, orographic lifting, and two basic forms of cyclones—transitory frontal cyclones, which move inland from the Pacific Ocean, and continental cyclones, which develop over the Great Basin. Because a large part of the moisture is carried from the Pacific Ocean to the basin by prevailing westerly winds, the intervening mountains form barriers, and rain shadows exist on the leeward side of those mountains. This accounts for the low average annual precipitation in many of the interior valleys.

Two types of storms—cyclonic and convectional—characterize the seasonal pattern of precipitation in the Great Basin. The cyclonic (or frontal) storm, an atmospheric disturbance caused by interacting air masses, commonly distributes moisture over a large area, occasionally in rather large amounts. Much of the precipitation in the Great Basin during October–June results from cyclonic action.

The convectional storm, commonly called a thunderstorm, is characterized by rainfall of high intensity and short duration in a small area (table 1). Dorroh (1946, p. 5) stated: "Although rainfall may occur at many locations on a given day, there is little conformity in either rates or amounts that may occur at two different places, since very localized atmospheric conditions are the predominating factors involved." Because heating of the air near the ground is the main cause of convective action, thunderstorm occurrences decrease in cold weather. The intensity and amount of precipitation from a single thunderstorm in the Great Basin apparently decrease with increasing latitude (Reidel and Hansen, 1972).

Even though the two types of storms result from different forms of atmospheric disturbance, they often occur together. When widespread low-intensity rainfall from frontal storms is accompanied by local high-intensity rainfall from convective storms, large volumes of runoff may result.

Streamflow in the Great Basin comes mainly from snowmelt and rainfall. Probably more than 50 percent of the streamflow that reaches the valley floors originates from snow that accumulates in mountains above the 7,000-ft altitude (Lamke and Moore, 1965).

THE FLOODING PROBLEM

Introduction

As used in this report, a flood is defined as the occurrence of water in excess of channel capacity such that overbank flow inundates part or all of the flood plain or that channel banks are eroded. A flood by itself does not constitute a hazard; a flood hazard develops because people occupy flood-prone areas. Traditionally, lands along rivers and on alluvial fans attract people because water usually is readily available, the land is fertile, flat, and easy to farm and build on, and the surroundings are aesthetically pleasing. Occupancy of a flood plain or alluvial fan, especially one in the arid and semiarid regions, is generally sparse at first, usually by farmers and ranchers. In time, however, the density of occupancy may increase and the former farm and ranch lands become urbanized. Highways and railroads are built on the low-lying river flatlands. The final result often is the large-scale placement of people, their structures, and agriculture in the path of floods.

Recognizing that future floods are inevitable and that development of flood-prone areas will continue, Congress has passed laws (the National Flood Insurance Act of 1968, which is Title 13 of Public Law 90–448, and the Flood Disaster Protection Act of 1973, which is Public Law 93–2340) requiring, among other things, that flood-prone areas be delineated and that flood insurance be made available to the users of such areas.

Historically, most of the flood-related problems in the Great Basin have centered around a few of the larger cities—Salt Lake City, Ogden, Reno, Carson City—and along a few major streams, where most of the population is centered. Floods occur in other areas of the Great Basin, but usually do not become major problems because of the sparsity of people. The population, however, is rapidly increasing, and the pressure for more development of public land, which encompasses a large part of the Great Basin, is mounting.

Significant areas of public land in the Great Basin eventually will be subject to development, according to Richard Jewell (U.S. Bureau of Land Management, oral commun., 1980). Before any action can be taken to approve development of public land, however, the responsible Federal management agency must, as directed by Executive Order 11988, determine whether the area is flood prone and whether the chance of flooding in any given year is 1 percent or greater.

Types and Examples of Floods

Major floods occur in most of the Great Basin. These floods are caused by (1) snowmelt, (2) frontal rains, (3) frontal rains on snow, and (4) convective rainfall during localized thunderstorms. Snowmelt floods, which typically occur during April–June, develop when a large accumulation of snow melts rapidly. Floods from frontal rain and frontal rain on snow generally develop during November–March. Many such floods have been recorded in the western part of the Great Basin along the Sierra Nevada (Butler and others, 1966). Many other floods in the Great Basin result from intense rainfall during summer thunderstorms of small areal coverage. Often, the flood-producing thunderstorms are centered in the foothills along mountain fronts; however, they also occur in mountains and in flat desert areas.

The floods of April–June 1952 in Utah and Nevada are examples of the snowmelt type. According to Somers (1957), the floods were triggered by above-normal temperatures that induced rapid melting of a record snow accumulation. Rainfall apparently played an insignificant part in the flooding. Peak discharges of record were reached on the lower Weber River, Ogden River, Spanish Fork, lower Provo River, and Jordon River in Utah; the Humboldt River and its tributaries draining the north area of the basin in Nevada; and the central Bear River in Idaho and Wyoming. Damage in the Great Basin reached $10 million (Somers, 1957), and two people lost their lives.

Floods in California and western Nevada in January–February 1963 are examples of rain-type floods resulting from the inland movement of two frontal systems (Rantz and Harris, 1963). The first system crossed California on January 30 on a path centered over watersheds drained by the Yuba and American Rivers on the west side of the Sierra Nevada and the Truckee River on the east side; the second, whose path was about 150 miles to the south over watersheds drained by the Kaweah, Tule, and Kern Rivers, crossed California on January 31. According to Rantz and Harris (1963), the storms were orographically influenced, and several precipitation stations in the Sierra Nevada reported storm totals in excess of 20 in. Of the basins mentioned, only the watershed drained by the Truckee River is in the Great Basin.

The January–February 1963 storms caused an estimated $4.4 million loss in the Great Basin (Rantz and Harris, 1963). Had storage in manmade reservoirs not retarded much of the runoff, damage to urban areas probably would have been even greater. Damage was greatest in the Truckee River basin, mainly because of urbanization in the Reno, Nevada, area. Peak flows exceeded the maximum previously recorded at several gaging stations on both the main stream and tributaries of the Truckee River. About 20 square blocks in the downtown area of Reno were inundated to depths of as much as 4 ft. Flooding in the nearby Carson and Walker River basins primarily affected irrigation systems and ranch lands and caused heavy damage to highways.

The floods of February 10–15, 1962, in northeastern Nevada and southern Idaho are examples of the rainfall-on-snow type. An unusual combination of prolonged light rainfall, an extensive area of snow at low altitudes, an extended period of above-freezing temperatures, and deeply frozen ground contributed to the severe flooding. The magnitude

Table 1. Major short-period storms of record in and near the Great Basin

[Adapted from Reidel and Hansen, 1972, table 1]

Location	Latitude	Longitude	Altitude (ft)	Date	Duration (min)	Precipitation[1] (in.)
			Arizona			
Fort Mohave	35°02'	114°36'	550	Aug. 16, 1898	45	8
			California			
Chiatovich Flat	37°44'	118°15'	10,320	July 19, 1955	150	8.2
			Nevada			
Elko	40°50'	115°40'	5,075	Aug. 27, 1970	60	3.6
Palmetto	37°27'	117°42'	6,700	Aug. 11, 1890	60	8.8
			Utah			
Morgan	41°03'	111°38'	5,150	Aug. 16, 1958	60	7

[1]Some of the amounts are labeled as questionable by Reidel and Hansen.

of the flood along the upper Humboldt River and tributaries in Nevada exceeded that of the 50-year flood (Thomas and Lamke, 1962).

The flood of September 14, 1974, in Eldorado Canyon, a tributary to the Colorado River, is an example of the thunderstorm type. Glancy and Harmsen (1975, p. 1) stated, "A devastating flash flood of thunderstorm origin struck Eldorado Canyon, a 22.9-square-mile drainage with a history of flooding, in southern Nevada, at about 2:30 p.m., September 14, 1974. The flood killed at least nine people, destroyed 5 trailer houses and damaged many others, obliterated a restaurant, destroyed 38 vehicles, 19 boat trailers, 23 boats, half of the boat-docking facilities, and the gas dock. The severe runoff resulted from intense basinwide rain and hail at rates up to 3 inches of precipitation per half an hour. The storm moved downbasin and generally increased in intensity, which compounded runoff rates. Peak discharge was estimated to be 76,000 cubic feet per second just upstream from the developed area near the canyon mouth."

The flood of July 3–4, 1975, in Las Vegas, Nev., is another example of a thunderstorm type. According to Katzer and others (1976), large amounts of thunderstorm precipitation on the afternoon of July 3, 1975, between metropolitan Las Vegas and the mountains to the south, west, and north caused flash flooding. Total storm precipitation equaled or exceeded 3 in. in some areas. The period of intensive rainfall was about 6 hours; however, the intensity may have exceeded 1 in/h in some areas. Precipitation on alluvial-fan areas produced most of the flow at the storm peak. According to Katzer and others (1976), field evidence indicates that runoff from mountainous areas did not contribute to flooding in the city. Total damage was estimated to be $4–5 million, and two people lost their lives.

The Eldorado Canyon and Las Vegas thunderstorms happened in areas just outside the boundary of the Great Basin. However, they are typical of those in the Great Basin and throughout desert areas of the southwestern United States. The floods are considered noteworthy and were described in detail because they happened in populated areas and severe damage was done. Most flash floods in the Great Basin are not reported because they take place in sparsely populated areas.

Hazards in Flood-Prone Areas

Mountains

The flood hazard along definable channels in mountains primarily involves inundation, very high flow velocities, erosion, and moving debris. Even moderate flooding can be dangerous and potentially destructive, especially in steep, narrow canyons. Generally, when a major flood occurs, easily movable materials along the flow path—clay, sand, gravel, boulders, trees, and man's structures and equipment—are rapidly washed out and moved downstream. Man's alteration of the natural conditions in mountainous watersheds during construction of buildings and roads, in timber harvesting and mining, and for recreation purposes can contribute significantly to the amount of debris available to be moved by floods. Maximum flood depths in a typical canyon will increase if the canyon becomes partially blocked by debris. Mountain canyons usually are fairly narrow, and the area inundated during a major flood is not great.

Other hazards in mountainous regions may result from sheetflow across steep slopes and from rolling boulders, landslides, and mudflows during and following periods of heavy rainfall. Man's activities may contribute to the susceptibility of mountainous areas to such occurrences.

Alluvial Fans

The degree of flood hazard at different points on an alluvial fan is difficult to predict except in a probabilistic or general way. A flood flow issuing from a mountainous area travels at rather high velocity, carries a large suspended debris load, and moves large amounts of coarse material—often including large boulders—along the stream bed. In the vicinity of the fan apex, the velocity of flow usually decreases, a significant part of the debris is deposited, part of the water moves away as shallow sheetflow, part discharges through identifiable temporary distributary channels, and part discharges through a main channel. A large amount of water infiltrates, and the peak flow usually is reduced significantly by infiltration and by storage that results from the spreading of the flow. The deposition of debris on the upper part of a fan during a single flood may block a distributary or main channel and, as a result, redistribute the flood on the fan. Because the distributary and main channels are embedded in fairly coarse sand and gravel, they erode easily. Therefore, the deposition, blockage, and redistribution of flow may lead to erosion, with resultant changes in the size, direction, and location of distributary and main channels. The flow from several distributary channels may combine. The net result is that a flood moving across the upper part of an alluvial fan may not follow the same flow path, have the same velocity, depth, and distribution of flow, have the same sediment load, or cause the same channel blockage as a previous flood of the same peak-flow magnitude.

As a flood moves across the lower part of a typical alluvial fan, the distribution of water and debris is, as on the upper part, determined mainly by the terrain. The land slope normally is less than that on the upper part, and if the terrain has no definable channels, water movement is as sheetflow with depths usually less than 3 ft. Moving debris normally is finer than that on the upper part. If the alluvial terrain is moderately dissected, part of the flow may move downstream as shallow sheetflow and part may be confined to a channel, which may branch and rebranch into many smaller unstable channels and may eventually become discontinuous. The flow in several distributary channels may combine into one main channel.

Man's structures and equipment on an alluvial fan can contribute to the erratic nature of the movement of water and debris during a flood.

The erratic behavior of the flow, the pattern of erosion, and the pattern of deposition during a flood on an alluvial fan subject all parts of the fan to flood hazards. The degree of hazard, as previously indicated, is difficult to predict with accuracy. However, the hazards are known to decrease significantly with distance downslope from the fan apex. The specific flood hazards may involve (1) inundation by sheetflow or by flow in channels; (2) deposition of and inundation by debris; (3) high water velocities in main channels, especially near the apex, and lesser velocities for the sheetflow; (4) rapidly moving debris, especially in channels near the apex; and (5) erosion.

Valley Floors

Hazards on valley floors are considered, for this report, to be different for three types of terrain: Type 1 terrain represents a valley floor that has a major incised channel, and type 3 terrain represents a valley floor with no major incised channel. Type 2 is transitional between types 1 and 3; basically, it represents a reach of valley where a major incised channel becomes discontinuous.

The hazard in type 1 terrain normally involves inundation, high velocities, and erosion and deposition of sediment. A channel in an alluvial valley in an arid region generally will adjust its size to convey the rate of flow that is dominant (Leopold and Maddock, 1953; Burkham, 1972; Stevens and others, 1975; Burkham, 1981). In the absence of floods for a long period, the size of channel usually decreases, and a meander pattern may develop. When a major flood occurs in the valley, therefore, inundation on the flood plain may be considerable, and the channel may change its size and shape.

Major floodflows in type 1 terrain exert great force on the stream-channel banks and on objects, including man's structures, in the main flow path. The floodflows also can cause channels to enlarge. During a major flood, the main flow path generally is straight down the valley, and for some streams, the banks of the meandering low-water channel behave as objects in the main flow path (Burkham, 1972; Burkham and others, 1980). Although the meandering pattern is intact and part of the flow is directed along the meandering stream, great turbulence is developed along the streambanks. As a result of the stresses produced by the turbulent forces along the streambanks and around other stationary objects, changes take place. The stream-channel banks may erode, trees may be uprooted and flushed downstream, protective grasses may be removed, and alluvial fans at the mouths of tributaries may be greatly eroded. The end result of all the changes generally is a wider and cleaner stream channel that is more conducive to rapid movement of floodflows and debris.

Inundation by shallow flow and by debris is the primary flood-related hazard in type 2 terrain, although erosion may also be a problem. Type 2 terrain, like an alluvial fan, is a dynamic system. In type 2 terrain, floodwater normally spreads unevenly across the valley floor; all debris, except perhaps silt and clay-size sediment, is deposited, often unevenly, across the area. This deposition of sediment may change the flow pattern of subsequent floods.

Inundation by shallow, slow-moving flow is the primary flood-related hazard on type 3 terrain. The floodflow may come from type 2 terrain, from an alluvial fan, or directly from a thunderstorm centered on the valley floor.

Playas

Inundation by flood water is the hazard in playas or playa lakes. A number of the playa lakes in the Great Basin may receive water annually from contributing watersheds, and the areal extent within the shorelines and the depth of water in the lakes respond accordingly. Many playas and playa lakes, however, receive surface-water inflow only infrequently.

CLASSIFICATION OF FLOOD-MAPPING METHODS AND CRITERIA FOR THEIR APPRAISAL

Five general methods for delineating flood-hazard areas—detailed, historical, analytical, physiographic, and reconnaissance—were appraised for possible use on BLM lands in the Great Basin. These methods are, in turn, considered to represent three levels of sophistication: Comprehensive, intermediate, and approximate. The comprehensive level is considered to be the most accurate, but it is also the most expensive to use. The detailed and historical methods are classed as comprehensive, whereas the analytical and physiographic methods are of the intermediate level and the reconnaissance method is of the approximate level.

In the appraisal of the several flood-mapping methods the following tasks were performed: (1) Assumptions used in the development of the method were scrutinized for technical soundness; (2) applications, limitations, and uncertainties of the method were examined; (3) a brief inventory of data needed for a basin-wide application of the method was made; (4) a brief examination of the method was made to determine whether it is easily understood and whether it would be accepted by the intended user; and (5) the feasibility of using the method relative to the time and cost of other methods was examined in a general way.

DETAILED METHOD

Introduction

The detailed method of flood mapping consists of three basic steps: (1) Determining a T-year discharge[1], (2) determining a water-surface profile (T-year profile) for that discharge, and (3) developing a flood-boundary map. A T-year discharge is ascertained on the basis of a flood-frequency analysis. The objective of the analysis is to determine the magnitude of the flood that will, on the average over a long period of time, be equaled or exceeded once in a specified period of years; this specified period is known as the recurrence interval. Different approaches may be used in the flood-frequency analysis, depending on whether the site of interest is a gaged site (for this report, a gaged site is defined as one where a continuous record of discharge for 15 or more years is available), an ungaged site on a gaged stream (records of discharge for gaged sites elsewhere on the same stream are available), or an ungaged site on an ungaged stream.

The detailed method of determining profiles for T-year discharges basically involves the solution of the dynamic equation of gradually varied flow. The graphical-integration method, direct integration method, and step method are three broad classes of procedures for determining flow profiles in open channels (Chow, 1959). Only the step method, the most commonly used, is presented herein.

The development of a flood-boundary map, according to the detailed procedure, involves the transferring of altitudes from a water-surface profile to a map. The task is to outline on maps the areas inundated at these altitudes.

Determining T-Year Discharges at Gaged Sites

The development of a flood-frequency relation for a gaged site requires some method for determining the distribution of flow events. An empirical distribution, or cumulative-probability curve, can be computed directly from streamflow records if the data series contains a large number of annual peak-discharge events. Most discharge records for streams in the Great Basin are not of sufficient length to make this procedure practical; therefore, available data are used with various theoretical formulas to describe the distribution. Frequency curves are often based on a plotting of flood data. Several theoretical formulas may be used to determine the plotting position for each data point. Sokolov and others (1976) give detailed descriptions of the six empirical formulas most commonly used in different parts of the world. The most popular one in the United States and the one recommended by the Hydrology Committee in Bulletin 17B (1981) is:

$$P_m = m/(n+1), \quad (1)$$

in which

P_m = exceedance probability,
n = number of years in an array of discharge values, and
m = rank or order number, starting with 1 for the greatest discharge and ending with a number equal to n for the smallest discharge.

The data are plotted on probability graph paper and curves are fit to them so as to relate discharges to the probability of the event being equaled or exceeded in any one year. The equation for relating T, the recurrence interval in years, and probability is:

$$T = 1/P_m. \quad (2)$$

Many types of theoretical probability distributions have been proposed for use in flood-frequency studies, but the theoretical probability distributions used most often are those that can be defined by no more than three statistics: Arithmetic mean; standard deviation or coefficient of variation; and coefficient of skew. Records of annual maximum discharges are invariably too short to permit the computation of more than these three statistics.

The Hydrology Committee of the U.S. Water Resources Council (1967, 1976, and 1977) has recommended (1) that a log-Pearson type III distribution, a continuous binomial distribution with a log transformation of flood data, be used as the basic theoretical distribution for defining annual flood series for gaged sites, (2) that the technique be adopted for use in all Federal planning involving water and related land resources, and (3) that the technique be used by state governments, local governments, and private organizations. The U.S. Geological Survey concurs with the Council's recommendation. Use of the procedure is recommended by the Hydrology Committee in Bulletin 17A (1977) and Bulletin 17B (1981).

Determining T-Year Discharges at Ungaged Sites on Gaged Streams

Flood information based on streamflow records for a gaged site can be transferred to an ungaged site of interest on the same stream by one of several methods. For streams that are gaged at several sites, the flood-frequency data for an ungaged intermediate site may be estimated by direct interpolation or by a routing procedure. Usually, direct interpolation is used to approximate the T-year discharge when

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[1]A T-year discharge (Q_T) is the peak rate of discharge during a flood that occurs, on an average, once in T years, where T may be, for example, 25, 100, or 500 years. Statistically, a 100-year discharge (Q_{100})—a peak discharge that occurs, on an average, over a long period of time, once in 100 years—has a 1-percent chance of occurring in any one year. Unless otherwise stated, a T-year depth is the water-surface altitude or gage height for the T-year discharge minus the channel-bottom altitude or gage height at a point of zero flow (that is, the point at which flow ceases to move in the channel). A T-year profile is the water-surface profile for a T-year discharge.

the ungaged intermediate site is near a gaged site and the loss or gain of discharge is small relative to the *T*-year discharge; otherwise, the routing procedure may be used. The user of the routing procedure must have considerable knowledge of the hydraulic conditions—width, depth and velocity of flow, rates of inflow and outflow, and resistance to and obstruction of flow—along the channel through which the flow is routed.

Another method for determining *T*-year discharges at sites near gaging stations on the same stream involves the equation:

$$Q_{T(u)}=Q_{T(g)}(A_u/A_g)^y, \quad (3)$$

in which

$Q_{T(u)}$ = *T*-year discharge at an ungaged site on a gaged stream, in cubic feet per second;
$Q_{T(g)}$ = *T*-year discharge at the gaged site, in cubic feet per second;
A_u = drainage area for the ungaged site, in square miles;
A_g = drainage area for the gaged site, in square miles; and
y = exponent.

The value of y for a hydrologic region must be evaluated or estimated; usually it is assumed to be equal to the exponent of A_g when $Q_{T(g)}$ is regressed against A_g. Generally, y ranges from 0.3 to 0.8 for arid regions in the United States (Kennon, 1954, figs. 8 and 9; Butler and others, 1966, figs. 4–7; Lowham, 1976; Waananen and Crippen, 1977, table 2; Harenberg, 1980, p. 33). The accuracy of values of $Q_{T(u)}$ obtained using equation 3 rapidly decreases as the ratio A_u/A_g becomes increasingly larger or smaller than 1.

The three procedures cited here—direct interpolation, routing, and the method based on equation 3—are considered suitable for use in the Great Basin to transfer flood information from gaged sites to other sites on a gaged stream. Normally, any one of the three procedures would give reliable results if the difference in basin size for the intermediate and gaged sites is fairly small and the loss or gain of discharge is small. If the difference in basin size is large or if the increase or decrease in discharge is suspected of being large, more than one of the procedures should be tried and the most reasonable results accepted.

Determining *T*-Year Discharges at Ungaged Sites on Ungaged Streams

The transfer of flood-frequency information from gaged streams to sites on streams that are ungaged usually is done by use of an empirical equation or relation, the unit-hydrograph method, or a simulation model. Four types of empirical equations or relations are discussed in this report: regression equation, index-flood relation, area-altitude relation, and rational equation.

Regression equation

One method for the transfer of flood-frequency information from gaged sites to sites on an ungaged stream involves regression equations, one of which has the following form:

$$Q_T=a(X_1)^b(X_2)^c(X_3)^d \ldots, \quad (4)$$

in which

Q_T = *T*-year discharge,
$X_1,X_2,X_3\ldots$ = variables representing physiographic, hydraulic-geometry, or climatic characteristics, and
$a,b,c,d\ldots$ = regression coefficients.

Variables representing physiographic characteristics may be drainage area, main-channel slope, basin slope, main-channel length, basin-storage factor representing lakes and swamps, average basin altitude, forest-cover factor, azimuth of the main channel, latitude, soil-infiltration factor, and regional hydrologic factors. Hydraulic-geometry characteristics may be channel width and depth between depositional bars and channel width at bankfull stage. Variables representing climatic characteristics may include mean annual precipitation and a depth-duration-frequency characteristic usually represented by a rainfall intensity.

Inherent in the application of a regression equation (or any other empirical equation or relation) for computing flood-frequency curves for ungaged streams are three basic assumptions of considerable importance: (1) Man's alteration of the watersheds drained by the gaged and ungaged streams would not significantly alter the flood regime; (2) the magnitude and distribution of historical floods experienced for gaged streams will be repeated in the future; and (3) the precipitation pattern, runoff pattern, and basin characteristics for watersheds drained by the gaged streams are representative of those drained by the ungaged streams. Reports by Butler and Cruff (1971), Waananen and Crippen (1977), and Harenberg (1980), and work by Otto Moosburner (U.S. Geological Survey, written commun., 1979) give results of studies in which *T*-year discharges obtained by using the log-Pearson type III distribution are related to basin and climatic characteristics for streams in parts of the Great Basin. Reports by Lowham (1976) and Craig and Rankl (1978) give similar results for Wyoming; because Wyoming includes only a small part of the Great Basin, however, the results of these two studies are not discussed further in this report. Reports by Moore (1974), Fields (1975), and Harenberg (1980) give results of studies in which *T*-year discharges (from the log-Pearson type III distribution) have been related to channel geometry for streams in part of the Great Basin.

The study reported by Butler and Cruff (1971) mainly involves peak flows for Utah. However, some data for parts of the Great Basin in Utah, Idaho, and Wyoming were included. The study used streamflow records collected to 1968 for continuous-record stations and to 1969 for partial-record stations. Two sets of regression equations developed by Butler and Cruff (1971), for their regions A and D, have application in parts of the Great Basin. Equations for region A are applicable only to sites where floodflows are virtually natural (little effect from human activities) and drainage areas range from 1 to 2,500 mi^2. Equations for region D are applicable only to sites where flood flows are virtually natural and drainage areas range from 1 to 1,500 mi^2. The authors apparently assume that only precipitation during May–October can cause peak discharges of the Q_5 and Q_{10} sizes (5- and 10-year discharges, respectively) in region D. The standard errors of estimate are about 70 percent for the region A equations, and about 100 percent for those of region D.

The study by Waananen and Crippen (1977) involved floods and streams in California. The areal scope of the study included that part of the Great Basin in California. The study used streamflow records collected to 1973. Two sets of regression equations developed by Waananen and Crippen (1977) have application to the Great Basin in California. The set for the Sierra region involves six equations and is applicable to streams that have virtually natural flow and for which drainage-basin area, mean annual precipitation, and altitude index are within the ranges 0.14–9,020 mi^2, 7–85 in., and 100–9,700 ft, respectively. Six equations applicable to the Great Basin in California south of Mono Lake, which give Q_T for T values of 2, 5, 10, 25, 50, and 100 years, also are applicable to streams that have virtually natural flow and a drainage-basin area within the range 0.01 to 25 mi^2. The standard errors of estimate are 87, 80, 66, 75, 87, and 96 percent, respectively, for the equations for the Sierra region, and 186, 90, 78, 80, 84, and 88 percent, respectively, for the equations for the Great Basin south of Mono Lake.

The study by Otto Moosburner (U.S. Geological Survey, written commun., 1979) involved floods and streams in Nevada. The areal scope of the study includes that part of the Great Basin in Nevada, and it used streamflow records collected to 1978. Moosburner developed four equations, which are applicable to (1) streams where reservoirs, diversions, or urbanization have an insignificant effect on flood discharges; (2) drainage areas that range from 0.2 to 100 mi^2; (3) mean basin altitudes that range from 2,000 to 10,000 ft above sea level; and (4) basin latitude in the range from 36° to 43°. The standard errors of estimates range from 86 to 113 percent.

The study in which Harenberg (1980) regressed T-year discharges against basin and climatic characteristics and channel-geometry properties involved floods and streams in Idaho. The areal extent of the study included that part of the Great Basin in Idaho, and it used streamflow records collected to 1978. Four sets of regression equations developed by Harenberg (1980) have application in the Idaho part of the Great Basin. The standard errors of estimate for the equations ranged from 57 to 62 percent. The limitations of the four sets of equations were not described by Harenberg (1980).

Moore (1974) developed three equations in which T-year discharge was correlated with channel-geometry characteristics. The study used streamflow records collected to 1972. Moore's equations are for two different hydrologic zones in Nevada. The standard error of estimate for each of the three equations is about 40 percent. Moore stated (1974, p. 39) that "because the flood discharges were poorly defined for several of the streams and because record lengths are short, it is difficult to determine the true standard error of estimate using channel-geometry measurements."

Fields (1975) related mean annual streamflow and Q_{25} and Q_{50} (the 25- and 50-year peak flows, respectively) to channel-geometry characteristics. Although mainly for Utah, the study included that part of the Great Basin in Utah, Idaho, and Wyoming; it used streamflow records collected to 1970. Two of the equations for area 1 (Fields, 1975, fig. 2) have application to Great Basin streams in Utah, Idaho, and Wyoming. The standard errors of estimate for the two equations are 34 and 40 percent. The equation for Q_{25} probably is not applicable to stream widths outside the range of 14–155 ft and the equation for Q_{50} probably is not applicable to widths outside the range of 14–49 ft.

Index-Flood Relation

The approach used by Butler and others (1966) to develop relationships between Q_T, size of contributing area, and altitude is different, although perhaps insignificantly, from regression procedures. The index-flood procedure is described in detail by Kennon (1954) and Dalrymple (1960). Basically, the index-flood method involved four steps: (1) Preparation of a flood-frequency curve for each gaging station; (2) definition of homogeneous flood regions on the basis of the individual flood-frequency curves; (3) development of a dimensionless flood-frequency curve for each flood region (using the ratio of the Q_T to the mean annual flood); and (4) correlation of the mean annual flood (from step 1) with basin characteristics. All the relations in the report by Butler and others (1966) were determined graphically. Streamflow records for the base period 1938–59 were used for the study.

Butler and others (1966, pls. 1 and 2) developed dimensionless flood-frequency curves for four flood regions and related the mean annual flood to drainage area and altitude for eight hydrologic areas. According to Butler and others (1966, pl. 2), a large part of the Great Basin was poorly characterized by flood data.

Butler and others (1966) treated the flood analysis for the Bear, Weber, Provo, Sevier, Walker, Carson, Humboldt, and Truckee Rivers differently from that for the other streams, because manmade development had changed the flood regime for these major streams. For each of the rivers, Butler and others (1966, figs. 8–15) developed graphs that showed the relation between Q_{50} and distance along the river from a reference point. Presumably, the techniques described in the section of the present report on "Determining *T*-Year Discharges at Ungaged Sites on Gaged Streams" were used, when applicable, as a basis for these graphs.

Undoubtedly, additional alteration of the flood regime for the major streams in the Great Basin has occurred since 1959, and the curves developed by Butler and others (1966, figs. 8–15) are no longer useful. Results of flood-frequency studies for several of the major streams in the Great Basin by the U.S. Army Corps of Engineers (Herbert Hereth, oral commun., 1981) probably would better portray the current flood regime. These results are on file in the Corps of Engineers district office in Sacramento, Calif.

Area-Altitude Relation

A method described by Moore (1976) relates flood discharges per unit drainage area to the drainage areas within different altitude zones in Nevada. The relations, which can be used to estimate 10-yr peak discharge, were developed as follows: (1) Streamflow records were selected that consisted of continuous data for 10 yr or more at sites on streams where peak discharges were not significantly regulated; (2) the drainage area upstream from each site of interest was divided into 1,000-ft altitude zones, and the area for each zone between two adjacent 1,000-ft contour lines was measured on topographic maps; (3) by trial, a flood discharge per unit area for each zone was determined for each gage; (4) the sum of the products of the area of each altitude zone and its respective unit-flood discharge was determined for each gage and compared to the 10-yr peak discharges computed by log-Pearson type III analysis; (5) if this comparison indicated that the sum of products was considerably larger or smaller than the peak discharge obtained from the log-Pearson type III analysis, the estimated unit-flood discharge for each altitude zone was adjusted toward a better agreement; and (6) steps 3 to 5 were repeated until the best fit was obtained between the peak discharges. Moore (1976, fig. 1) identified two homogeneous regions in Nevada: a northern region and a southern region. Unit-flood discharges by altitude zones for the two regions in Nevada are given in Moore (1976, table 2). He also (1976, p.15) discussed the accuracy and limitation of the method as follows:

> The accuracy of the 10-year peak discharges computed from gage records used in this study, is considered only fair owing to the very short periods of record available ***.
>
> The use of basin area within elevation zones to estimate peak discharges appears to give satisfactory results for the 10-year flood. It is not suggested that this method gives an exact peak discharge for the 10-year frequency, but it does appear to give a reasonable estimate that can be used to check estimates made by other methods or can be used as an independent method if no other method is available.
>
> The peak discharge estimates made with the method agree reasonably well with results derived from the station records when used in the mountain blocks or areas having large topographic relief. The method, however, *does not seem to produce good results in drainage basins that have 20 percent or more of their drainage areas on the valley floor or in areas of small topographic relief.* [Emphasis added.]

Rational Method

The rational method of computing peak discharge is used for many hydrologic studies mainly because of its simplicity. The rational equation is:

$$Q=C_1 iA, \tag{5}$$

in which

Q = peak discharge, in cubic feet per second;
C_1 = dimensionless coefficient whose magnitude depends on basin characteristics;
i = the average rainfall intensity, in inches per hour, for a storm that has a duration equal to the time of concentration (time of concentration is defined as the time required for the runoff to become established, so that flow from the remote part of the drainage area reaches the site under consideration); and
A = drainage area, in acres.

The rational method has been applied to areas as large as 5 mi^2, but, according to Wright-McLaughlin Engineers (1969), it probably should not be applied to areas larger than 200 acres.

The rational method is based primarily on the following two assumptions (American Society of Civil Engineers, 1969): (1) The frequencies of peak discharge and peak rainfall rates are identical—a 100-yr discharge will result from a 100-yr rainfall—and (2) the peak rate of runoff at any site is a direct function of the average precipitation intensity during the time of concentration.

The rational method is thought to have only limited application for determinating *T*-year discharges for ungaged streams in the Great Basin. This conjecture is based on the following:

1. The two assumptions given in the preceding paragraph generally are not valid, except perhaps for small watersheds.

2. The implied assumption that C_1 is a constant for any basin is not valid. The value of the coefficient C_1 includes the effect of many time-variant factors, including infiltration, ground cover, surface and depression storage, and antecedent precipitation. It also varies with the magnitude of the flood event being considered.

3. The method is intended for use with small, simple watersheds no larger than 5 mi^2 and preferably no larger than 0.3 mi^2. According to Rantz (1971), even a small

watershed offers complications if its mainstream has one or more tributaries of significant size because, ideally, the rational method should be applied separately to each tributary stream and the tributary flows then routed and combined to obtain the *T*-year discharge. A complete hydrograph is needed for direct routing to a site of interest.

4. Depth-duration-frequency values of precipitation for all sites of interest in the Great Basin would have to be available. Resolving problems relative to this implied task may prove to be difficult.

Unit-Hydrograph Method

The unit hydrograph is a useful tool for certain types of hydrologic work and is described in many hydrology texts (for example, Linsley and others, 1949, p. 444–459). The unit hydrograph shows the time distribution of surface runoff resulting from a storm that produces 1 in. of runoff excess over a watershed of interest in some selected interval of time. Rainfall excess is defined as that part of the rainfall that is available to produce surface runoff, after depletion by infiltration and retention. Given an applicable unit hydrograph for a watershed and the precipitation distribution for a given storm, the resulting hydrograph of surface runoff can be produced.

Application of the unit-hydrograph method for determining *T*-year discharges involves the following assumptions: (1) All parts of the watershed of interest are assumed to produce rainfall excess at a rate of 1 in. per some selected interval of time, (2) the time bases of all floods caused by rainfall of equal duration are assumed to be the same, and (3) the lag time for a basin is assumed to be constant.

The first assumption is largely invalid for thunderstorms in watersheds larger than about 2–5 mi^2 because of the typically uneven distribution of precipitation during a thunderstorm and because of the equally variable infiltration rate. As previously indicated, the distribution of precipitation during a thunderstorm is not uniform in space or time, even on fairly level terrain; the distribution in mountainous regions is even more erratic. Similarly, assumptions two and three cannot be entirely true for many watersheds in the Great Basin. This appraisal is based on the following considerations:

1. The effects of channel storage on duration of floods vary with stage. Flood hydrographs for watersheds significantly larger than 5–10 mi^2 typically indicate that the time required for flow to recede to some fixed value increases with peak flow.
2. The effects of channel storage on hydrograph shapes for many watersheds may vary with time (Burkham, 1976, figs. 8–10).
3. Lag time probably is time-variant for many watersheds in the Great Basin (Burkham, 1976, figs. 2–5).

Despite the apparently invalid assumptions listed in this report and the limitation discussed by Linsley and others (1949, p. 444–445), the unit-hydrograph method may be a viable procedure for studying the magnitude and frequency of discharges resulting (1) from frontal rainfall-type storms in watersheds ranging in area from about 2 to 1,000 mi^2 and (2) from thunderstorms in watersheds ranging from about 2 to 10 mi^2. Successful application of the unit-hydrograph method to these types of storms in watersheds of the indicated size would require innovations or significant adjustments in the procedure and much analytical work. The procedure, with such innovations and adjustments, has been used many times in flood-frequency analyses for these types of floods in natural or altered watersheds of the indicated sizes and even larger. The adjustments in the procedure often have involved flood routing; ideally, the unit-hydrograph method should be applied separately to each tributary stream, and the tributary flows then should be routed downstream and combined. By use of the documented experience from these studies, which can be found in many reports and in the files of the U.S. Army Corps of Engineers and the U.S. Soil Conservation Service (1972, 1973), and with the aid of high-speed computers, the unit-hydrograph method can be applied to determine *T*-year discharges for streams in the Great Basin.

The unit-hydrograph method is not directly applicable to flood-frequency analyses for floods resulting from snowmelt or from rain on snow. With innovative adjustments, however, the method has been applied with some success for these conditions (Brater and Sherrill, 1975). The unit-hydrograph method also is not directly applicable for studies involving floods in watersheds where the boundary of the contributing area cannot be readily determined—for example, floods caused by thunderstorms centered on large alluvial fans.

Simulation Model

The use of hydrologic basin modeling to theoretically simulate storm rates and amounts may be the most rational approach for approximating *T*-year discharges at sites on ungaged streams where the evaluation of manmade effects is required. Application of the method has been made possible by the development and use of digital computers. Detailed description of the method, which is beyond the scope of this report, is given in many other reports. Several simulation models are altered versions of the Stanford watershed model (Crawford and Linsley, 1966), which is based on bulk, or lumped, variable approximations of the physical laws governing infiltration, soil-moisture accretion and depletion, and surface-water runoff. The model uses precipitation and pan evaporation as hydrometeorological inputs; it maintains a water budget that is balanced at short intervals (usually every 15 min during storm periods in small watersheds). The model requires a short period of runoff record for calibration.

The Stanford watershed model and many others can be used to generate streamflow records from which discharge-frequency relations can be developed through standard statistical analysis (Ott and Linsley, 1972; Feldman, 1979; G. H. Leavesley, U.S. Geological Survey, oral commun., 1981). The steps involved in developing flood-frequency values include: (1) Statistical analysis of historical rainfall records, (2) generation of a long record of synthetic rainfall, (3) modeling of the rainfall-runoff process for the full record or for selected events, and (4) statistical analysis of all flood peaks or selected events to arrive at discharge-frequency curves.

The simulation-model approach should be seriously considered for use in flood-frequency studies of ungaged streams in the Great Basin and for ungaged playas where the evaluation of the effects of regulation and other manmade changes is required. Factors and criteria to be considered in appraising the simulation-model approach are the following: (1) The approach would be more time consuming than the use of regression equations, (2) the approach requires much data (more than 20 variables are involved in the Stanford model), (3) the accuracy of the procedure when used for ungaged streams is not known, (4) selection of which simulation model to use would require significant research effort, and (5) the simulation model and the unit-hydrograph approach may be the only options available for flood-frequency studies on some regulated streams, in basins where urban development is increasing, and on playas.

Determining Water-Surface Profiles for a *T*-Year Discharge

Two broad classes of detailed procedures are available for determining *T*-year profiles. One class involves flood routing, which is not evaluated here, and the other basically involves the solution of the dynamic equation of gradually varied flow. Three approaches may be used to obtain solutions to the dynamic equation for gradually varied flow (Chow, 1959): graphical integration, direct integration, and the step method. Only the last, which is the most commonly used, is described herein.

The step method for determining water-surface profiles (Chow, 1959) is designed for a uniform flow in which the water-surface profile and energy gradient are parallel to the streambed and in which the cross-section area, hydraulic radius, and depth remain constant through the reach. The method is assumed to be valid for a gradually varied flow in nonprismatic, rigid channels.

Data needed to determine a profile for a given reach of a stream, according to the step method, comprise topographic and channel-roughness information. The topographic data—altitudes and distances to common bases—may be obtained by field survey or by a combination of field survey and photogrammetry. Ground altitudes and distances can be determined very accurately in field surveys. Although ground altitudes can be determined by photogrammetry without introducing significant errors, a moderate amount of field verification is nonetheless necessary.

A combination of field survey and photogrammetry is often used to develop contours on topographic maps. Altitudes and distances needed for the step-method computations may be obtained from such maps. The altitudes obtained by these procedures are assumed to have an accuracy equal to one-half of the contour interval.

The channel roughness is represented by a characteristic known as Manning's *n*. Its value during flow in a natural channel depends on several time-variant factors (Burkham, 1978; Arcement and Schneider, 1984).

Computer programs have been developed that can be used to make the computations required for the step method of determining water-surface profiles. Three commonly used computer programs are HEC–2, developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers; HY–7, replacing E–431 and J–635, developed by the U.S. Geological Survey; and WSP–2, developed by the U.S. Soil Conservation Service. Each of these computer programs is based on the same assumptions and attempts to solve the same equation of flow; however, there are some basic differences between the programs, as described by Motayed and Dawdy (1979).

To analyze the mathematical uncertainties in the computation of water-surface profile by the three programs, Motayed and Dawdy (1979) selected a reach about 4 mi long for tests. As a result of the test, they concluded:

> (1) All other things being equal, the E–431 conveyance calculations compute a stage for the 100-yr flood that is higher for the study reach than HEC–2 and WSP–2; (2) average expansion and contraction coefficient in HEC–2 lower the stage another 0.4 ft *** for a 1.2-ft *** difference; and (3) WSP–2 assumptions of no minor losses drop the stage 0.7 ft *** further than the HEC–2 to a total difference of about 1.9 ft *** from E–431. It is seen from this comparison between the three computer programs that the USGS E–431 will give the greatest depths of flow, the SCS WSP–2 the least depth of flow, and the USCE HEC–2 an intermediate depth for a given study reach of the type used in the analysis.

The comparison among methods was for one reach only. When the methods are compared for a variety of reaches and conditions, the three models give fairly close results.

Results of a study conducted by Bailey and Ray (1966) give an indication of the accuracy of the step method for determining *T*-year profiles. The study was made to determine the accuracy of the method in duplicating stage-discharge relations at 28 gaged sites on natural streams. These sites covered a wide range in hydraulic conditions that prevail at gaging stations. Bailey and Ray determined that the standard error of the computed discharge was 18 percent. Bias apparently was insignificant. The standard error of estimate for stream depths would be significantly less than 18 percent (Burkham, 1978).

The use of the step method is assumed to be limited to flow in channels for which the energy losses can be properly accounted for. The method is assumed to be valid only for rigid channels. Nonetheless, the method also has been used, often with questionable results, for flow in channels having a movable bed but fairly stable banks. The step method is not suitable for use (1) in a sand-channel stream, where both the bed and bank have elastic characteristics, (2) on a typical alluvial fan, or (3) at or near the point on a valley floor where a channel becomes discontinuous.

Determining Flood Boundaries for a *T*-Year Discharge

The development of a flood-boundary map involves transferring altitudes from a water-surface profile to a map (Burkham, 1978). The task is to define the intersection of the water-surface altitudes with the ground surface. The altitudes can be transferred (1) directly during a field survey, (2) by means of a combination of field survey and aerial photography, or (3) by using altitude contours on a topographic map. Maps having contour intervals greater than about 5 ft usually are not used alone to establish flood boundaries.

HISTORICAL METHOD

Introduction

The area inundated during a *T*-year discharge can be approximated from records of a major historical flood, if certain data are available (Burkham, 1976). The required data include the peak discharge of the major flood and the altitudes of high-water marks referenced to a common datum. Aerial photographs taken during or soon after the flood also represent useful information. As with the detailed method, the components of the historical method can be grouped into three steps: (1) Determining the *T*-year discharge, (2) determining the *T*-year water-surface profile, and (3) developing a flood-boundary map. Only step 2 is described in this section, because it is the only one that differs from the steps previously described for the detailed method.

Determining Water-Surface Profiles for a *T*-Year Discharge

The water-surface profile for a *T*-year discharge can be approximated as follows: (1) Develop a profile for the historical flood on the basis of high-water marks; (2) determine the frequency of the historical flood; (3) define ratios of observed flood depths to depths for discharges of various recurrence intervals; (4) using these ratios, determine the adjustment needed to convert from the historical profile to the *T*-year profile; and (5) add (or subtract) those adjustments to the profile obtained in step 1. Normally, such adjustments are less than 5 ft and can be estimated by using one of several flow equations (Chow, 1959) or by using an empirical equation developed specifically for the purpose.

The water-surface profile for the historical flood can be readily determined if high-water marks are adequate. Unfortunately, high-water marks and profiles for floods in the Great Basin seldom are documented except in urban areas.

ANALYTICAL METHOD

Introduction

The analytical procedure of flood mapping consists of four basic steps: (1) Determining a *T*-year discharge, (2) determining a *T*-year depth, (3) determining a *T*-year profile, and (4) developing a flood-boundary map. Only steps 2 and 3 differ from the steps previously described for the detailed method, and discussions are limited to these items.

Determining Water Depths and Water-Surface Profiles for a *T*-Year Discharge

The *T*-year depth may be computed by any one of the many uniform-flow formulas. The *T*-year profile is obtained by adding *T*-year depths to the channel-bed profile for the stream of interest.

The Chezy formula and the Manning formula are the most popular ones used for this purpose. Chow (1959) has presented three different methods for solution of the Manning flow equation, which he designated the algebraic, trial-and-error, and design-chart methods. Burkham (1977) has presented a fourth method, called a simplified technique, for solving the Manning uniform-flow equation. Chow's trial-and-error solution, Burkham's simplified method, and techniques for determining *T*-year depths on alluvial fans reported by Dawdy (1979) and by Magura and Wood (1980) are briefly described in this section.

Trial-and-error procedure

Chow (1959) transposed the Manning flow equation to obtain:

$$AR^{2/3}=(Q_T)(n)/(1.49S^{1/2}), \qquad (6)$$

in which

A = cross-sectional area for a *T*-year flood at a specific site, in square feet;

R = hydraulic radius at the cross section, in feet, which equals the cross-sectional area, in square feet, divided by the wetted perimeter, in feet;

Q_T = T-year discharge, in cubic feet per second;
n = roughness coefficient; and
S = energy gradient.

Assuming that the T-year discharge is known, a numerical value for the right side of equation (6) can be obtained by using values for n and S that can be readily estimated in the field. When a numerical value for the right side of equation 6 has been obtained, a trial-and-error computation can be made to obtain a T-year depth for the reach of interest. The trial-and-error computation requires that relations between depth and area of flow and between depth and hydraulic radius are determined for each cross section along the reach.

Many investigators have used the trial-and-error method, or an altered version of it, to determine T-year depths along streams. The method usually gives usable results if the investigator recognizes the fact that the Manning equation was developed for conditions of uniform flow in which (1) the water-surface profile and energy gradient are parallel to the streambed and (2) the cross-sectional area is constant throughout the reach of interest. The equation is also assumed valid for gradually varied flow, if the energy gradient is modified to reflect only the losses due to boundary friction.

Simplified Technique

In addition to the usual assumptions for the application of the Manning equation, the simplified technique (Burkham, 1977, p. 3) is based on the following premises: (1) A T-year discharge is known; (2) depths for the T-year discharge do not vary greatly in a fairly long reach of a natural, rigid-boundary channel; the water-surface profile approximately parallels the channel-bottom profile and the average depth adequately represents depths throughout the reach; (3) depth of flow at a site in a rigid channel is a function of discharge and the physical characteristics—channel size, shape, slope, and roughness—of lengths of channel in the reach that are partial or true controls; (4) depth of flow in the length of channel having the characteristics of a partial control can be adequately determined using a small amount of field data; and (5) the average of computed depths for a few representative partial controls in a reach can be used to represent average depth for the entire reach.

Burkham (1977) noted that the relation between discharge and depth for relatively high flows (for example, a T-year flood) in channels with channel-control conditions usually can be adequately represented as a straight line on logarithmic graph paper. The general equation for the discharge-depth relation is:

$$d=CQ^f, \tag{7}$$

in which

d = depth of water, in feet;
C = coefficient, which equals the effective depth when discharge, Q, equals 1 ft³/s; and
f = slope of the discharge-depth relation.

Equations for C and f are:

$$C=[n/(a_1(a_2)^{5/3}(1.49)(S_o)^{1/2})]^f \text{ and} \tag{8}$$

$$f=3/(5+3x), \tag{9}$$

in which

a_1 and x = coefficient and exponent, respectively, for the equation
$$W=a_1(d)^x; \tag{10}$$
W = top width of flow, in feet;
a_2 = coefficient for the equation
$$\bar{d}=a_2 d; \tag{11}$$
$\bar{d}$ = mean cross-sectional depth, which equals the cross-sectional area divided by W; and
S_o = channel slope.

Equation 10 is used to compute values of a_1 for a cross section; this requires a reference depth, d_r, and a reference width, W_r. The reference depth is assumed, and the corresponding value for W_r is measured in the field. The widths may be obtained directly from a topographic map if the contour interval and scale are adequate. The assumed reference depth is based on the judgement that $W/(d)^x$, which equals a_1, approximately equals $W_r/(d_r)^x$. The variable x is a function of channel shape; it is 0 for a rectangular shape, ½ for a parabolic shape, and 1 for a triangular shape.

The variable a_2 also is a function of channel shape. It is 1 for a rectangular shape, ½ for a triangular shape, and ⅔ for a parabolic shape.

The typical natural, rigid channel has an approximately parabolic shape, for which x would be ½ and f would be 0.46. Burkham (1977) determined that the average value of f was 0.42 for the high-discharge segment of 539 stage-discharge relations for selected sites at streamflow gaging stations in Iowa, Maryland, Minnesota, New York, North Carolina, Ohio, and Wisconsin; the standard deviation for the 539 sites was 0.12. An average value of f for streams in the Great Basin can be estimated on the basis of stage-discharge relations for gaged sites there.

Dawdy's Procedure for Alluvial Fans

Dawdy (1979) recommended a procedure for defining flood profiles on alluvial fans that is based on three basic assumptions: (1) A log-Pearson type III distribution applies to the peak discharges at the apex of the fan; (2) each flood event forms a single channel, and flow remains in that channel for the duration of the event; and (3) channels from prior flood events are distributed uniformly across any contour on the fan. Three other assumptions are inherent in the Dawdy procedure: (4) The channel referred to in assumption 2 stabilizes approximately at the point where $dD/dW=-0.005$ (Dawdy, 1979, p. 1408); (5) the channel formed by a flood flow on an alluvial fan should stabilize at a channel width (in feet) equal to $9.5Q_1^{0.4}$ and channel depth (in feet) equal to $0.07Q_1^{0.4}$, in which Q_1 is the flood flow forming the channel, in cubic feet per second; and (6) the position of a flood on the surface of the fan tends to be random.

Dawdy (1979) gives equations that can be used to determine the width of a *T*-year discharge at contours on the alluvial fan.

Dawdy's first assumption may be reasonable; however, some of the other assumptions are suspect. McGinn (1980) has presented strong arguments that tend to refute assumptions 2, 3, and 6. If assumption 2 is not valid, then assumptions 4 and 5 probably are not valid either. Because the basic assumptions are questionable, Dawdy's procedure appears to need further testing before it is used for flood studies in the Great Basin.

Magura and Wood's Procedure for Alluvial Fans

The technique described by Magura and Wood (1980) is based on three stated or implied basic assumptions: (1) The *T*-year discharge at the apex of the fan is known; (2) when the channel gradient approaches or exceeds a certain critical slope, the critical state of flow may be assumed to accurately represent the potential depth and velocity of flow at that point; and (3) the channel pattern on the surface of the alluvial fan does not change with time.

Magura and Wood (1980) suggest that one must designate separate reaches along which flow characteristics are similar. They suggest that possible reach boundaries are the fan apex, points of substantial change from an entrenched channel to a braided channel, points of change in overbank encroachments (Man's structures), and points of substantial change in gradient. Each reach is to have unique but fairly constant properties of channel cross-sectional area, shape, slope, and width to which overbank flow can spread. Magura and Wood give guidelines for the analysis needed to determine *T*-year depths for the various types of reaches. Most of the analysis is for reaches included in their category 3, which they describe as the "majority of areas where natural fan processes, such as trenching, lateral migration of channels, and sediment deposition, are free to take place." They list two general subcategories, the untrenched fan and the fan that is entrenched only at the upper end. Magura and Wood's guidelines and discussion for the two subcategories (1980, p. 60–61) are as follows:

> Untrenched fans. The lack of entrenchment often occurs on fans with relatively small upstream canyons where, immediately upon leaving the canyon mouth, flow spreads out. Critical depth analysis alone is employed in these cases ***. If the range of discharges presented on this figure is not appropriate for a particular area under study, the investigator can easily compute one that meets his specific requirements by using any hydraulic computer model. After the 100-year discharge has been computed, *** a resultant depth may be established at the point on the curve to which the ratio d/W, where *d* is the difference in depth of flow and *W* is the difference in width of the flowpath, becomes sufficiently small. Based upon field experience accrued from observations of historical flood events on alluvial fans, an average value for the ratio of *d*/*W* has been established as 0.005 foot per foot. This value should be used for all cases unless a different ratio appears to be more representative for a particular situation based on observational or other mitigating evidence. Utilizing the established ratio, an increase in the width of flow of 100 feet results in a change in depth of flow of 0.5 foot. Additional increases in *W* (width) result in a rapid decrease in *d* (depth). Since the AF (alluvial fan) zones are rounded to the nearest one foot depth increment for flood-insurance study purposes, this characteristic depth and associated velocity are applied to the locus of points equidistant from the apex of the fan, regardless of location on the fan relative to an apparent flow path. On larger alluvial fans in this catagory, minor drainage patterns often develop in response to runoff generated on the fan surface itself. However, it cannot be expected that flows originating up-canyon will follow such courses to the exclusion of lesser-developed flow paths.
>
> Entrenched fans. This second category should be applied to those cases where an unbroken flow path exists which conveys up-canyon flow down-fan to a point where sediment deposition takes place. Such entrenched channels may be straight or meandering single channels, or a network of interwoven channels. In either case, an average channel cross section is determined for each reach from either field inspection, large-scale topographic mapping, or actual field survey. For the discharge of interest, a curve of *d* vs. *W* is developed. Potential flood depth may be determined using the 0.005 foot per foot criterion, unless this ratio seems inappropriate. The resultant depth is applied across the entire fan under the assumption that the main channel may shift at the fan apex during a flood, forming a new channel elsewhere on the surface of the fan. Wherever flow characteristics change sufficiently, *** a different reach is established and analyzed separately. *** In a given zone bounded by reach limits, the potential for flood damage may be defined by the velocities and depths of flow computed by the method outlined above.

Magura and Wood's basic assumptions 1 and 2 may be valid; assumption 3, however, is questionable. The boundaries shown in their figure 8 may not be a realistic representation of the true *T*-year boundary if the distribution of flow near the apex changes significantly during a flood.

PHYSIOGRAPHIC METHOD

Introduction

Most of the following discussion about the physiographic method was taken directly from a report by Burkham (1978). The hydraulic and topographic properties of a river reach embedded in alluvium are a function of the discharge of water and debris (Leopold and Maddock, 1953), which in turn is a function of the physical and climatic characteristics of the drainage basin. These facts are the basis for the physiographic method of flood mapping. The components of the method are grouped into four tasks: (1) Determining *T*-year discharges, (2) determining *T*-year depths, (3) developing *T*-year profiles, and (4) developing a flood-boundary map. Tasks 1, 3, and 4 have previously been described and are not repeated here.

Determining Water Depths for a *T*-year Discharge

Two general procedures for making depth-frequency analyses have been used recently by the USGS. They are herein termed the index-flow method and the area-parameter method.

Index-Flow Method

The basic concepts for the index-flow method given in this section are from a detailed description by Thomas (1964). The method involves four basic steps: (1) Development of flood-frequency curves and determination of *T*-year discharges for selected gaging stations; (2) development of stage-discharge relations and determination of *T*-year depths from the *T*-year discharges; (3) development of graphs showing the relation between the index flow and the *T*-year depth (Thomas, 1964, used $Q_{2.33}$, the mean annual flood, as the index); and (4) development of graphs showing the relation between the mean annual flood and drainage-basin characteristics.

Thomas (1964) used streamflow records from 45 gaging stations in New Jersey for his study. At each station, $Q_{1.5}$, $Q_{2.33}$, Q_5, Q_{10}, Q_{15}, Q_{25}, and Q_{50} were determined from flood-frequency curves for the years 1922–60. The flood-frequency curves were constructed using methods outlined by Dalrymple (1960). A depth for a *T*-year discharge was determined by subtracting a channel-bottom gage height from the gage height for the *T*-year discharge. Thomas (1964) developed graphs showing relations between the index flow (discharge) and the 1.5-, 2.33-, 5-, 10-, 15-, 25-, and 50-year depths for gaged sites in two different regions—the coastal plain and piedmont—in New Jersey. He developed curves showing the average relation between size of basin and mean annual flood discharge for four areas having similar hydrologic characteristics. The user of the method needs first to determine the size of the basin. The mean annual flood (discharge), derived graphically from a relation between mean annual flood and drainage area, is then used to estimate the *T*-year depths at the site in question. For basins in New Jersey, the standard error of estimate for the index-flow method of determining 50-year depths is 21 percent (Thomas, 1964).

An index-flow method also was used by Winget (1976) to determine *T*-year depths in Illinois; however, Q_2 was used to represent the index flow. Depth-frequency equations were developed from regression analyses on data from 177 gaging sites. For streams in Illinois, the standard error of estimate was 23 percent.

Area-Parameter Method

The area-parameter method of determining *T*-year depths differs from the index-flow method in one general respect. The *T*-year depths are correlated with specific basin and climatic characteristics. The resulting regression equation gives *T*-year depths directly.

The area-parameter method was used to determine *T*-year depths for 13 states during 1960–78 (Burkham, 1978, table 3). Comprehensive investigations to develop regression equations and determine their accuracy have been made in five of those States—Alabama, Colorado, Illinois, Kansas, and Oklahoma. Reconnaissance studies to develop relations between *T*-year depths and drainage area and to determine the standard errors for those relations were made in the eight remaining States.

In Alabama, 100-year depths for 129 gaged sites were regressed against 13 basin and climatic parameters. According to C.F. Hains (U.S. Geological Survey, written commun., 1976), the 100-year depths (d_{100}) show a relation principally to drainage area (A). Hains combined the effects of the remaining significant parameters to obtain the following equation:

$$d_{100} = C_x A^{0.2}, \qquad (12)$$

in which the coefficient C_x is different for each of six hydrologic regions. The apparent standard error for the regression equation was 17 percent; however, this value does not include the effects of error introduced when the hydrologic regions were delineated (C.F. Hains, written commun., 1976).

The comprehensive studies made in Colorado, Illinois, Kansas, and Oklahoma were similar to that made in Alabama.

The average standard error for the regression equations developed as part of the comprehensive investigations is inferred to be 23 percent, on the basis of the following values: 17 percent for Alabama, 27 percent for Colorado, 28 percent for Illinois, 19 percent for Kansas, and 24 percent for Oklahoma (Burkham, 1978, table 3).

The physiographic method should only be applied to streams with channel characteristics similar to those used in the development of the relations. This method is not applicable to stream channels modified by man or affected by backwater from downstream obstructions, nor can it be used where nonrepresentative channel conditions exist.

RECONNAISSANCE METHOD

The reconnaissance method, as the name implies, is a relatively imprecise approach to delineating flood-hazard zones. A general examination of the stream of interest is used as a basis for approximating the area that would be inundated during a major flood. In addition, maps and photographs may also provide guidance in approximating flood-prone areas. The study may also include the collection and use of general information about (1) topographic features such as old and new channel banks, old and new sand and gravel bars, terraces, and stepped topography; (2) vegetation features such as distinctive vegetation, vegetation form related to high water, and microvegetation related to high water; and (3) pedologic conditions, such as soil development, stratification, and drainage.

The user of the procedure would need considerable experience in several related fields, including hydraulics of open-channel flow, geomorphology, sedimentation, soil mechanics, and botany. The breadth of knowledge required may be a significant hindrance to the widespread, successful use of the reconnaissance method. Other drawbacks of the method are: (1) A relation between the *T*-year discharge and the boundary of the inundated area is not established; and (2) the probable accuracy of the method is not known. The method may, however, be the most rational one for delineating flood-hazard areas on some alluvial fans and in places on valley floors where channels become discontinuous.

APPLICABILITY OF THE FIVE METHODS

The detailed method is applicable to hydraulic and topographic conditions found in many parts of the Great Basin. Generally, the method can be used when the *T*-year discharge can be determined directly from flood data, by experimental equations, by unit hydrograph, or by simulation model. The detailed method has only limited application for sheetflow, for flow on alluvial fans, and for flow in channels having readily movable boundaries. The overall standard error of estimate for the detailed method of determining *T*-year depths is probably larger in the Great Basin than in a more humid climate. The standard errors for *T*-year depths for streams in New Mexico, a state with streams and flow conditions similar to those in the Great Basin, ranged from 21.5 to 60.5 percent of the true depth (Anderson-Nichols and Co., written commun., 1980). Of the five methods, the detailed method probably is the most accurate, but it also is the most expensive to use.

The historical method can be used for a wide range of hydraulic and topographic conditions in the Great Basin, but only if enough flood data are available. Experience and judgment, however, are required to obtain meaningful results, especially when the depth adjustment is greater than about 50 percent of the mean *T*-year depth in the reach of interest. The historical method has only limited application for flow in channels with readily movable boundaries. The overall standard error of estimate for the historical method for appropriate streams in the Great Basin probably is about equal to that of the detailed method. Because it is less costly, the historical method is preferred over the detailed method. Unfortunately, however, available data are seldom adequate to permit use of the historical method.

The analytical method can be used for a wide range of hydraulic and topographic conditions in situations where the *T*-year discharge can be determined directly from flood data, by regression equations, by unit hydrographs, or by simulation model where the Manning equation applies. The method has only limited application for sheetflow, for flow on alluvial fans, and for flow in channels having readily movable boundaries. Chow's (1959) trial-and-error technique and Burkham's (1977) simplified technique for determining *T*-year depths, water-surface profiles, and flood boundaries probably could be used for flood-inundation studies in most natural rigid-boundary channels. Experience, good judgment, and a thorough knowledge of the hydraulic principles of open-channel flow are required to obtain adequate results when either technique is used. The Dawdy (1979) procedure needs further testing before it is applied to alluvial fans of the Great Basin. Similarly, the problem of unstable conditions on the typical alluvial fan should be considered before the technique described by Magura and Wood (1980) is applied. The different analytical-method techniques are less accurate than the detailed method, but they are also less expensive.

The physiographic method is applicable to natural channels having rigid boundaries. The method is not necessarily suitable (1) for characterizing a specific individual site, (2) for determining *T*-year depths on alluvial fans and at or near sites where channels become discontinuous, or (3) for determining flood-boundary altitudes of sheetflow. The overall standard error of estimate for flood-boundary altitudes determined using the physiographic method would be slightly larger than that for the detailed method. This method should only be used in channels similar to those used in developing the relations used in the method.

The reconnaissance method is a relatively imprecise approach to delineating flood-hazard zones. The method may, however, be the most rational one for delineating flood-hazard areas on some alluvial fans and in places on valley floors where channels become discontinuous.

GENERAL CONCLUSIONS

1. Major floods, which occur in most parts of the Great Basin, result from snowmelt, frontal-storm rainfall, and localized cloudburst rainfall. Snowmelt floods typically occur during April–June. Floods resulting from frontal rain and frontal rain on snow generally occur during November–March. Floods resulting from convective rainfall during

localized thunderstorms occur most commonly during the summer months.

2. The dominant flood hazards along definable channels in steeply sloping hills and mountains involve inundation, very high flow velocities, erosion, and moving debris. Other hazards in mountainous regions may result from sheetflow across steep slopes and from rolling boulders, landslides, and mudflows during and following periods of heavy rainfall.

3. On alluvial fans, the erratic behavior of flow, the pattern of erosion, and the deposition of debris subject all parts to hazards. The degree of hazard, however, generally decreases with distance downslope from the fan's apex. The specific flood hazards include high velocities of water and debris, erosion and deposition of sediment, and inundation by water and debris.

4. Hazards in flood-prone areas on valley floors are significantly different for three types of terrain. For a major incised channel, the hazards may involve inundation, high flow velocity, erosion, and deposition of sediment. Where a major channel becomes discontinuous, inundation by shallow flow and by debris typically is the primary flood-related hazard. On a valley floor that has no major incised channel, inundation with shallow, slow-moving sheetflow typically is the primary hazard.

5. Methods for mapping flood-hazard areas are, for this report, categorized into three levels of sophistication: Comprehensive, intermediate, and approximate. Comprehensive methods usually are considered to be the most accurate, but they also usually are the most expensive to use. The detailed and historical methods are of the comprehensive type, the analytical and physiographic methods are intermediate in level, and the reconnaissance method is of the approximate variety.

6. Methods representing each of the three levels can be used to map flood-hazard areas along rigid-boundary channels in mountainous regions and on valley floors.

7. Methods from each of the three levels can be used to map flood-hazard areas along sand channels. However, the accuracy of results obtained using a comprehensive method may not be significantly better than that obtained using an intermediate method.

8. Only an approximate method is recommended for mapping flood-hazard areas on alluvial fans. Intermediate methods can be applied, but the accuracy of results probably would be no better than that of an approximate method.

9. A comprehensive method would provide the most suitable means of developing inundation maps for rigid-bank streams in basins with urban areas. Preparation of guidelines on the use of the specific method chosen would be an important preliminary step to such a study.

10. Only an approximate-level procedure seems justified for mapping flood-hazard zones in currently undeveloped areas, unless development (for example, urbanization) is imminent. Guidelines on the use of such a procedure would be desirable.

11. For streams not considered in items 9 and 10, an intermediate-level procedure, along with guidelines for its use, would be applicable.

12. Improved procedures for defining boundaries of *T*-year discharges on alluvial fans and on valley floors where major incised channels become discontinuous would be useful, particularly in urbanizing areas.

13. Discharge-frequency and depth-frequency studies would provide valuable information on flood characteristics in the Great Basin.

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