

STREAMFLOWS IN WYOMING



Prepared in cooperation with the
U.S. BUREAU OF LAND MANAGEMENT and the
WYOMING HIGHWAY DEPARTMENT



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By H.W. Lowham

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CONVERSION FACTORS AND VERTICAL DATUM

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

| <u>Multiply</u> | <u>By</u> | <u>To obtain</u> |
|-----------------------|-----------|------------------------|
| cubic foot per second | 0.02832 | cubic meter per second |
| foot | 0.3048 | meter |
| foot per mile | 0.1894 | meter per kilometer |
| inch | 2.54 | centimeter |
| mile | 1.609 | kilometer |
| square mile | 2.590 | square kilometer |

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

A description of the occurrence and variability of surface waters in Wyoming is presented along with explanations of both streamflow-data collection and methods for estimating streamflow characteristics at gaged and ungaged sites. Mountain ranges separate the major drainage basins and have a significant effect on precipitation and runoff that occur in Wyoming. Streams that originate in the mountains provide the most dependable source of runoff; streams that originate in the plains and deserts generally have extended periods of no flow.

Streamflow data for several hundred gaged sites in the State are available for engineering and management purposes. When gaged data are not available, methods for estimating flows are needed. Methods presented in this report for estimating streamflow characteristics have been developed through the use of refined analytical techniques and an updated data base.

Peak-flow characteristics and mean annual flow at ungaged sites can be estimated by using regression equations, with either basin characteristics or channel width as independent variables. Log-linear regression equations are used for depicting streamflow characteristics in the mountains. Curvilinear equations of double-exponential form were determined to be more appropriate than log-linear equations for depicting peak flows in the plains and deserts.

Regression relations were determined to be unsuitable for estimating mean monthly streamflows. Because of geographical differences in runoff patterns, data for streamflow gages near the ungaged site can be used to estimate mean monthly flows. The procedure requires an estimate of mean annual flow, with mean monthly flow determined as a percentage of mean annual flow from records of nearby gaged sites.

INTRODUCTION

Water is one of the most basic and essential of our resources, and surface waters are the main source of water used in Wyoming. The occurrence and availability of surface waters vary greatly throughout the State partly due to the effect that mountain ranges have on the quantity of precipitation and resulting runoff. Although several major rivers flow across the plains and desert areas of the State, the main source of perennial flow in these rivers is from snowmelt in the mountains. Information concerning streamflows, including floodflows, is needed to plan and design irrigation projects, roads, bridges, and other stream-related developments.

This report is the product of several technical investigations of streamflows in Wyoming. The investigations were done by the U.S. Geological Survey in cooperation with the U.S. Bureau of Land Management and the Wyoming Highway Department, to provide streamflow information needed for land-use planning and for design of stream-related developments. This report presents: (1) A history of surface-water use and developments affected by surface water, (2) an explanation of factors affecting streamflow, (3) a description of record collection at sites having streamflow-gaging stations, and information on how users may obtain these records, (4) a description of improved methods for estimating streamflow characteristics at ungaged sites, and (5) a summary of historical floods.

Acknowledgments

The assistance of A. Mainard Wacker, Hydraulics Engineer, Wyoming Highway Department, and W.O. Thomas, hydrologist, Office of Surface Water, U.S. Geological Survey, in developing an improved regression model for depicting peak-flow characteristics in the plains and desert areas of Wyoming is gratefully acknowledged. Mr. Wacker and his staff observed that equations from previous reports did not adequately depict peak-flow characteristics over a complete range of drainage sizes, and they suggested that an improved model was needed. The applicability of a double-exponential equation was suggested by Mr. Thomas, who assisted the author with the development and computer programming of the curvilinear model. The contributions of Mr. Wacker and Mr. Thomas are greatly appreciated.

History of Surface-Water Development in Wyoming

Exploration and Early Development

A group of Spaniards may have been the first explorers, other than the native Indians, to venture into what is now Wyoming. On the basis of scant evidence, historian C.G. Coutant (1899a, p. 23) concluded that one of numerous Spanish expeditions from Mexico traveled as far north as the Missouri River and explored the Yellowstone country during the sixteenth or seventeenth century.

During 1807-08, John Colter explored the headwaters of the Yellowstone and Snake Rivers in northwestern Wyoming while attempting to establish a fur trade with the Indians. This exploration opened up a significant fur trade that flourished from 1823 through the 1830's. Gold miners were next to explore streams of the unknown West. The first discovery of gold in Wyoming was in 1842 along the Sweetwater River (Coutant, 1899b, p. 637-674); this stimulated further exploration and discoveries in other areas.

Trappers and miners led the way to the West and were fundamental to the exploration of the territories; however, the largest number of settlers were drawn by the promise of land ownership and the opportunities of agriculture. "Go West, young man, go West," was the advice given to young Americans in the mid-1800's. The choice land in the East had been settled, and the greatest opportunity for ambitious persons was in the western territories of abundant land and resources.

Thousands of emigrants passed through the Wyoming Territory during 1840-90. Some of them stayed and settled, and the prime croplands along flowing streams were soon claimed. This did not deter the emigrants. "Where the plow goes, the rain will follow," was a notion that was popular among developers and hopeful pioneers when the West was being opened for settlement (Smith, 1947). Many residents of the East actually believed that God or nature would provide rain to fields that were cultivated in arid western lands. Unfortunately, hundreds of settlers lost their life savings or their lives before the notion was abandoned.

Streams were used during the development of the West for the transporting of timber. The building of the transcontinental railroad in 1867 spurred the timber industry to meet the need for railroad ties in the construction and maintenance of the railroad, and also for timbers used in the mines that supplied coal to the railroad. Because the railroad was built mainly across flat areas of the plains and deserts, streams--such as the Laramie, North Platte, Green, and Bear Rivers--that flowed from the mountains to the railroad were used whenever possible to transport the timber.

Some early pioneers and technical persons, who were cautious about full-scale opening of western lands, advised Congress and developers of the realities new settlers might incur (Stegner, 1960). Major John Wesley Powell, one of the most knowledgeable experts on the resources of the West, gained firsthand knowledge of the West and its water resources from expeditions made in 1869 and 1872 down the Colorado River. These expeditions began on the Green River in Wyoming. On the basis of his field investigations, Powell (1878) stated that much of the West was arid grazing land, of value only when used in large quantities. His opinion was that most of the prime and easily-irrigable lands along streams had already been settled. Powell drew up a bill stipulating that new ranches on the remaining lands should be no less than 2,560 acres, but Congress did not pass it (Stegner, 1960, p. 239).

However, in 1877, Congress did pass the Desert Land Act that allowed homesteading of certain 640-acre tracts requiring irrigation in order to raise a crop. Water commonly was not available, and only about a quarter of the filings resulted in patents. The Carey Act, passed by Congress in 1890, transferred land to the states. The states could then grant water rights for 160-acre blocks. After blocks had been settled upon and cultivated, clear title was then granted. Wyoming adopted this plan in 1894.

Irrigation Development

The main use of water in Wyoming is for irrigation. Although growing seasons are sufficient for many crops at lower elevations in Wyoming, the successful growing of these crops generally requires irrigation because precipitation is usually small and unpredictable. Irrigated grass hay lands and pastures constitute a large use of water along streams in Wyoming. Snowmelt from the mountains is the main source of streamflow in the many streams and rivers used for irrigation. Irrigated areas and mountainous regions in Wyoming are highlighted on plate 1a (at back of report), which is a mosaic of infrared imagery taken from a Landsat satellite. The imagery uses false colors that distinctly show certain features, such as vegetation and bedrock.

Exactly when the first irrigation began in Wyoming is subject to debate. Historian David J. Wasden (1973, p. 153-154) presents evidence that the first irrigation ditch in what is now Wyoming may have been constructed along the Hams Fork in the 1830's by a colony of Mexican settlers.

A number of successful irrigation projects were developed by Mormon settlers, who were noted for their irrigation knowledge. A group of Mormons journeyed from Salt Lake City to establish an agricultural settlement known as Fort Supply on the Smiths Fork in 1853 (plate 1a). Fort Supply was later abandoned, but other irrigation projects were developed, including some in the Star Valley and the Bighorn Basin.

Most irrigation began as diversion of natural flows. As development flourished, it was realized that storage was needed to supply water through the complete irrigation season. Landowners subsequently organized and formed development companies to construct and operate reservoirs (Frank J. Trelease, III, Assistant State Engineer for Wyoming, oral commun., 1987). For example, Wyoming Development Company Reservoir No. 1, with a storage capacity of 5,360 acre-feet, was constructed in 1897 as an off-channel reservoir of Sybille Creek, a tributary of the Laramie River. The project was successful, and the development company was changed to an irrigation district. After filing for water rights in 1898, the district also completed Wheatland No. 2 Reservoir, with a storage capacity of 98,300 acre-feet, on the Laramie River in 1904. Similar efforts of group enterprise were instrumental in the development of successful irrigation throughout Wyoming, especially along smaller and medium-sized streams and rivers.

The Federal Reclamation Act of 1902 authorized Congress to allow the Reclamation Service to begin construction of major projects that would develop streamflow for irrigation and power production. As a result, large dams and reservoirs have been constructed on the North Platte, Wind-Bighorn, Shoshone, Green, and Belle Fourche Rivers. These projects have contributed greatly to the agricultural and industrial economies of Wyoming.

Transportation Systems

As the agricultural development in the western states progressed, there was a movement by Congress to assist farmers and ranchers in transporting their products to market by developing paved roads (A. Mainard Wacker, Hydraulic Engineer, Wyoming Highway Department, oral commun., 1987). The construction of paved highways was greatly expanded during the 1920's and 1930's. With the development of improved roads, tourism also began to flourish, especially as a result of travel to Yellowstone National Park, the first area set aside in the United States as a national park.

A major consideration in the design of highways is the size of structure needed for stream and river crossings. Before about 1960, engineers with the Wyoming Highway Department used empirical methods to determine structure size. During the 1960's, the Department began a program with the U.S. Geological Survey to collect and summarize floodflow data specific to Wyoming.

Energy Development and Urbanization

The development of energy minerals, including oil and gas, coal, and uranium, has become a major industry in Wyoming along with agriculture and tourism. Many of the towns and cities in the State have experienced growth and population increases associated with the mineral industry. Information needed by industry regarding surface water generally is for water-supply purposes and also for design of stream-related structures. Municipalities and land-use agencies, such as the U.S. Bureau of Land Management, also are concerned with water-supply and flood information. Planning associated with floods in urban areas was especially strengthened by the National Flood Insurance Act of 1968 (Public Law 90-448) and the closely related Flood Disaster Protection Act of 1973 (Public Law 93-234) (U.S. Water Resources Council, 1979, p. VI-3).

FACTORS AFFECTING STREAMFLOW

Various types of streams exist in Wyoming due to differences in climate and physical features such as geology. Perennial streams generally originate in the mountainous areas as a result of significant annual precipitation and geologic conditions that foster ground-water discharge. Streams originating in the semiarid and arid plains and desert areas generally are ephemeral, flowing mainly in direct response to rainstorms and snowmelt.

The major part of annual runoff in streams draining mountainous areas occurs during spring and early summer as a result of snowmelt. A hydrograph typical of a mountainous stream is shown in figure 1. Streamflow generally peaks during June; however, this varies from year-to-year depending on both local weather conditions and physical features of individual basins. Late summer, fall, and winter flows are largely the result of ground-water inflows. Minimum streamflows generally occur during January through March. The total runoff that occurs during any particular year is closely related to the precipitation for that year.

Intermittent and ephemeral streams draining the plains and desert areas flow only periodically and often have extended periods of no flow (fig. 2). These streams may receive some ground-water inflows in addition to direct surface runoff; however, the ground-water inflows are insufficient to sustain flow throughout the year. Springs are present in some areas of the plains and deserts, and these springs commonly contribute small perennial inflows to streams. However, losses of water to evaporation, transpiration, and seepage, and storage as ice generally limit the extent of these flows to short reaches downstream from the springs.

Climate

Streamflows are closely related to climate, especially precipitation (fig. 3). The climate of Wyoming varies greatly with the season and by location due to the effects of altitude and mountain terrain on wind, air temperature, and precipitation. The distribution of average annual precipitation is shown on plate 1b.

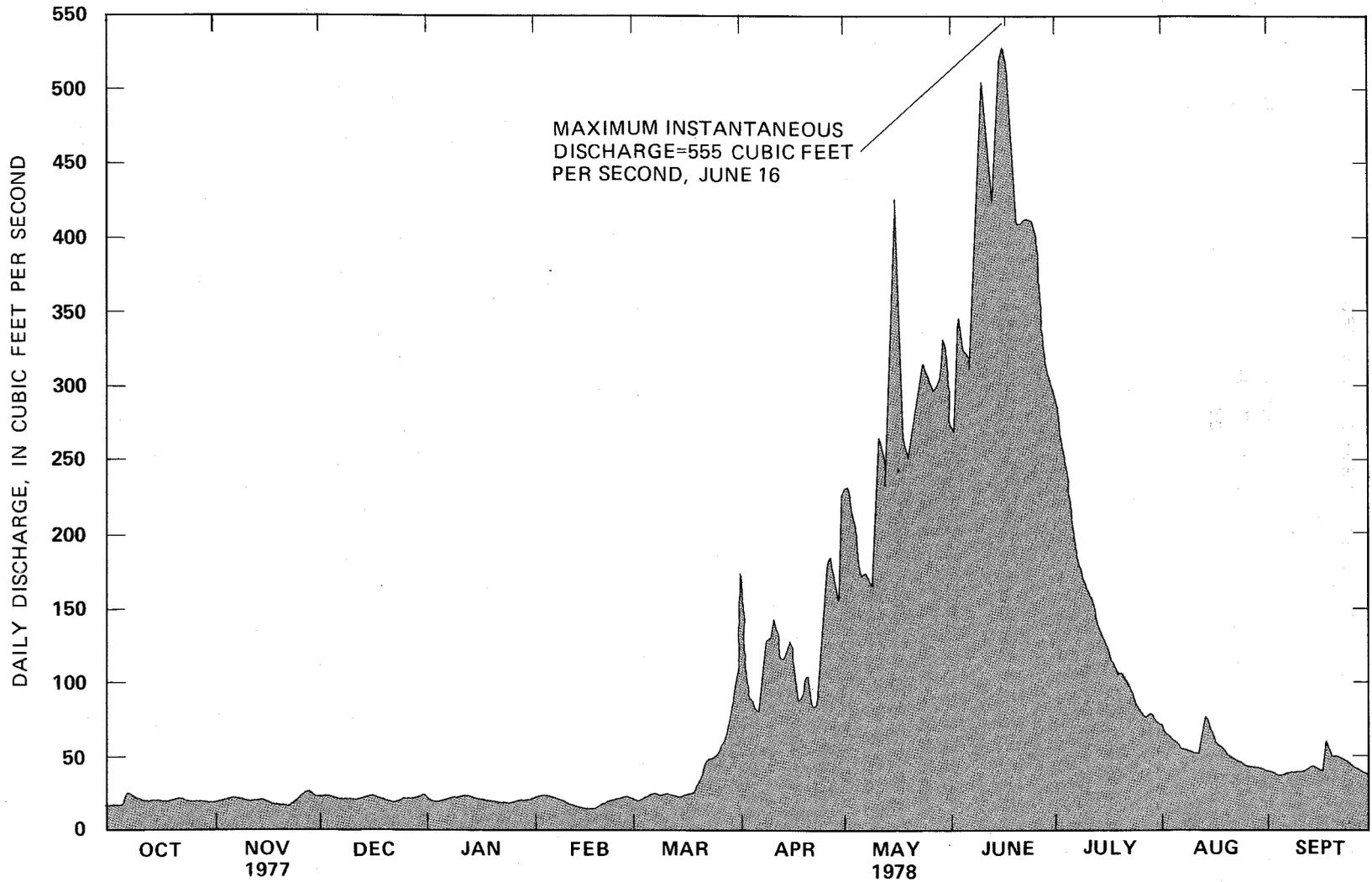


Figure 1.--Daily discharge for Fontenelle Creek, which drains a mountainous area in western Wyoming. (Record is for streamflow-gaging station 09210500, 1978 water year.)

7

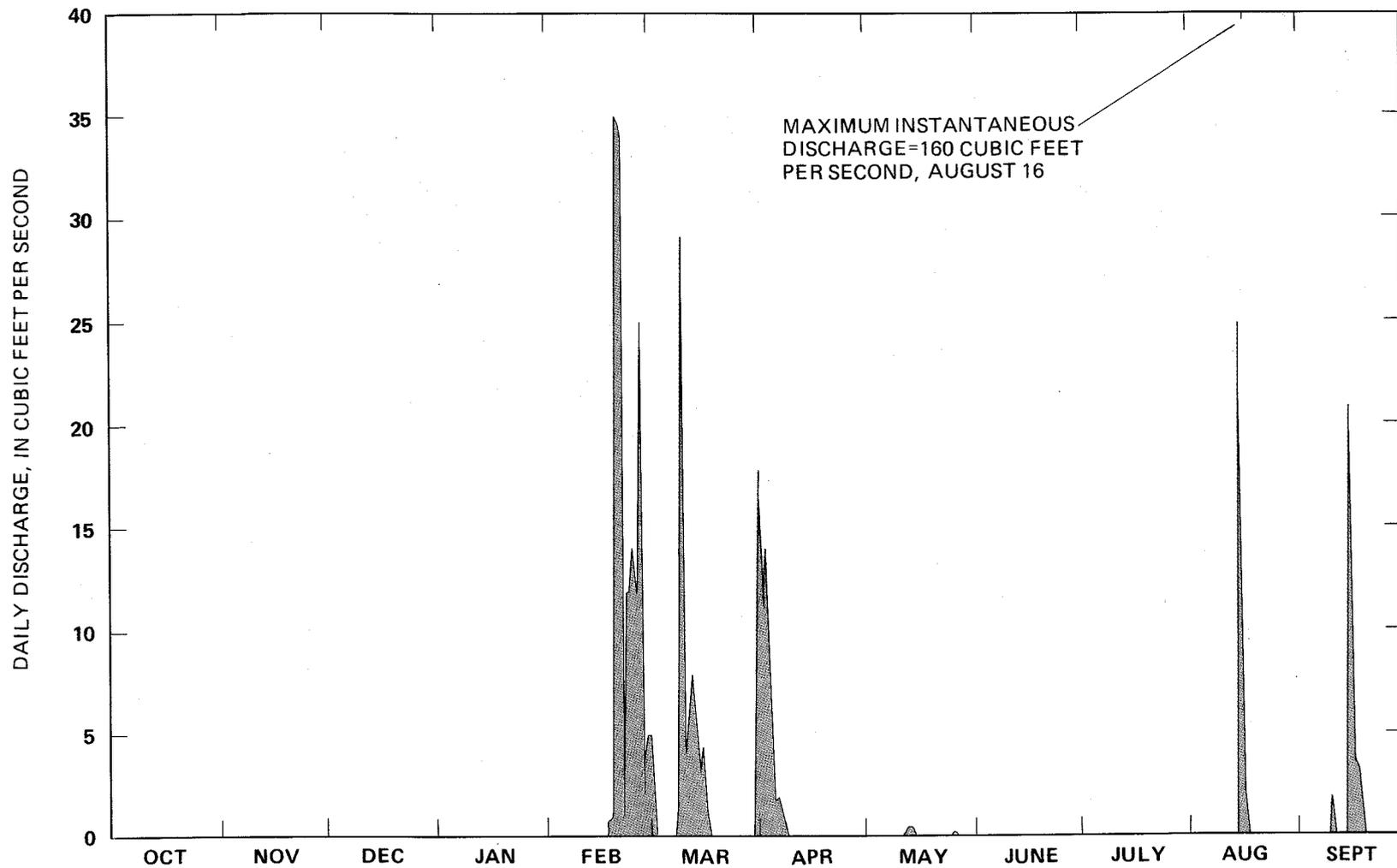


Figure 2.--Daily discharge for East Fork Nowater Creek, which drains a plains area in north-central Wyoming. (Record is for streamflow-gaging station 06267400, 1980 water year.)

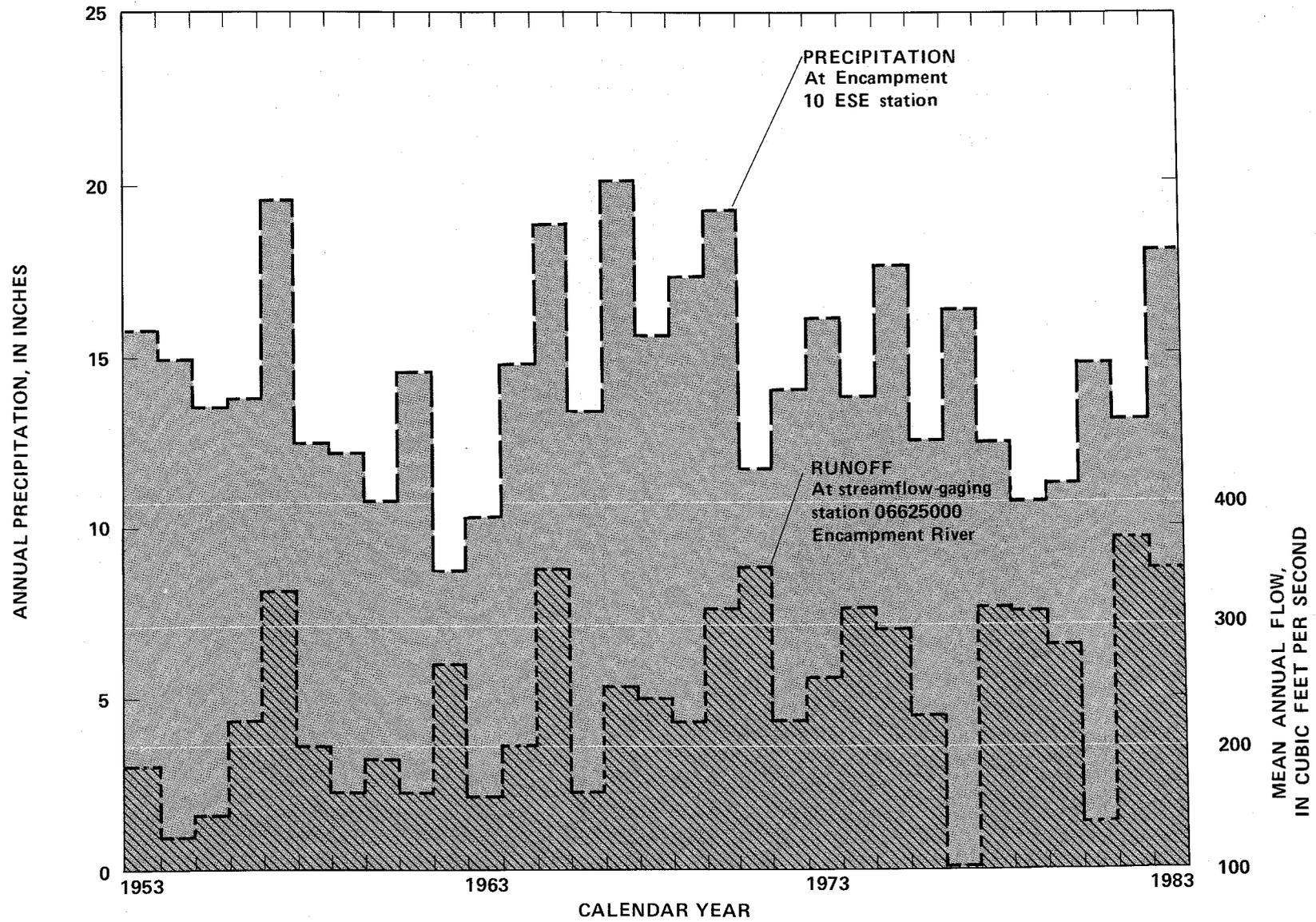


Figure 3.--Comparison of annual precipitation and runoff, 1953-83.

A summary of climate in the State follows. This summary and the precipitation map on plate 1b are based on a report prepared by J.D. Alyea (1980) for the U.S Geological Survey.

Maritime airflows from the Pacific Ocean are the source of moisture for most of the annual precipitation in Wyoming. The air masses are borne eastward by the prevailing westerly winds, although coastal mountain ranges cause much of the moisture to precipitate before reaching Wyoming.

Most wintertime precipitation is in the form of snow. Snowstorms with the greatest precipitation occur when cold airflows from the north move into the area and wedge under the warmer surface air; the warm air is forced upward, causing snow. In the mountains, the cold temperatures allow much of the snow to be retained until spring melting. In the interior plains and deserts, much snowfall is quickly sublimated by the wind and sun, and retention occurs mainly as drifts in draws and shaded areas.

Summertime precipitation occurs as light rain and from occasional, intense convective storms that generally move in an easterly direction. The warmer atmosphere in spring has increased moisture-carrying capacity, which results in the relatively large quantities of precipitation during April, May, and June (fig. 4).

As summer progresses and the atmosphere continues to warm, more moisture is available for precipitation, but the cumulus clouds are formed much higher above the land surface. Precipitation from these clouds has a relatively long path through dry air, and much of it evaporates before reaching the land surface.

Mountain ranges greatly affect the occurrence of precipitation in Wyoming. Precipitation increases with elevation, and the mountainous areas commonly receive 25 inches or more precipitation annually, while the plains and deserts receive as little as 6 or 7 inches.

The precipitation map on plate 1b indicates the average annual precipitation that occurs throughout Wyoming. For the plains and desert areas of the State, the percentage of average annual precipitation that occurs during the months of May through September also is shown. During this period, precipitation in the form of rain or hail generally occurs from convective storms; during the remainder of the year, precipitation generally occurs as light rainfall and snowfall. The percentages infer that precipitation from convective storms is more predominant in the northern and eastern plains than in the southern and central desert areas of the State.

Surficial Geology and Soils

Surficial geology and soil type affect infiltration and thus have a significant effect on streamflow. Generally, coarse-grained surficial materials such as sand and gravel (alluvial and glacial deposits) and sandstone have more rapid infiltration rates than fine-grained materials such as clay, silt, siltstone and shale. However, infiltration rates in some fine-grained rocks and limestone are increased by fracturing resulting from geologic movement. Slow infiltration occurs in areas of clayey soils. The rate of infiltration especially affects runoff resulting from snowmelt and

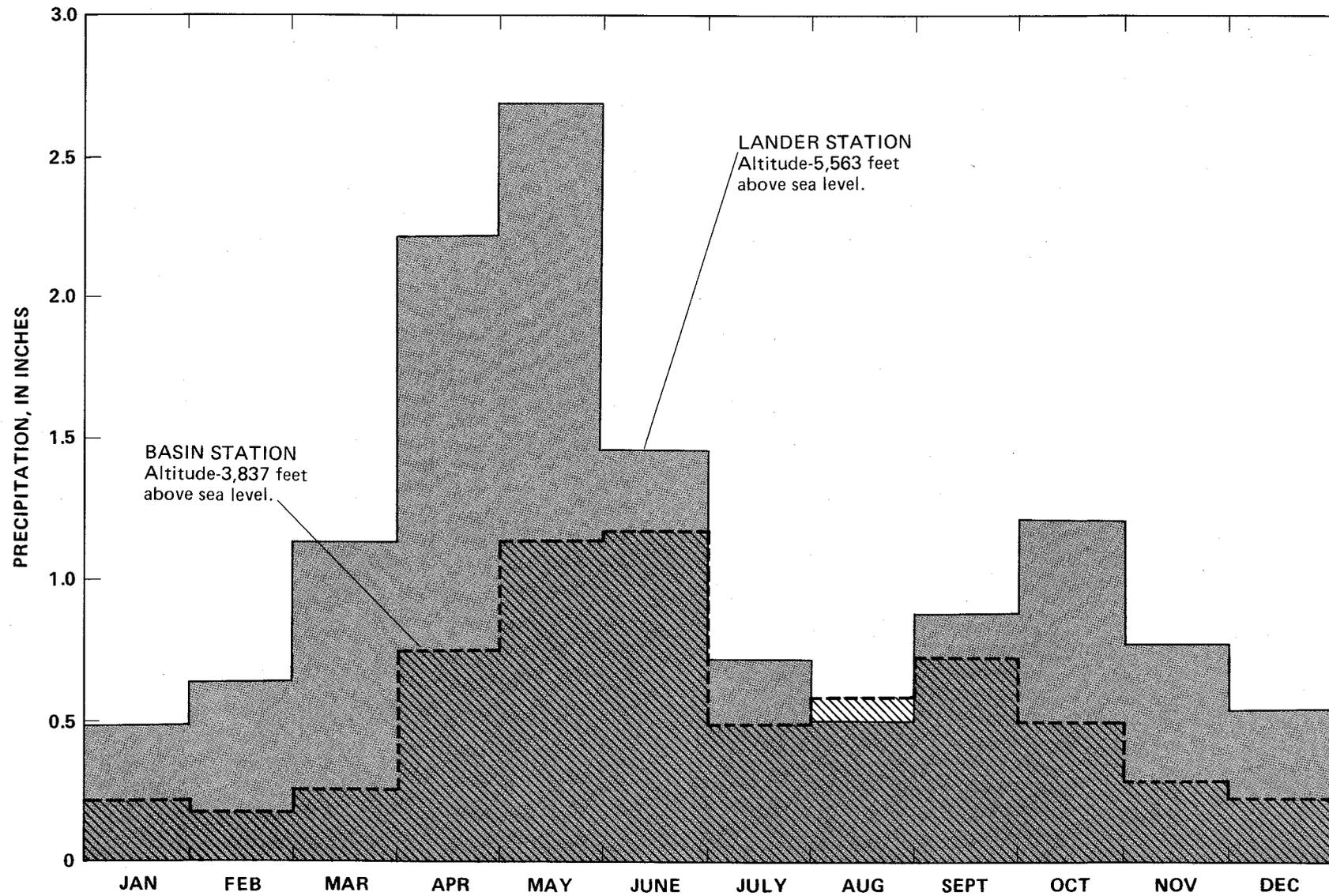


Figure 4.--Normal monthly precipitation at selected weather stations, 1951-80. Warming of the atmosphere causes relatively large amounts of precipitation during April, May, and June. (National Oceanic and Atmospheric Administration, 1982.)

rainstorms of moderate intensity. Intense rainstorms produce runoff that is less affected by infiltration rates than for moderately intense storms because the precipitation and resulting runoff occur very quickly. In addition, for very large storms of high intensity, infiltration is insignificant in affecting runoff because the total precipitation generally is so much greater than the part of the precipitation that infiltrates into the soil.

STREAMFLOW-GAGING STATIONS

When the design or management of a development requires streamflow data, a gaging station may be installed. Streamflow-gaging stations have been operated on Wyoming streams since 1888, when the first gage was installed on the Laramie River by the Wyoming Territorial Engineer and the U.S. Geological Survey. Since then, several hundred gages have been operated throughout the State for differing time periods. The majority of gages are operated by the U.S. Geological Survey in cooperation with other Federal and State agencies. Other gages are independently operated by the University of Wyoming, State agencies, the U.S. Soil Conservation Service, and private concerns such as mining companies.

Continuous Records

A continuous-record station has a recorder whereby a continuous record of stage (water level) is recorded. Using discharge measurements (fig. 5) made at the site, a relation between stage and discharge (stage-discharge rating) is developed to enable discharge to be determined for any stage of the stream. By combining the rating with the record of stage, a continuous record of stream discharge is determined. This record may be expressed as average daily, monthly, and yearly rates, or volumes of flow. Instantaneous peak flows or total runoff for a particular period also may be determined. A diagram summarizing the procedure for streamflow-data collection is shown in figure 6. For a comprehensive description of standardized stream-gaging procedures, the reader is referred to U.S. Geological Survey Water-Supply Paper 2175 (Rantz, 1982).

Peak-Flow Gages

For certain purposes, such as for the design of bridges and culverts, only peak-flow data are needed. A special gage that records the maximum stages of floods is used to collect this type of data (fig. 7).

Visits are made periodically to inspect the gage for high-water marks that may have occurred from intervening floods. The peak discharge for each maximum recorded stage is determined from a stage-discharge rating developed for the site. These gages are often referred to as crest-stage stations (Rantz, 1982, p. 77-79). The amount of equipment and work needed to maintain crest-stage stations are much less than that needed for continuous-record stations; hence, they are less expensive to operate. A statewide network of crest-stage gages was operated during 1959-85 as part of a cooperative program between the Wyoming Highway Department and the U.S. Geological Survey.

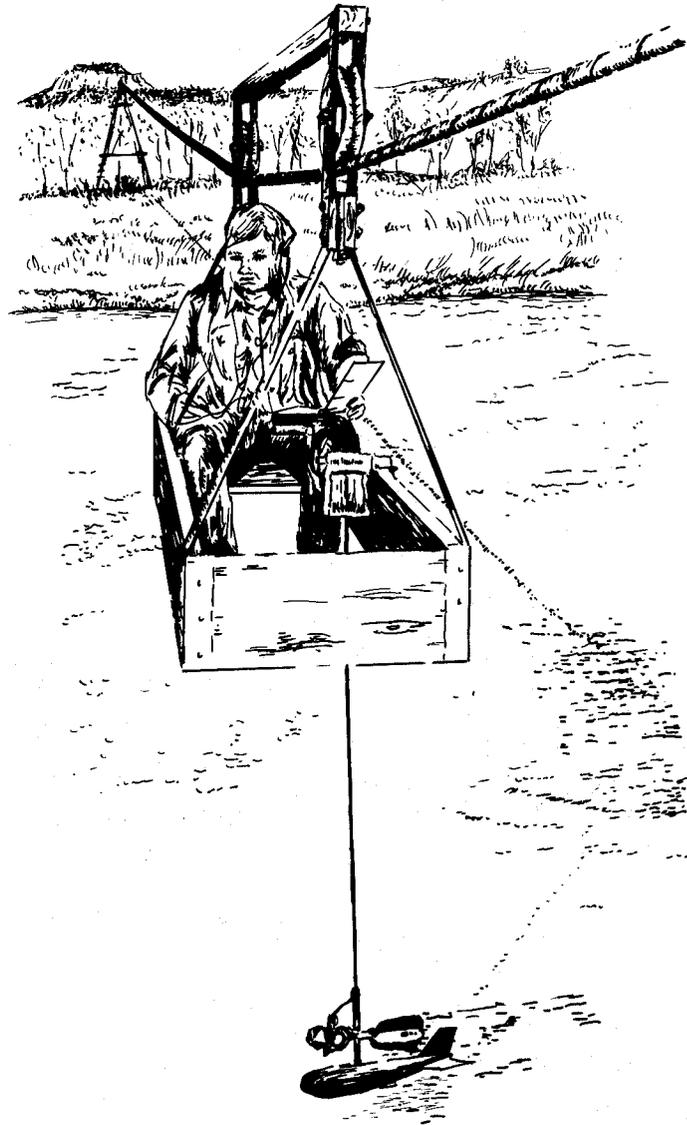
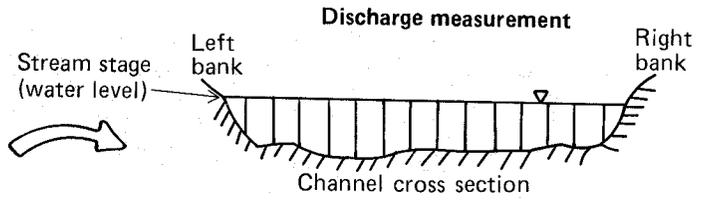
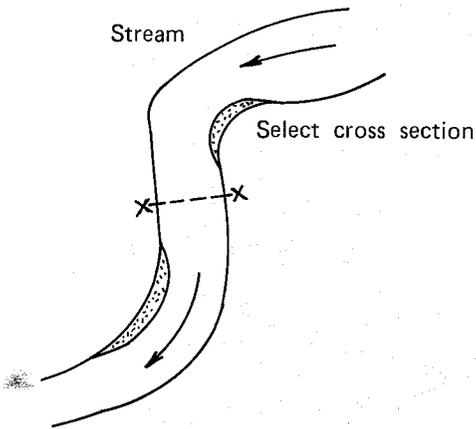


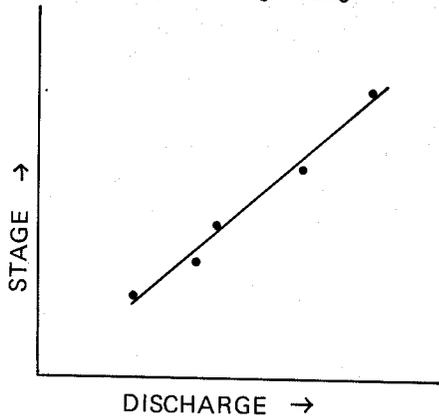
Figure 5.--Discharge being measured from a cableway.

Measurement-site selection



Subdivide cross section and measure width, depth, and mean velocity of each subsection. Multiply width, depth, and velocity to obtain discharge for each subsection. Sum increments to determine total discharge of stream

Stage-discharge rating



Construct stage-discharge rating from measured discharges at various stages

Collect continuous record of stage at gaging station. Combine rating with stage record to yield discharge record

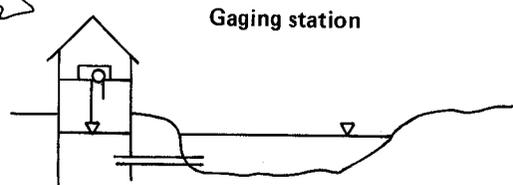


Figure 6.--Procedure for collection of streamflow data.

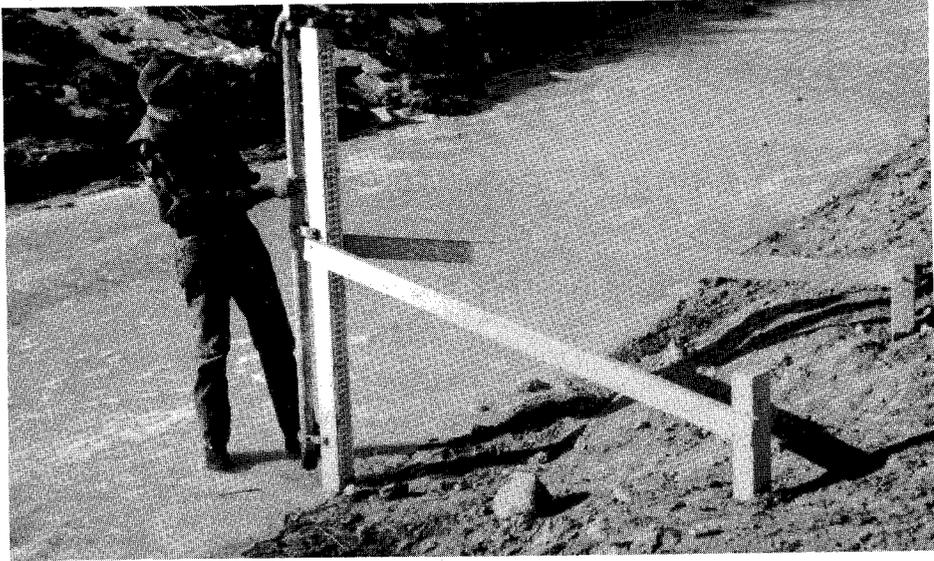


Figure 7.--Peak stages of floods are recorded by a crest-stage gage.

Availability of the Data

Streamflow data collected by the Geological Survey are published in annual reports and also are available from computerized files. Further information concerning streamflow records for Wyoming may be obtained by contacting offices of the Water Resources Division in Cheyenne, Casper, or Riverton.

STREAMFLOW CHARACTERISTICS AT GAGING STATIONS

When streamflow data are needed in planning and engineering, averages or statistical summaries of gaged data are often used. For example, if a planner or builder of an irrigation project were interested in runoff of a stream, monthly and yearly runoff values probably would be examined in comparison with the water demand for the irrigation period. If a bridge or culvert were to be installed on a stream, records and computations of high flows would be used as input to the design.

Streamflow-gaging stations that were used in this study are listed in table 7a; locations of the stations are shown on plate 1c. Peak-flow characteristics and mean annual flows at these stations are listed in table 7b. Drainage-basin characteristics are listed in table 7c. (Tables 7a through 7c are at the end of this report.) Only stations with records representative of natural streamflows, which were virtually unaffected by man-caused effects, were selected; 361 stations were used in the final analysis. The tables summarize data in the computer files of the U.S. Geological Survey as of December 1986, which generally included all data available through the 1985 water year.

As indicated in tables 7a to 7c and on plate 1c, a large data base exists for perennial streams draining mountainous areas of the State; however, a shortage of continuous records exists for small streams in the plains and desert areas of the State. To alleviate this shortage of runoff data, the records of 21 seasonal gages, which were operated during the principal rainfall months of May through September of 1963-73, were included in the analysis. These gages were operated on ephemeral streams to calibrate rainfall-runoff relations for small drainage basins as part of a cooperative program between the U.S. Geological Survey, Wyoming Highway Department, and Federal Highway Administration (Craig and Rankl, 1978). The peak-flow characteristics listed in table 7b for these stations are from the Craig-Rankl report.

The runoff data collected by the 21 seasonal gages were published by Rankl and Barker (1977). A review of similar streams having year-round records indicated that, on a statewide average, 60 percent of the mean annual flow of ephemeral streams in the plains and desert areas occurs during May through September. Therefore, it was assumed that 60 percent of the actual mean annual flow was measured during May through September. An estimated mean annual flow at each of the 21 seasonal gages was computed on this basis. It is realized that differences do occur from year-to-year and from site-to-site, and the values are considered to be approximate; however, they do constitute a valuable data base that was very useful in the subsequent regional analysis.

Flood Magnitude

The floodflow characteristics presented for the stations in table 7b are annual peak discharges for selected recurrence intervals, as determined by the Pearson Type III probability distribution with logarithmic transformation of annual flood data (log-Pearson Type III distribution). The procedure recommended in Bulletin 17B of the U.S. Water Resources Council (1981) was used. Peak-flow characteristics in this report are abbreviated as P_t , with P being the annual peak flow, in cubic feet per second, and t being the recurrence interval, in years. For example, P_{100} refers to an annual peak discharge that would be expected to be exceeded at intervals averaging 100 years.

The technical methods recommended in Bulletin 17B have improved the peak-flow characteristics over those derived by previous methods, especially in the plains and desert areas of Wyoming. When dealing with short periods of record, use of a generalized skew coefficient and addition of historical data from outside the gaged period of record are helpful in refining the frequency curve. Significant adjustments to the records of 10 gaging stations (table 7b) were made on the basis of field investigations of historical floods by Maurice E. Cooley (written commun., 1986).

Annual Runoff

The runoff at gaging stations listed in table 7b is expressed as mean annual flow, in cubic feet per second, which is abbreviated in this report as Q_a . Runoff was computed only for those stations having 5 or more complete years of record.

ESTIMATION OF STREAMFLOW CHARACTERISTICS AT UNGAGED SITES

Time and cost constraints prevent the installation and operation of gages at every site where streamflow information may be needed. If no gaging station has been operated at or near a site where stream-related development is planned, estimates of streamflow are useful. Several methods are available for estimating streamflow; however, one technique has become widely used during recent years, and that is to develop equations that relate streamflow characteristics to features of the drainage basin. The equations are developed through a statistical process known as regression analysis. Data used in the regression analysis are for gaged streams; the resultant equations depict streamflow and may be applied to ungaged streams where estimates are needed. Basin features for an ungaged site are used in the equations to obtain estimated streamflow characteristics at that site.

Methods are presented in this report for estimating peak-flow characteristics and mean monthly and annual flows of Wyoming streams. Two independent methods of estimating peak-flow characteristics and mean annual flow are presented: (1) The basin-characteristics method--developed by relating physical and climatic characteristics of the drainage basin to flow characteristics of the stream, and (2) the channel-geometry method--developed by relating channel features to flow characteristics. The methods were analyzed and developed separately due to inherent differences between basin characteristics and channel features. Basin characteristics (including

precipitation) are considered to be cause-effect variables because they produce or affect the outcome of flows. In contrast, channel features are considered to be resultant-effect variables; that is, the dimensions of a channel are the result of past flows. The advantage of presenting both methods in this report is that the users may select the one most suitable for their purposes. If both methods are used, a comparison of the results may be made.

Regression Models

The estimating equations were developed using a digital computer and multiple regression programs of the Statistical Analysis System (SAS Institute, Inc., 1982). The equations express flow characteristics (dependent variables) in relation to either basin characteristics or channel-geometry features (independent variables). The data were transformed to logarithms before relations were developed; experience has proved that linear relations can be approached by such transformation of hydrologic variables. After converting the results to antilogarithms, the form of the resultant equation is:

$$P = aA^b B^c C^d \dots\dots,$$

where P = the flow characteristic (a dependent variable);
 A, B, and C = basin characteristics or channel features
 (independent variables);
 a = the regression constant; and
 b, c, and d = regression coefficients.

Equations of the above form plot as straight lines on graph paper having logarithmic scales.

In the analysis for the plains and desert areas of Wyoming, a curvilinear relation (after logarithmic transformation) was determined to be more applicable than a linear relation as a model for estimating peak-flow characteristics when using drainage area as one of the independent variables. The resultant equation uses the following double-exponential form:

$$P = aA^{bA^c} C^d \dots\dots,$$

where P = the flow characteristic;
 A = drainage area and C is another basin characteristic;
 b and d = regression coefficients; and
 c = a coefficient that designates the amount of curvature
 (or nonlinear component) in the relation.

Equations of the above form plot as a curved line on logarithmic-scaled graph paper.

The curvilinear relations are applicable for describing peak-flow characteristics in the plains and deserts due to the nature of precipitation that occurs in these areas. Precipitation from convective storms often is intense and produces much greater unit runoff than general rainstorms or snowmelt produce. However, convective storms rarely cover areas of more than 10 square miles. In small basins, the largest flows generally are the result of runoff from convective storms. In large basins (several hundred square

miles or more), the largest flows generally are the result of widespread general rainstorms or snowmelt. As basin size increases, the unit rate of runoff decreases nonlinearly because the most dominant type of storm-runoff event changes from convective storms to general rainstorms and snowmelt. A curvilinear regression model accounts for this transition. A visual comparison of data plots as well as a comparison of the regression statistics verified that the curvilinear model provided a much better fit than the linear model.

Hydrologic Regions

Wyoming has a diverse terrain, and streamflow varies greatly from the mountains to the plains and deserts due to differences in climate, topography, and geology. These conditions cannot be wholly defined or explained by numeric variables. Therefore, it is necessary to develop more than one set of equations for estimating streamflow throughout the State. Different sets of equations are necessary--one set for each region of hydrologic similarity. In an earlier study, Lowham (1976) analyzed streamflows in the State using four regions. In the current study, advanced analytical methods and more complete streamflow data indicate that three regions are adequate. These regions (shown on plate 1a) were defined initially through the use of color infrared imagery that highlighted areal differences in surface geology, vegetation, and soil moisture. Boundaries of the regions were then refined on the basis of known streamflow and climatic characteristics. The three hydrologic regions are the same for both the basin-characteristics and channel-geometry methods, and for both peak-flow characteristics and mean annual flows.

The major mountainous areas of the State are designated in this report as being in the **Mountainous Regions**. Streamflows in these areas occur mainly as a result of snowmelt runoff. Peak flows in the **Mountainous Regions** are small in relation to flows in the other regions, but annual runoff is larger.

In the plains and desert areas of the State, streamflows occur primarily as a result of rainstorm runoff. In the northern and eastern plains and deserts, intense activity from convective storms causes peak flows to be relatively large but highly variable in occurrence from year-to-year. These areas are mainly high plains and are designated in this report as being in the **Plains Region**.

Streams in the south-central and southwestern plains and desert areas have peak flows that are relatively smaller than those of the **Plains Region**. This is a result of precipitation occurring more in the form of widespread general rainstorms and snow and less as activity from convective storms. These areas are largely desert and are designated as being in the **High Desert Region**.

Geographic Factors

During the analyses of data for streams in the **Plains and High Desert Regions** it became apparent that peak-flow characteristics at groups of gaging stations in particular areas had larger or smaller values than would be estimated by the regression equations. The differences between the gaged and estimated values were plotted on a map of the State, and a comparison of the plot with the color infrared imagery of the State showed that certain areas

were yielding larger or smaller peak flows due to geographic and orographic differences that were not quantified by the independent variables. For example, several areas of the State have extensive sand dunes where infiltration is high, and for which flood runoff should be relatively small. Using residual values of the regression for groups of stations, and color differences on the imagery that were due to differences in surface geology and vegetation, lines of equal geographic factors (G_p) were constructed that account for part of the differences in peak-flow characteristics. The residual values for regressions from both the basin-characteristics and channel-geometry methods were used to help determine the geographic factor. The lines of equal geographic factors for Wyoming are shown on plate 1d; these factors are included in the equations for estimating peak-flow characteristics in the **Plains** and **High Desert Regions**. Similar development and application of geographic factors in equations for estimation of peak-flow characteristics in Montana have been made by Omang and others (1986, p. 14-17).

Basin-Characteristics Method

Regression using basin characteristics is based on the assumption that certain physical and climatic variables produce or affect streamflow from a basin. The equations express flow characteristics (dependent variables) as being correlated to basin characteristics (independent variables). The method has the advantage of being an "office" technique. The basin characteristics are determined from maps of the drainage basin, and a field visit is not required.

Ten physical variables measured for each of the gaged basins include contributing drainage area; channel slope, length, and aspect; area of lakes and ponds; soils-infiltration rate; mean basin latitude and elevation; percent forest cover; and basin slope. Three climatic variables measured for each basin include average annual precipitation, intensity of rainstorm precipitation, and average length of growing season.

For the **Mountainous Regions**, drainage area, mean basin elevation, and mean annual precipitation were statistically significant as independent variables in estimating peak-flow characteristics and mean annual flow. Mean basin elevation and mean annual precipitation were determined to be highly correlated. Therefore, one set of equations using drainage area and mean basin elevation as independent variables is presented; a second set using drainage area and mean annual precipitation as independent variables is also presented. Based on the regression statistics, the equations using elevation should yield a slightly more accurate estimate of discharge, on the average. However, the equations using precipitation are much simpler to apply and, for most applications, are considered the most feasible to use.

For the **Plains Region**, drainage area and basin slope were determined to be significant as independent variables for estimating peak flows. For the **High Desert Region**, drainage area and mean annual precipitation were determined to be significant for estimating peak-flow characteristics. The geographic factor from plate 1d also is included in the the equations for both of these regions. Mean annual flow in the **Plains** and **High Desert Regions** also was determined to be significantly related to drainage area and average annual precipitation.

A description of the variables that were determined to be significant follows:

Contributing drainage area (A), in square miles, as measured by a planimeter on the best available topographic maps.

Mean basin elevation (ELEV), in feet above sea level, measured on 1:250,000-scale topographic maps. The measurement can be made by either: (1) laying a grid over the map, determining the elevation for at least 25 evenly-spaced intersections within the basin, and averaging those elevations, or (2) by determining the subareas within each contour interval, multiplying the subareas by the intermediate elevation, totaling the products, and then dividing by the total basin area. When possible, the contour intervals selected to be measured should provide not less than four subareas.

Average annual precipitation (PR), in inches. For gaged basins in Wyoming, the value of average annual precipitation was determined from plate 1b; for basins outside Wyoming, it was obtained from similar precipitation maps for the respective states. The measurement is made by sketching the drainage boundary on a transparent overlay on plate 1b, and computing the basin average by weighting subareas for each respective precipitation interval.

Basin slope (S_B), in feet per mile, determined by measuring the lengths, in miles, of contour lines within the drainage boundary, multiplying by the contour interval in feet, and dividing by the drainage area, in square miles. For basins of 50 square miles or less, maps of 1:24,000-scale are recommended to determine the basin slope. Reasonable accuracy generally can be obtained by measuring only the 100-foot contour lines. For basins of 50 to 300 square miles, 1:250,000-scale topographic maps are recommended. For basins larger than 300 square miles, basin slope generally approaches an average value of about 500 feet per mile. Due to the difficulty in measuring this characteristic for large basins, using a value of 500 feet per mile is recommended when the equations are applied to basins larger than 300 square miles.

The basin characteristics of significance in the regression analysis are listed for the gaged sites in table 7c (at end of this report).

Use

The basin-characteristics method requires locating the site in question on the most accurate map available, preferably a 1:24,000-scale Geological Survey topographic map, or equivalent. The basin boundary is then delineated, and the contributing drainage area is determined. Depending on the set of equations used, the geographic factor and other necessary variables are determined. The map of the basin should be examined to determine whether significant manmade works could affect natural streamflows. Although a field visit is not required to use the method, it is advisable to determine any unusual conditions. For example, detention dams and other works may have been constructed after completion of the most recent mapping. Example applications are given in a subsequent section (page 36).

Limitations

The basin-characteristics method is applicable only to sites having virtually natural streamflows. The equations should not be applied to estimate streamflows that are significantly affected by major dams, diversions, or other works of man. The equations could be applied in such cases to estimate what the natural flows were before the manmade works were constructed. In situations where flood characteristics of urban watersheds are needed, the equations for the basin-characteristics method can be used in conjunction with adjustments described by Sauer and others (1983).

Channel-Geometry Method

The size of a natural channel is an indication of flow magnitude. Large flows create large channels; smaller flows create smaller channels. A channel forms primarily during floodflows when a stream has tremendous energy and is transporting large quantities of sediment. Erosion and deposition occur as the stream sculpts its channel to a size large enough to accommodate its flows.

Streamflows of about bankfull magnitude usually dominate channel formation (Wolman and Miller, 1960). Although bankfull discharge, which has a recurrence interval of about 2 years (Lowham, 1982, p. 20-24), is most dominant in channel formation, other discharge characteristics, such as the 50- and 100-year peak flows and mean annual flow, are related to bankfull discharge. These additional characteristics are related to channel size, and estimation equations can be developed through regression analysis.

Several channel-geometry features, including width, depth, and the width-to-depth ratio of the stream channel, were measured and tested as independent variables for determining streamflow characteristics. Channel-geometry features were measured at nearly all of the gaged sites used in this study where the channels were suitable for measurement.

In a previous study (Lowham, 1976) for Wyoming streams, channel width was the only significant variable in estimating discharge. Depth of the channel is difficult to measure accurately and consistently because the streambeds of many channels are scoured during floodflow but fill in as the flow recedes. Rather than using depth or the width-to-depth ratio as independent variables, it was considered that a more accurate measurement of channel shape would be indicated by some measurement of the streambed and bank material. This approach was based on the results of several previous studies. For example, the percentage of silt and clay in the streambed and banks was found by Schumm (1960) to have a significant effect on channel shape. In addition to channel-geometry features, channel sediment properties were used by Osterkamp (1977) to develop equations for estimating mean discharge of Kansas streams, and by Osterkamp and Hedman (1982) to develop equations for perennial streams in the Missouri River basin.

To determine whether channel sediment properties could be used to improve the channel-geometry relations for the plains and desert areas of Wyoming, samples of the streambeds and banks at 23 gaged sites were collected for testing. A regression study was made for just these sites to determine whether the equations, using width as an independent variable, could be improved by the addition of a variable describing channel material. Several

measurements of streambed and bank composition (including particle size, percent silt and clay, and soil cohesiveness) were collected and tested; however, none proved to be significant in the analysis. The conclusion was, that although the composition of channel material is presumably interrelated to channel size and discharge, the variable nature of surficial deposits in the plains and deserts of Wyoming masked the attempt to quantitatively describe magnitude of streamflow with any channel feature other than width.

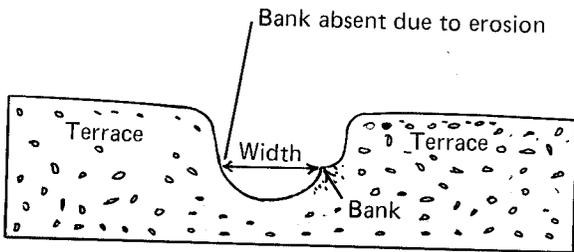
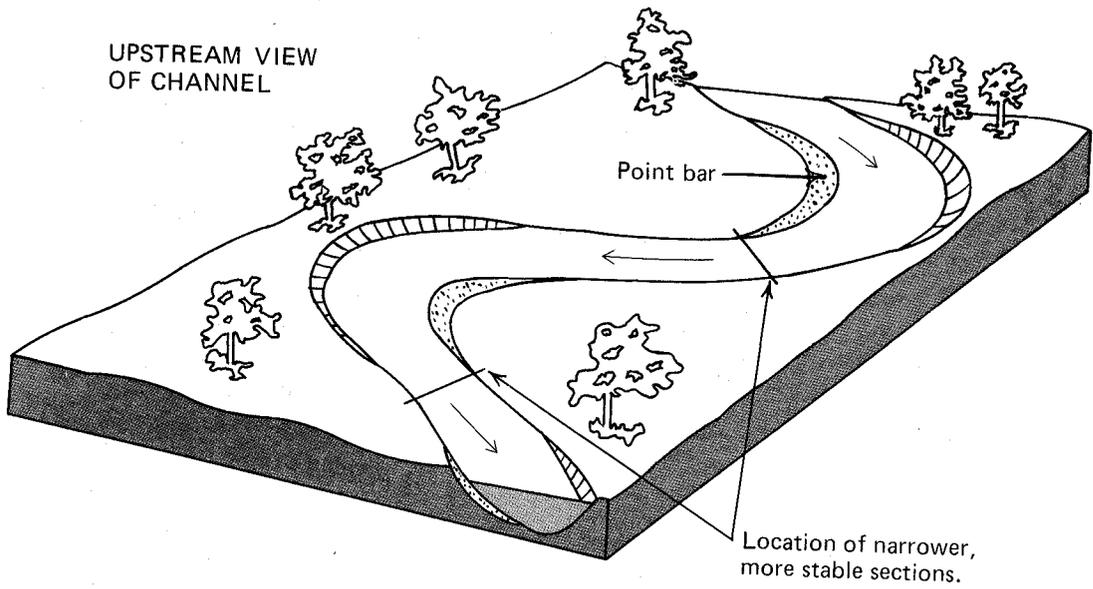
The width (WIDTH) of the channel was determined to be a significant independent variable for estimating streamflow in all regions of the State. Widths of all channels that were measured are listed in table 7c. The geographic factor (G_f) from plate 1d also is included in the equations for estimating peak-flow characteristics in the **Plains and High Desert Regions**.

Use

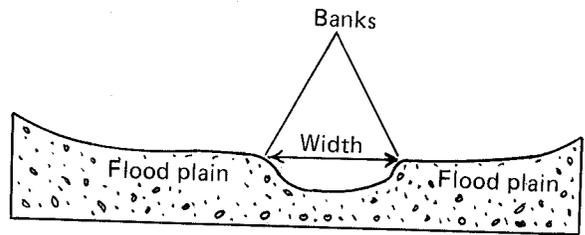
Although measuring channel features is fairly simple, some experience is required. A field visit is necessary to measure the channel width. A width measurement is made of the stream channel at the narrowest section of a straight reach. The section should have a stable appearance; that is, it should be one that has been fairly permanent for several years and not severely disturbed by large floods. It is a good practice to measure channel widths downstream from several meanders and then average the results. The distance from the top of one bank to the top of the adjacent bank of the stream channel is measured. (The top of the bank is defined as that spot where the flood plain and channel meet, and it is distinguished by a break in slope.) If a person were to climb out of a stream channel, they generally would dig in their toes to climb the bank, but could begin walking on flat ground when they reached the top (break in slope) of the bank.

Sketches in figure 8 show where the channel width should be measured. As shown in the sketches, the measurement is made of the narrowest, most stable section of a channel, generally just downstream from a curve or reach of rapids where large amounts of energy are dissipated. Streamflow dissipates energy in curves and rapids; therefore, the channel just downstream from these features reflects the relatively low energy and minimum erosion potential of the streamflow. When a point bar is present, the narrowest section generally will be located at the point where the downstream end of the bar meets the bank. Little or no erosion generally will be evident at this section.

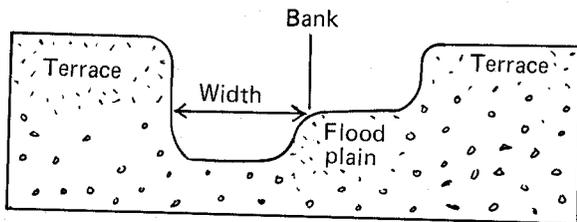
Photographs in figures 9-12 show examples of widths measured in several channels. A large collection of color slides that clearly show where measurements were made on a variety of channel types is on file in the Geological Survey office in Cheyenne. Persons who plan to use the method would benefit from viewing these slides, as well as from field instruction by someone who is experienced with the method.



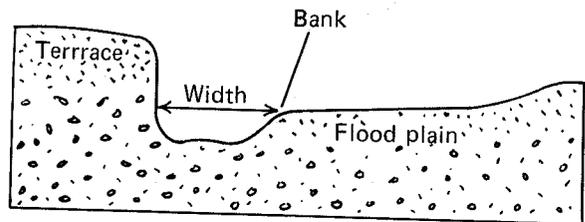
Channel whose streambed has eroded in recent past due to a change in climate or land use. Banks will be present if the channel has stabilized to existing conditions.



Channel with well-developed flood plain.



Channel whose streambed has eroded in past. The channel has stabilized and a new flood plain is developing.



Meandering channel whose lateral movement causes it to be eroding the valley terrace.

Figure 8.--Cross sections of various types of stream channels where width should be measured.

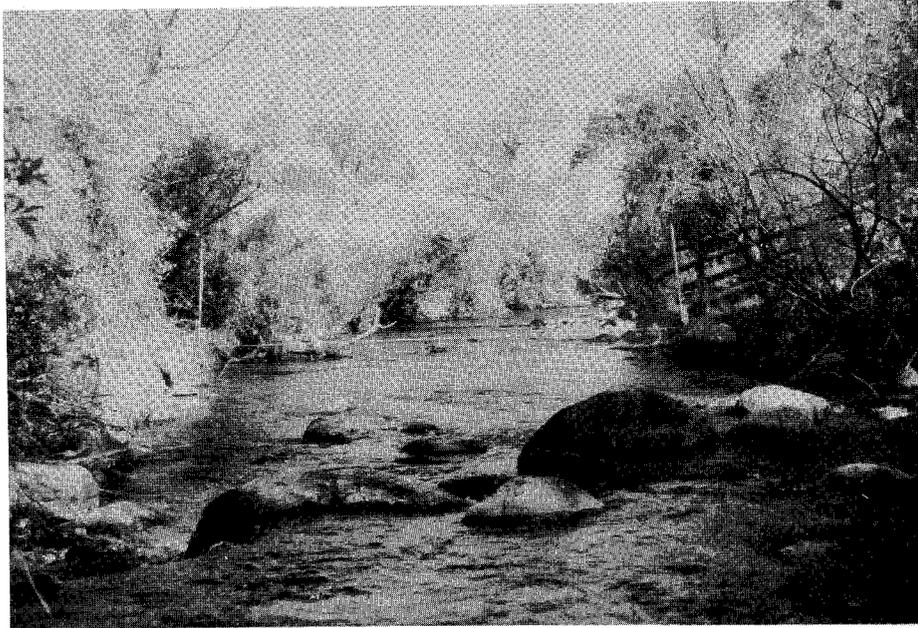


Figure 9.--Tape and stakes show where channel width was measured on North Fork Crazy Woman Creek near Buffalo. View is downstream, width = 24 feet.



Figure 10.--Tape and stakes show where channel width was measured on Cache Creek near Jackson. View is downstream, width = 12 feet.

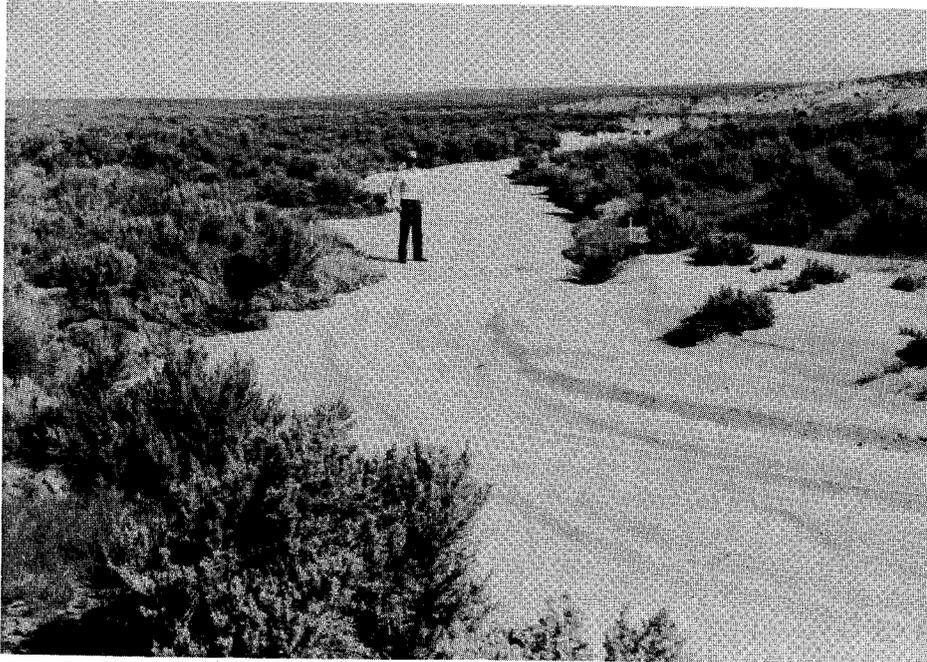


Figure 11.--Tape and stakes show where channel width was measured on Sand Springs Draw near Pinedale. View is downstream, width = 16 feet.

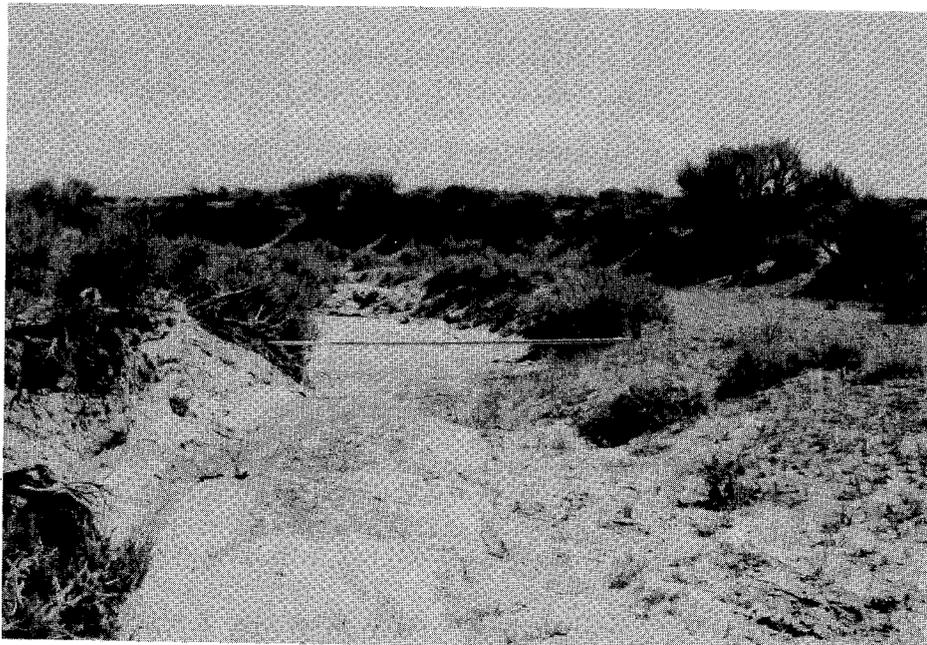


Figure 12.--Rod and stakes show where channel width was measured on tributary to the New Fork River near Big Piney. View is downstream, width = 12 feet.

Limitations

The channel-geometry method should not be used on certain stream reaches. These include reaches having:

1. Flows that are not frequent enough to form and maintain a channel. Flow is conveyed in a grassy swale that does not have well-defined banks. In general, stream channels with widths less than 2 feet in the **Mountainous Regions** and less than 4 feet in the **Plains and High Desert Regions** are not well defined and should not be used.
2. Braided channels. Streambanks in such channels are unstable, and flow often is in multiple channels. A stable channel reach occasionally can be found either upstream or downstream from the braided reach.
3. Potholes. On some intermittent streams the ground-water level is near the streambed elevation but inflow to the stream channel is insufficient to sustain perennial flow. During much of the year evaporation equals or exceeds the seepage inflow. Although the channel contains ponded water, there is no flow in the stream. The dissolved-solids concentration of the ponded water gradually increases to a level that vegetation cannot survive. The bed material of the channel is loosened by the buoyant forces of ground-water seepage, and subsequent flows erode the bed and form potholes.
4. Significant alterations such as diking and channelization, or reaches that are near enough to such alterations to have been significantly influenced or altered.
5. Large reservoirs or diversions upstream. On streams where large dams have been constructed, gaged data generally are available.

The criterion necessary to apply the channel-geometry method is that the channel to be measured should have been formed primarily by the forces of streamflow under its present regime. The method is not applicable when other influences, such as overgrowth of vegetation, wind deposits, movement of livestock and wildlife, and developments of man, are more dominant than the streamflow in forming the size and shape of the channel.

Regression Relations

Tables 1 to 4 present the estimation equations, the number of stations used in each regression analysis, the average standard error of estimate, and the correlation coefficient. The equations were developed using inch-pound units and must be entered with inch-pound units unless applicable conversion factors are applied. The equations should be used for estimating streamflow characteristics only within the ranges of data used for their development. A summary showing the ranges of data available for the regression analyses is listed in table 5. Extending the equations to estimate flow characteristics outside the defined ranges is discouraged.

Table 1.--Summary of regression relations for estimating peak-flow characteristics and mean annual flow of streams in the Mountainous Regions

[P_t , annual peak flow, in cubic feet per second, with subscript t designating the recurrence interval, in years; Q_a , mean annual flow, in cubic feet per second; A , contributing drainage area, in square miles; ELEV, mean basin elevation, in feet; PR, average annual precipitation, in inches, as determined from plate 1b; WIDTH, channel width, in feet]

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|--|--------------------------|--|----------------------------|
| Equations based on contributing drainage area (A) and mean basin elevation (ELEV) | | | |
| $P_2 = 0.012 A^{0.88} \left(\frac{\text{ELEV}}{1,000}\right)^{3.25}$ | 170 | 55 | 0.93 |
| $P_5 = 0.13 A^{0.84} \left(\frac{\text{ELEV}}{1,000}\right)^{2.41}$ | 170 | 46 | .95 |
| $P_{10} = 0.45 A^{0.82} \left(\frac{\text{ELEV}}{1,000}\right)^{1.95}$ | 170 | 44 | .95 |
| $P_{25} = 1.75 A^{0.80} \left(\frac{\text{ELEV}}{1,000}\right)^{1.46}$ | 170 | 44 | .94 |
| $P_{50} = 4.29 A^{0.79} \left(\frac{\text{ELEV}}{1,000}\right)^{1.13}$ | 170 | 47 | .94 |
| $P_{100} = 9.63 A^{0.77} \left(\frac{\text{ELEV}}{1,000}\right)^{0.85}$ | 170 | 50 | .93 |
| $P_{200} = 25.9 A^{0.75} \left(\frac{\text{ELEV}}{1,000}\right)^{0.47}$ | 170 | 54 | .91 |
| $P_{500} = 63.4 A^{0.74} \left(\frac{\text{ELEV}}{1,000}\right)^{0.14}$ | 170 | 61 | .89 |
| $Q_a = 0.0015 A^{1.01} \left(\frac{\text{ELEV}}{1,000}\right)^{2.88}$ | 140 | 57 | .91 |

Table 1.--Summary of regression relations for estimating peak-flow characteristics and mean annual flow of streams in the Mountainous Regions--Continued

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|--|--------------------------|--|----------------------------|
| Equations based on contributing drainage area (A) and average annual precipitation (PR) | | | |
| $P_2 = 0.51 A^{0.81} PR^{1.13}$ | 170 | 71 | .89 |
| $P_5 = 2.36 A^{0.79} PR^{0.78}$ | 170 | 56 | .92 |
| $P_{10} = 5.35 A^{0.78} PR^{0.59}$ | 170 | 52 | .93 |
| $P_{25} = 13.5 A^{0.77} PR^{0.38}$ | 170 | 50 | .93 |
| $P_{50} = 23.8 A^{0.77} PR^{0.25}$ | 170 | 50 | .93 |
| $P_{100} = 40.7 A^{0.76} PR^{0.13}$ | 170 | 52 | .92 |
| $P_{200} = 73.1 A^{0.75} PR^{-0.001}$ | 170 | 55 | .91 |
| $P_{500} = 136 A^{0.74} PR^{-0.15}$ | 170 | 61 | .89 |
| $Q_a = 0.013 A^{0.93} PR^{1.43}$ | 140 | 57 | .92 |

Table 1.--Summary of regression relations for estimating peak-flow characteristics and mean annual flow of streams in the Mountainous Regions--Continued

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|---|--------------------------|--|----------------------------|
| Equations based on channel width (WIDTH) | | | |
| $P_2 = 1.94 \text{ WIDTH}^{1.58}$ | 98 | 39 | 0.96 |
| $P_5 = 4.33 \text{ WIDTH}^{1.47}$ | 98 | 33 | .96 |
| $P_{10} = 6.60 \text{ WIDTH}^{1.41}$ | 98 | 36 | .95 |
| $P_{25} = 10.4 \text{ WIDTH}^{1.34}$ | 98 | 43 | .93 |
| $P_{50} = 13.9 \text{ WIDTH}^{1.30}$ | 98 | 49 | .91 |
| $P_{100} = 18.1 \text{ WIDTH}^{1.27}$ | 98 | 56 | .88 |
| $P_{200} = 28.0 \text{ WIDTH}^{1.23}$ | 98 | 63 | .85 |
| $P_{500} = 31.0 \text{ WIDTH}^{1.19}$ | 98 | 73 | .81 |
| $Q_a = 0.087 \text{ WIDTH}^{1.79}$ | 77 | 46 | .91 |

Table 2.--Summary of regression relations for estimating peak-flow characteristics of streams in the Plains Region

[P_t , annual peak flow, in cubic feet per second, with subscript t designating the recurrence interval, in years; A , contributing drainage area, in square miles; S_B , basin slope, in feet per mile; G_f , geographic factor, as determined from plate 1d; WIDTH, channel width, in feet]

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|--|--------------------------|--|----------------------------|
| Equations based on contributing drainage area (A), basin slope (S_B), and geographic factor (G_f) | | | |
| $P_2 = 41.3 A^{0.60} A^{-0.05} G_f$ | 115 | 97 | 0.76 |
| $P_5 = 63.7 A^{0.60} A^{-0.05} S_B^{0.09} G_f$ | 115 | 71 | .85 |
| $P_{10} = 76.9 A^{0.59} A^{-0.05} S_B^{0.14} G_f$ | 115 | 63 | .87 |
| $P_{25} = 94.2 A^{0.59} A^{-0.05} S_B^{0.19} G_f$ | 115 | 62 | .88 |
| $P_{50} = 112 A^{0.58} A^{-0.05} S_B^{0.23} G_f$ | 115 | 66 | .87 |
| $P_{100} = 130 A^{0.58} A^{-0.05} S_B^{0.25} G_f$ | 115 | 73 | .85 |
| $P_{200} = 182 A^{0.57} A^{-0.05} S_B^{0.26} G_f$ | 109 | 82 | .80 |
| $P_{500} = 245 A^{0.57} A^{-0.05} S_B^{0.27} G_f$ | 109 | 98 | .76 |

Table 2.--Summary of regression relations for estimating peak-flow characteristics of streams in the Plains Region--Continued

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|--|--------------------------|--|----------------------------|
| Equations based on channel width (WIDTH) and geographic factor (G_f) | | | |
| $P_2 = 7.60 \text{ WIDTH}^{1.18} G_f$ | 41 | 59 | 0.87 |
| $P_5 = 20.5 \text{ WIDTH}^{1.14} G_f$ | 41 | 45 | .91 |
| $P_{10} = 34.6 \text{ WIDTH}^{1.11} G_f$ | 41 | 44 | .91 |
| $P_{25} = 60.9 \text{ WIDTH}^{1.09} G_f$ | 41 | 48 | .90 |
| $P_{50} = 88.0 \text{ WIDTH}^{1.07} G_f$ | 41 | 53 | .87 |
| $P_{100} = 123 \text{ WIDTH}^{1.06} G_f$ | 41 | 60 | .85 |
| $P_{200} = 166 \text{ WIDTH}^{1.04} G_f$ | 41 | 68 | .82 |
| $P_{500} = 239 \text{ WIDTH}^{1.03} G_f$ | 41 | 78 | .77 |

Table 3.--Summary of regression relations for estimating peak-flow characteristics of streams in the High Desert Region

[P_t , annual peak flow, in cubic feet per second, with subscript t designating the recurrence interval, in years; A, contributing drainage area, in square miles; PR, average annual precipitation, in inches, as determined from plate 1b; G_f , geographic factor, as determined from plate 1d; WIDTH, channel width, in feet]

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|--|--------------------------|--|----------------------------|
| Equations based on contributing drainage area (A), average annual precipitation (PR), and geographic factor (G_f) | | | |
| $P_2 = 6.66 A^{0.59} A^{-0.03} PR^{0.60} G_f$ | 43 | 67 | 0.80 |
| $P_5 = 10.6 A^{0.56} A^{-0.03} PR^{0.81} G_f$ | 43 | 57 | .82 |
| $P_{10} = 13.8 A^{0.55} A^{-0.03} PR^{0.90} G_f$ | 43 | 54 | .82 |
| $P_{25} = 19.4 A^{0.53} A^{-0.03} PR^{0.98} G_f$ | 43 | 53 | .81 |
| $P_{50} = 24.2 A^{0.52} A^{-0.03} PR^{1.02} G_f$ | 43 | 54 | .80 |
| $P_{100} = 30.1 A^{0.51} A^{-0.03} PR^{1.05} G_f$ | 43 | 55 | .78 |
| $P_{200} = 36.0 A^{0.51} A^{-0.03} PR^{1.07} G_f$ | 43 | 58 | .75 |
| $P_{500} = 47.1 A^{0.50} A^{-0.03} PR^{1.09} G_f$ | 43 | 62 | .71 |

Table 3.--Summary of regression relations for estimating peak-flow characteristics of streams in the High Desert Region--Continued

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|--|--------------------------|--|----------------------------|
| Equations based on channel width (WIDTH) and geographic factor (G_f) | | | |
| $P_2 = 5.46 \text{ WIDTH}^{1.22} G_f$ | 27 | 64 | 0.82 |
| $P_5 = 14.6 \text{ WIDTH}^{1.16} G_f$ | 27 | 59 | .83 |
| $P_{10} = 25.5 \text{ WIDTH}^{1.12} G_f$ | 27 | 58 | .82 |
| $P_{25} = 47.3 \text{ WIDTH}^{1.06} G_f$ | 27 | 59 | .81 |
| $P_{50} = 71.4 \text{ WIDTH}^{1.01} G_f$ | 27 | 60 | .79 |
| $P_{100} = 105 \text{ WIDTH}^{0.97} G_f$ | 27 | 61 | .77 |
| $P_{200} = 149 \text{ WIDTH}^{0.93} G_f$ | 27 | 63 | .74 |
| $P_{500} = 233 \text{ WIDTH}^{0.87} G_f$ | 27 | 66 | .71 |

Table 4.--Summary of regression relations for estimating mean annual flow of streams in the Plains and High Desert Regions

[Q_a , mean annual flow, in cubic feet per second;
 A^a , contributing drainage area, in square miles; PR,
 average annual precipitation, in inches, as determined
 from plate 1b; WIDTH, channel width, in feet]

| Regression equation (inch-pound units) | Number of stations | Average standard error, in percent | Correlation coefficient |
|---|--------------------------|--|----------------------------|
| Equation based on contributing drainage area (A) and average annual precipitation (PR) | | | |
| $Q_a = 0.0021 A^{0.88} PR^{1.19}$ | 45 | 96 | 0.95 |
| Equation based on channel width (WIDTH) | | | |
| $Q_a = 0.00046 WIDTH^{2.42}$ | 20 | 117 | .93 |

Table 5.--Applicable range of the estimation relations

| Region and equation | Drainage area, in square miles | Mean basin elevation, in feet above sea level | Average annual precip- itation, in inches | Basin slope, in feet per mile | Channel width, in feet |
|----------------------------|--------------------------------------|---|---|--|------------------------------|
| Mountainous Regions | | | | | |
| Peak flows | 0.52 - 3,465 | 3,700 - 11,100 | 12 - 55 | -- | 2 - 180 |
| Annual flow | 6.30 - 3,465 | 5,000 - 10,800 | 14 - 55 | -- | 12 - 180 |
| Plains Region | | | | | |
| Peak flows | 0.04 - 5,270 | -- | -- | 115 - 1,620 | 6 - 120 |
| Annual flow | 0.69 - 5,270 | -- | 7 - 22 | -- | 5 - 120 |
| High Desert Region | | | | | |
| Peak flows | 1.26 - 1,178 | -- | 7 - 17 | -- | 3 - 60 |
| Annual flow | 0.69 - 5,270 | -- | 7 - 22 | -- | 5 - 120 |

Correlation with Nearby Gaged Streams

In the **Mountainous Regions**, where streamflow occurs mainly from snowmelt and there is relatively low variability of annual and seasonal runoff, an alternative to estimating runoff characteristics by regression is to correlate the discharge of an ungaged stream to the discharge of one or more nearby gaged streams. The gaged streams need to be located in basins having characteristics (drainage area, elevation, and aspect) similar to those of the ungaged basin. Streamflows from both gaged and ungaged basins need to be virtually unaffected by storage reservoirs and diversions.

Mean Annual Flow

Riggs (1969) describes a procedure for estimating mean annual flow by measuring the discharge of the ungaged stream near mid-month each calendar month for a year. These measured discharges are related to concurrent daily mean discharges at a nearby streamflow-gaging station using a separate relation of 45-degree slope for each month. The monthly mean flow at the gaged site is transferred through the appropriate relation to obtain an estimate of the monthly mean at the ungaged site. The annual mean flow for the year is computed from the 12 monthly means; it can be adjusted to an estimate of the mean annual flow on the basis of records for several nearby gaging stations. For a step-by-step description of the procedure, the reader is referred to Riggs (1969).

Mean Monthly Flow

Regression equations were investigated as a possible means of estimating mean monthly streamflows; however, on a statewide basis no useful relations were determined. If mean monthly streamflows are to be estimated, use of data for one or more gaged streams in the vicinity of the ungaged basin is desirable. The procedure is as follows:

Using the regression relations in this report, or the method of monthly measurements described by Riggs (1969), an estimate of mean annual flow is obtained for the ungaged site. Average monthly flows, expressed in percent of annual flow, are determined for each of the nearby gaged basins. The overall average percentage for each month is computed for the gaged sites, and these averages are multiplied by the estimate of mean annual flow to determine the estimated mean monthly streamflows at the ungaged site.

Flood Characteristics at Gaged Sites with Short Records

If streamflow characteristics are needed for a site that has been gaged, generally the station record is used--provided the period of record is sufficient to adequately define the values. However, when the period of record is relatively short, the distribution of peak discharges at the station may not be representative of the long-term flood history for the site. This is because a short period of record has the possibility of occurring within either a wet or dry climatic cycle. On the basis of the

author's experience working with flood data, and a time-error analysis by Wahl (1970), this is especially possible for Wyoming streams having records for less than about 15 years for the **Mountainous Regions** and about 25 years for the **Plains and High Desert Regions**.

If the station record is considered to be relatively short and subject to error from a wet or dry climatic cycle, a weighting method (Sauer, 1974) may be used to provide a more accurate estimate of flood frequency at a gaged site on an unregulated stream. The method weights the peak discharge computed from the station flood frequency with the peak discharge estimated from the regional regression equation according to their respective years of record. The equation used for the weighting method is:

$$Q_{t(w)} = \frac{Q_{t(s)}N + Q_{t(r)}E}{N + E}$$

- where $Q_{t(w)}$ = the weighted peak discharge, in cubic feet per second, for the recurrence interval of t-years;
 $Q_{t(s)}$ = the station value of the flood based on the historical record, in cubic feet per second, for the recurrence interval of t-years;
 N = the number of years of station data used to compute $Q_{t(s)}$;
 $Q_{t(r)}$ = the regression estimate of the peak discharge, in cubic feet per second, for the recurrence interval of t-years;
and
 E = the equivalent years of record for $Q_{t(r)}$ = 10 years (based on recommendation by the U.S. Water Resources Council (1981, p. 21) for the 100-year peak discharge, which for the purposes of this report is assumed applicable to other recurrence intervals).

Example Applications

Procedures for estimating streamflow characteristics are given in the following examples:

Example A. Basin-characteristics method--Mountainous Regions

An estimate of the 100-year peak discharge is needed for the preliminary design of a bridge. The estimate is needed immediately; time is insufficient to make a field visit to obtain channel measurements at the proposed site. The contributing drainage area is 126 square miles, and the mean basin elevation is 8,350 feet above sea level, both measured from maps. From plate 1b, average annual precipitation for the basin is determined to be 20 inches. The equation (from table 1) based on drainage area and mean basin elevation for P_{100} in the **Mountainous Regions** is:

$$P_{100} = 9.63 A^{0.77} \left(\frac{\text{ELEV}}{1,000} \right)^{0.85}$$

Substituting A = 126 square miles and ELEV = 8,350 feet,

$$P_{100} = 9.63 (126)^{0.77} \frac{8,350}{1,000}^{0.85}$$
$$= 2,420 \text{ cubic feet per second.}$$

The equation based on contributing drainage area and average precipitation is:

$$P_{100} = 40.7 A^{0.76} PR^{0.13}.$$

Substituting A = 126 square miles and PR = 20 inches per year,

$$P_{100} = 40.7 (126)^{0.76} (20)^{0.13}$$
$$= 2,370 \text{ cubic feet per second.}$$

It is decided to use an average of the two results, determined as:

$$\frac{(2,420 + 2,370)}{2} = 2,400 \text{ cubic feet per second.}$$

Example B. Basin-characteristics method--Plains Region

An estimate is needed of the 50-year peak discharge for a tributary of Shawnee Creek at the site shown in figure 13. The basin is located about 12 miles southeast of Douglas (plate 1d). The drainage area is 2.12 square miles, and the basin slope is determined as follows: Length of 100-foot contour intervals in the basin (fig. 13) is 14.9 miles; therefore, basin slope is:

$$S_B = \frac{14.9 (100)}{2.12} = 703 \text{ feet per mile.}$$

The equation (from table 2) based on drainage area and basin slope is:

$$P_{50} = 112 A^{0.58} A^{-0.05} S_B^{0.23} G_f.$$

From plate 1d, the geographic factor (G_f) is 1.4. Substituting A = 2.12 square miles, S_B = 703 feet per mile, and G_f = 1.4:

$$P_{50} = 112 (2.12)^{0.58} (2.12)^{-0.05} (703)^{0.23} (1.4)$$
$$= 1,080 \text{ cubic feet per second.}$$

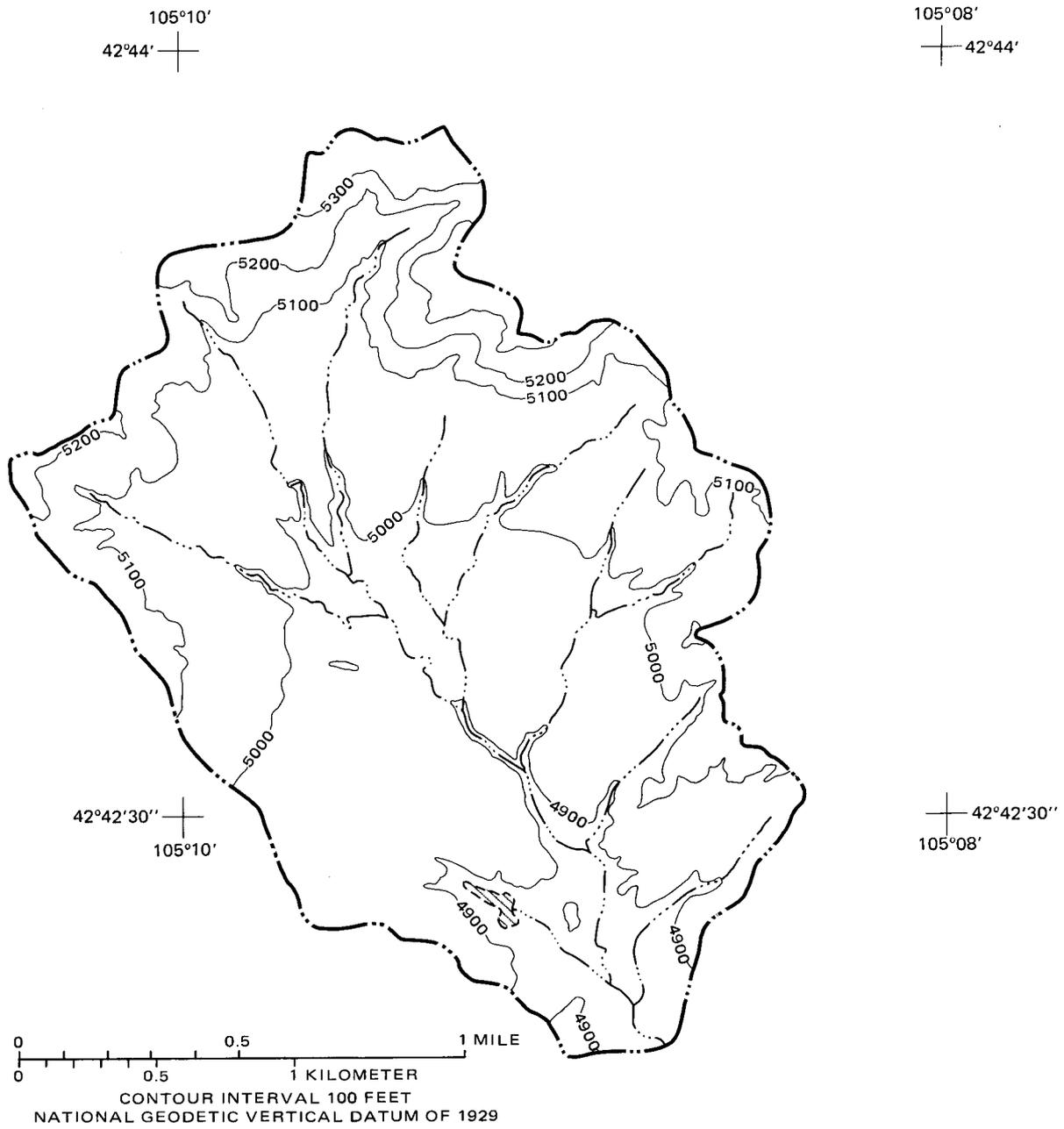


Figure 13.--Drainage basin for tributary of Shawnee Creek near Douglas.

Example C. Comparison of basin-characteristics and channel-geometry methods

A structure is to be built on a tributary to the New Fork River near the site shown in figure 12. The ungaged stream is located in the **High Desert Region** about 16 miles east of Big Piney (plate 1d). The design is to be based on a peak discharge having a 25-year recurrence interval. The channel width is measured at several sections and averages 12 feet. The drainage area measures 10.7 square miles, average annual precipitation as shown by plate 1b averages 9 inches, and the geographic factor as shown by plate 1d is 0.6.

By use of the equations from table 3, the basin-characteristics method indicates:

$$\begin{aligned} P_{25} &= 19.4 A^{0.53} A^{-0.03} P_R^{0.98} G_f \\ &= 19.4 (10.7)^{0.53} (10.7)^{-0.03} (9)^{0.98} (0.6) \\ &= 323 \text{ cubic feet per second.} \end{aligned}$$

The channel-geometry method indicates:

$$\begin{aligned} P_{25} &= 47.3 \text{ WIDTH}^{1.06} G_f \\ &= 47.3 (12)^{1.06} (0.6) \\ &= 395 \text{ cubic feet per second.} \end{aligned}$$

The channel-geometry method yields a slightly greater estimated peak discharge than the basin-characteristics method. It is decided to use an average of the two results, determined as:

$$\frac{(323 + 395)}{2} = 359 \text{ cubic feet per second.}$$

Example D. Drainage is situated in more than one hydrologic region

If parts of one drainage area lie in two separate hydrologic regions, a weighted averaging technique may be used to estimate the flow characteristics. An estimate is made for each region assuming the drainage area is contained entirely within that region. The average is computed by weighting each estimate with the proportion of drainage area contained in the corresponding hydrologic region.

A stream has a drainage area of 54 square miles, of which 40 square miles lie in the **Mountainous Region** and 14 square miles lie in the **Plains Region**. That part of the basin in the **Mountainous Region** has an average

annual precipitation of 20 inches. The proposed structure needs to be able to withstand a 100-year flood. Equations from table 1 are used to estimate the 100-year peak discharge for the **Mountainous Regions**, thus:

$$P_{100} = 40.7 A^{0.76} PR^{0.13}$$

Substituting A = 54 square miles and PR = 20 inches per year,

$$\begin{aligned} P_{100} &= 40.7(54)^{0.76}(20)^{0.13} \\ &= 1,250 \text{ cubic feet per second.} \end{aligned}$$

That part of the drainage basin in the **Plains Region** has a geographic factor of 1.2, and a basin slope of 500 feet per mile. From the **Plains Region** equations of table 2, the 100-year peak discharge is:

$$\begin{aligned} P_{100} &= 130 A^{0.58} A^{-0.05} S_B^{0.25} G_f \\ &= 130 (54)^{0.58} (54)^{-0.05} (500)^{0.25} (1.2) \\ &= 4,910 \text{ cubic feet per second.} \end{aligned}$$

The weighted average of P_{100} is determined as:

$$\begin{aligned} P_{100} &= (1,250)\frac{40}{54} + (4,910)\frac{14}{54} \\ &= 2,200 \text{ cubic feet per second.} \end{aligned}$$

Example E. Mean monthly streamflows

Estimates of mean monthly flows are needed for an ungaged stream in the mountains southwest of Encampment. Runoff from the area is primarily snowmelt, and the runoff pattern of a nearby gaged stream, Encampment River (streamflow-gaging station 06623800), is fairly consistent from year to year. The ungaged stream (drainage area is 40.0 square miles, average annual precipitation is 28 inches) has basin characteristics similar to the upstream drainage of the Encampment River (drainage area is 72.7 square miles, average annual precipitation is 26 inches).

The regime of the ungaged stream is believed to be similar to that of the Encampment River. Mean monthly flows of the Encampment River at station 06623800 are shown in table 6, expressed both as a rate and percentage of the mean annual flow. The mean monthly flows of the ungaged stream are assumed to occur in the same proportions as those of the Encampment River. Mean annual flow can be estimated either by a regression equation or by the monthly measurement method. The monthly measurement method requires 12 months to complete, which is a greater time period than is available for the project design. Therefore, it is decided to use one of the regression equations to estimate mean annual flow.

The equation (from table 1) for estimating mean annual flow in the **Mountainous Regions**, based on drainage area and average annual precipitation is:

$$Q_a = 0.013 A^{0.93} PR^{1.43}$$

where A = 40.0 square miles,
 PR = 28 inches per year, and
 Q_a = 47 cubic feet per second.

The mean monthly flows at the ungaged site are then determined, as shown in table 6, by multiplying the respective percentage for each month by the product of the mean annual flow times 12 months.

Table 6.--Summary of data and results for estimating mean monthly flow

| <u>Encampment River, at station 06623800</u> | | | | | <u>Ungaged site</u> | |
|--|-------------------|-------------------|---|--|--------------------------|-----|
| <u>Mean monthly flow</u> | | | | | <u>Mean monthly flow</u> | |
| | <u>Cubic feet</u> | | | | <u>Cubic feet</u> | |
| | <u>per second</u> | <u>Percentage</u> | | | <u>per second</u> | |
| October | 31 | 2.2 | } x 47 cubic feet per second x 12 months = | | | 12 |
| November | 24 | 1.7 | | | | 9.6 |
| December | 22 | 1.6 | | | | 9.0 |
| January | 19 | 1.4 | | | | 7.9 |
| February | 18 | 1.3 | | | | 7.3 |
| March | 19 | 1.3 | | | | 7.3 |
| April | 34 | 2.5 | | | | 14 |
| May | 256 | 18.1 | | | | 102 |
| June | 653 | 46.3 | | | | 261 |
| July | 249 | 17.6 | | | | 99 |
| August | 51 | 3.6 | | | | 20 |
| September | 34 | 2.4 | | | | 14 |
| Annual | 117 | 100 | | | 47 | |

Example F. An ungaged site on a gaged stream

A structure is being designed for the Bear River at Evanston, and estimates of the 50- and 100-year peak discharges are needed. These flood characteristics at selected streamflow-gaging stations on the Bear River are plotted against drainage area in figure 14. Drainage area upstream from Evanston is computed and entered on the graph to give estimates of the 50- and 100-year peak discharges of 3,700 and 4,000 cubic feet per second, respectively.

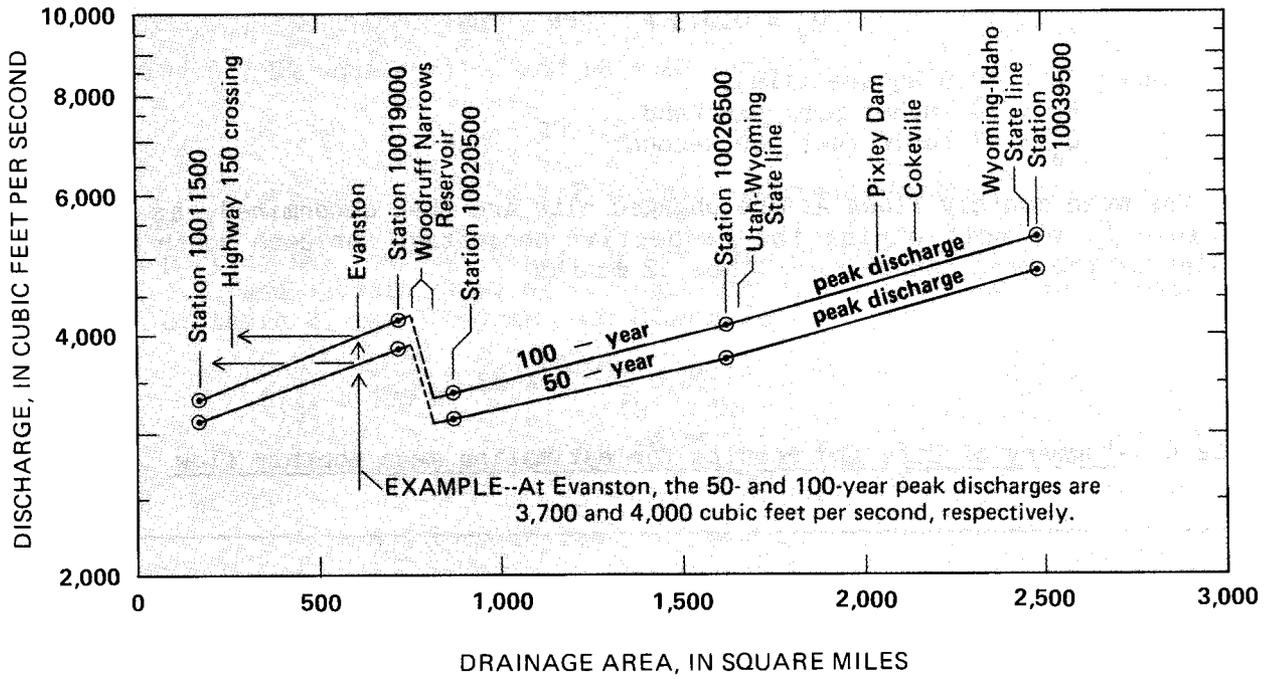


Figure 14.--Relation of peak discharge to drainage area for the Bear River.

HISTORICAL FLOODS IN WYOMING

The flow characteristic most frequently needed for planning and design of stream-related structures is peak discharge. The 100-year flood generally is used for identification of flood-prone areas and in the design of important or expensive structures. The 200- and 500-year floods may be considered in situations where there is potential danger to human life or property. Minor structures, such as culverts on county roads, frequently are designed to pass 10- or 25-year floods.

Lay persons who observe annual snowmelt occurring in the perennial streams of mountainous areas, as compared to the usually dry stream channels of the plains and desert areas, may conclude that mountainous streams have the highest floodflows. Just the opposite is true. For similar-sized drainage areas or channel widths, streams of the Plains and High Desert Regions have much larger floods than streams of the Mountainous Regions. Many of the large floods in plains and desert areas are not observed because they occur in remote areas and at night as a result of late-afternoon or evening convective storms.

Streams in Wyoming may have large floods, even though only minimal or no flows may have been observed for many years. When a large flood does occur, it can cause loss of life and great destruction, as in the case of the August 1, 1985, flood of Dry Creek in Cheyenne (Druse and others, 1986). Twelve deaths, 70 injuries, and \$61.1 million in damage were the result of flooding caused by a massive storm that drenched downtown Cheyenne with as much as 7 inches of rain and hail between approximately 6 p.m. and 10 p.m. (figs. 15 and 16).

To illustrate that large floods have occurred in Wyoming, plots that show the relation between known peak discharge and corresponding drainage area are presented for each of the three hydrologic regions (figs. 17-19). The figures include large floods at miscellaneous sites, as well as the largest peaks of record at streamflow-gaging stations. Also shown on the figures are: (1) The relation of 100-year peak discharge to drainage area, computed using equations from tables 1-3; (2) the enveloping line defined by maximum observed discharges; and (3) the enveloping line for maximum discharges of the Rocky Mountain area (Crippen and Bue, 1977).



Figure 15.--Dry Creek in north Cheyenne the day after the flood of August 1, 1985. View is upstream.

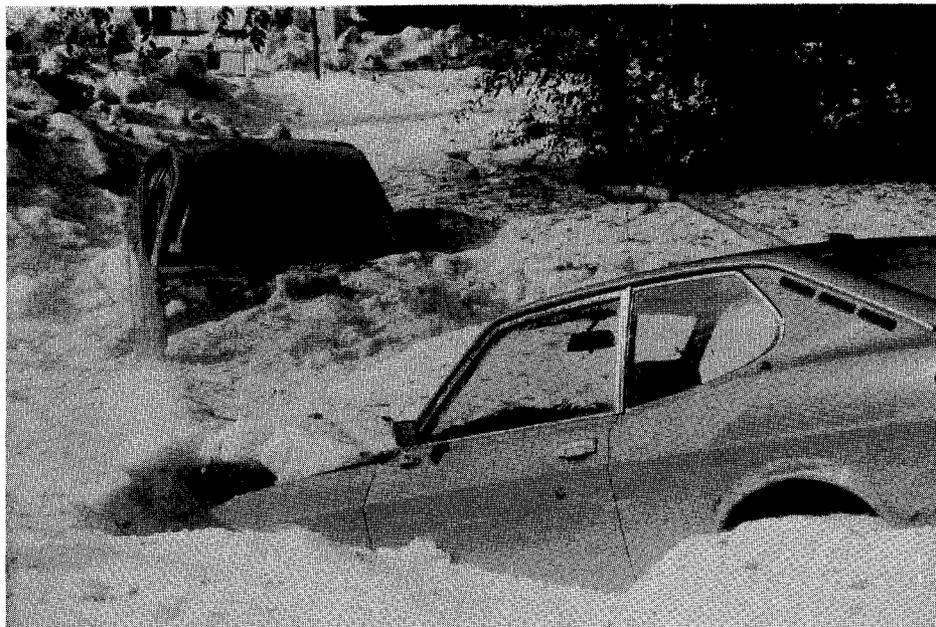


Figure 16.--Hail accumulation in a low area of Cheyenne following the flood of August 1, 1985. Photograph courtesy of Mark Junge.

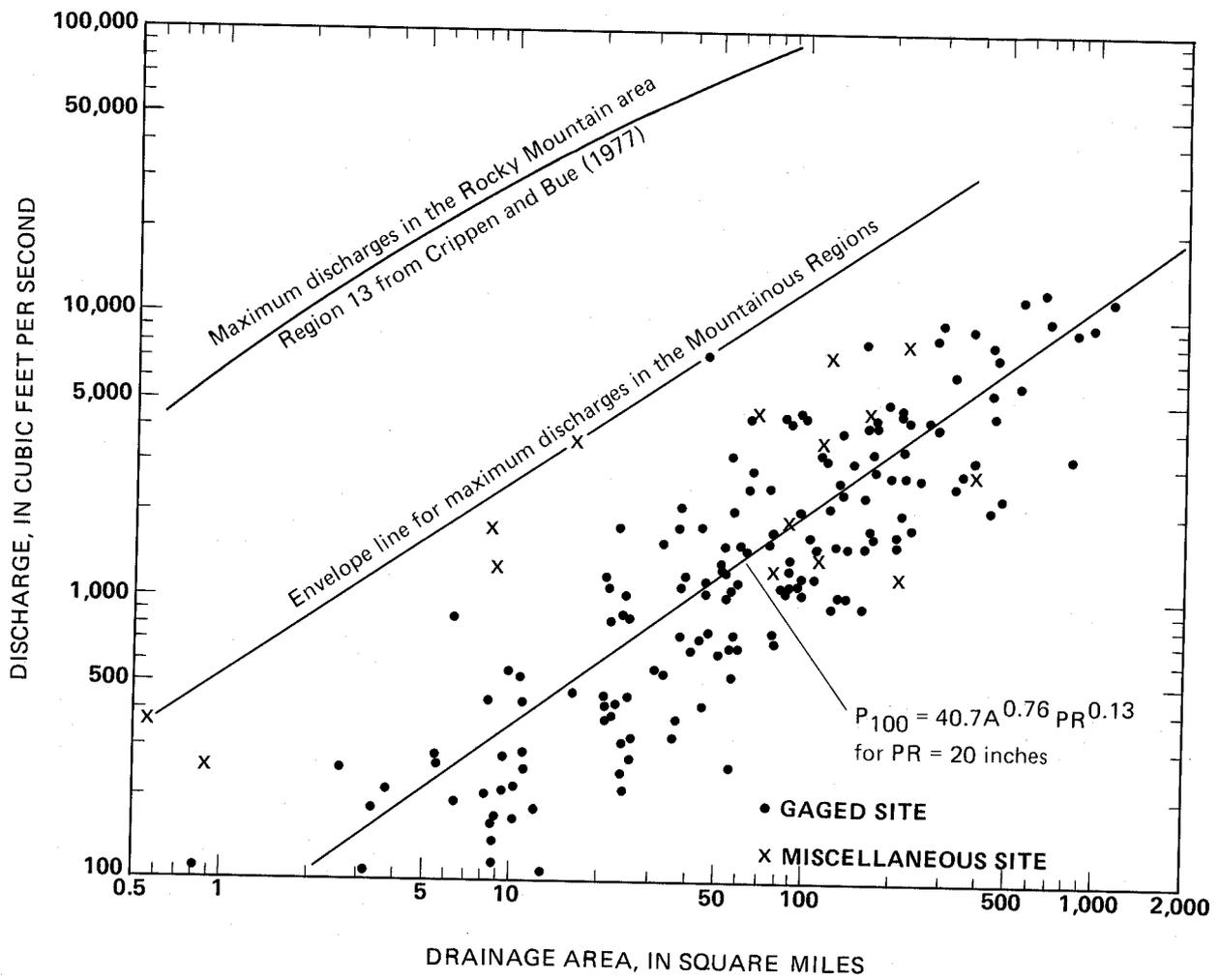


Figure 17.--Relation of maximum known peak discharge to drainage area for the Mountainous Regions.

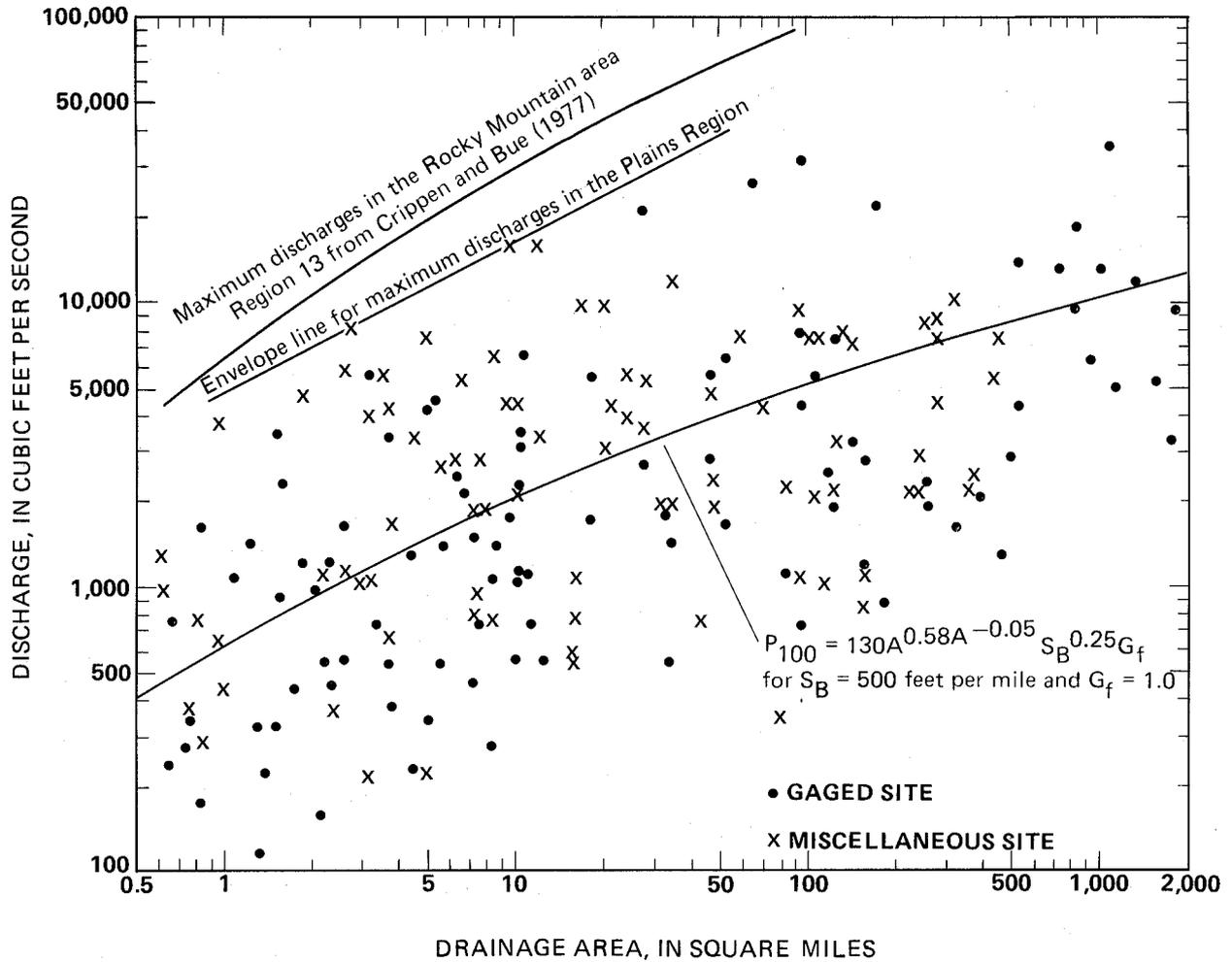


Figure 18.--Relation of maximum known peak discharge to drainage area for the Plains Region.

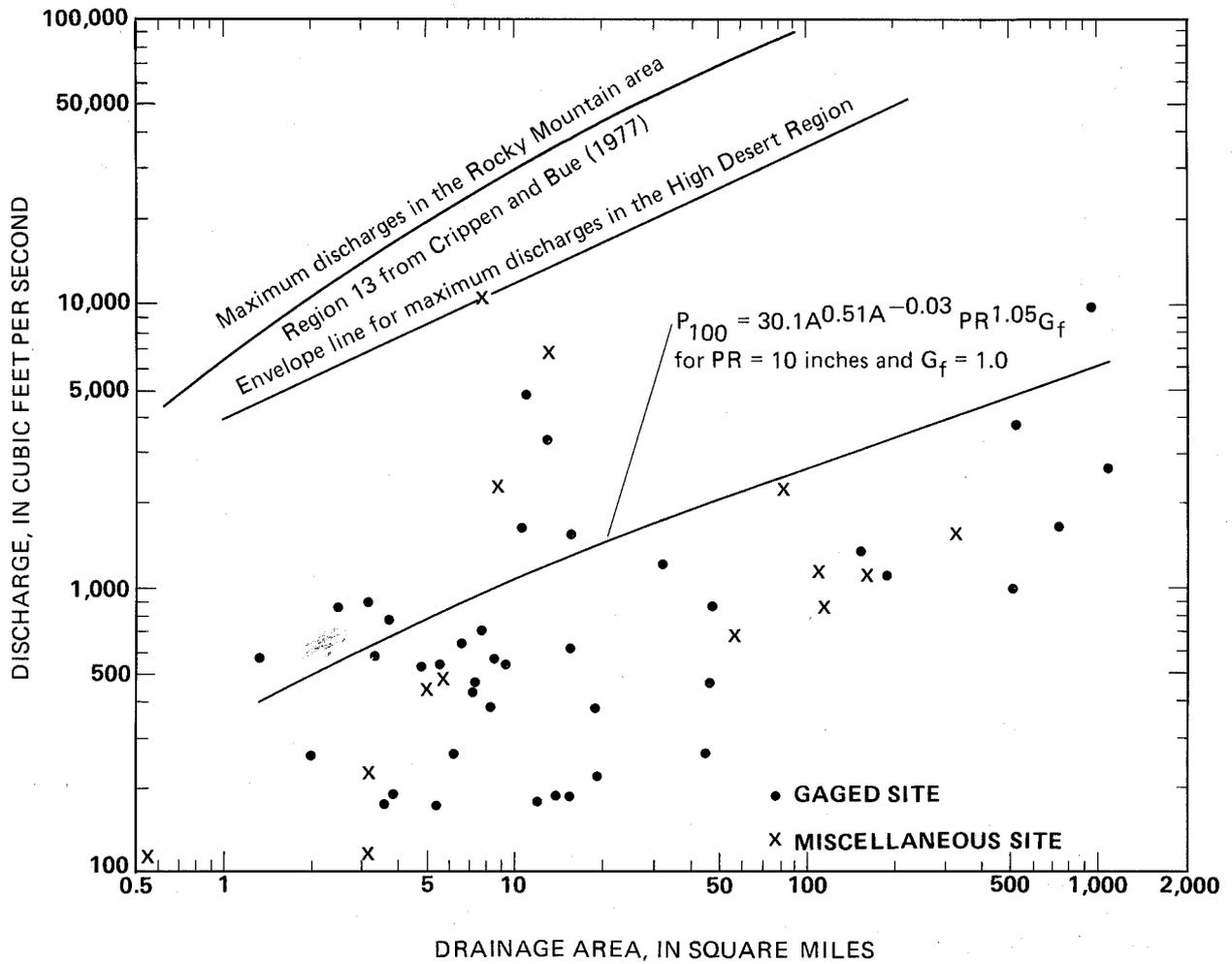


Figure 19.--Relation of maximum known peak discharge to drainage area for the High Desert Region.

SUMMARY

Streams were important in the early development of Wyoming, which included trapping, gold mining, agriculture, and logging. They continue to be a vital natural resource for the above uses and for tourism and the energy-mineral industry. Streams have various characteristics throughout the State due to large differences in climate, geology, and topography. Perennial streams with source drainage areas in the mountains provide the most runoff in Wyoming. However, for similarly-sized drainage areas or channel widths, streams draining the plains and deserts produce much larger peak flows than streams draining the mountains.

Streamflow characteristics are available for several hundred sites in Wyoming where streamflow gages have been operated. Time and cost constraints prevent the installation and operation of gages at every site where data may be needed. Methods of estimating streamflow characteristics at ungaged sites have been developed by using data at gaged sites.

Peak-flow characteristics at streamflow-gaging stations were determined by fitting the data to the Pearson Type III probability distribution using refined procedures recommended by the U.S. Water Resources Council. The procedures include use of (1) a generalized skew coefficient, which improves the accuracy of peak-flow characteristics for gages with short records, and (2) use of an historical adjustment, which allows data from outside the gaged period of record to be used in defining the peak-flow characteristics. The refinements have improved peak-flow determinations, especially for gaging stations in the plains and desert areas where streams are subject to high annual variability.

A large data base is available for defining mean annual runoff of perennial streams draining mountainous areas of the State; however, a shortage of these data exists for small streams in the plains and desert areas. To help overcome this deficiency, the records of 21 seasonal gages, which were operated on small streams in the plains and desert areas during the principal rainfall months of May through September of 1963-73, were used. These partial-year data were adjusted to provide an estimated mean annual flow for each of the sites on the basis of a comparison with year-round records for similar streams. Peak-flow characteristics of these 21 seasonal gages also were used.

Regression equations are presented in this report for estimating peak-flow characteristics and mean annual flows of ungaged Wyoming streams. The equations were developed through an analysis of data for gaged basins that were considered to be representative of natural conditions. Records for 361 streamflow-gaging stations were used in the final analysis.

The regression analysis used equations that express flow characteristics in relation to either basin characteristics or channel-geometry features. The basin characteristics tested in the regression analysis included 10 physical and three climatic variables. Only contributing drainage area, mean basin elevation, average annual precipitation, and basin slope were determined to be significant to various regression relations defining the flow characteristics. The channel-geometry features tested included the width, depth, and width-to-

depth ratio of the stream channel, and measurements of the sediment composition of the streambed and banks. Only channel width was found to be significant for estimating the flow characteristics. The basin characteristics may be measured or determined from maps; whereas, the channel width must be measured on-site.

Due to diverse climatic and physical conditions that cannot be wholly defined by numeric variables, it was necessary to develop separate sets of estimation equations for three regions of different hydrologic settings. The three regions are: (1) The **Mountainous Regions**, which include the major mountainous areas of the State where snowmelt has a dominant influence on streamflows, (2) the **Plains Region**, which includes the northern and eastern plains and deserts where runoff from convective storms has a significant influence on peak flows, and (3) the **High Desert Region**, which includes the south-central and southwestern plains and desert areas where widespread general rainstorms and snow have a major effect on peak flows.

For the **Mountainous Regions**, the regression model uses equations of exponential form, which plot as straight lines on logarithmic graph paper. However, for the **Plains and High Desert Regions**, a curvilinear model was determined to be more applicable for estimating peak flows using basin characteristics. The curvilinear model uses equations of double-exponential form, which plot as curved lines on logarithmic graph paper. The curvilinear model has the advantage of converging toward zero runoff for zero drainage area while still fitting the data points for the complete range of drainage sizes for the gaged streams. The need for a curvilinear model is the result of a decrease in precipitation intensity and an associated decrease in unit runoff as drainage area increases. The intensity decreases with basin size as the most dominant type of storm-runoff event changes from convective storms to general rainstorms and snowmelt.

Regression analysis also was investigated as a method for estimating monthly flows; however, it was determined that local differences in runoff characteristics complicated the results. Estimates of monthly streamflows can be more accurately made by correlating with data for nearby gaged streams.

Examples are provided to familiarize users with application of the estimation methods. In addition, a summary of historical floods that have occurred both at streamflow-gaging stations and at miscellaneous sites is presented.

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