ESTIMATION OF NATURAL STREAMFLOW CHARACTERISTICS IN WESTERN COLORADO

By James E. Kircher, Anne F. Choquette, and Brian D. Richter

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4086

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

Lakewood, Colorado
1985

UNITED STATES DEPARTMENT OF THE INTERIOR

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GLOSSARY

Water-resource terms are defined in the GLOSSARY and are italicized when first used in this report.

basin characteristics.--Physical and climatic conditions of a basin that are used in the regression models to predict streamflow. Basin characteristics defined in the final regression models include:

drainage area, in square miles, computed by planimeter from the best available U.S. Geological Survey topographic maps.

mean basin slope, in feet per feet, based on the average of 25 or more slope values taken at equal-spaced grid points on 1:50,000-scale U.S. Geological Survey topographic maps (Lystrom and others, 1978).

mean basin elevation, in feet above the National Geodetic Vertical Datum of 1929, determined from 25 or more equal-spaced grid points from 1:50,000-scale U.S. Geological Survey topographic maps.

mean annual precipitation, in inches to the nearest 0.1 inch, the average of 25 or more mean annual precipitation values at equal-spaced grid points on an isohyetal map (Colorado Climate Center, 1984).

flood-frequency relation.--A graph showing the probability that the annual peak discharge for a given year will exceed the indicated amount.

flow-duration series.--Daily flows that are, on the average, equaled or exceeded 10, 25, 50, 70, or 90 percent of the time. Flow values were interpolated from duration curves (U.S. Geological Survey, 1979) of daily flows during the period of gaged record.

gaging station.--A particular site on a stream or other body of water where systematic observations of gage height, discharge, or water quality constituents (or any combination of these) are obtained.

log-Pearson Type III frequency distribution.--A statistical distribution used in flood-frequency analysis, which is described by three parameters: mean, standard deviation, and coefficient of skewness of the logarithms of the sample observations (see U.S. Water Resources Council, 1981).

mean annual discharge.--The mean of a series of annual water discharges, in cubic feet per second.

mean monthly discharge.--The mean of a series of monthly mean discharges for each calendar month.

mean standard error.--The mean of positive and negative departures of observed values from values predicted by the regression relation; a measure of how well observed data agree with the regression estimates.

minimum 7-day discharge.--The minimum mean discharge occurring over a period of seven consecutive days, with average recurrence intervals of 2, 10, and 50 years. Also referred to as low flows throughout this report.

maximum 7-day discharge.--The maximum mean discharge occurring over a period of 7 consecutive days, with average recurrence intervals of 2, 10, 50, and 100 years. Also referred to as high flows throughout this report.

multiple-regression relations.--A statistical technique by which a relation between a dependent variable and two or more independent variables can be derived. The result usually is expressed as a regression equation.

natural flow.--Stream discharge that is not significantly affected by human land use or water use, such as flow diversion, regulation, or vegetative alteration.

normalize.--To transform a variable so that the probability distribution of the transformed variable approximates a normal distribution.

orographic effect.--The lifting of moisture-laden air over a high barrier such as a mountain range resulting in a consequent release of precipitation.

parameter.--A descriptive measure of a population, such as a mean, a measure of variability, or a regression coefficient.

peak discharge.--Instantaneous maximum discharges that were exceeded on the average of once every 2, 5, 10, 25, 50, 100, 200, and 500 years.

recurrence interval.--The mean interval of time, in years, within which a given flood discharge will be exceeded once.

regression.--A statistical technique applied to paired data to determine the degree of mutual association between a dependent variable and one or more independent variables.

residual.--The discrepancy between measured streamflow and the regression estimate of flow at that site.

METRIC CONVERSION FACTORS

Inch-pound units used in this report may be converted to International System of Units (SI) by using the following conversion factors:

To convert inch-pound unit	*Multiply by*	*To obtain metric unit*
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

Regression relations were determined for estimating mean annual discharge, mean monthly discharge, flow-duration series, peak discharge, and minimum and maximum 7-day discharges for natural-flow streams in western Colorado. The techniques can be applied to both gaged and ungaged streams. Multiple regression analyses were used to determine the best regression relations for each of the streamflow characteristics. Separate regression relations were developed for each of four hydrologically distinctive regions in the study area. The mean standard errors associated with the regression relations generally were less than 100 percent except for the low-flow relations which had standard errors ranging from 62 to greater than 200 percent. Basin drainage area, mean annual precipitation, mean basin elevation, and mean basin slope are used in the regression relations to determine flow characteristics of streams in the study area.

INTRODUCTION

Description of Study Area

The study area, located in western Colorado (pl. 1), extends westward from the Front Range in the northeast and the Sangre de Cristo Mountains in the southeast to the Colorado-Utah state line. The eastern border of the study area follows the 7,500-ft elevation contour in the Platte River basin and the 9,500-ft contour in the Arkansas River basin and coincides approximately with the boundary between the Southern Rockies and the Great Plains physiographic provinces (Fenneman, 1931).

In the eastern part of the study area, the major landforms are the Rocky Mountains which range in elevation from about 7,500 to more than 14,000 ft. The western part of the study area consists predominantly of broad plateaus and mesas; elevations range from about 5,000 to 7,500 ft except for Grande Mesa, 11,000 ft, the Uncompahgre Plateau, 10,000 ft, and the Roan Plateau, 8,500 ft. Annual precipitation ranges from less than 7 in. at lower elevations to more than 60 in. in the high mountains (Colorado Climate Center, 1984).

Mountains in the eastern part of the study area are underlain primarily by Precambrian igneous and metamorphic rocks and Paleozoic sediments. The San Juan Mountains, in the south-central part of the region, consist predominantly of Tertiary volcanics. Rock types in the western part of the study area consist predominantly of sandstones, siltstones, shales, and conglomerates of Cretaceous and Tertiary age.

The North Platte, South Platte, Arkansas, and Rio Grande Rivers drain the eastern part of the study area. All rivers in the western part drain into the Colorado River and include: (1) The Yampa and White Rivers in the northwest, (2) the main stem of the Colorado River and the Gunnison River in the west-central, and (3) the Dolores, Animas, and San Juan Rivers in the southwest.

Previous Studies

Several previous reports have presented methods for estimating flow characteristics of natural basins in the study area. A series of reports in the mid- to late-1960's defined *flood-frequency relations* for the South Platte (Matthai, 1968), Arkansas (Patterson, 1964), Rio Grande (Patterson, 1965), and Colorado (Patterson and Somers, 1966) River basins. McCain and Jarrett (1976) used improved techniques for estimating flood frequency and additional streamflow records to estimate flood characteristics for streams in Colorado. Livingston (1970) developed relations for a range of flow characteristics, similar to those included in this study, for the mountains of Colorado. For the mountain region of Colorado, Hedman and others (1972) improved the accuracy of some of Livingston's (1970) models by relating measurements of channel geometry to mean annual and peak flows.

This study differs from these previous studies in areal coverage, range of flow characteristics being estimated, number of *gaging stations,* lengths of gaged-runoff records, and methods used to define the *regression relations*. The reports by Patterson (1964, 1965), Patterson and Somers (1966), and Matthai (1968) are based on regional flood-frequency analyses derived using the index-flood method (Dalrymple, 1960). Subsequent reports are based on flow characteristics derived from a *log-Pearson Type III frequency distribution.* Compared to most of the previous studies, this study is based on up to 13 additional years of gaged-flow measurements, a recently revised areal-precipitation map (Colorado Climate Center, 1984), and improved statistical techniques for model selection.

Purpose and Scope

This study provides methods for estimating flow characteristics of natural-flow streams in western Colorado. Equations were developed for a total of 33 flow characteristics, which include *mean annual and mean monthly discharge*, *flow-duration series*, *peak discharge*, and *minimum* and *maximum 7-day discharges* of *recurrence intervals* ranging from 2 to 100 years. The procedures for estimating flow differ depending on whether the estimate is for a gaged or ungaged site, and whether the *drainage area* above the site crosses hydrologic region boundaries or state lines.

The study was conducted in cooperation with the U.S. Bureau of Land Management to provide a methodology to assess streamflow characteristics for land use, planning, impact assessment, and identifying potential project locations.

The regression relations were developed using multiple regression analyses and are based on 10 or more years of streamflow records for 264 stations located in and adjacent to the study area (pl. 1). The study area was divided into four hydrologic or streamflow-characteristic regions to remove geographic bias resulting from differences in basin physiography and climate. Separate regression relations were developed for each of these four regions.

DEVELOPMENT OF ESTIMATING RELATIONS

Analytical Technique

The regional regression relations discussed in this report are regression equations that relate streamflow characteristics to easily measured drainage basin and climatic measurements. The streamflow characteristic being estimated, the dependent variable, is determined from a selected set of *basin characteristics,* the independent variables. The expected accuracy of the regression estimates is indicated by the difference between the estimates and the gaged streamflow data.

Dividing an area into smaller subregions may reduce the variability of streamflow from site to site and result in more accurate streamflow estimates from regression equations. Regional analysis is based on the spatial variation of streamflow due to regional differences in the physical characteristics that directly or indirectly affect streamflow. Accuracy of the resulting streamflow regression relations for each hydrologic region is limited by: (1) The accuracy with which basin and climatic characteristics can be measured; (2) the difficulty in describing and measuring more variable or complex factors, such as vegetation water use, soil depth, and soil permeability that affect streamflow; and (3) the adequacy of the selected regression models to describe the hydrologic system.

Logarithmic transformations were performed on all streamflow and basin characteristics prior to the regression analyses. These data were transformed in order to: (1) *Normalize* the variables and *residuals*; (2) obtain a constant variance of the residuals about the regression line; and (3) obtain linear relations between dependent and independent variables. All of these specifications are needed to meet the statistical assumptions of regression analyses and to derive unbiased regression estimates.

The *multiple-regression relations* based on logarithmic transformations of variables are of the form:

$$\log Y = \log B_0 + B_1 \log X_1 + B_2 \log X_2 + \ldots + B_n \log X_n$$

or, taking antilogs,

$$Y = B_o X_1^{B_1} X_2^{B_2} \ldots X_n^{B_n}$$

where Y = streamflow characteristic (dependent variable),
B_0, B_1, B_2, B_n = regression coefficients,
X = basin or climatic characteristic (independent variable) upstream from the site for which the estimate is being made, and
n = number of basin and climatic characteristics in the model.

The regression coefficients are determined by regression analyses of information collected at gaged sites.

Data Used

Streamflow Records

Data from continuous-record gaging stations (pl. 1) were used to develop the regional streamflow regression relations. The continuous-record stations are operated by the U.S. Geological Survey in cooperation with other Federal and state agencies. The records used in this study included data collected through September 1981. Of the 810 past or present gaging stations located in the study area (see Richter and others, 1984), 264 stations were selected; these stations had 10 or more years of gaged record and were located in basins that were largely unaffected by urbanization or man-made structures, such as reservoirs or diversions. Stations were omitted if more than 10 percent of the basin's area was irrigated by upstream diversions or the amount of water in reservoir storage exceeded more than 10 percent of the volume of *mean annual discharge*. Plots of drainage areas versus lengths of record for the stations used in this study are shown in figure 1.

The streamflow characteristics determined are mean annual discharge, mean monthly discharge, flow-duration series, minimum 7-day discharge, maximum 7-day discharge, and peak discharge. The streamflow characteristics, which include those commonly needed for planning and design, were determined from the gaging-station records. The flow values are calculated *parameters* obtained from the U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) (see Hutchinson, 1975). All of the flow measurements are in cubic feet per second. Determination of annual discharge values was based on the October through September water year. Flow frequencies were estimated using the log-Pearson Type III frequency distribution (U.S. Water Resources Council, 1981).

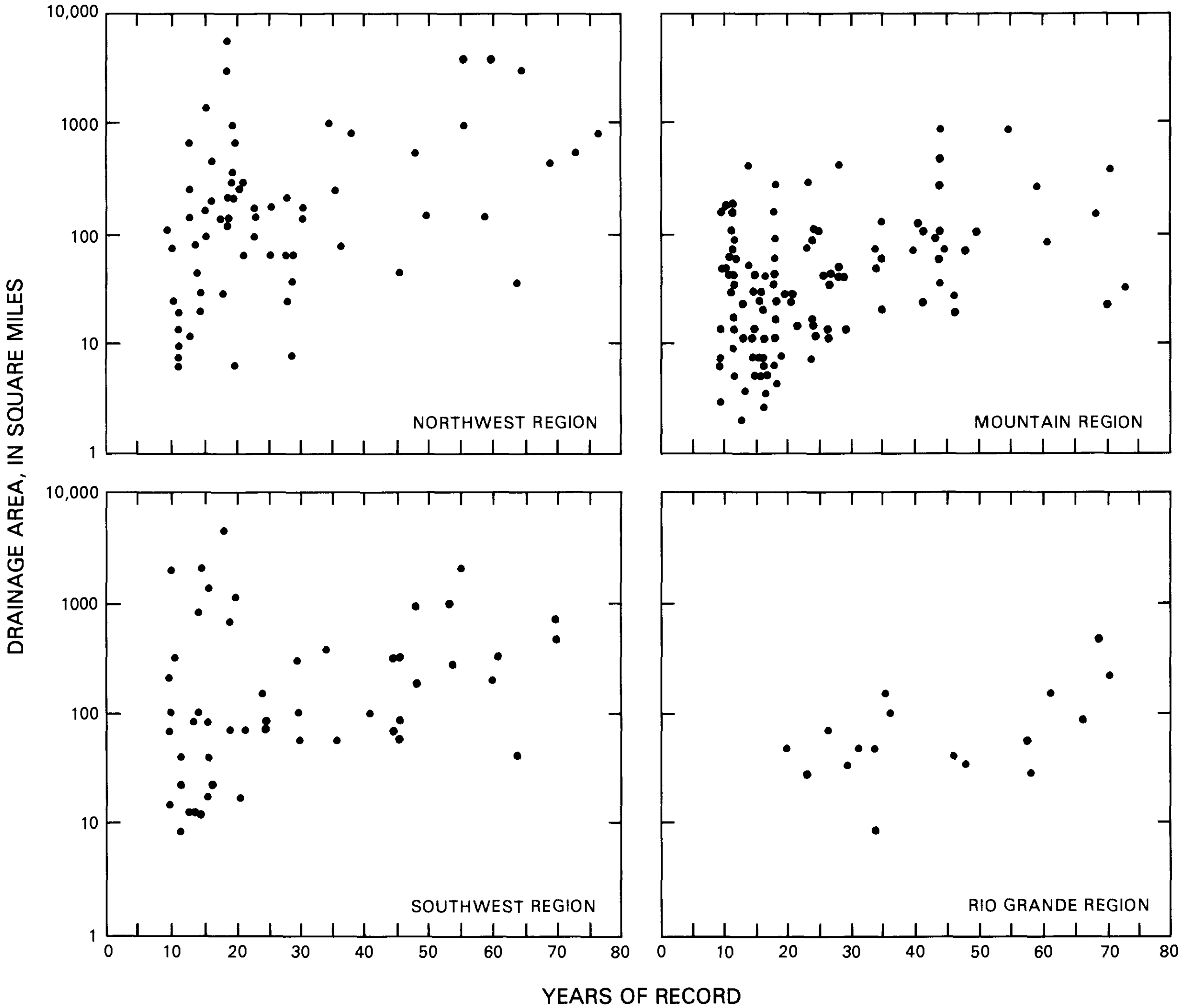

Figure 1.--Basin drainage area and length of record for the gaging stations used in the regression analyses.

Values for each of the streamflow characteristics in the study basins (tables 1-4) are included in a comprehensive summary of data for all gaged basins in Colorado (Richter and others, 1984).

Basin and Climatic Characteristics

Based on the results of previous streamflow regionalization studies (for example Thomas and Benson, 1970; McCain and Jarrett, 1976) and consideration of physical characteristics that affect streamflow, a set of basin and climatic characteristics was tested initially in the regression analyses. The set of predictor characteristics that were initially tested in the regression analysis included the following physiographic, climatic, vegetation, and land use variables.

Physiographic characteristics:

1. Drainage area;
2. basin length;
3. mean basin aspect;
4. mean basin width;
5. *mean basin slope*;
6. channel length;
7. mean channel elevation;
8. mean channel slope;
9. mean channel aspect;
10. area covered by lakes and ponds; and
11. gaging-station elevation.

Climatic characteristics:

1. *Mean annual precipitation*;
2. maximum 24-hour precipitation intensity having a 2-year recurrence interval; and
3. mean annual January temperature.

Vegetation and land use characteristics:

1. Percentage of basin area covered by forest;
2. percentage of basin area used for agriculture;
3. percentage of basin area used for rangeland;
4. percentage of basin area classified as urban; and
5. percentage of basin area irrigated.

Richter and others (1984) define these characteristics in greater detail and summarize these basin characteristics for the study basins in this report.

Hydrologic Regions

Hydrologic regions were selected on the basis of an iterative procedure that delineated regional similarities in the relation between streamflow and basin characteristics. Initially, regression relations were developed for

Table 1.--*Gaging-station records used to determine regression relations for the mountain region*
[X, gaging station was used in the analysis]

Station number	Station name	Mean annual discharge	Mean monthly discharge	Flow-duration series	Minimum 7-day discharge	Maximum 7-day discharge	Peak discharge
06615500	Michigan River near Lindland, Colo.	X	X	X	X	X	X
06619500	Canadian River at Cowdrey, Colo.	X	X	X	X	X	X
06623800	Encampment River above Hog Park Creek near Encampment, Wyo.	X	X	X	X	X	X
06698500	Tarryall Creek near Jefferson, Colo.	X	X	X	X	X	X
06706000	North Fork South Platte River below Geneva Creek at Grant, Colo.	X	X	X	X	X	X
06716500	Clear Creek near Lawson, Colo.	X	X	X	X	X	X
06722500	South St. Vrain Creek near Ward, Colo.	X	X	X	X	X	X
06725500	Middle Boulder Creek at Nederland, Colo.	X	X	X	X	X	X
06726000	North Boulder Creek at Silver Lake, Colo.	X	X	X	X	X	
06729000	South Boulder Creek near Rollinsville, Colo.	X	X	X	X	X	
06732000	Glacier Creek near Estes Park, Colo.	X	X	X	X	X	X
06748200	Fall Creek near Rustic, Colo.	X	X	X	X	X	X
06748510	Little Beaver Creek near Idylwilde, Colo.	X	X	X	X	X	X
06748530	Little Beaver Creek near Rustic, Colo.	X	X	X	X	X	X
06748600	South Fork Cache la Poudre River near Rustic, Colo.	X	X	X	X	X	X
07079500	East Fork Arkansas River near Leadville, Colo.	X	X	X	X	X	X
07081000	Tennessee Creek near Leadville, Colo.	X	X	X	X	X	X
07082000	Lake Fork above Sugar Loaf Reservoir, Colo.	X	X	X	X	X	
07083000	Halfmoon Creek near Malta, Colo.	X	X	X	X	X	X
07086500	Clear Creek above Clear Creek Reservoir, Colo.	X	X	X	X	X	X
07089000	Cottonwood Creek below Hot Springs, near Buena Vista, Colo.	X	X	X	X	X	X
07093500	South Arkansas River near Salida, Colo.	X	X	X	X	X	X
09010500	Colorado River below Baker Gulch, near Grand Lake, Colo.	X	X	X	X	X	X
09010501	Colorado River below Baker Gulch plus Grand River Ditch, Colo.	X	X	X	X	X	
09011000	Colorado River near Grand Lake, Colo.	X	X	X	X	X	X
09016500	Arapaho Creek at Monarch Lake Outlet, Colo.	X	X	X		X	X
09020000	Willow Creek near Granby, Colo.	X	X	X	X	X	X
09024000	Fraser River near Winter Park, Colo.	X	X	X	X	X	X
09026500	St. Louis Creek near Fraser, Colo.	X	X	X	X	X	X
09032000	Ranch Creek near Fraser, Colo.	X	X	X	X	X	X
09032500	Ranch Creek near Tabernash, Colo.	X	X	X	X	X	X
09033000	Meadow Creek near Tabernash, Colo.	X	X	X	X	X	X
09034000	Fraser River at Granby, Colo.	X	X	X	X	X	
09034900	Bobtail Creek near Jones Pass, Colo.	X	X	X	X	X	X
09035500	Williams Fork below Steelman Creek, Colo.	X	X	X	X	X	X
09035700	Williams Fork above Darling Creek, near Leal, Colo.	X	X	X	X	X	
09035800	Darling Creek near Leal, Colo.	X	X	X	X	X	X
09035900	South Fork of Williams Fork near Leal, Colo.	X	X	X	X	X	X
09036000	Williams Fork near Leal, Colo.	X	X	X	X	X	X
09036500	Keyser Creek near Leal, Colo.	X	X	X	X	X	X

Table 1.--*Gaging-station records used to determine regression relations for the mountain region*--Continued

Station number	Station name	Mean annual dis-charge	Mean monthly dis-charge	Flow-duration series	Mini-mum 7-day dis-charge	Maxi-mum 7-day dis-charge	Peak dis-charge
09037500	Williams Fork near Parshall, Colo.	X	X	X	X	X	X
09039000	Troublesome Creek near Pearmont, Colo.	X	X	X	X	X	X
09040000	East Fork Troublesome Creek near Troublesome, Colo.	X	X	X	X	X	X
09041100	Antelope Creek near Kremmling, Colo.	X	X	X	X	X	X
09046600	Blue River near Dillon, Colo.	X	X	X	X	X	
09047000	Blue River at Dillon, Colo.	X	X	X	X	X	X
09047500	Snake River near Montezuma, Colo.	X	X	X	X	X	X
09047700	Keystone Gulch near Dillon, Colo.	X	X	X	X	X	X
09048000	Snake River at Dillon, Colo.	X	X	X	X	X	X
09050100	Tenmile Creek below North Tenmile Creek at Frisco, Colo.	X	X	X	X	X	X
09050500	Tenmile Creek at Dillon, Colo.	X	X	X	X	X	X
09052000	Rock Creek near Dillon, Colo.	X	X	X	X	X	X
09052400	Boulder Creek at Upper Station, near Dillon, Colo.	X	X	X	X	X	X
09052800	Slate Creek at Upper Station, near Dillon, Colo.	X	X	X	X	X	X
09053000	Slate Creek (Upper Station) near Dillon, Colo.	X	X	X	X	X	X
09053500	Blue River above Green Mountain Reservoir, Colo.	X	X	X	X	X	X
09054000	Black Creek below Black Lake near Dillon, Colo.	X	X	X	X	X	X
09055300	Cataract Creek near Kremmling, Colo.	X	X	X	X	X	X
09057500	Blue River below Green Mountain Reservoir, Colo.	X	X	X	X	X	
09058500	Piney River below Piney Lake, near Minturn, Colo.	X	X	X	X	X	X
09058610	Dickson Creek near Vail, Colo.	X	X	X	X	X	X
09058700	Freeman Creek near Minturn, Colo.	X	X	X	X	X	X
09058800	East Meadow Creek near Minturn, Colo.	X	X	X	X	X	X
09060500	Rock Creek near Toponas, Colo.	X	X	X	X	X	X
09063200	Wearyman Creek near Red Cliff, Colo.	X	X	X	X	X	X
09063400	Turkey Creek near Red Cliff, Colo.	X	X	X	X	X	X
09063500	Turkey Creek at Red Cliff, Colo.	X	X	X	X	X	X
09065100	Cross Creek near Minturn, Colo.	X	X	X	X	X	X
09065500	Gore Creek at Upper Station near Minturn, Colo.	X	X	X	X	X	X
09066000	Black Gore Creek near Minturn, Colo.	X	X	X	X	X	X
09066100	Bighorn Creek near Minturn, Colo.	X	X	X	X	X	X
09066150	Pitkin Creek near Minturn, Colo.	X	X	X	X	X	
09066200	Booth Creek near Minturn, Colo.	X	X	X	X	X	X
09066300	Middle Creek near Minturn, Colo.	X	X	X	X	X	X
09066400	Red Sandstone Creek near Minturn, Colo.	X	X	X	X	X	X
09066500	Gore Creek near Minturn, Colo.	X	X	X	X	X	X
09069500	Gypsum Creek near Gypsum, Colo.	X	X	X	X	X	X
09073500	Roaring Fork River at Aspen, Colo.	X	X	X	X	X	X
09073700	Hunter Creek above Midway Creek, near Aspen, Colo.	X	X	X	X	X	X
09073800	Midway Creek near Aspen, Colo.	X	X	X	X	X	X

Table 1.--*Gaging-station records used to determine regression relations for the mountain region*--Continued

Station number	Station name	Mean annual discharge	Mean monthly discharge	Flow-duration series	Minimum 7-day discharge	Maximum 7-day discharge	Peak discharge
09073900	No Name Creek near Aspen, Colo.	X	X	X	X	X	X
09074000	Hunter Creek near Aspen, Colo.	X	X	X	X	X	X
09074800	Castle Creek above Aspen, Colo.	X	X	X	X	X	X
09075700	Maroon Creek above Aspen, Colo.	X	X	X	X	X	X
09077200	Fryingpan River near Ivanhoe Lake, Colo.	X	X	X	X	X	
09077800	South Fork Fryingpan River at Upper Station near Norrie, Colo.	X	X	X	X	X	
09078000	Fryingpan River at Norrie, Colo.	X	X	X	X	X	X
09078100	North Fork Fryingpan River above Cunningham Creek near Norrie, Colo.	X	X	X	X	X	X
09078200	Cunningham Creek near Norrie, Colo.	X	X	X	X	X	X
09078500	North Fork Fryingpan River near Norrie, Colo.	X	X	X	X	X	X
09080100	Fryingpan River at Meredith, Colo.	X	X	X	X	X	X
09082800	North Thompson Creek near Carbondale, Colo.	X	X	X	X	X	X
09084000	Cattle Creek near Carbondale, Colo.	X	X	X	X	X	X
09089000	West Divide Creek below Willow Creek, near Raven, Colo.	X	X	X	X	X	X
09096000	Plateau Creek at Upper Station near Collbran, Colo.	X	X	X	X	X	X
09096800	Buzzard Creek below Owens Creek, near Heiberger, Colo.	X	X	X	X	X	X
09097600	Brush Creek near Collbran, Colo.	X	X	X	X	X	X
09110000	Taylor River at Almont, Colo.	X	X	X	X	X	X
09110500	East River near Crested Butte, Colo.	X	X	X	X	X	X
09111500	Slate River near Crested Butte, Colo.	X	X	X	X	X	X
09112000	Cement Creek near Crested Butte, Colo.	X	X	X	X	X	X
09112200	East River below Cement Creek near Crested Butte, Colo.	X	X	X	X	X	X
09112500	East River at Almont, Colo.	X	X	X	X	X	X
09113300	Ohio Creek at Baldwin, Colo.	X	X	X	X	X	X
09113500	Ohio Creek near Baldwin, Colo.	X	X	X	X	X	X
09114500	Gunnison River near Gunnison, Colo.	X	X	X	X	X	X
09115500	Tomichi Creek at Sargents, Colo.	X	X	X	X	X	X
09117000	Tomichi Creek at Parlin, Colo.	X	X	X	X	X	X
09118000	Quartz Creek near Ohio City, Colo.	X	X	X	X	X	X
09119000	Tomichi Creek at Gunnison, Colo.	X	X	X	X	X	X
09122000	Cebolla Creek at Powderhorn, Colo.	X	X	X	X	X	X
09122500	Soap Creek near Sapinero, Colo.	X	X	X	X	X	X
09123500	Lake Fork at Lake City, Colo.	X	X	X	X	X	X
09124500	Lake Fork at Gateview, Colo.	X	X	X	X	X	X
09125000	Curecanti Creek near Sapinero, Colo.	X	X	X	X	X	X
09127500	Crystal Creek near Maher, Colo.	X	X	X	X	X	X
09130600	West Muddy Creek near Ragged Mountain, Colo.	X	X	X	X	X	X
09132900	West Hubbard Creek near Paonia, Colo.	X	X	X	X	X	X
09139200	Ward Creek near Grand Mesa, Colo.	X	X	X	X	X	X
09140200	Kiser Creek near Grand Mesa, Colo.	X	X	X	X	X	X
09143000	Surface Creek near Cedaredge, Colo.	X	X	X	X	X	X
09147100	Cow Creek near Ridgway, Colo.	X	X	X	X	X	X
09244500	Elkhead Creek near Clark, Colo.	X	X	X	X	X	X
09302450	Lost Creek near Buford, Colo.	X	X	X	X	X	X

Table 2.--*Gaging-station records used to determine regression relations for the Rio Grande region*
[X, gaging station was used in the analysis]

Station number	Station name	Mean annual discharge	Mean monthly discharge	Flow-duration series	Minimum 7-day discharge	Maximum 7-day discharge	Peak discharge
08216500	Willow Creek at Creede, Colo.	X	X	X	X	X	X
08218500	Goose Creek at Wagonwheel Gap, Colo.	X	X	X	X	X	X
08219500	South Fork Rio Grande at South Fork, Colo.	X	X	X	X	X	X
08220500	Pinos Creek near Del Norte, Colo.	X	X	X	X	X	X
08223500	Rock Creek near Monte Vista, Colo.	X	X	X	X	X	X
08224500	Kerber Creek at Ashley Ranch, near Villa Grove, Colo.	X	X	X	X	X	X
08227000	Saguache Creek near Saguache, Colo.	X	X	X	X	X	X
08227500	North Crestone Creek near Crestone, Colo.	X	X	X	X	X	X
08230500	Carnero Creek near La Garita, Colo.	X	X	X	X	X	X
08231000	La Garita Creek near La Garita, Colo.	X	X	X	X	X	X
08236000	Alamosa Creek above Terrace Reservoir, Colo.	X	X	X	X	X	X
08240500	Trinchera Creek above Turners Ranch, near Fort Garland, Colo.	X	X	X	X	X	X
08241000	Trinchera Creek above mouth Home Reservoir near Fort Garland, Colo.	X	X	X	X	X	X
08241500	Sangre De Cristo Creek near Fort Garland, Colo.	X	X	X	X	X	X
08242500	Ute Creek near Fort Garland, Colo.	X	X	X	X	X	X
08246500	Conejos River near Mogote, Colo.	X	X	X	X	X	X
08248000	Los Pinos River near Ortiz, Colo.	X	X				X

Table 3.--*Gaging-station records used to determine regression relations for the southwest region*
[X, gaging station was used in the analysis]

Station number	Station name	Mean annual dis-charge	Mean monthly dis-charge	Flow-dura-tion series	Mini-mum 7-day dis-charge	Maxi-mum 7-day dis-charge	Peak dis-charge
09145000	Uncompahgre River at Ouray, Colo.	X	X	X	X	X	X
09146000	Uncompahgre River below Ouray, Colo.	X	X	X	X	X	X
09146400	West Fork Dallas Creek near Ridgway, Colo.	X	X	X	X	X	X
09146500	East Fork Dallas Creek near Ridgway, Colo.	X	X	X	X	X	X
09146600	Pleasant Valley Creek near Noel, Colo.	X	X	X	X	X	X
09165000	Dolores River below Rico, Colo.	X	X	X	X	X	X
09166500	Dolores River at Dolores, Colo.	X	X	X	X	X	X
09167500	Dolores River near McPhee, Colo.	X	X	X	X	X	X
09168100	Disappointment Creek near Dove Creek, Colo.	X	X	X	X	X	X
09169500	Dolores River at Bedrock, Colo.	X	X	X	X	X	X
09171100	Dolores River near Bedrock, Colo.	X	X	X	X	X	X
09172500	San Miguel River near Placerville, Colo.	X	X	X	X	X	X
09175500	San Miguel River at Naturita, Colo.	X	X	X	X	X	X
09177000	San Miguel River at Uravan, Colo.	X	X	X	X	X	X
09179500	Dolores River at Gateway, Colo.	X	X	X	X	X	X
09339900	East Fork San Juan River above Sand Creek, near Pagosa Springs, Colo.	X	X	X	X	X	X
09340000	East Fork San Juan River near Pagosa Springs, Colo.	X	X	X	X	X	X
09340500	West Fork San Juan River above Barns Lake near Pagosa Springs, Colo.	X	X	X	X	X	X
09341500	West Fork San Juan River near Pagosa Springs, Colo.	X	X	X	X	X	X
09342000	Turkey Creek near Pagosa Springs, Colo.	X	X	X	X	X	X
09342500	San Juan River at Pagosa Springs, Colo.	X	X	X	X	X	X
09343000	Rio Blanco near Pagosa Springs, Colo.	X	X	X	X	X	X
09343300	Rio Blanco below Blanco Diversion Dam, near Pagosa Springs, Colo.	X	X	X	X	X	
09343500	Rio Blanco near Pagosa Springs, Colo.	X	X	X	X	X	X
09344000	Navajo River at Banded Peak Ranch, near Chromo, Colo.	X	X	X	X	X	X
09344300	Navajo River above Chromo, Colo.	X	X	X	X	X	X
09344400	Navajo River below Oso Diversion Dam, near Chromo, Colo.	X	X	X	X	X	
09345200	Little Navajo River below Lake Oso Diversion Dam, near Chromo, Colo.	X	X	X	X	X	
09345500	Little Navajo River at Chromo, Colo.	X	X	X	X	X	X
09346000	Navajo River at Edith, Colo.	X	X	X	X	X	X
09346400	San Juan River near Carracas, Colo.	X	X	X	X	X	X
09347500	Piedra River at Bridge Ranger Station near Pagosa Springs, Colo.	X	X	X	X	X	X
09349500	Piedra River near Piedra, Colo.	X	X	X	X	X	X
09349800	Piedra River near Arboles, Colo.	X	X	X	X	X	X
09350500	San Juan River at Rosa, N. Mex.	X	X	X	X	X	X
09352900	Vallecito Creek near Bayfield, Colo.	X	X	X	X	X	X
09353500	Los Pinos River near Bayfield, Colo.	X	X	X	X	X	X
09355000	Spring Creek at La Boca, Colo.	X	X	X	X	X	X
09357500	Animas River at Howardsville, Colo.	X	X	X	X	X	X
09359000	Mineral Creek near Silverton, Colo.	X	X	X	X	X	X

Table 3.--*Gaging-station records used to determine regression relations for the southwest region*--Continued

Station number	Station name	Mean annual dis-charge	Mean monthly dis-charge	Flow-dura-tion series	Mini-mum 7-day dis-charge	Maxi-mum 7-day dis-charge	Peak dis-charge
09359500	Animas River above Tacoma, Colo.------------	X	X	X	X	X	X
09361000	Hermosa Creek near Hermosa, Colo.-----------	X	X	X	X	X	X
09361500	Animas River at Durango, Colo.--------------	X	X	X	X	X	X
09362000	Lightner Creek near Durango, Colo.----------	X	X	X	X	X	X
09363000	Florida River near Durango, Colo.-----------	X	X	X	X	X	X
09363100	Salt Creek near Oxford, Colo.---------------	X	X	X	X	X	X
09363500	Animas River near Cedar Hill, N. Mex.-------	X	X	X	X	X	X
09365500	La Plata River at Hesperus, Colo.-----------	X	X	X	X	X	X
09366000	Cherry Creek near Red Mesa, Colo.-----------	X	X	X	X	X	X
09366500	La Plata River at the Colorado-New Mexico State line--------------------------------	X	X	X	X	X	X
09369000	East Mancos River near Mancos, Colo.--------	X	X	X	X	X	X
09369500	Middle Mancos River near Mancos, Colo.------	X	X	X	X	X	X
09371500	McElmo Creek near Cortez, Colo.-------------	X	X	X	X	X	X
09372000	McElmo Creek near Colo-Utah State line------	X	X	X	X	X	X

Table 4.--*Gaging-station records used to determine regression relations for the northwest region*
[X, gaging station was used in the analysis]

Station number	Station name	Mean annual discharge	Mean monthly discharge	Flow-duration series	Minimum 7-day discharge	Maximum 7-day discharge	Peak discharge
09040500	Troublesome Creek near Troublesome, Colo.---	X	X	X	X	X	X
09059500	Piney River near State Bridge, Colo.--------	X	X	X	X	X	X
09067500	Eagle River at Eagle, Colo.-----------------	X	X	X	X	X	X
09068000	Brush Creek near Eagle, Colo.---------------	X	X	X	X	X	X
09069000	Eagle River at Gypsum, Colo.----------------	X	X	X	X	X	X
09070000	Eagle River below Gypsum, Colo.-------------	X	X	X	X	X	X
09080300	Rocky Fork Creek near Meredith, Colo.-------	X	X	X	X	X	X
09080400	Fryingpan River near Ruedi, Colo.-----------	X	X	X	X	X	
09081550	Crystal River at Placita, Colo.-------------	X	X	X	X	X	X
09081600	Crystal River above Avalanche Creek near Redstone, Colo.----------------------	X	X	X	X	X	X
09082500	Crystal River near Redstone, Colo.----------	X	X	X	X	X	X
09083000	Thompson Creek near Carbondale, Colo.-------	X	X	X	X	X	X
09085200	Canyon Creek above New Castle, Colo.--------	X	X	X	X	X	X
09085300	East Canyon Creek near New Castle, Colo.----	X	X	X	X	X	X
09085400	Possum Creek near New Castle, Colo.---------	X	X	X	X	X	X
09089500	West Divide Creek near Raven, Colo.---------	X	X	X	X	X	X
09091500	East Rifle Creek near Rifle, Colo.----------	X	X	X	X	X	
09092000	Rifle Creek near Rifle, Colo.---------------	X	X	X	X	X	X
09092500	Beaver Creek near Rifle, Colo.--------------	X	X	X	X	X	X
09093000	Parachute Creek near Parachute, Colo.-------	X	X	X	X	X	X
09093500	Parachute Creek at Parachute, Colo.---------	X	X	X	X	X	X
09095000	Roan Creek near De Beque, Colo.-------------	X	X	X	X	X	X
09097500	Buzzard Creek near Collbran, Colo.----------	X	X	X	X	X	X
09104500	Mesa Creek near Mesa, Colo.-----------------	X	X	X	X	X	X
09123000	Soap Creek at Sapinero, Colo.---------------	X	X	X	X	X	X
09128500	Smith Fork near Crawford, Colo.-------------	X	X	X	X	X	X
09130500	East Muddy Creek near Bardine, Colo.--------	X	X	X	X	X	X
09132500	North Fork Gunnison River near Somerset, Colo.--------------------------	X	X	X	X	X	X
09134500	Leroux Creek near Cedaredge, Colo.----------	X	X	X	X	X	X
09136200	Gunnison River near Lazear, Colo.-----------	X	X	X	X	X	X
09137800	Dirty George Creek near Grand Mesa, Colo.---	X	X	X	X	X	X
09141200	Youngs Creek near Grand Mesa, Colo.---------	X	X	X	X	X	X
09143500	Surface Creek at Cedaredge, Colo.-----------	X	X	X	X	X	X
09144200	Tongue Creek at Cory, Colo.-----------------	X	X	X	X	X	X
09146200	Uncompahgre River near Ridgway, Colo.-------	X	X	X	X	X	X
09147000	Dallas Creek near Ridgway, Colo.------------	X	X	X	X	X	X
09147500	Uncompahgre River at Colona, Colo.----------	X	X	X	X	X	X
09150500	Roubideau Creek at mouth, near Delta, Colo.-	X	X	X	X	X	X
09239500	Yampa River at Steamboat Springs, Colo.-----	X	X	X	X	X	X
09242500	Elk River near Trull, Colo.-----------------	X	X	X	X	X	X
09244100	Fish Creek near Milner, Colo.---------------	X	X	X	X	X	X
09244410	Yampa River below Diversion, near Hayden, Colo.-----------------------------	X	X	X	X	X	X
09245000	Elkhead Creek near Elkhead, Colo.-----------	X	X	X	X	X	X
09245500	North Fork Elkhead Creek near Elkhead, Colo.----------------------------	X	X	X	X	X	X
09247000	Fortification Creek at Craig, Colo.---------	X	X	X		X	X

Table 4.--*Gaging-station records used to determine regression relations for the northwest region*--Continued

Station number	Station name	Mean annual dis-charge	Mean monthly dis-charge	Flow-dura-tion series	Mini-mum 7-day dis-charge	Maxi-mum 7-day dis-charge	Peak dis-charge
09248600	East Fork of Williams Fork above Willow Creek, Colo.	X	X	X	X	X	X
09249000	East Fork of Williams Fork near Pagoda, Colo.	X	X	X	X	X	X
09249200	South Fork of Williams Fork near Pagoda, Colo.	X	X	X	X	X	X
09249500	Williams Fork at Hamilton, Colo.	X	X	X	X	X	X
09250000	Milk Creek near Thornburgh, Colo.	X	X	X	X	X	X
09251000	Yampa River near Maybell, Colo.	X	X	X	X	X	X
09251500	Middle Fork Little Snake River near Battle Creek, Colo.	X	X	X	X	X	X
09253000	Little Snake River near Slater, Colo.	X	X	X	X	X	X
09255000	Slater Fork near Slater, Colo.	X	X	X	X	X	X
09257000	Little Snake River near Dixon, Wyo.	X	X	X	X	X	X
09258000	Willow Creek near Dixon, Wyo.	X	X	X	X	X	X
09259700	Little Snake River near Baggs, Wyo.	X	X	X	X	X	X
09260000	Little Snake River near Lily, Colo.	X	X	X	X	X	X
09302800	North Fork White River near Buford, Colo.	X	X	X	X	X	X
09303000	North Fork White River at Buford, Colo.	X	X	X	X	X	X
09303500	South Fork White River near Buford, Colo.	X	X	X	X	X	X
09304000	South Fork White River at Buford, Colo.	X	X	X	X	X	X
09304200	White River above Coal Creek, near Meeker, Colo.	X	X	X	X	X	X
09304300	Coal Creek near Meeker, Colo.	X	X	X	X	X	X
09304500	White River near Meeker, Colo.	X	X	X	X	X	X
09304800	White River below Meeker, Colo.	X	X	X	X	X	X
09306200	Piceance Creek below Ryan Gulch, near Rio Blanco, Colo.	X	X	X	X	X	X
09306222	Piceance Creek at White River, Colo.	X	X	X	X	X	X
09306500	White River near Watson, Utah	X	X	X	X	X	X

selected flow characteristics using data from all of the gaging stations. These relations included four independent variables selected from the previously defined set of basin and climatic characteristics and were defined using stepwise regression procedures (explained in the following section titled, "Regression Relations"). Residuals, which are the differences between the logs of measured and estimated flow values, then were plotted on a location map of the gaging stations. Boundaries were drawn around physiographic regions in which the regression relations tended to overestimate or underestimate streamflow.

After these initial regions were defined, regression relations were determined independently for each region. Techniques used to select variables for the final regression relations are described in detail later in this report. The regions then were reevaluated on the basis of areal plots of the residuals obtained from these refined models. If consistent deviations occurred in specific areas of a hydrologic region, regional boundaries were redefined, and regression relations were then redetermined. This procedure was repeated until residuals failed to show systematic areal distributions, and further subdivision failed to improve the precision of the estimates from the regression relation.

Four hydrologic regions were delineated in the study area (pl. 1), based on relations between streamflow and basin characteristics. These regions are subsequently referred to as the mountain region, Rio Grande region, southwest region, and northwest region.

The mountain region consists predominantly of the high peaks of the Rocky Mountains north of the Rio Grande drainage basin. Minimum elevation in this region is 7,500 ft, and the area exhibits high topographic relief. The Rio Grande region includes the Rio Grande drainage basin and the headwaters of the Arkansas drainage basin on the eastern slope of the Sangre de Cristo Mountains. The Rio Grande region includes the eastern San Juan Mountains, the San Luis Valley, and the Sangre de Cristo Mountains; elevations range from about 7,500 to 14,000 ft. The southwest region includes an area that extends west from the Continental Divide in the San Juan Mountains and south from the Uncompahgre Plateau. Elevations in this region range from about 5,000 ft near the Colorado-Utah border to 14,000 ft along the Continental Divide. The northwest region is located north of the Uncompahgre Plateau and west of the mountain region and is an area of comparatively low elevations. Elevations in this region range from about 5,000 to 7,500 ft, with the exception of the 8,000 to 9,000-ft high Roan Plateau in the central part of the region.

The boundaries between the hydrologic regions were determined initially on the basis of statistical analyses, physiography, and climate. The Continental Divide forms a topographic barrier between the mountain and Rio Grande regions and between the Rio Grande and southwest regions. The Uncompahgre Plateau, which reaches elevations of 9,000 to 10,000 ft, separates the northwest and southwest regions. The Uncompahgre Plateau forms a major *orographic* barrier to air masses moving from the south and southwest; annual precipitation south of the Uncompahgre Plateau, in the southwest region, ranges from about 12 to 25 in., decreasing to 8 in. at the lower elevations north of the Uncompahgre Plateau in the northwest region (Colorado Climate Center, 1984).

The 7,500-ft elevation contour forming the boundary around the northwest region approximately follows the boundary that separates snowmelt-dominated floods in the higher elevations from rainfall-dominated floods at the lower elevations (Jarrett and Costa, 1982; Elliott and others, 1982; McCain and Jarrett, 1976).

Regression Relations

Regression relations were selected using stepwise regression procedures by the Statistical Analysis System (SAS Institute, 1982, p. 101-110) and all possible subsets of independent variables (SAS Institute, 1982, p. 85-90). Stepwise algorithms were used to eliminate independent variables that failed to explain a significant part of the variation of the streamflow characteristics. All possible subset and stepwise regression procedures then were performed on the remaining set of variables to determine the final models. Mallows' Cp statistic (Mallows, 1964, 1973; SAS Institute, 1982, p. 103), the coefficient of determination (r^2), the *mean standard error*, and ease of measurement of the independent variables were all considered in the selection of variables to include in the models.

The streamflow regression relations developed for the four regions of the study area are summarized in table 5, the mountain region; table 6, the Rio Grande region; table 7, the southwest region; and table 8, the northwest region. Only the coefficients significant to the regression relations are listed. In addition to the regression relations, the tables show the number of stations used to develop each relation, and the mean standard error associated with the regression relations. Regression relations are not included for some of the low-flow characteristics due to the large mean standard errors. Methods for measuring the basin and climatic characteristics that appear in the regression relations are defined for each variable in the "Glossary."

Application of Regression Relations

The first step in determining streamflow characteristics at a site is to locate the site on plate 1 and determine if the site is gaged or ungaged; then one of several computational procedures may be used. The techniques for determining flow for each of these categories are described below.

Gaged Sites

For determining station streamflow characteristics, except for peak discharge, a mean of the value of the station's streamflow characteristic from the station's historical record (Richter and others, 1984) and an estimate from the appropriate regression relation (tables 5-8) should be used. For determining peak discharge, a weighted estimate is considered to be the best estimate of flood frequency at a gaged site on an unregulated stream.

Table 5.--*Summary of regression relations for the mountain region*

Model: $Q = aA^{(b_1)} P^{(b_2)} E_B{}^{(b_3)} S_B{}^{(b_4)}$

[Q, discharge, in cubic feet per second; A, drainage area in square miles; P, (mean annual precipitation, in inches -10 inches); E_B, (mean basin elevation, in feet -5,000 feet) per 1,000 feet; S_B, mean basin slope, in feet per feet; a, b_1, b_2, b_3, b_4, regression coefficients]

Discharge characteristic Q	Regression constant a	Regression coefficient of basin characteristics				Number of stations	Mean standard error (in percent)
		b_1	b_2	b_3	b_4		
Annual mean--------	4.22×10^{-2}	0.852		2.15		123	43
October mean-------	1.64×10^{-3}	.969		3.16		123	50
November mean------	2.43×10^{-3}	1.02		2.65		123	43
December mean------	2.05×10^{-3}	1.04		2.55		123	45
January mean-------	1.76×10^{-3}	1.05		2.52		123	49
February mean------	2.65×10^{-3}	1.06		2.24		123	49
March mean---------	1.78×10^{-2}	1.06		1.21		123	43
April mean---------	1.27×10^{-1}	1.07	.373			123	56
May mean-----------	5.60×10^{-1}	.895	.602			123	58
June mean----------	4.74×10^{-2}	.800		3.04		123	51
July mean----------	3.94×10^{-4}	.859		5.19		123	63
August mean--------	2.01×10^{-4}	.963		4.81		123	70
September mean-----	3.96×10^{-4}	.965		4.12		123	63
90 percent duration	5.54×10^{-4}	1.09		2.94		123	59
70 percent duration	1.53×10^{-3}	1.04		2.70		123	46
50 percent duration	2.25×10^{-3}	0.998		2.84		123	45
25 percent duration	6.79×10^{-3}	0.934		2.97		123	53
10 percent duration	1.55×10^{-1}	.813		2.11		123	52
2-year-7-day low---	2.77×10^{-4}	1.08		3.31		122	62
10-year-7-day low--	2.54×10^{-5}	1.14		4.27		122	101
50-year-7-day low--	3.39×10^{-6}	1.18		5.13		122	158
2-year-7-day high--	4.23×10^{1}	.736			.861	123	50
10-year-7-day high-	5.45×10^{1}	.754			.721	123	42
50-year-7-day high-	6.38×10^{1}	.760			.668	123	42
100-year-7-day high	6.74×10^{1}	.761			.652	123	43
2-year peak ------	7.43×10^{1}	.693			.894	112	51
5-year peak--------	8.15×10^{1}	.698			.719	112	46
10-year peak-------	8.61×10^{1}	.699			.635	112	45
25-year peak-------	9.15×10^{1}	.699			.550	112	44
50-year peak-------	9.49×10^{1}	.699			.497	112	44
100-year peak------	9.85×10^{1}	.698			.452	112	45
200-year peak------	1.02×10^{2}	.697			.412	112	45
500-year peak------	1.06×10^{2}	.696			.364	112	46

Table 6.--*Summary of regression relations for the Rio Grande region*

$$\text{Model: } Q = aA^{(b_1)}\, P^{(b_2)}\, E_B^{(b_3)}\, S_B^{(b_4)}$$

[Q, discharge, in cubic feet per second; A, drainage area in square miles; P, (mean annual precipitation, in inches -10 inches); E_B, (mean basin elevation, in feet -5,000 feet) per 1,000 feet; S_B, mean basin slope, in feet per feet; a, b_1, b_2, b_3, b_4, regression coefficients]

Discharge characteristic Q	Regression constant a	Regression coefficient of basin characteristics b_1	b_2	b_3	b_4	Number of stations	Mean standard error (in percent)
Annual mean--------	5.71×10^{-3}	0.821	1.89			17	69
October mean-------	6.36×10^{-3}	.755	1.65			17	61
November mean------	1.02×10^{-2}	.766	1.37			17	61
December mean------	7.18×10^{-3}	.748	1.40			17	56
January mean-------	6.85×10^{-3}	.775	1.33			17	58
February mean------	8.70×10^{-3}	.809	1.22			17	51
March mean---------	1.19×10^{-2}	.889	1.11			17	42
April mean---------	1.34×10^{-2}	.948	1.40			17	57
May mean-----------	2.63×10^{-2}	.853	1.72			17	69
June mean----------	5.45×10^{-3}	.792	2.39			17	87
July mean----------	3.67×10^{-3}	.750	2.24			17	82
August mean--------	1.31×10^{-2}	.666	1.73			17	65
September mean-----	4.19×10^{-3}	.714	1.93			17	75
90 percent duration	3.39×10^{-4}	.671	2.49			16	105
70 percent duration	5.33×10^{-3}	.750	1.53			16	62
50 percent duration	7.74×10^{-3}	.751	1.53			16	59
25 percent duration	4.66×10^{-3}	0.774	2.01			16	71
10 percent duration	7.51×10^{-3}	.793	2.16			16	80
2-year-7-day low---	4.73×10^{-4}	.691	2.31			16	93
10-year-7-day low--	8.20×10^{-6}	.778	3.40			16	131
50-year-7-day low	----- No Usable Relation Defined -----						
2-year-7-day high--	1.07×10^{-2}	.781	2.27			16	81
10-year-7-day high-	1.88×10^{-1}	.739	1.59			16	61
50-year-7-day high-	1.09	.721	1.14			16	51
100-year-7-day high	2.05	.715	.976			16	49
2-year peak--------	5.04×10^{-2}	.806	1.87			17	70
5-year peak--------	2.29×10^{-1}	.777	1.55			17	61
10-year peak-------	4.87×10^{-1}	.760	1.40			17	58
25-year peak-------	1.06	.742	1.25			17	57
50-year peak-------	1.75	.730	1.16			17	57
100-year peak------	2.71	.719	1.07			17	58
200-year peak------	4.01	.708	1.00			17	59
500-year peak------	6.40	.695	.918			17	63

Table 7.--*Summary of regression relations for the southwest region*

$$Q = aA^{(b_1)} P^{(b_2)} E_B^{(b_3)} S_B^{(b_4)}$$

Model: see equation above.

[Q, discharge, in cubic feet per second; A, drainage area in square miles; P, (mean annual precipitation, in inches -10 inches); E_B, (mean basin elevation, in feet -5,000 feet) per 1,000 feet; S_B, mean basin slope, in feet per feet; a, b_1, b_2, b_3, b_4, regression coefficients]

Discharge characteristic Q	Regression constant a	Regression coefficient of basin characteristics				Number of stations	Mean standard error (in percent)
		b_1	b_2	b_3	b_4		
Annual mean--------	9.70×10^{-2}	0.888		1.74		54	55
October mean-------	2.84	.806			1.11	54	100
November mean------	1.83	.815			1.13	54	87
December mean------	1.22	.872			1.26	54	77
January mean-------	9.33×10^{-1}	.916			1.34	54	77
February mean------	6.47×10^{-1}	.913			.906	54	77
March mean---------	1.24×10^{-1}	.861	0.502			54	53
April mean---------	4.22×10^{-2}	.961	1.13			54	62
May mean-----------	1.00×10^{-1}	.948		2.24		54	55
June mean----------	3.17×10^{-2}	1.01		2.76		54	98
July mean----------	1.12×10^{1}	.850			1.68	54	123
August mean--------	5.13	.790			1.32	54	135
September mean-----	3.65	.811			1.30	54	142
90 percent duration	1.35	.902			2.08	54	179
70 percent duration	1.61	.863			1.56	54	108
50 percent duration	2.10	.855			1.30	54	106
25 percent duration	6.51	.862			1.34	54	88
10 percent duration	2.01×10^{1}	0.857			1.34	54	65
2-year-7-day low---	1.87	.830			2.22	54	177
10-year-7-day low	------ No Usable Relation Defined ------						
50-year-7-day low	------ No Usable Relation Defined ------						
2-year-7-day high--	5.01×10^{-1}	.847		1.89		54	51
10-year-7-day high-	1.54	.845		1.58		54	41
50-year-7-day high-	3.24	.834		1.36		54	37
100-year-7-day high	4.27	.829		1.28		54	38
2-year peak--------	7.87	.732		.847		51	38
5-year peak--------	5.39×10^{1}	.686				51	42
10-year peak-------	6.94×10^{1}	.685				51	41
25-year peak-------	9.11×10^{1}	.683				51	41
50-year peak-------	1.09×10^{2}	.682				51	43
100-year peak------	1.28×10^{2}	.680				51	45
200-year peak------	1.49×10^{2}	.679				51	47
500-year peak------	1.79×10^{2}	.677				51	52

Note: The results for stations used in this study suggest that the peak-flow models for the southwest region tend to overestimate peak flow by about 25 to 100 percent when site elevation is lower than about 5,500.

Table 8.--*Summary of regression relations for the northwest region*

Model: $Q = aA^{(b_1)}\ P^{(b_2)}\ E_B^{\ (b_3)}\ S_B^{\ (b_4)}$

[Q, discharge, in cubic feet per second; A, drainage area in square miles; P, (mean annual precipitation, in inches -10 inches); E_B, (mean basin elevation, in feet -5,000 feet) per 1,000 feet; S_B, mean basin slope, in feet per feet; a, b_1, b_2, b_3, b_4, regression coefficients]

Discharge characteristic Q	Regression constant a	Regression coefficient of basin characteristics				Number of stations	Mean standard error (in percent)
		b_1	b_2	b_3	b_4		
Annual mean--------	2.05×10^{-2}	0.973		2.63		69	56
October mean-------	2.95×10^{-3}	1.01		3.13		69	74
November mean------	2.86×10^{-3}	1.05		2.92		69	71
December mean------	2.78×10^{-3}	1.05		2.84		69	71
January mean-------	2.79×10^{-3}	1.05		2.77		69	71
February mean------	4.53×10^{-3}	1.05		2.45		69	67
March mean---------	2.72×10^{-2}	1.04		1.44		69	62
April mean---------	1.08×10^{-1}	.916	0.804			69	67
May mean-----------	1.44×10^{-1}	.878	1.17			69	85
June mean----------	9.59×10^{-3}	1.04		3.76		69	88
July mean----------	8.28×10^{-4}	1.07		4.58		69	77
August mean--------	8.13×10^{-4}	1.01		4.21		69	92
September mean-----	9.96×10^{-4}	1.00		3.89		69	95
90 percent duration	1.00×10^{-4}	1.05		4.81		69	137
70 percent duration	1.37×10^{-3}	1.04		3.34		69	78
50 percent duration	3.33×10^{-3}	1.02		3.02		69	63
25 percent duration	1.04×10^{-2}	1.02		2.80		69	56
10 percent duration	4.30×10^{-2}	.989		2.77		69	74
2-year-7-day low---	4.89×10^{-4}	1.03		4.34	.766	68	149
10-year-7-day low	------ No Usable Relation Defined ------						
50-year-7-day low	------ No Usable Relation Defined ------						
2-year-7-day high--	1.94×10^{-1}	.875	1.26			69	90
10-year-7-day high-	6.23×10^{-1}	.843	1.09			69	70
50-year-7-day high-	1.15	.825	.990			69	65
100-year-7-day high	1.42	.818	.959			69	66
2-year peak--------	7.95×10^{-1}	.820	1.00			67	71
5-year peak--------	1.86	.794	.871			67	65
10-year peak-------	2.86	.781	.802			67	63
25-year peak-------	4.45	.768	.732			67	63
50-year peak-------	5.90	.759	.686			67	63
100-year peak------	7.54	.752	.646			67	63
200-year peak------	9.49	.745	.609			67	65
500-year peak------	1.24×10^{1}	.737	.565			67	67

"Weighted estimates are used for unregulated streams to reduce the time-sampling error that may occur in a station flood-frequency estimate. This time-sampling error is associated with the length of record for a station. A station with a short period of record may have a large time-sampling error because its record may not be representative of the actual flood history of the site which would be based on a large number of years. The observed period of record at a station has the possibility of falling within a wet or dry climatic cycle. The weighted estimate of flood frequency should be a better indicator of the true values because the regression estimate is an average of the flood histories of many gaging stations over a long period of time" (Thomas and Lindskov, 1983).

The weighting procedure to use for peak discharge in this report is described by Sauer (1974). This procedure weights the station flood frequency and the regression estimate of flood frequency by the years of record at the station and the equivalent years of record of the regression estimate. The following equation should be used:

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

where $Q_{T(w)}$ = The weighted discharge, in cubic feet per second, for recurrence interval T-years;

$Q_{T(s)}$ = the station value of the flood based on the historical record, in cubic feet per second, for recurrence interval T-years (from Richter and others, 1984);

N = the number of years of station data used to compute $Q_{T(s)}$;

$Q_{T(r)}$ = the regression estimate of the flood, in cubic feet per second, for recurrence interval T-years; and

E = the equivalent years of record for $Q_{T(r)}$ = 10 years (U.S. Water Resources Council, 1981, p. 21).

The Water Resources Council's (U.S. Water Resources Council, 1981, p. 21) recommendation for equivalent years of record only pertains to the 100-year flood; therefore, the assumption for this study is that the equivalent years of record = 10 years applies to other recurrence intervals.

Ungaged Sites

This method consists of using the regional relations shown in tables 5-8. Hydrologic characteristics at ungaged sites can be computed by one of the following procedures: Procedure 1 is for sites where the regression relations for one region are used. Procedure 2 is for sites that are near regional boundaries. Procedure 3 is for sites that are near state boundaries.

Procedure 1 is used when the entire drainage area of a basin falls in a single hydrologic region (see pl. 1).

Procedure 2 is used when the basin drainage area upstream from the site of interest crosses over a hydrologic region boundary. Where a site is near a regional boundary, the estimates of that particular characteristic can be quite different depending on the regional relation used. Therefore, a weighting procedure is recommended that utilizes the regression relations for both regions whereby each estimate is weighted by the percentage of the drainage area that lies in each region, and then the two are summed. For example, if the 10-year peak discharge is to be determined at a site where 50 percent of the drainage area lies in the mountain region and 50 percent of the drainage area lies in the northwest region, then the 10-year peak discharge is computed using the appropriate relation (P_{10}) for the northwest region multiplied by 0.50 and the appropriate relation (P_{10}) for the mountain region multiplied by 0.50. The two results then are added together to get the estimate of the 10-year peak discharge at the ungaged site.

Procedure 3 applies to sites where the upstream drainage area of the site crosses a state line. Studies presenting relations for peak discharge characteristics have been completed in Utah (Thomas and Lindskov, 1983), Wyoming (Lowham, 1976) and New Mexico (Thomas and Gold, 1982), and each of these states is working on updates which will include relations for estimating additional streamflow characteristics. No major differences are apparent between the results of this study and those for Utah, New Mexico, and Wyoming. However, when a station lies near a state line, streamflow characteristics should be determined by averaging estimates from the relations for both states. For example, to determine the 10-year peak discharge at a site near the Colorado-Wyoming State line, the 10-year peak discharge should be calculated using both Colorado's relation (tables 5-8) and Wyoming's relation (Lowham, 1976); then an arithmetic mean of the two results should be considered the best estimate of the 10-year peak discharge.

Limitations and Accuracy

The regression relations defined in this study provide estimates of flow in streams where the flow is not significantly altered by regulation, diversion, or other man-made influences. The relations cannot be used to estimate present or future flows in streams in urban areas unless the effects of urbanization on streamflow are insignificant. For example, the relations could be applied to a large stream (large rural drainage) flowing in a natural channel through an urban area.

The mean standard error of the regression relations applies only to flow estimates derived for basins in which the values of the independent variables are within the range of the measurements in the gaged basins. The range and distribution of the variables that appear in the regression relations are shown in figure 2. The accuracy of the regression relations for ungaged basins having climatic or physiographic characteristics outside the range of the gaged basins is untested and therefore is unknown.

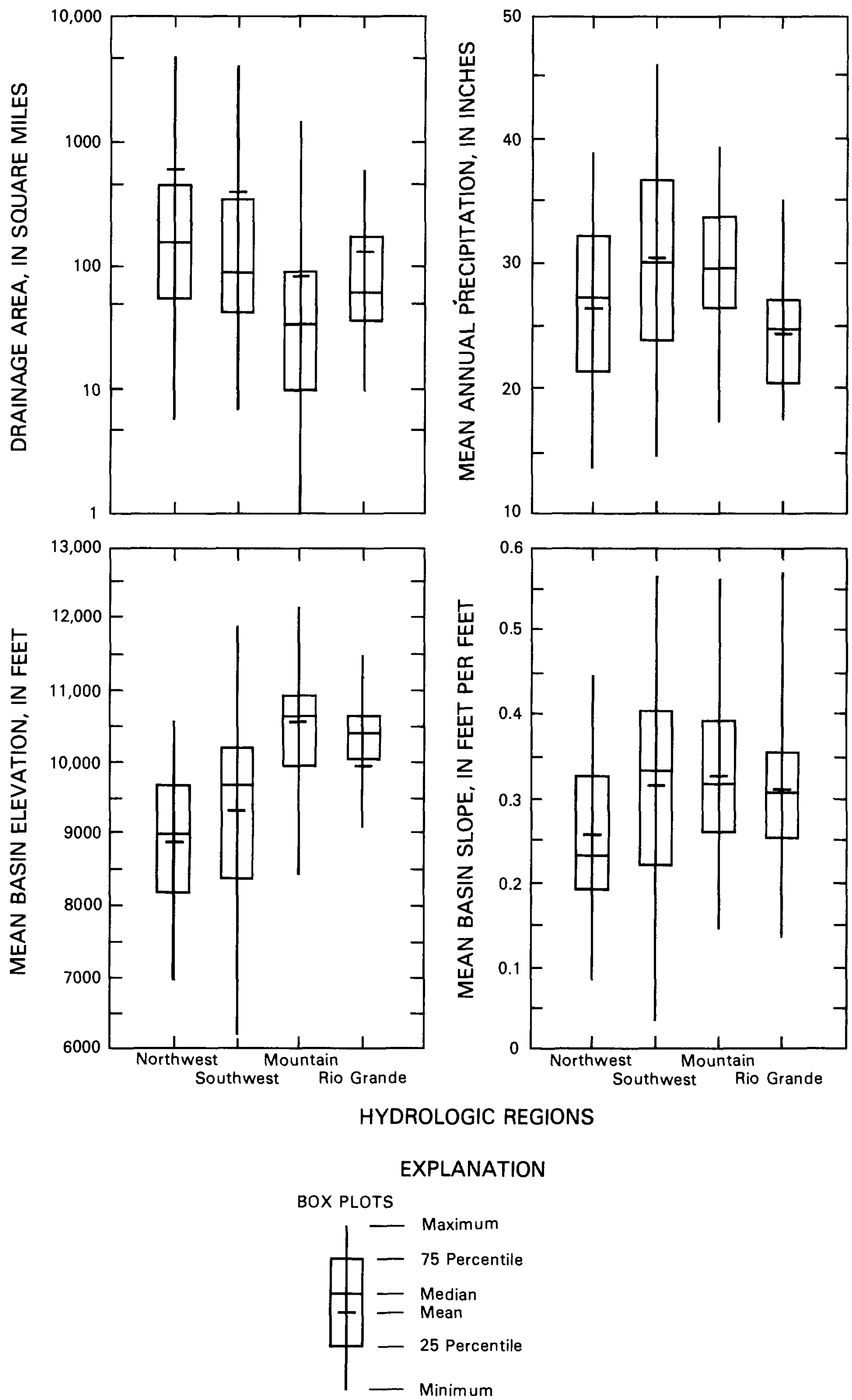

Figure 2.--Range and distribution of basin characteristics used in regression relations for each hydrologic region.

The accuracy of the regression relations differs between hydrologic regions and specific flow characteristics (fig. 3). Based on averages of the mean standard error for all types of flows excluding minimum 7-day discharges, the accuracy of the predictions decreases in the following order: mountain region, 49 percent; Rio Grande region, 64 percent; northwest region, 73 percent; and southwest region, 73 percent. The regression relations show the smallest mean standard error (about 45 to 70 percent) for estimates of mean annual discharge and flood volumes. The accuracy of the regression relation varies by month for mean monthly discharge but generally is best during November through March, except in the southwest region, where the February through May regression relations show the smallest mean standard error. However, discharges and the range in discharge are generally small during November through March, and comparisons between monthly standard errors (in percent) can be misleading.

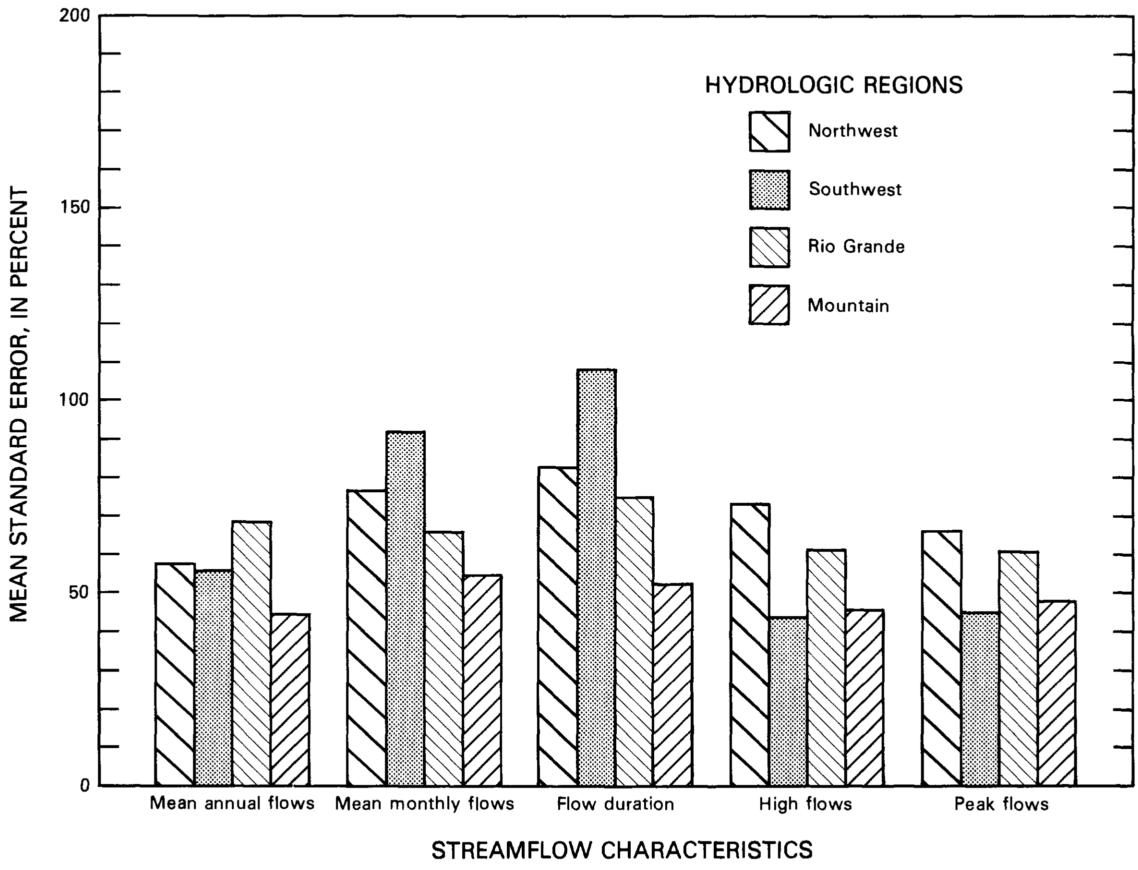

Figure 3.--Mean standard error of regression estimates for selected flow characteristics in each hydrologic region.

Mean standard errors associated with low-flow relations were commonly in excess of 100 percent, and in five of the nine attempted relations, no usable relation could be defined because of exceedingly high mean standard errors. The difficulty of modeling low-flow volumes reflects large low-flow variability that is not explained by independent variables that can be easily quantified. Low flows can be strongly affected by factors such as structure of the bedrock, depth and permeability of soils, and type and density of vegetation. In addition, even small irrigation diversions can affect low-flow volumes and contribute to the variability of gaged low flows.

For these reasons, most reported attempts at low-flow regionalization encompassing large geographic regions have been unsuccessful (Riggs, 1973). More reliable results generally can be obtained at an ungaged site by relating a series of low flows at an ungaged site to concurrent flows at a nearby gaging station at which the low-flow frequency curve is defined (Riggs, 1965, 1970; Hardison and Moss, 1972). Based on this relation, other low-flow characteristics at the ungaged site can be extrapolated from the frequency curve for the gaged site.

The residuals of the peak-discharge relations in the southwest region indicate that for site elevations lower than about 5,500 ft, the peak-discharge relations tend to overestimate flow by about 50 percent (mean standard error). Because few gaging stations in the southwest region are located below 5,500 ft, the consistency of this bias is uncertain; however, the peak discharge estimates from the regression equations may overestimate flood volumes at other low-elevation sites in this region.

Several guidelines apply to use of the estimates obtained from the regression relations. The mean standard error (tables 5-8) is only an approximate indication of the expected accuracy of the estimate; based on the data from which the relations were developed, the discrepancy between the estimate and actual streamflow will exceed the mean standard error about 30 percent of the time. The large mean standard errors associated with low-flow estimates (tables 5-8) indicate that estimates of low-flow volumes, including minimum 7-day discharge, mean monthly discharge for low-flow months, or flow-durations involving base flow, are only approximate estimates of actual flows. These flow characteristics might be better estimated using other techniques (Riggs, 1970, 1972).

An additional source of error may be associated with estimates of flows having long recurrence intervals. The median length of record in the four hydrologic regions was about 20 years, and the maximum length of record was about 70 years. Length of record has been shown to be the most important single factor affecting the accuracy of streamflow values estimated by the log-Pearson distribution (Benson, 1952; Ott, 1971; Nasseri, 1976).

Because distribution of streamflow-gaging stations on natural-flow channels is not uniform throughout western Colorado (pl. 1), site location is an additional factor to consider in evaluating the accuracy of the regression relations for ungaged basins. Several areas that are physiographically or geologically distinctive and contain few or no gaging stations include the following:

(1) San Luis Valley (below an elevation of about 8,000 ft);
(2) Uncompahgre Plateau;
(3) Roan Plateau;
(4) North Park and South Park; and
(5) Low-elevation areas (less than about 6,000 ft) in the western part of the northwest hydrologic region.

The lack of streamflow records that met the specifications of this study prevented verification of the hydrologic similarity of these areas to other parts of the hydrologic region in which they occur. When such areas lacking gaging stations were located near hydrologic region boundaries, boundaries necessarily were determined by considering other physical controls on streamflow amounts such as topography, geology, and climatic characteristics.

SUMMARY AND CONCLUSIONS

Regression relations for estimating streamflow characteristics were developed for western Colorado. Regression relations were determined for 33 flow characteristics, which include mean annual and mean monthly discharges, flow-duration series, peak discharge, and minimum and maximum 7-day discharges of various recurrence intervals. The study area was divided into four hydrologically distinct regions to decrease the variablilty in streamflow caused by differences in basin physiography and climate. Records from 264 stations located in the study area were used to determine relations for the four hydrologic regions.

Drainage area was the most significant variable in all of the streamflow relations. Other significant variables in the regression relations were mean annual precipitation, *mean basin elevation*, and mean basin slope. The final regression relations include these four basin and climatic characteristics.

It is not recommended that the relations be applied where basin characteristics are outside the range of the data from which the relations were developed or are in local regions of the study area where gaged records of *natural flow* were not available to develop the relations. The low-flow relations should be used only as an indicator of expected flows because of large mean standard errors associated with the regression estimates of low flows.

REFERENCES CITED

Benson, M.A., 1952, Characteristics of frequency curves based on a theoretical 1000 years record *in* Dalrymple, Tate, 1960, Flood-frequency analyses: U.S. Geological Survey Water-Supply Paper 1543-A, p. 51-74.

Colorado Climate Center, 1984, Colorado average annual precipitation, 1951-80, 1:500,000 scale map: Colorado Climate Center, Colorado state University, Fort Collins, Colo.

Dalrymple, Tate, 1960, Flood-frequency analyses: U.S. Geological Survey Water-Supply Paper 1543-A, 80 p.

Elliott, J.G., Jarrett, R.D., and Ebling, J.L., 1982, Annual snowmelt and rainfall peak-flow data on selected foothills region streams, South Platte River, Arkansas River, and Colorado River basins, Colorado: U.S. Geological Survey Open-File Report 82-426, 86 p.

Fenneman, N.M., 1931, Physiography of the western United states: McGraw-Hill, Inc., New York, 534 p.

Hardison, C.H., and Moss, M.E., 1972, Accuracy of low-flow characteristics estimated by correlation of base-flow measurements, *in* Manual of Hydrology--Part 2, Low-flow Techniques: U.S. Geological Survey Water-Supply Paper 1542-B, p. 35-55.

Hedman, E.R., Moore, D.O., and Livingston, R.K., 1972, Selected streamflow characteristics as related to channel geometry of perennial streams in Colorado: U.S. Geological Survey open-file report, 24 p.

Hutchinson, N.E., 1975, WATSTORE--National Water Data Storage and Retrieval System of the U.S. Geological Survey--User's Guide: U.S. Geological Survey Open-File Report 75-426, 791 p.

Jarrett, R.D., and Costa, J.E., 1982, Multidisciplinary approach to the flood hydrology of foothill streams in Colorado, *in* Johnson, A.I., and Clark, R.A., eds., 1982, International Symposium on Hydrometeorology, Proceedings: American Water Resources Association, p. 565-569.

Livingston, R.K., 1970, Evaluation of the streamflow data program in Colorado: U.S. Geological Survey open-file report, 72 p.

Lowham, H.W., 1976, Techniques for estimating flow characteristics of Wyoming streams: U.S. Geological Survey Water-Resources Investigations 76-112, 83 p.

Lystrom, D.J., Rinella, F.A., Rickert, D.A., and Zimmerman, Lisa, 1978, Regional analysis of the effects of landuse on stream-water quality, methodology, and application in the Susquehanna River basin, Pennsylvania and New York: U.S. Geological Survey Water-Resources Investigations 78-12, 60 p.

Mallows, C.L., 1964, Choosing variables in a linear regression, a graphical aid: Manhattan, Kans., Institute of Mathematical Statistics, May 7-9 Central Regional Meeting.

_____1973, Some comments on Cp: Technometrics, v. 15, p. 661-675.

Matthai, H.F., 1968, Magnitude and frequency of floods in the United states, Part 6-B, Missouri River basin below Sioux City, Iowa: U.S. Geological Survey Water-Supply Paper 1680, 491 p.

McCain, J.F., and Jarrett, R.D., 1976, Manual for estimating flood characteristics of natural-flow streams in Colorado: Colorado Water Conservation Board, Technical Manual no. 1, 68 p.

Nasseri, I., 1976, Regional flow-frequency analysis using multistation stochastic and deterministic models: Palo Alto, Calif., Stanford University, Department of Civil Engineering, Technical Report no. 210, v. 1.

Ott, R.F., and Linsley, R.K., 1971, Streamflow frequency using stochastically generated hourly rainfall: Palo Alto, Calif., Stanford University, Department of Civil Engineering, Technical Report no. 151, 14 p.

Patterson, J.L., 1964, Magnitude and frequency of floods in the United states, Part 7, Lower Mississippi River basin: U.S. Geological Survey Water-Supply Paper 1681, 636 p.

_____1965, Magnitude and frequency of floods in the United states, Part 8, Western Gulf of Mexico basins: U.S. Geological Survey Water-Supply Paper 1682, 506 p.

Patterson, J.L., and Somers, W.P., 1966, Magnitude and frequency of floods in the United states, Part 9, Colorado River basin: U.S. Geological Survey Water-Supply Paper 1683, 475 p.

Richter, B.D., Kircher, J.E., Remmers, M.A., and Forst, B.A., 1984, Summary of basin and streamflow characteristics for selected basins in western Colorado and adjacent states: U.S. Geological Survey Open-File Report 84-137, 226 p.

Riggs, H.C., 1965, Estimating probability distributions of drought flows: Water and Sewage Works, v. 112, no. 5, p. 153-157.

_____1970, The transfer value of information collected on representative basins: Wellington, New Zealand, International Association of Scientific Hydrology Publication 96, p. 614-631.

_____1972, Low-flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 4, chap. B1, 18 p.

_____1973, Regional analyses of streamflow characteristics: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 4, chap. B3, 15 p.

Sauer, V.B., 1974, Flood characteristics of Oklahoma streams: U.S. Geological Survey Water-Resources Investigations 52-73, 301 p.

Statistical Analysis System (SAS) Institute, Inc., 1982, SAS User's Guide: Statistics, 1982 Edition: Cary, N. C., SAS Institute, Inc., 584 p.

Thomas, B.E., and Lindskov, K.L., 1983, Methods for estimating peak discharge and flood boundaries of streams in Utah: U.S. Geological Survey Water-Resources Investigations 83-4129, 77 p.

Thomas, D.M., and Benson, M.A., 1970, Generalization of streamflow characteristics from drainage basin characteristics: U.S. Geological Survey Water-Supply Paper 1975, 55 p.

Thomas, R.P., and Gold, R.L., 1982, Techniques for estimating flood discharges for unregulated streams in New Mexico: U.S. Geological Survey Water-Resources Investigations Report 82-24, available from National Technical Information Service, Springfield, Va., as PB 82-264 953, 42 p.

U.S. Water Resources Council, 1981, Guidelines for determining flood flow frequency: Hydrology Committee Bulletin 17B, 180 p.

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