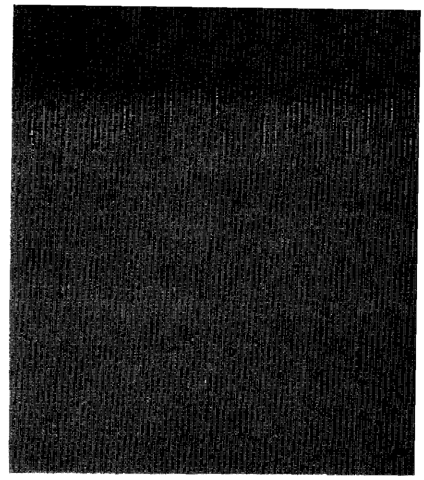
Streamflow Characteristics Related to Channel Geometry of Streams in Western United States



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

Streamflow Characteristics Related to Channel Geometry of Streams in Western United States

By E. R. Hedman and W. R. Osterkamp

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Streamflow Characteristics Related To Channel Geometry of Streams in Western United States

By E. R. Hedman *and* W. R. Osterkamp

Abstract

Assessment of surface-mining and reclamation activities generally requires extensive hydrologic data. Adequate streamflow data from instrumented gaging stations rarely are available, and estimates of surface- water discharge based on rainfall-runoff models, drainage area, and basin characteristics sometimes have proven unreliable. Channel-geometry measurements offer an alternative method of quickly and inexpensively estimating stream-flow characteristics for ungaged streams. The method uses the empirical development of equations to yield a discharge value from channel-geometry and channel-material data. The equations are developed by collecting data at numerous streamflow-gaging sites and statistically relating those data to selected discharge characteristics.

Mean annual runoff and flood discharges with selected recurrence intervals can be estimated for perennial, intermittent, and ephemeral streams. The equations were developed from data collected in the western one-half of the conterminous United States. The effect of the channel-material and runoff characteristics are accounted for with the equations.

INTRODUCTION

The judicious management of land resources requires knowledge of the hydrologic characteristics of an area and how those characteristics may be modified by various land uses. Recently renewed emphasis on the recovery of coal resources from both public and private lands of the United States has produced an awareness that hydrologic information for most coal-resource areas is inadequate. The problem is acute in some parts of the western United States where the development of coal resources is limited by the availability of water. In these areas, coal-mine development is dependent partly on reasonable assessments of the useable surface-water and ground-water resources, as well as the means to discharge excess (unuseable) water from the mine area during periods of both normal and peak streamflow. Discharge information, however, may be completely lacking.

For areas where gaged streamflow data are unavailable, various indirect methods have been developed to estimate total runoff and flood-discharge characteristics (flow rates for specified recurrence intervals). Initial attempts were applied largely to humid and subhumid areas. They included the transfer of streamflow records from gaged to adjacent or nearby ungaged basins, and the estimation of runoff from drainage area and precipitation. More recent methods, designed to be more universally applicable than the earlier efforts, relied on numerous basin characteristics and multiple- regression analysis to estimate discharge characteristics (Thomas and Benson, 1970). Further development of these techniques led to various models relating rainfall (precipitation) and runoff. Although some of these newer techniques have worked well for relatively moist areas and some limited areas with arid or semiarid climates, they also have proven to be ineffective for general use in dry regions haveing complex patterns of topography, vegetation, and hydrology (Riggs, 1978). The sophisticated techniques, such as rainfall-runoff models, potentially can yield realistic estimates of discharge characteristics regardless of climate, but they are hampered by the need for extensive input data. Some of these data can be difficult to collect, and others, such as soil moisture, are variable with time.

An alternative method of indirectly estimating streamflow, using channel geometry as a modification of the hydraulic-geometry concept (Leopold and Maddock, 1953), was reported by Moore (1968) in Nevada and by Hedman (1970), in California. The method has the advantage of being easily applied, and the estimates are based on channel characteristics formed by the water and sediment discharge of a stream. Thus, the size of an alluvial channel is indicative of the water conveyed through that channel, and the shape of the channel is largely the result of the sediment transported by the stream. The data commonly used to estimate discharge characteristics by this technique, therefore, are measurements of geometry (principally width) and the particle- size distributions of the material forming the channel perimeter.

Results of studies undertaken to develop channel-geometry relations applicable to the western United States are presented in this report. The purposes of the study are: (1) to provide a general description of the channel-geometry technique, (2) to present equations useful for the determination of streamflow characteristics in areas generally lacking hydrologic data, and (3) to extend the technique of active-channel geometry to intermittent and ephemeral streams of semiarid and arid regions.

CHANNEL-GEOMETRY TECHNIQUE

The basis of all channel-geometry relations is the continuity equation for discharge (water) of a stream:

$$Q_i = WDV, \qquad (1)$$

where

Q_i = instantaneous discharge, in cubic feet per second;
W = water-surface width, in feet;
D = mean depth of water, in feet; and
V = mean velocity of water, in feet per second.

Considering numerous stream sites of various flow characteristics, the simplifying assumption is made that the rates of change of W, D, and V with Q_i are constant and, therefore, can be expressed by a multiple regression equation. This assumption requires that Q_i represents the same flow frequency (flow duration or recurrence interval) at all sites considered.

$$Q_i = kW^b D^f V^m, \qquad (2)$$

where k is a coefficient and b, f, and m are exponents. The multiple regression form of the continuity equation (equation 2) can be expressed as three simple functions:

$$Q_i \sim W^b \qquad (3)$$
$$Q_i \sim D^f \qquad (4)$$
$$Q_i \sim V^m \qquad (5)$$

The practical use of relations 3, 4, and 5 requires that water-surface width, mean water depth, and mean water velocity be measured for the same flow frequency at all sites considered. This requirement cannot be met because: (1) stream stage cannot be related to a flow-duration value if the site is ungaged, and (2) the three parameters cannot be measured at many or most flow durations for intermittent and ephemeral streams.

To avoid the necessity of water-related measurements, therefore, the channel-geometry method relies on measurements obtained from a geomorphic reference feature recognizable at all channel sites. When using the level of a geomorphic feature as a basis of evaluating flow characteristics, velocity, of course, cannot be measured (relation 5). Mean channel depth generally is measured and related to discharge (relation 4), but variability of channel profiles and the capacity for measurement error commonly lead to unreliable results. Thus, most channel-geometry relations include or are limited to channel-width measurements as an independent variable and yield a specified measure of discharge as the dependent variable. Expanding relation 3 to equation form gives:

$$Q_v = aW^b, \qquad (6)$$

where "a" is a coefficient, and Q_v is a measure of streamflow, such as mean discharge or a flood discharge of specified recurrence interval.

Implicit in equation 6 is the assumption that similar hydraulic and sorting processes produce similar channel features at each site and, therefore, that measurements taken from those features are comparable. Equal widths of perennial- and ephemeral-stream channels may yield similar estimates for the discharge of floods with selected recurrence intervals, but that width might correlate with greatly different values for the mean annual runoff of the two streams. Even though the widths may be the same, the mean annual runoff will be much greater for a perennial stream that flows most of the time than for an ephemeral stream that flows for a short period of time. Thus, separate equations for annual runoff are presented for channels having perennial, intermittent, and ephemeral streamflow. Ephemeral streams are further subdivided into three groups depending on the number of flow days per year.

Difficulty might arise when trying to determine which equations are applicable to an ungaged site. Normally, however, consideration of channel appearance, riparian vegetation, and regional climate dictate which group of equations is appropriate.

Separate equations are provided for the differences in channel shapes that result from variations in the sediment-discharge characteristics. These equations for annual runoff are based on particle sizes of the material forming the channel perimeter.

Channel-geometry relations generally are developed using measurements taken from one of three geomorphic reference points, as shown in figure 1. These points define the depositional-bar level (A-A′), the active-channel level (B-B′), and the bankfull level (C-C′). Where feasible, data for this study were collected from each of the three reference levels in order to ascertain which feature would yield the best estimates of discharge characteristics.

The lowest of the three levels, defined by the surfaces of depositional bars, is described by R. F. Hadley in Hedman, Moore, and Livingston, (1972, p. 4) as a "...longitudinal, in-channel feature formed along the borders of a stream channel at a stage of the flow regime when the local competence of the stream is incapable of moving the sediment particles on the submerged surface of the bar "(shown as reference level A-A′ in figure 2). Experience has shown that the depositional-bar level is a useful feature for channels with a well-graded sediment supply. If the channel material is predominantly sand and fine gravel, however, which is the case for numerous ephemeral and intermittent streams of the western United States, depositional bars may be poorly formed or absent. Hence, the depositional-bar data collected for this study produced inconsistent results and are not provided.

The active-channel level, shown as reference level B-B′ of figure 1, was used by Hedman, Kastner, and Hejl (1974) to determine flood-frequency discharge and later described by Osterkamp and Hedman (1977, p. 256) as "...a short-term geomorphic feature subject to change by prevailing discharges. The upper limit is defined by a break in the relatively steep bank slope of the active channel to a more gently sloping surface beyond the channel edge. The break in slope normally coincides with the lower limit of permanent vegatation so that the two features, individually or in combination, define the active channel reference level. The section beneath the reference level is that portion of the stream entrenchment in which the channel is actively, if not totally, sculptured by the normal process of water and sediment discharge. "

At most perennial and intermittent streams the active-channel level is exposed between 75 and 94 percent of the time. The active-channel level of many ephemeral

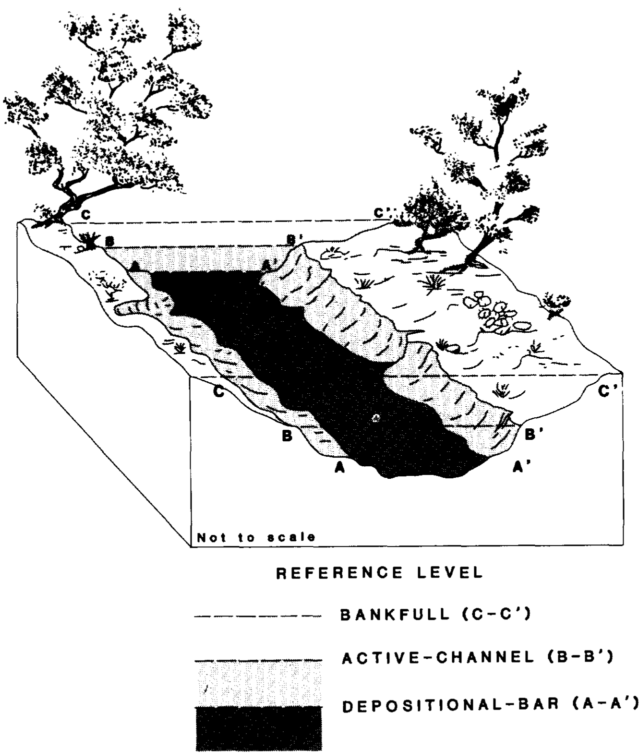

Figure 1. Commonly used reference levels.

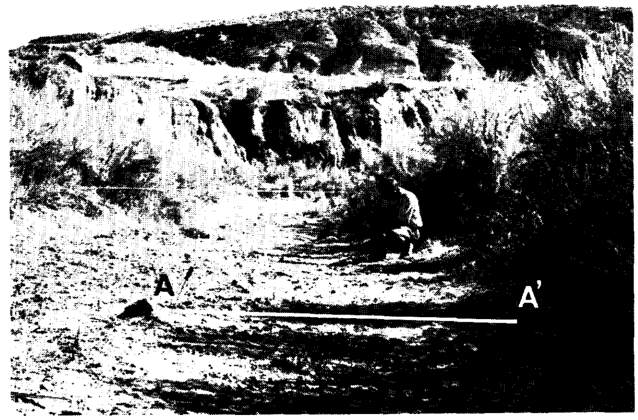

Figure 2. Reference points for bar geometry (A-A′) in a reach of an ephemeral-stream channel in Wyoming.

Figure 3. Reference points for active-channel geometry (B-B′) in a reach of a perennial-stream channel in Montana.

Figure 4. Reference points for active-channel geometry (B-B′) in a reach of an ephemeral-stream channel in New Mexico.

streams may be exposed more than 99 percent of the time. The stage corresponding to mean discharge of most perennial streams approximates that of the active-channel level, shown as reference level B-B′ in figure 3, but is lower than the active-channel level of the highly ephemeral stream channels, shown as reference level B-B′ in figure 4.

The highest reference level at which channel-geometry measurements commonly are made is bankfull stage, as shown by reference level C-C′ in figure 5. Bankfull stage is defined as the level of the active flood plain and, therefore, is the stage at which overbank flooding occurs (Wolman, 1955, p. 29). The bankfull level of many perennial-stream channels approximates the stage of a flood with a recurrence interval ranging from 1.5 to 3 years. Thus, the bankfull level of these channels is exceeded a very small percentage of the time. Flow at bankfull stage in ephemeral-stream channels generally is more infrequent than that in perennial or intermittent stream channels.

A disadvantage of the bankfull reference level is that its use requires the recognition of a flood-plain level or a bench, features that are not easily recognized in incised channels as shown in figure 6. In addition, changes in bankfull geometry generally occur much more slowly than do those of the active channel and may not be representative of prevailing conditions of water and sediment discharge. Bankfull-geometry data routinely were collected for this study, but, owing to the difficulties described above, the data did not yield suitable results.

Figure 5. Reference points for bankfull level (C-C′) in a reach of an ephemeral-stream channel in New Mexico.

Figure 6. An incised channel in southeastern New Mexico with well-defined active-channel reference points (B-B′) but lacking a defined bankfull level.

ACTIVE-CHANNEL GEOMETRY

The geometry of the active channel can be identified and measured at selected sites in virtually all alluvial stream channels although the significance of the measurements at some streams, such as those with a braided channel pattern, may be questioned. Because the active channel is identifiable at almost all channel reaches and because it is indicative of relatively recent conditions of water and sediment discharge, relations presented in this paper are based on active-channel geometry.

Collection and Compilation of Data

Channel surveys were made at continuous-record streamflow-gaging stations with relatively stable channels where channel-geometry reference levels could be identified and where streamflow records provided good estimates of streamflow characteristics. The width and the average depth were measured in feet.

At most sites, samples of bed and bank material were collected from the perimeter of the active channel. Three composite samples were collected, one from portions of material taken at equal intervals across the channel bed and one each taken at intervals up each bank to the reference point.

Streamflow data for this study were tabulated from published records for various gaging stations operated by the U.S. Geological Survey. Values of mean annual runoff for gaged sites are based on the most recent 10 years of streamflow records; flood discharges of specified recurrence interval necessarily were calculated from longer term records. For mean annual runoff in particular, records for the past 10 years can produce results quite different than are obtained from long-term records owing to changes in land- and water-use practices or variation in precipitation patterns. As an example, figure 7 illustrates changes in runoff during 67 years (represented by 38 years of runoff records) for Rio San Jose at Grants, New Mexico. The records show that the mean annual runoff during the 1970 through 1979 water years is less than 4 percent of the mean annual runoff for the long-term (38 years) period of record. The channel width at the Grants site presently reflects recent runoff rates rather than the longer term average (fig. 7).

In the initial regression analyses, a digital computer was used to relate the mean annual runoff and each of the flood-frequency discharges to the channel characteristics. Only the active-channel width provided useable relations, so the data were grouped according to channel-material, and regional-runoff characteristics (whether streamflow is perennial, intermittent, or ephemeral), and reanalyzed. The data were analyzed using a program developed by the University of California School of Medicine (Dixon, 1965). The program provides linear-regression equations with statistical summaries and residuals for the individual input values. The equations for flood discharges provide estimates of discharge rates in cubic feet per second. This unit loses meaning, however, when applied to mean discharges of intermittent and ephemeral streams. Thus, mean annual runoff is used and expressed in acre-feet per year, the depth (in feet) to which the average annual discharge of a stream would cover an area of 1 acre. The coefficients and exponents of some equations were adjusted slightly to provide simplicity and ordered variation among the equations.

Advantages and Disadvantages

Equations for estimating discharge by the channel-geometry technique are defined by data collected from numerous gaged stream sites. The accuracy of the method, therefore, varies with the overall accuracy of the records from which the equations are computed. Both precision and accuracy also depend on the type of stream measured, the discharge parameter being estimated, the regional conditions of climate, geology, and topography, and the experience of the person collecting and applying the data.

Wahl (1977) reported on a test that was made in northern Wyoming to determine how consistently individuals could measure channel geometry for the three different reference levels. Seven participants independently

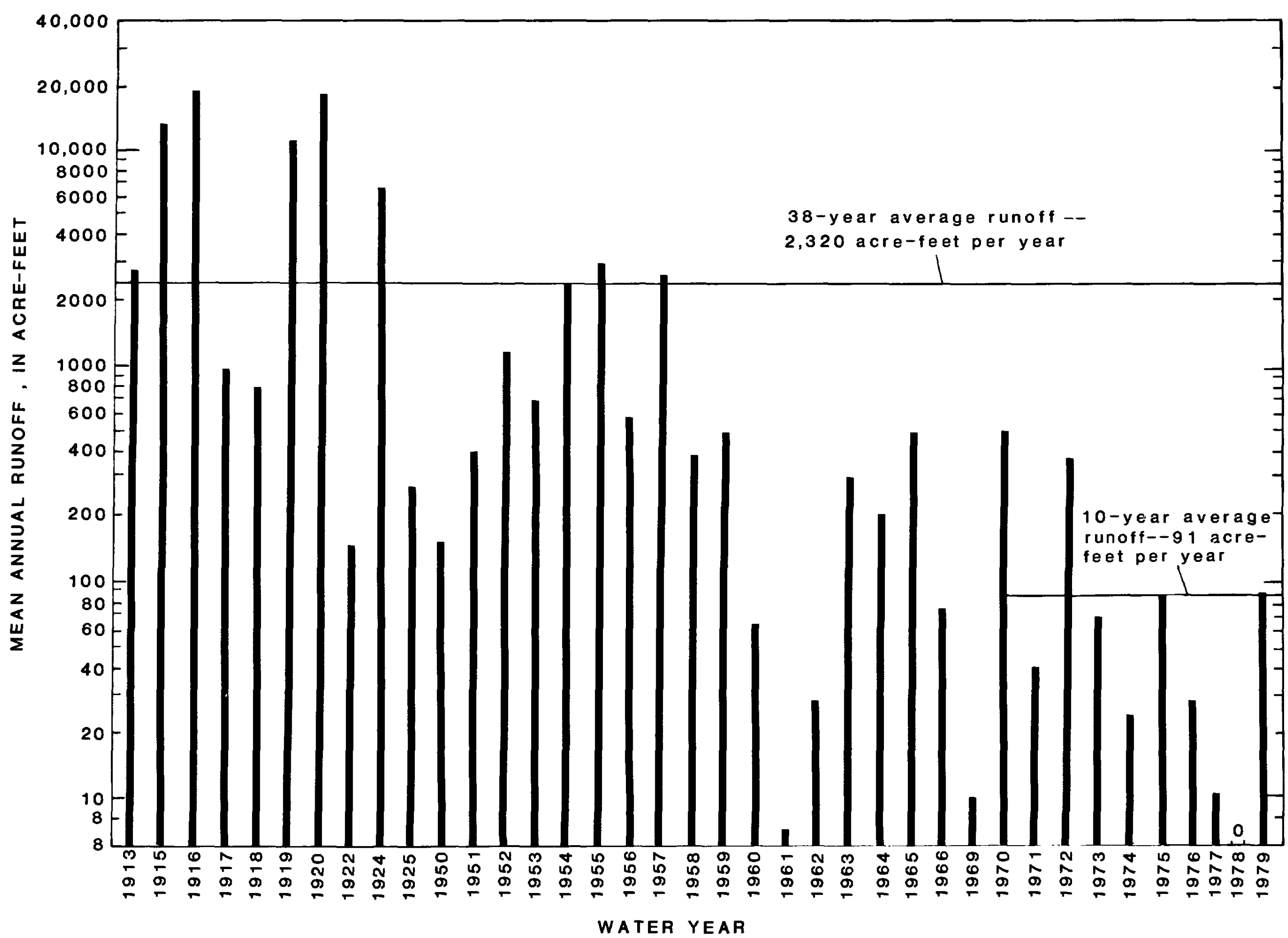

Figure 7. Changes in mean annual runoff, Rio San Jose at Grants, New Mexico.

visited 22 sites and measured the geometry in sections of their choosing. An average standard error for discharge of about 30 percent was attributed to differences in width measurements alone.

The method, as indicated by standard errors of estimate and other statistical measures, is most accurate when applied to perennial streams with stable banks. Examples are upland streams with coarse material (armor) protecting the bed and banks from erosion, and valley streams with well- vegetated banks formed largely of cohesive silt and clay. Conversely, the use of channel geometry probably is least accurate when applied to streams of flashy or erratic discharge (including ephemeral streams) that have sandy, noncohesive banks, and lack of well-developed growth of riparian vegetation.

TYPES AND GROUPINGS OF DATA

The data upon which this study is based are listed in table 1. Each data set is identified by the number and name of the streamflow-gaging station as assigned by the U.S. Geological Survey; the location of each station is indicated in figure 8. Data shown for each station generally include active- channel width, active-channel depth, and sediment characteristics of the channel bed and banks. Discharge characteristics were obtained from the streamflow- and basin-characteristics file of the U.S. Geological Survey, and channel gradients were computed from topographic maps.

All relations provided herein express mean annual runoff (Q_A) or a flood discharge for a specified recurrence interval (Q_n) as the dependent variable. A 5-year flood discharge (Q_5), for example, is the discharge rate which is expected to be equaled or exceeded an average of once every 5 years or has a 20-percent chance of occurring during 1 year. The independent variable for the relations is active-channel width (W_{AC}). All other data provided in table 1 were used in the original multiple-regression analyses and in the final analyses either to classify and group the width-discharge data or to evaluate the reliability of the data.

Owing to the purposes of this study, most data (table 1) pertain to channel sites in arid to semiarid parts of the western United States. Most of the gage sites are located on channels of ephemeral or intermittent streams. Some perennial-stream data are included in table 1, but most of these data were collected in mountainous and other upland areas where snowmelt and relatively large precipitation rates sustain perennial streamflow in an otherwise water-deficient region. The data of table 1, therefore, are used primarily to define width-discharge relations for channels of ephemeral and intermittent streams.

The width of an alluvial stream channel is a function of the geology and climate of the basin that the channel drains. Because the geologic and climatic conditions of the western United States have wide ranges, the relations of active-channel width with a variable of discharge (Q_2, for example) likewise show large ranges. To permit reasonable estimates of discharges from width, therefore, it is necessary to group data according to the characteristics of climate and geology. The groupings of data for this study rely on differences of flow frequency, channel-material characteristics, and runoff characteristics as reflected in potential evapotranspiration.

Grouping by Flow Frequency

All channel data for this study (table 1) were separated into groups representing perennial, intermittent, or ephemeral streamflow to define annual runoff. Ephemeral streamflow was further subdivided depending on number of flow days per year. Although the percentage of days that streamflow occurs in these channels was a major criterion for grouping, the terms perennial, intermittent, and ephemeral, when related to streamflow, are qualitative and cannot be applied precisely. For the purposes of classifying streamflow, the following definitions (modified from Meinzer, 1923, p. 57–58) were used:

A perennial stream—or stream reach, has measurable surface discharge more than 80 percent of the time. Discharge is at times partly to totally the result of springflow or ground-water seepage because the streambed is lower than surrounding ground-water levels.

An intermittent stream—or stream reach, has surface discharge generally between 10 and 80 percent of the time. Because an intermittent- stream channel is at or near the water-table surface, discharge can be the result of a discontinuous supply from springs or ground-water seepage, a discontinuous supply from surface sources, including runoff of rainfall and seasonal snowmelt, or both. If a channel has sustained periods of no streamflow interrupted by a seasonal period of continuous steamflow, at least 1 month in length, the stream or streams is intermittent.

An ephemeral stream—or stream reach, is one that flows only in direct response to precipitation; measurable discharge generally occurs less than 10 percent of the time. It receives no long-continued supply from melting snow or other surface sources. Because an ephemeral-stream channel is at all times above the water table, it also receives no water from springs or sustained ground-water seepage.

The data sets of table 1 were divided according to the above definitions. The channels of the ephemeral group were divided further into groups having discharge approximately 6 to 9 percent of the time, 2 to 5 percent of the time, and 1 percent of the time or less. Relations between active-channel width and mean discharge were developed for each group. Channels with steady, perennial discharge are shaped by limited discharge ranges, and commonly are narrow relative to mean discharge. An ephemeral stream

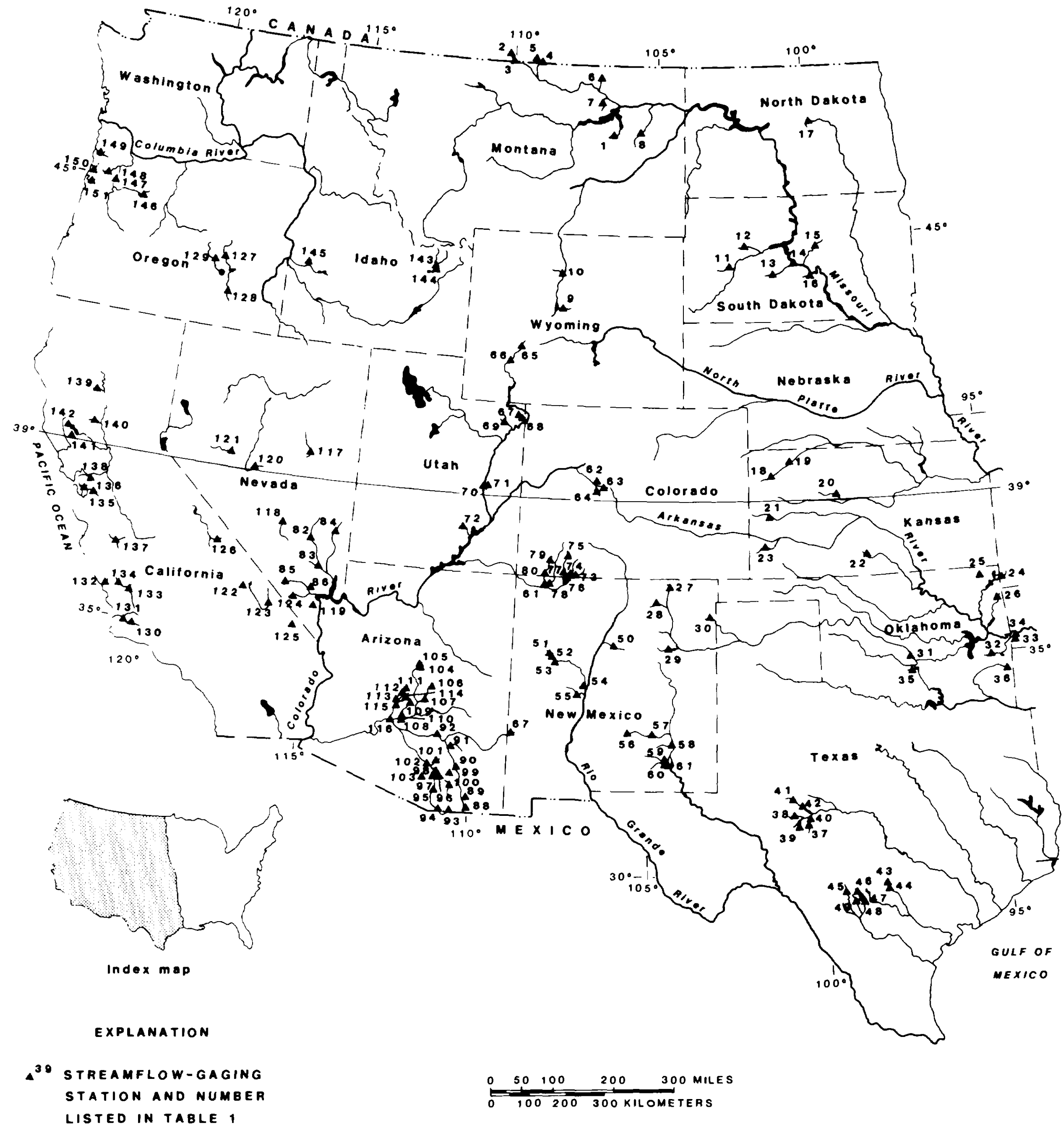

Figure 8. Location of measurement sites.

channel with discharge occurring less than 1 percent of the time, however, is shaped by flow that might occur less frequently than once per year. Owing to the extended no-flow periods, the mean discharge of these channels is very small, and channel widths generally are large relative to mean discharge. The infrequent discharges, however, help shape channels regardless of whether a channel has perennial, intermittent, or ephemeral streamflow. Therefore, it was not necessary to develop separate relations between channel width and flood discharges for the flow-frequency groups.

Table 1. Channel and streamflow characteristics at selected gaging stations.

WAC, WIDTH OF ACTIVE CHANNEL, IN FEET; DAC, DEPTH OF ACTIVE CHANNEL, IN FEET; BDS, BED SILT-CLAY, IN PERCENT; D50, MEDIAN PARTICLE SIZE OF BED MATERIAL, IN MILLIMETERS; BSH, BANK SILT-CLAY-HIGH, IN PERCENT; NF, NO-FLOW DAYS, IN PERCENT; RL, RECORD LENGTH, IN WATER YEARS; DA, DRAINAGE AREA, IN SQUARE MILES; GRA, CHANNEL GRADIENT, IN FEET PER FOOT.

MAP NO	STATION NO	STATION NAME	WAC	DAC	BDS	D50	BSH	NF	RL	DA	GRA
1	06131000	BIG DRY CR NR VAN NORMAN, MT	91	1.70	6	1.0	44	21	34	2554	.00230
2	06135500	SAGE CR AT Q RANCH NR WILD HORSE, ALBERTA	9.0	1.58	14	.78	60	76	44	175	
3	06136000	SAGE CR AT INTERNAT BOUNDARY	15	1.26	57	.05	61	74	33	220	
4	06150500	E FK BATTLE CR NR INTERNAT BOUNDARY	15	2.86	6	3.5	60	90	50	89.5	
5	06151000	LYONS CR AT INTERNAT BOUNDARY	16	1.61	24	.32	54	89	52	66.7	
6	06170200	WILLOW CR NR HINSDALE, MT	37	3.05	41	.08	68	68	8	283	.00075
7	06174000	WILLOW CR NR GLASGOW, MT	20	1.98	59	.04	76	56	24	538	.00060
8	06177500	REDWATER R AT CIRCLE, MT	9.4	2.60	27	.14	68	29	39	547	.00089
9	06256900	DRY CR NR BONNEVILLE, WY	14	.79				73	11	52.6	.00810
10	06268500	FIFTEEN MILE CR NR WORLAND, WY	28	2.49				70	21	518	.00260
11	06425500	ELK CR NR ELM SPRINGS, SD	34	.85	89	.06	6	45	28	540	.00160
12	06439000	CHERRY CR NR PLAINVIEW, SD	44		6	5.8	83	65	32	1190	.00240
13	06441000	BAD R AT MIDLAND, SD	42	2.56	3	7.4	94	51	32	1460	.00120
14	06441500	BAD R NR FORT PIERRE, SD	63	2.94				49	48	3107	.00097
15	06442000	MEDICINE KNOLL CR NR BLUNT, SD	14	.89	7	2.5	8	82	27	317	.00024
16	06442500	MEDICINE CR AT KENNEBEC, SD	20	1.94	27	.12	56	77	23	465	
17	06467600	JAMES R NR MANFRED, ND	6.0	.65	40	100	30	60	19	253	.00047
18	06844700	S FK SAPPA CR NR BREWSTER, KS	28	1.35				98	11	74.0	.00098
19	06944900	S FK SAPPA CR NR ACHILLES, KS	19	2.28				69	19	446	.00120
20	06863900	N FK BIG CR NR VICTORIA, KS	12	1.80	26	2.6	97	63	16	54	.00120
21	07138650	WHITEWOMAN CR NR LEOTI, KS	26	.98	37	.54	86	98	12	750	.00130
22	07144850	S FK S FK NINNESCAH R NR PRATT, KS	44	1.44	55	.05	58	93	17	21	.00190
23	07156220	BEAR CR NR JOHNSON, KS	51	1.03	43	.08	69	97	12	835	.00180
24	07188500	LOST CR AT SENECA, MO	31	1.79	3	25	39	0	11	42	.00210
25	07190600	BIG CABIN CR NR PYRAMID CORNERS, OK	23	2.07	17	2.0	36	25	9	71.1	.00077
26	07196000	FLINT CR NR KANSAS, OK	72	1.95	0	16	30	0	19	110	.00180
27	07199000	CANADIAN R NR HEBRON, NM	71			.20		6	31	229	.00540
28	07207000	CIMARRON R NR CIMARRON, NM	17	1.19		50		0	27	294	.01410
29	07222500	CONCHAS R NR VARIADERO, NM	62	1.85		.20		28	41	523	
30	07227200	TRAMPEROS CR NR STEAD, NM	76	1.50				72	11	556	.00240
31	07229300	WALNUT CR AT PURCELL, OK	77	2.37	0	.34	78	0	10	202	.00100
32	07247500	FOURCHE MALINE NR RED OAK, OK	35				78	2	37	122	
33	07249400	JAMES FK NR HACKETT, AR	58	5.00			76	2	19	147	.00057
34	07249500	COVE CR NR LEE CR, AR	45	1.99		50	15	4	20	35.3	.00360
35	07329500	RUSH CR NR MAYSVILLE, OK	32	1.73	2	.31	75	10	21	206	.00140
36	07335700	KIAMICHI R NR BIG CEDAR, OK	69	3.02		50	23	6	10	40.1	
37	08128000	S CONCHO R AT CHRISTOVAL, TX	25	1.90	2	10	25	0	47	409	.00150
38	08128400	M CONCHO R AB TANKERSLEY, TX	72	3.20	1	7.0	56	22	16	2436	.00140
39	08130500	DOVE CR AT KNICKERBOCKER, TX	23	2.80	2	11	70	0	17	229	.00200
40	08131400	PECAN CR NR SAN ANGELO, TX	14	.82	0	50	17	61	16	83.2	
41	08133500	N CONCHO R AT STERLING CITY, TX	16	1.34	6	6.2	31	72	38	605	
42	08134000	N CONCHO R NR CARLSBAD, TX	33	1.94	2	3.8	46	69	53	605	.00180
43	08184000	CIBOLO CR NR BULVERDE, TX	42	1.47	5	4.0	25	94	19	198	.00130
44	08185000	CIBOLO CR AT SELMA, TX	46	2.27				87	31	274	.00190
45	08198000	SABINAL R NR SABINAL, TX	49	2.81				0	35	206	.00210
46	08200000	HONDO CR NR TARPLEY, TX	85	1.90	0	14	28	0	25	86.2	.00200
47	08200500	HONDO CR NR HONDO, TX	62	1.00				85	12	132	.00250
48	08200700	HONDO CR AT KING WATERHOLE NR HONDO, TX	50	1.84	0	50	17	44	17	142	
49	08202700	SECO CR AT ROWE RANCH NR D'HANIS, TX	72	1.02		10		94	16	168	.00170
50	08318000	GALISTEO CR AT DOMINGO, NM	154	0.70	0	.66		72	26	640	.00310
51	08343000	RIO SAN JOSE AT GRANTS, NM	5.2	.65	53	.06	54	96	34	1020	.00500
52	08343100	GRANTS CANYON AT GRANTS, NM	12	.52	15	.18	37	98	14	13.0	.00560
53	08343500	RIO SAN JOSE NR GRANTS, NM	15					0	39	2300	.00500
54	08353000	RIO PUERCO NR BERNADO, NM	63	.66	37	.09	57	69	35	7350	.00098
55	08355300	ARROYO DE LA MATANZA NR SOCORRO, NM	28	2.19				95	6	46.0	.01600
56	08387000	RIO RUIDOSO AT HOLLYWOOD, NM	16	1.50				0	22	120	.00430
57	08390500	RIO HONDO NR ROSWELL, NM	16	2.00				75	36	947	.00330
58	08394500	RIO FELIX NR HAGERMAN, NM	42	2.50				87	36	932	.00270
59	08398500	RIO PENASCO AT DAYTON, NM	24	1.00				89	24	1060	.00360
60	08400000	FOURMILE DRAW NR LAKEWOOD, NM	22	1.00				99	24	265	.00350
61	08401200	S SEVEN RS NR LAKEWOOD, NM	20	1.00				98	12	220	.00450
62	09073400	ROARING FK R NR ASPEN, CO	39	1.50	0	1.3		0	13	108	.01090
63	09074800	CASTLE CR AB ASPEN, CO	23	1.30	0	30		0	8	32.2	.03330
64	09075700	MAROON CR AB ASPEN, CO	31	2.00				0	8	35.4	.02600
65	09215000	PACIFIC CR NR FARSON, WY	18	.80				69	19	500	
66	09216000	BIG SANDY R BL EDEN, WY	51	2.23				0	24	1610	
67	09235600	POT CR AB DIVERSIONS, NR VERNAL, UT	5.8	1.43	34	.16	59	34	19	25	.00540
68	09235800	POT CR NR VERNAL, UT	6.0	.77			72	51	19	106	.00540
69	09270500	DRY FK AT MOUTH, NR DRY FK, UT	60					0	22	116	.02400
70	09315500	SALERATUS WASH AT GREEN R, UT	30	1.93	2	.57	55	34	22	180	.00350

Table 1. Channel and streamflow characteristics at selected gaging stations—Continued

QA, AVERAGE ANNUAL RUNOFF, IN ACRE-FEET; QN, FLOOD DISCHARGE OF SPECIFIC RECURRENCE INTERVAL; N EQUALS 2, 5, 10, 25, 50, OR 100 YEARS, IN CUBIC FEET PER SECOND; PA, AVERAGE ANNUAL PRECIPITATION, IN INCHES; P2-24, 2-YEAR, 24-HOUR PRECIPITATION, IN INCHES.

MAP NO	STATION NO	QA	Q2	Q5	Q10	Q25	Q50	Q100	PA	P2-24
1	06131000	36880	2840	8290	14100	24400	34400	46400	11.0	1.30
2	06135500	5520	579	1470	2330	3740	5020	6490	13.0	1.60
3	06136000	730	29	43	52	63	71	80	13.0	1.60
4	06150500	2120	329	782	1190	1800	2330	2910	12.0	1.60
5	06151000	1040	220	512	773	1170	1510	1890	12.0	1.60
6	06170200	15720							12.0	1.60
7	06174000	51510	2690	7170	11800	19700	27400	36500	12.0	1.80
8	**06177500**	**9930**	**758**	**3460**	**7080**	**14300**	**21900**	**31400**	**13.0**	**1.40**
9	**06256900**	**2210**	**209**	**598**	**1020**	**1800**	**2570**	**3550**	**6.9**	**1.00**
10	06268500	7900	1090	1790	2340	3130	3780	4490	7.2	1.20
11	06425500	18480	1290	3060	4880	8130	11400	15500	16.9	2.00
12	06439000	33760	1470	3670	6120	10300	14300	19300	13.3	2.00
13	06441000	35070	2550	5060	7420	11400	15200	19900	15.9	2.20
14	06441500	93460	6120	13900	21700	35100	48200		16.3	2.20
15	06442000	2930	73	442	1110	2950	5510	9600	17.4	2.30
16	06442500	10360	539	1600	2880	5490	8400	12400	17.5	2.30
17	06467600	2760	103	310	525	887	1220	1610	16.6	1.80
18	06844700	127	65	265	548	1180	1930	3000	19.5	2.30
19	06944900	2530	456	1440	2620	4930	7410	10700	19.5	2.30
20	06863900	3160	464	1380	2440	4480	6640	9460	24.0	2.60
21	07138650	659	661	1600	2530	4100	5580	7360	17.0	2.40
22	07144850	3040	519	1730	3200	6050	9070	13000	24.0	3.00
23	07156220	2120	829	2800	5230	10100	15400	22500	16.0	2.40
24	07188500	20340	956	3270	5970	11000	16100	22500	42.5	4.00
25	07190600	22750	4720	9010	12300	17100	20900	25000	41.0	4.00
26	07196000	82590	4560	11300	17600	27600	36600	46700	44.5	4.10
27	07199000	3590	2660	6400	10100	16400	22300	29500	18.0	2.35
28	07207000	14490	349	773	1160	1790	2360	3030	20.0	2.00
29	07222500	6570	3630	8860	14400	24300	34300	47000	15.0	2.00
30	07227200	3170	652	6710	22400	90200	182000	378000	16.0	2.26
31	07229300	39340	9400	15100	19200	24500	28600	32700	33.0	3.75
32	07247500	107950	6360	12300	17200	24200	30000	36200	43.9	4.10
33	07249400	94910	7080	13300	18100	24700	30000	35500	43.0	4.00
34	07249500	27460	5530	10600	14700	20300	24800	29600	48.0	4.00
35	07329500	38470	7340	13500	18400	25200	30700	36500	34.0	3.75
36	07335700	54050	9630	14800	18300	22700	25900	29100	52.0	4.25
37	08128000	26520	2850	16600	37300	82000	131000	194000	16.5	3.30
38	08128400	17460	1990	5870	10100	17900	25700	35300	20.0	3.50
39	08130500	19560	2370	6310	10320	17220	23780	31630	18.0	3.30
40	08131400	1530	458	1580	3140	6670	11000	17500	18.0	3.80
41	08133500	2610	2110	5630	9200	15300	21000	27800	18.0	3.00
42	08134000	8620	6250	21600	38100	66200	91800	121000	20.0	3.10
43	08184000	7240	2510	8610	15800	29600	43600	61300	32.5	3.90
44	08185000	11300	4140	21300	36500	53800	63600	71000	28.5	3.90
45	08198000	62090	4040	14100	26100	48900	72200	102000	25.0	3.70
46	08200000	38470	6490	18000	29700	49900	69000	91700	32.6	3.80
47	08200500	12020	5210	17900	33100	62200	92400	131000	28.0	3.80
48	08200700	15360	8490	18600	27500	41100	52700	65700	25.0	3.80
49	08202700	9420	3000	9460	17700	35100	55200	83700	25.0	3.80
50	08318000	7390	6310	11000	14700	19900	24300	29000	13.0	1.51
51	08343000	188							10.0	1.50
52	08343100	101	327	762	1190	1900	2570	3380	10.0	1.50
53	08343500	4670	231	581	942	1580	2200	2970	10.0	1.50
54	08353000	26520	4420	7960	10800	14900	18300	22000	10.0	1.22
55	08355300	315	478	1400	2450	4410	6440	9030	10.0	1.50
56	08387000	12030	215	417	590	853	1080	1340	25.0	1.87
57	08390500	7610	2950	8480	14900	27200	40200	57500	18.0	1.92
58	08394500	8170	5030	15800	25100	37900	47200	56000	16.0	1.98
59	08398500	3330	2770	7970	13800	24700	36000	50500	18.0	2.02
60	08400000	2930	470	3650	9620	25200	45000	74100	14.0	2.00
61	08401200	2330	2610	11900	26100	60400	104000	168000	14.0	2.00
62	09073400	60400	733	970	1110	1280	1390	1500	20.0	1.40
63	09074800	27310	340	390	417	447	466	484	20.0	1.40
64	09075700	42460	508	592	638	688	721	751	20.0	1.40
65	09215000	3620	258	555	808	1180	1500	1840	8.7	1.00
66	09216000	42600	500	840	1080	1390	1620	1850	10.0	1.50
67	09235600	2910	66	136	193	274	340	409	20.0	1.00
68	09235800	1440	49	117	178	272	354	443	20.0	1.00
69	09270500	25290	463	945	1350	1950	2460	3020	20.0	1.50
70	09315500	2170	2490	4770	6620	9290	11500		7.5	.97

Table 1. Channel and streamflow characteristics at selected gaging stations—Continued

WAC, WIDTH OF ACTIVE CHANNEL, IN FEET; DAC, DEPTH OF ACTIVE CHANNEL, IN FEET; BDS, BED SILT-CLAY, IN PERCENT; D50, MEDIAN PARTICLE SIZE OF BED MATERIAL, IN MILLIMETERS; BSH, BANK SILT-CLAY-HIGH, IN PERCENT; NF, NO-FLOW DAYS, IN PERCENT; RL, RECORD LENGTH, IN WATER YEARS; DA, DRAINAGE AREA, IN SQUARE MILES; GRA, CHANNEL GRADIENT, IN FEET PER FEET

MAP NO	STATION NO	STATION NAME	WAC	DAC	BDS	D50	BSH	NF	RL	DA	GRA
71	09316000	BROWNS WASH NR GREEN R, UT	46	1.34	21	.19	53	95	19	75	.00700
72	09334000	N WASH NR HANKSVILLE, UT	63	1.50	4	3.6	29	54	20	136	.01200
73	09346400	SAN JUAN R NR CARACCAS, CO	133	4.10	1	25	46	0	14	25.3	.00340
74	09349800	PEIDRA R NR ARBOLES, CO	79	2.16	0	25	79	0	15	629	.00430
75	09352900	VALLECITO CR NR BAYFIELD, CO	64	1.97	0	100		0	15	72.1	.02600
76	09354500	LOS PINOS R AT LA BOCA, CO	65	1.64	0	20	50	0	27	510	.00680
77	09355000	SPRING CR AT LA BOCA, CO	37	1.95	6	.25	56	0	27	58	.00720
78	09364500	ANIMAS R AT FARMINGTON, NM	160	3.85				0	64	1360	.00430
79	09365500	LAPLATA R AT HESPERUS, CO	24	.82		20		0	61	37	.01600
80	09366500	LA PLATA R AT CO-NM STATE LINE	26	1.41				2	57	331	.00530
81	09367500	LA PLATA R NR FARMINGTON, NM	28	1.46	3	.43	43	5	37	583	.00540
82	09415600	PAHRAGUT VALLEY TRIB NR HIKO, NV	16	.91	10	2.3	12	100	14	17	.01200
83	09416000	MUDDY R NR MOAPA, NV	24	3.50	16	.09	54	0	39	3820	.00400
84	09418500	MEADOW VALLEY WASH NR CALIENTE, NV	21	1.44	1	70	61	0	21	1670	.00900
85	09419610	LEE CANYON NR CHARLESTON PEAK, NV	26	1.15	0	18	33	0	14	9.2	.06700
86	09419650	LAS VEGAS WASH AT N LAS VEGAS, NV	76	.41	12	.15	72	90	15	1300	.00500
87	09444000	SAN FRANCISCO R NR GLENWOOD, NM	64	1.80				0	48	1653	.00620
88	09470500	SAN PEDRO R AT PALOMINAS, AZ	64	1.65	2	.45	74	18	35	741	.00140
89	09471000	SAN PEDRO R AT CHARLESTON, AZ	91	1.52	2	.51	74	0	66	1219	.00240
90	09472000	SAN PEDRO R NR REDINGTON, AZ	72	2.53	1	1.4	34	41	23	2939	.00380
91	09473000	ARAVAIPA CR NR MAMMOTH, AZ	93	1.35	0	14	40	0	22	541	.00590
92	09474000	GILA R AT KELVIN, AZ	91	2.50	0	.84	52	0	66	8011	.00230
93	09480000	SANTA CRUZ R NR LOCHIEL, AZ	51	1.09	2	1.4	43	6	28	82.2	
94	09480500	SANTA CRUZ R NR NOGALES, AZ	350		1	1.1	80	24	58	533	.00390
95	09482000	SANTA CRUZ R AT CONTINENTAL, AZ	99	2.18			78	89	32	1662	.00810
96	09482400	AIRPORT WASH AT TUCSON, AZ	26	.83			41	95	12	23	.00620
97	09482500	SANTA CRUZ R AT TUCSON, AZ	46	1.59	4	.50	67	85	72	2222	.00310
98	09483000	TUCSON ARROYO AT VINE AVE., TUCSON, AZ	21	1.07	2	1.2	64	82	21	8.2	.00750
99	09483100	TANQUE VERDE CR NR TUCSON, AZ	21	1.27	1	1.8	29	48	11	43.0	.03000
100	09484560	CIENEGA CR NR PANTANO, AZ	93	1.22	11	2.0	57	94	8	289	
101	09486300	CANADA DEL ORO NR TUCSON, AZ	70	.75	7	.88	19	97	12	250	.00720
102	09486500	SANTA CRUZ R AT CORTARO, AZ	101	.67	3	.54	61	11	34	3503	.00260
103	09486800	ALTAR WASH NR THREE POINTS, AZ	185	1.20	5	.82	76	93	10	463	.00440
104	09505250	RED TANK DRAW NR RIMROCK, AZ	35	1.38	2	200	50	56	20	49.4	.02100
105	09505350	DRY BEAVER CR NR RIMROCK, AZ	95	1.97	0	15	4	72	17	142	.01100
106	09510100	E FK SYCAMORE CR NR SUNFLOWER, AZ	22	1.30	1	10	18	27	16	4.49	.03700
107	09510200	SYCAMORE CR NR FORT MCDONALD, AZ	58	.85	0	3.3	64	3	16	164	.00970
108	09512200	SALT R TRIB AT PHOENIX, AZ	29	.44	2	2.8	52	99	16	1.75	.01600
109	09512300	CAVE CR NR CAVE CR, AZ	70	1.40	1	3.1	47	96	7	121	.00830
110	09512400	CAVE CR AT PHOENIX, AZ	32	2.75	1	.71	43	97	20	252	.00490
111	09513780	NEW R NR ROCK SPRINGS, AZ	55	2.40	0	1.6	4	71	12	67.3	.00850
112	09513800	NEW R AT NEW RIVER, AZ	145	3.00	2	.76	8	79	16	83.3	.00520
113	09513835	NEW R NR PEORIA, AZ	162	2.00	1	.70	60	98	10	187	.00460
114	09513860	SKUNK CR NR PHOENIX, AZ	56	1.65	7	.26	25	98	10	64.6	.00570
115	09513910	NEW R AT GLENDALE, AZ	460	2.50	9	.35	27	96	6	323	.00320
116	09513970	AGUA FRIA R AT AVONDALE, AZ	430	2.50	2	.39	31	0	9	2013	.00120
117	10245800	NEWARK VALLEY TRIB NR HAMILTON, NV	7.7	.43	63	.04	87	97	15	157	
118	10247860	PENOYER VALLEY TRIB NR TEMPIUTE, NV	12	.94	5	2.1	27	0	12	1.48	.02000
119	10248510	ELDORADO VALLEY TRIB NR NELSON, NV	17	.32		6.1		0	12	1.41	.03700
120	10249300	S TWIN R NR ROUND MOUNTAIN, NV	12	1.15	0	30	40	0	12	20	.03500
121	10249411	CAMPBELL CR TRIB NR EASTGATE, NV	2.8	.28	0	15	75	76	14	2.14	.01300
122	10250600	WILDROSE CR NR WILDROSE STATION, CA	26	1.22	0	7.6	61	0	10	23.7	.06300
123	10251300	AMARGOSA R AT TECOPA, CA	7.9	2.00	47	.06	90	21	15		.00900
124	10251980	LOVELL WASH NR BLUE DIAMOND, NV	15	.75	0	14	8	96	11	52.8	
125	10252300	CHINA SPRING CR NR MOUNTAIN PASS, CA	8.6	.54	2	2.1	13	0	11	.94	
126	10282480	MAZOURKA CR NR INDEPENDENCE, CA	90	1.00		20		0	10	15.6	.08000
127	10393500	SILVIES R NR BURNS, OR	52	5.00				0	64	934	.00069
128	10396000	DONNER UND BLITZEN R NR FRENCHGLEN, OR	56	4.00				0	47	200	.00260
129	10403000	SILVER CR NR RILEY, OR	26	1.34				0	26	228	
130	11139000	LABREA CR NR SISQUOC, CA	42	1.00	6	.58		79	22	93.8	.00800
131	11140000	SISQUOC R NR GAREY, CA	265	1.50	2	.41	13	83	36	471	.00310
132	11142500	ARROYO DE LA CRUZ NR SAN SIMEON, CA	78	2.78	1	10	33	54	27	41.2	.00340
133	11147800	CHOLAME CR NR SHANDON, CA	55	1.10	2	.42	71	92	12	227	.00230
134	11148500	ESTRELLA R NR ESTRELLA, CA	185	1.80	4	.30	53	69	23	922	.00270
135	11176000	ARROYO MOCHO NR LIVERMORE, CA	7.1	.96		5.0	18	25	32	38.2	.00640
136	11180500	DRY CR AT UNION CITY, CA	25	3.09	2	2.7	47	63	21	9.39	.00420
137	11255500	PANOCHE CR BL SILVER CR, NR PANOCHE, CA	40	.75	4	.56	27	58	11	293	.00640
138	11337500	MARSH CR NR BYRON, CA	28	1.37	0	14	56	67	22	42.6	.00510
139	11378800	RED BANK CR NR RED BLUFF, CA	99	2.18	0	12	78	52	17	93.5	
140	11390672	STONE CORRAL CR NR SITES, CA	16	1.88	10	.36	54	62	17	38.2	.00310

Table 1. Channel and streamflow characteristics at selected gaging stations—Continued

QA, AVERAGE ANNUAL RUNOFF, IN ACRE-FEET; QN, FLOOD DISCHARGE OF SPECIFIC RECURRENCE INTERVAL; N EQUALS 2, 5, 10, 25, 50, OR 100 YEARS, IN CUBIC FEET PER SECOND; PA, AVERAGE ANNUAL PRECIPITATION, IN INCHES; P2-24, 2-YEAR, 24-HOUR PRECIPITATION, IN INCHES.

MAP NO	STATION NO	QA	Q2	Q5	Q10	Q25	Q50	Q100	PA	P2-24
71	09316000	688	1700	3550	5130	7500	9530	11800	7.5	1.00
72	09334000	869	1180	3070	5000	8340	15400	20100	10.0	1.15
73	09346400	384710	3800	5940	7470	9510	11100	12700	30.0	1.80
74	09349800	251400	2290	3940	5140	6740	7960	9200	27.0	1.70
75	09352900	98530	1320	2110	2660	3370	3890	4410	46.0	2.60
76	09354500	157200	1340	2330	3090	4170	5050	5990	12.0	1.40
77	09355000	23470	335	638	882	1240	1550	1880	12.0	1.39
78	09364500	566600	6120	9190	11400	14200	16400	18700	29.0	1.50
79	09365500	27460	452	772	1000	1310	1550	1800	35.0	2.20
80	09366500	23330	766	1560	2240	3240	4100	5040	35.0	1.60
81	09367500	17170	1250	2220	2990	4090	5000	5990	29.0	1.50
82	09415600	1.4							10.0	1.30
83	09416000	29420	209	548	916	1600	2300	3190	6.3	1.30
84	09418500	8550	474	1060	1610	2530	3380	4380	7.5	1.30
85	09419610	13	24	169	464	1360	2740	5130	19.5	1.70
86	09419650	643	180	1150	3040	8550	16700	30400	6.0	1.40
87	09444000	57310	2540	5110	7310	10700	13600	16800	17.6	1.80
88	09470500	21080	6370	10200	12900	16500	19300	22200	17.9	1.90
89	09471000	33760	6920	12500	17800	26700	35300	45900	16.5	1.90
90	09472000	25860	8710	16800	23400	33100	41400	50400	15.5	1.90
91	09473000	15360	4560	8820	12300	17200	21300	25700	16.2	2.00
92	09474000	267300	21400	45600	66600	98400	126000	156000	20.0	2.50
93	09480000	1930	1700	3510	5040	7330	9270	11400	18.2	1.90
94	09480500	20580	4320	7930	10900	15200	18800	22900	18.7	2.00
95	09482000	12530	4460	8630	12000	17000	21100	25500	18.1	2.10
96	09482400	329	320	572	764	1030	1240	1470	10.8	1.80
97	09482500	13040	5140	8820	11600	15600	18800	22100	16.9	2.10
98	09483000	650	1000	2300	3300	4400	5500	6900	11.0	1.80
99	09483100	6430	1040	2020	2810	3970	4920	5950	17.0	2.00
100	09484560	1700	920	2690	4600	8000	11300	15400	16.6	1.90
101	09486300	6590	2180	5450	8610	13800	18600	24200	16.4	2.00
102	09486500	41730	8340	13200	16600	21000	24200	27500	16.3	2.00
103	09486800	5400	5700	10100	13500	18100	21800	25600	15.6	2.20
104	09505250	6220	507	2340	5130	11700	19700	31400	21.6	2.40
105	09505350	28040	2880	8550	14900	26700	38700	53900	23.1	2.50
106	09510100	484	30	158	362	850	1460	2340	24.5	3.00
107	09510200	18480	1660	5650	10400	19600	29100	41400	21.2	2.70
108	09512200	4.4	35	181	418	1010	1760	2900	9.0	1.60
109	09512300	2770	2010	4900	7730	12500	16900	22200	15.7	2.30
110	09512400	3280	417	1200	2040	3540	5030	6870	9.0	1.60
111	09513780	7140	1580	5760	11100	22300	34700	51500	20.0	2.40
112	09513800	7610	2100	7220	13600	26400	40300	58800	19.5	2.30
113	09513835	5750	1470	5110	9650	18800	28800	42100	15.6	1.90
114	09513860	1130	1200	4750	9600	20100	32100	48900	12.2	1.90
115	09513910	8190	2390	8380	15900	31100	47600	69600	13.8	1.80
116	09513970	6670	249	2400	7550	24900	53000	103000	16.3	1.70
117	10245800	120	23	95	202	448	749	1190	10.3	1.20
118	10247860	1.4	.5	8.2	37	185	524	1340	8.0	1.10
119	10248510	5.8	2.8	62	320	1820	5620	15500	6.0	1.30
120	10249300	4950	38	79	116	175	228	289	15.4	1.60
121	10249411	55	3.5	20	51	135	253	447	16.0	1.50
122	10250600	20	8.2	166	705	3000	7290		8.0	1.10
123	10251300	1990	234	972	2050	4540	7580	12000	4.0	1.10
124	10251980	198	40	411	1390	5130	11900	25400	9.0	1.70
125	10252300	.6	3.0	22	47	100			7.0	1.10
126	10282480	61							6.0	1.40
127	10393500	134000	1280	2130	2760	3620	4310	5030	19.0	1.00
128	10396000	94190	1270	2030	2570	3270	3810	4350	14.0	1.00
129	10403000	31590	552	1030	1430	2020	2530	3090	20.0	1.00
130	11139000	2930	169	951	2350				23.0	3.20
131	11140000	45720	1290	5130	10500	22200	36000	54400	20.0	3.50
132	11142500	42240	7590	14600	19800	26600	31700	36700	31.0	3.50
133	11147800	4880	113	1190	3740	12000	24600	46100	10.0	1.50
134	11148500	40140	387	2810	7020	17000	28800	44900	13.0	1.90
135	11176000	3780	167	574	1010	1760	2450	3220	16.0	3.50
136	11180500	2480	136	568	1100	2090	3050	4200	22.0	2.90
137	11255500	1340	290	1670	3750	8220	13100	19400	14.0	2.00
138	11337500	6570	459	1650	2970	5250	7370	9810	16.0	2.30
139	11378800	42380	4180	7080	9240	12200	14500	17000	26.0	3.00
140	11390672	4380	1180	2450	3540	5160	6550	8080	20.0	2.50

Table 1. Channel and streamflow characteristics at selected gaging stations—Continued

WAC, WIDTH OF ACTIVE CHANNEL, IN FEET; DAC, DEPTH OF ACTIVE CHANNEL, IN FEET; BDS, BED SILT-CLAY, IN PERCENT; D50, MEDIAN PARTICLE SIZE OF BED MATERIAL, IN MILLIMETERS; BSH, BANK SILT-CLAY-HIGH, IN PERCENT; NF, NO-FLOW DAYS, IN PERCENT; RL, RECORD LENGTH, IN WATER YEARS; DA, DRAINAGE AREA, IN SQUARE MILES; GRA, CHANNEL GRADIENT, IN FEET PER FEET

MAP NO	STATION NO	STATION NAME	WAC	DAC	BDS	D50	BSH	NF	RL	DA	GRA
141	11448500	ADOBE CR NR KELSEYVILLE, CA	22	.99	0	15	59	35	22	6.36	.00440
142	11449100	SCOTTS CR NR LAKEPORT, CA	42	2.76	0	8.6	32	46	16	55.2	.00210
143	13112000	CAMAS CR AT CAMAS, ID	31	1.57				29	50	400	
144	13114000	BEAVER CR AT CAMAS, ID	15	1.10				85	49	510	
145	13207000	SPRING VALLEY CR NR EAGLE, ID	9.0	.60				48	16	20.9	
146	14179000	BREITENBUSH R AB CANYON CR, NR DETROIT, OR	123	2.60		50		0	45	106	.01200
147	14192000	MILL CR AT SALEM, OR	45	2.01				0	38	110	.00160
148	14193000	WILLAMINA CR NR WILLAMINA, OR	64	2.77				0	43	64.7	.00350
149	14301500	WILSON R NR TILLAMOOK, OR	125	3.10		25		0	47	161	.00120
150	14303600	NESTUCCA R NR BEAVER, OR	150	3.61				0	13	180	.00370
151	14305500	SILETZ R AT SILETZ, OR	130	4.32		10		0	58	202	.00160

Grouping by Channel-Material Characteristics

Channel-geometry studies for the Rocky Mountain States and the Missouri River basin (Osterkamp and Hedman, 1977; 1982) indicate that width-discharge relations of perennial-stream channels vary measurably with the channel- material characteristics. In general, streams that transport predominantly fine-grained material (silt and clay) form relatively narrow and deep channel sections with cohesive banks of fine material. Predominantly sandy channels tend to be wide and shallow, the banks lacking the cohesiveness necessary to resist erosive discharges and maintain a stable, well-defined shape. Channels armored with increasingly larger material sizes (gravel through boulders) tend to have the narrow shape, relative to mean annual runoff, of the fine-grained channel sections. Armored streams (generally alpine streams in these studies) have relative narrowness and pronounced stability because the material forming the channel perimeter is immobile except during uncommonly large flows. The armor, that is the coarse-material sizes, provides the same stabilizing effect for these channels as does the cohesiveness of silt-clay channels.

The data collected for this study are sufficient to define three groups of channels: (1) silt-clay channels—those with a median-particle size (d_{50}) of the bed material of less than 0.1 mm (millimeter) or a bank- material silt-clay content of at least 70 percent and a d_{50} of the bed material of no greater than 5.0 mm; (2) sand channels—those with a d_{50} of the bed material ranging from 0.1 to 5.0 mm and silt-clay contents of the banks of less than 70 percent; and (3) armored channels—those with d_{50} of the bed material greater than 5.0 mm.

Separate relations between active-channel width and annual runoff were developed for each of the channel-material groups. The basic equations developed by regression analyses for each flow-frequency group and geographic area were used to define approximately the coefficients and exponents. The separate relations were then developed graphically for the channel-material groups. This procedure was necessary because there were not enough data sets for a regression analysis of each group. Because equivalent standard errors could not be determined for the graphical analyses, the approximate standard errors shown are for the basic regression equations. It is assumed that the standard errors for the separate relations are at least equal to and probably less than those shown. The use of channel-material groups to define relations between active-channel width and flood discharges showed minimal statistical significance, and therefore separate channel-material relations are not included to estimate the flood discharges.

Grouping of Runoff Characteristics

Different groupings of the data sets were made depending upon whether the intended relations estimated mean annual runoff or flood discharge. The intermittent-stream data were divided into northern and southern groups for the purpose of relating width to mean-annual runoff. The two groups are approximately separated by a latitude 39° N. (fig. 9). To develop equations yielding flood-discharge estimates, each data set in table 1 was placed in one of four groups. The first includes alpine and pine-forested drainage areas. The other three groups are defined similarly to those of the mean annual runoff data of intermittent streams. Thus, latitude 39° N. again separates the plains that are east of the Rocky Mountains. A fourth group includes the intermontane areas that are west of the Rocky Mountains.

Regression analyses were made of various groupings of the data in table 1 to yield equations that estimate mean annual runoff and flood discharges. The results provided here represent the groupings of data that appeared to produce the most consistent and statistically significant re-

Table 1. Channel and streamflow characteristics at selected gaging stations—Continued

QA, AVERAGE ANNUAL RUNOFF, IN ACRE-FEET; QN, FLOOD DISCHARGE OF SPECIFIC RECURRENCE INTERVAL; N EQUALS 2, 5, 10, 25, 50, OR 100 YEARS, IN CUBIC FEET PER SECOND; PA, AVERAGE ANNUAL PRECIPITATION, IN INCHES; P2-24, 2-YEAR, 24-HOUR PRECIPITATION, IN INCHES.

MAP NO	STATION NO	QA	Q2	Q5	Q10	Q25	Q50	Q100	PA	P2-24
141	11448500	8980	956	1330	1560	1850	2060	2270	41.0	4.50
142	11449100	62450	4390	7970	10700	14600	17800	21100	30.0	3.00
143	13112000	35650	380	690	910	1180	1390	1590	10.0	1.20
144	13114000	13110	110	170	210	250	280	310	10.0	1.20
145	13207000	1850	52	130	204	326	438	568	14.0	1.30
146	14179000	455700	6260	8890	10700	13100	14900	16700	77.0	3.70
147	14192000	96360							40.0	3.00
148	14193000	205800	3850	5240	6210	7500	8490	9530	87.5	4.90
149	14301500	907100	17400	22600	26000	30100	33200	36300	102.5	5.50
150	14303600	844800	14500	20100	24000	28900	32600	36300	110.0	5.80
151	14305500	1159000	20900	26600	30200	34300	37300	40200	117.7	5.70

sults. In order to develop easily applied equations of general utility, however, the data groupings are intentionally broad and necessarily different for the mean annual runoff and flood-discharge equations.

Users of the equations need to realize that latitude 39° N. and the edges of the Rocky Mountains (fig. 9) are not exact boundaries. These divisions need to be considered transition zones. Because the computed discharge

Table 2. Equations for determining mean annual runoff for streams in western United States.

Flow frequency	Areas of similar regional-runoff characteristics a/	Percentage of time having discharge	Channel-material characteristics b/	Equation c/	Standard error of estimate (percent)	Equation number
Perennial	Alpine	More than 80	Silt-clay and armored	$Q_A = 64W_{AC}^{1.88}$	28	(7)
Intermittent	Plains north of latitude 39°N.	10 to 80	Silt-clay and armored	$Q_A = 40W_{AC}^{1.80}$	50 d/	(8)
			Sand	$Q_A = 40W_{AC}^{1.65}$	50 d/	(9)
	Plains south of latitude 39°N.	10 to 80	Silt-clay and armored	$Q_A = 20W_{AC}^{1.65}$	50 d/	(10)
			Sand	$Q_A = 20W_{AC}^{1.55}$	50 d/	(11)
Ephemeral	Northern and southern plains and intermontaine areas	6 to 9	Silt-clay and armored	$Q_A = 10W_{AC}^{1.55}$	e/	(12)
			Sand	$Q_A = 10W_{AC}^{1.50}$	e/	(13)
		2 to 5	Silt-clay and armored	$Q_A = 4.0W_{AC}^{1.50}$	40 d/	(14)
			Sand	$Q_A = 4.0W_{AC}^{1.40}$	40 d/	(15)
	Deserts of the Southwest	1 or less	Silt-clay and armored	$Q_A = 0.04W_{AC}^{1.75}$	75 d/	(16)
			Sand	$Q_A = 0.04W_{AC}^{1.40}$	75 c/	(17)

a/ Areas of climatic characteristics shown in figure 9.

b/ Silt-clay channels--bed material d_{50} less than 0.1 millimeter or bed material d_{50} equal to or less than 5.0 millimeters and bank silt-clay content equal to or greater than 70 percent.

Sand channels--bed material d_{50} = 0.1-5.0 millimeters and bank silt-clay content less than 70 percent.

Armored channels--bed material d_{50} greater than 5.0 millimeters.

c/ Active-channel width, W_{AC}, in feet; discharge, Q_A, in acre-feet per year.

d/ Approximate--standard error of estimate of the basic regression equation.

e/ Standard error of estimate not determined; graphical analyses.

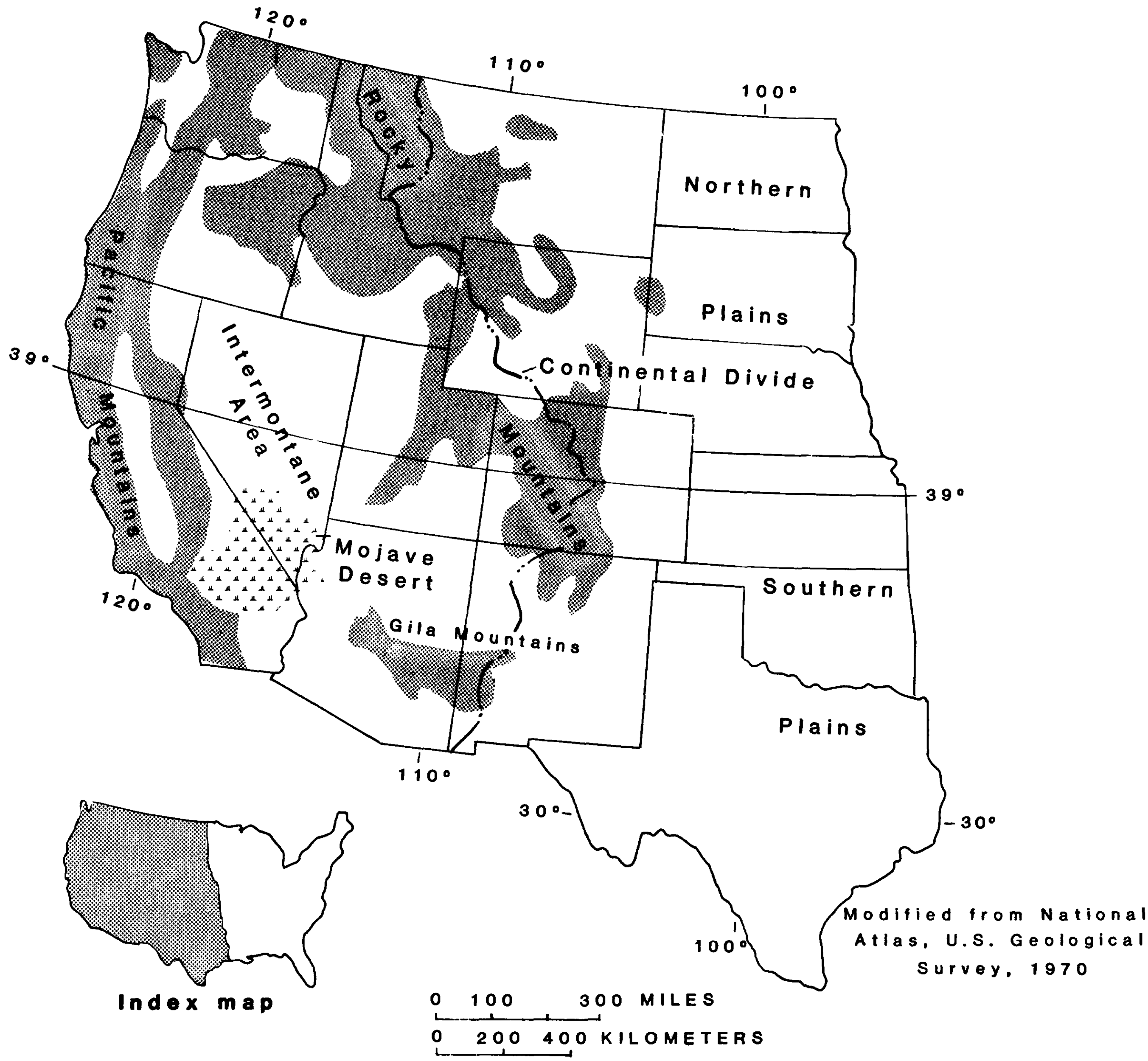

Figure 9. Areas of similar hydrology and channel geometry.

values can differ as much as 100 percent from one area to another, it may be necessary to compute discharge values with both equations if the drainage areas of the stream are separated by one of the boundaries. The discharge values then need to be adjusted on the basis of that part of the drainage basin which is in each area (table 2).

APPLICATION OF THE METHOD

Collection of Channel-Geometry Data

A reach of channel for which the discharge characteristics are desired needs to be thoroughly investigated to locate at least three cross sections, one or more stream widths apart, that are representative of the channel. Care needs to be taken not to select cross sections upstream or downstream from tributaries that would significantly change the drainage area. At cross sections where the reference points for the active-channel width are adequately defined, a tape or graduated tag line needs to be stretched tightly across and perpendicular to the channel, as shown by line B-B′ in figure 1. The width is measured between the reference points and recorded. A photograph of the cross section with the tape in place needs to be taken to show the location and for possible review at a later date. Detailed procedures for collecting channel-geometry data are given by Hedman and Kastner (1977).

Field training and experience are necessary for effective selection of the active-channel reference levels. Unusually shaped channel cross sections need to be avoided. Relatively straight or stabilized reaches of meandering channels need to be selected where active bank cutting or deposition is not in the process of changing the channel width. Braided reaches need to be avoided, as well as reaches in the channel that indicate the channel has been widened or realigned by an extreme flood or by construction work and has not had time to readjust. Likewise, reaches with banks that cannot be rapidly sculptured by the water (that is, banks composed of resistant material, such as bedrock, and reaches lined with riprap or concrete that have abnormally narrow widths) need to be avoided. Reaches with large pools or steep inclines also need to be avoided.

Channel-Material Sampling Procedures

At least one set of samples of bed-and bank-material need to be collected at each site at which the channel-geometry technique is used. Samples of bed and bank material should be collected from the perimeter of the active channel. Three composite samples should be collected, one from portions of material taken at equal intervals across the channel bed, and one each taken at intervals up each bank to the reference point. Because fluvial sorting processes are different for the bed and banks, care should be exercised to insure that the bed samples are not contaminated with bank material, or the reverse. Specific sampling procedures at channel-geometry sites are described by Osterkamp (1979, p. 87–88). A particle-size analysis (Guy, 1969) is made for each of the three channel-material samples, with the results being expressed as percent of the sample finer than the various specified sizes.

COMPUTATION OF MEAN ANNUAL RUNOFF

Mean annual runoff for various types of streams in the western United States can be computed from equations given in table 2. The equations are separated on the basis of flow frequency, runoff, and channel-material characteristics.

Perennial Streams

Mean annual runoff for all perennial streams with silt-clay or armored channel can be computed with equation 7. This is an easily recognized class of stream. The active-channel reference level is well developed, easy to identify, and the equation has a minimum standard error of estimate.

Intermittent Streams

Mean annual runoff for intermittent streams can be computed with equations 8–11. This is a broad group of streams with regard to the flow frequency (10 to 80 percent), and identification will require thorough knowledge of the area and the climate. To be classified intermittent, the stream should have flow 10 to 80 percent of the days. Most of the streams with drainage areas greater than 500 square miles, except those in the arid southwest, will generally have discharge for more than 10 percent of the time due to prolonged snowmelt in the northern States and due to larger and more frequent precipitation events in the southern States, generally east of New Mexico. The areas of the northern and southern plains and intermontane areas are approximately separated by latitude 39° N. (fig. 9).

Ephemeral Streams

Mean-annual runoff for ephemeral streams can be computed with equations 12–17. To be classified ephemeral, the streams should have flow on the average of less that 10 percent of the days. Ephemeral streams are further separated into those that have flow 1 percent or less of the days, 2 to 5 percent of the days, and 6 to 9 percent of the days.

Identification of the streams that are ephemeral and the groups within the ephemeral classification again will require thorough knowledge of the area and the climate. All available hydrologic, geologic and climatic information should be used to determine the flow frequency of ungaged streams. All gage records should be examined because streams within large general areas commonly have about the same flow frequency. Local residents can provide valuable information on the number of low events. Inspection of channel and flood-plain debris and vegetation will give clues on the frequency of flow events. The channel material and basin soil types should be investigated. Streams with sandy channels and sandy drainage basins will have fewer runoff events than those with fine material sizes.

COMPUTATION OF FLOOD-FREQUENCY DISCHARGE

Flood-frequency discharge, in cubic feet per second, for the indicated recurrence intervals in years can be computed with the equations in table 3. The equations are given for four separate groups—alpine streams, including streams with pine-forested drainage areas, and three geographic areas to account for the variation in runoff characteristics (fig. 9). The equations are applicable for all three flow-frequency groups (ephemeral, intermittent, and perennial).

Table 3. Equations for determining flood-frequency discharge for streams in western United States.

Areas of similar climatic characteristics [a]	Equation [b]	Standard error of estimate (percent)	Equation number
Alpine and pine-forested	$Q_2 = 1.3W_{AC}^{1.65}$	44	(18)
	$Q_5 = 2.8W_{AC}^{1.60}$	37	(19)
	$Q_{10} = 4.4W_{AC}^{1.55}$	38	(20)
	$Q_{25} = 7.0W_{AC}^{1.50}$	42	(21)
	$Q_{50} = 9.6W_{AC}^{1.45}$	45	(22)
	$Q_{100} = 13W_{AC}^{1.40}$	50	(23)
Northern plains and intermontane areas east of Rocky Mountains	$Q_2 = 4.8W_{AC}^{1.60}$	62	(24)
	$Q_5 = 24W_{AC}^{1.40}$	42	(25)
	$Q_{10} = 46W_{AC}^{1.35}$	40	(26)
	$Q_{25} = 61W_{AC}^{1.30}$	44	(27)
	$Q_{50} = 130W_{AC}^{1.30}$	51	(28)
	$Q_{100} = 160W_{AC}^{1.25}$	58	(29)
Southern plains east of Rocky Mountains (subject to intensive precipitation events)	$Q_2 = 7.8W_{AC}^{1.70}$	66	(30)
	$Q_5 = 39W_{AC}^{1.60}$	57	(31)
	$Q_{10} = 84W_{AC}^{1.55}$	56	(32)
	$Q_{25} = 180W_{AC}^{1.50}$	57	(33)
	$Q_{50} = 270W_{AC}^{1.50}$	59	(34)
	$Q_{100} = 370W_{AC}^{1.50}$	62	(35)
Plains and intermontane areas west of Rocky Mountains	$Q_2 = 1.8W_{AC}^{1.70}$	120	(36)
	$Q_5 = 7.0W_{AC}^{1.60}$	73	(37)
	$Q_{10} = 14W_{AC}^{1.50}$	60	(38)
	$Q_{25} = 22W_{AC}^{1.50}$	62	(39)
	$Q_{50} = 44W_{AC}^{1.40}$	71	(40)
	$Q_{100} = 59W_{AC}^{1.40}$	83	(41)

[a] Areas of runoff characteristics shown in figure 9.

[b] Active-channel width, W_{AC}, in feet; discharge, Q_n, in cubic feet per second, where n is the recurrence interval, in years.

Flood-frequency discharge for alpine streams, including all streams with pine-forested drainage areas, can be computed with equations 18–23. These streams have small floods in relation to total discharge and to active- channel width. Much of the precipitation is stored and released later as springflow or gound-water seepage.

Flood-frequency discharge for all other streams (excluding alpine and those with pine-forested drainage areas) can be computed with equations 24–41.

CONCLUSIONS

Active-channel geometry measurements can be used to determine mean annual runoff and flood-frequency discharges for streams in the western United States. The method offers an alternative for estimating streamflow characteristics for ungaged streams. The equations yield discharge values from active-channel width and channel-material data. The principal advantage is that the discharge values can be determined quickly and inexpensively.

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UNITS AND CONVERSION FACTORS

For those readers who may prefer to use metric units rather than inch- pound units, the conversion factors for the International System (SI) of Units used in this report are as follows:

Multiply inch-pound units	*By*	*To obtain SI units*
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	square hectometer
square mile	2.590	square kilometer
cubic foot per second	0.02832	cubic meter per second
acre-foot per year	0.001233	cubic hectometer per year

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