Determining Streamflow Characteristics Based on Channel Cross-Section Properties

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Channel dimensions have proved to be valid indicators of streamflow characteristics. Use of channel geometry requires definition of a relation between the desired flow characteristic and stream-channel size based on data at gaging stations; estimates of the flow characteristic can then be made at ungaged sites by obtaining the channel dimensions. Regional analyses have been made in many western states and in some eastern states by the U.S. Geological Survey. These analyses are summarized and some results are compared. Three reference levels have been used to define the channel dimensions. The principal differences between the channel-geometry approach and conventional approaches that use basin characteristics are that (a) the ungaged site must be visited to measure the channel size before an estimate can be made and (b) some field training is required before an individual can identify the channel reference level. Variability among channel measurements by trained individuals effectively increases the error of the estimate over the standard error of the estimate defined during calibration. The increase is dependent on the variability in channel type, but extremely variable conditions could increase a calibration error of 42 percent to an application error of 55 percent.

Engineers and hydrologists frequently are required to estimate flow characteristics at ungaged sites. Conventional techniques have used relations between flow characteristics and physical characteristics of drainage basins, such as size of drainage area, to transfer information to ungaged sites. Flow characteristics in arid and semiarid regions, however, generally are only poorly related to the size of the drainage basin. Relations between flow characteristics and stream-channel size offer a promising alternative.

That streams are the authors of their channels has long been recognized; nevertheless, methods of quantifying the interrelation between flow characteristics of rivers and channel size have developed only in recent years. The regime concept, as originated by Kennedy and Lindley (1) for canals in India and Pakistan, gave empirical relations for the hydraulic properties of stable canals. This concept, however, was not extended to natural rivers in the United States until half a century later.

The initial impetus for the studies of canals stemmed from the need for improved design techniques. Similarly, the early work with rivers was oriented toward expressing channel dimensions as functions of a formative or dominant discharge. In recent years efforts have begun to focus on using the dimensions of the stream channel as indexes of flow characteristics, particularly flood-frequency characteristics. These approaches are not unrelated; nevertheless, the latter approach does not require definition of a dominant discharge.

The purpose of this paper is to examine the evolution of relations between dimensions of river channels and discharge characteristics, to summarize the regional relations that have been developed, and to examine the sources of error. The focus will be on attempts to use these relations as tools in estimating flow characteristics of rivers; the emphasis will be on flood characteristics rather than on use of the information in channel design. Consequently, the regime concept as it relates to canals only will be considered in relation to its bearing on rivers. Because of the emphasis on regional relations, the variation at a station of hydraulic geometry exponents is not included.

HYDRAULIC-GEOMETRY APPROACH

A channel is considered to be in regime if it can accommodate its flow for 1 yr or more without a net change in hydraulic characteristics (2). Within that period, scour or deposition may occur in either the lateral or vertical direction as long as they are transient phenomena.

The morphology of regime canals has been the subject of many investigations since Kennedy (1) stated his empirical equation of nonscouring velocity for the canals of Punjab in 1895. The basic principle generally was not applied to rivers in the United States, however, until Leopold and Maddock (3) reported their analysis of the relationships between hydraulic properties of the cross section and river discharge. They theorized that the hydraulic geometry of river channels in approximate equilibrium could be expressed as exponential functions of discharge such that

$$W = aQ^b \quad (1)$$

$$D = cQ^f \quad (2)$$

$$V = kQ^m \quad (3)$$

where

W = width,
D = mean depth,
V = mean velocity,
Q = discharge, and
a,c,k,b,f, and m = numerical constants.

The numerical constants for the above relations were developed empirically from data collected on rivers representing a variety of hydrologic conditions. Mean annual discharge was used as the independent variable, because it provided a discharge of approximately the same frequency throughout the area of investigation, which permitted comparison between relations. The values of the exponents b, f, and m were relatively constant, and the average values agreed quite closely with previously defined values for regime canals. The coefficients a, c, and k, however, varied between river systems.

Leopold and Maddock (3) were not the first to apply the regime concept to rivers, although their analysis was one of the first to gain wide acceptance. In 1935 Lacey extended his earlier empirical equations for Punjab canals by including limited data for rivers from the United States, Europe, and Punjab (4); however, he grouped river data by discharge and used averages. Pettis (5) independently developed similar regime equations based on natural streams in the Miami River basin of Ohio. Pettis' relations were intended for use in river channelization; therefore, his discharge was a flood discharge, apparently near the bank-full stage (5, p. 150).

In 1947 Rybkin (6) developed a set of relations based on rivers in the upper Volga and Oka basins of the U.S.S.R. These relations were in terms of long-term average discharge and river gradient but contained a modulus term that permitted computation of the hydraulic properties for discharges other than the long-term mean. Rybkin's hydraulic-geometry variables, like those of Leopold and Maddock (3), were properties at the particular discharge rather than dimensions based on a specific feature of the channel. In 1950 Altunin confirmed that the general regime equation for width with b = 0.50 was valid for rivers of central Asia. He also concluded that the coefficient a varied with slope to the -0.20 power. Whether the width used in Altunin's analysis is based on a specific channel feature is not clear, but Kondrat'ev (6) gives some insight when he observes, "[Altunin's] formulas are true only for a certain channel-forming discharge, whose value is taken as that of discharges with a 10-20 percent reliability. These discharges are usually accommodated within the height of the channel edges."

Most of the preceding studies, including the 1953 work of Leopold and Maddock, although furthering the status of knowledge, were of limited practical value because the hydraulic-geometry variables used were those of specific discharges and could not be identified with recognizable channel features. Thus the analysis by Wolman (7) of the Brandywine Creek drainage in Pennsylvania, in which he related hydraulic geometry to bank-full discharge, was significant. In addition, he analyzed the hydraulic-geometry relationships with flows of 50, 15, and 2 percent duration. The recurrence interval of flows exceeding the bank-full stage on Brandywine Creek ranged between 1 and 3 yr and averaged 2.2 yr.

Although simple in concept, the bank-full stage may be interpreted in a number of different ways, each associated with different values of width and depth and yielding a different bank-full discharge. Williams (8) gave a comprehensive review of definitions of bank-full stage. He identified and discussed 11 definitions that have been used by investigators. He also concluded (8, p. 1141): "Bank-full discharge does not have a common recurrence frequency among the rivers studied, and the discharge corresponding to the 1.5-year recurrence interval in most cases does not represent the bank-full discharge."

Most later investigations of hydraulic geometry by Wolman (7) were directed at one or more of the following problems:

1. Physically identifying the bank-full stage,
2. Determining the significance (such as the recurrence interval) of bank-full discharge,
3. Determining the exponents in the hydraulic-geometry equations either theoretically or empirically for a specific region or channel type, or
4. Application of the concept to solve practical problems.

Except for the theoretical analyses, many studies involve several of the classifications. The hydraulic-geometry exponents for selected empirical and theoretical studies are summarized in Table 1.

DISCHARGE RELATED TO CHANNEL DIMENSIONS

Ideally, a channel feature used as an index to discharge should be a unique, recognizable feature of the channel. It should also be active, that is, free to adjust to changes in the flow regime. This thinking, and a need for a reconnaissance technique to estimate discharge characteristics at ungaged sites, led to the recent attempts to relate an active, within-channel feature to discharge characteristics. The approach was apparently first suggested in 1966 by W.B. Langbein of the U.S. Geological Survey.

The concept as well as the feature differed from the earlier work. With the bank-full-stage concept, the emphasis had been on relating the bank-full channel properties (dependent variables) to some formative or dominant discharge (independent variable). Langbein's suggested approach by using the within-channel feature was to empirically relate the average annual discharge, as the dependent variable, to dimensions of recognizable active features of the channel. This permits estimates of the discharge characteristic to be made at ungaged sites on the basis of channel dimensions. The approach infers that the discharge characteristic to be estimated is related directly to the formative discharge of streams in the area of investigation but does not require identification of that formative discharge.

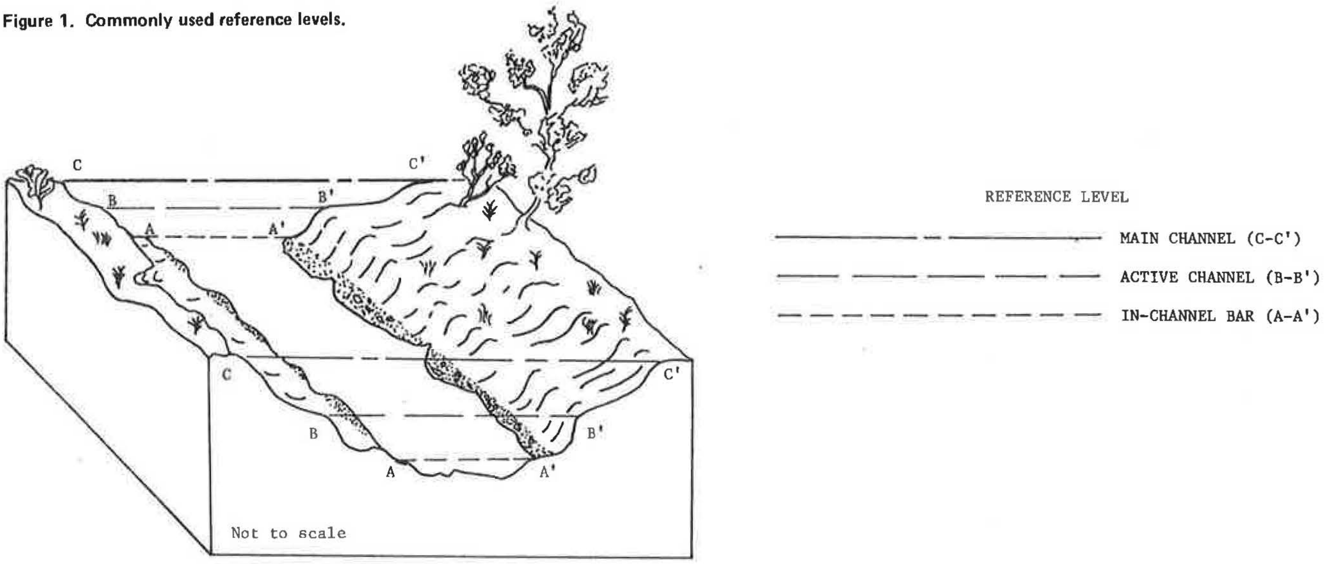
Several reference levels have been used; the levels are referred to in this paper as the section defined by within-channel bars, the active-channel

Table 1. Exponents of discharge in regime equations for width (b), depth (f), and velocity (m).

Region and Literature Reference	b	f	m	Discharge
Empirical Study				
Indian canals and rivers (4)	0.50	0.333	0.167	Equilibrium
Miami River, Ohio (5)	0.50	0.30	0.20	Bank-full
Volga and Oka basins, USSR (6)	0.57	0.22	0.21	Mean annual
Midwest United States (3)	0.50	0.40	0.10	Mean annual
Brandywine Creek, Pennsylvania (7)	0.58	0.40	0.02	2 percent duration
Ephemeral streams in Southwest (9)	0.50	0.30	0.20	Mean annual
Rivers in England and Wales (10, 11)	0.53	0.27	0.20	Bank-full
Appalachian streams (12, pp. 145-181)	0.55	0.36	0.09	Bank-full
Canadian rivers and Colorado canals (13)	0.50	0.40	0.10	3- to 5-yr flood
Illinois rivers (14)	0.48	0.36	0.16	Of measurement
Average for Alaska rivers (15)	0.50	0.35	0.15	Bank-full
Rivers in central Idaho (16)	0.54	0.34	0.12	Bank-full
Colorado gravel-bed streams[a] (17)	0.480	0.374	0.146	Bank-full
Theoretical Approach				
Leopold and Langbein (18)	0.55	0.36	0.09	
Langbein (19, 20)	0.50	0.37	0.13	
Acker (21)	0.53	0.35	0.12	
Engelund and Hansen (22)	0.525	0.317	0.158	
Joering (23)	0.50	0.375	0.125	
Smith (24)	0.6	0.3	0.1	
Li, Simons, and Stevens (25)	0.46	0.46	0.08	

[a] Average of values for thick and light bank vegetation.

Figure 1. Commonly used reference levels.



section, and the main-channel section [Figure 1 (26)]. Regional investigations by hydrologists of the U.S. Geological Survey are summarized in Table 2 by the reference level used. Those studies and other investigations are discussed in the sections that follow.

Within-Channel Bars

Langbein suggested a reference level defined by the tops of point bars that are (a) the highest bed forms of which the particles are subject to annual sediment movement and (b) the lowest prominent bed forms. He also noted that the reference level could be related to vegetation zones if (a) the channel below the reference level generally is free of non-aquatic vegetation; (b) the zone between the tops of the bars and the floodplain is occupied by annuals (forbs and grasses); and (c) the true floodplain is occupied by shrubs. The within-channel bar has been described in more detail by Moore (27); Hedman (28); and Hedman, Moore, and Livingston (29).

Table 2. Summary of regional analyses by U.S. Geological Survey.

	Characteristic Used		
Region and Literature Reference	Year Published	Mean Annual Flow	Flood Flows
Within-Channel-Bar Section			
Nevada (27)	1968	X	–
Coastal and southern California (28)	1970	X	–
Kansas (29)	1972	X	–
Colorado (perennial streams) (30)	1972	X	X
Nevada (31)	1974	–	X
Utah (32)	1975	X	X
Missouri River basin[a] (33)	1977	X	X
Active-Channel Section			
Kansas (34)	1974	X	X
New Mexico (35)	1976	–	X
Missouri River basin[a] (33)	1977	X	X
Western United States (34)	1982	X	X
Kansas (regulated streams) (35)	1981	X	–
Ohio (36)	1981	–	X
Tennessee (Cumberland Plateau) (37)	1981	X	X
Missouri River basin (26)	1982	X	X
Main-Channel Section			
Western mountain areas (38)	1974	–	X
Wyoming (39)	1976	X	X
Owyhee County, Idaho (40)	1976	–	X
Idaho (41)	1980	–	X

[a] Includes both the within-channel bar and active-channel section.

Early studies using the within-channel bar defined relations only for mean annual flow. More recent investigations also have defined relations for floods of selected frequency. Relations between the 10-yr flood and within-channel bar width are compared for selected studies in Figure 2.

The first published analysis that used the within-channel feature was that by Moore (27) for streams in Nevada. He graphically related mean annual discharge to the width and average depth of the channel cross section defined by the tops of the channel bars and gave separate results for perennial and ephemeral streams.

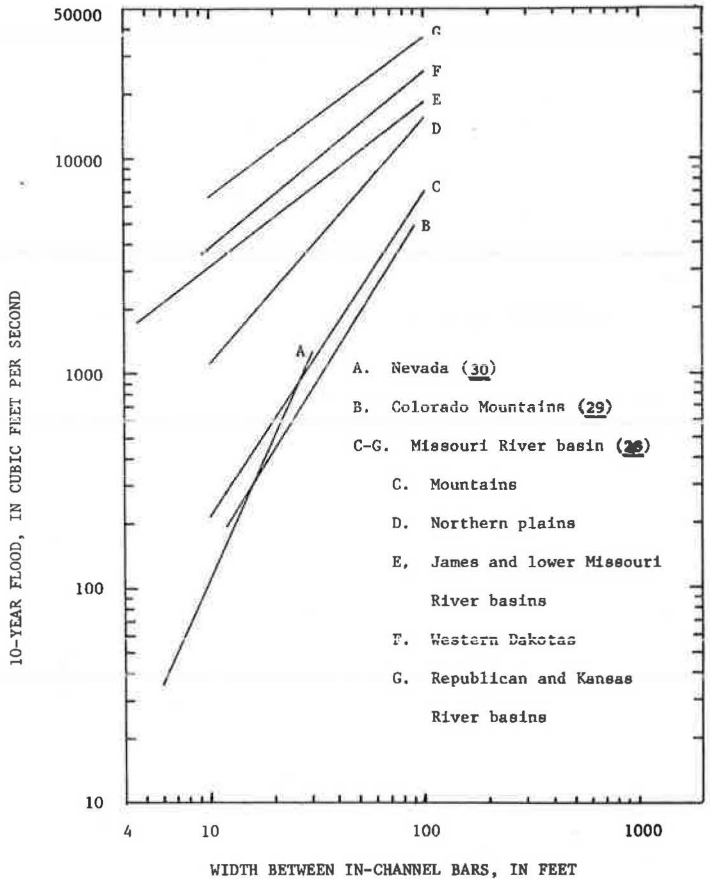
In a related study, Hedman (28) equated mean annual flow of 48 California streams to the dimensions of the cross section defined by the within-channel bars. Like Moore (27), he developed separate relations for ephemeral (20 sites) and perennial (28 sites) streams.

Kopaliani and Romashin (31) analyzed relations between the flood-channel width and the 2-yr flood for rivers in western Georgia, U.S.S.R. Based on the following description of the flood channel, the width used seems to be compatible with the within-channel feature treated in this section (31): "The flood channel is that part of the valley which is systematically flooded by high water and within which sediments are continuously redistributed so that there is no vegetation. On mountain rivers it is a wide gravelly-bouldery strip, which dries out during the low-water period. Its relief consists of gentle mobile placer deposits of the side-bar or midstream-bar type." In a logarithmic plot relating 2-yr flood and flood-channel width, the data separate into three distinct but parallel groups. In order of decreasing discharge for a given width, they were braided reaches, reaches with mid-channel and side-channel bars, and meandering reaches. Although Kopaliani and Romashin were defining width as a function of discharge (and gradient), Wahl deduced a relation of

$$Q = aW^{1.5} \quad (4)$$

from a plot of their data. This general relation

Figure 2. Relations between 10-yr flood and within-channel bar width.



would apply to all three classes of streams, but the constant of proportionality (a) would vary; average standard error of the estimate (graphical) would be in the range of 30 to 40 percent.

Equations for estimating mean annual flow from channel geometry in Kansas were developed by Hedman and Kastner (32). They used the within-channel bar and gave separate results for perennial and ephemeral streams.

One of the first studies to relate flood characteristics to channel dimensions in the United States was done by Hedman, Moore, and Livingston (29). They related mean annual discharge and 2-, 5-, 10-, 25-, and 50-yr flood peaks to width and mean depth of the within-channel cross section for perennial streams in Colorado. The standard errors of the estimate for their flood equations ranged from about 30 to 45 percent and were significantly less than comparable conventional relations between flood characteristics and basin characteristics. Including mean depth and drainage area in the equations did not significantly decrease the standard errors nor did the use of a second-degree polynomial.

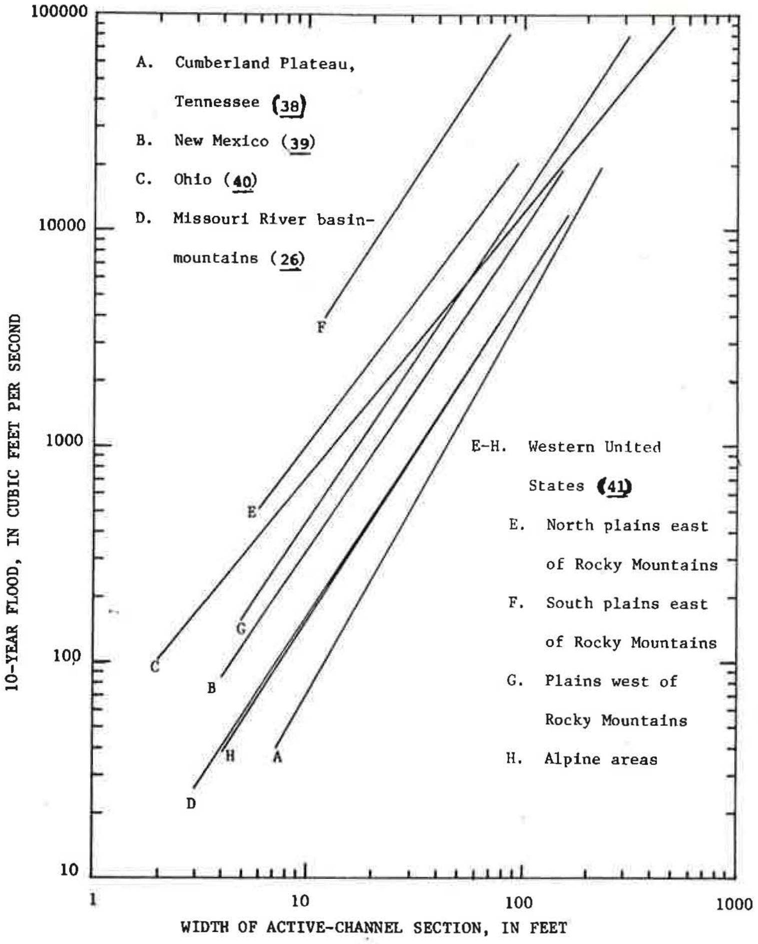
DeWalle and Rango (33) used data from 27 small basins (19.59 to 303.44 acres) in Maryland, New Hampshire, New Jersey, Pennsylvania, Vermont, and West Virginia to develop linear relations between the logarithms of mean annual flood and properties of the channel cross section. Their channel width was defined as the horizontal distance from the top of the lowest bank to the opposite bank wall. The description seems to be consistent with that of the within-channel bar based on their statement: "The more obvious upper banks which may be associated with a discharge greater than the mean annual flow were discarded." The results are of limited practical use because only 34 percent of the sample variance was explained by an equation using width; a relation that used only precipitation explained 83 percent of the sample variance. In an earlier study of small drainage areas in the Sleeper's River basin of northern Vermont, Zimmerman, Goodlett, and Comer (34) found that stream width did not increase in the downstream direction for a drainage area less than 0.8 mile^2. They attributed this to the effect of vegetation, mostly tree roots, and to relatively small annual peak discharges. This may partly explain the poor results obtained by DeWalle and Rango (33).

Moore (30) extended his earlier study (27) for Nevada to include the 10-yr flood characteristic. He developed separate relations for perennial and ephemeral streams. The 10-yr flood was a function of both width and depth for ephemeral streams but was related only to width for perennial streams.

Fields (34a) developed statewide relations for the mean annual discharge and the 25-yr and 50-yr floods in Utah by using the within-channel bar. The state was divided into three hydrologic areas for floods, and separate relations were developed for the individual areas; flood flows were related to only the width of the section.

In one of the first studies of a large geographical region, Hedman and Kastner (35) related mean annual flow and flood flows for the Missouri River basin to the width of both the within-channel bar and the active channel. Relations also were defined between the flow characteristics and conventional basin characteristics. The basin was divided into six hydrologic areas for both mean annual flow and floods, but the regions for mean annual flow generally differed from those for floods. Standard er-

Figure 3. Relations between 10-yr flood and active-channel width.



rors of the estimate were comparable for relations that used the width of the within-channel bar and the width of the active channel; however, standard errors of relations based on drainage area and climatic characteristics generally were greater except for mean annual flow in southwestern Iowa and northern Missouri.

Active-Channel Section

While studying Kansas streams in 1972, E.R. Hedman of the U.S. Geological Survey recognized a channel feature somewhat higher than the within-channel bars that had been used previously. He first referred to this feature as the active floodplain but redefined it as the active channel (36). In effect it is a side bar that would no longer be called a bed feature. Because of annual vegetation, the feature virtually has become a part of the bank, but it is still well within the overall channel. The active channel was described by Osterkamp and Hedman (37, 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 vegetation 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.

The active-channel section has since been used in numerous studies to define mean annual and flood flows in the western states and in selected eastern states. These investigations are summarized in Table 2, and 10-yr flood relations are compared for selected studies in Figure 3.

The active-channel section was first used by Hedman, Kastner, and Hejl (36) to define flood-frequency relations in Kansas. They proposed that because the active-channel feature was formed by infrequent flows, the active-channel section was a better descriptor of floods than was the within-channel-bar section.

Scott and Kunkler (39) related the width of the active channel to characteristics of the 2- through 50-yr floods in New Mexico. One set of relations was used for the state; however, an area in the southeastern part of the state was excluded because the channels were actively entrenching. The relations using channel width gave significantly smaller standard errors of the estimate than similar relations that used basin and climatic characteristics.

A similar study for Ohio (40) defined one set of equations that could be used statewide to estimate the 2- through 100-yr floods; the average standard errors of the estimate ranged from 42 to 55 percent.

Glazzard (38) defined relations for the mean annual flow and 2- through 100-yr floods in the Cumberland Plateau, Tennessee, by using the active-channel width. The average standard errors of estimate were about 60 percent for floods. He also used variables representing stream gradient and percentage of silt, clay, and coal in stream-bank material. Although the additional variables produced some decrease in standard error for mean annual flow, there was no improvement in the flood relations.

Hedman and Osterkamp (41) used the active-channel section in an analysis of mean annual and flood characteristics (2- through 100-yr floods) for the western half of the conterminous United States. Their final equations expressed the flow characteristics as functions of only the active-channel width. For floods, the area was subdivided into four areas based on similarity of climatic conditions. The four areas were (a) alpine and pine forested, (b) northern plains east of the Rocky Mountains, (c) southern plains east of the Rocky Mountains, and (d) plains and intermontane areas west of the Rocky Mountains. Their results are shown in Table 3 (41).

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

Areas of Similar Climatic Characteristics	Equation[a]	Standard Error of Estimate (%)
Alpine and pine forested	$Q_2 = 1.3W_{AC}^{1.65}$	44
	$Q_{10} = 4.4W_{AC}^{1.55}$	38
	$Q_{25} = 70W_{AC}^{1.50}$	42
	$Q_{50} = 9.6W_{AC}^{1.45}$	45
	$Q_{100} = 13W_{AC}^{1.40}$	50
Northern plains east of Rocky Mountains	$Q_2 = 4.8W_{AC}^{1.60}$	62
	$Q_{10} = 46W_{AC}^{1.35}$	40
	$Q_{25} = 61W_{AC}^{1.30}$	44
	$Q_{50} = 130W_{AC}^{1.30}$	50
	$Q_{100} = 160W_{AC}^{1.25}$	58
Southern plains east of Rocky Mountains[b]	$Q_2 = 7.8W_{AC}^{1.70}$	66
	$Q_{10} = 84W_{AC}^{1.55}$	56
	$Q_{25} = 180W_{AC}^{1.50}$	57
	$Q_{50} = 270W_{AC}^{1.50}$	59
	$Q_{100} = 370W_{AC}^{1.50}$	62
Plains and intermontane areas west of Rocky Mountains	$Q_2 = 1.8W_{AC}^{1.70}$	120
	$Q_{10} = 14W_{AC}^{1.50}$	60
	$Q_{25} = 22W_{AC}^{1.50}$	62
	$Q_{50} = 44W_{AC}^{1.40}$	71
	$Q_{100} = 59W_{AC}^{1.40}$	83

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

[b] Subject to intensive precipitation events.

Osterkamp and Hedman (26) expanded on the earlier Missouri River basin study by Hedman and Kastner (35) by considering the effect of channel-sediment properties, channel gradient, and discharge variability. They concluded (35, p. 1): "Results show that channel width is best related to variables of discharge, but that significant improvement, or reduction of the standard errors of estimate, can be achieved by considering channel-sediment properties, channel gradient, and discharge variability." They did not include terms in the regression relations to represent the additional factors; instead, the data were stratified based on those factors, and each group of data was analyzed separately.

Main-Channel Section

The third and highest reference level used is the main-channel section (also referred to as the whole-channel section). This section was described by Riggs (42, p. 53) as "variously defined by breaks in bank slope, by the edges of the flood plain, or by lower limits of permanent vegetation." He also notes: "In selecting the channel width, one should avoid a high reference level that does not reflect the present flow regime. This is most often a possibility on ephemeral streams."

When the preceding descriptions are compared with the various descriptions of the bank-full stage, it is evident that the main-channel section and the bank-full section are the same for perennial streams. The relationship is less obvious for ephemeral streams where distinct floodplains may not be formed; however, there is no evidence to indicate that the sections are not the same when determined properly.

The study by Riggs (42) presented reconnaissance-level relations between 10-yr flood and main-channel width (whole-channel width) for ephemeral streams in Utah and Wyoming and perennial streams in Alaska. Relations also were compared for the 50-yr flood in the western mountains, Kansas, and Kentucky.

Riggs and Harenberg (43) demonstrated for Owyhee County, Idaho, how channel-geometry measurements could be used to provide estimates of flood characteristics without a visit to the site. The relationship between the 10-yr flood and main-channel width was developed and used to estimate the 10-yr flood at 79 sites in and adjacent to Owyhee County. The resulting estimates and those for 33 gaging stations were plotted on a map of the county; the map can be used for interpolation to make estimates at intermediate sites.

Lowham (44) used the main-channel section to define relations for mean annual flow and 2- through 100-yr flood characteristics for Wyoming. For floods, the state was divided into four hydrologic areas and separate relations were defined for each area. Average standard errors of the estimate for all frequencies ranged from about 34 to 75 percent and were smaller than standard errors for comparable relations that used drainage basin and climatic variables. More recently, Lowham (45) developed a relation between the geometric mean of peak discharges (approximately the 2-yr flood) and main-channel width for Wyoming that had an average standard error of the estimate of 47 percent. The relation applies (45, p. 37) "to all types of streams, including perennial, intermittent, and ephemeral types of either the mountains or plains, provided the channel is stable and has been formed by the hydraulic forces of floodflows."

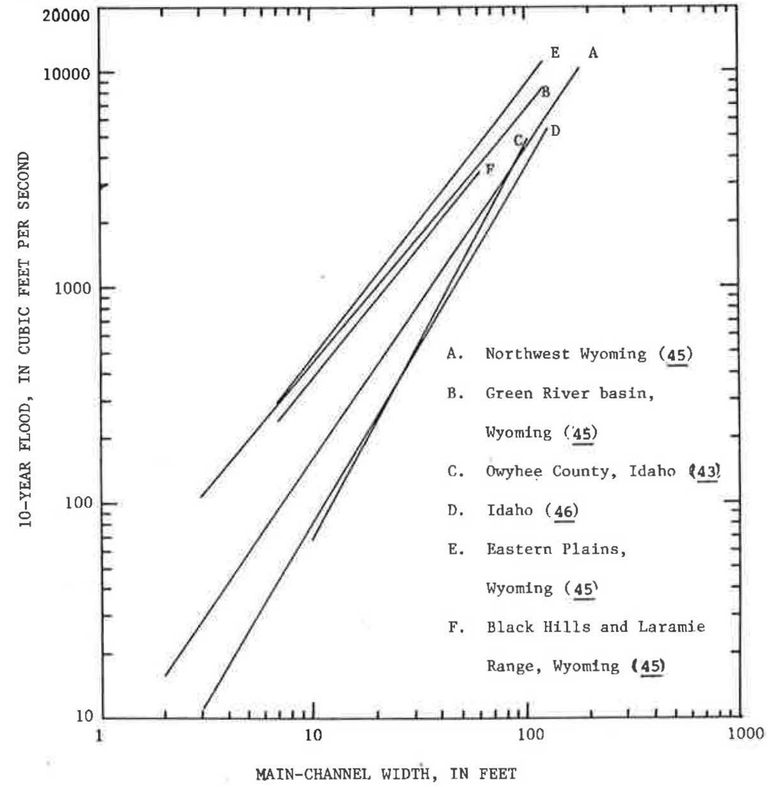
Harenberg (46) used the bank-full width to define relations for the 1.5- through 100-yr floods for Idaho. He reports that his bank-full width is equivalent to the whole-channel width used in the Owyhee County report. The equations were applicable statewide and had average standard errors of about 70 percent.

The relations between 10-yr flood and main-channel width for these studies are shown in Figure 4.

USE OF CHANNEL-GEOMETRY RELATIONS

Channel-geometry measurements are proven indexes for use in estimating flood-frequency characteristics at ungaged locations. The technique can be used where relations between flow characteristics and traditional basin and climatic characteristics are poor, or channel measurements may be used to provide virtually independent estimates for comparison with the traditional approaches. Nevertheless, the method may not provide reliable results for areas in which bedrock prevents the channel from adjusting to accommodate the normal regimen of flow. Similarly, the approach is not applicable on braided, sand-channel streams where channels have not stabilized. Where possible, sections should be located in straight reaches where flows are approximately uni-

Figure 4. Relations between 10-yr flood and main-channel width.



form. In meandering streams, Lowham (44) suggests locating sections in the crossover area, midway between bends. Channel dimensions need to be measured at two or three cross sections separated by at least one channel width, and average values should be used in computations.

Regardless of which of the three sections is used, experience is needed to identify the proper reference level. Before channel measurements are made, a few days of field instruction should be obtained from a person experienced in the technique. Training needs to be done in a hydrologic environment that is similar to that in which the relations will be used; the various sections generally are much easier to identify on perennial streams than on ephemeral streams. In using an existing relation, only those variables contained in the relation need to be measured. If a new relation is being developed, however, other factors such as channel slope and bed and bank material should be obtained in addition to the width and average depth of the section.

RELIABILITY

The reliability of flow estimates from channel characteristics depends on both the applicability of the regional relation (calibration and model errors) and the ability of different individuals to recognize and measure the channel dimensions used as independent variables (application error).

The calibration and model errors include errors in estimates of the discharge characteristics used to develop the relations and are reflected in the standard errors of the estimate reported for individual studies. At this time, however, the components cannot be separated; that is, the contributions attributed to errors in the calibration discharge estimates, to the use of the power-function relation, and to measurement errors by the individuals developing the relations cannot be identified separately. In most investigations that use channel geometry it has been found that standard errors of the estimate are equal to or less than the standard errors for conventional methods.

The principal difference between the conventional regression relations and those that use channel geometry is in the degree of subjectivity involved in defining the independent variables. For example, there may be numerous maps of an area giving mean annual precipitation, but if a particular map is specified, all users could derive about the same estimated value for a particular basin. With relations based on channel geometry, however, the user needs to be able to both recognize the feature and measure it consistently.

VARIATION BETWEEN INDIVIDUALS

Wahl (47, pp. 311-319) conducted and reported on a test designed to define the possible variability of channel measurements by individuals. An added objective of the test was to gain insight into potential advantages and disadvantages of the three reference levels. The test was conducted in northern Wyoming. Seven individuals, all experienced in using channel-geometry techniques, independently visited 22 sites and measured channel dimensions in sections of their choosing. Only general reaches of each stream were identified, so the cross sections at which individuals measured channel dimensions were of their own choosing; thus, the variability of measurements between individuals reflected the combined effects of differences in cross-section location within the test reach and differences in identification of the reference levels. This should reflect the variability resulting from having trained individuals measure channel size in an ungaged reach.

A summary of the statistics of cross-correlation coefficients between measurements for width and av-

Table 4. Summary of cross correlations between measurements by individuals.

	Statistics of Correlation Coefficients		
Section	Mean	Standard Deviation	Range
Low bar			
Width	0.95	0.055	0.74-0.99
Depth	0.74	0.128	0.51-0.93
Active channel			
Width	0.97	0.028	0.91-0.99
Depth	0.59	0.164	0.27-0.83
Main channel			
Width	0.92	0.067	0.79-0.99
Depth	0.59	0.193	0.16-0.89

erage depth of the three reference levels is given in Table 4 (47, pp. 311-319). The data in Table 4 show high correlation between width measurements for all three reference levels, but the correlation between depth measurements is low. This can be rationalized by considering that depths are relatively shallow and that slight differences in locating the top of a reference level will have little effect on the overall measurement of width but a significant effect on the average depth. Wahl (47, pp. 311-319) also used analysis of variance to test for differences among individuals in the average values of a given channel-size dimension. The hypothesis of no difference among means for individuals was accepted at the 95 percent level for widths of all three reference levels.

Relations between a discharge characteristic (Q) and channel width (W) usually take the following form:

$$Q = aW^b \tag{5}$$

where a and b are numerical constants. This is a linear relation when expressed in logarithms:

$$\log Q = \log a + b \log W \tag{6}$$

For the Wyoming test, the average standard deviation of log W (base 10 logarithms) for the seven individuals was 0.089. Given a relation of the form of Equation 6, the standard error in log Q produced by variation in estimates of W is b times the standard error of log W. Wahl (47, pp. 311-319) assumed that b averaged about 1.5 and arrived at an estimate of the standard error in log Q of 0.13 log unit due to variation in width measurements alone. This converts to an error of about 30 percent in estimated discharge. In addition, Wahl (47, pp. 311-319) noted an average bias (with respect to the mean) in log W of 0.06 log unit, or about 14 percent.

The effect of the variation in channel-width measurements by individuals is to increase the error of applying a relation to more than that indicated by the standard error of the estimate, which shows the calibration and model error. Assuming that the three errors are independent, the true error would be the square root of the sums of the squares of the individual components. For example, the 25-yr flood for the alpine area from Table 3 shows an average standard error of the estimate of 42 percent, or 0.178 log unit. The true error (in log units) of using this relation, which would account for both variation and possible bias in width measurements, would be

$$[(0.178)^2 + (0.13)^2 + (0.06)^2]^{0.5} = 0.228 \tag{7}$$

This yields an average error of 55 percent compared with the calibration error of 42 percent.

It should be noted, however, that the sites in the Wyoming test were chosen for their diversity. The sites ranged from ephemeral streams in a near-desert environment to perennial streams in a high-mountain environment. The variability of measurements in this test probably is greater than normally would be encountered in applying channel-geometry measurements in a particular hydrologic area.

SOME COMPARISONS

Comparing published results for different physiographic areas is difficult because the areas have morphological and hydrological differences. In addition, three different reference levels have been used, and some relations include independent variables not used in other studies. Nevertheless, general comparisons are possible for studies that have overlapped or covered similar physiographic regions. For example, agreement shown in Figure 2 between the 10-yr flood results for the mountains of Colorado (29) and those for the mountains of the Missouri River basin (35) is good. Results for the mountains of Nevada (30) also compare with the preceding results.

Similar comparisons in Figure 3 show that for the 10-yr flood and the active-channel width, the relations for the alpine areas of the western United States (41) and for the mountains in the Missouri River basin (35) are almost identical. The relation for New Mexico (39) has about the same exponent but has a different intercept.

Selected relations for the 10-yr flood and the main-channel section are shown in Figure 4. Only the results for Owyhee County, Idaho (43), and the statewide study for Idaho (46) are directly comparable; they are quite similar.

NEEDED RESEARCH

Studies to date (1982) have clearly shown that stable channel dimensions are valid indexes of the flow characteristics of rivers. Much needs to be done, however, to fully realize the potential of this approach. A number of features, including the within-channel-bar section, active-channel section, and the main-channel or whole-channel section, are now being used to define flow characteristics. Consequently, it is difficult to make comparisons between studies, and the applicability of individual results depends on the ability of a user to identify the feature used in developing the relation.

Research is needed to define relations between the dimensions of the various reference levels and the areas over which the relations apply. Riggs (48) developed the following relation between main-channel width and active-channel width:

$$MC = 1.75AC^{0.96} \tag{8}$$

where MC is the main-channel width and AC is the active-channel width. All units are in feet. He suggested that this relation could be used in semiarid regions to estimate one width from another, but a similar relation developed by Wahl (47, pp. 311-319) for the Wyoming test data produced unusable results. This probably was because of the extreme variation in stream types in the Wyoming test.

Additional work is needed to determine the role of other variables. Several investigators (26,38, 49) have examined the relation between channel size and sediments in the bed and banks. Results to date (1982) have varied from region to region. Andrews (17) examined data for gravel-bed streams in Colorado and separated the data into two groups depending on whether bank vegetation along the study reach was light or thick. He made width, depth, and velocity dimensionless by dividing each by the median particle diameter in the riverbed surface. Regression relations for hydraulic-geometry exponents showed no significant difference between data for light and thick bank vegetation; nevertheless, the regression coefficients a, c, and k were significantly different. This implies that exponents for gravel-bed rivers are the same, regardless of region.

Examination of the hydraulic-geometry exponents in Table 1 suggests that for a given channel type, a fixed relation should exist between a formative discharge and channel width. There appears to be justification for imposing a slope for width-discharge relations and allowing the constant (intercept) to be determined by the data. This would minimize the variability among relations that is now produced by fitting curves to a limited range of data. Based on the theoretically derived relations for the regime equations, formative discharge should relate to width raised to the 1.8 to 2.0 power. However, this would only be true for the formative discharge; using the same exponent for other discharges would imply that the variability of flows of large streams is as large as that of small streams. Osterkamp and Hedman (37) have attempted this approach, but additional work is needed.

Much of the work to date has dealt with efforts to define regional relations (calibration). Ways should be sought to make the calibration results more useful. Additional work also is needed to refine estimates of the application errors. The application errors estimated by Wahl (47) probably are anomalously large because of the extreme variability designed in the experiment.

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Tree-Ring Data: Valuable Tool for Reconstructing Annual and Seasonal Streamflow and Determining Long-Term Trends

CHARLES W. STOCKTON AND WILLIAM R. BOGGESS

Two examples are discussed that demonstrate how information derived from the annual growth rings of certain tree species can be used as a proxy source of data to extend hydrologic records back in time. In the first case, tree-ring reconstructions of the annual flow of the upper Colorado River show that the period of record used as a basis for the 1922 Colorado River Compact was anomalously wet, in fact, the wettest comparable period in the entire 450 yr of reconstructed annual discharge at Lee Ferry, Arizona. The full impact of this overestimated flow has yet to be felt. In the second example, data from 13 carefully selected sites were used to reconstruct the annual and seasonal flows of the Salt and Verde Rivers back to 1580. These two rivers, draining some 13,000 miles^2 in central Arizona, furnish water for municipal, industrial, and agricultural use as well as hydroelectric power for the metropolitan Phoenix area. Future water supply and flooding potential are both critical problems due to rapid escalation of population. Results show that several periods of prolonged low flows have occurred that were more severe than any comparable period since 1890. These low-flow periods have an apparent recurrence interval of about 22 yr on the Salt River. Also, the gaged records contain an above-average number of high seasonal and annual flows when compared with the entire 400 yr of reconstruction.

Planning and design for controlling and managing water are predicated on the analysis of historic data to determine both the magnitude and the frequency of annual water yields that have been measured over a finite period of time. In general, statistical procedures used to forecast annual flows are hampered by the relatively short time span covered by instrumented records. This is true throughout the Western Hemisphere and especially so in most developing countries, where hydrologic rec-