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SELECTED STREAMFLOW CHARACTERISTICS AS RELATED TO CHANNEL GEOMETRY OF PERENNIAL STREAMS IN COLORADO

By

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CONTENTS

ILLUSTRATIONS

TABLES

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ABSTRACT

The mean annual runoff and peak discharges having selected recurrence intervals have been related to the width and average depth of cross sections between channel and point bars for 53 gaged sites on perennial streams in the mountain region of Colorado. These relations and measures of channel dimensions can be used to estimate streamflow characteristics for ungaged streams in the Colorado mountain region. The standard error of estimate is 18.3 percent for the relation with mean annual runoff, and ranges from about 30 percent to 45 percent for the relations with peak discharges having recurrence intervals of 2, 5, 10, 25, and 50 years. The standard error of estimate generally increased with the recurrence interval for peak discharges.

INTRODUCTION

Purpose and Scope

The purpose of this study was to assess the effectiveness of using stream channel size and shape measurements for estimating flow characteristics at ungaged sites. Previous investigations by W. B. Langbein (written commun., 1966), by Moore (1968) in Nevada, by Hedman (1970) in California, and by Hedman and Kastner (1972) in Kansas have indicated the feasibility of estimating the mean flow magnitude from the width and average depth measured at cross-sections between depositional bars in the stream channel. This study further tested the use of width and depth measures for estimating on mountain streams both mean flow and flood flow magnitudes.

Planners and designers need quick and reliable techniques for estimating flow characteristics. Stream gaging produces reliable estimates of flow characteristics only after collection of records for several years. Relations have been defined for quickly estimating flow characteristics at ungaged sites from drainage basin indices measured on available maps; but for arid or mountain regions such estimates are sometimes of low reliability. Channel size and shape indices may improve the reliability of estimates by such relations.

The mountain region of Colorado was selected for this study because defined relations between flow characteristics and basin indices measured from available maps produce flow estimates of relatively low reliability (Livingston, 1970). Flow records of 17 or more years length were available for 53 sites on streams where flow is virtually unaffected by diversion or regulation.

General Characteristics of the Region and the Streams

The flow records used in this study are from streams in Colorado, most of which have headwaters at the Continental Divide. The mean annual precipitation for the region ranges from less than 7 inches in the valleys in the south to more than 50 inches in some of the high mountains. Although torrential (cloudburst) rainfall occurs in most of the region, it is extremely rare at high altitudes where most of the precipitation occurs as snow during the winter. The greatest runoff occurs as a result of melting snow in late spring and early summer. By early summer most of the snow has melted and evapotranspiration rates have increased resulting in a substantial decrease in streamflow. This pattern produces typical snowmelt hydrographs with moderate peak discharges and gradual recessions.

The channels of most of the streams are rocky and stable. Ample alluvium is available to form the bars that are used as reference levels.

Selected basin, channel, and streamflow characteristics of 53 gaged perennial streams in the mountain region of Colorado were determined and are listed by gaging station number and name in table 1. The mean annual runoff is the average discharge for the period of record. The peak discharges are represented by discharges from the flood-frequency curves at recurrence intervals of 2, 5, 10, 25, and 50 years. Neither the annual runoff nor the peak discharges are exact. The standard error of estimate can be expected to increase with the recurrence interval of the peak discharges because the length of record for some stations is not long enough to exactly define these discharges.

Table 1.--*Basin characteristics above, and streamflow characteristics at selected gaging stations*

Station number	Station name	Length of record (years)	Basin characteristics: Channel geometry width (feet)	Channel geometry depth (feet)	Drainage area (sq mi)	Mean annual precipitation (inches)	Mean basin elevation (feet)	Streamflow characteristics: Mean annual runoff (ac-ft)	2-year flood discharge (cfs)	5-year flood discharge (cfs)	10-year flood discharge (cfs)	25-year flood discharge (cfs)	50-year flood discharge (cfs)
6-6160	N. Fk. Michigan nr Gould	20	16.8	0.650	21.2	26	9,800	12,610	192	250	279	308	326
6-7005	Goose Cr. at Chessman Lake	33	21.0	.950	86.6	19	10,100	20,580	169	268	340	437	514
6-7105	Bear Cr. at Morrison	55	37.5	.910	164	23	8,800	39,050	428	1,110	2,030	4,140	6,870
6-7165	Clear Cr. nr Lawson	24	41.0	1.710	147	26	10,800	99,260	993	1,530	1,870	2,280	2,580
6-7195	Clear Cr. nr Golden	60	60.5	1.420	399	22	9,600	165,200	1,570	2,690	3,670	5,200	6,580
6-7225	S. St. Vrain Cr. nr Ward	21	20.2	.895	14.4	23	10,500	20,290	235	309	348	389	414
6-7240	St. Vrain Cr. at Lyons	79	47.0	1.270	212	22	8,900	94,180	1,020	1,810	2,610	4,060	5,560
6-7255	Middle Boulder Cr. at Nederland	63	31.5	.925	36.2	27	10,400	39,120	463	646	751	868	944
6-7330	Big Thompson R. at Estes Park	24	49.5	.805	137	31	10,200	91,290	973	1,390	1,640	1,930	2,120
7-0830	Halfmoon Cr. nr Malta	24	25.5	.760	23.6	21	11,800	21,080	259	341	387	438	472
7-0865	Clear Cr. ab Clear Cr. Res.	24	32.5	1.280	67.1	23	11,800	51,440	633	887	1,050	1,250	1,390
7-0890	Cottonwood Cr. bl Hot Springs nr Buena Vista	34	30.0	1.230	65	25	11,300	42,380	330	469	573	717	835
7-1110	Huerfano R. at Manzanares Crossing nr Redwing	47	23.8	.647	73	21	10,100	23,330	293	623	971	1,600	2,230
7-1140	Cucharas R. at Boyd Ranch nr La Veta	36	17.0	.549	56	25	9,900	17,030	153	292	389	509	595
8-2205	Pinos Cr. nr Del Norte	26	22.0	.585	53	30	10,500	17,820	193	347	467	634	769
8-2235	Rock Cr. nr Monte Vista	23	13.0	.526	32.9	15	10,400	8,190	86.8	151	193	244	279
8-2245	Kerber Cr. at Ashley Ranch nr Villa Grove	37	18.7	.495	36	19	10,500	9,060	96.0	167	224	310	383
8-2270	Saguache Cr. nr Saguache	58	29.7	1.297	595	16	10,200	51,000	344	571	730	935	1,090
8-2275	N. Crestone Cr. nr Crestone	23	13.2	.727	10.7	20	11,300	7,970	90.9	152	202	279	346
8-2305	Carnero Cr. nr La Garita	28	15.0	.470	117	20	10,100	8,330	162	339	486	699	875
8-2310	La Garita Cr. nr La Garita	27	16.7	.475	61	18	10,100	9,710	179	321	421	548	642
8-2360	Alamosa Cr. ab Terrace Res.	44	44.7	.700	107	29	11,000	83,320	992	1,400	1,680	2,060	2,350
8-2405	Trinchera Cr. ab Turners Ranch nr Ft. Garland	37	20.7	.533	45	22	10,400	16,880	124	238	336	486	618
8-2425	Ute Cr. nr Ft. Garland	47	15.5	.636	32	16	10,000	14,920	146	223	277	349	405
8-2475	San Antonio R. at Ortiz	30	18.7	.291	110	11	9,500	18,620	512	876	1,130	1,470	1,720
8-2460	Los Pinos R. nr Ortiz	51	45.0	.486	167	24	9,900	89,110	1,350	1,950	2,340	2,830	3,190
9-0105	Colorado R. bl Baker Gulch nr Grand Lake	17	35.0	1.120	53.4	26	10,600	43,540	587	792	905	1,010	1,190
9-0165	Arapaho Cr. at Monarch Lake Outlet	26	35.0	1.100	46.9	25	10,600	59,630	873	1,070	1,160	1,250	1,300
9-0360	Williams Fk. nr Leal	37	42.5	1.000	89.3	24	10,900	73,170	966	1,320	1,480	1,620	1,700
9-0400	E. Fk. Troublesome Cr. nr Troublesome	23	21.5	.765	76.0	24	9,300	19,490	244	419	[illegible]	798	1,000
9-0475	Snake R. nr Montezuma	23	29.5	1.130	57.7	27	11,400	43,610	530	799	[illegible]	[illegible]	[illegible]
9-0630	Eagle R. at Red Cliff	41	27.0	1.060	70.0	25	10,800	36,880	421	651	[illegible]	[illegible]	[illegible]
9-0680	Brush Cr. nr Eagle	20	26.5	1.040	69.7	28	9,800	31,590	287	455	[illegible]	[illegible]	[illegible]
9-0780	Frying Pan R. at Norrie	29	44.5	1.070	90.6	31	10,900	89,110	998	1,280	[illegible]	[illegible]	[illegible]
9-0785	N. Fk. Frying Pan R. at Norrie	29	27.5	.995	42.0	30	10,600	37,460	540	780	943	[illegible]	[illegible]
9-0975	Buzzard Cr. nr Collbran	49	27.0	.895	139	27	8,500	33,690	559	896	1,130	1,420	1,630
9-1125	East R. at Almont	48	70.3	1.310	289	31	10,200	247,800	2,240	3,200	3,950	5,040	5,950
9-1135	Ohio Cr. nr Baldwin	22	32.3	.830	121	22	10,000	64,480	674	943	1,096	1,262	1,370
9-1155	Tomichi Cr. at Sargents	39	35.3	.931	149	23	10,100	45,210	365	564	634	821	913
9-1180	Quartz Cr. nr Ohio	24	32.0	1.097	106	25	10,700	39,340	365	508	590	683	745
9-1190	Tomichi Cr. at Gunnison	33	64.3	1.360	1,061	22	10,100	123,200	785	1,200	1,470	1,830	2,090
9-1245	Lake Fk. at Gateview	33	65.3	1.210	334	24	10,900	175,300	1,674	2,210	2,540	2,950	3,240
9-1250	Curecanti Cr. nr Saginero	25	23.0	.616	35.0	22	9,700	23,690	266	385	462	555	623
9-1285	Smith Fk. nr Crawford	35	27.7	.512	43.7	23	9,200	29,990	319	460	550	622	666
9-1470	Dallas Cr. nr Ridgway	20	24.3	.804	96.2	26	9,200	27,100	395	594	742	949	1,120
9-1665	Dolores R. at Dolores	59	89.7	1.310	556	30	9,800	311,500	3,360	5,120	6,370	8,030	9,310
9-2395	Yampa R. at Steamboat Sprgs.	63	83.5	1.610	604	25	8,800	336,200	3,680	4,630	5,180	5,790	6,190
9-2410	Elk R. at Clark	52	70.0	1.500	206	37	9,000	244,900	2,590	3,230	3,620	4,090	4,400
9-2530	L. Snake R. nr Slater	25	67.0	.805	285	31	8,600	155,800	2,110	2,760	3,130	3,570	3,860
9-2550	Slater Fk. nr Slater	39	37.5	.710	161	22	8,400	51,870	854	1,140	1,260	1,370	1,430
9-3030	N. Fk. White R. at Buford	25	68.0	1.460	254	32	9,600	223,900	1,290	1,820	2,210	2,760	3,200
9-3040	S. Fk. White R. at Buford	20	69.0	1.160	170	34	9,800	184,000	1,850	2,260	2,520	2,850	3,100
9-3575	Animas R. at Howardsville	35	36.0	.907	55.9	31	11,900	75,350	969	1,270	1,490	1,770	1,990

COLLECTION OF FIELD DATA

The channel surveys were made in September and October 1971. D. O. Moore and T. W. Danielson made the surveys in the north, and E. R. Hedman and R. K. Livingston in the south part of the region. Sites with well-defined and consistent channel and point bars were selected at each gaging station. Channel and point bars are the same features used and described in previous studies by Moore (1968), Hedman (1970), and Hedman and Kastner (1972). These bars have been further described by R. F. Hadley (written commun., 1972) as follows:

"Channel bar.--A longitudinal, in-channel depositional 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. Emerged channel bars are generally free of perennial vegetation. A channel bar may extend for a considerable distance along the channel or it may be one of a series of bars that occupy similar relative positions in the channel. These features previously have been termed berms in the literature (Moore, D. O., 1968, p. 34, and Hedman, E. R. 1970, p. E5). It is proposed that the term channel bar be used exclusively for this in-channel feature to avoid confusion. Channel bars are used as reference levels in channel geometry measurements of width and mean depth in estimating flow characteristics." Figure 1 shows channel bars along the banks of a perennial stream, station 09-1665.

"Point bar.--A point bar is a depositional feature formed by lateral accretion on the inside, or convex side, of a channel bend. Deposition on the convex edge of the channel and the concomitant erosion of the concave bank both tend to be greatest just downstream from the position of maximum curvature. The processes of erosion and deposition tend to maintain a constant channel width during lateral shifting of the channel (Wolman and Leopold, 1957). The surface of a point bar may be used, together with channel bars or mid-channel bars, to obtain channel geometry measurements of width and mean depth in estimating flow characteristics." Figure 2 shows a point bar along the bank of a perennial stream, station 08-2270.

The bars used for the reference level were within the low-water channel and lower than the flood plain. The bars were generally 0.3 to 0.6 foot above the water surface with a few only 0.1 and two more than 1.0 foot.

Methods for selecting the bars and measuring the cross sections have been fairly well standardized. However, field training and experience are necessary, especially for selecting the bars to be used to establish the reference levels. Any obstruction in a channel (boulder, log, bridge pier, and other) can cause scour and a depositional bar, and it is very important not to use these isolated

Figure 1. --Photograph showing channel bar along bank of perennial stream.

Figure 2. --Photograph showing point bar along bank of perennial stream.

bars. The bars that are used to determine the reference levels should continue or reappear along the stream and the reference levels should consistently be about the same elevation above the streambed.

At cross sections where bars adequately define reference levels, a line was stretched tightly across and perpendicular to the low water channel as shown in figure 3. The width, in feet, was measured between the streamward shoulders of the bars at the reference level (A-A' in fig. 3). The depths, in feet, were measured from the line to the streambed at about 15 equidistant points, and the mean depth computed by the midsection method. The depth to water surface at each bank was measured and the "n" value (roughness coefficient) was selected for the site. Stereoscopic color photographs were taken at each site. Average width and depth was computed at several cross sections.

Where pools and riffles existed in the channel, cross sections were measured at or near the riffles. Because the channel dimensions of width and depth vary along the channel, two or three cross sections were surveyed at each of the 53 gaging sites. Cross sections were located one or more stream widths apart and the reference levels for each were determined from separate bars. The average values for each site are shown in table 1.

MULTIPLE REGRESSION ANALYSES

Linear Relationship with Logarithmic Transformation of Variables

In the first analysis all data were transformed to logarithms before defining the relationships by multiple regression techniques. Past experience has shown that with this transformation linear relationships often can be approached. By taking antilogs the defined linear regression equations have the general form:

$$Q = a\, W^{b_1}\, D^{b_2} \qquad (1)$$

for the relationship of discharge to channel geometry alone, and

$$Q = a\, W^{b_1}\, D^{b_2}\, E^{b_3}\, P^{b_4}\, A^{b_5}\, V^{b_6}\, N^{b_7} \qquad (2)$$

in cases when all the variables could be included.

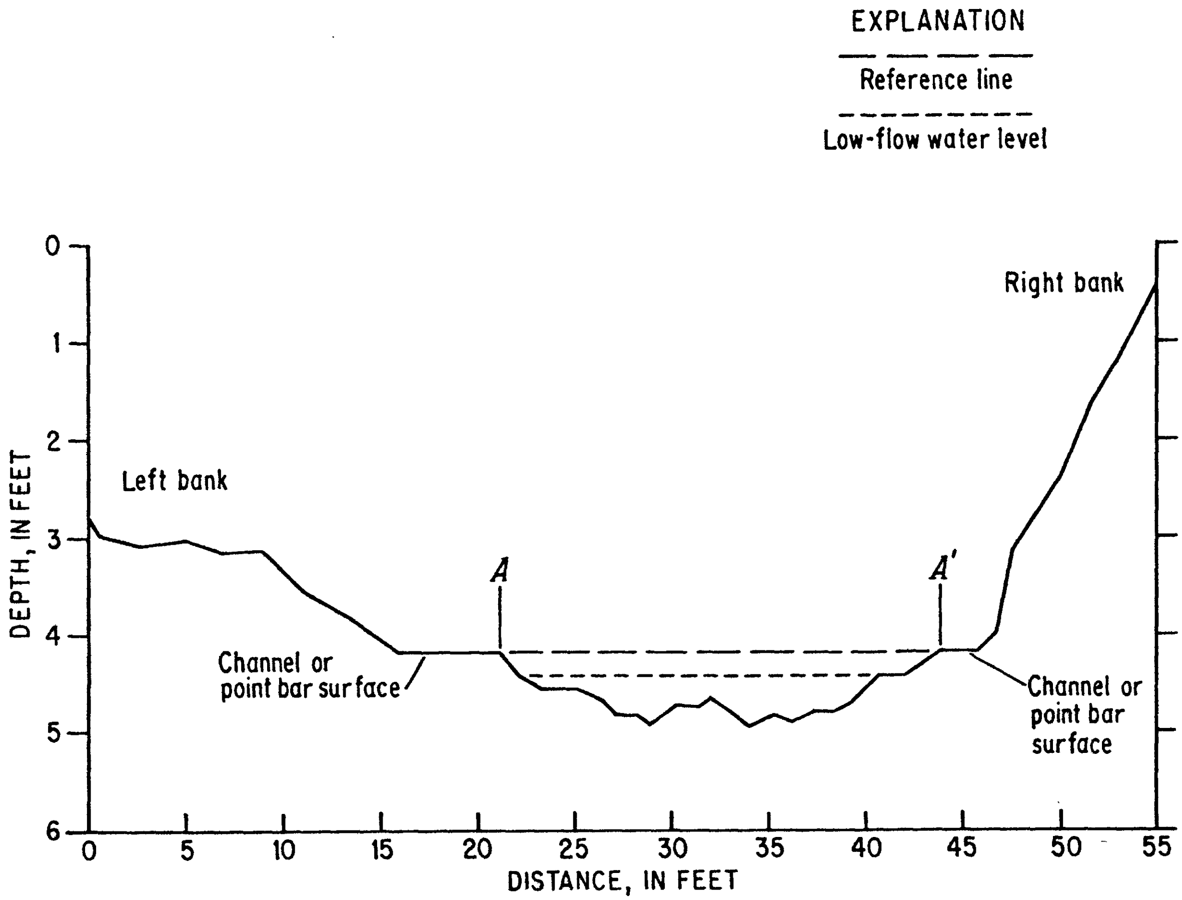

Figure 3.--Typical stream cross section.

In the equations, Q is either Q_a, the mean annual runoff in acre-feet, or Q_2, Q_5, . . ., Q_{50}, the peak discharge in cubic feet per second for the indicated recurrence interval in years; W is average width in feet; D is average depth in feet; E is mean basin elevation, in 1,000 feet above mean sea level; P is mean annual precipitation in inches, to nearest inch; A is drainage area of the basin in square miles; V is mean velocity of the water flowing through the cross section at the time of the channel geometry measurement, in feet per second; and N is the "n" value (roughness coefficient). The a is a regression constant obtained in the analysis and the b's are the regression coefficients.

The gaging station number and name; the length of record; the basin characteristics, W, D, A, P, and E, to be used as independent variables; and the streamflow characteristics, Q_a, Q_2, Q_5, Q_{10}, Q_{25}, and Q_{50} to be used as dependent variables are all listed in table 1.

The regression program used was stepwise regression program BMD02R from the Biomedical Computer Programs developed by the School of Medicine at the University of California (Dixon, 1965). The program forms a sequence of linear regression equations in a stepwise manner. In step one a simple relation is defined with the one independent variable that most effectively explains the site-to-site variation of a selected flow characteristic. In each subsequent step, one variable is added to the equation. The variable added is the one that, by itself, makes the largest reduction in the standard error of estimate of the equation and, therefore, can be considered to be the variable which will strengthen the equation more than any of the other unused available variables. This program also permits the inclusion of a specified variable in the equation regardless of its value in strengthening the equation.

The program provides regression equations, standard errors of estimate, and coefficients of determination (R^2) that indicate the proportion of the total variance in the dependent variable that has been explained by the equation. The criterion for inclusion of variables in the defined equations was based on a reduction in the standard error.

Analyses using W, D, A, P, and E for 53 stations gave the following equations, standard errors, and coefficients of determination (R^2):

Equation	Standard error, percent	R^2	
$Q_a = 49.7\ W^{1.961}$	19.3	0.96	(3)
$= 78.6\ W^{1.838}\ D^{0.232}$	18.3	.97	(4)
(A, P, and E did not reduce the standard error)			
$Q_2 = 0.991\ W^{1.797}$	32.3	.89	(5)
$= .666\ W^{1.904}\ D^{-0.201}$	32.2	.89	(6)
(A, P, and E did not reduce the standard error)			
$Q_5 = 2.40\ W^{1.663}$	31.1	.88	(7)
$= 1.42\ W^{1.804}\ D^{-0.267}$	30.5	.89	(8)
$= 1.53\ W^{1.682}\ D^{-0.251}\ A^{0.077}$	30.4	.89	(9)
(P and E did not reduce the standard error)			
$Q_{10} = 3.64\ W^{1.604}$	33.8	.86	(10)
$= 2.06\ W^{1.757}\ D^{-0.288}$	33.0	.87	(11)
$= 2.38\ W^{1.530}\ D^{-0.259}\ A^{0.143}$	32.1	.88	(12)
(P and E did not reduce the standard error)			
$Q_{25} = 5.49\ W^{1.551}$	39.7	.80	(13)
$= 2.98\ W^{1.713}\ D^{-0.307}$	39.0	.81	(14)
$= 3.70\ W^{1.372}\ D^{-0.263}\ A^{0.215}$	36.9	.84	(15)
(P and E did not reduce the standard error)			
$Q_{50} = 6.99\ W^{1.521}$	45.4	.75	(16)
$= 3.81\ W^{1.684}\ D^{-0.308}$	44.8	.76	(17)
$= 4.93\ W^{1.274}\ D^{-0.256}\ A^{0.257}$	42.1	.80	(18)
(P and E did not reduce the standard error)			

The variable V was available for 20 stations, so an analysis was made to test the significance of V and also N. These variables did not significantly reduce the standard error of estimate.

Split-Sample test of the Accuracy of the Equations

Equations (3-18) might be used to estimate mean annual runoff and peak discharges at ungaged locations. The best test of the prediction ability of the equations is their application to locations other than those used to define the equations. This has been accomplished with split-sample testing. The list of 53 gaging stations shown in table 1, which are in downstream order within major drainage basins, were split alternately, that is, every other station was assigned to sample A (27 stations) and the remainder to sample B (26 stations). Equations with the two independent variables W and D were defined for each sample and the equations were applied to the other sample. Standard errors were computed for the equations and for the application to the other sample to show the prediction ability for the streamflow characteristics. The standard errors for equations 4, 6, 8, 11, 14, 17, and the results of the split-sample test are shown in table 2.

Curvilinear Relationship

Trend surface analysis was used to develop a curvilinear relationship with a second degree polynomial equation with the general form:

$$Q = a + b_1 W + b_2 D + b_3 W^2 + b_4 WD + b_5 D^2 \qquad (19)$$

This analysis did not show any significant improvement over the linear relationship with logarithmic transformation.

LIMITS OF DEFINITION

Because regression analyses do not define actual physical relationships, equations 3-18 can be considered as defining relationships only within the range of data used. Equations 3-18 were defined from data on Colorado mountain streams having perennial and virtually natural flows. One might expect that the equations would be valid in other regions, however, it has not been demonstrated that the equations define relations for streams where flows are intermittent or ephemeral, or for streams where flows are significantly affected by regulation or diversion. The equations also were defined only for measured widths of 13.0 to 89.7 feet and measured average depths of 0.29 to 1.71 feet; the degree to which the equations reflect relationships outside these ranges is unknown.

Table 2.--*Standard errors of estimate, using W and D for equations and application to split-samples*

Streamflow characteristics	Standard error of estimate, in percent				
	Equation for sample A and B	Equation for sample A	Application to sample B	Equation for sample B	Application to sample A
Q_a	18.3	20.2	19.1	16.2	22.3
Q_2	32.2	40.5	24.5	22.1	42.1
Q_5	30.5	36.4	25.6	25.4	36.5
Q_{10}	33.0	38.5	29.1	28.5	38.9
Q_{25}	39.0	45.7	35.1	32.7	50.8
Q_{50}	44.8	53.2	40.5	35.8	56.9

CONCLUSIONS

The study indicates that for perennial natural flow streams in the mountain region of Colorado the mean annual runoff can be estimated reliably from the width and average depth between channel and point bars. The standard error of estimate by linear regression equations with logarithmic transformation of variables is 18.3 percent using both width and depth, and is 19.3 percent using width only. Drainage area, precipitation, velocity of low stage water, "n" value, and average elevation of the basins did not reduce the standard errors. Livingston (1970) obtained a standard error of 47 percent in regression of mean annual runoff on basin characteristics measured on maps.

The analyses also indicate that peak discharges with selected recurrence intervals can be estimated reliably from channel geometry information. Using width and average depth between channel and point bars in a linear equation with logarithmic transformation of variables the standard error for estimating peak discharges with a 2-year recurrence interval is 32.2 percent; with a 5-year interval is 30.5 percent; with a 10-year interval is 33.0 percent; with a 25-year interval is 39.0 percent; and with a 50-year interval is 44.8 percent. Use of only width increased standard errors by less than 0.9 percent. These standard errors are less than those reported by Livingston (1970) for relations defined to estimate flood peaks from basin characteristics measured on maps.

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