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EFFECT OF CHANNEL MATERIAL ON WIDTH-DISCHARGE RELATIONS FOR PERENNIAL STREAMS, WITH EMPHASIS ON STREAMS IN KANSAS--A PROGRESS REPORT

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ABSTRACT

Using consistent procedures for width measurement at established streamflow-gaging stations, data were compiled to develop a power-function relation between width and mean discharge for high-gradient perennial streams. High-gradient channels, which generally exhibit low variability for most factors influencing the width-discharge relation, were selected to define a standard exponent in the power-function equation. Regression analysis of silt-clay channels of Kansas gave an exponent similar to that determined for high-gradient streams, thus supporting the use of a standard exponent.

To account for the effect of sediment on channel morphology, silt-clay percentages of bed and bank material from 98 perennial streams of the western and midwestern United States were introduced into the standard width-discharge relations. Bed and bank cohesiveness, as indicated by silt-clay content, is considered a measure of channel resistance to erosion. Multiple-regression analysis of data limited to Kansas streams yielded an equation more typical of stable conditions than that of the larger area, because widespread destructive flooding and channel widening have not occurred in Kansas recently. The regression equations provide refinement to the channel-geometry technique of estimating discharge characteristics of ungaged basins. The equations also provide a means of anticipating changes in channel morphology resulting from hydraulic structures.

Effect of channel material on width-discharge relations for perennial streams, with emphasis on streams in Kansas -- A progress report

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INTRODUCTION

During the last 30 years considerable attention has been given to the relations between discharge and the parameters of width, depth, and velocity of natural alluvial stream channels. During this period, quantitative methods have been developed to relate flow characteristics to parameters of channel size. The influence on channel morphology of the sediment transported by a stream also long has been recognized, but only limited attention by geomorphologists, mostly during the last two decades, has been given to the quantitative manner by which sediment helps control channel shape.

This study was designed to demonstrate that the channel widths of alluvial streams vary in a predictable manner with the caliber of the sediment, as well as with the discharge characteristics of the stream. The relation can be described quantitatively, although other variables generally can alter the sediment and channel-morphology relation. The purpose of this study is to develop a multiple-regression equation that permits more accurate estimates of mean discharge for Kansas streams than previously have been possible by channel-geometry techniques. The means to this objective is the introduction of parameters related to bed and bank material into a power-function relation between channel width and mean discharge.

Early papers describing the variation of channel width with average discharge included that of Kennedy (1895), who collected data from canals of India, and one by Lacey (1930), who proposed a power-function relation between width and discharge. Influenced by these two works, Leopold and Maddock (1953) published a widely accepted paper of the association between perennial discharge and channel properties of natural alluvial streams. Among the equations they presented was one describing the variation of width with average discharge in the downstream direction (Leopold and Maddock, 1953, p. 8):

$$w = aQ^b$$

where w is the channel width at mean or average discharge, Q; a is a coefficient dependent on the units used, and b is an exponent. The value of "b" that they proposed, 0.5, is identical to that of Lacey (1930).

In the years since publication of the hydraulic-geometry paper by Leopold and Maddock (1953), several studies, mostly of specific areas, have tested the values of the exponents. Consistent results have not been obtained for the "b" exponent, the rate of change of channel width with discharge in the downstream direction. Part of the reason for the varied results possibly was inconsistent use of reference levels at which width measurements were made. The principal cause of variation, however, is inferred to have been a failure to consider the variables, such as riparian vegetation, effects of floods, and sediment characteristics, that influence the width-discharge relation.

Recent use of channel-geometry measurements has been directed towards defining mean annual or peak-discharge frequency characteristics from ungaged basins. Most of the studies have resulted in simple-regression analyses to obtain power-function relations describing the width-discharge relation for streams of the area, climate, or channel type of interest. The regression equations generally have given discharge as the dependent variable because width measurements were taken to estimate discharge characteristics. Hence, the exponents are comparable to the reciprocal, or 2.0, of the 0.5 value reported by Lacey (1930) and Leopold and Maddock (1953). Exponents given in various reports for the width-discharge relation in the downstream direction mostly range from 1.8 to 2.0, but values as high as 2.1 (Stall and Fok, 1968), and as low as 1.3 (Hedman and Kastner, in press) have been proposed.

Previous channel-geometry studies of Kansas streams have yielded regression equations for both average annual discharge and peak discharges. A study by Hedman and Kastner (1972) used the top edges of the depositional bars, the lowest prominent bed forms and highest channel features subject to annual bed-material movement, as the reference level at which widths were measured. A later study (Hedman, Kastner, and Hejl, 1974) used the active-channel reference level for width measurements. In this report all width measurements are related to the top of the active channel, which, as described by Osterkamp and Hedman (in press) is "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." It is assumed that use of the active-channel reference level provides a standardized basis of width measurement that minimizes error due to human judgement in the regression relation.

The study described herein, which extends the methods and results provided by Hedman and Kastner (1972), and Hedman, Kastner, and Hejl (1974), is part of a cooperative program between the Kansas Water Resources Board and the U.S. Geological Survey.

APPROACH

Many workers have observed that the shape of alluvial channels is influenced by the sediment transported by the stream. Without definition of the manner in which discharge affects channel geometry, however, the influence of sediment could only be described qualitatively. Schumm (1960) showed that the silt-clay percentages of the bed and banks of alluvial channels can be correlated with width-depth ratios. Thus, the effect of discharge on channel size largely was eliminated from consideration. This technique demonstrates the influence of sediment, specifically silt-clay percentages, on channel geometry, but cannot be used to estimate discharge from ungaged basins.

To refine the channel-geometry method in the present study, a width-discharge relation defined here was modified by introducing the silt-clay percentages of the bed and bank material of streams. Sediment samples of bed and bank material were collected for particle-size analysis at most of the measured sites, but in some cases the bank silt-clay content was estimated by visual examination. Almost all data were collected at or near U.S. Geological Survey stream-gaging stations where discharge records are available. The width, average discharge, and silt-clay data were analyzed by digital computer, yielding simple- or multiple-regression equations describing the manner in which average discharge of perennial streams varies with the width and sediment character of those streams. A description of the computer program used and methods of collecting channel-geometry data can be found in a report by Hedman, Kastner, and Hejl (1974).

PLATE 1 (near here)

Many of the data were collected from Kansas, but streams of other western and midwestern states, mostly within the Missouri River basin, are represented (pl. 1). Data from high-gradient (generally mountainous) and low-gradient streams were obtained, but they were used in separate regressions owing to different sediment characteristics. Data from sites on regulated streams are included in the regression analyses, but most were collected on unregulated streams. Standard techniques of particle-size analysis were employed for bed- and bank-material samples, but only the silt-clay contents (portion with particle sizes less than 0.062 mm-diameter) were included in the regression analyses.

Bed and bank material samples, when taken at the time of width measurement, were collected separately. At most sampling sites that could be waded, a composite, or width-integrated, sample composed of 5 to 10 portions of bed material was hand collected at equal distances along the width of the active-channel section. Only the top inch of the bed was sampled in the horizontal to subhorizontal part of the section that could be confidently considered the channel bed. A similar composite sample was collected from the two banks. Parts of the channel cross-section intermediate between bed and banks were not included in the sampling procedure. A standard bed-material sampler, or an improvised sampler and small boat, was used to obtain samples at those streams too deep for hand collection.

Plate 1.--Map showing measurement and sampling sites.

SIMPLE-REGRESSION ANALYSES

To establish the effect that sediment exerts on channel widths, it is necessary to define accurately the general variation of width with a parameter of discharge. Initial assumptions leading to identification of a standard width-discharge relation are based in part on previously cited studies; they include: 1) a power-function relation exists between width and average discharge for most streams, and has the form:

$$W_A = a\overline{Q}^b$$

where W_A is the active-channel width and $\overline{Q}$ is average discharge; 2) the exponent, b, is constant expressing rate of change, not a variable as the lack of agreement in previous studies implies; and 3) the value of the coefficient, a, besides being dependent on the units used, is a function of all variables that affect the rate of change of width with discharge. A series of simple-regression analyses was designed to demonstrate that these three assumptions are reasonable, and to identify a standard value for the exponent.

Data defining a straight-line relation on logarithmic coordinates are evidence that a power-function equation between two variables applies. The first assumption can be supported, therefore, if data describe a straight line through several orders of magnitude. Previous studies have developed conflicting values of "b" mainly because the magnitudes of the data were too limited, and no attempts were made to account for the effects, as indicated by the coefficient, of variables influencing the width-depth relation.

The variables that were judged to produce the greatest scatter in the width-discharge relation are discharge variability of a stream, sediment characteristics, climate and riparian vegetation, and elements of channel roughness. Variable discharge, particularly flooding, affects the relation by causing bank erosion, flood-plain destruction, and channel widening (Schumm and Lichty, 1963; Burkham, 1972), whereas active channels tend to heal and narrow at lower discharge rates (Hedman, Kastner, and Hejl, 1974). The other variables all help determine the ability of the bed and banks of an active channel to resist widening by high discharges. Identification of a standard exponent, therefore, is facilitated by the use of data from selected streams where the effective range of these variables is minimal.

To identify the value of the power-function exponent, width and discharge data (Osterkamp and Hedman, in press) from 32 streams of channel gradient exceeding 0.0080 ft/ft (foot per foot) were related. The active-channel widths of the various streams were measured by several different hydrologists. High-gradient streams were selected to assure consistency in the selection of measurement sites, but nearly all stations visited (pl. 1, table 1) were in mountainous areas of the western United States. High-gradient, alpine stream channels were selected because generally they are more stable, and the controls affecting the width-discharge relation show less variability than is true of other groups of streams. Peak discharges of high-gradient perennial streams generally occur from spring runoff of melted snow, and are not as flashy or erosive as floods of many streams of lower channel gradient. Suspended-sediment discharge of high-gradient streams generally is very low, but the caliber of bed and bank material, hence roughness, is commonly high relative to other streams. Alpine climates and riparian vegetation also have minimal variation within the western United States.

TABLE I → (near here)

Table 1.--Basic data for high-gradient streams.

Table Number (H)	Station Number	Station Name	Active-channel width (ft)	Average discharge (acre-ft/yr)	Channel gradient (ft/ft)	Length of discharge record (yr.)	Source of width meas.[a]
1	6048500	Bridger Creek nr Bozeman, Mt.	22.0	26,520	0.0152	24	1
2	6061500	Prickly Pear Creek nr Clancy, Mt.	24.0	34,990	.0158	40	1
3	6062500	Tenmile Creek nr Rimini, Mt.	19.0	12,610	.0216	59	1
4	6077000	Sheep Creek nr White Sulphur Springs, Mt.	25.0	23,110	.0083	31	1
5	6109800	S. Fk. Judith River nr Utica, Mt.	20.0	14,780	.0179	15	1
6	6115500	N. Fk. Musselshell River nr Delpine, Mt.	17.0	8,690	.0082	33	1
7	6191000	Gardner River nr Mammoth, Yellowstone Nat. Park, Wy.	55.0	159,400	.0170	34	1
8	6271000	Ten Sleep Creek nr Ten Sleep, Wy.	51.0	105,800	.0190	41	1,2
9	6289000	Little Bighorn River at State Line near Wyola, Mt.	49.0	109,400	.0118	34	1
10	6298000	Tongue River nr Dayton, Wy.	52.0	135,500	.0143	44	1,2
11	6298500	Little Tongue River nr Dayton, Wy.	16.0	9,350	.0238	20	1,2
12	6311000	N. Fk. Powder River nr Hazelton, Wy.	16.0	10,360	.0091	27	1,2
13	6314500	N. Fk. Crazy Woman Creek nr Grueb, Wy.	20.0	13,400	.0309	24	1
14	6315500	M. Fk. Crazy Woman Creek nr Grueb, Wy.	25.0	16,160	.0123	31	1
15	6317500	N. Fk. Clear Creek nr. Buffalo, Wy.	18.0	10,060	.0280	20	1,2
16	6318500	Clear Creek nr Buffalo, Wy.	35.0	45,280	.0240	47	1,2
17	6409000	Castle Creek above Deerfield Res. nr Hill City, S. D.	13.0	7,240	.0082	25	1
18	6431500	Spearfish Creek at Spearfish, S. D.	34.0	36,320	.0141	27	1
19	6616000	N. Fk. Michigan River nr Gould, Co.	18.0	12,820	.0089	24	1
20	6710500	Bear Creek at Morrison, Co.	38.0	39,270	.0357	59	1,2
21	6712000	Cherry Creek nr Franktown, Co.	13.0	6,500	.0250	34	1
22	6716500	Clear Creek nr Lawson, Co.	58.0	9,260	.0136	28	1
23	6719500	Clear Creek nr Golden, Co.	73.0	165,200	.0195	64	1,2
24	6722500	S. St. Vrain Creek nr Ward, Co.	21.0	20,360	.0391	24	1
25	6725500	M. Boulder Creek at Nederland, Co.	32.0	39,270	.0231	67	1,2

Table 1.--Basic data for high-gradient streams (continued).

Table Number (H)	Station Number	Station Name	Active-channel width (ft)	Average discharge (acre-ft/yr)	Channel gradient (ft/ft)	Length of discharge record (yr.)	Source of width meas.[a]
26	6730300	Coal Creek nr Plainview, Co.	8.0	3,350	.0352	15	2
27	6733000	Big Thompson River at Estes Park, Co.	50.0	92,010	.0098	28	1
28	8387000	Rio Ruidoso at Hollywood, N. M.	16.0	9,350	.0087	21	3
29	9073400	Roaring Fork River nr Apsen, Co.	39.0	108,000	.0109	10	2
30	9074800	Castle Creek above Aspen, Co.	23.0	30,570	.0333	5	2
31	9075700	Maroon Creek above Aspen, Co.	31.0	45,060	.0260	5	2
32	9442692	Tularosa River above Aragon, N. M.	9.0	2,510	.0083	8	3

a - Field investigations by H. R. Hedman and W. M. Kastner (1); W. R. Osterkamp (2); A. G. Scott and J. L. Kunkler (3).

(H)- Designates table number and letter (H) for high-gradient stream stations shown in figure 1.

FIG 1 → (near here)

Regression analysis of the width-discharge data of table 1 yields the equation:

$$\overline{Q} = 41.2\ W_A^{1.98}$$

which has a standard error of estimate of 0.0975 log units (+25, -20, and average 23 percent), a correlation coefficient (R) of 0.98, and a level of significance of 0.05 percent ($F_{1,30} = 728$). The data and regression line, which are shown in figure 1, extend through about 2 and 3 orders of magnitude respectively for width and discharge. To extend the regression line and further support the exponent of 1.98, flume data (Leopold and Wolman, 1957; Wolman and Brush, 1961) also are plotted (fig. 1). These data were not included in the regression analysis, but their proximity to the extrapolated regression line provides evidence of the accuracy of the exponent. The widths of the flume channels were measured under conditions of constant discharge and assumed equilibrium. The imposed channels of the flume studies were initially narrow and were allowed to widen to stability. Only data for channels of gradient exceeding 0.0080 ft/ft are included (fig.1).

Figure 1.--Logarithmic plot and regression line of high-gradient stream and flume data.

A second simple-regression analysis provides additional evidence that the three assumptions are justified, and that the exponent indicated by the high-gradient channel data is accurate and constant. Width-discharge data from 13 perennial streams of relatively low gradient were used. The silt-clay content of the bed material at all measurement sites equaled or exceeded 70 percent. A limited range of climate and riparian vegetation was assured by including channel data restricted to the eastern two-thirds of Kansas. Widths of the streams represented ranged from 11.0 to 125 ft (feet), and discharges varied from 9,130 to 1,207,000 acre-ft/yr (acre-feet per year). The resulting regression equation is:

$$\overline{Q} = 102\ W_A^{1.95}$$

The standard error of estimate is 0.1167 log units (+30, -24, and average 27 percent), indicating precision approaching that achieved for the high-gradient regression. The correlation coefficient (R) is 0.98, and the level of significance is 0.05 percent ($F_{1,11} = 261$).

The two groups of streams represent opposite extremes for conditions of bed-material size, gradient, and channel roughness; typical climatic conditions and vegetation are much different, as is discharge variability. The only significant similarity between the two channel groups is the tendency for both to have stable, cohesive banks that are not easily eroded and widened by peak flows. In spite of the differences, the exponents given by the two regression analyses are similar, suggesting that a constant exponent does apply to a power-function relation between width and discharge in the downstream direction. More than a two-fold difference in the coefficient, however, supports the third assumption by demonstrating that channel widths of perennial streams of similar discharge can be much different depending on the variables affecting the width-discharge relation.

If an exponent of 2.0 is assumed constant and accurate to two significant figures (Osterkamp and Hedman, in press), all variations in the width-discharge relation must be indicated by changes in the coefficient, a. Simple-regression analysis of several groups of perennial streams, each group representing a limited range of bed and bank material, results in a range of values for "a", and demonstrates that bed and bank material exerts a strong influence on the width-discharge relation (table 2). In each regression an exponent of 2.0 was imposed on the relation, forcing the coefficient to change as a result of the different sediment characteristics. Results show that the silt-clay content of both the bed and bank material affects channel morphology. Because the cohesiveness of alluvium decreases with an increasing proportion of sand, channels with a sandy bed and banks are easily widened by floods. Hence, greater width variability and standard error (table 2) occurs for this type of stream than does for the channel groups of high silt-clay content.

Table 2.--Width-discharge relations of selected sediment-type channels.

Character group	Number of sites	Regression equation	Standard of error
Silt-clay of bed, 70-100%	13	$\overline{Q} = 86.3\ W_A^{2.0}$	0.1167 (+31,-24,ave.27%)
Silt-clay of bed, 30-69%	11	$\overline{Q} = 47.5\ W_A^{2.0}$	0.1070 (+28,-22,ave.25%)
Silt-clay of bed, 7-29%	26	$\overline{Q} = 40.6\ W_A^{2.0}$	0.2272 (+69,-41,ave.55%)
Silt-clay of bed, <7%; silt-clay of banks, ≥50%	11	$\overline{Q} = 32.3\ W_A^{2.0}$	0.1906 (+55,-36,ave.45%)
Silt-clay of bed, <7%; silt-clay of banks, <50%	20	$\overline{Q} = 11.0\ W_A^{2.0}$	0.2451 (+76,-43,ave.59%)

FIG 2 (near here)

Results of the sediment-group regressions are illustrated in figure 2. Included for comparison is the regression line for high-gradient streams, which has a position corresponding to moderate amounts of channel silt and clay. Most high-gradient stream channels are armored by gravel, cobbles, and boulders, and this protection apparently provides a similar effect on channel geometry as does the cohesiveness of silt and clay. Armoring by coarse material is not considered quantitatively in this report, but it is recognized to have a strong influence on the geometry of many Kansas streams. Particularly in the eastern part of the State, where limestone outcroppings provide a source of gravel and cobbles to streams, estimates of average discharge based on width and silt-clay data may be substantially in error.

Figure 2.--Regression relations of stream channels of specified sediment characteristics.

MULTIPLE-REGRESSION ANALYSES

The simple-regression analyses indicate that the widths of perennial streams of similar discharge vary inversely with the silt-clay content of both the bed and bank material. For streams of low to moderate gradient, as are typical of Kansas, these two quantities are descriptive of the ability of the bed and banks to withstand the widening effects of high flow events; they suggest the degree of active-channel narrowing that will occur after a channel has been widened by a flood. By introducing parameters of bed and bank silt-clay content into the power-function relation for width and discharge, a multiple-regression equation can be developed to estimate average annual discharge.

Returning to the width-depth relation for the downstream direction:

$$\overline{Q} = aW_A{}^b$$

evidence has been presented to show that the exponent, b, has a constant value of approximately 2.0. The coefficient, a, depends on the units used and is a function of all variables that affect the width-discharge relation. Thus:

$$a = f\ (X_1, X_2, X_3, X_4, \ldots .X_n)$$

where X is any variable affecting the relation. If X_1 and X_2, respectively, are designated as the silt-clay percentages of the bed and banks, and a power-function relation is assumed, it follows that:

$$a = X_1{}^x\ X_2{}^y\ a'$$

where

$$a' = f\ (X_3, X_4, \ldots .X_n)$$

Thus, the coefficient, a', is dependent on all variables influencing the width-depth relation other than channel silt and clay content. Substitution yields a new equation:

$$\overline{Q} = a' \, W_A^{2.0} \, SC_{bd}^{x} \, SC_{bk}^{y}$$

where $\overline{Q}$ is mean discharge, W_A is active-channel width, SC is the silt-clay percentage of the bed (bd) or banks (bk), x and y are exponents to be defined by regression analysis, and a' is the newly developed coefficient, also to be evaluated during regression.

Listed in table 3, following the References, are 98 sites (shown in plate 1) for which average-discharge, active-channel-width, and sediment data are available. Most of these data were collected at gaging-station sites for which at least 20 years of discharge records are available. A few data sets of table 3 pertain to sites not at a gage, but where a reasonably accurate average discharge could be estimated. Most of the bed and bank samples were collected and analyzed by personnel of the U.S. Geological Survey. A few analyses were provided by the U.S. Army Corps of Engineers (written commun., 1974). The width and silt-clay data of table 3 mostly were acquired recently, but some were collected for studies by S. A. Schumm from 1958 to 1961 (Schumm, 1960; 1963). Owing to differences in analytical procedures, some of the particle-size data collected by Schumm have been modified. The channel widths reported (Schumm, 1960, p. 19-20; written commun., 1975) are inferred to be identical to active-channel widths, however, and are unaltered. The silt-clay percent of bank material for some sites (table 3) has been estimated on the bases of data from nearby stations, bed-material analyses, and basin geology, but all are presumed sufficiently accurate to avoid significant error. All of the simple-regression analyses for the sediment groups (table 2) were based on data listed in table 3.

Multiple-regression analysis of the width, discharge, and sediment data of table 3 yields the equation:

$$\overline{Q} = 2.0\ W_A^{2.0}\ (SC_{bd})^{0.22}\ (SC_{bk})^{0.57}$$

where $\overline{Q}$ is expressed in acre-feet per year, W_A in feet, and silt-clay content as percentages ranging from 1 to 100. As shown by the simple regressions, the equation indicates that silt-clay contents of both the bed and banks of active channels exert a significant influence on channel morphology. Bed material of natural alluvial channels can vary from total sand and coarser sizes (1 percent silt-clay when using the above equation) to total silt-clay, a range resulting in a nearly three-fold difference of possible predicted discharges. If other variables are constant, a channel of 100 percent bank silt-clay has a predicted mean discharge about 4 times greater than one of 10 percent silt-clay. Natural channel banks in Kansas and elsewhere are rarely lacking in fine-grained material, but the predicted average discharge of such a stream would be about 7 percent that of a stream with banks totally composed of silt- and clay-sized material.

The standard error of estimate of the multiple-regression analysis is 0.238 log units (+73, -42, and average 58 percent), the coefficient of multiple correlation (R) is 0.73, and the level of significance is 0.05 percent ($F_{2,95} = 53$). The level of significance for the bed silt-clay term is greater than that of bank silt-clay. The principal causes of error, or scatter of data points, are inferred to be unstable channel conditions resulting from relatively recent floods, improper selection of the width measurement site, unrepresentative discharge data, and unrepresentative bed-material data. Widening due to flooding possibly has the greatest effect on the standard error. Error resulting from improper sampling or estimated values of bank silt-clay is assumed to be comparatively minor because variation of bank material with time and location along a short stream reach is generally less extensive than that of bed material.

In Kansas, destructive flooding has not occurred in many streams since the catastrophic floods of 1951, and sufficient time has passed to permit significant healing and narrowing. Therefore, many of the 53 data sets for Kansas streams (table 3) represent active channels that are not anomalously wide owing to the effects of flooding. Using only Kansas data in table 3 and an imposed exponent of 2.0 for the width-discharge relation, multiple-regression analysis yielded the equation:

$$\overline{Q} = 1.55\ W_A^{2.0}\ (SC_{bd})^{0.17}\ (SC_{bk})^{0.68}$$

with a standard error of estimate of 0.1838 log units (+53, -34, and average 44 percent), a coefficient of multiple correlation (R) of 0.82, and a level of significance of 0.05 percent ($F_{2,50} = 50$). By comparison, simple-regression analysis of the same width-discharge data resulted in the relation:

$$\overline{Q} = 160\ W_A^{1.62}$$

where the exponent was not imposed. The standard error of estimate is 0.2813 log units (+91, -48, and average 69 percent), the correlation coefficient is 0.91, and the level of significance is 0.05 percent ($F_{1,51} = 241$).

CONCLUSIONS

Two variables significantly influence the width-discharge relation: (1) floods and other degrees of discharge variability, and (2) erosional resistance of the material forming the channel. Discharge variability, particularly as indicated by elapsed time since an erosive flood, appears to be a main cause for inconsistent results when applying individual data sets to the multiple-regression equations. This conclusion is supported by the studies of Schumm and Lichty (1963) and Burkham (1972), as well as by observations of this study. Much of the standard error of estimate for the various regression analyses is no doubt the result of excessive channel width caused by recent flooding. Assuming that recent conditions of weather, land use, and other relevant variables have not been anomalous, deviation of data sets from the regression relations owing to varying amounts of excessive width relative to average discharge may be an indication of the degree to which a channel differs from stable or equilibrium conditions.

During the last 25 years, excessive widening of Kansas streams by floods generally has been less extensive than for the other streams of table 3. A standard error of estimate that is lower for the Kansas data than for all data of table 3 is an indication of relative stability of Kansas streams at present (1976). Comparisons of the regression analyses for the two groups of data support the premise that a stream narrows toward a condition of stability or equilibrium. If discharge remains relatively stable, no opportunity for renewed widening exists, and a relatively narrow channel results. Thus, narrow channels relative to average discharge and sediment characteristics are the expected result of flow regulation by reservoirs.

In the multiple-regression analyses of this report, silt-clay contents of the bed and banks represent channel cohesiveness. That these parameters do not accurately measure channel resistance to erosion is a second principal cause of scatter of data sets about the regression relations. Percent silt-clay of bed and bank material, however, represents cohesiveness of channel material well enough that significant refinement is possible for the width-discharge relation. A reduction in average standard error from 69 to 44 percent, or a reduction of 36 percent of the error, resulted when sediment data were introduced into the width-discharge relation for Kansas streams. Other important variables of channel competence and stability that are not directly considered in this paper include climate, riparian vegetation, and armoring by coarse sediment sizes.

A principal utility of the multiple-regression equations of this study is improved precision of the channel-width technique for estimating discharge from ungaged basins (Hedman, Kastner, and Hejl, 1974). Use of sediment data as a surrogate for channel resistance to erosion is considered justification for eliminating variable exponents from regression analyses of areal or regional studies. Instead, it appears that inclusion of sediment data in a regression analysis should be accompanied by use of a constant exponent for the width-discharge relation. Data of this study suggest that the standard value for the exponent should be 2.0 (Osterkamp and Hedman, in press).

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Table 3.--Basic data used in the multiple-regression analyses.

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay Bed	Percentage Silt-Clay Banks
1	06131000	Big Dry Creek nr Van Norman, Mt.	39,630	30	32.5	13	33
2	06177500	Redwater River at Circle, Mt.	10,580	36	6.6	22	33
3	06182500	Big Muddy Creek at Daleview, Mt.	11,370	24	16.0	18	23
4	06256650	Badwater Creek at Lysite, Wy.	14,490	7	50.0	3	44
5	06309500	Middle Fk. Powder River at Kaycee, Wy.	50,420	20	35.0	13	55
6	06312500	Middle Fk. Powder River nr Kaycee, Wy.	96,300	32	47.0	13	58
7	06316400	Crazy Woman Creek nr Arvada, Wy.	35,570	--	33.0	2	73
8	06325500	Little Powder River nr Broadus, Mt.	28,690	20	40.0	5	81
9	06334000	Little Missouri River nr Alzada, Mt.	55,930	49	40.0	37	82
10	06340500	Knife River at Hazen, N. D.	131,000	40	48.0	1	54
11	06345500[R]	Heart River nr Richardton, N. D.	75,350	49	67.0	6	46
12	06348000[R]	Heart River nr Lark, N. D.	158,700	27	80.0	1	41

Table 3.--Basic data used in the multiple-regression analyses (continued).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay Bed	Percentage Silt-Clay Banks
13	06349000[R]	Heart River nr Mandan, N. D.	186,200	40	104	2	35
14	06441500	Bad River nr Ft. Pierre, S. D.	112,300	45	63.0	1	75[E]
15		White River at Chadron, Nb.[A]	20,000[E]	--	25.0	35	70
16	06480000	Big Sioux River nr Brookings, S. D.	122,400	20	63.0	10	70[E]
17	06481000	Big Sioux River nr Dell Rapids, S. D.	199,200	25	75.0	17	73[E]
18	06600500	Floyd River at James, Ia.	130,400	38	80.0	1	75[E]
19	06606600	Little Sioux River at Correctionville, Ia.	500,600	46	115	1	75[E]
20	06607200	Maple River at Mapleton, Ia.	165,900	32	115	2	75[E]
21	06608500	Soldier River at Pisgah, Ia.	90,560	33	88.0	1	75
22	06685000	Pumpkin Creek nr Bridgeport, Nb.	22,820	41	22.0	40	56
23	06695000	S. Platte River ab Elevenmile Canyon Reservoir, Co.	57,890	35	41.5	1	51

Table 3.--Basic data used in the multiple-regression analyses (continued).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay	
						Bed	Banks
24	06712000	Cherry Creek nr Franktown, Co.	6,500	34	13.0	8	44
25	06784000	South Loup River at Saint Michael, Nb.	178,200	29	123	1	30
26	06786000	North Loup River at Taylor, Nb.	333,300	35	153	1	25[E]
27	06787500	Calamus River nr Burwell, Nb.	216,000	32	151	1	38
28	06789000	North Loup River at Scotia, Nb.	626,000	33	392	1	15
29	06797500	Elkhorn River at Ewing, Nb.	130,400	25	89.0	1	39
30	06799000	Elkhorn River nr Norfolk, Nb.	373,300	27	205	3	44
31	06824500	Republican River at Benkelman, Nb.	67,230	31	123	5	22
32	06825500	Landsman Creek nr Hale, Co.	2,830	23	11.0	15	71[E]
33	06827500[R]	S. Fk. Republican River nr Benkelman, Nb.	41,010	42	100	1	30
34	06834000[R]	Frenchman River at Palisade, Nb.	67,090	24	36.0	8	89

Table 3.--Basic data used in the multiple-regression analyses (continued).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay Bed	Percentage Silt-Clay Banks
35	06835000	Stinking Water Creek nr Palisade, Nb.	31,590	23	29.0	7	69[E]
36	06837000	Republican River at McCook, Nb.	153,600	19	115	1	41
37	06838000	Red Willow Creek nr Red Willow, Nb.	31,200	33	45.0	22	84
38	06841000	Medicine Creek ab Harry Strunk Lake, Nb.	51,080	22	32.0	8	70[E]
39	06845000	Sappa Creek nr Oberlin, Ks.	12,800	33	16.0	66	89
40	06845200	Sappa Creek nr Beaver City, Nb.	27,750	36	26.0	16	94
41	06846500	Beaver Creek at Cedar Bluffs, Ks.	16,160	29	13.5	92	98
42	06847500	Sappa Creek nr Stamford, Nb.	55,500	27	43.0	1	95
43	06847900	Prairie Dog Creek ab Norton Reservoir, Ks.	8,770	12	16.0	16	72
44	06848000[R]	Prairie Dog Creek at Norton, Ks.	24,050	31	45.0	1	53
45	06853500[R]	Republican River nr Hardy, Nb.	467,300	41	154	1	27

Table 3.--Basic data used in the multiple-regression analyses (continued).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay	
						Bed	Banks
46		Republican River nr Napanee, Nb.[A]	526,000[E]	--	127	1	37
47	06855800	Buffalo Creek nr Jamestown, Ks.	58,320	15	24.0	82	94
48	06855900	Wolf Creek nr Concordia, Ks.	9,130	12	11.0	88	96
49	06856000[R]	Republican River at Concordia, Ks.	573,100	29	150	25	30[E]
50	06856001[R]	Republican River at Concordia, Ks.	573,100	29	250	1	30
51	06856600[R]	Republican River at Clay Center, Ks.	755,700	57	300	1	10
52		Republican River at Junction City, Ks.[A,R]	900,000[E]	--	300	1	41
53	06859500	Ladder Creek bl Chalk Creek nr Scott City, Ks.	6,590	23	8.0	9	70[E]
54	06860000	Smoky Hill River at Elkader, Ks.	26,720	35	45.0	1	38
55	06862700[R]	Smoky Hill River nr Schoechen, Ks.	25,140	10	28.0	1	50[E]
56	06863500	Big Creek nr Hays, Ks.	30,500	26	30.0	2	75[E]

Table 3.--Basic data used in the multiple-regression analyses (continued).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay	
						Bed	Banks
57	06863900	N. Fk. Big Creek nr Victoria, Ks.	3,950	12	8.0	13	71
58	06864000[R]	Smoky Hill River nr Russell, Ks.	150,000	35	110	1	20
59	06867000	Saline River nr Russell, Ks.	87,660	23	46.0	1	91[E]
60	06867500	Paradise Creek nr Paradise, Ks.	14,060	19	20.0	17	71
61	06869500[R]	Saline River at Tescott, Ks.	165,000	55	36.0	90	92
62		Saline River nr Salina, Ks.[A,R]	165,000	55	56.0	49	92
63	06871000	N. Fk. Solomon River at Glade, Ks.	23,980	22	38.0	4	50[E]
64	06871500	Bow Creek nr Stockton, Ks.	10,650	23	23.0	1	50[E]
65	06871900	Deer Creek nr Phillipsburg, Ks.	2,520	8	13.5	5	50[E]
66	06872500[R]	N. Fk. Solomon River at Portis, Ks.	107,200	29	52.0	1	87
67	06873000	S. Fk. Solomon River ab Webster Reservoir, Ks.	52,310	29	36.0	1	50[E]
68	06873700	Kill Creek nr Bloomington, Ks.	1,910	11	12.0	22	74

Table 3.--Basic data used in the multiple-regression analyses (continued).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay	
						Bed	Banks
69	06874000[R]	S. Fk. Solomon River at Osborne, Ks.	99,280	28	38.0	30	85
70	06875900[R]	Solomon River nr Glen Elder, Ks.	112,300	10	25.5	16	72
71	06876700	Salt Creek nr Ada, Ks.	43,830	15	25.5	79	93
72	06876900[R]	Solomon River at Niles, Ks.	418,800	63	73.0	91	91
73		Solomon River at Bennington, Ks.[A,R]	418,800	63	112	4	90
74	06877600[R]	Smoky Hill River at Abilene, Ks.	1,207,000	40	125	87	97
75	06878000	Chapman Creek nr Chapman, Ks.	60,060	20	25.0	96	98
76	06878500	Lyon Creek nr Woodbine, Ks.	78,250	20	35.0	54	84
77	06884000	Little Blue River nr Fairbury, Nb.	264,400	49	118	1	50[E]
78	06884200	Mill Creek at Washington, Ks.	74,620	15	39.0	14	71
79	06884400	Little Blue River nr Barnes, Ks.	477,400	16	165	4	50[E]

Table 3.--Basic data used in the multiple-regression analyses (continued).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay Bed	Percentage Silt-Clay Banks
80	06885500	Black Vermillion River nr Frankfort, Ks.	99,980	21	27.0	91	97
81	06888000	Vermillion Creek nr Wamego, Ks.	65,780	26	37.0	56	86
82	06889140	Soldier Creek nr Soldier, Ks.	7,020	10	16.0	1	30[E]
83	06891500	Wakarusa River nr Lawrence, Ks.	133,000	43	42.0	84	95
84	06892000	Stranger Creek nr Tonganoxie, Ks.	158,000	46	42.0	82	94[E]
85	06897500	Grand River nr Gallatin, Mo.	813,600	52	130	1	65
86	06914000	Pottawatomie Creek nr Garnett, Ks.	156,000	33	63.0	30	78
87	06915000	Big Bull Creek nr Hillsdale, Ks.	63,700	16	33.5	24	50
88	06917500	Marmaton River nr Fort Scott, Ks.	204,000	40	60.0	22	77[E]
89	06919500	Cedar Creek nr Pleasant View, Mo.	210,800	28	72.0	6	80[E]
90	07117600	Chicoso Creek nr Fowler, Co.	2,960	6	8.3	30	37

Table 3.--Basic data used in the multiple-regression analyses (concluded).

Table Number	Station Number	Station Name	Ave. Disch. (acre-ft/yr)	Length of record (yr)	Width (ft)	Percentage Silt-Clay	
						Bed	Banks
91	07141200	Pawnee River nr Larned, Ks.	55,860	50	33.0	77	93
92	07141900	Walnut Creek at Albert, Ks.	46,500	14	22.0	70	90
93	07142300	Rattlesnake Creek nr Macksville, Ks.	25,500	15	33.0	24	50
94	07143300[R]	Cow Creek nr Lyons, Ks.	49,300	25	28.0	10	50
95	07144200[R]	Little Arkansas River at Valley Center, Ks.	180,000	50	78.0	3	50
96	07145500R	Ninnescah River nr Peck, Ks.	365,100	37	137	1	20
97	07157500	Crooked Creek nr Nye, Ks.	31,000	30	32.0	1	50[E]
98	07184000	Lightening Creek nr McCune, Ks.	91,300	21	45.0	16	72

A - Sampling site was not at a U.S. Geological Survey streamflow-gaging station; the station name is assigned for the purposes of this report.

E - Estimated value.

R - Flow partially or fully regulated by one or more upstream reservoirs.

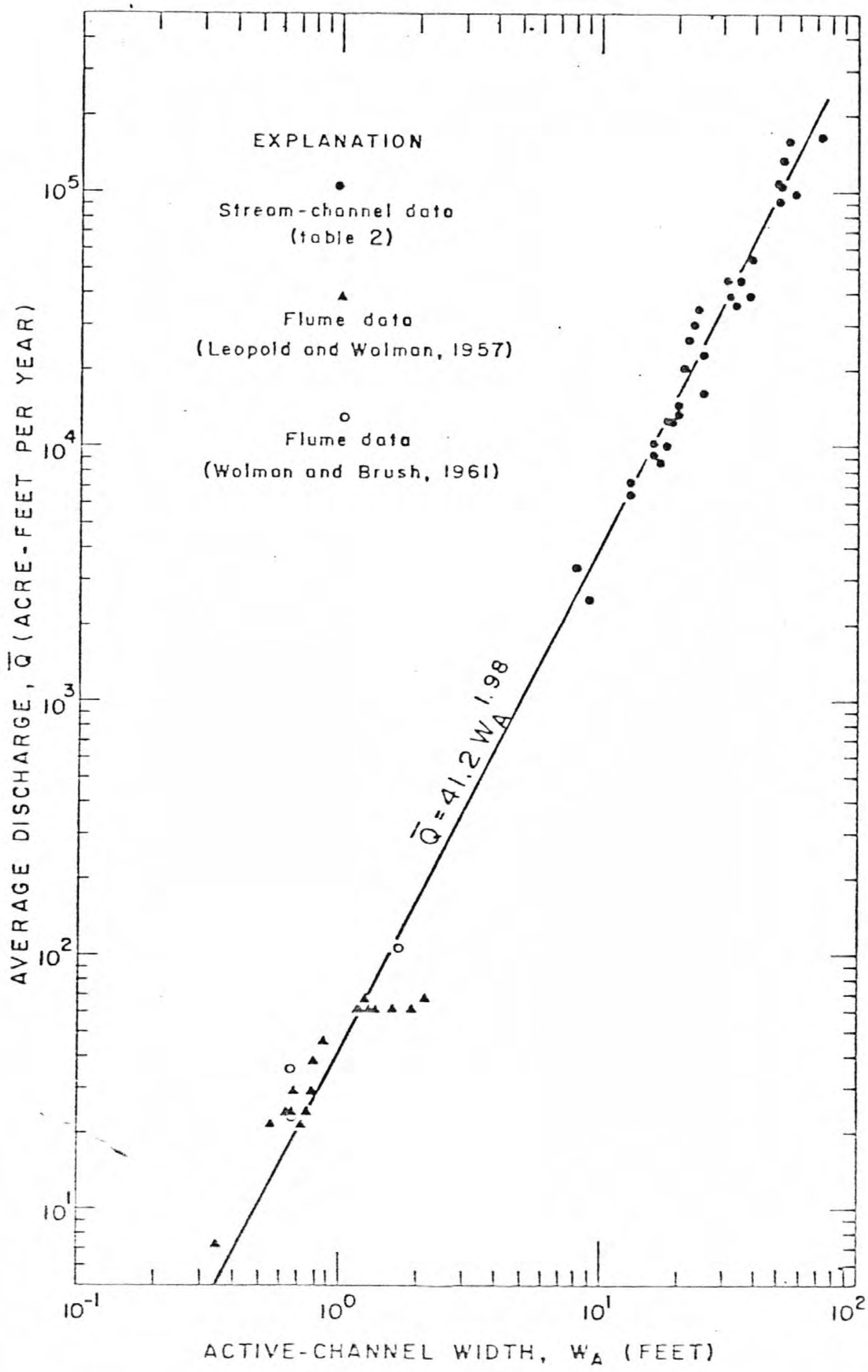

Figure 2. -- Logarithmic plot and regression line of high-gradient stream and flume data.

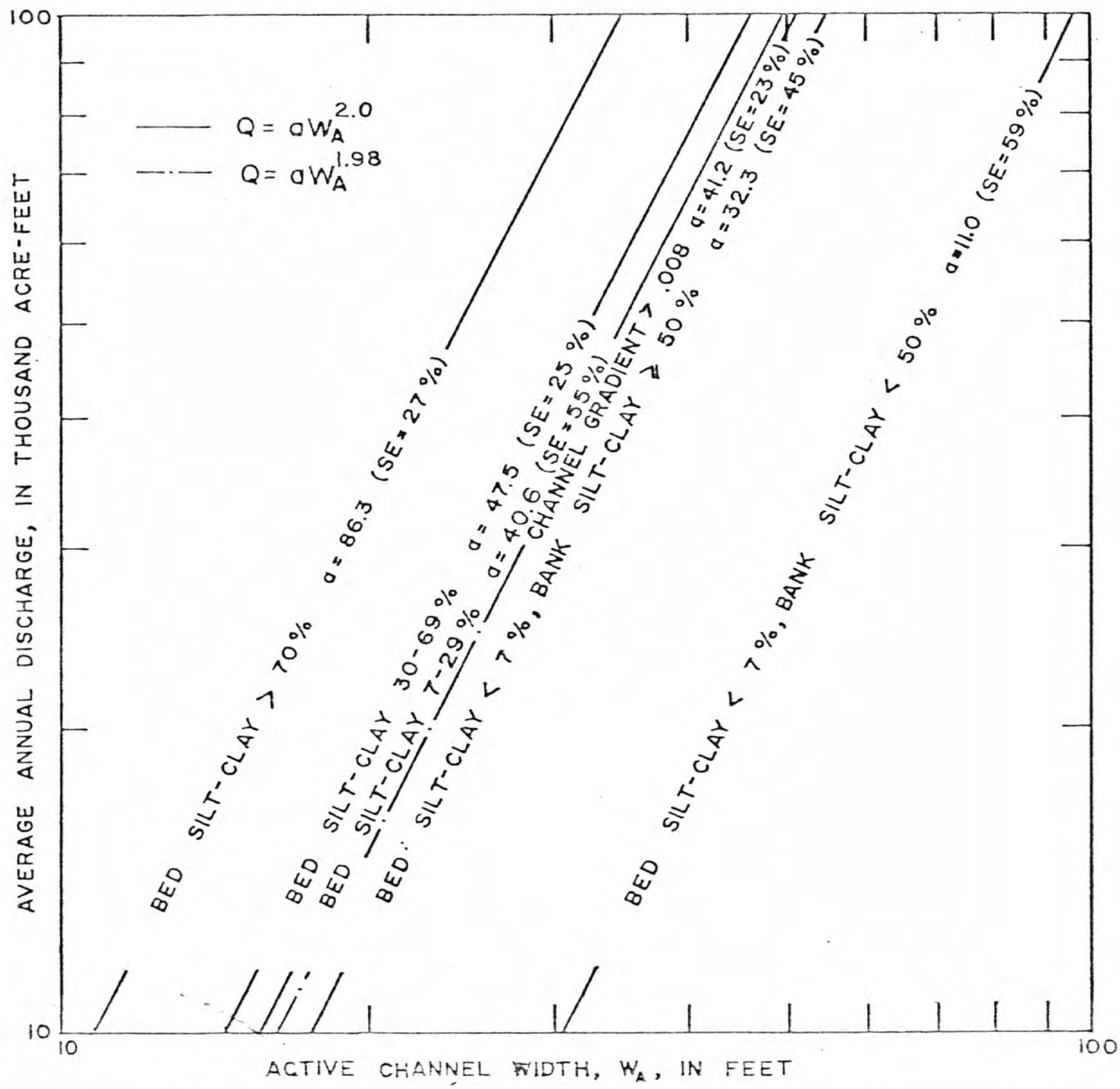

Figure 3. -- Regression relations of stream channels of specified sediment characteristics.