VARIATION OF ALLUVIAL-CHANNEL WIDTH WITH DISCHARGE AND CHARACTER OF SEDIMENT

U.S. GEOLOGICAL SURVEY

Water-Resourses Investigations 79-15

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle VARIATION OF ALLUVIAL-CHANNEL WIDTH WITH DISCHARGE AND CHARACTER OF SEDIMENT			5. Report Date June 1979 6.
7. Author(s) W. R. Osterkamp			8. Performing Organization Rept. No. WRI 79-15
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 1950 Avenue "A" - Campus West Lawrence, Kansas 66045			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 1950 Avenue "A" - Campus West Lawrence, Kansas 66045			13. Type of Report & Period Covered Final 14.

15. Supplementary Notes

16. Abstracts

When estimating mean discharge ($\overline{Q}$) from active-channel width (W_A) using the equation $\overline{Q} = aW_A^b$, it is proposed that the exponent, b, should be of fixed value for most natural, perennial, alluvial stream channels and that the coefficient, a, varies with the characteristics of the bed and bank material.

Three groups of perennial streams were selected for study. The groups were: (1) 32 channels of gradient exceeding 0.0080, low suspended-sediment discharge, high channel roughness, and low discharge variability; (2) 13 streams of similar climatic conditions and having at least 70 percent silt and clay in the bed material; and (3) 18 spring-discharge channels with steady discharge and similar climate. Values for the exponent for the three groups are 1.98, 1.97, and 1.97, respectively; coefficient values are 0.017, 0.042, and 0.011 (when using metric units). Assuming a constant exponent of 2.0, equations were developed expressing the manner in which channel sediment affects the width-discharge relation.

17. Key Words and Document Analysis. 17a. Descriptors

Alluvial streams, bed material, bank material, channel stability

17b. Identifiers/Open-Ended Terms

Width-discharge relation, fixed exponent, springs

17c. COSATI Field Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
No restriction on distribution	20. Security Class (This Page) UNCLASSIFIED	22. Price

VARIATION OF ALLUVIAL-CHANNEL WIDTH WITH DISCHARGE AND CHARACTER OF SEDIMENT

By W. R. Osterkamp

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS 79-15

June 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, SECRETARY

GEOLOGICAL SURVEY

H. WILLIAM MENARD, DIRECTOR

For additional information write to:

U.S. Geological Survey, WRD
1950 Ave. A - Campus West
University of Kansas
Lawrence, Kansas 66045

CONTENTS

ILLUSTRATIONS

ABSTRACT

Use of channel measurements to estimate discharge characteristics of alluvial streams has shown that little agreement exists for the exponent of the width-discharge relation. For the equation $\overline{Q} = aW_A{}^b$, where $\overline{Q}$ is mean discharge and W_A is active-channel width, it is proposed that the exponent, b, should be of fixed value for most natural, perennial, alluvial stream channels and that the coefficient, a, varies with the characteristics of the bed and bank material.

Three groups of perennial stream channels with differing characteristics were selected for study using consistent procedures of data collection. A common feature of the groups was general channel stability, that is, absence of excessive widening by erosive discharges. Group 1 consisted of 32 channels of gradient exceeding 0.0080, low suspended-sediment discharge, high channel roughness, and low discharge variability. Group 2 consisted of 13 streams in Kansas having at least 70 percent silt and clay in the bed material and having similar discharge variability, climate, gradient, and riparian vegetation. Group 3, in southern Missouri, consisted of discharge channels of 18 springs having similar conditions of very low discharge variability, climate and vegetation, but variable bed and bank material. Values for the exponent for the three groups of data are 1.98, 1.97, and 1.97, respectively, whereas values of the coefficients are 0.017, 0.042, and 0.011 when discharge is expressed in cubic meters per second and width is in meters. The relation for high-gradient channels (group 1) is supported by published data from laboratory flumes.

The similarity of the three values of the exponent demonstrates that a standard exponent of 2.0, significant to two figures, is reasonable for the width-mean discharge relation of perennial, alluvial stream channels, and that the exponent is independent of other variables. Using a fixed exponent of 2.0, a family of simple power-function equations was developed expressing the manner in which channel sediment affects the width-discharge relation.

INTRODUCTION

Relations between hydrologic and geomorphic variables of alluvial stream channels have been recognized for centuries. Because of the extreme complexities of alluvial channels, however, quantitative treatment of those relations has been difficult to achieve. Among the first to approach the problem was Kennedy (1895), who showed that simple power functions could be used to express relations between several of the hydraulic and geometric variables of streams and canals of India. The hydraulic-geometry method later was applied to natural streams by Leopold and Maddock (1953), a study which has prompted numerous similar studies during the last two decades.

Studies of channel geometry as a means of estimating discharge characteristics of alluvial streams began about 12 years ago. The technique requires geometry measurements of a channel from a definable geomorphic reference level rather than from the water surface of a stream; it is based on the assumption that channel shape and size is the result of the integrated effects of the water and sediment discharges conveyed by that channel. Channel-geometry relations, as do relations of hydraulic geometry, rely on a continuity equation:

$$Q = WDV \tag{1}$$

where, for a specified reference level of the channel cross section, W, D, and V are, respectively, width, mean depth, and mean velocity measured for a discharge, Q, flowing beneath that reference level. By using geomorphic features, channel-geometry studies are feasible regardless of stream stage (assuming a stream is physically accessible and the intended reference level is not inundated). From the continuity equation, power functions express the relation between discharge and width, depth, or velocity:

$$W = gQ^h \tag{2}$$

$$D = iQ^j \tag{3}$$

$$V = nQ^p \; . \tag{4}$$

Because a general purpose of channel-geometry investigations is to estimate a parameter of discharge, equations 2, 3, and 4 are ordinarily rewritten as:

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

$$Q = cD^f \tag{6}$$

$$Q = kV^m \tag{7}$$

where Q is a specified measure of discharge (such as mean discharge or a flood event with a 5-year recurrence interval); W, D, and V are, respectively, channel width, depth, and the associated mean velocity; a, c, and k are coefficients; and b, f, and m are exponents. In practice, most channel-geometry studies employ equation 5 or a modification of it because width generally can be measured with less error than depth or velocity.

Power functions empirically relating measurements of width and a specified discharge parameter, and thereby defining the coefficient and exponent of equation 5, have proven useful. These relations typically have relatively high standard errors of estimate, however, and much variation has been reported for the values of the coefficient and exponent. The cause of the disagreement is that several variables, including channel sediment characteristics, climate and riparian vegetation, and discharge variability, exert significant influence on the width-discharge relation.

A purpose of this paper is to demonstrate that the value of the exponent, b, in equation 5 can be considered of fixed value. Data collected for this purpose are widths measured at the active-channel reference level (Hedman and others, 1974; Osterkamp and Hedman, 1977), and mean discharges of streams gaged by the U.S. Geological Survey, generally in excess of 20 years. Using a relation between width and discharge with an exponent of known or fixed value permits the isolation and identification of the effects of other pertinent variables. The technique allows the development of a family of simple power-function equations expressing the manner in which the width-discharge relation, hence the coefficient of equation 5, varies with differing conditions of channel sediment. Alternatively, a multiple power-function relation with an imposed exponent for width can be developed. Both approaches result in a sophistication of the channel-geometry method of estimating discharge and a reduction in the standard error of estimate.

APPROACH

To establish a constant exponential relation between channel width and mean discharge, data sets from three groups of perennial streams were collected. Each group was selected to provide: (1) a large range of widths and mean discharges for the streams within the group, (2) conditions of general channel stability in order that a well-defined power-function equation would result from the width-discharge data of the group, (3) relatively constant conditions of the variables identified as having a significant influence on the width-discharge relation, and (4) conspicuous differences in the complicating variables among the groups.

To the extent practical, consistent methods were employed for the collection of all data used in this study (Osterkamp, in press). The width-discharge data of each group were analyzed by digital computer. The program used for the analyses was BMD02R of the Biomedical Computer Programs, a series of programs that was developed by the University of California School of Medicine (Dixon, 1965). Output of the program includes the linear (or power-function) relation that results in the least possible error sum of squares, the standard error of estimate, the correlation coefficient, and residuals for the individual data pairs.

RESULTS

High-Gradient Stream Channels

The first group of stream channels considered were 32 channels in the Western United States (Osterkamp and Hedman, 1977). Mean discharges of these perennial streams range from 0.10 to 6.46 m^3/s (cubic meters per second). All of the channels have gradients exceeding 0.0080 m/m (meters per meter) and almost all are in alpine areas. Hence the streams of the group all exhibit high channel roughness owing to extensive armoring of bed and banks by gravel, cobbles, and boulders. Likewise, the streams of the group all show similar riparian vegetation owing to similar climatic conditions, low suspended-sediment discharge, and relatively low, meltwater flood peaks. The combined effects of extensive channel armoring, a mature and woody riparian growth, and the lack of erosive discharge events produce stable channels that appear well adjusted to the discharges they convey.

The power-function relation developed from these data (Osterkamp and Hedman, 1977, p. 258) is presented in figure 1 and expressed by the equation:

$$\overline{Q} = 0.017\ W_A^{1.98} \tag{8}$$

where $\overline{Q}$ is mean discharge (m^3/s) and W_A is active-channel width (m). The standard errors of estimate for the analysis are 25 percent and -20 percent (average 23 percent). Pertinent data from flume studies (Leopold and Wolman, 1957; Wolman and Brush, 1961) also are plotted in figure 1. Although these flume data are for unvegetated banks and laboratory conditions, they represent stable or equilibrium channels with constant discharge, low suspended-sediment transport, and gradients exceeding 0.0080 m/m. The flume data were not considered in the curve-fitting analysis, but support extension of the relation from the discharges of the natural streams to much lower discharges (fig. 1). Thus, equation 8 appears accurate and valid through more than four orders of magnitude for discharge (Osterkamp and Hedman, 1977).

Silt-Clay Bed Streams of Eastern Kansas

Data for a second group of stable alluvial channels were collected from 13 perennial streams of eastern Kansas (Osterkamp, 1977, p.10). The channels of this group differed from those of the first group by having relatively low gradients and bed material containing at least 70 percent silt and clay (particle-size diameters not exceeding 0.062 millimeter) at the time of measurement. In addition, these streams transport significant amounts of suspended sediment and, owing to climatic and geologic conditions, have greater discharge variability than do the alpine streams. The silt-clay bed streams of eastern Kansas all have lush riparian vegetation, which with the cohesiveness provided by the abundant fine-grained channel sediment, causes narrow and stable channels. When flood discharges occur, the cohesiveness and vegetation of the banks generally are sufficient to minimize channel widening by erosion.

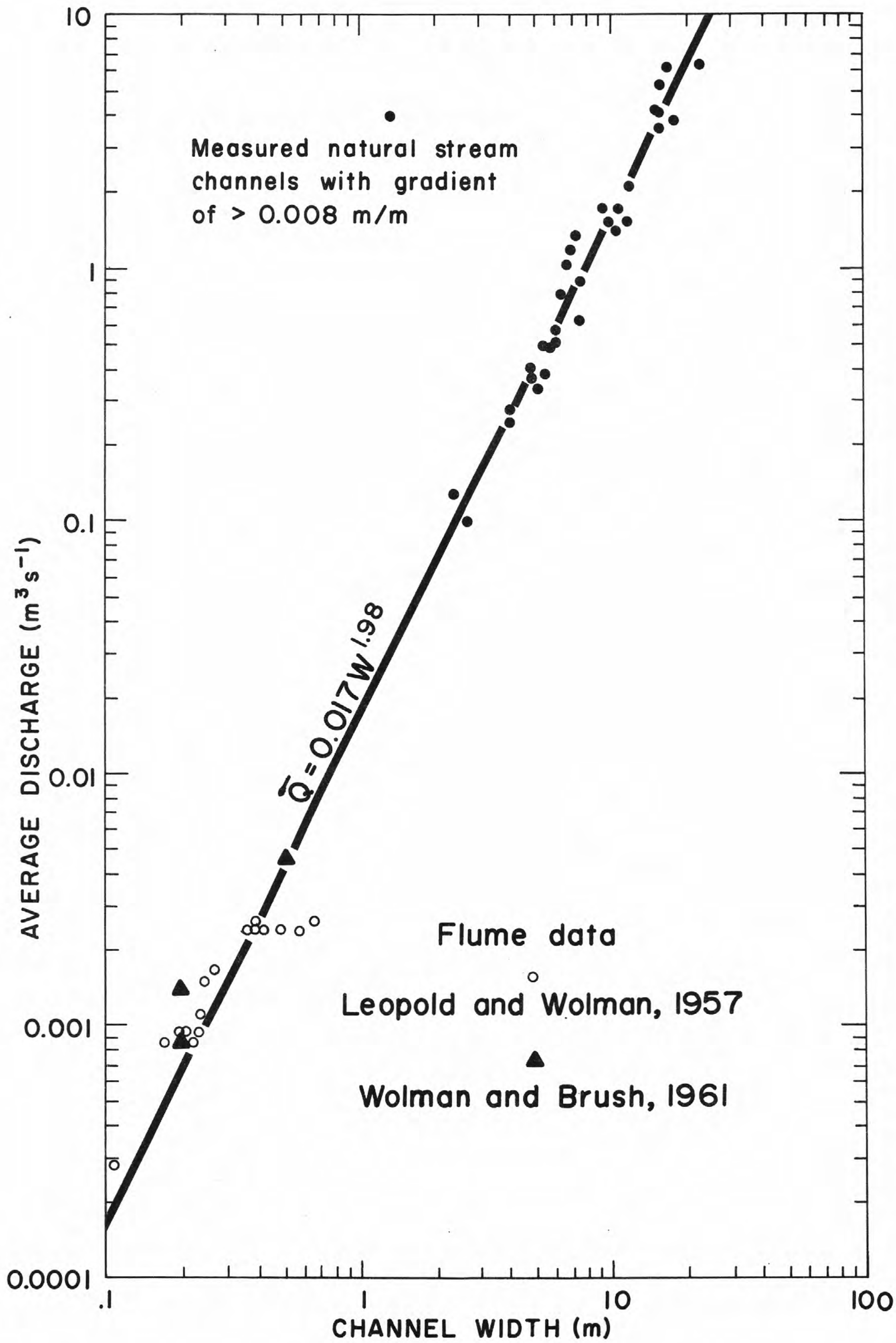

Figure 1.--Graph showing logarithmic plot and power-function relation of high-gradient stream data.

The Kansas data, which extend through more than two orders of magnitude for discharge, and the resulting power-function relation are given in figure 2. The equation for these data is:

$$\overline{Q} = 0.042\ W_A^{1.97} \tag{9}$$

The standard errors of estimate are 40 percent and -29 percent (average 34 percent) (Osterkamp, 1977, p. 10).

Springs of Southern Missouri

The final group of streams selected to identify a possible constant exponent in the relation between width and mean discharge include 18 spring-effluent channels of southern Missouri. Alluvial channels of springs were selected because they have uniquely stable discharge relative to other natural streams. The springs of southern Missouri exhibit variations in discharge, but erosive or channel-widening flow events are extremely unlikely unless there is significant contributing drainage area above the spring. Furthermore, all 18 of the springs have similar climate and bank vegetation, and all discharge virtually no suspended sediment. Disadvantages of using this group of channels include varying conditions of bed and bank material, poor reliability for some values of mean discharge, and damming, lining, or other alteration of several of the channels. Mean discharges of the springs range from about 0.066 to 12.3 m^3/s, more than two orders of magnitude.

The equation for the 18 spring channels is:

$$\overline{Q} = 0.011\ W_A^{1.97}\ . \tag{10}$$

Results and data points are shown in figure 3. The standard errors of estimate are 50 percent and -33 percent (average 41 percent). The greater error or scatter of the spring data relative to the other two groups is inferred to be largely the result of inaccurate values for mean discharge, and differing conditions of channel sediment.

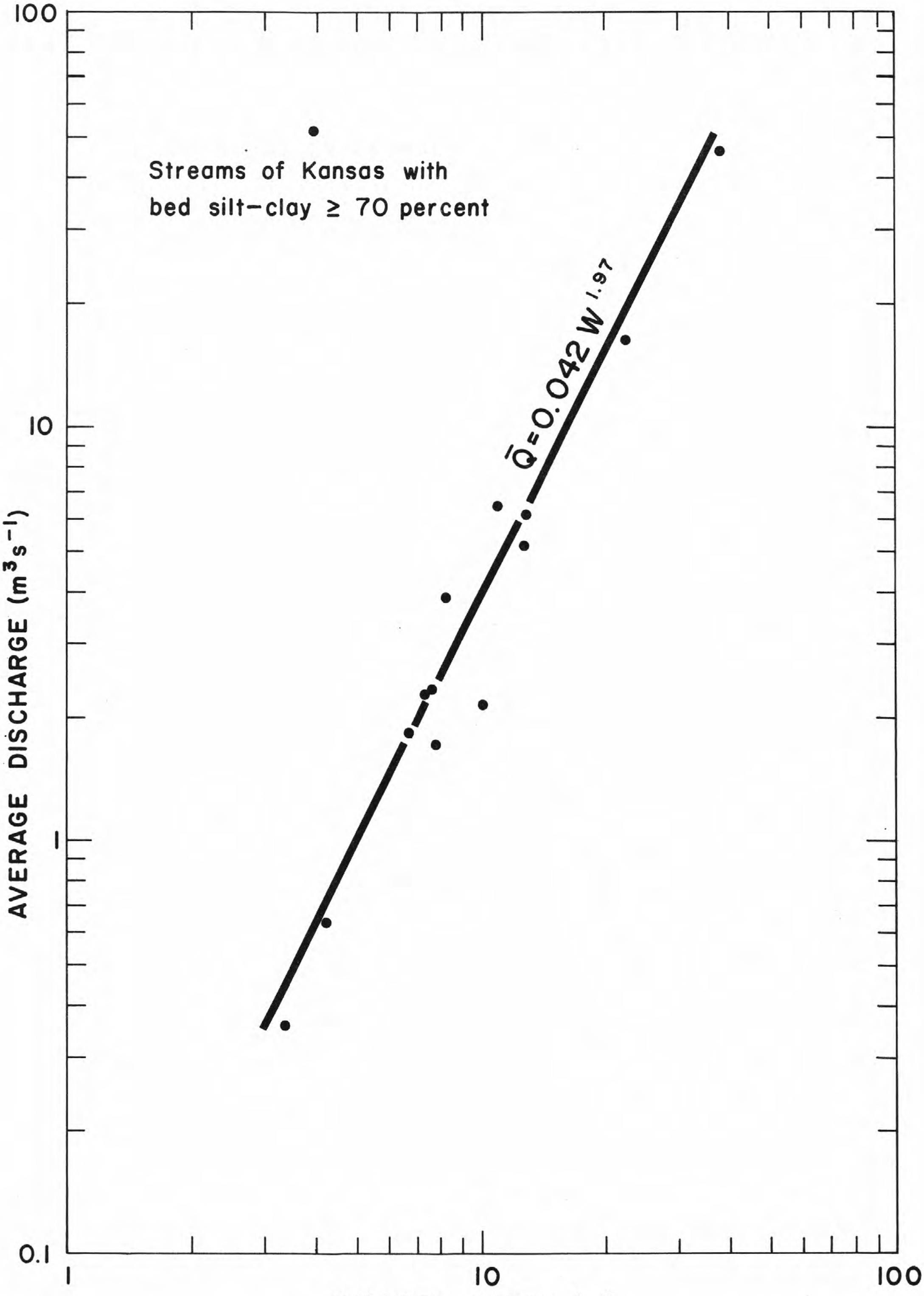

Figure 2.--Graph showing logarithmic plot and power-function relation of silt-clay bed stream data.

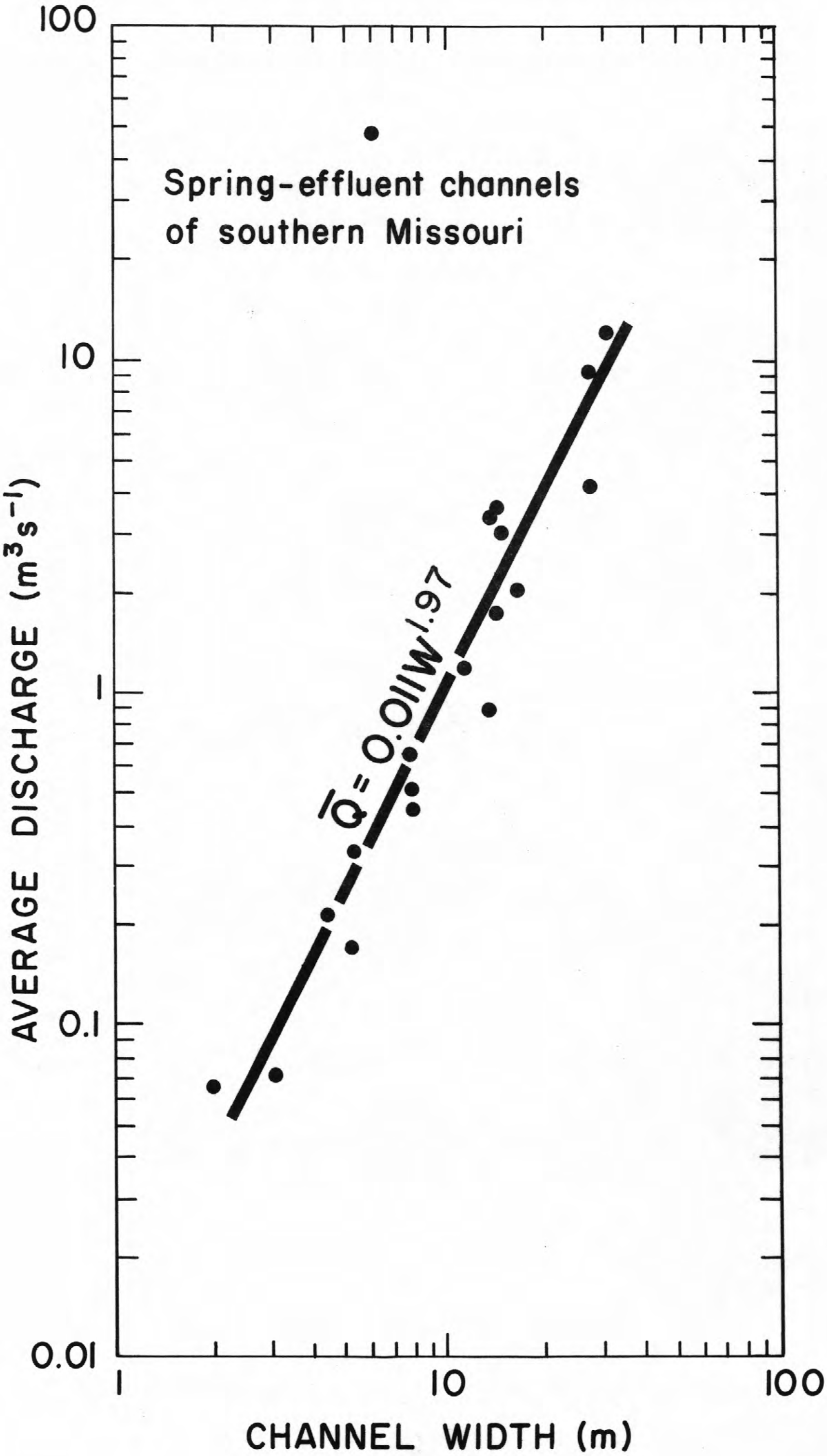

Figure 3.--Graph showing logarithmic plot and power-function relation of spring-effluent channel data.

SIGNIFICANCE AND APPLICATION

Comparison of equations 8, 9, and 10 shows nearly a four-fold variation in the coefficients, but virtually no variation for the exponents. These results suggest that when all variables which can affect channel width other than discharge are held constant, the relation between active-channel width and mean discharge is a power function having a constant exponent. Variations in the width-discharge relation caused by other variables of perennial alluvial streams are expressed solely in the coefficient.

The very close similarity of the exponents empirically calculated for this study probably is, in part, coincidence. The agreement does suggest, however, that the value is accurate to two significant figures. It seems possible, therefore, that the relation between active-channel width and mean discharge of all natural, perennial, alluvial stream channels is described by:

$$\overline{Q} = aW_A^{2.0} \tag{11}$$

where the coefficient, a, varies with the effects of all complicating variables (Osterkamp, 1977, p.13). The identification of a fixed exponent in the relation permits quantitative treatment of other relevant variables, which otherwise would not be feasible.

The characteristics of bed and bank material of alluvial channels are among the variables which exert a substantial influence on channel width relative to discharge. This influence can be demonstrated by collecting width-discharge data from various groups of streams having similar conditions of channel material or sediment. An exponent of 2.0 is imposed on the power-function relation developed for each group, whereas the magnitude of the coefficient, which is partly dependent on the channel material, expresses that dependence.

Width, discharge, and channel-sediment data were collected from 114 gage sites on perennial streams of the central United States (Osterkamp, 1977, p.18-25). The data were separated into groups of which (1) bed silt-clay content exceeds 70 percent, (2) bed silt-clay content ranges from 30 to 69 percent, (3) bed silt-clay content ranges from 7 to 29 percent, (4) bed silt-clay content is less than 7 percent and bank material contains at least 50 percent silt and clay, and (5) bed silt-clay content is less than 7 percent and bank material contains less than 50 percent silt and clay. Power functions with an imposed exponent of 2.0 were calculated for each group, and results are shown in figure 4 (Osterkamp, 1977, p. 12).

Perhaps the most important result demonstrated by figure 4 is the extent to which channel sediment influences channel width. For example, for two streams of similar width, the mean discharge of one with bed material predominantly of silt-clay sizes is roughly eight times greater than one which has low content of silt and clay in both bed and banks. In addition, figure 4 suggests that if the bed material contains significant amounts of silt and clay (at least 7 percent), the effect on the width-discharge relation by other variations in channel-material composition is relatively small. If, however, the bed material is almost all sand and gravel, the width-discharge relation shows much variation with the silt-clay content of the bank.

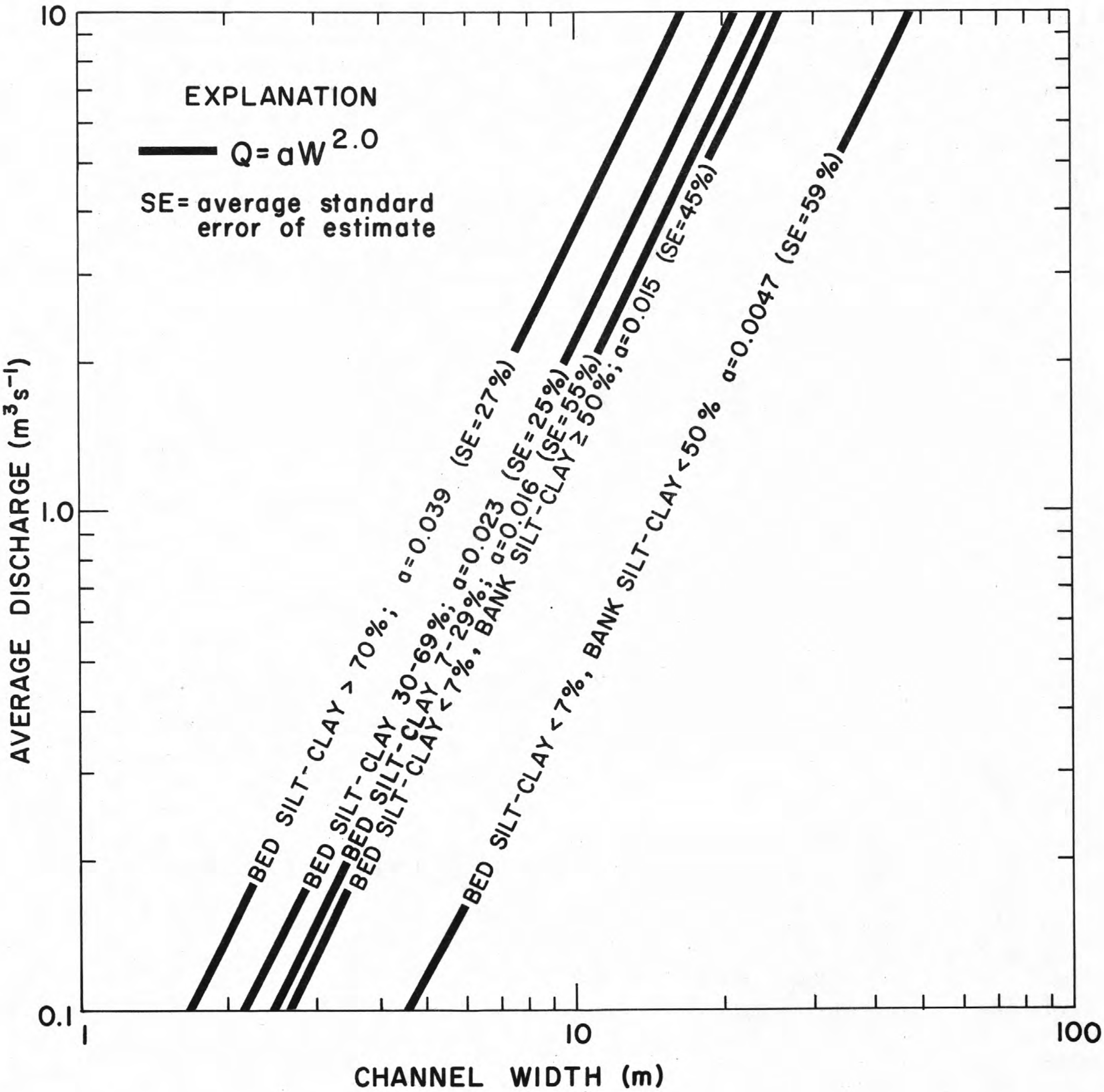

Figure 4.--Graph showing power-function relations for stream channels of specified sediment characteristics.

REFERENCES

Dixon, W. J., ed., 1965, BMD, Biomedical computer programs: University of California School of Medicine, Los Angeles, 620 p.

Hedman, E. R., Kastner, W. M., and Hejl, H. R., 1974, Selected streamflow characteristics as related to active-channel geometry of streams in Kansas: Kansas Water Resources Board Technical Report No. 10, 21 p.

Kennedy, R. C., 1895, Prevention of silting in irrigation canals: Institute of Civil Engineers, v. 119, p.281-290.

Leopold, L. B., and Maddock, Thomas, Jr., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geological Survey Professional Paper 252, 56 p.

Leopold, L. B., and Wolman, M. G., 1957, River channel patterns: braided, meandering, and straight: U.S. Geological Survey Professional Paper 282-B, 47 p.

Osterkamp, W. R., 1977, Effect of channel sediment on width-discharge relations, with emphasis on streams in Kansas: Kansas Water Resources Board Bulletin 21, 25 p.

______, Bed- and bank-material sampling procedures at channel-geometry sites: Proceedings of the National Conference on Sampling, Validation, and Quality Control of Environmental Measurements, [in press].

Osterkamp, W. R., and Hedman, E. R., 1977, Variation of width and discharge for natural high-gradient stream channels: Water Resources Research, v. 13, no. 2, p. 256-258.

Wolman, M. G., and Brush, L. M., Jr., 1961, Factors controlling the size and shape of stream channels in coarse noncohesive sands: U.S. Geological Survey Professional Paper 282-G, p. 183-210.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979—667-263/17