The Hydraulic Geometry of the Middle and Upper Portions of Mosca Creek, Sangre De Cristo Range, Colorado

MICHAEL C. ROBERTS[1], **Oklahoma State University, Stillwater**

INTRODUCTION

Empirical knowledge of streams and fluvial processes has been increasing rapidly in recent years. Much of this research has been in the area of hydraulic geometry, a term taken from the work of Leopold and Maddock (1953). Though much has been accomplished in humid and semi-arid lowland environments, little has been done with respect to alpine or mountain streams. The basic reference with regard to alpine stream hydraulic geometry is the investigation of Miller (1958) in central New Mexico.

Alpine streams are those described in traditional physiographic terms as being in the stage of youth. Such terminology as the stage of youth, with its genetic implications, is not particularly useful in understanding the relations of the variables that describe a stream. This study concentrates on the linear aspects of a stream channel in a mountainous area.

THEORETICAL BACKGROUND

It is impossible in this paper to give even a summary of the theoretical work in the field of the hydraulic geometry of streams, and instead only the theoretical issues that have a place with the present problem will be dealt with. Knowledge of the regularity and lawfulness of stream processes and geometry is well advanced in lowland and hilly regions as evidenced from the work of Brush (1961), Hadley (1960), Leopold and Miller (1965), and Leopold and Wolman (1957) among others. The lack of empirical data on mountain streams prevents the extension of the theory to these areas. It is not known whether a law developed for lowland areas will apply in a mountainous environment.

The gap in research findings has been partially closed by Gerber's (1959) work on the erosive capability of mountain streams. He was concerned with showing how an alluvial area would be developed as the river cut into the mountain slopes. However, theory in terms of hydraulic geometry has been investigated only by Miller (1958) for mountainous areas. He (p. 52) believes that,

> "Despite their generally steep slopes, high mountain streams have many properties in common with streams at lower altitudes."

The need is now to expand the number of study areas, to see whether this statement is verified by empirical evidence.

Many simple but also important questions about these streams need to be answered in objective, numerical terms. Such questions as—"Do mountain streams invariably have coarse loads?" or "Is channel width a function of distance to headwaters in an alpine stream?", are given in such textbooks as Lake (1952), Thornbury (1954) and Finch and Trewartha (1957). These authors suggest that the norm is a steep-sided valley with a fast-flowing stream moving a coarse load. Lacking quantitative data these descriptions are only assertions or hypotheses that need testing.

---

[1] Present address: Oregon State Univ., Corvallis, Ore.

THE STUDY AREA

The study area (Mosca Creek Basin) is located in south central Colorado on the western flank of the Sangre de Cristo Mountains. The headwaters of Mosca Creek extend on either side of Mosca Pass, while the lower part of the stream drains, in a rather indeterminant fashion, into Medano Creek near the Great Sand Dunes National Monument (Fig. 1). The drainage basin is cut into a complex of igneous and metamorphic rocks. The Sangre de Cristos are composed of two belts of rocks, igneous in the west and sedimentary in the east. Chronologically, the former are Pre-Cambrian and the latter Palaeozoic. Curtis (1961) has described the structure of these mountains as being some of the most involved in the southern Rocky Mountains.

STATEMENT OF PROBLEM

As indicated in the Introduction the actual amount of data on high mountain streams is small, and this paper is designed to overcome part of this deficiency. Stated more precisely the problem is to describe and analyze the variations in the channel dimensions and load of Mosca Creek.

Table I lists the variable names and summary statistics, based on field data from 37 stations on the creek, of the seven variables used in this study. The numbering system in Table I applies also in Table II and equations where variable identification is needed.

THE ANALYSIS

The initial part of the investigation was to test a hypothetical framework that had been set up. If the data verified these hypotheses it could be shown that highland streams exhibit the same general tendencies as lowland streams, at least in terms of direction or relationship. The hypotheses were expressed as follows (a hypothesis is short where there is a definite reference to it in the literature):

1. Channel slope has a positive relationship with valley slope. Only in cases of great inequilibrium will these variables be anything other than positively associated.

2. Channel slope has a positive relationship with median grain size (Hack, 1957).

3. Channel slope has a negative relationship with distance from the head of the stream (Brush, 1961). Fig. 2.

4. Valley slope has a positive relationship with median grain size (Hack, 1957).

5. Valley slope has a negative relationship with channel depth. This hypothesis was generated on the grounds that, in the alpine environment of this study area, the only places of high alluviation are where there is low valley slope. The alluvial fills permit rapid down-cutting, leading to deeper channels.

6. Valley slope has a negative relationship with distance from the head of the stream. Virtually all longitudinal profiles of streams can be described by an exponential curve, and this suggested the hypothesis. Fig. 3.
7. Channel width has a positive relationship with distance from the head of the stream (Hack and Young, 1959).

8. Channel width has a positive relationship with channel depth (Schumm, 1960). Fig. 4.

9. Median grain size has a negative relationship with distance from the head of the stream (Hack, 1957).

TABLE I. MEANS AND STANDARD DEVIATIONS OF THE VARIABLES

	Name of Variable	Units of Measurement	Mean	Standard Deviation
1	Ratio of channel depth to width	dimensionless	0.222	0.077
2	Channel slope	degrees	6.888	4.664
3	Valley slope	degrees	6.047	4.640
4	Channel width	feet	19.570	13.534
5	Channel depth	feet	4.365	2.883
6	Medium grain size of load	inches	0.530	0.514
7	Distance from the head of the stream	feet	475.000	266.927

TABLE II. THE SIMPLE CORRELATION MATRIX

	1	2	3	4	5	6
1						
2	–0.126					
3	–0.232	0.935*				
4	–0.106	–0.289	–0.268			
5	0.263	–0.322	–0.330*	0.791*		
6	–0.206	0.596*	0.652*	0.060	–0.139	
7	0.192	–0.679*	–0.700*	0.339*	0.287	–0.092

*Significant at the 5% level

The Pearsonian coefficients (Table II) that apply to the hypotheses are underlined; the other coefficients in the table are simply the by-product of the matrix.

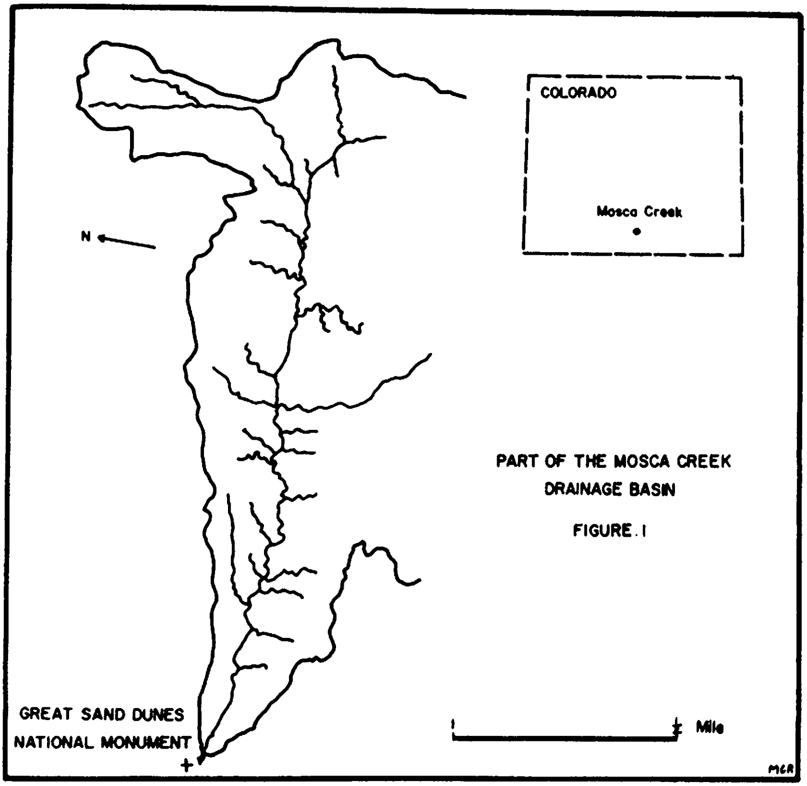
The results of the simple correlation analysis (Table II) indicate acceptance of hypotheses one through eight, while hypothesis nine is rejected. The failure of nine is, on first examination, rather surprising, since theory would strongly support the empirical verification. However, re-examination of the Mosca Creek situation shows that several factors are acting to cause its rejection. First of all, only the upper portion of Mosca Creek was sampled. Secondly, the alternating bedrock and alluvial sections have a distinct bearing on grain size, and destroy the theoretical notion of decreasing median grain size downstream. Instead, grain size reflects the local conditions of any given reach of the stream.

All correlation coefficients involved in the hypothesis structure are significant at the 5% level, except that of hypothesis 9. These coefficients relate to linear estimating equations. However, the plotted data in Figs. 2 and 3 indicate that probably a second degree polynomial would be a better fit. Further research is needed to accurately determine the kind of curves that need to be fitted. It is sufficient for the present work to use the linear model.

In a search to see how this system of interlinked variables (Table II) are connected it is felt that the important variables (importance being based on the results of previous studies—see section on theoretical background) should be tested in a multiple regression framework. Three factors are selected as dependent variables: channel width (X_4), channel depth (X_5), and valley slope (X_3).

A. Channel width—The beta coefficients indicate that only four of the six variables used were of importance, X_1, X_3, X_5, X_6. The dominant member of the regression was channel depth X_5. One of the great benefits of examining the beta coefficients is the way in which they show that the simple '*r*'s are a poor guide in setting up a multivariate equation. An example is the significant '*r*' of 0.339 between channel width and distance from the head of the stream, yet X_7 has a negligible effect on the multiple *R*.

B. Valley slope—The regression equation has three variables X_2, X_6 and X_7 that are most effective. Variable X_5 has little effect on the total amount of explanation even though it has a simple correlation with the dependent of 0.330.



PART OF THE MOSCA CREEK DRAINAGE BASIN

FIGURE. I

C. Channel depth—Variables X_1, and X_4 play the major role, with X_3 and X_6 having only a minor effect.

The multivariate situations above can be summarized in the following way:

$$X_4 = a + bX_1 + bX_3 + bX_5 + X_6$$
$$X_3 = a + bX_2 + bX_6 + bX_7$$
$$X_5 = a + bX_1 + bX_4$$

CONCLUSIONS

The study shows that orderly relations exist among certain of the parameters that can be used to describe the hydraulic geometry of alpine streams. Further, although one stream is not a sufficient sample, it would appear reasonable to draw the conclusion that mountain streams have characteristics similar to those of lowland streams. The difference betwen these environments is not one of direction of relationship, but rate of change within it.

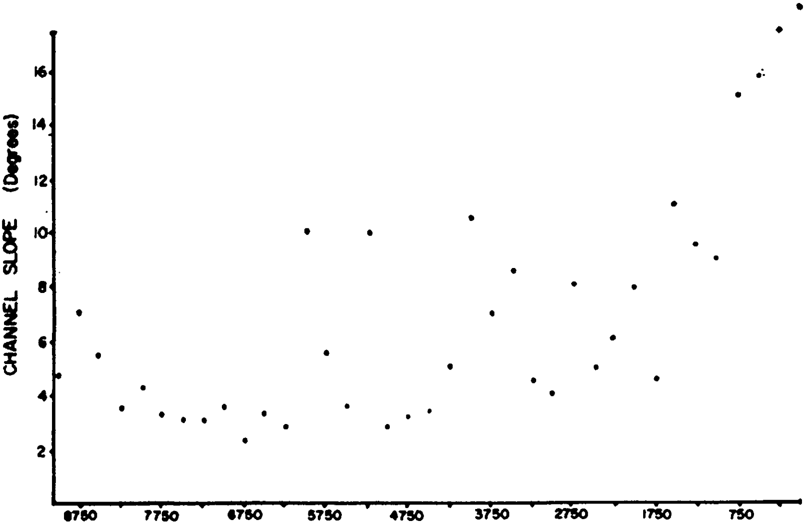


FIGURE. 2

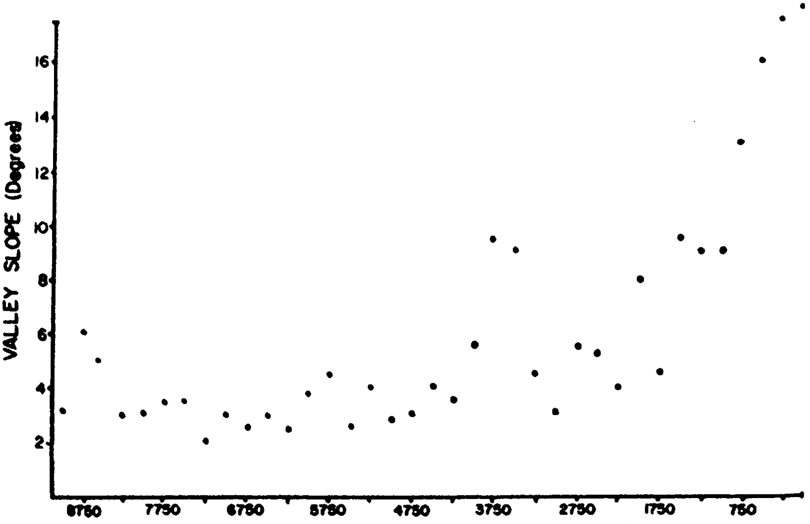


FIGURE. 3

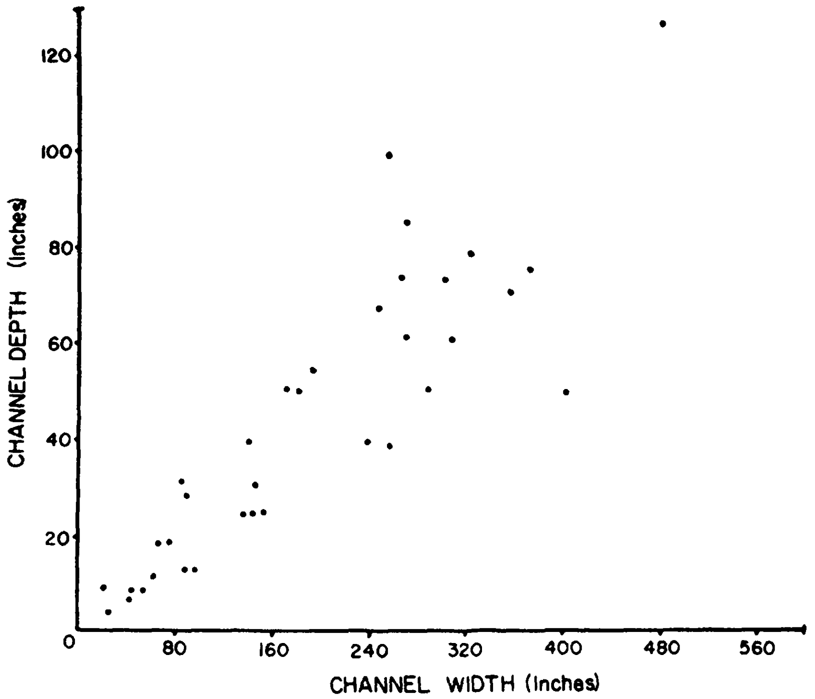


FIGURE 4

LITERATURE CITED

Brush, L. M. 1961. Drainage basins, channels, and flow characteristics of selected streams in central Pennsylvania. U. S. Geol. Surv. Prof. Paper 282-F.

Curtis, B. F. 1961. Major geologic features of Colorado, Guide to the geology of Colorado. Rocky Mt. Assoc. Geol.

Finch, V. C., G. T. Trewartha, and E. H. Hammond. 1957. *Elements of Geography*. McGraw-Hill, New York.

Gerber, E. 1959. Form and Bildung Alpiner Talbodens. Geog. Helvetica 14: 117-236.

Hack, J. T. 1957. Studies of longitudinal stream profiles in Virginia and Maryland. U. S. Geol. Surv. Prof. Paper 294-B.

Hadley, R. F. 1960. Recent sedimentation and erosional history of Fivemile Creek, Fremont County, Wyoming. U. S. Geol. Surv. Prof. Paper 352-A.

Lake, P. 1952. *Physical Geography*. Cambridge University Press, Cambridge.

Leopold, L. B. and T. Maddock. 1953. The hydraulic geometry of stream channels and some physiographic implications. U. S. Geol. Surv. Prof. Paper 252.

Leopold, L. B., and J. P. Miller. 1956. Ephemeral streams—hydraulic factors and their relation to the drainage net. U. S. Geol. Surv. Prof. Paper 282-A.

Leopold, L. B., and M. G. Wolman. 1957. River channel patterns: braided, meandering and straight. U. S. Geol. Surv. Prof. Paper 282-B.

Miller, J. P. 1958. High mountain streams: effects of geology on channel characteristics and bed material. State Bureau of Mines and Mineral Resources, New Mexico. Mem. No. 4.