MEASUREMENT OF THE PHYSICAL CHARACTERISTICS OF DRAINAGE BASINS

TECHNICAL BULLETIN No. 5

A. COULSON
P. N. GROSS

INLAND WATERS BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
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Introduction

Runoff from a drainage basin is determined to a large extent by the climatic conditions in the area. The total volume of runoff is dependent on the amount of precipitation and the timing of runoff varies with the form of precipitation. In other words, the more rain or snow that occurs, the greater will be the runoff and whereas a rainstorm will cause runoff in the stream channels almost immediately, snow may remain on the ground for several months before it melts and releases water to runoff. Temperature also affects both the timing and quantity of runoff. Low temperatures in the winter prevent snowmelt, warm temperatures in the spring cause snowmelt and high temperatures in the summer increase evaporation and thereby decrease runoff. Wind and humidity also affect evaporation and, therefore, runoff.

Although climate determines runoff from a particular drainage basin, two drainage basins subjected to the same climate may have dissimilar runoff characteristics. For instance, the slopes in one basin may be steeper than in the other basin resulting in an increased rate of runoff; the ground cover may be different in the two basins, with a consequent difference in evaporation losses; one basin may have a northern aspect and the other a southern aspect thereby causing a difference in the timing and rate of snowmelt. These, and many other differences in the physical characteristics of the two basins cause differences in the runoff characteristics.

If the physical characteristics are to be used to explain the runoff characteristics quantitatively, then it is necessary to describe the physical characteristics quantitatively. The purpose of this bulletin is to outline methods of obtaining quantitative descriptions of certain physical characteristics of drainage basins.

The physical characteristics considered are: drainage area; drainage density; basin slope; basin aspect; channel slope; channel profile; channel system distribution; and channel tortuosity.

This is not a complete list, of course, of all physical characteristics that affect runoff. Others include: geology; soil types; forest cover; land use; natural storage in channels, lakes and swamps; and position of basin relative to direction of storm travel. Any of these characteristics may be of particular significance in a specific drainage basin.

The drainage basins used for examples in this bulletin are those of

Marmot Creek and Streeter Creek, two of the experimental basins of the East Slopes (Alberta) Watershed Research Program. These basins were chosen because good topographic maps were readily available and because the results could be immediately useful in the research program.

Drainage Area

Once the drainage boundary has been delineated on a map, it is a relatively simple matter to determine the drainage area. Reid and Stone (1960) describe in detail one method of determining the drainage area from topographic maps.

However, it is not always an easy matter to delineate the drainage boundary accurately. The boundary for the Marmot Creek Basin shown on Figure 1 was positioned partly by consideration of the contours on the topographic map and partly by field inspection, and it differs quite considerably at some points from that used by Curry (1964). The reason for the difficulty in this case is that parts of the basin are heavily forested, making it impossible to produce accurate ground contours by aerial photogrammetry. In such a case, the only sure way of delineating the drainage boundary is by field survey and this has not yet been done for Marmot Creek.

The drainage areas used in this study for the Marmot and Streeter basins are given in Table 1. Maps of the two basins are given in Figures 1 and 2, but the working maps used in this study were at larger scales and with smaller contour intervals.

Basin	Drainage area square miles
Marmot	
Middle Fork Creek in Circe	0.44
Middle Fork Creek	1.10
Twin Creek	1.02
Cabin Creek	0.82
Marmot Creek	3.63
Streeter	
East Streeter Creek	0.20
Middle Streeter Creek	0.35
West Streeter Creek	0.53

Table 1. - Drainage areas for Marmot and Streeter Basins.

Basin Slope

Many methods have been used to evaluate the land slope in a basin. The most commonly used method is that described by Linsley and others (1949 p.250) which involves obtaining a sample of slopes normal to contours at 50 to 100 grid intersections within the basin. Sribnyi (1961) however, describes what is probably the oldest method of all. This method simply defines the average land slope as being the contour interval times the total length of contours divided by the drainage area.

Both methods have been used to compute the land slopes for the Marmot Creek and Streeter Creek basins. The sampling method had already been used by Curry (1964) to compute the slope for Marmot Creek.

Grids of various sizes were used in the sampling method for the present study, the sizes being chosen for each basin to give a minimum of 50 points and also a considerably larger number of points for comparison. The slope was also computed based on various contour intervals by the contour length method. Tables 2 to 5 compare the results obtained by the different intensities of sampling, by the different methods and by different workers.

Table 2 shows there is very little difference between the results obtained by the sampling method when using a minimum of 50 points and when using about ten times that number and, therefore, there is no advantage in using more than 50 points.

Table 3 shows that good results are obtained by the contour length method even when very few contours cross the basin. Thus, this method may be used with confidence when only maps with a large contour intervals, which would be unsuitable for the sampling method, are available.

Table 4 shows that there is good agreement between the results obtained by the sampling method and by the contour length method. There is nothing to choose between the two methods with regard to the time involved in the computations. However, the sampling method does yield a frequency distribution of slope within the basin whereas the contour length method gives only the mean slope. It is also thought that the contour length method might be less accurate for basins of undulating or hummocky topography. It is therefore suggested that the sampling method should be used whenever suitable contour maps are available.

Table 5 gives a comparison of the results obtained for this study and those obtained by Curry (1964) using the same size of grid for the sampling method. With the exception of Twin Creek, Curry's values are somewhat lower. There are two possible reasons for this: first, as previously mentioned, the drainage boundaries used in the two studies were not identical and, second, the mechanics of computation differed slightly.

In this study, the slope at each grid intersection was read and noted and the mean slope computed from the sum of all the individual readings. Curry, on the other hand, assigned class intervals of slope and checked

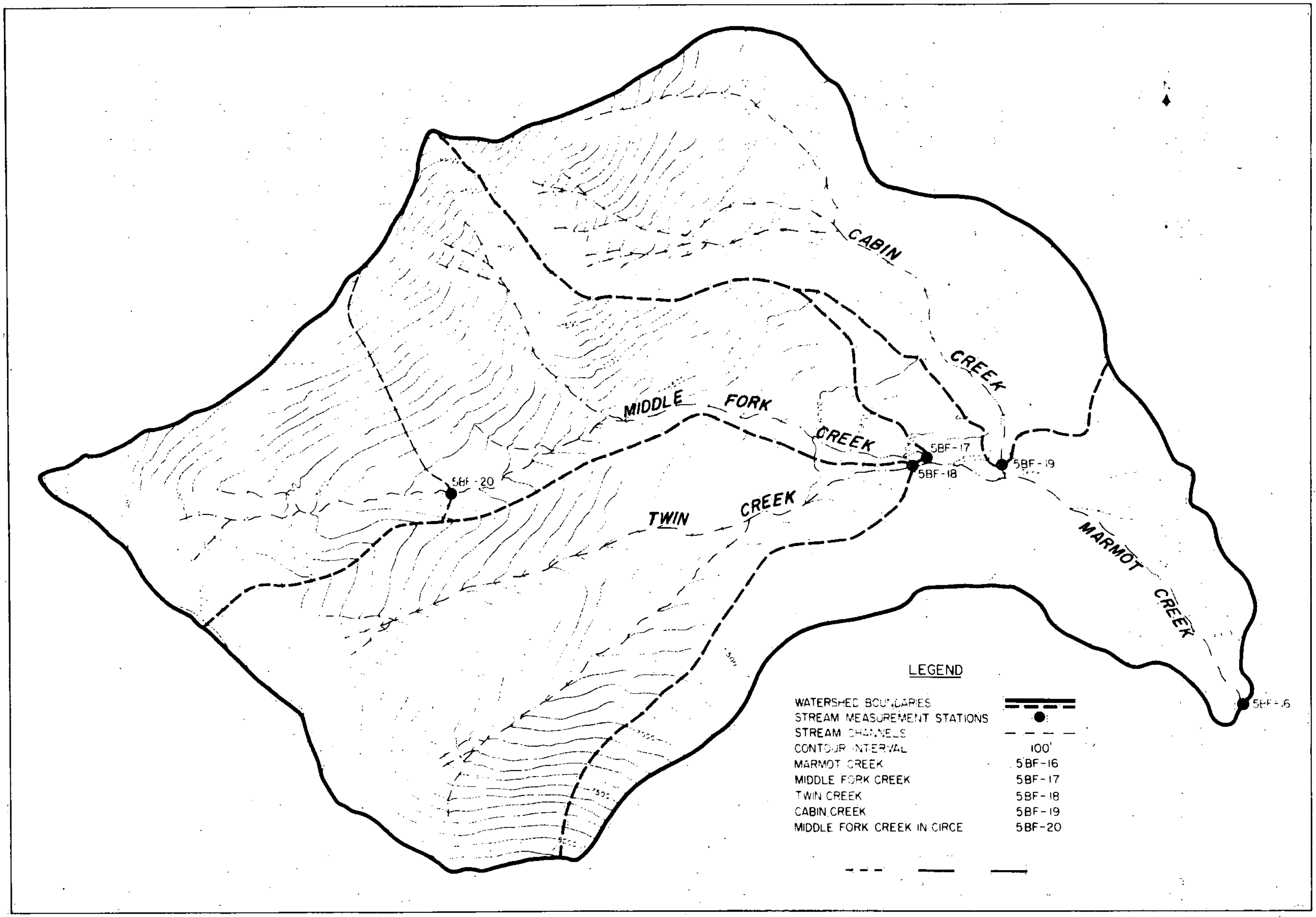


Figure 1 - Marmot Creek Basin

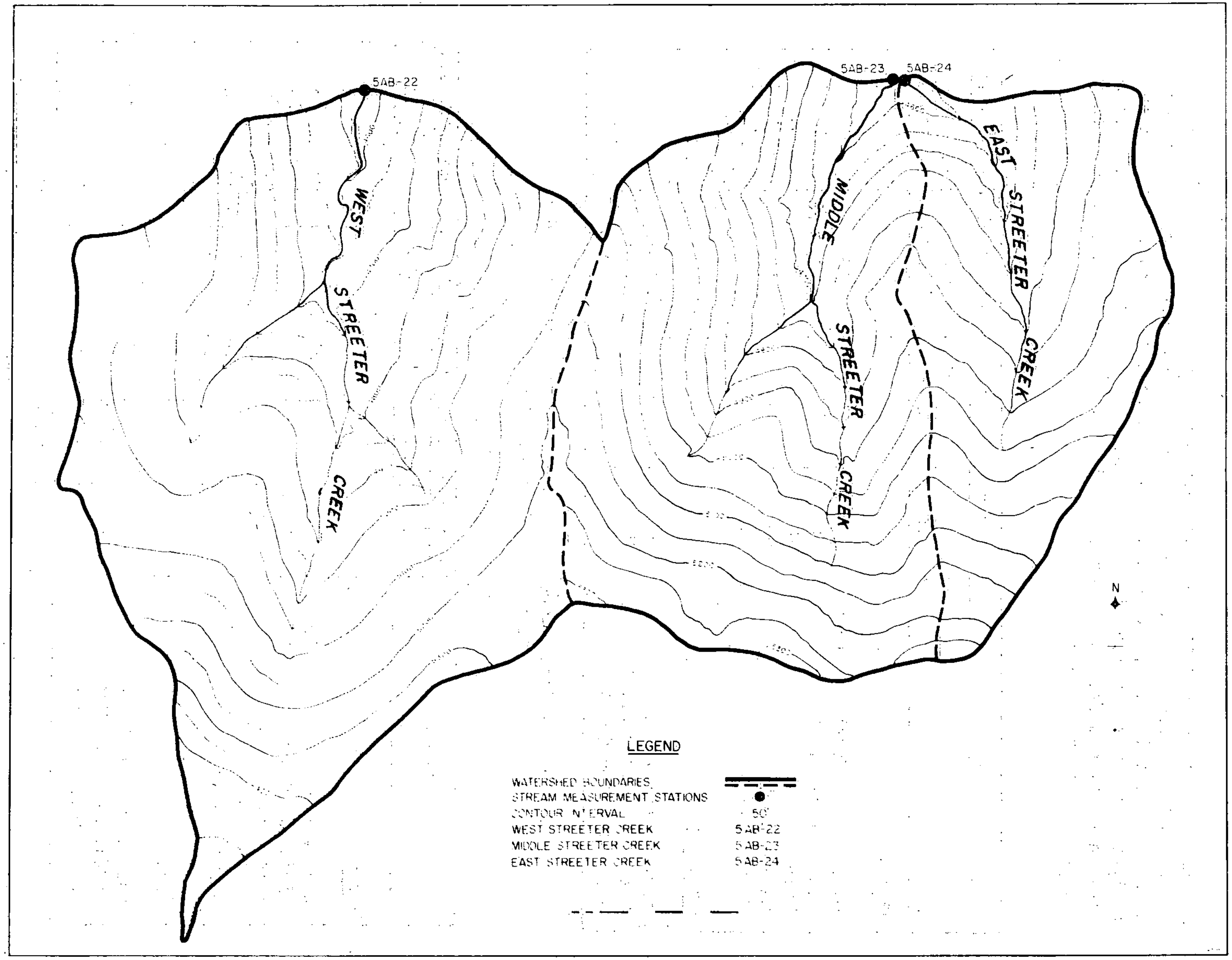


Figure 2 - Streeter Creek Basin

the number of intersections falling into each class interval. While this method is perfectly acceptable and is, indeed, much simpler for computing the distribution, Curry has suggested (personal communication) that it might introduce a personal bias in that slopes falling very close to a class interval boundary may unconsciously always be placed either in the lower or the higher class.

Basin	Small number of points		Large number of points	
	Number of points	Per cent slope	Number of points	Per cent slope
Marmot				
Middle Fork Creek in Circe	60	52	338	51
Middle Fork Creek	76	52	883	52
Twin Creek	70	44	820	41
Cabin Creek	60	40	651	39
Marmot Creek	254	43	2,905	41
Streeter				
East Streeter Creek	62	20	553	21
Middle Streeter Creek	107	28	988	27
West Streeter Creek	165	28	1,487	27

Table 2. - Land slopes determined by sampling method for Marmot and Streeter Basins.

Basin	Per cent slope at indicated contour interval					
	20'	50'	100'	200'	500'	1,000'
Marmot						
Middle Fork Creek in Circe	50	-	50	51	61	73
Middle Fork Creek	-	-	52	52	53	54
Twin Creek	-	-	44	44	43	36
Cabin Creek	-	-	43	43	42	42
Marmot Creek	-	-	43	43	42	39
Streeter						
East Streeter Creek	-	20	20	20	-	-
Middle Streeter Creek	-	28	28	29	-	-
West Streeter Creek	-	27	28	27	-	-

Table 3. - Land slopes determined by contour length method for Marmot and Streeter Basins.

Basin	Per cent slope	
	Sampling method	Contour length method
Marmot		
Middle Fork Creek in Circe	52	50
Middle Fork Creek	52	52
Twin Creek	44	44
Cabin Creek	40	43
Marmot Creek	43	43
Streeter		
East Streeter Creek	20	20
Middle Streeter Creek	28	28
West Streeter Creek	28	27

Table 4. - Comparison of land slopes determined by sampling method and contour length method.

Basin	Per cent slope	
	This study	Curry
Marmot		
Middle Fork Creek in Circe	51	51.5
Middle Fork Creek	52	46.3
Twin Creek	41	42.3
Cabin Creek	39	35.5
Marmot Creek	41	39.4

Table 5. - Comparison of land slopes determined by sampling method for this study and by Curry (1964).

Basin Aspect

Quantitative descriptions of aspect have apparently not been used to any great extent in the past. This has probably been due to the tedium of obtaining any worthwhile value for aspect. Several methods are described by Lee (1963) but the one which appears to be most promising is his suggestion of the watershed "lid". The "lid" is simply the plane surface fitted statistically through the perimeter of the catchment and can be described fully by the azimuth of the maximum slope and by the maximum inclination.

The watershed "lid" is computed very easily by defining evenly spaced points along the perimeter in terms of X, Y, Z coordinates and solving the multiple regression equation $Z = C + k_1 X + k_2 Y$ where C is a constant, k_1 is the slope of the plane in the X direction and k_2 is the slope in the Y direction.

The line of maximum slope then has a bearing (b) from X direction, which is given by

$$b = \tan^{-1} \frac{K_2}{K_1}$$

and the maximum inclination (k) is given by

$$K = \tan^{-1} \frac{K_1}{\cos b}$$

The lids have been computed for Marmot Creek, Streeter Creek and their sub-basins and are given in Table 6.

Channel system distribution

Sribnyi (1961) has shown that distribution of a channel system within a catchment may be described by drainage factor, ν. If a drainage graph is constructed by plotting drainage area (A_x) at a point distance x along the stream channel from the divide, then a curve of the form

$$A_x = A(x/L)^{\nu+1}$$

may be fitted to the drainage graph, where A is the total drainage area and L is the total length of the channel from the divide to the outlet. Different values of ν make it possible to differentiate between the various distributions of the channel system or, in other words, to describe the "hydrologic shape" of the basin which is not necessarily the same as the geometric shape. When $\nu=0$ the hydrologic shape has the form of a rectangle, when $0<\nu<1$ that of a parabola, when $\nu=1$ that of a triangle and when $\nu>1$ that of a reverse parabola.

Values of ν for the Marmot and Streeter basins are given in Table 7, and the drainage graphs are illustrated in Figures 3 and 4.

Drainage density

Drainage density is the average length of streams per unit area within the basin and is fully described in Chow (1964 p. 4-52). While it is potentially a significant characteristic, its use in routine hydrologic studies is open to question because it is very difficult to obtain comparable measurements from basin to basin or even from one part of a basin to another part. If good topographic maps can be used in conjunction with field checks and a study of aerial photographs, comparable results

Basin	Equation of Lid*	Correlation Coefficient	Orientation of Lid	
			Inclination	Aspect
<u>Marmot</u>				
Middle Fork Creek in Circe	Z = 8,898+0.2864X +0.1540Y	0.90	0.32	118°
Middle Fork Creek	Z = 8,406-0.3009X +0.2484Y	0.98	0.39	130°
Twin Creek	Z = 1,004-0.2436X -0.1478Y	0.99	0.28	59°
Cabin Creek	Z = 1,050-0.3025X +0.0275Y	0.94	0.30	95°
Marmot Creek	Z = 9,521-0.2343X +0.0427Y	0.96	0.24	100°
<u>Streeter</u>				
East Streeter Creek	Z = 4,728-0.564X +0.1218Y	0.95	0.13	25°
Middle Streeter Creek	Z = 4,467+0.0854X +0.1229Y	0.97	0.15	325°
West Streeter Creek	Z = 4,913-0.0282X +0.1228Y	0.94	0.13	19°

* Z = elevation
X = West - east coordinate
Y = South - north coordinate

Table 6. - Watershed "lids" for Marmot and Streeter Basins.

may be obtained. If, however, topographic maps alone are relied upon the results are very much in doubt. Even on the 1:50,000 series of topographic maps there is, at times, a large variation in the detail with which stream channels are shown between adjacent sheets, and drainage densities computed from these maps could be very much in error.

Basin	Drainage factor (ν)
Marmot	
Middle Fork Creek in Circe	0.8
Middle Fork Creek	0.2
Twin Creek	0.9
North Twin Creek	0.0
South Twin Creek	0.2
Cabin Creek	0.6
Marmot Creek	0.9
Streeter	
East Streeter Creek	1.0
Middle Streeter Creek	1.0
West Streeter Creek	0.5

Table 7. - Drainage factors ν for Marmot and Streeter Basins.

Values of drainage density were not computed for Marmot and Streeter basins.

Channel slope

Many methods of describing channel slope have been proposed but only two of these are considered here.

Benson (1962) found that the "85-10" slope factor was the most satisfactory in his study of floods in New England. This factor is the slope between points 85 per cent and 10 per cent of the distance along the stream channel from the basin outlet to the divide. It is simple to compute from topographic maps, but it should be noted that the distance is measured to the divide and not to the end of the defined stream channel.

An alternative factor is the mean constant slope, which is determined by plotting the stream profile from the outlet to the divide and drawing a straight line of mean slope such that the area under this line is equal to the area under the profile. In the case of a concave profile, the straight line passes through a point corresponding to the elevation of the outlet, and, in the case of a convex profile, through a point corresponding to the elevation of the divide. When the profile is

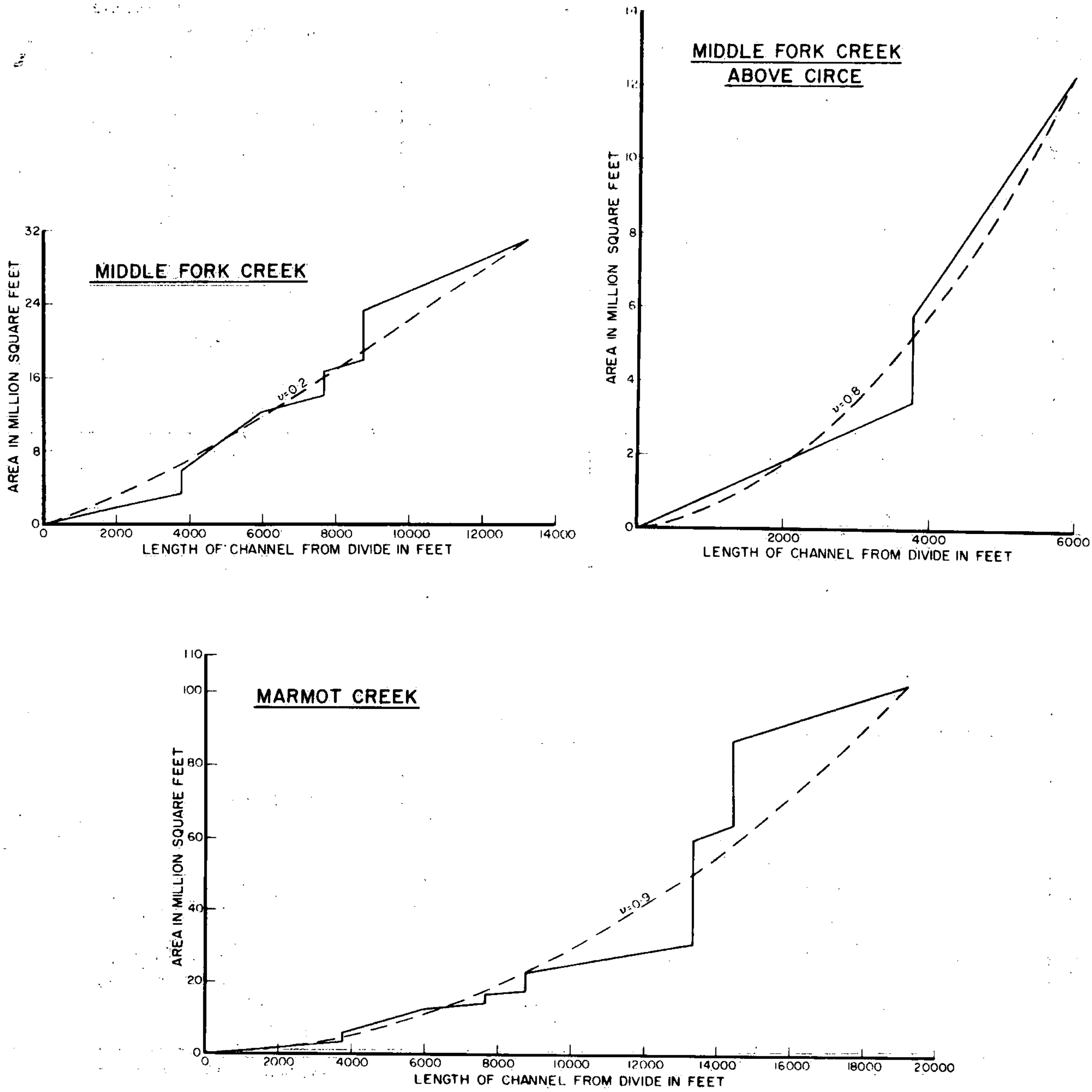


Figure 3 - Channel system distribution for Marmot Basin (Sheet 1 of 2)

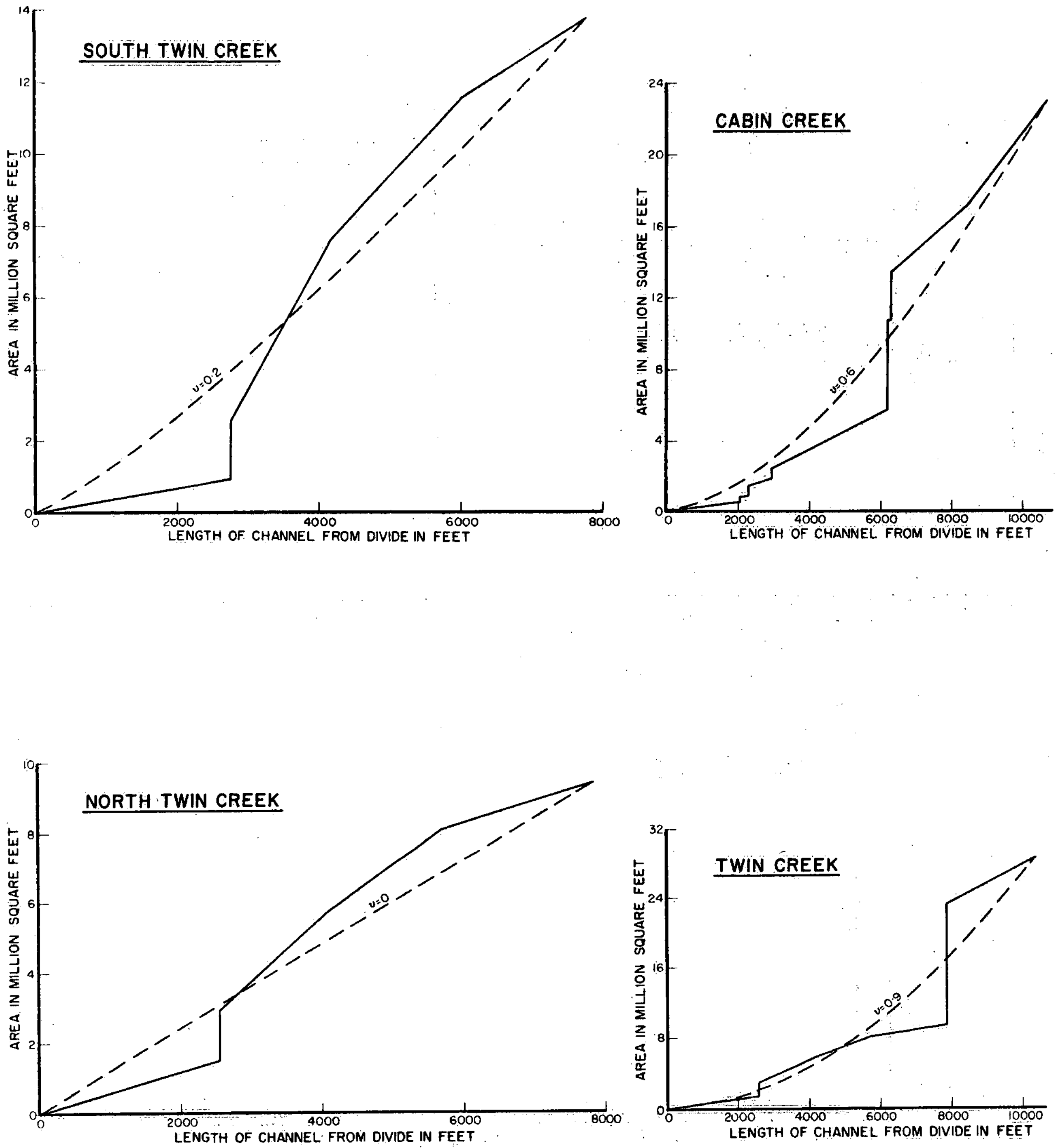


Figure 3 - Channel system distribution for Marmot Basin (Sheet 2 of 2)

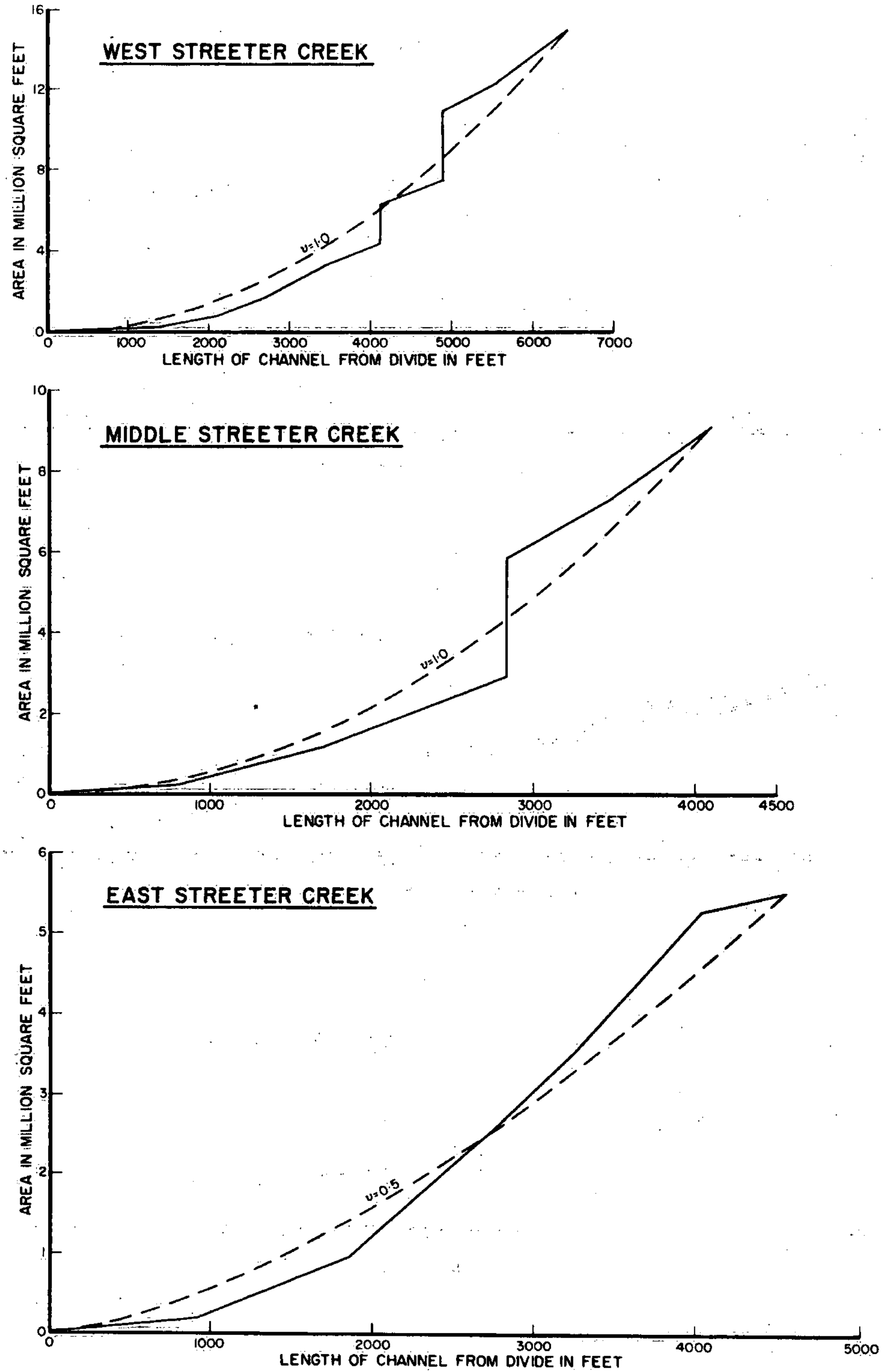


Figure 4 - Channel system distribution for Streeter Basin

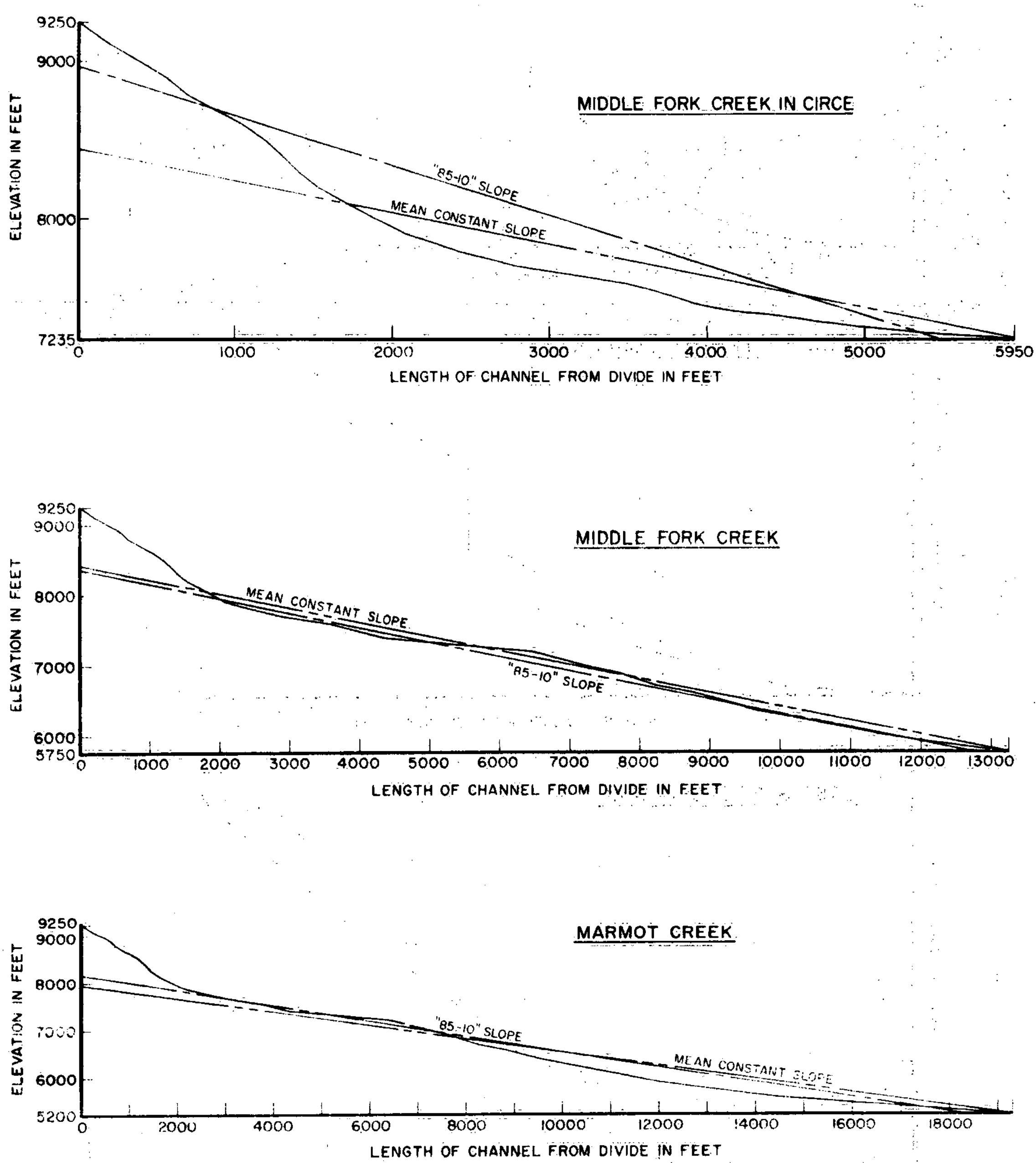


Figure 5 - Channel slopes for Marmot Basin (Sheet 1 of 2)

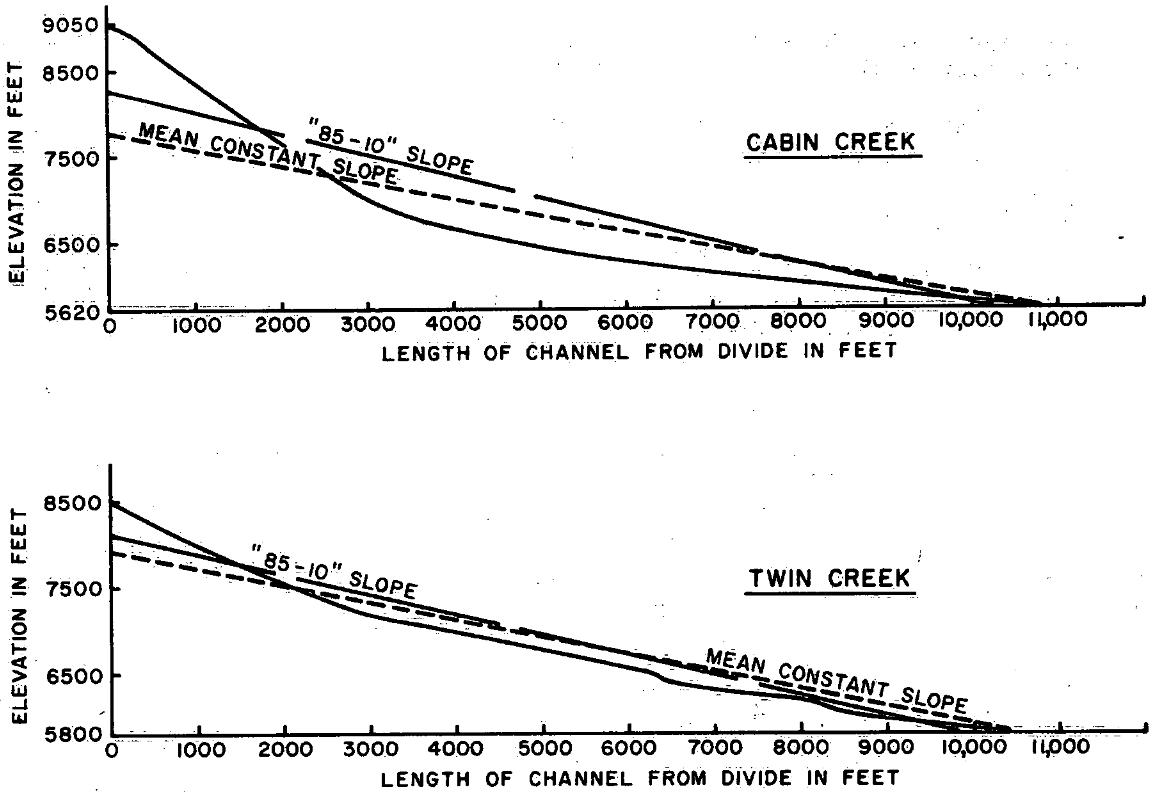


Figure 5 - Channel slopes for Marmot Basin (Sheet 2 of 2)

Basin	Slope	
	"85-10"	Mean Constant
Marmot		
Middle Fork Creek in Circe	0.31	0.21
Middle Fork Creek	0.21	0.20
Twin Creek	0.23	0.20
Cabin Creek	0.26	0.20
Marmot Creek	0.16	0.14
Streeter		
East Streeter Creek	0.17	0.11
Middle Streeter Creek	0.17	0.11
West Streeter Creek	0.15	0.13

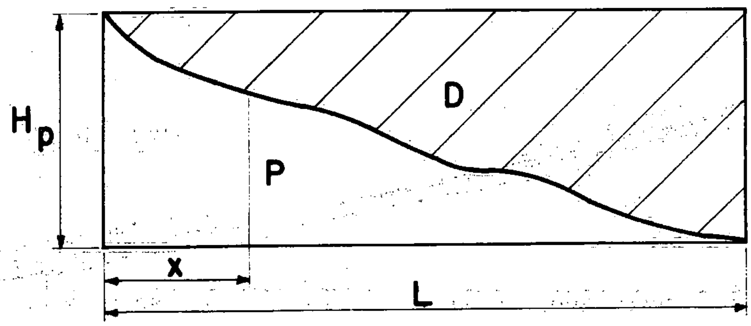
Table 8. - Channel slopes for Marmot and Streeter Basins.

convex-concave, the straight line can be either higher or lower than both the outlet or the divide elevations (Sribnyi 1961).

Table 8 gives the slopes for Marmot and Streeter Creeks computed by these two methods, and they are illustrated on Figure 5 and 6.

Channel profile

Sribnyi (1961) presents an interesting discussion on the analytical generalization of longitudinal profiles of streams and his factors ζ may prove to be useful in describing the channel profile.



Referring to the above sketch, if D, the shaded area, is the area of relief deficiency and if the individual deficient areas along x are denoted by D_x, then the generalized parabolic outline of the longitudinal profile, for the distance x from the divide, gives the relation:

$$D_x = D(x/L)^{\zeta + 1}$$

and

$$D = (LHp)/(1 + \zeta)$$

or

$$\zeta = (LHp/D) - 1$$ where Hp is the height of the divide above the outlet and L is the length of the profile.

From this relation it is an easy matter to compute the value of ζ. For a rectangular outline of area D, $\zeta = 0$; for a parabolic outline, $0<\zeta\leq 1$; for a triangular outline, $\zeta = 1$; and for an inverted parabolic outline, $\zeta>1$.

Values of ζ for Marmot and Streeter creeks and their sub-basins are given in Table 9 and the computed profiles are illustrated on Figures 7 and 8.

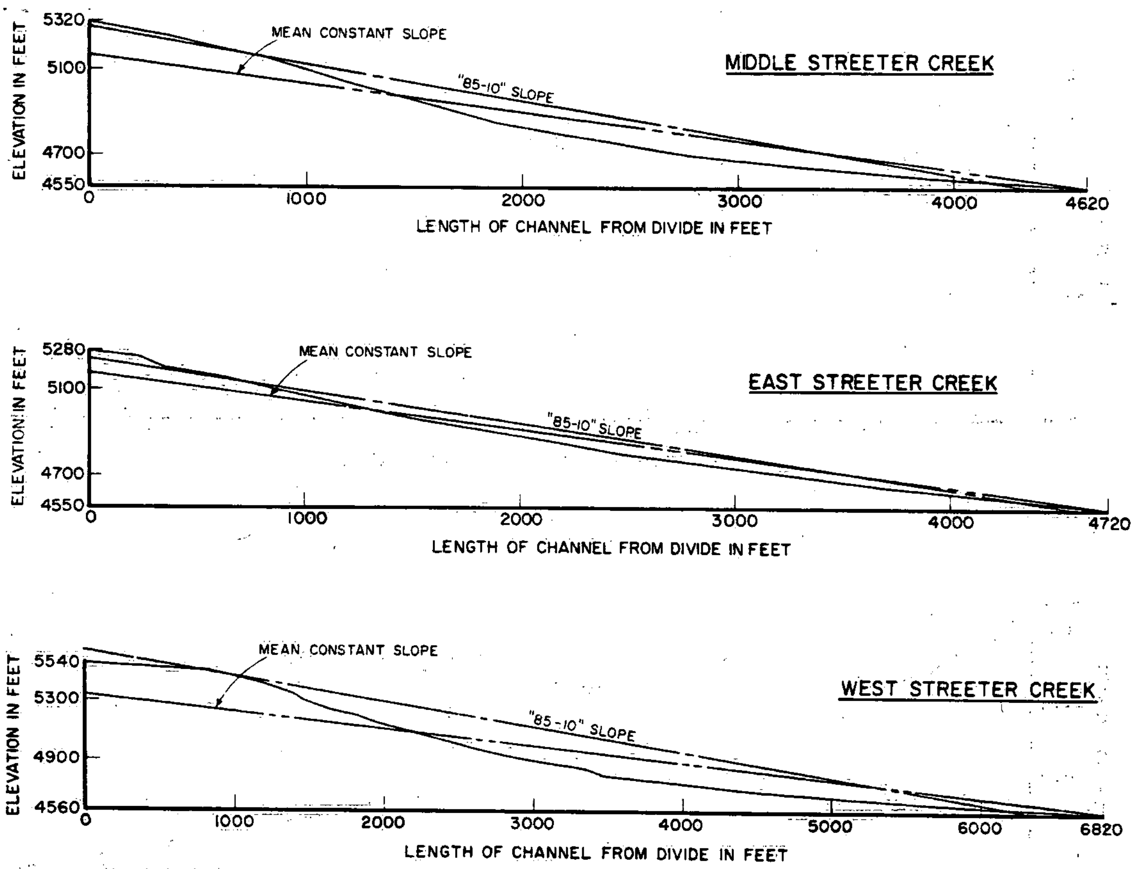


Figure 6 - Channel slopes for Streeter Basin.

Basin	Channel profile factors (ζ).
Marmot	
Middle Fork Creek in Circe	0.44
Middle Fork Creek	0.67
Twin Creek	0.61
Cabin Creek	0.46
Marmot Creek	0.51
Streeter	
East Streeter Creek	0.63
Middle Streeter Creek	0.63
West Streeter Creek	0.72

Table 9. - Channel profile factors ζ for Marmot and Streeter Basins.

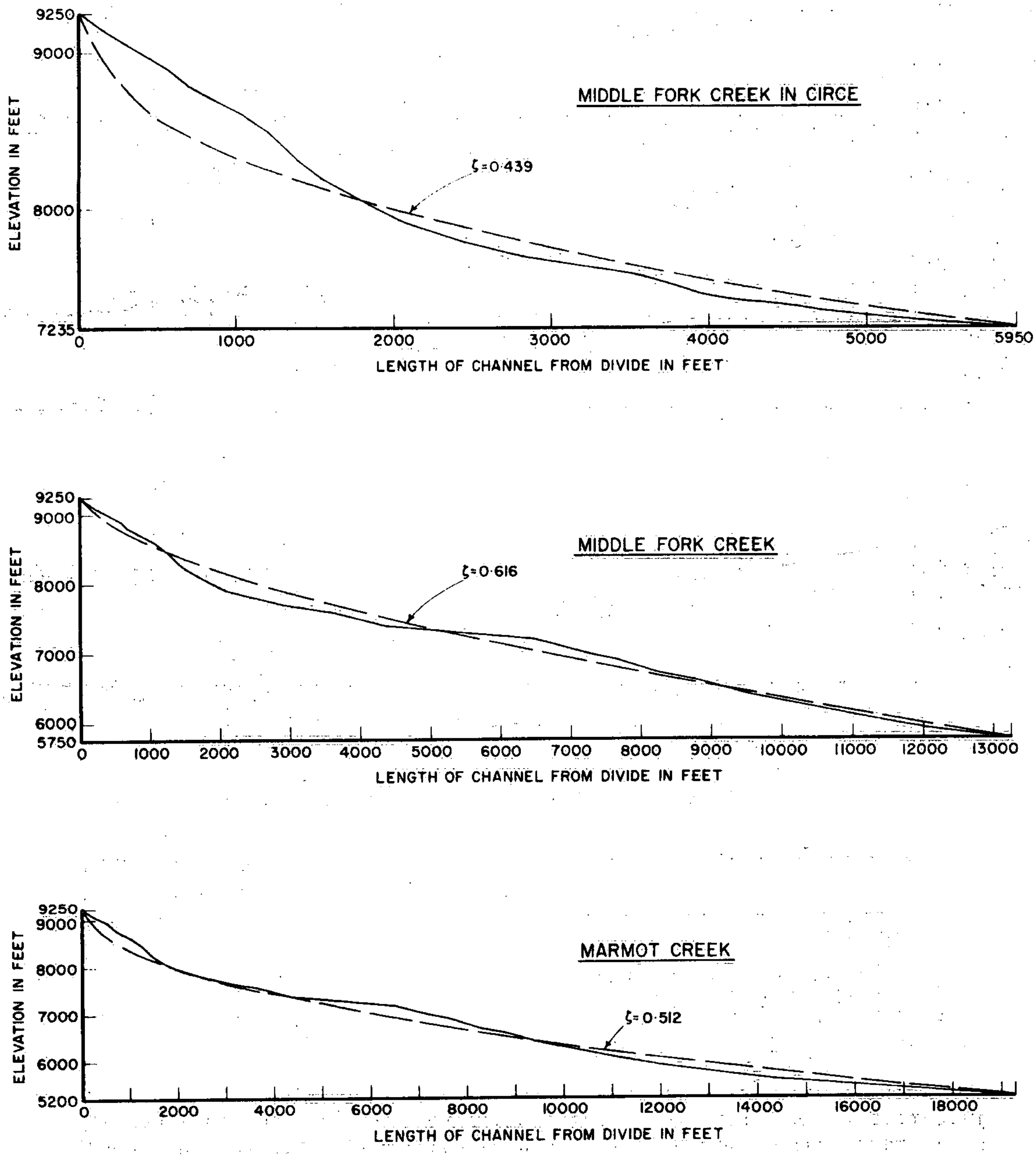


Figure 7 - Channel profiles for Marmot Basin (Sheet 1 to 2)

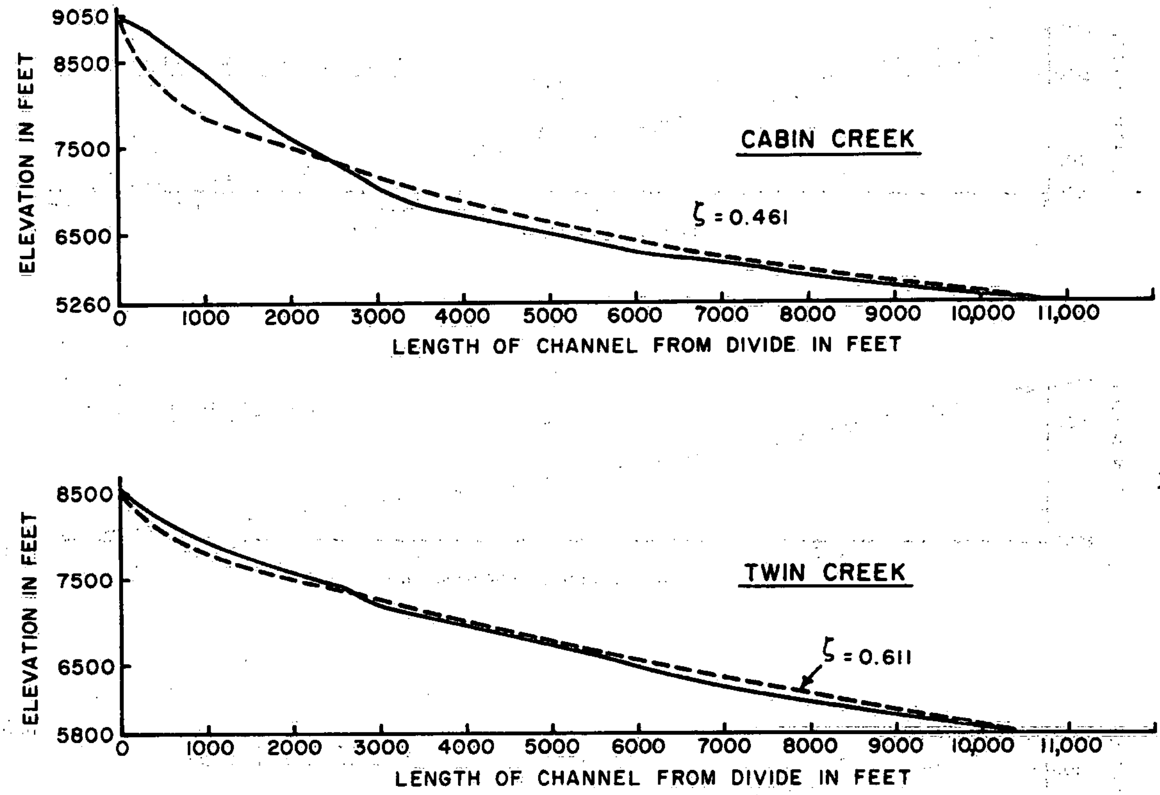


Figure 7 - Channel profiles for Marmot Basin (Sheet 2 of 2).

Channel tortuosity

Sribnyi (1961) suggests using the ratio of the actual stream length to the length omitting meanders and small bends as an index of channel tortuosity. This ratio was determined for Marmot and Streeter basins and the results are given in Table 10.

The measurement of channel tortuosity depends greatly on individual judgement in measuring the "length omitting meanders and small bends". Each individual worker will arrive at a different ratio for the same stream. However, if one worker measures the gorge tortuosity of a set of streams being studied, applying the same standards to each measurement, his results should be of value in a correlation.

In this study, the length omitting meanders and small bends was drawn on the basin plans and measured. Sribnyi suggests measuring the

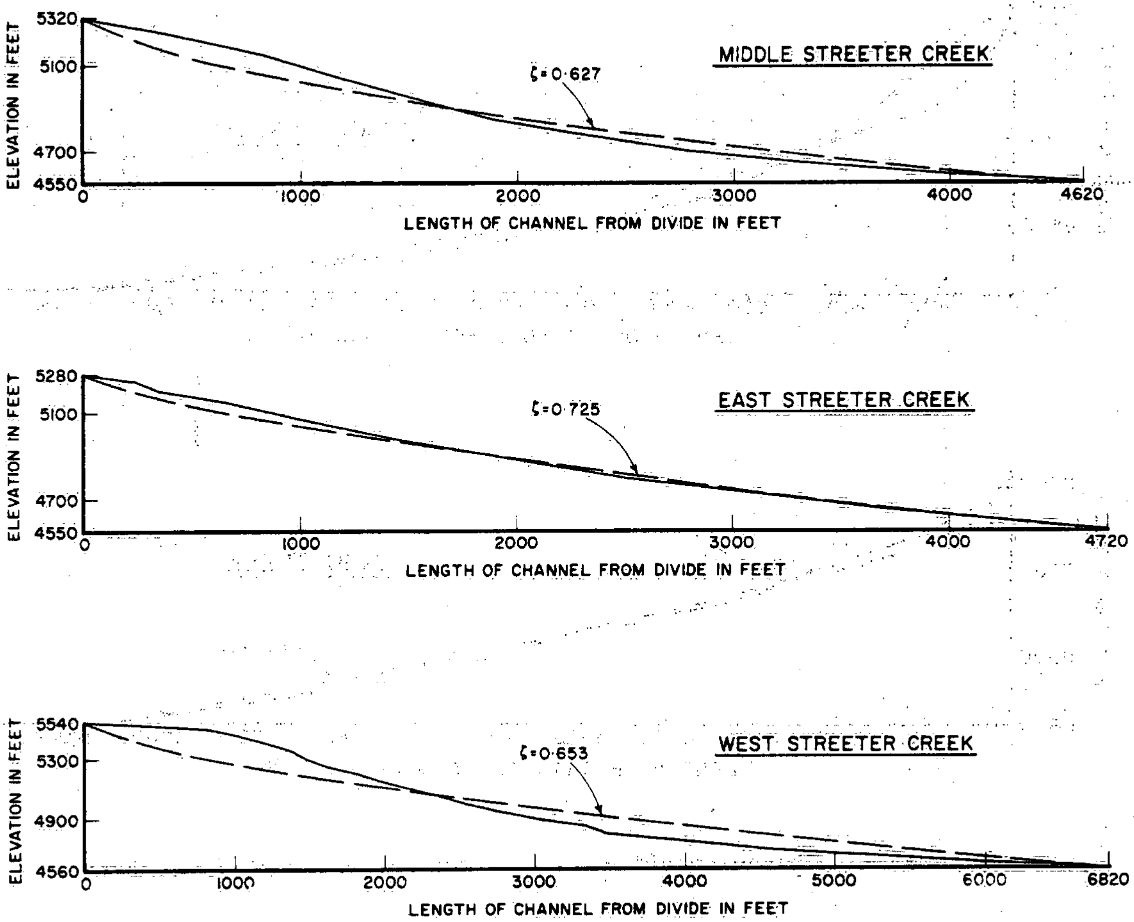


Figure 8 - Channel profiles for Streeter Basin

stream length on two maps, one large scale (say 1:50,000) and one small scale (say 1:500,000) and using the length from the small scale map as the "length omitting meanders and small bends".

Basin	Channel Tortuosity
Middle Fork Creek in Circe	1.054
Middle Fork Creek	1.035
Twin Creek	1.023
Cabin Creek	1.059
Marmot Creek	1.041
East Streeter Creek	1.038
Middle Streeter Creek	1.007
West Streeter Creek	1.023

Table 10. - Channel tortuosity factors for Marmot and Streeter Basins.

Additional references

In addition to the references quoted in this text, Langbein and others (1947) and Golding and Low (1960) are also recommended as excellent sources of information for description of physical features.

Summary

This bulletin has outlined some of the more useful methods of describing certain physical features of drainage basins. It has not attempted to describe the significance of the various features nor to give full descriptions of their computation. The references should be consulted for this information.

The results presented for the Marmot Creek and Streeter Creek basins may be of use to the workers of the many agencies involved in research in these basins.

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