6-1969

Relationships among geomorphological variables affecting water yield from small watersheds

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Recommended Citation

Chaturbhujanathiah, Kalappa C., "Relationships among geomorphological variables affecting water yield from small watersheds. " Master's Thesis, University of Tennessee, 1969.
https://trace.tennessee.edu/utk_gradthes/8435

To the Graduate Council:

I am submitting herewith a thesis written by Kalappa C. Chaturbhujanathiah entitled "Relationships among geomorphological variables affecting water yield from small watersheds." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

C. H. Shelton, Major Professor

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Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

March 10, 1969

To the Graduate Council:

I am submitting herewith a thesis written by Kalappa C. Chaturbhujanathiah entitled "Relationships Among Geomorphological Variables Affecting Water Yield from Small Watersheds." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

C. H. Shelton
Major Professor

We have read this thesis and
recommend its acceptance:

John I. Sewell

M. E. Springer

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

RELATIONSHIPS AMONG GEOMORPHOLOGICAL VARIABLES AFFECTING WATER YIELD FROM SMALL WATERSHEDS

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Kalappa C. Chaturbhujanathiah
June 1969

ACKNOWLEDGMENTS

The writer desires to express sincere appreciation to Professor Curtis H. Shelton for his interest and assistance in this study. Without his close supervision and guidance, the work would not have been possible.

Gratitude is also expressed to Dr. John I. Sewell and Dr. Maxwell E. Springer for their valuable suggestions and advice.

The author is greatly indebted to Dr. John J. McDow, Head of Agricultural Engineering Department, for his help in completion of this study.

The writer is also indebted to the Agency for International Development, The United States of America, and the Government of India for their financial assistance.

The author is indebted to the University of Agricultural Sciences, Bangalore, India, for the opportunity given him to study at The University of Tennessee.

ABSTRACT

The objectives of this study were (1) to develop numerical expressions for geomorphological parameters affecting water yield which would be compatible with computer analysis, and (2) to determine the minimum number of parameters necessary to relate geomorphological factors to the water yield from small watersheds. Ten watersheds located in four physiographic regions of Tennessee were selected for this study. Four of the watersheds are located near Oak Ridge in the Valley and Ridge physiographic region; two are near Spring Hill in the Central Basin physiographic region; two are near Milan in the Gulf Coastal Plain physiographic region, and two are near Crossville in the Cumberland Plateau region. Seventeen numerical expressions for the selected physiographic parameters were determined from topographic maps. Numerical expressions of soil and land-use were determined from USDA-SCS soil-cover index numbers.

Rotated factor analyses were used to find the minimum number of parameters required to represent the original variables. Seven of the seventeen parameters were found to account for most of the information contained in the variables. They were (1) area, (2) form, (3) mean elevation, (4) elevation distribution, (5) total relief, (6) mean slope, and (7) stream order one. In an analysis in which the soil-cover parameter was included, this parameter was shown to be important, but not as pronounced as the others. This might have been due to the fact

that the numerical differences were not great among the soil-cover indices for the six watersheds for which the soil-cover index was used. The depth of soil profile was also found to be a factor which should be included.

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CHAPTER I

THE PROBLEM

I. INTRODUCTION

In all societies, from the most primitive to the highly industrialized, man has always been dependent upon an adequate supply of water. The ever-increasing demand for water by industry, public utility systems, and private users constitutes one of the most serious problems in society today. According to Kazmann (17), in 1968 the United States was using about 350×10^9 gallons of water daily, and "most important, the level of consumption is growing almost exponentially." This statement indicates the trend in the demand for water. Blank and Beer (4) stated, "It is estimated that water needs for industry by the year 2000 may be more than 650 billion gallons daily." The seriousness of this problem of water supply is so great that deliberate attention must be given to it, not only from the standpoint of water supply and use, but also with regard to the factors affecting the water yield of water catchment areas (watersheds). An analysis of these factors on gaged watersheds should contribute to better prediction of water yield on ungaged watersheds.

At the outset, a distinction between runoff and water yield may be necessary, since the two terms are often used interchangeably. Runoff is that portion of precipitation that makes its way toward drainage channels, either by surface or subsurface flow. Runoff over a sustained period of time (approximately a year) constitutes water yield. Water yield may be defined as that portion of precipitation which can reasonably be expected to be captured on the watershed and thereby made available for future use.

A knowledge of the hydrologic regime of small watersheds is enhanced through quantitative analysis of those factors affecting water yield. The factors affecting the water yield of any given watershed are climatic or physiographic in character. Climatic factors include such aspects as precipitation, evaporation, temperature, humidity, and wind. Physiographic factors include such variables as topography, geology, soil and land use. These physiographic variables are not only interrelated in many instances, but are also difficult to measure quantitatively.

II. STATEMENT OF THE PROBLEM

The purpose of this study was to investigate the interrelationships of geomorphological variables affecting water yield from small watersheds.

III. OBJECTIVES OF THE STUDY

The objectives of this study were:

1. To develop numerical expressions for geomorphological parameters affecting water yield which would be compatible with computer analysis.

2. To determine the minimum number of parameters necessary to relate geomorphological factors to water yield from small watersheds.

CHAPTER II

REVIEW OF LITERATURE

Previous studies concerned with the analysis of factors affecting water yield have provided guidance in the present study. This chapter is devoted to a review of the literature related to the physiographic factors affecting water yield, to methods of numerically describing those factors, and to methods of analysis used in the establishment of relationships among the factors.

I. PHYSIOGRAPHIC FACTORS

In 1932, Veihmeyer (33) stated that the water applied to soil may be accounted for in the following ways: (1) loss by runoff; (2) evaporation from the free water surface while the water is being applied; (3) deep percolation below the roots of plants; (4) evaporation directly from the surface of the soil; (5) water used by plants; and (6) water remaining in the soil. All of the above affect, directly or indirectly, the water yield from watersheds.

Horton (16) described the factors related to the properties, distribution and circulation of water on a drainage basin surface, in its soil and underlying rocks, and in the atmosphere. These factors are:

1. Morphologic--factors which depend only on the topography of the drainage basin and on the form and extent of the stream system or drainage net of the basin.

2. Soil--factors which are descriptive of the materials forming the groundwork of the drainage basin, including all those physical properties involved in the moisture relationships of soils.

3. Geologic--factors relating to the depths and characteristics of the underlying rocks and the nature of the geologic structures insofar as they are related to ground water conditions, or otherwise to the hydrology of the drainage basin.

4. Vegetational--factors which depend entirely, or in part, on the vegetation, natural or cultivated, growing within the drainage basin.

5. Climatic-hydrologic--factors such as temperature, humidity, rainfall and evaporation. Hydrologic factors relate especially to conditions dependent on the operation of the hydrologic cycle, particularly with reference to runoff and groundwater.

Horton also indicated that one of the central problems of hydrology is the correlation of the hydrologic characteristics of a drainage basin with its morphology, soils, and vegetation. Furthermore, he suggested that it would be possible to express the characterization of the drainage basin by determining numerical values for the various factors involved, and to study chiefly those factors for which a pronounced correlation with runoff phenomena is found to exist.

The direct relationship between a rapid increase of runoff and a slope increase from zero to about 3 percent was confirmed by Duley and Hays (10), who also found that the increase in runoff was slight for slope increase beyond 3 percent. With an increase in slope, however, Duley and Kelly (11) found that the amount of total water intake and the infiltration rate decreased slightly. They also found that the change in infiltration rate was very small and very gradual with an increase in slope beyond approximately 2 percent.

Ursic and Thames (32) collected hydrologic and meterologic data for individual storms occurring in small Mississippi headwater catchments representing three types of cover. They found that surface runoff and peak flows were greatest from abandoned fields, intermediate from depleted upland hardwood forests, and least from 20-year-old loblolly pine plantations established on eroding farm land. Under forests and on abandoned fields, the surface runoff increased with an increasing proportion of loessial soils, as compared with Coastal Plain soils. They also found that a shallow fragipan doubled the amount of surface runoff and increased peak flow.

In 1962, Dreibelbis (9) reported soil moisture distribution in 8-foot profiles on four watersheds and indicated that the zone of major hydrologic activity lies in the upper foot of soil, particularly in the top seven inches. He found that the extent of hydrologic activity varied with the type of soil. The narrow range of hydrologic activity in Keene soil resulted in a greater amount of surface runoff, and, under favorable conditions, the wider range in the lower part of the profile indicated more rapid percolation and thus a higher rate of infiltration. Dreibelbis suggested that such factors as soil profile characteristics, soil position and elevation on the slope, soil moisture levels and the possibility of sub-surface lateral flow, must be considered in addition to the area factor in the extrapolation of hydrologic data from small plots to larger land areas.

In 1963, Hendrickson, et al. (15) reported a study of runoff on Cecil soils in continuous cotton cultivation. Their study showed that plots 70 feet in length on 7 percent slope lost an average of 22 percent of the annual rainfall as runoff. Furthermore, the use of 70-foot plots instead of 35-foot plots only slightly increased the percentage of runoff.

II. NUMERICAL EXPRESSION OF FACTORS

The Tennessee Valley Authority (29) reported attempts to transform field data to quantitative terms have scales of hydrologic significance. It was pointed out that, although the majority of the quantitative terms were expressed as linear functions, the possibility of an exponential or power function expression of a factor, as well as various interaction terms, should not be overlooked. The paper lists numerical values used to represent 16 compositional factors.

Shelton (22), using the factors previously cited from Horton, listed quantitative expressions of water yield parameters, and developed a method of determining numerical expressions for soil and land-use factors.

III. METHODS OF ANALYSIS

In 1949, Spreen (26) described a graphical correlation technique for relating mean winter precipitation in Western Colorado to the topographic parameters: elevation, maximum slope of the land, exposure, and orientation. This was done by obtaining graphically the value of precipitation as a function of elevation for various grades of slope. With this method, Spreen obtained a multiple correlation coefficient of 0.94, indicating that about 88 percent of the original variance was attributable to the four topographic parameters. He also developed a regression coefficient of 0.55, which indicated that 30 percent of the variation in precipitation was attributable to elevation.

As a means of better understanding the storm runoff process in watersheds, Betson (3) developed a nonlinear mathematical model, starting with the integral of an infiltration capacity function. The results obtained from fitting the equation to various sets of data indicated that storm runoff, at least in the geographic region studied, frequently occurred from only a small part of the watershed. This was found to be true on a small test watershed area, and it appeared to be true for larger watersheds with complex land-use patterns.

Harrold, *et al*. (14) presented methods of analyzing and reporting data on the minimum runoff from agricultural watersheds of 29 to 17,540 acres near Coshocton, Ohio. Of the various regressions attempted, the relation of log P to Q (P = annual precipitation in inches; Q = annual stream flow in inches) gave the best fit to these data. He found that, within the range of data and at the lower end of the relationship, a uniform reduction of precipitation resulted in a greater reduction of runoff. For the locality studied, it was also evident that the dependable runoff values decreased as the drainage area became smaller.

In 1960, Sharp, et al. (20) reported the effectiveness of the use of the multiple correlation approach in evaluating parameters affecting the water yield of river basins. Results of several analyses of annual and monthly streamflow of the Delaware River Basin in Kansas were presented to provide a background for an examination of the method used. These researchers concluded that hydrologic data in general, and the factors affecting water yield in particular, may not fit the premises upon which the multiple regression method of analysis is based, i.e., (1) no errors exist in the independent variables; errors occur only in the dependent variables; (2) the variance of the dependent variable (streamflow) does not change with changing levels of the independent variables (precipitation, for example); and (3) the observed dependent variables are uncorrelated random events. They concluded that (1) although the multiple regression approach will result in a line of best fit and the best estimating equation for hydrologic data, it is not safe to place too much reliance on values estimated by such equations, particularly at levels far removed from the mean, despite very high correlation coefficients, and (2) some of the more modern statistical procedures may be better tools than the multiple regression approach for evaluating the effects of watershed parameters on water yield.

In 1961, Harris, et al. (13) reported that the inference drawn from the ordinary multiple regression approach may be questionable when this method is used to analyze hydrologic data. They developed a statistical model that avoided some of the uncertainties, employing a Taylor series expansion to obtain exponential and interaction terms and using orthogonal transformations to extract some of the variables for use as predictors. Also, they developed a rule for the selection of the single most important (based on ability to explain variance in the dependent variable) independent variable, testing its significance and removing its effects on all remaining variables. A second rule was developed for selecting, in turn, the next most important, independent variable, testing its significance and removing its effect from other variables. Finally, they developed a rule for stopping the selection of independent variables when they would not contribute significantly to the further reduction of unexplained variances in the dependent variable.

The net result of the study by Harris, et al. (13) was the selection of a few from many variables to use in a "near best" prediction equation, from which they proposed a method for obtaining the multiple regression equation using only the selected variables. They concluded that the statistical procedures outlined by them, and as illustrated by a trial application, do not eliminate assumptions intrinsic in the multiple regression approach, but are believed to offer an approach adaptable to many hydrologic problems. In their opinion, the chief virtue of their model lay in its ability to evaluate successively the importance of many unique variables after the effects of previously selected variables had been removed. In the usual multiple regression method, the effect of a given independent variable is mingled with the effects of all other independent variables and the relative importance of selected parameters cannot be determined.

Snyder (25) proposed the technique of multivariate analysis for certain hydrologic applications wherein the multiple regression approach produced unsatisfactory results. He compared the results of multiple regression and multivariate analysis and concluded that the multivariate analysis offered a better solution to the problem of estimating independent variable effects whenever the independent variables are correlated. He illustrated, by analytic derivation of a recession curve, that the multivariate method provides a reasonably rapid convergence to a solution.

A technique known as factor analysis was used by Dawdy and Feth (6) to study the results of chemical analyses of 103 water samples from wells in the Upper and Middle Mojave Valley, San Bernadino County, California. The study was made to learn the relative importance of each principal ion in determining the variations among the samples, and to examine the possibility of chemical equilibrium between aqueous and solid phases in aquifers. It appeared that most of the covariance in the system was accounted for by five variables. The authors concluded that factor analysis furnished the critical information on the chemical relationships basic to the deductions.

The Tennessee Valley Authority (28) reported the application of factor analysis in studying the design of a more efficient hydrologic condition survey. The study showed that only 24 of 46 selected variables were needed to provide independent measures of hydrologic conditions.

In 1968, Shelton and Sewell (23) reduced selected variables from four watersheds near Oak Ridge to numerical form for computer use. Through the use of principal components and varimax rotated factor analysis, they found the necessity of retaining only six of seventeen original variables. The retained variables were: area, total relief, mean slope, drainage density, stream order one, and stream order two.

From the foregoing survey of literature, the need for better quantitative descriptions of physiographic variables affecting water yield became obvious. It appeared that factor analysis showed promise as a method of explaining the second objective of the study, that is, to determine the minimum number of parameters necessary to relate geomorphological factors to the water yield of small watersheds.

CHAPTER III

FACTOR ANALYSIS

From the review of literature presented in the preceding chapter, it appeared that factor analysis would be an appropriate technique for the study of the relationships among watershed factors affecting water yield. Chapter III, therefore, is concerned with a brief explanation of factor analysis.

Factor analysis is a form of multivariate analysis dealing with the resolution of a set of descriptive variables in terms of a small number of factors or categories. The resolution of the variables is achieved by the analysis of the intercorrelations of those variables (12). In factor analysis all the given variables are treated as coordinates with regard to independence or dependence. A satisfactory solution will produce factors which convey the essential information of the original set of variables. The object of factor analysis is to account for the given variables, or their intercorrelations, in terms of a small number of derived variables (factors). The number of factors should be the smallest possible number consistent with acceptable residual errors. The factorial problem demands that there shall be a meaningful interpretation of the small number of derived variables in terms of which the whole set of given variables can be comprehended (30).

Watersheds VII and VIII are located on The University of Tennessee Agricultural Field Station near Milan, in the Gulf Coastal Plain physiographic region. Watershed VII consists of cultivated land, pasture, and woods. Watershed VIII is in cultivation. Soils in these watersheds are Loring Silt Loam, Calloway Silt Loam, Fillover Calloway Silt Loam, and Henry Silt Loam.

Watersheds IX and X are located on The University of Tennessee Grassland Field Station near Crossville in the Cumberland Plateau physiographic region. Each of these watersheds is partly in pasture and partly in woods. The soils are Hartsells Fine Sandy Loam, Atkins Very Fine Sandy Loam, Philo Sandy Loam, and Tilsit Silt Loam.

II. DETERMINATION OF NUMERICAL EXPRESSIONS

Numerical expressions for 17 selected physical variables were determined as indicated below. It is not intended to imply, however, that all relevant variables are included.

Morphologic Factors

Measures of morphologic factors were obtained from topographic maps of the ten watersheds prepared by the Department of Agricultural Engineering at The University of Tennessee. In these maps, two scales of drawing were used: 1" = 50' or 1" = 100'. The contours were drawn at intervals of 2, 4, 5, and 10 feet, depending upon topography. With Watershed IV (Figure 2) as an example, numerical expressions of the variables were determined as follows:

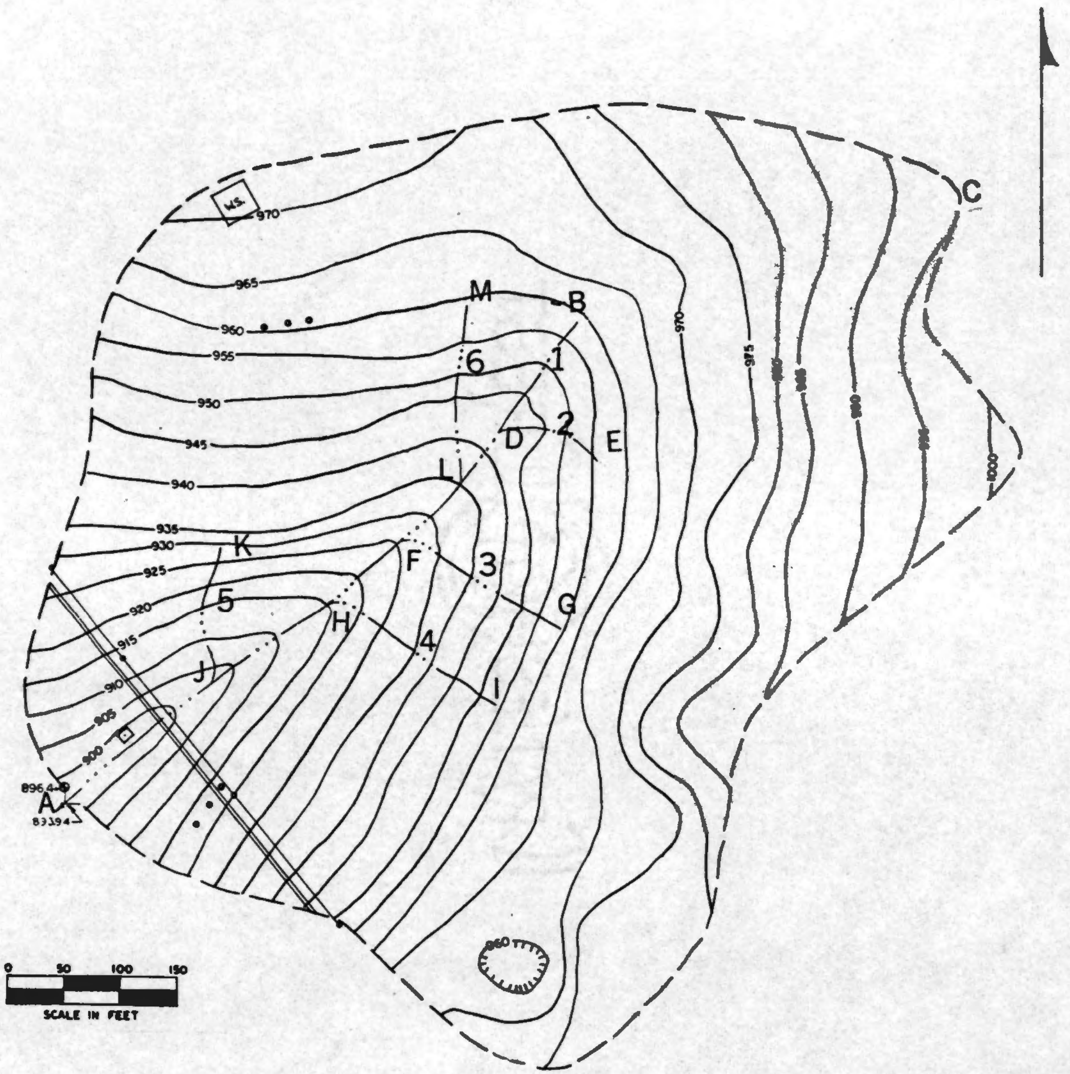

Figure 2. Topographic Map of Watershed IV.

1. Area (A). The watershed areas were determined from the topographic maps by use of the planimeter. The area in acres was determined by using the relation:

$$A = \frac{B\,S^2}{43560} \qquad (1)$$

where A = area (acres),

B = planimeter reading (in.^{2}),

S = scale used for the drawing,

43560 = number of square feet to an acre.

Using this formula, the area of Watershed IV was determined to be 11.4 acres.

2. Form (F). The form of a watershed is defined as the ratio of its width to its length, calculated by the equation:

$$F = \frac{A}{L^2} \qquad (2)$$

where F = form factor,

A = area (ft.^{2}),

L = length in feet measured from the stream gage to a point on the watershed divide opposite the head of the main stream. In Figure 2, the value L was determined by scaling the distance from point A through B to C . The form factor for Watershed IV was 0.5.

3. Compactness (C). The compactness factor is the ratio of watershed perimeter to that of a circle of equal area. The formula is:

$$C = \frac{P}{2(\pi A)^{1/2}} \qquad (3)$$

where P = perimeter (ft.),

A = area (ft.^{2}),

π = constant = 3.1416.

To determine the perimeter, one end of a thin thread was placed at a fixed point on the watershed boundary line, then laid taut over the entire boundary line until the starting point was reached. The thread was then stretched over a scale and the length determined. The compactness factor for Watershed IV was 1.1.

4. Mean Elevation (ME). Mean elevation (above zero datum at the stream gage) is the ratio of the sum of the product of the average elevation of each pair of adjacent contours and the area between those contours to the total area of the watershed. The equation used to obtain this value is:

$$ME = \frac{\sum a \frac{(h_1 + h_2)}{2}}{A} \qquad (4)$$

where ME = elevation above zero datum at stream gaging station (ft.),

a = area (ft.^{2}) between a pair of adjacent contours at elevations h_1 and h_2 ,

A = area of watershed (ft.^{2}) .

The mean elevation computed for Watershed IV was 62.5 ft.

5. Elevation Distribution (ED). This variable was determined by plotting a curve of $\frac{h}{H}$ against $\frac{a}{A}$ and finding $\frac{a}{A}$ at mean h . In this case, "H" refers to the difference in elevation between the high point of the watershed (1002.8 ft. and 893.9, respectively, for Watershed IV). The symbol "h" refers to increments of height above zero datum to the respective contour lines, "A" refers to area of the watershed, and "a" refers to increments of area between successive contours determined as in (4) above. The elevation distribution for Watershed IV was determined as 0.4.

6. Total Relief (TE). The total relief is the difference in elevation between the high point of the watershed and zero datum at the stream gaging station. The total relief (108.9 ft.) for Watershed IV was computed as the difference between the elevation at point C (1002.8 ft.) and point A (893.9 ft.).

7. Median Elevation (MD). Median elevation (MD) is the elevation above zero datum at which 50 percent of the watershed area is above and 50 percent is below. On Watershed IV the elevations are shown with reference to mean sea level. The median elevation of Watershed IV was calculated to be 966.2 ft. (MSL). From this elevation, the zero datum

of 893.9 ft. was subtracted to get the median elevation of 72.3 ft. above the stream gage.

8. <u>Mean Slope</u> (S). Mean slope is the ratio of the product of total length of contours and the contour interval to the watershed area, and is obtained by the equation:

$$S = \frac{h \sum l}{A} \tag{5}$$

where S = mean slope (ft./ft.),

h = contour interval (ft.),

l = length of contour (ft.), and

A = area (ft.^{2}).

Mean slope for Watershed II was determined to be 0.2 ft./ft.

9-12. <u>Slope Distribution</u>. Slope distribution is the percentage of watershed area containing selected slope ranges as follows: S_1 = 0-5 percent, S_2 = 5-10 percent, S_3 = 10-20 percent, and S_4 = 20-40 percent. Since the map for Watershed IV was drawn to a scale of 1" = 50' and the contour interval was five feet, if the shortest distance between the contours on the map were more than two inches, the slope would be in the 0-5 percent range. If the shortest distance on the map were between one and two inches, the slope would be in the 5-10 percent category, etc. In Watershed IV, S_1 constitutes 4 percent of the watershed area, S_2 constitutes 28.1 percent, S_3 constitutes 55.1 percent, and S_4 constitutes 12.8 percent.

13. Drainage Density (D). Drainage density is the ratio of the total length of defined drainage channel to the total drainage area. It is calculated from the equation:

$$D = \frac{\sum d}{A} \tag{6}$$

where D = drainage density (ft./acre),

d = length of drainage channel (ft.). In Figure 2, page 20, channels are indicated as A-B, D-E, F-G, H-I, J-K, and L-M.

A = area (acres).

The drainage density for Watershed IV was 232.5 ft./acre.

14-16. Stream Order. Stream order indicates the extent of branching or bifurcation in the drainage basin. Stream-order-one (SO_1) indicates a non-branching tributary, stream-order-two (SO_2) is formed by the junction of two first order tributaries, and stream-order-three (SO_3) is formed by the junction of two second order tributaries. Watershed IV was found to have six first order tributaries (D-B, D-E, F-G, H-I, J-K and L-M), and one second order tributary (A-D).

17. Average Slope of Streams (SS). The average slope of streams was determined by plotting a profile for each tributary and drawing a slope line so that the area under the slope line equalled the area under the profile. The average slope of all streams in a watershed was calculated from the equation:

$$SS = (\frac{f_1 + f_2 \dots f_n}{d_1 + d_2 \dots d_n}) 100 \qquad (7)$$

where SS = average stream slope (percent),

$f_1, f_2 \dots f_n$ = elevation at source minus elevation at mouth for streams 1, 2, ..., n ,

$d_1, d_2 \dots d_n$ = horizontal distance between mouth and source for streams 1, 2, ..., n .

The average slope of streams for Watershed IV was 12.2 percent.

Soil-Cover Factors

A soil-cover index number (SCI) combining the hydrologic soil group and land-use parameters was determined for Watersheds I and IV and IX and X. Data were not available for Watersheds V and VIII. The hydrologic classification of soils on those watersheds was obtained from the United States Department of Agriculture, Soil Conservation Service Handbook, Hydrology, Part I: Watershed Planning (31). In this classification, soils having high infiltration rates are classified as A ; those with moderate infiltration rates as B ; those with slow infliltration rates as C ; and those with very slow infiltration rates as D . With this hydrologic soil group classification, runoff curve numbers were available for various land uses.

The following method was used by Shelton (22) to determine the soil-cover index numbers. From the average $(\overline{X})$ of runoff curve numbers for each land-use and hydrologic soil group a reference value of 29 was subtracted, resulting in an index number for each land-use and soil-group category. The reference value of 29 was used in order to reduce the lowest $\overline{X}$ (30, for meadow) to a value of unity. Thus, the index number for meadow under soil group A is 1, representing the runoff curve number, 30, minus the reference value, 29 . Likewise, the index number for woods under soil group B would become $(66 + 60 + 55)/3-29$, or 31. After determining the percent land use for each soil group (Table II), a single soil-cover index number was obtained by multiplying that value by the cover index number as obtained above, then totaling all of them under different soil groups and land uses. In Watershed IX, for example, the Hartsells and Ramsey soils (both in soil group B) constituted 75.1 percent of the watershed area in pasture, and 18.7 percent of area in woods. Similarly, the Atkins and Tilsit soils (soil group C) constituted 0.4 percent of the watershed under pasture, and 5.8 percent under woods. The index number for group B soils under pasture was 33, while for the same soils under woods it was 31. For the group C soils, the index number was 49 under pasture, and 44 under woods. The soil-cover index number for Watershed IX, therefore was:

$$(0.751 \times 33) + (0.187 \times 31) + (0.004 \times 49) + (0.058 \times 44) = 33.3.$$

Geologic Factors

The average depth of soil profile (G) was used as a numerical expression of the geologic factor. The average depths of soil borings

TABLE II

HYDROLOGIC SOIL GROUPS AND SOIL-COVER INDEX NUMBERS FOR WATERSHEDS AT OAK RIDGE AND CROSSVILLE

Watershed	Soils	Soil Group	Percent Land Use		Soil-Cover Index No. (SCI)
			Pasture	Woods	
I	Fullerton	B		100.0	31.0
II	Fullerton	B		100.0	31.0
III	Fullerton	B	100.0		33.0
IV	Fullerton	B	100.0		33.0
IX	Hartsells	B	75.1	18.7	33.3
	Ramsey	B			
	Atkins	C	0.4	5.8	
	Tilsit	C			
X	Philo	B	83.4	16.6	32.8
	Hartsells	B			
	Ramsey	B			

for watersheds at Oak Ridge and Crossville were calculated by totaling the depth of borings and dividing by the number of borings made at each watershed. Details concerning the number of borings and their depths were obtained from test hole logs made by the United States Department of Agriculture, Soil Conservation Service. Table III shows the number and average depth of soil borings on Watersheds I-IV and IX-X.

III. SCREENING OF VARIABLES

A numerical expression for each variable on each watershed was determined and tabulated. The arithmetic mean and standard deviation were determined for each variable, and correlation coefficient matrices were determined for three separate analyses. The three analyses were:

(1) seventeen physical variables on ten watersheds,
(2) seven physical variables on ten watersheds, and
(3) nine physical variables on six watersheds.

Output for the study was obtained through use of a computer program BMD03M--General Factor Analysis as described by Dixon (8). An IBM 7040 Digital Computer at The University of Tennessee Computing Center was used to produce the output.

Decisions relative to retention or deletion of variables were based on: (1) loadings in the rotated factor weight matrices, logical relationships among variables, and consideration of variable measurement. A factor loading having an absolute value of 0.80 or greater was used as a criterion for initial screening.

TABLE III

NUMBER AND AVERAGE DEPTH OF SOIL BORINGS

Watershed	Number of Soil Borings	Average Depth (ft.)
I	17	12
II	8	12
III	14	12
IV	6	10
IX	21	4
X	28	3

CHAPTER V

RESULTS AND DISCUSSION

I. NUMERICAL EXPRESSIONS OF GEOMORPHOLOGICAL PARAMETERS

Table IV contains the numerical expressions obtained for selected geomorphological parameters on the watersheds included in this study. It may be observed that the numerical expressions vary considerably in magnitude. For example, watershed areas range from 9.5 acres for Watershed VIII to 198.6 acres for Watershed VI. The mean area was 46.5 acres with a standard deviation of 59.2 acres. Mean elevation above zero datum at the stream gaging station ranged from 7.9 ft. for Watershed V to 93.0 ft. for Watershed I. For all watersheds, the mean was 45.3 ft. and the standard deviation was 40.6 ft. Total relief ranged from 12.7 ft. for Watershed VIII to 193.6 ft. for Watershed I; with a mean of 70.4 ft. and a standard deviation of 60.4 ft. Watershed II was found to have only 0.9 percent area in the 0-5 percent slope distribution class, whereas 100 percent of the area of Watershed VIII was under that category.

The wide variation among some variables for the watersheds studied indicates the necessity for having more cases (watersheds) than variables. The relatively low magnitude of some variables, such as SO_1 and SO_2 , might indicate the need for better (more hydrologically significant) numerical expressions of those variables.

TABLE IV

NUMERICAL EXPRESSIONS OF GEOMORPHOLOGICAL PARAMETERS

Watershed	Variables and Symbols																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	A	F	C	ME	ED	TE	MD	S	S_1	S_2	S_3	S_4	D	SO_1	SO_2	SO_3	SS	SCI	G
I	46.7	.4	1.1	93.0	.6	193.6	90.8	.2	4.5	18.5	54.4	22.6	106.8	11	1	0	10.2	31.0	12
II	19.0	.6	1.1	66.8	.6	148.2	67.7	.2	0.9	16.9	62.0	20.2	161.1	7	2	1	10.0	31.0	12
III	46.3	.4	1.2	89.5	.6	183.4	84.3	.1	4.6	23.0	53.1	19.3	128.1	8	2	1	9.2	33.0	12
IV	11.4	.5	1.1	62.5	.4	108.9	72.3	.2	4.0	28.1	55.1	12.8	232.5	6	1	0	12.2	33.0	10
V	12.0	1.1	1.1	7.9	.8	19.9	6.1	.1	69.6	30.4	00.0	00.0	50.7	1	0	0	1.5	--	--
VI	198.6	.5	1.1	25.5	.7	61.0	25.5	.1	76.4	22.6	1.0	0.0	86.1	15	2	1	1.7	--	--
VII	66.9	.4	1.3	23.8	.3	34.4	24.7	.1	92.9	0.5	2.1	0.4	65.6	6	1	0	1.8	--	--
VIII	9.5	.7	1.1	8.3	.6	12.7	8.7	.1	100.0	0.0	0.0	0.0	123.6	4	1	0	1.6	--	--
IX	25.1	.3	1.2	31.3	.5	57.0	31.9	.1	83.5	16.2	0.3	0.0	151.1	7	1	0	3.9	33.3	4
X	75.8	.4	1.2	44.2	.6	79.0	39.4	.1	37.9	57.0	5.1	0.0	115.8	13	2	1	3.7	32.8	3
Mean	46.5	.5	1.0	45.3	.5	70.4	36.7	.1	47.0	19.9	17.9	5.3	111.5	6.7	1.2	.4	4.6	32.5	8.8
S.D.	59.2	.3	.4	40.6	.2	60.4	32.2	.1	41.8	17.1	27.0	8.6	65.0	4.7	0.8	.5	4.3	1.2	4.2

II. SEVENTEEN PHYSICAL VARIABLES ON TEN WATERSHEDS

The first analysis included all variables with the exception of variables 18 (soil-cover index) and 19 (depth of profile). The correlation coefficient matrix (Table V) shows the degree of association of each variable with each of the other sixteen variables. From the highly correlated pairs of variables, an attempt could be made to condense the number of variables at this stage. For example, the obviously high correlation between variables 11 and 12 (slope distribution 10-20 percent and 20-40 percent) indicates that the contribution of one of the variables is almost the same as the other, and perhaps only one of them needs to be retained.

The high correlation between mean elevation and median elevation (variables 4 and 7, respectively) suggests that one of them could be deleted. Mean slope and stream slope (variables 8 and 17, respectively) appear to be highly correlated and, since they are similar in character, one of them might be deleted. Slope distribution class three (variable 11) and stream slope (variable 17) also appear to be highly correlated and therefore one of them could be deleted. Mean slope and slope distribution (variables 8 and 11, respectively) show a high degree of correlation, indicating that one of them could be retained.

To reduce the correlation matrix to a fewer number of variables, the principal components (eigenvectors) of the correlation matrix of seventeen variables on ten watersheds were computed (Table VI). The

TABLE V

CORRELATION COEFFICIENTS MATRIX OF SEVENTEEN PHYSICAL VARIABLES ON TEN WATERSHEDS

	Variables and Symbols																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Row	A	F	C	ME	ED	TE	MD	S	S_1	S_2	S_3	S_4	D	SO_1	SO_2	SO_3	SS
1	1.00	-.10	.30	.25	.37	.06	.26	.16	.30	.26	.23	.23	.12	.81	.56	.56	.22
2		1.00	.52	.05	.78	-.03	.05	.09	.34	.26	.02	.02	.17	-.11	-.08	-.05	.05
3			1.00	.34	.65	.37	.33	.34	.46	.35	.17	.16	.53	.51	.52	.24	.31
4				1.00	.38	-.22	.97	-.23	.51	.48	-.54	-.55	.03	.41	.12	.04	-.33
5					1.00	.24	.38	.20	.32	.54	.02	.05	.23	.45	.41	.45	.08
6						1.00	-.20	.91	-.60	.36	.88	.90	.62	.42	.73	.68	.87
7							1.00	-.22	.45	.58	-.51	-.53	.03	.46	.17	.11	-.31
8								1.00	-.61	.32	.94	.91	.81	.24	.54	.44	.97
9									1.00	-.21	-.73	-.71	-.21	.10	-.15	-.35	-.63
10										1.00	.14	.08	.29	.54	.41	.50	.28
11											1.00	.98	.67	.08	.45	.40	.95
12												1.00	.57	.06	.47	.46	.89
13													1.00	.32	.47	.15	.80
14														1.00	.86	.75	.17
15															1.00	.87	.46
16																1.00	.32
17																	1.00

TABLE VI

PRINCIPAL COMPONENTS (EIGENVECTORS) OF SEVENTEEN PHYSICAL VARIABLES ON TEN WATERSHEDS

	Variables and Symbols																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Vector	A	F	C	ME	ED	TE	MD	S	S_1	S_2	S_3	S_4	D	SO_1	SO_2	SO_3	SS
1	.03	.03	.15	-.10	.11	.37	-.08	.36	-.22	.16	.35	.34	.28	.17	.28	.25	.35
2	.31	.13	.28	.36	.32	-.01	.37	-.07	.26	.27	-.18	-.18	.03	.35	.22	.19	-.19
3	-.35	.55	.32	.06	.28	-.06	.03	.11	.22	.03	.05	.02	.25	-.28	-.24	-.33	.12
4	.34	.31	.16	-.43	.26	-.01	-.45	-.13	.23	-.32	.01	.09	-.23	.05	.12	.17	-.14
5	.09	-.33	.33	.05	-.32	-.01	-.02	.05	.39	-.47	.00	-.03	.38	.16	.16	-.28	.11
6	.44	.09	-.07	-.27	-.11	-.26	-.21	-.03	-.14	.41	.03	-.26	.31	.24	-.23	-.20	.20
7	-.01	.11	-.61	.10	.35	-.24	.02	.13	-.04	-.39	-.05	-.08	.46	.10	.11	.13	-.03
8	-.48	.17	.07	-.31	-.28	-.26	-.00	-.29	.02	.20	-.03	-.14	.20	.10	.49	.21	-.09
9	.14	.21	.19	.15	-.30	-.62	.14	.41	-.13	-.16	.27	.05	-.21	-.01	-.04	.23	-.00
10	.24	-.16	.25	-.10	.00	-.00	.12	-.17	-.15	-.03	-.11	-.05	.03	-.56	-.21	.46	-.09
11	-.08	.23	.09	-.04	-.07	.24	.27	-.38	-.26	-.38	.24	-.32	-.06	.33	-.29	.13	.25
12	.04	.09	.12	-.31	-.00	.01	.38	.06	-.35	-.11	-.27	.44	.11	.24	-.06	.27	-.42
13	-.06	-.29	-.09	.57	.24	-.07	.47	.23	.34	.05	.23	-.18	-.13	-.04	-.07	.02	.09

eigenvectors are linear combinations of the original variables. They could be said to be the perpendicular projections of correlation coefficients on the orthogonal axes. Interpretation in terms of the original variables is difficult at this stage because of the low values of the linear combinations.

Table VII shows that the 17 × 13 principal components matrix has been reduced to a 17 × 9 factor weight matrix. For this reason, the factor weight matrix is somewhat better than the principal components matrix. The factor weight matrix, however, cannot be interpreted physically. Only five variables have loadings above 0.80 on the general factor (factor 1), and the other factors do not contain high loadings. The arbitrary choice of the axes (factors) has not contributed to the selection of variables, since the variables have diverse loadings on the factors.

A rotated factor weight matrix (Table VIII) provides information necessary for the analysis and interpretation of the results. Rotation has maximized the number of vectors with zero projections on the reference axes. A comparison of Table VII and Table VIII shows that many variables have increased loadings on factors 1-5 after rotation. Since one of the objects of this study was to determine the minimum number of parameters necessary to relate geomorphological factors to water yield, the screening of the variables was based on the results in Table VIII. Using a factor loading having an absolute value of 0.80 or greater as criterion, as well as other reasons given, the variables to be retained were selected as indicated below:

TABLE VII

FACTOR WEIGHT MATRIX OF SEVENTEEN PHYSICAL VARIABLES ON TEN WATERSHEDS

Variables and Symbols		Factor Loadings									
		1	2	3	4	5	6	7	8	9	10
1	A	.07	.67	-.51	.40	.09	.27	-.00	-.18	.02	.00
2	F	.07	.28	.80	.37	-.34	.06	.05	.06	.03	.00
3	C	.40	.62	.46	.09	.34	-.04	-.28	.02	.03	.00
4	ME	-.24	.79	.08	-.51	.05	-.16	.05	-.12	.02	-.00
5	ED	.29	.70	.41	.30	-.32	-.07	.16	-.10	-.05	.00
6	TE	.97	-.02	-.08	-.01	-.00	-.16	-.11	-.09	-.10	-.00
7	MD	-.20	.81	.04	-.53	-.02	-.13	.10	-.00	.02	.00
8	S	.95	-.15	.16	-.15	.05	-.02	.06	-.10	.06	-.00
9	S_1	.58	.56	.32	.27	.39	-.09	.02	.01	-.02	-.00
10	S_2	.41	.59	.04	-.38	-.48	.25	-.17	.07	-.03	-.00
11	S_3	.91	-.39	.07	.01	.00	.02	-.02	-.01	.04	-.00
12	S_4	.89	-.39	.03	.10	-.03	-.16	-.03	-.05	.01	-.00
13	D	.74	.07	.37	-.27	.39	.09	.21	.07	-.03	.00
14	SO_1	.44	.76	-.41	.05	.16	.15	.05	.04	-.00	-.00
15	SO_2	.73	.49	-.34	.14	.16	-.14	.05	.18	-.01	-.00
16	SO_3	.65	.41	-.48	.20	-.29	-.18	.06	.08	.04	.00
17	SS	.92	-.24	.18	-.17	.11	.12	-.01	-.03	-.00	-.00

TABLE VIII

ROTATED FACTOR WEIGHT MATRIX OF SEVENTEEN PHYSICAL VARIABLES ON TEN WATERSHEDS

Variables and Symbols		Factor Loadings									
		1	2	3	4	5	6	7	8	9	10
1	A	-.27	.90	.04	-.03	.12	.11	-.04	-.32	-.00	-.00
2	F	.00	-.17	.96	.00	.18	.05	-.09	.03	.05	-.00
3	C	.26	.29	.45	-.24	.76	.05	-.00	.00	.01	.00
4	ME	-.25	.13	.09	-.94	.13	.02	-.02	-.04	-.02	-.00
5	ED	.08	.37	.87	-.27	.08	.04	-.03	-.03	-.07	.00
6	TE	.90	.36	.03	.04	.04	-.17	-.07	.07	-.14	-.00
7	MD	-.25	.18	.08	-.93	.10	.03	-.14	.04	.00	.00
8	S	.99	.10	.09	.00	.00	.06	-.03	.02	.05	.00
9	S_1	-.65	.03	.29	-.25	.56	.13	.32	-.04	.03	-.00
10	S_2	.24	.31	.29	-.50	-.08	-.00	-.71	-.00	.00	-.00
11	S_3	.94	.05	.01	.32	-.03	.00	-.07	.05	.04	-.00
12	S_4	.92	.09	.04	.33	-.05	-.15	.04	.10	-.01	-.00
13	D	.77	.04	.11	-.18	.24	.54	.02	.00	.00	.00
14	SO_1	.13	.90	.01	-.31	.16	.15	-.12	.04	-.00	-.00
15	SO_2	.46	.82	.03	-.12	.15	.02	.03	.26	-.02	-.00
16	SO_3	.36	.83	.13	-.05	-.21	-.25	-.11	.21	.01	.00
17	SS	.97	.03	.01	.11	.07	.16	-.13	.03	-.01	-.00
		Percent Variance of Matrix									
		36.4	20.8	12.4	15.1	6.7	2.9	4.1	1.4	0.2	

(1) Area has a high loading (.90) on factor 2.

(2) Form has a high loading on factor 3.

(3) Mean elevation has a high loading on factor 4 , and is related to median elevation which also has a high loading on factor 4.

(4) Elevation distribution has a high loading on factor 3 and is not logically related to form, which has a similar loading.

(5) Total relief has a high loading on factor 1, and is easy to measure.

(6) Mean slope has a high loading on factor 1. A similar loading of variable 11 could mean that the mean slope is within the 10-20 percent slope class.

(7) Stream-order-one has a high loading on factor 2, but is not logically related to area which has a similar loading.

Although variables 11, 12, and 17 had high loadings, they were deleted because they were considered to be represented by the mean slope.

The high loadings of total relief, mean slope, slope classes 10-20 percent and 20-40 percent, and stream slope might indicate that factor 1 is a slope factor. High loadings of area, stream-order-one, stream-order-two, and stream-order-three might indicate that factor 2 is an area factor. However, the number of channels of a given stream order is not necessarily related to watershed area. The reasonably similar loadings on factor 3 might imply some relationship between form and elevation distribution. The highly similar loadings of variables 4 and 7 on factor 4 strongly indicate this to be an elevation factor.

From Table VIII, page 38, it can be seen that 84.7 percent of the total variance of the rotated factor weight matrix is explained by the first four factors. Furthermore, 72.4 percent of the variance in factor 1 is explained by the five variables with high loadings. In factor 2, the four variables above 0.80 loading explain 84.9 percent of variance of that factor. Variables 2 and 5 explain 79.7 percent of the variance of factor 3, whereas 68.2 percent of the variance of factor 4 is explained by variables 4 and 7.

III. SEVEN PHYSICAL VARIABLES ON TEN WATERSHEDS

In an attempt to verify the selection of the seven variables mentioned above, a second rotated factor weight matrix (Table IX) was obtained. It is seen that loadings of many variables have been increased. For example, the high loading of variable 1 (area) has increased from 0.90 to 0.96. Factors 1 and 2, containing only four variables with high loadings, now account for 61.1 percent of the total variance. The reduction in number of variables relative to number of watersheds, therefore should result in more stable predictions.

Four of the seven variables selected in this study were also retained in a similar study of the four Oak Ridge watersheds by Shelton and Sewell (23). These four variables were area, total relief, mean slope

TABLE IX

ROTATED FACTOR WEIGHT MATRIX OF SEVEN PHYSICAL VARIABLES ON TEN WATERSHEDS

Variable and Symbol		Factor Loadings						
		1	2	3	4	5	6	7
1	A	-.21	.96	.10	-.01	-.02	.17	.00
2	F	-.33	-.52	.69	-.23	.31	.01	.00
4	ME	-.32	.12	.05	.94	-.02	.01	.00
5	ED	-.01	.16	.98	.13	.06	-.01	.00
6	TE	.94	.15	-.06	-.22	-.16	-.03	.00
8	S	.96	-.09	-.09	-.18	.10	-.01	.00
14	SO_1	.26	.92	-.00	.19	-.04	-.20	.00
		Percent Variance of Matrix						
		30.7	30.4	21.1	15.4	2.0	0.4	.00

and stream-order-one. Differences in the results of the two studies could have been caused by differences among the watersheds.

IV. NINE PHYSICAL VARIABLES ON SIX WATERSHEDS

This analysis included, for Watersheds I-IV and IX-X, the seven variables used in the preceding analysis, plus variable 18 (soil-cover index) and variable 19 (depth of profile). The rotated factor weight matrix (Table X) shows that depth of profile has a high negative loading on factor 1. Depth of profile, therefore, acts in the same manner as total relief (variable 6) and mean slope (variable 8), but acts in a manner opposite to that of mean elevation (variable 8). Since soil-cover index has a loading of only 0.80 on factor 4, this variable could be considered moderately important. This appears to indicate the necessity of numerical expressions more representative of the hydrologic significance of this variable. Nevertheless, 10.1 percent of the total variance of the rotated factor weight matrix is explained by factor 4, 70.1 percent of which is explained by the variable soil-cover index. Factors 1, 2, and 3 explain 86.2 percent of the total variance of the rotated factor weight matrix. The percent variance of these three factors explained by their high loading variables is found to be 88.6, 91.5 and 72.2 percent, respectively.

TABLE X

ROTATED FACTOR WEIGHT MATRIX OF NINE PHYSICAL VARIABLES ON SIX WATERSHEDS

Variable and Symbol		Factor Loadings					
1	A	.14	.95	.15	.24	.06	.00
2	F	-.24	-.15	.95	-.10	-.00	.00
4	ME	.93	.18	-.31	-.08	.10	.00
5	ED	-.04	.83	-.02	-.20	.52	.00
6	TE	-.96	.20	-.00	-.16	.11	.00
8	S	-.85	-.31	.27	-.31	-.09	.00
14	SO_1	.14	.97	-.10	-.00	-.14	.00
18	SCI	.58	.01	-.15	.80	-.07	-.00
19	G	-.94	-.21	.16	-.19	.06	-.00
		Percent Variance of Matrix					
		42.6	30.8	12.8	10.1	3.7	.00

CHAPTER VI

SUMMARY AND CONCLUSIONS

The objectives of this study were:

1. To develop numerical expressions for geomorphological parameters affecting water yield which would be compatible with computer analysis.

2. To determine the minimum number of parameters necessary to relate geomorphological factors to the water yield from small watersheds.

For this study, ten watersheds presently being investigated under the University of Tennessee Agricultural Experiment Station Project H-204, "Factors Affecting Water Yield from Small Watersheds and Shallow Ground Aequifers," were selected.

Seventeen physical variables, identified by their numerical characterization, were used in a rotated factor weight matrix analysis. Seven parameters were found to account for most of the information contained in the original seventeen. The seven parameters were: area, form, mean elevation, elevation distribution, total relief, mean slope, and stream-order-one. A second rotated factor weight matrix analysis involving the seven retained parameters indicated that the selection was valid.

Two additional parameters, soil-cover index and depth of soil profile, were used in a subsequent analysis. This analysis indicated that the soil-cover index emerged as a moderately important factor. This might have been due to the fact that the numerical differences among the soil-cover index numbers for the six watersheds were relatively small. Apparently better numerical expressions for this variable are necessary.

Results obtained from the study indicate the following conclusions:

1. More research is needed relative to the reduction of watershed parameters to numerical form subsequent to analysis. Consideration should be given to exponential relationships among variables, and to interactions among variables.

2. Rotated factor analysis provides a good method for condensing the number of watershed parameters necessary for water yield studies and for examining relationships among those parameters.

LIST OF REFERENCES

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1. Anderson, T. W. *Introduction to Multivariate Statistical Analysis*. New York: John Wiley and Sons, 1958.

2. Barnett, A. P. "How Intense Rainfall Affects Runoff and Soil Erosion," *Agricultural Engineering*, 39:703-707, 711, 1958.

3. Betson, R. P. "What is Watershed Runoff?" *Journal of Geophysical Research*, 69:1541-1552, 1964.

4. Blank, David, and C. E. Beer. "Factors Affecting Water Yield from Small Watersheds in Iowa." Paper read at 1967 Winter Meeting, American Society of Agricultural Engineers, Detroit, Michigan, December 12-15, 1967.

5. Cattell, Raymond B. "Factor Analysis: An Introduction to Essentials," *Biometrics*, 21:190-212, 405-434, 1965.

6. Dawdy, D. R., and J. H. Feth. "Applications of Factor Analysis in Study of Chemistry of Groundwater Quality Mohave River Valley, California," *Water Resources Research*, 3:505-510, Second Quarter, 1967.

7. Diaz, Guillermo, J. I. Sewell, and C. H. Shelton. "An Application of Principal Component Analysis and Factor Analysis in the Study of Water Yield," *Water Resources Research*, 4:299-305, April, 1968.

8. Dixon, W. J. (Ed.). *Biometrical Computer Programs*. Los Angeles: Health Science Computing Facility, University of California, September 1, 1965.

9. Dreibelbis, F. R. "Some Aspects of Watershed Hydrology as Determined from Soil Moisture Data," *Journal of Geophysical Research*, 67:3425-3435, August, 1962.

10. Duley, F. L., and O. E. Hays. "The Effect of the Degree of Slope on Runoff and Soil Erosion," *Journal of Agricultural Research*, 45:349-360, September, 1932.

11. ______, and L. L. Kelly. *Effect of Soil Type, Slope, and Surface Conditions on Intake of Water*. *Agricultural Experiment Station Research Bulletin 112*. Lincoln, Nebraska: College of Agriculture, University of Nebraska, May, 1939.

12. Harman, H. H. *Modern Factor Analysis*. Chicago: The University of Chicago Press, 1960.

13. Harris, B., *et al*. "An Improved Statistical Model for Evaluating Parameters Affecting Water Yield of River Basin," *Journal of Geophysical Research*, 66:3319-3329, 1961.

14. Harrold, L. L., *et al*. *Influence of Land Use and Treatment on the Hydrology of Small Watersheds at Coshocton, Ohio, 1938-1957*. United States Department of Agriculture Technical Bulletin Number 1256, January, 1962.

15. Hendrikson, B. H., *et al*. *Runoff and Erosion Control Studies on Cecil Soils in the Southern Piedmont*. Agricultural Research Service, United States Department of Agriculture Technical Bulletin 1281, 1963.

16. Horton, Robert E. "Drainage Basin Characteristics," *Transactions of the American Geophysical Union*, 13:350-360, 1932.

17. Kazmann, Raphael G. *Modern Hydrology*. New York: Harper and Row, 1968.

18. Kendall, M. G. *A Course in Multivariate Analysis*. New York: Hafner Publishing Company, 1957.

19. Schwab, Glenn O., *et al*. *Soil and Water Conservation Engineering*. Second edition. New York: John Wiley and Sons, Inc., 1966.

20. Sharp, A. L., *et al*. "Application of the Multiple Regression Approach in Evaluating Parameters Affecting Water Yield of River Basins," *Journal of Geophysical Research*, 65:1273-1286, 1960.

21. Shelton, Curtis H. "Factors Affecting Water Yield from Small Watersheds in Tennessee." Report to Cooperative Regional Project S-53, Tennessee Contributing Project, Agricultural Experiment Station, College of Agriculture, The University of Tennessee, March 19, 1968 (mimeographed).

22. _______. "Quantitative Expressions of Water Yield Parameters." Unpublished research instructional materials, Agricultural Engineering Department, College of Agriculture, The University of Tennessee, 1968 (Mimeographed).

23. _______, and John I. Sewell. "Parameter Screening for Watershed Analysis." Paper presented at the 1968 Winter Meeting of American Society of Agricultural Engineers, Chicago, Illinois, December, 1968.

24. ______, J. I. Sewell, and A. L. Kennedy. "Water Yield from Agricultural Watersheds," Tennessee Farm and Home Science, Progress Report 60. Knoxville: Agricultural Experiment Station, University of Tennessee, October-December, 1966, pp. 10-11.

25. Snyder, W. M. "Some Possibilities for Multivariate Analysis in Hydrologic Studies,"Journal of Geophysical Research, 67:721-729, 1962.

26. Spreen, W. C. "Determination of the Effect of Topography upon Precipitation," Transactions of the American Geophysical Union, 28:285-290, 1947.

27. Steel, R. G. D., and J. H. Torris. Principles and Procedures of Statistics. New York: McGraw-Hill Book Company, Inc., 1966.

28. Tennessee Valley Authority, Division of Water Control Planning. Design of a Hydrologic Condition Survey Using Factor Analysis. Research Paper No. 5. Knoxville: Tennessee Valley Authority, November, 1965.

29. ______. Bradshaw Creek-Elk River. A Pilot Study in Area-Stream Factor Correlation. Research Paper No. 4, Knoxville, Tennessee, April, 1964.

30. Thurstone, L. L. Multiple Factor Analysis. Chicago: The University of Chicago Press, 1947.

31. United States Department of Agriculture, Soil Conservation Service. Hydrology, Part I: Watershed Planning. SCS National Engineering Handbook, Section 4, Washington: United States Department of Agriculture, Soil Conservation Service, 1964.

32. Ursic, S. J., and J. L. Thames. "Effect of Cover Types and Soils on Runoff in Northern Mississippi," Journal of Geophysical Research, 65(2):663-667, 1960.

33. Veihmeyer, F. J. "The disposal of Moisture from the Aerated Portion of Soils," Transactions of American Geophysical Union, 13:330-331, 1932.

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