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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

LITHOSTRATIGRAPHIC UNITS: THEIR INFLUENCE ON THE PREDICTIVE ACCURACY OF THE CONVERGENT MEAN MODEL

A DISSERTATION

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Norman, Oklahoma

1973

LITHOSTRATIGRAPHIC UNITS: THEIR INFLUENCE

ON THE PREDICTIVE ACCURACY OF THE

CONVERGENT MEAN MODEL

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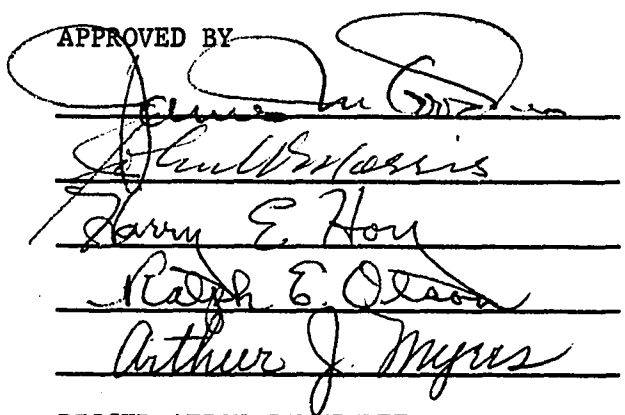

DISSERTATION COMMITTEE

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CHAPTER I

INTRODUCTION

The Law of Stream Numbers has been the subject of investigation since its formulation by Robert E. Horton in 1945. Horton stated the law as follows: "The number of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and the ratio is the bifurcation ratio."[1] Geomorphic significance of the law derives from its uniqueness in that it is the only one of Horton's four laws concerned entirely with a topological characteristic of drainage basins.[2]

Analysis of topological[3] characteristics of fluvial systems permits study of the basic structure and interconnectedness of fluvial systems as part of the landscape envelope,[4] and permits the study of

---

[1]Robert E. Horton, "Erosional Development of Streams and their Drainage Basins--Hydrophysical Approach to Quantitative Morphology," Geological Society of America Bulletin, LVI (March, 1945), 291. (Hereinafter referred to as "Erosional Development.")

[2]Adrian E. Scheidegger, "Horton's Law of Stream Numbers," Water Resources Research, IV (June, 1968), 656.

[3]Topology is defined ". . . as the study of intrinsic qualitative properties of sets of points." A set denotes a collection of objects and a point refers to a member of a set; see Maynard J. Mansfield, Introduction to Topology (New York: D. Van Nostrand Company, 1963), pp. 1-2.

[4]Landscape envelope is defined as the surface of the earth where the atmosphere, hydrosphere and lithosphere impinge and interact;

fluvial systems within the framework of general systems theory.[5] Thus by topologic transformation (that is, reducing drainage systems to order and frequency of streams per order) it is possible (1) to analyze the hierarchical structure of drainage systems, (2) to compare drainage systems to other systems such as biological and urban systems, and (3) to develop models relating to the origin and structure of fluvial systems.

Stream Classification

Underlying the law of stream numbers is the method of stream (channel) classification. Horton proposed a method of classification by which the channels in a fluvial system are arranged in a hierarchy in which the trunk stream assumes highest order. Streams that receive no tributaries are assigned to the lowest order in the hierarchy and are designated first order. The trunk stream and each parent stream are extended to the head of the system (Figure 1). When two tributaries join, the parent stream is defined as the stream that most closely parallels the trunk stream or if both have the same angle the longer of the two tributaries assumes higher order.[6]

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see S. V. Kalesnik, "General Geographic Regularities of the Earth," Annals of the Association of American Geographers, LIV (March, 1964), 160.

[5]David Harvey, Explanations in Geography (London: Edward Arnold, 1969), pp. 217-19.

[6]Horton, "Erosional Development," pp. 281-82.

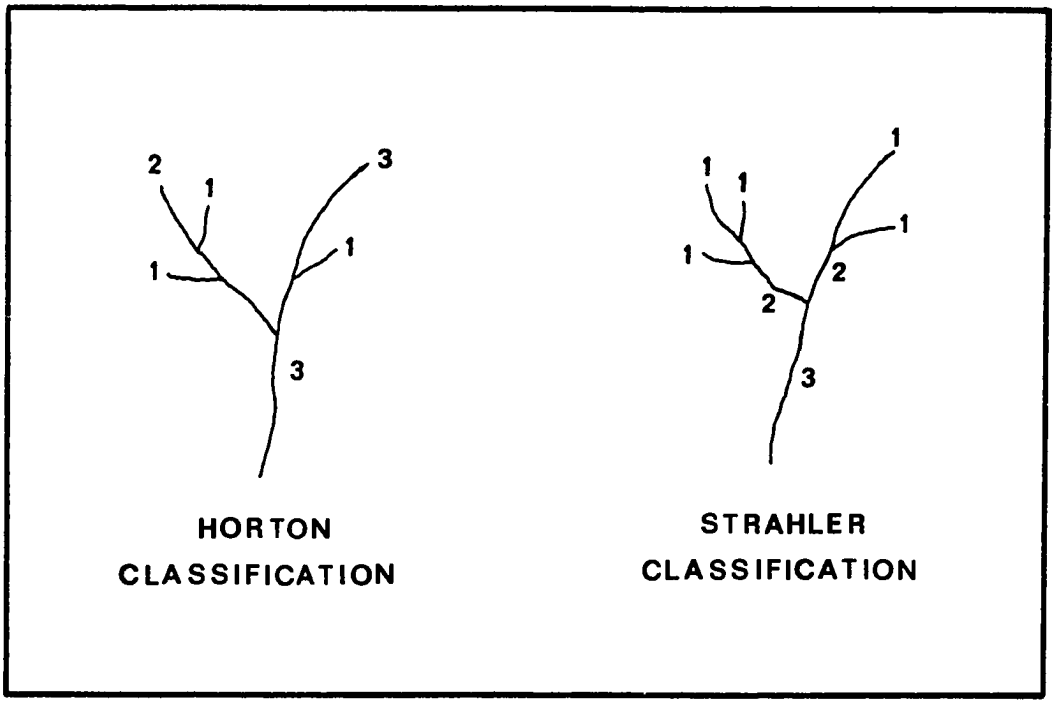

Fig. 1.--Horton and Strahler classification systems

In 1952, Strahler modified Horton's method of classification. According to the Strahler method all fingertip tributaries are designated first order and the junction of two equal order streams initiates a higher order stream.[7] The Strahler method has two primary advantages: (1) it is topological in that it refers only to the interconnections of channels, not to lengths, or orientations and (2) it is less arbitrary in that it can be derived from concepts of combinational analysis. However, it has a disadvantage in that it violates the distributive law because it does not permit the junction of lower order segments to increase the order of the main stream channel.[8] Smart, Shreve, Scheidegger, and Woldenberg have proposed other methods of classification, but the Strahler method remains in common use[9] and is the method used in the models to be discussed in this dissertation. Analysis of results obtained from basins classified by the Horton and Strahler method has shown that when either method is used there is a similar exponential relationship between the number of stream channels per order and stream order.[10]

---

[7]Arthur N. Strahler, "Hypsometric (Area-Altitude) Analysis of Erosional Topography," Geological Society of America Bulletin, LXIII (November, 1952), 1120. (Hereinafter referred to as "Hypsometric Analysis.")

[8]Peter Haggett and Richard J. Chorley, Network Analysis in Geography (New York: St. Martin's Press, 1970), pp. 14-15.

[9]Ibid., p. 12.

[10]Luna B. Leopold, M. Gordon Wolman, and John P. Miller, Fluvial Processes in Geomorphology (San Francisco: W. H. Freeman and Company, 1964), p. 135. (Hereinafter referred to as Fluvial Processes.)

Models

Controversy has developed as models have been proposed o simulate the relationship between the number of stream channels per order and the bifurcation ratio. Leopold and Langbein,[11] Shreve,[12] Scheidegger,[13] and Smart[14] have employed probability models from which they infer that the relationship of the number of stream channels to order can be replicated by a stochastic process. Results obtained from this approach compare favorably with field data, and as a consequence researchers have postulated that Horton's law is not a law in the physical sense but represents a statistical relationship.[15]

Interpretation of the significance of bifurcation ratios derived from stochastic models has proven difficult. Horton states: "The bifurcation ratio ranges from about 2 for flat or rolling drainage basins up to 3 or 4 for mountainous or highly dissected drainage

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[11]U.S., Department of Interior, Geological Survey, The Concept of Entropy in Landscape Evolution, by Luna B. Leopold and Walter B. Langbein, United States Geological Survey Professional Paper 500-A (Washington, D.C.: Government Printing Office, 1962), pp. A1-A20. (Hereinafter referred to as Concept of Entropy.)

[12]Ronald L. Shreve, "Statistical Law of Stream Numbers," Journal of Geology, LXIV (January, 1966), 17-37.

[13]Scheidegger, "Horton's Law of Stream Numbers," pp. 655-58.

[14]J. S. Smart, "Topologic Properties of Channel Networks," Geological Society of America Bulletin, LXXX (September, 1969), 1757-74. (Hereinafter referred to as "Topologic Properties.")

[15]K. L. Bowden and J. R. Wallace, "Effect of Stream-Ordering Technique on Horton's Laws of Drainage Composition," Geological Society of America Bulletin, LXXV (August, 1964), 769.

basins."[16] Bifurcation ratios produced by stochastic models generally range from 2 to 4 while approximating 3.5.[17] These results agree with average bifurcation ratios of observed fluvial systems.[18] However, lack of flexibility in the bifurcation ratio between orders in fluvial systems has posed difficulties when model data are compared with observed data. In natural fluvial systems, between order bifurcation ratios frequently deviate from the mean for the system;[19] as a consequence, the Hortonian structure of fluvial systems has been questioned. Based on his graph ensemble model, Scheidegger concludes: (1) that river nets are topologically bifurcating arborescences; (2) that if nature operates at random all possible arborescences are probable; and (3) that there is no necessity to view fluvial systems as structurally Hortonian.[20] He defines a structurally Hortonian system as one in which on the average confluence of two first order streams forms a

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[16]Horton, "Erosional Development," p. 290.

[17]Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Geological Society of America Bulletin, LXXX (January, 1969), 104. (Hereinafter referred to as "Spatial Order in Fluvial Systems," 1969.)

[18]Leopold, Wolman, and Miller, Fluvial Processes, p. 138.

[19]Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Harvard Papers in Theoretical Geography, No. 13 (Office of Naval Research Tech. Report, Proj. N.R. 389-147, Harvard University, 1968), p. 38. (Hereinafter referred to as "Spatial Order in Fluvial Systems," 1968.)

[20]Scheidegger, "Horton's Law of Stream Numbers," p. 657.

second order stream, and thus through this process the system grows according to the bifurcation ratio.[21, 22]

In contrast to the stochastic approaches, Woldenberg proposed that a deterministic model, the convergent mean model, originally developed by him as an equilibrium model for urban systems, was applicable to fluvial systems. He cites three major advantages of his model: (1) it is predicated on the assumption that a fluvial system is composed of a basin of highest order and subsets of lower order basins; (2) it reflects a growth process (allometric growth); and (3) it allows for flexibility in the bifurcation ratio between orders in the system.[23] Comparison of his model to observed fluvial systems has shown a goodness of fit that indicates further consideration of the deterministic approach is justified.

Research Problem

The problem isolated for investigation is as follows: What effect do lithostratigraphic units in the western portion of the West Gulf Coastal Plain and the eastern portion of the Central Texas section of the Great Plains have on the accuracy with which the

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[21] Ibid., p. 656.

[22] The term Hortonian structure was not defined by Horton, but has been inferred from his discussion of bifurcation. For an example of usage of the term see ibid., p. 657.

[23] Woldenberg, "Spatial Order in Fluvial Systems," 1968, pp. 35-36.

convergent mean model[24] predicts the number of streams (basin areas) per order?

Significance of Research Problem

Lithology

The influence of lithology on the predictive accuracy of the model has not been determined although Woldenberg infers that one of the restraints of the model should be areas of homogeneous lithology. He states that ". . . the number of drainage basins in a fluvial system developed on a homogeneous surface is predictable or explainable."[25] He further notes that "the model agrees with empirical data in cases where the land surface is reasonably uniform with regard to lithology and structure."[26] However, he does not attempt to isolate the influence of lithology from that of structure, nor does he define the term reasonably uniform.

Isolation of the influence of lithology on the predictive accuracy of the model is critical for the following reasons: (1) lithology is a significant variable in landform evolution; (2) equilibrium (quasi-equilibrium) is attainable within areas of diverse lithologies; and (3) the model, an equilibrium model, is postulated to predict the

---

[24]The term convergent mean model refers to the deterministic model developed by Woldenberg to predict the number of streams (basin areas) per order in fluvial systems. Derivation of the model is discussed on pages 27-31.

[25]Woldenberg, "Spatial Order in Fluvial Systems," 1969, p. 97.

[26]*Ibid*.

number of streams per order for fluvial systems in areas of homogeneous lithology.

Lithology is a variable in landform evolution in that lithology, as well as structure, influences the resistance of rock to the gradational forces of the environment.[27, 28] Consequently, as rock weathering occurs within an area differences in lithology may be reflected in landforms. These differences may persist even though an equilibrium (balance) between the forces of erosion and the resistance of the rock to erosion has been attained.[29] Equilibrium neither requires homogeneous lithology nor precludes the existence of form differences. Equilibrium has been inferred for large areas within the Appalachians where differences in lithology occur and where these differences are reflected in the landforms.[30]

Since equilibrium is permitted for areas of diverse lithologies, and since the convergent mean model is postulated to be an equilibrium model,[31] the restraint of the model to areas of homogeneous lithology is questioned. It is inferred that the model should not

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[27]William D. Thornbury, Principles of Geomorphology (2d ed.; New York: John Wiley and Sons, Inc., 1969), p. 19.

[28]Leopold, Wolman, and Miller, Fluvial Processes, pp. 97-98.

[29]John T. Hack, "Interpretation of Erosional Topography in Humid Temperate Regions," American Journal of Science, CCLVIII-A (Bradley Volume, 1960), 81.

[30]Ibid.

[31]Woldenberg, "Spatial Order in Fluvial Systems," 1969, p. 103.

be significantly influenced by differences in lithology within a drainage system if equilibrium has been attained within the system. That is, an equilibrium model should replicate drainage systems that are in equilibrium regardless of differences in lithologies.

Lithostratigraphic Units

In this study the influence of lithology on the model will be assessed as lithology is reflected in the lithostratigraphic unit. A lithostratigraphic unit is defined as a "unit consisting of stratified, marly sedimentary rocks grouped on the basis of lithologic rather than biological characteristics or time value."[32] In the study areas the landforms have developed in sedimentary rocks which have been grouped into lithostratigraphic units in accordance with the "Code of Stratigraphic Nomenclature" of the American Commission of Stratigraphic Nomenclature.[33] Although microscopic lithologic variations may occur within the mapped units, sufficient similarity exists within each unit to justify its classification as a distinct unit based on lithologic characteristics. That is, each unit has a distinctive lithology and recognizable boundaries that permit delimiting it from adjacent units.[34]

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[32]National Academy of Sciences--National Research Council, Supplement to the Glossary of Geology and Related Sciences (2d ed.; Washington, D.C.: National Academy of Sciences, 1960), p. 38.

[33]American Commission on Stratigraphic Nomenclature, "Code of Stratigraphic Nomenclature," Bulletin of the American Association of Petroleum Geologists, XLV (May, 1961), 645-73.

[34]Ibid., p. 649.

Significance of the Convergent Mean Model

The convergent mean model is unique in geomorphology in that it is situated between the traditional deterministic explanations of drainage evolution and the stochastic models of Shreve,[35] Smart,[36] Leopold and Langbein,[37] and Scheidegger.[38] The convergent mean model neither complies entirely with the definition for deterministic models nor entirely with the definition for stochastic models. A deterministic model is defined as one in which a given event can be completely predicted on the basis of previous events.[39] In contrast, a stochastic model is one in which the relationship among variables is not exactly predictable because of a random component.[40] A random component is defined as ". . . an empirical phenomenon that obeys probabilistic, rather than deterministic laws."[41]

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[35]Shreve, "Statistical Law of Stream Numbers," pp. 17-37.

[36]Smart, "Topologic Properties," pp. 1757-74.

[37]Leopold and Langbein, Concept of Entropy, pp. 11-19.

[38]Adrian E. Scheidegger, "Stochastic Branching Processes and the Law of Stream Orders," Water Resources Research, II (Second Quarter, 1966), 199-203. (Hereinafter referred to as "Stochastic Branching Processes.")

[39]Richard J. Chorley and Barbara A. Kennedy, Physical Geography: A Systems Approach (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1971), p. 185.

[40]George S. Koch, Jr. and Richard F. Link, Statistical Analysis of Geological Data (New York: John Wiley and Sons, Inc., 1970), p. 19.

[41]Emanuel Parzen, Stochastic Processes (San Francisco: Holden Day, 1967), p. 7.

The convergent mean model is based on the general hypothesis: "the power function relationship in rivers, which have been called allometric growth, derive from approximate geometric progressions in the size of hexagonal basins."[42] The model is somewhat deterministic in that it assumes that a growth process, allometric growth, operates within fluvial systems and that this growth process operates within the restraints of a hexagonal determinism. However, the model does not fit the strict definition for deterministic models because it contains a random component.

A random component enters both the construction of the model and its theoretical base. The model is based on a convergent mean $\frac{(\text{geometric mean} + \text{arithmetic mean})}{2}$ which is the value used to predict the number of streams (basin areas) per order. The convergent mean is derived from a group of numbers selected sequentially from geometric progressions at the bases three, four, and seven. There is no limit to the number of integers that may be chosen from these progressions provided integers are chosen in ascending order and are not repeated. Thus, there is a degree of flexibility or randomness permitted within the limits of the hexagonal progressions.[43]

Theoretically the model is based on the assumption that drainage basins are the product of allometric growth. That is, the specific growth rate of a component part of the system is a constant fraction

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[42]Woldenberg, "Spatial Order in Fluvial Systems," 1969, p. 109.

[43]Woldenberg, "Spatial Order in Fluvial Systems," 1968, pp. 4-15.

of the specific growth rate of the whole system.[44] Woldenberg infers that the growth process may be a probabilistic version of allometry; he states, ". . . growth probabilities of entities within the system are a random proportion of the previous value of the entity (law of proportionate effect)."[45] He attributes the random proportion to ". . . many factors acting in many ways."[46] Woldenberg postulates that the convergent mean model can explain random deviations from perfect geometric progressions on the basis of the convergent mean.[47]

The convergent mean model thus offers an alternative to the stochastic models of Leopold and Langbein,[48] Shreve,[49] Scheidegger,[50] and Smart.[51] Their models are predicated on the assumption that the relationship between Strahler stream segments and order is a probability function. In contrast, the convergent mean model offers a theoretical statement of probability within the restraint of an underlying hexagonal determinism. Therefore, testing the validity of the model

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[44]Michael J. Woldenberg and Brian J. L. Berry, "Rivers and Central Places: Analogous Systems?" Journal of Regional Science, VII (Winter, 1967), 131.

[45]Ibid., p. 132.

[46]Woldenberg, "Spatial Order in Fluvial Systems," 1969, p. 104.

[47]Ibid.

[48]Leopold and Langbein, Concept of Entropy, pp. 11-19.

[49]Shreve, "Statistical Law of Stream Numbers," pp. 17-37.

[50]Scheidegger, "Stochastic Branching Processes," pp. 199-203.

[51]Smart, "Topological Properties," pp. 1757-74.

and the influence of variables such as lithology on the model is significant. If the model is demonstrated to be valid it has potential for partial resolution of the question of randomness in fluvial system topology as well as offering a partial explanation for the underlying nature of fluvial development.

Selection of Study Sites and Data Collection Procedure

Areas in the western portion of the West Gulf Coastal Plain and eastern portion of the Central Texas section of the Great Plains are selected for study (Figure 2) because they meet the following criteria: (1) lithostratigraphic units have sufficient surface exposures to permit the development of fifth order streams on a single lithostratigraphic unit; (2) erosional systems can be selected where structural controls do not disturb the normal stratigraphic sequence of formations; and (3) study areas are climatically similar.

Within the study areas twenty-two sets of three fifth order stream basins are chosen for analysis. Fifth order drainage basins are chosen for analysis because basins of higher order are usually developed on more than one lithostratigraphic unit and basins of lower order would limit the validity of the study by providing fewer orders with which to compare the model. In each set one fifth order drainage basin is located on a single lithostratigraphic unit; and a second fifth order drainage basin is located on an adjacent lithostratigraphic unit; and a third fifth order drainage basin is developed on both units (Figure 3). Significance of difference between observed

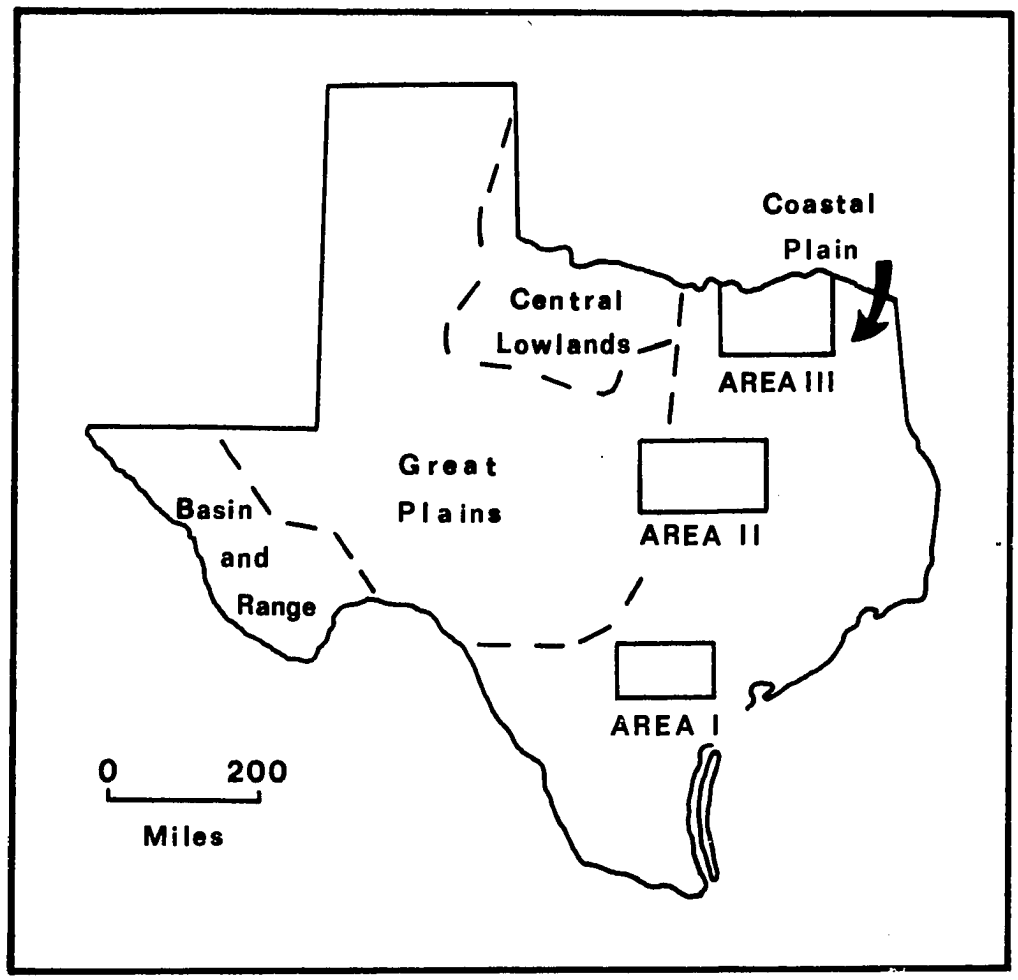

Fig. 2.--Location of study areas

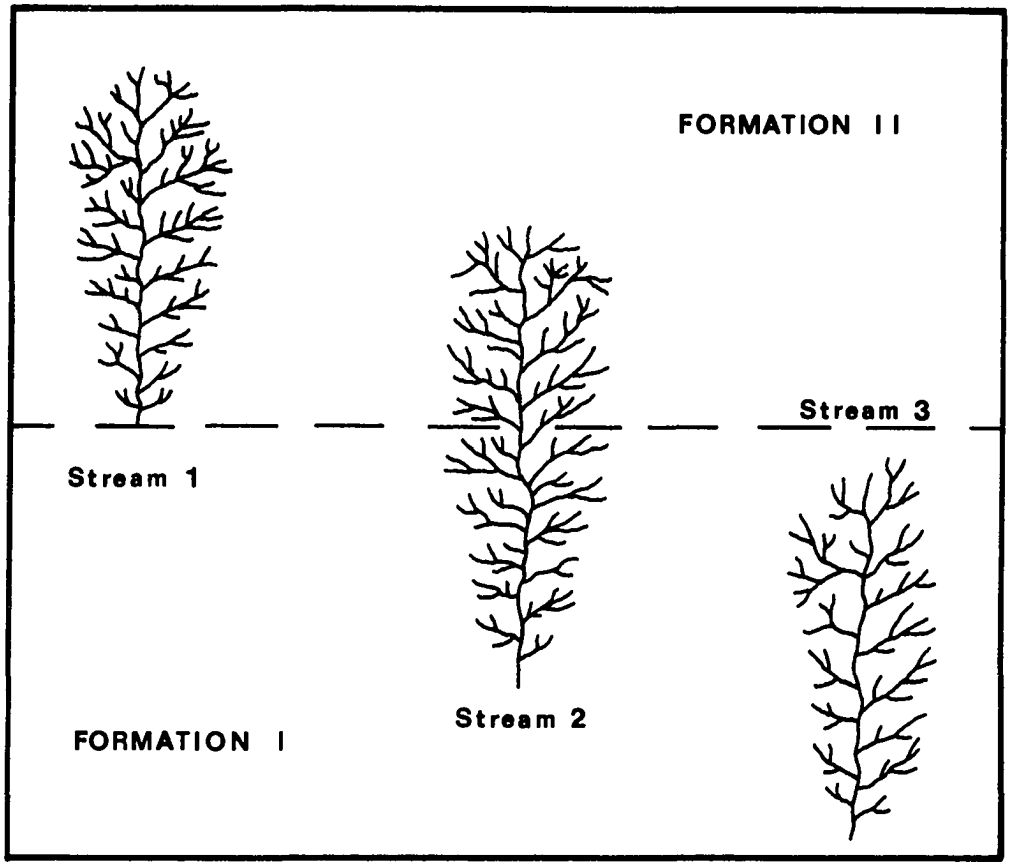

Fig. 3.--Hypothetical set of three basins

data and model data is tested for each set to determine if model data fit the drainage basins developed on a single lithostratigraphic unit better than the drainage basin developed on two units.

Drainage channel data are taken from United States Geological Survey topographic maps at a scale of 1:24,000. Drainage channels indicated by blue lines on these maps are extended to include lower order tributaries. This is accomplished by extending streams where one contour has an inflection angle of 135° or less or where three successive contours[52] have inflection angles of 150° or less (Figure 4). In this study a contour "inflection angle is defined as the angle a contour makes with itself."[53] The method of extending channels is a modification of a method used by LuBowe in her study of junction angles.[54] The modified method herein used has been tested in the field and found to be valid. Once drainage channels are identified, classification is accomplished by the Strahler method of classification.[55]

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[52]The contour interval for maps used in this study is ten feet.

[53]Joan Kremer LuBowe, "Stream Junction Angles in the Dendritic Drainage Pattern," American Journal of Science, CCLII (March, 1964), 325-39.

[54]Ibid.

[55]Strahler, "Hypsometric Analysis," p. 1120.

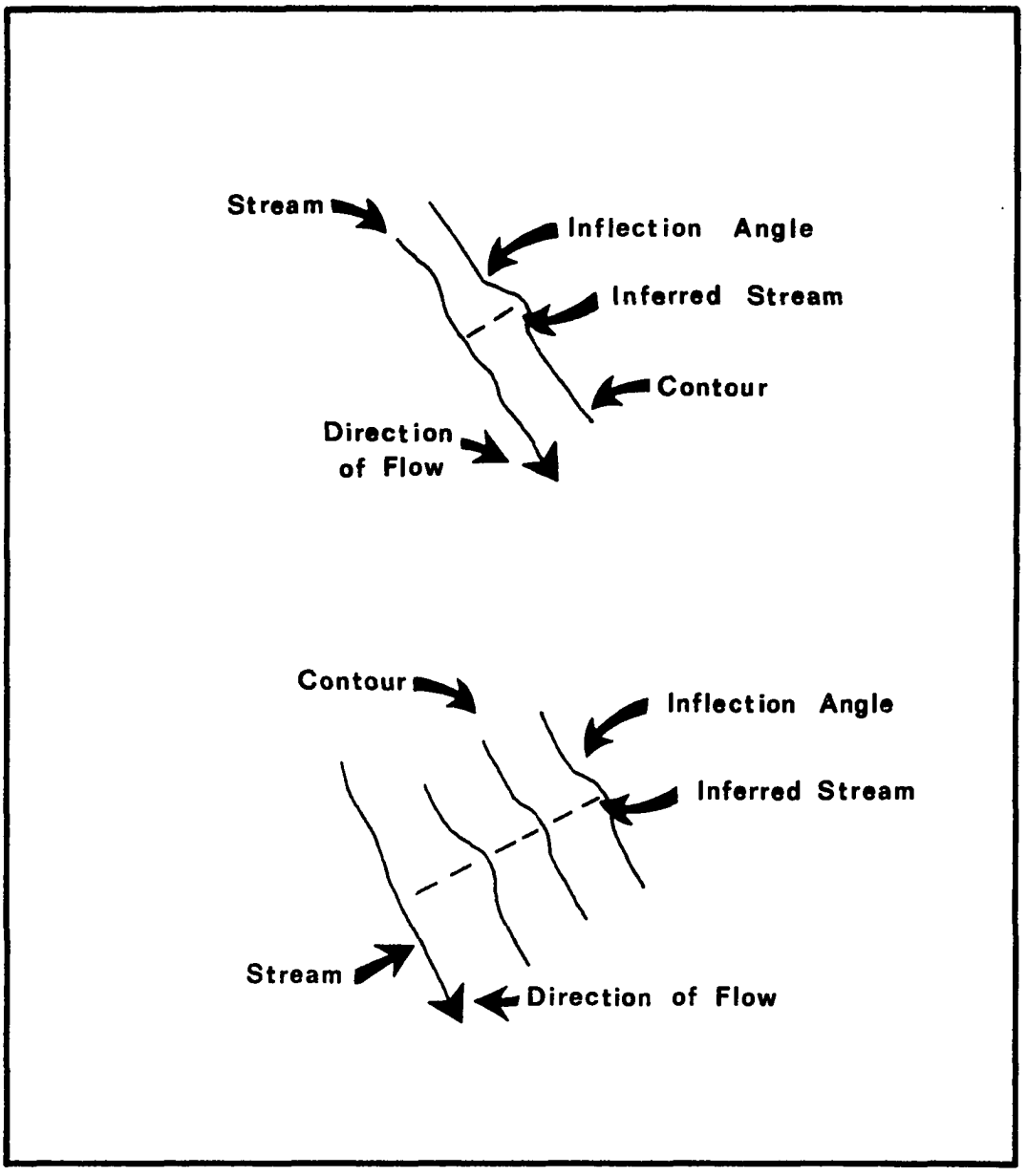

Fig. 4.--LuBowe method of measuring inflection angles

CHAPTER II

THE WOLDENBERG MODEL

The model to be tested in this study was originally developed by Michael Woldenberg as an equilibrium model to predict the number of complementary regions surrounding cities in a central place hierarchy. Conceptually the model is based on the central place theory of Walter Christaller who postulated that cities (central places) and their complementary regions on a homogeneous plain can be arranged in a functional hierarchy.

Christaller Model

In the Christaller model a central place is defined as a functional center (city) which serves a complementary region areally larger than itself.[1] The order (rank) of a central place in the hierarchy is determined by the regional extent of the central functions it performs. Christaller defined central functions as those goods and services that central places provide their surrounding complementary regions. The boundary of complementary regions is determined primarily by the minimum (or threshold) level of demand necessary to support the central place. Demand is primarily a function of

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[1]Walter Christaller, Central Places in Southern Germany, trans. by Carlisle W. Baskin (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1966), pp. 16-17.

economic distance (time + cost) from the central place. Those central places which have central functions that extend to only the immediate vicinity are designated as central places of lower order, whereas those whose central functions extend over larger regions are designated central places of higher order.[2] Likewise, complementary regions of higher order central places are assigned higher rank in the regional hierarchy while complementary regions of lower order central places are assigned lower order in the regional hierarchy.[3] Throughout the hierarchy, the system functions by regional demands for goods and services being supplied by central places in which surpluses are available for distribution. Therefore, central places and their complementary regions form functional units in which there is an equilibrium among central places and their complementary regions.[4] Christaller postulated that under the restraint of a homogeneous plain with equal access in all directions that central places of similar hierarchical position will be evenly distributed and that each complementary region will be hexagonal in shape.[5]

Christaller postulated that the hexagonal hierarchies of central place systems are based on geometric progressions and emphasized the bases three, four, and seven. Other bases for the progressions

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[2] Ibid., p. 17.

[3] Ibid., p. 21.

[4] Ibid., p. 22.

[5] Ibid., p. 63.

were investigated, but Christaller demonstrated from his work in Germany that three, four, and seven were common. He felt that the base three represented dominance of the market principle, four the transportation principle, and seven the administrative principle. The particular base the progression followed was determined by the dominance of one of the three principles.[6] In 1950 Christaller suggested mixing hierarchies of three, four, and seven[7] to provide a hierarchy in those areas in which each of the three principles is operative.

Based on Christaller's model, Woldenberg developed a mixed hexagonal progression model to predict the number of market areas per hierarchical order in central place systems. Woldenberg tested his model using cities in Nigeria, Ghana, Finland and data from Christaller's 1933 study of the Munich area of Germany. For the data analyzed, the model provided a significant fit.[8]

The Hexagon

Use of the hexagon in central place theory is based on the geometric characteristics of the hexagon. It is the most economical

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[6] Ibid., pp. 66, 68, 73, 79.

[7] Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Harvard Papers in Theoretical Geography, No. 13 (Office of Naval Research Tech. Report, Proj. N.R. 389-147, Harvard University, 1968), p. 10. (Hereinafter referred to as "Spatial Order in Fluvial Systems," 1968.)

[8] Michael J. Woldenberg, "Energy Flow and Spatial Order," Geographical Review, LVIII (October, 1968), 552-74.

polygon that fills all space in a two dimensional Bravais lattice.[9] A Bravais lattice is by definition "a parallel net-like arrangement of points . . .[10] [in which] the lattice points obey the lattice condition that every point shall have the same environment in the same orientation."[11] There are five Bravais point lattices which when repeated over space produce space filling sequences. They are the parallelogram, primitive rectangle, centered rectangle, square, and hexagon (Figure 5).[12] Of these five polygons the hexagon is the most compact and most closely approaches a circle. The circle[13] is the most economical regular polygon in terms of (1) accessibility from the center and (2) economy of perimeter. However, the circle will not fill all space without overlapping. The regular polygon that most closely approaches a circle in terms of perimeter and accessibility from the center is the hexagon. In terms of radius and perimeter the hexagon is about four-fifths as efficient as the circle.[14]

August Losch demonstrates that in economic considerations when market areas are considered around points on a plain that average

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[9]Charles Kittel, Introduction to Solid State Physics (2d ed.; New York: John Wiley and Sons, Inc., 1957), p. 8.

[10]Ibid., p. 2.

[11]Ibid., p. 8.

[12]Ibid., pp. 8-9.

[13]The circle is a regular polygon with an infinite number of sides.

[14]Peter Haggett and Richard J. Chorley, Network Analysis in Geography (New York: St. Martin's Press, 1970), p. 51.

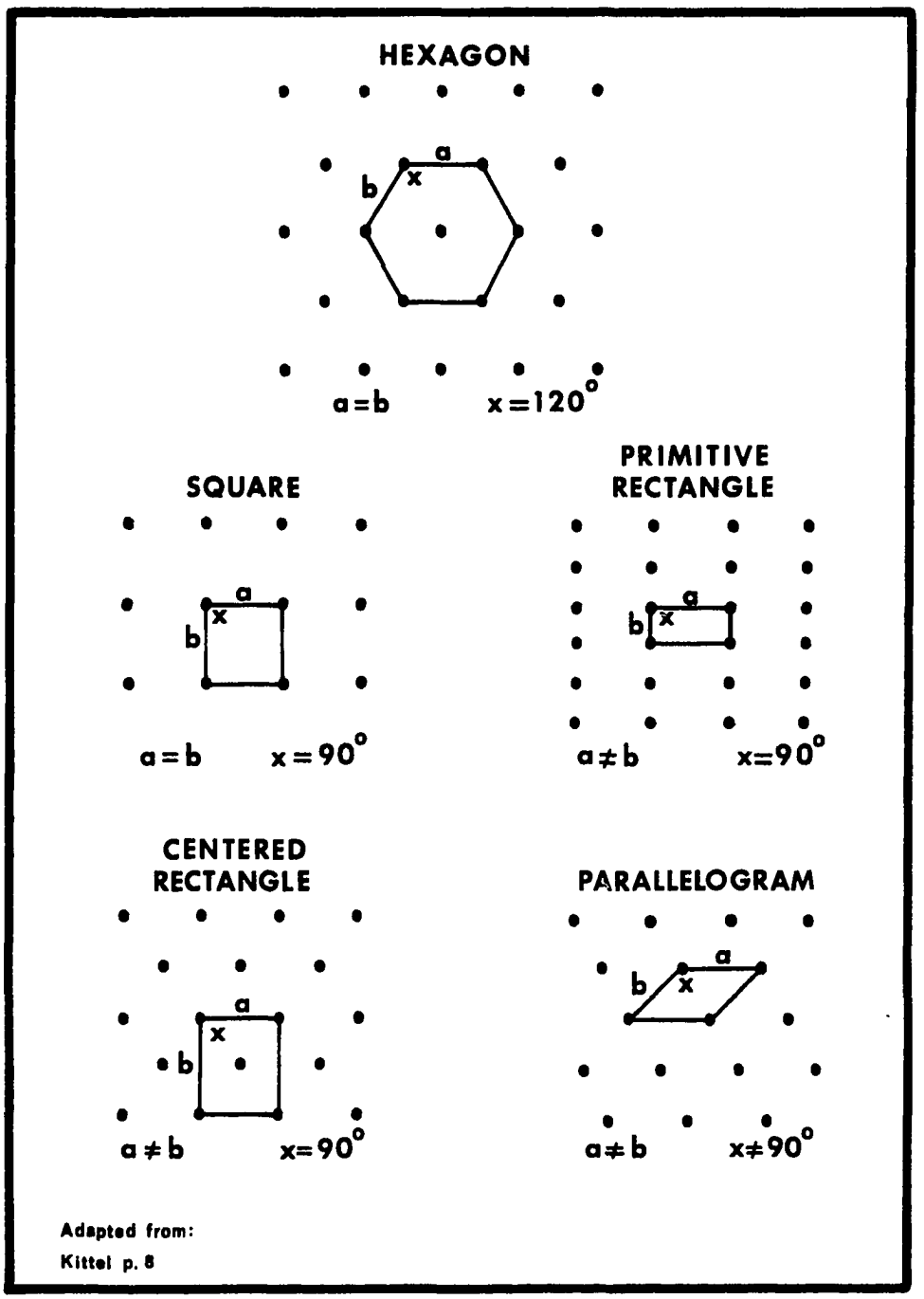

Fig. 5.--Two dimensional Bravais lattices

demand is greatest when a small circular area is considered, but notes that the circle leaves empty space. Therefore, it does not meet the criteria of a plain with all areas in regions that do not overlap. He further notes

> that demand per unit area in the case of the hexagon exceeds that not only of a square and triangle, but even that of a circle. In other words, among all the possibilities of realizing the same total demand, the most land is required with a triangle and the least with a regular hexagon. The honeycomb is, therefore, the most advantageous shape for economic regions.[15]

Losch expanded the size of the smallest hexagons in the regional structure from the three, four, and seven proposed by Christaller. Losch proposed that the ten smallest areas would have the following nearest neighbors (settlements): 3, 4, 7, 9, 12, 13, 16, 19, 21, 25.[16] Losch did not assume that area in the ten smallest hexagons formed bases from which the hierarchy would grow. In the Christaller method the smallest sizes included either three, four, or seven nearest neighbors. While at the same time the three smallest areas formed bases at which the area hierarchy grew.[17] Losch states that one of the most important results of his array is that ". . . with discontinuous settlement, the possible size of the market area and number of settlements they contain also grow discontinuously."[18]

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[15]August Losch, The Economies of Location, trans. by William H. Woglom and Wolfgang F. Stolper (2d ed.; New Haven: Yale University Press, 1954), p. 112.

[16]Ibid., p. 119.

[17]Christaller, Central Places in Southern Germany, pp. 63-80.

[18]Losch, The Economies of Location, p. 120.

Actually the array proposed by Losch is similar to the array proposed by Christaller. Dacey shows that the entire set as derived by Losch is a function of the law of cosines:

$$Q = \left\{U^2 + UV + V^2\right\}$$

Q = set of market sizes where
U and V are nonnegative integers
such that $U \leq V$ and $V = 1, 2, \ldots$[19]

Hudson shows that the Losch array is almost the same as that generated by Christaller using the bases three, four, and seven. Hudson demonstrates that $C = \left\{U_1{}^3, 3^n, 4^n, 7^n\right\}$ is a proper subset of $Q = \left\{U^2 + UV + V^2\right\}$ and notes that the whole Losch array is divisible by factoring to combinations of the powers three, four, and seven with the exception of the subset $A = (6I + 1)$.[20]

Bases other than those of three, four, and seven are eliminated from the Woldenberg Model. Woldenberg's justification for not using combinations of the powers three, four, seven, and 6I + 1 (where I is a positive integer different from 1) is that the model is concerned with the number of lower order basins to be included in higher order basins. When the area ratio of outer to inner hexagons equals three, four, or seven, the central hexagon is completely surrounded by portions of other hexagons (Figure 6). If the area were twelve,

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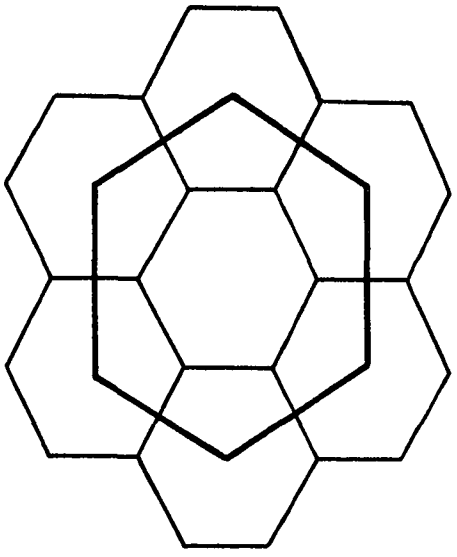
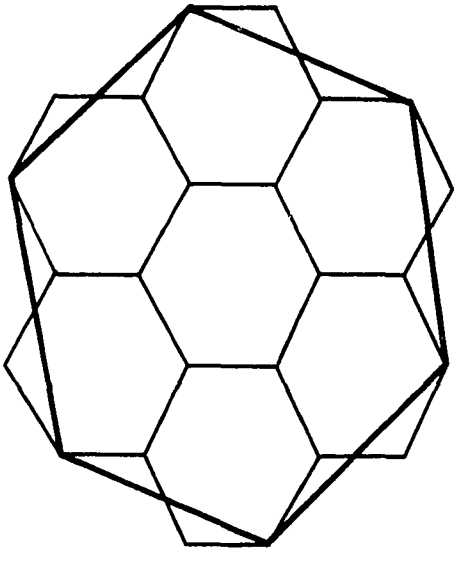
[19]Michael F. Dacey, "An Interesting Number Property in Central Place Theory," The Professional Geographer, XVII (September, 1965), 32-33.

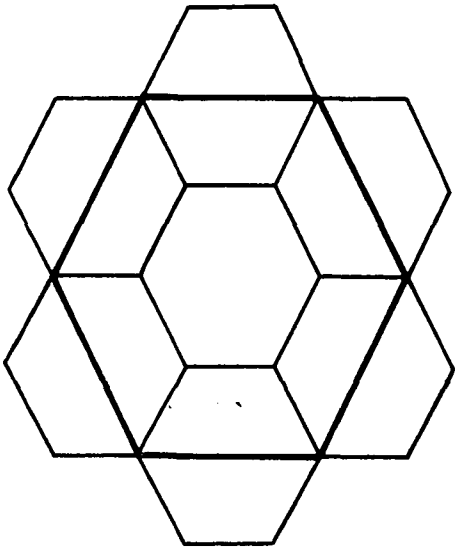
[20]John C. Hudson, "An Algebraic Relation Between the Losch and Christaller Central Place Networks," The Professional Geographer, XIX (May, 1967), 133-35.



Base 3



Base 7



Base 4

Adapted from:

Woldenberg, 1968

Fig. 6.--Hexagonal hierarchies at bases 3, 4, and 7

thirteen, or nineteen the "path of many streams to a single hexagonal basin would be impeded by a basin ridge."[21]

Construction of Model

The first phase in the construction of the model is the development of a mixed hexagonal progression (Table 1). The mixed hexagonal progression consists of numbers chosen in ascending order from three geometric progressions at the bases three, four, and seven (Table 2). Numbers in ascending order are chosen from the mixed hexagonal progression until sufficient numbers have been chosen such that their convergent mean approximates the number of basins per order for the fluvial system under investigation (Table 3).

Woldenberg considers the convergent mean to be a least work equilibrium derived from the arithmetic and geometric means of numbers chosen from the mixed hexagonal progression. He infers that the convergent mean thus represents an equilibrium state.[22] He states that "for a river, the equilibrium is between least work in overland movement of material to the channel, and economies of scale."[23] Justification for the convergent mean as an equilibrium state is predicated on the assumption that the group (numbers from mixed hexagonal progression) arithmetic mean is a large number and its reciprocal is small. The group geometric mean is a small number and its reciprocal

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[21]Woldenberg, "Spatial Order in Fluvial Systems," 1968, p. 9.

[22]Ibid., pp. 4-15.

[23]Ibid., p. 14.

TABLE 1

MIXED HEXAGONAL PROGRESSION

1	64
1	81
1	243
3	256
4	343
7	729
9	1,024
16	2,401
27	4,096
49	16,807

TABLE 2

GEOMETRIC PROGRESSIONS AT BASES 3, 4, 7

Bases		
3	4	7
1	1	1
3	4	7
9	16	49
27	64	343
81	256	2,401
243	1,024	16,807
729	4,096	117,649

TABLE 3

CONVERGENT MEAN MODEL COMPUTED FOR KICASTER CREEK

Order	Number of Streams	Mixed Hexagonal Groups	Means		
			Arith-metic	Geo-metric	Con-vergent
5	1	1, 1, 1	1	1	1
4	3	3, 4	3.5	3.46	3.48
3	7	7, 9	8	7.93	7.96
2	37	16, 27, 49, 64	39	34.11	36.55
1	144	81, 243	162	140.29	151.14

is large. In both cases the reciprocal of the mean refers to area while the number refers to the number of basin areas. Based on this conclusion, areas associated with the arithmetic mean are small and therefore

> overland work (i.e., frictional loss) in movement to the channel is minimized. . . . Areas associated with the geometric mean are large, and flows within the channel are large. This will lead directly to gains in channel efficiency, as the wetted perimeter of the channel increases much less rapidly than volume carried by the channel. Thus frictional losses will be less as the capacity of the channel increases.

Therefore, because it represents an equilibrium state, the convergent mean is the number that is compared to the observed data.[24]

Theoretical Justification of Model

Justification for applying a central place model to fluvial systems is predicated on the positive analogy of these two systems. They are considered analogous in the following ways: (1) they are open systems; (2) they tend toward an equilibrium state of maximum entropy; (3) equilibrium is accomplished by a compromise between least work for the system and equal energy distribution throughout the system; (4) and power relationships exist between component parts of the system which have been referred to as allometric growth.[25]

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[24] Ibid., pp. 14-15.

[25] Michael J. Woldenberg and Brian J. L. Berry, "Rivers and Central Places: Analogous Systems?" Journal of Regional Science, VII (Winter, 1967), 129-37. (Hereinafter referred to as "Rivers and Central Places.")

Equilibrium in Open Systems

Von Bertalanffy defines an open system as a system that maintains itself in the exchange of materials with its environment. Contemporaneous with the exchange of materials with the environment the system may attain a time independent state during which the system remains constant.[26] That is, the system maintains integrity of form and organization simultaneous with the flow of material (mass and energy) from the environment.[27, 28] Therefore, in performing the work imposed upon it by the environment the system seeks a steady state equilibrium. Once a steady state equilibrium is attained or approached the system tends to maintain the equilibrium through self-regulation by operation of negative feedback mechanisms in a manner similar to the principle of Le Chatelier.[29]

Open System Equilibrium--Landforms

The concept of equilibrium is of long standing in landform studies. It is apparent that Playfair was referring to equilibrium when he discussed the "nice adjustment" of rivers to their declivities. In referring to rivers Playfair said:

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[26]Ludwig von Bertalanffy, "The Theory of Open Systems in Physics and Biology," Science, CXI (January, 1950), 23-24. (Hereinafter referred to as "Theory of Open Systems.")

[27]Robert Rosen, Optimality Principles in Biology (New York: Plenum Press, 1967), pp. 106-7.

[28]Jiri Klir and Miroslav Valach, Cybernetic Modelling, trans. by W. A. Ainsworth (London: Iliffe Books Ltd., 1967), p. 221.

[29]von Bertalanffy, "Theory of Open Systems," pp. 23-24.

> Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportional to its size, and all of them together forming a system of valleys, communicating with one another, and having such a nice adjustment of their declivities, that none of them join the principal valley, either on too high or too low a level, a circumstance which would be infinitely improbable if each of these valleys were not the work of the stream which flows in it.[30]

Although referring to different types of equilibrium, Gilbert[31] and Davis[32] were exponents of equilibrium. The term grade, originally proposed by Gilbert, was equated with equilibrium by both Gilbert and Davis. Since the term was introduced by Gilbert and popularized by Davis, definition and recognition have been the subject of controversy and confusion.[33] The concept was reviewed by Kesseli in 1941 who concluded that difficulties of definition were so great that the term should be abandoned.[34] Dury in his review of the subject reached a similar conclusion in 1966.[35] However, Mackin in his study supports

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[30]John Playfair, Illustrations of the Huttonian Theory of the Earth (a facsimile reprint of 1802 edition; New York: Dover Publications, 1964), p. 102.

[31]U.S., Department of Interior, Geological Survey, Geology of the Henry Mountains (Utah), by Grove Karl Gilbert, United States Geographical and Geological Survey of the Rocky Mountain Region (Washington, D.C.: Government Printing Office, 1877), p. 112.

[32]William Morris Davis, "Base-Level, Grade, and Peneplain," Journal of Geology, X (January-February, 1902), 86-91.

[33]Ronald C. Flemal, "The Attack on the Davisian System of Geomorphology: A Synopsis," Journal of Geological Education, XIX (January, 1971), 3-5.

[34]John E. Kesseli, "The Concept of the Graded River," Journal of Geology, XLIX (August-September, 1941), 561-88.

[35]George H. Dury, Essays in Geomorphology (New York: Elsevier, 1966), p. 231.

the use of the term and defines a graded stream as one in equilibrium.[36]

Recently grade or equilibrium has been reviewed in terms of the steady state in open systems. Strahler in 1950 suggested that landforms could be viewed as open systems which tend toward the development of steady state.[37] The concept as applied to landforms has been attributed to G. K. Gilbert whose ideas probably provided the philosophical background for the development of the concept as used by contemporary geomorphologists.[38]

In applying the open system concept to drainage systems, Strahler states that a graded drainage system develops topographic forms which "achieve a time-independent condition"[39] and that the forms developed "may be described as equilibrium forms."[40] In landform systems, viewed as open systems, the erosional and transportational processes produce a steady flow of water and waste through the system. Potential energy of position in the system is transformed

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[36]J. Hoover Mackin, "Concept of the Graded River," Bulletin of the Geological Society of America, LIX (May, 1948), 471.

[37]Arthur N. Strahler, "Equilibrium Theory Approached by Frequency Distribution Analysis," American Journal of Science, CCXLVIII (October, 1950), 676. (Hereinafter referred to as "Equilibrium Theory.")

[38]Richard J. Chorley, "A Re-evaluation of the Geomorphic Systems of W. M. Davis," in Frontiers in Geographical Teaching, ed. by Richard J. Chorley and Peter Haggett (London: Methuen, 1965), p. 24.

[39]Strahler, "Equilibrium Theory," p. 676.

[40]Ibid.

into kinetic energy of water and debris movement or heat. Continual readjustment of components in the system during the steady state occur as relief is lowered and available energy diminishes.[41] In a somewhat similar fashion Wolman in 1955 applied the steady state concept in his study of Brandywine Creek.[42]

Hack in 1960, based on his work in the central Appalachians, gives a philosophical statement of the concept of landforms as parts of an open system seeking a dynamic equilibrium. Concerning the view of dynamic equilibrium in an open system he states that "the landscape and the processes molding it are considered a part of an open system in a steady state of balance in which every slope and every form is adjusted to every other."[43] Hack notes that the concept of dynamic equilibrium was applied to the study of landforms by G. K. Gilbert and William Morris Davis. However, he concludes that Gilbert's equilibrium involved a "dynamic equilibrium of forces existing at the present time in actual drainage basins and the relation of these forces to the rocks."[44] Whereas in the Davis model equilibrium applied at first to parts of the drainage system and in time was

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[41] Ibid.

[42] U.S., Department of Interior, Geological Survey, The Natural Channel of Brandywine Creek, Pennsylvania, by M. Gordon Wolman, United States Geological Survey Professional Paper 271 (Washington, D.C.: Government Printing Office, 1955), pp. 1-56.

[43] John T. Hack, "Interpretation of Erosional Topography in Humid Temperate Regions," American Journal of Science, CCLVII-A (Bradley Volume, 1960), 81.

[44] Ibid., p. 83.

sequentially extended to other parts of the system.[45] Hack concludes that Gilbert's approach is valid and cites it as one of the bases of his statement. Hack further developed his ideas in field studies in the Shenandoah Valley and applied his concepts to the genesis of residual ore deposits.[46] Flint, in his study of drainage patterns in Connecticut, concludes that landforms in the study area seem compatible with the concepts set forth by Hack.[47]

Chorley in 1962 reviewed open and closed systems and concluded that geomorphic systems are open systems and that the Davis model was essentially that of a closed system while Gilbert's was an open system.[48, 49] He also points out that in the open system there is a tendency toward a dynamic equilibrium of forms that is a mean condition about which variations occur in time. He emphasizes, as had von Bertalanffy in 1950, that an important characteristic of the open

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[45] Ibid., p. 86.

[46] U.S., Department of Interior, Geological Survey, Geomorphology of the Shenandoah Valley Virginia and West Virginia and Origin of Residual Ore Deposits, by John T. Hack, United States Geological Survey Professional Paper 484 (Washington, D.C.: Government Printing Office, 1965), pp. 1-84.

[47] Richard F. Flint, "Altitude, Lithology, and the Fall Zone in Connecticut," Journal of Geology, LXXI (November, 1963), 690.

[48] U.S., Department of Interior, Geological Survey, Geomorphology and General Systems Theory, by Richard J. Chorley, United States Geological Survey Professional Paper 500 B (Washington, D.C.: Government Printing Office, 1962), p. B3.

[49] For a dissenting view see Michael Chisholm, "General Systems Theory and Geography," Institute of British Geographers Transactions, XLII (December, 1967), 45-51.

system is that it may "behave equifinally--in other words, different initial conditions can lead to similar ends";[50] a characteristic of open systems that is not permitted in the closed systems model of Davis. Chorley emphasizes that form adjustment in systems is brought about by self-regulation and postulates that La Chatelier's Principle, originally stated for closed systems, can be expanded to include the concept of the steady state in an open system.[51]

Energy distribution in terms of dynamic equilibrium has been investigated by Leopold and Langbein. They equate the term steady state with dynamic equilibrium as proposed by Hack.[52] They base their investigation of energy on the second law of thermodynamics which states that: (1) heat is disordered energy; (2) energy becomes heat as soon as it is disordered; and (3) in nature there is a "tendency for processes to tend toward a state of greater disorder."[53] Based on the second law of thermodynamics, they infer that in a system in dynamic equilibrium the rate of increase of entropy is zero.[54] They

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[50]Chorley, Geomorphology and General Systems Theory, p. B8.

[51]Ibid., p. 4.

[52]U.S., Department of Interior, Geological Survey, The Concept of Entropy in Landscape Evolution, by Luna B. Leopold and Walter B. Langbein, United States Geological Survey Professional Paper 500 A (Washington, D.C.: Government Printing Office, 1962), p. A4. (Hereinafter referred to as Concept of Entropy.)

[53]David Halliday and Robert Resnick, Physics for Students of Science and Engineering (New York: John Wiley and Sons, Inc., 1965), p. 551. (Hereinafter referred to as Science and Engineering.)

[54]Leopold and Langbein, Concept of Entropy, p. A4.

state that entropy treats the distribution of energy in the landscape and that the most probable condition exists "when energy in a river system is as uniformly distributed as may be permitted by the physical constraints."[55] Based on a comparison of their probability model with actual field data, they conclude "that the most probable river profile approaches the condition in which the downstream rate of production of entropy per mass is constant."[56] They further infer that the condition of maximum entropy in fluvial systems corresponds to a condition of least work. From their probability analysis they conclude "that relatively short intervals of time are needed to reach a state approaching the maximum probable, although the rate of adjustment to the theoretical most probable state thereafter may be quite slow if ever achieved."[57]

Commenting further (1964) on energy distribution within geomorphic systems Langbein and Leopold postulate that the most probable condition is an intermediate state between two opposing tendencies: (1) a "uniformly distributed rate of energy expenditure" and (2) "minimum total work expended in the system."[58] As these are opposing tendencies the system seeks a balance between the two tendencies which

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[55] Ibid., p. A1.

[56] Ibid.

[57] Ibid., p. A4.

[58] Walter B. Langbein and Luna B. Leopold, "Quasi-Equilibrium States in Channel Morphology," American Journal of Science, CCLXII (June, 1964), 784.

leads to a quasi-equilibrium.[59] The concept of least work had previously received consideration by Leopold and Langbein in their study of meanders in which they quote W. W. Ruby who, referring to river adjustments, states that the river adjusts its channel in such a way as to accomplish the work imposed on it with least expenditure of energy.[60]

Thus the writers cited view fluvial systems as open energy systems which tend toward a dynamic equilibrium within the constraints of uniform energy distribution and least work.

Urban Systems

Woldenberg and Berry maintain that cities are (1) open systems within the framework of central place theory; (2) tend toward an equilibrium state of least work and equal energy distribution; and (3) are subject to the law of allometric growth.[61]

Cities as systems have been reviewed by Berry who concludes that urban models are similar to models in other kinds of systems inquiry and that urban theory is amenable to general systems inquiry.[62] He points out that one model that treats cities in terms of systems is

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[59] Ibid., p. 793.

[60] Luna B. Leopold and M. Gordon Wolman, "River Meanders," Geological Society of America Bulletin, LXXI (June, 1960), 786.

[61] Woldenberg and Berry, "Rivers and Central Places," p. 133.

[62] Brian J. L. Berry, "Cities as Systems within Systems of Cities," The Regional Science Association Papers, XIII (1964), 148. (Hereinafter referred to as "Cities as Systems.")

Christaller's central place model which "applies to systems of central places in which the elements are viewed aggregatively."[63] Berry summarizes advantages of viewing cities as systems as follows: (1) general systems theory provides a framework for studying the nature of city systems; (2) information theory provides a framework within which to view the geometry of urban systems; and (3) systems may be viewed in terms of entropy.[64]

Identification of Central Place Hierarchy

One of the criteria for verifying that central place hierarchies exist is variation in the number of central place functions performed by cities at discrete population levels. Justification for use of this method of identifying central places is based on the inferred relationship of Zipf's rank size rule and the central place models of Christaller and Losch. Beckmann writes that the ". . . rank size rule as observed by Zipf is compatible with the ideas on hierarchies of market areas and their central cities as developed by Losch and other location theorists."[65, 66]

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[63] Ibid., p. 152.

[64] Ibid., p. 158.

[65] Martin J. Beckmann, "City Hierarchies and the Distribution of City Size," Economic Development and Cultural Change, VI (April, 1958), 246. (Hereinafter referred to as "City Hierarchies.")

[66] For a dissenting view see Michael F. Dacey, "Population of Places in a Central Place Hierarchy," Journal of Regional Science, VI (Winter, 1966), 27-33.

Berry and Garrison in their study of Snohomish County, Washington found that the central place hierarchy as proposed by Christaller is applicable to Snohomish County when cities are classified on the basis of functions. They conclude (1) that cities can be arranged into categories on the basis of the number of functions and population and (2) that as population increases the central place functions performed by each central place increases.[67] Berry and Barnum in 1962 reached a similar conclusion as a result of their principal component analysis of central places. They extrapolate that a continuum of central places and a classic central place hierarchy are found in any region if "a small homogeneous subregion is studied."[68] They also state that multiplication of functions within central places is a function of population increases.[69]

Berry, Barnum, and Tennant infer that in areas studied in Iowa that requirements of Christaller's theory of thresholds and ranges were verified. They state: "The spatial pattern of centers conform to a particular set of location principles (the principle of transportation); the nesting of trade areas does not. . . ."[70] They conclude

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[67]Brian J. L. Berry and William L. Garrison, "The Functional Bases of the Central Place Hierarchy," Economic Geography, XXXIV (April, 1958), 145-54. (Hereinafter referred to as "Functional Bases.")

[68]Brian J. L. Berry and H. Gardiner Barnum, "Aggregate Relations and Elemental Components of Central Place Systems," Journal of Regional Science, IV (Summer, 1962), 33.

[69]Ibid., p. 38.

[70]Brian J. L. Berry, H. Gardiner Barnum, and Robert J. Tennant, "Retail Location and Consumer Behavior," The Regional Science Association Papers, IX (1962), 102.

that empirical evidence in their study demonstrates that hierarchies are clearly identified.[71]

Urban Systems Equilibrium

Equilibrium in urban systems is viewed as open system equilibrium within the context of central place theory.[72] Berry and Garrison equate the rank-size rule of Zipf to Christaller's hierarchical classification and state that the rank-size distribution of Zipf is an equilibrium state in accordance with the second law of thermodynamics in which maximum entropy is achieved in a state of randomly distributed energy.[73]

Zipf's rank-size rule is an outgrowth of his principle of least effort. He postulated that each individual's movement is governed by his perception of behavior that will minimize future problems. In the principle he views least effort as a variant of least work.[74] In relating his theory to communities he states that a community "will be located in the least-work center of terrain, in the sense that its location will be a point whose sum of all least-work distances to every person on the terrain will be minimum."[75] He hypothesizes that

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[71] Ibid.

[72] Woldenberg and Berry, "Rivers and Central Places," p. 133.

[73] Berry and Garrison, "Functional Bases," p. 90.

[74] George Kingsley Zipf, Human Behavior and the Principle of Least Effort: An Introduction to Human Ecology (Cambridge: Addison-Wesley Press, Inc., 1949), p. 1.

[75] Ibid., p. 355.

the "number of communities of approximately equal size will be approximately equally spaced. . . ."[76] "The larger the community, the greater will be the number of communities it attracts."[77] That is, there are hierarchies of communities based on population. In substantiation of his theory he studied cities and observed that when cities are ranked according to population the relationship between the number of cities and population shows a rank-size relationship that approximates $y = ax^b$.[78]

According to Berry the rank-size rule applies all over the world for developed countries with a high degree of urbanization. He comments that if a system of cities assumes rank-size a most probable state of maximum entropy has been achieved.[79] He equates the lognormal relationship between city size and rank with a steady state. Therefore, rank-size is equated with an equilibrium state of maximum entropy in an open system.

According to Berry and Woldenberg a central place hierarchy represents a graded urban system which is a state of maximum probability analogous to equilibrium in fluvial systems. They maintain that in urban systems equilibrium is achieved by "a balance between total least work and equal distribution of energy expenditure throughout the

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[76]Ibid., p. 369.

[77]Ibid., p. 374.

[78]Ibid., p. 103.

[79]Berry, "Cities as Systems," p. 159.

system."[80] This is analogous to the state of maximum entropy defined for fluvial systems by Leopold and Langbein.[81]

Thus the writers cited view cities as component parts of open systems. Within this framework, cities are thought to seek a steady state or dynamic equilibrium by reacting to the socioeconomic environment in such a manner as to seek an equilibrium between total least work and equal energy distribution.

Allometric Growth

Fluvial and urban systems are each postulated to have geometries that reflect allometric growth.[82] Allometry is a term used by biologists to denote "the study of proportion changes correlated with variations in size of either the total organism or the part under consideration."[83] The term has been applied to fluvial systems by Nordbeck, Woldenberg and Berry, and Strahler and to urban systems by Woldenberg and Berry.[84]

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[80]Woldenberg and Berry, "Rivers and Central Places," p. 130.

[81]Ibid.

[82]Ibid., pp. 132-33.

[83]Jay Stephen Gould, "Allometry and Size in Ontogeny and Phylogeny," Biological Reviews, XLI (November, 1966), 629. (Hereinafter referred to as "Allometry and Size.")

[84]Woldenberg and Berry, "Rivers and Central Places," p. 133.

Fluvial Systems

Nordbeck equates the law of allometric growth to power function and cites the double logarithmic relationship of river basin geometry as reflecting allometric growth. He considers therefore that river networks represent a type of hierarchical allometric growth.[85, 86]

Woldenberg concurs with Nordbeck's observation and extends the "law of allometric growth" to graphs of stream order versus the logarithm of basin geometry and flow,[87] i.e., semi-logarithmic relationships. He proposes the hypothesis that "the power function relationships in rivers which have been called allometric growth, derive from approximate geometric progressions in the size of hexagonal basins."[88] Geometric progression of variables within the system is inferred to be a result of operation of the principle of equal partition of energy which states: ". . . available energy . . . distributes itself in equal shares to each of the independent ways in which the molecules can absorb energy."[89]

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[85]Stig Nordbeck, "The Law of Allometric Growth," Michigan Inter-University Community of Mathematical Geographers Discussion Paper, No. 7, June, 1965, pp. 2-12.

[86]Gould objects to equating allometry to power function since the term connotes size correlated shape to biologists. Gould, "Allometry and Size," pp. 638-39.

[87]Michael J. Woldenberg, "Horton's Laws Justified in Terms of Allometric Growth and Steady State in Open Systems," Geological Society of America Bulletin, LXXVII (April, 1966), 433. (Hereinafter referred to as "Allometric Growth.")

[88]Woldenberg, "Spatial Order in Fluvial Systems," 1968, p. 35.

[89]Halliday and Resnick, Science and Engineering, p. 507.

Woldenberg justifies the hypothesis that the law of allometry, defined as $y = ax^b$, is applicable to variables (stream length, area, and gradient) that are semi-logarithmetically related to stream order by stating that the relationship is actually double logarithmic. He infers that stream order plotted on the abscissa is dimensionless and may be contracted or expanded to give any slope value to the regression line.

> Thus two variables, the logs of which are related linerally to stream order are in fact related to each other allometrically. If b is kept constant, the log scales may differ; conversely, if the log scales are kept the same, the b will differ. This observation implies that stream order is itself a logarithm.[90]

Each successive stream order is inferred to be a new logarithmic cycle to the base of the system bifurcation ratio.[91]

Strahler infers that fluvial system development is in many respects analogous to development of biological systems.[92] He concludes that available data tend to confirm that the growth process is allometric growth.[93] He cites evidence for allometric growth as the straight line relationship of fluvial system variables (such as cumulative stream length and basin area) when plotted on log-log graphs.[94]

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[90]Woldenberg, "Allometric Growth," p. 433.

[91]Ibid., p. 431.

[92]For a discussion of allometric growth in fluvial and biological systems see Arthur N. Strahler, Physical Geography (3d ed.; New York: John Wiley and Sons, Inc., 1969), p. 488.

[93]Ibid., p. 489.

[94]Ibid., p. 490.

Urban Systems

The principle of allometric growth has been applied to urban systems by Beckmann,[95] Nordbeck,[96] Woldenberg,[97] and Woldenberg and Berry.[98] They equate the rank-size rule of Zipf to the allometric growth principle. They cite work by Berry and Garrison in which the rank-size rule is shown as a maximally probable distribution "resulting from either a log-normal or Yule growth process."[99] They therefore conclude that rank-size "represents achievement of system equilibrium under conditions of allometric growth in an open urban system."[100] They further cite as evidence supporting allometric growth that many of the "characteristics of central-place systems can be related by log-log regression, and thus also reflect an allometric system equilibrium."[101]

Thus based on the double logarithmic relationship of variables in fluvial and urban systems Woldenberg and Berry conclude that both systems are subject to allometric growth, and Woldenberg postulates

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[95]Beckmann, "City Hierarchies," pp. 246-48.

[96]Nordbeck, "The Law of Allometric Growth," p. 24.

[97]Michael J. Woldenberg, "Hierarchical Systems: Cities, Rivers, Alpine Glaciers, Bovine Livers and Trees" (unpublished Ph.D. dissertation, Columbia University, 1968), pp. 121-28.

[98]Woldenberg and Berry, "Rivers and Central Places," pp. 131-33.

[99]Ibid., p. 133.

[100]Ibid.

[101]Ibid.

that the power relationships in central place systems is a result of the law of allometry. He further proposes that his model, based on Christaller's central place theory, is applicable to both systems.[102]

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[102]Woldenberg, "Spatial Order in Fluvial Systems," 1968, p. 35.

CHAPTER III

RESEARCH THEORY

Research Hypothesis

In the study areas, the predictive accuracy of the convergent mean model is not significantly influenced by the lithostratigraphic units on which the streams are developed.

Null Hypothesis

In the study areas there is a significant difference in the accuracy with which the convergent mean model predicts the number of channels per order for fluvial systems developed on two lithostratigraphic units as compared to those developed on one lithostratigraphic unit.

Justification for Research Hypothesis

Drainage basins are complex morphological systems which tend toward the development of a steady state. Development of a steady state involves processes through which morphometric variables adjust to transmit mass and energy imposed on the system by the natural environment.[1] When the system has adjusted to a steady state, the

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[1]Arthur N. Strahler, "Equilibrium Theory Approached by Frequency Distribution Analysis," American Journal of Science, CCXLVIII (October, 1950), 673.) (Hereinafter referred to as "Equilibrium Theory."

inputs of energy and mass are balanced in such a way that the integrity of the level of integration is maintained.[2] During the steady state, form elements achieve a time independent state, which can be stated as follows:

$$\phi[(HD)/\theta, QK_e] = 0$$

where: $(HD)/\theta$ = geometry number
H = maximum basin relief
D = drainage density
θ = ground surface or channel gradient

QK_e = Horton number
Q = runoff intensity
K_e = an erosion proportionality factor (mass rate of debris removal per unit area/eroding stress per unit area)
ϕ = dimensionless quantities[3, 4]

In other words, the geometry number and the Horton number are balanced for dimensionless quantities.

In describing the steady state, Strahler states that "in mature topography a slope is the morphological manifestation of a steady state in which the forces which remove the material are so adjusted to the resistive properties of the surface as to provide a

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[2]Richard J. Chorley and Barbara A. Kennedy, Physical Geography: A Systems Approach (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1971), p. 356.

[3]Ibid., p. 321.

[4]The concept of dimensional analysis was originally discussed by Strahler; however, the equation and symbology herein used are derived from Chorley. For a discussion of dimensional analysis see Arthur N. Strahler, "Dimensional Analysis Applied to Fluvially Eroded Landforms," Geological Society of America Bulletin, LXIX (March, 1958), 279-99.

steady supply of debris to the streams."[5] He further writes that in the steady state a graded drainage system develops topographic forms which are time-independent and that these forms may be described as equilibrium forms.[6] When the steady state is achieved there is an equilibrium between drainage channels and slopes which contribute debris (mass) to the channel system.[7] "Ground and channel gradients, as well as drainage density achieve a form best adapted to maintaining a steady state in the removal of debris."[8] Strahler does not divorce the time dimension nor cyclical implication from his steady state theory, but states that flow of erosional and transportational processes is averaged over "periods of years or tens of years."[9] Readjustment of the steady state is envisioned during the erosion cycle as available relief lowers.[10]

Hack, as a result of his work in the Appalachians, developed a theory of dynamic equilibrium which embodies the steady state concept of Strahler and the equilibrium concepts of G. K. Gilbert. Hack states that

> in the concept of dynamic equilibrium the landscape and the processes molding it are considered a part of an open system in a

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[5]Strahler, "Equilibrium Theory," p. 677.

[6]Ibid., p. 676.

[7]Ibid., p. 685.

[8]Ibid., p. 688.

[9]Ibid., p. 676.

[10]Ibid.

> steady state of balance in which every slope and every form is adjusted to every other. Changes in topographic form take place as equilibrium conditions change.[11]

He further writes that equilibrium, attained by adjustment of at least seven variables, is a complex process in which many alternatives are possible; therefore, he theorizes that adjustment is arrived at quickly in the development of the valley.[12] The nature of adjustment is one in which there is a balance between opposing forces. He states that

> rather than a concept of balance between the load of a stream and the ability of the stream to move it, it is more useful in the analysis of topographic forms to consider the equilibrium of a particular landscape to involve a balance between the processes of erosion and the resistance of the rocks as they are uplifted or tilted by diastrophism.[13]

In addition, he proposes that, if diastrophic forces operate gradually enough, a balance can be maintained by erosive processes and the topography will remain in equilibrium as it evolves from one form to another. He postulates that in regions such as the Appalachians large areas of the topography are adjusted, and differences in form are primarily the result of differential erosion of diverse rock types.[14]

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[11]John T. Hack, "Interpretation of Erosional Topography in Humid Temperate Regions," American Journal of Science, CCLVIII-A (Bradley Volume, 1960), 81. (Hereinafter referred to as "Interpretation.")

[12]Ibid., p. 84.

[13]Ibid., p. 86.

[14]Ibid., p. 89.

In this research the steady state theory of Strahler and the dynamic equilibrium theory of Hack are in general accepted. However, reservations are held concerning completeness of the equilibrium attained and the time involved in equilibrium.

In view of the oscillating nature of uplift and rates of denudation, it is doubtful if the rate of uplift is at a constant rate long enough to permit the establishment of complete equilibrium over large areas. According to Ahnert, at present rates of denudation in middle latitudes, a constant rate of uplift for twenty million years would be required to establish a steady state.[15] However, it should be noted that Hack did not assume perfect equilibrium. He states: "every area includes features that are in equilibrium and some that are not."[16] In this research landforms are viewed as tending toward a dynamic equilibrium.

Time in this research is viewed in a manner somewhat similar to that of Schumm and Lichty.[17] During periods in which there is a quasi-equilibrium between the processes of erosion and the resistance

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[15]Frank Ahnert, "Functional Relationships Between Denudation, Relief, and Uplift in Large Mid-Latitude Drainage Basins," American Journal of Science, CCLXVIII (March, 1970), 243.

[16]U.S., Department of Interior, Geological Survey, Geomorphology of the Shenandoah Valley Virginia and West Virginia and Origin of Residual Ore Deposits, by John T. Hack, United States Geological Survey Professional Paper 484 (Washington, D.C.: Government Printing Office, 1965), p. 9. (Hereinafter referred to as Geomorphology of the Shenandoah Valley.)

[17]S. A. Schumm and R. W. Lichty, "Time, Space, and Causality in Geomorphology," American Journal of Science, CCLXIII (February, 1965), 110-19.

of the rocks to erosion a timeless steady state exists in which the equation $\phi[(HD)/\theta, QK_e] = 0$ is approximately satisfied. Changes in either climate or uplift or both may occur during which an imbalance in landform systems occurs. The disequilibrium phase is viewed as a relaxation phase during which feedback loops operate which eventually result in a new phase in which equilibrium is approached. Therefore, during the time trajectory in which a landscape is involved, the system constantly tends toward a steady state and probably approaches the steady state soon after disequilibrium phases.

Influence of Lithology

Equilibrium is attained in landform systems when there is "a balance between the processes of erosion and the resistance of the rock as they are uplifted or tilted by diastrophism."[18] Obviously, drainage basins composed of more than one lithostratigraphic unit may approach dynamic equilibrium if the erosive processes within the system have adjusted to the resistivity of each lithostratigraphic unit. This is not to imply that forms are the same, but that basin morphology whatever form taken, is in quasi-equilibrium. Hack, referring to different topographic forms within an area in equilibrium states: "differences from place to place are explainable by differences in the bedrock or in the processes acting on the bedrock."[19] He further states:

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[18]Hack, "Interpretation," p. 86.

[19]Hack, Geomorphology of the Shenandoah Valley, p. 5.

> Study of the topographic form in the Shenandoah Valley reveals a close dependence of the forms, relief, drainage pattern and other aspects of topography on the kind of bedrock. Some dissimilarities or differences in form that do exist within the same rock areas probably indicate that the equilibrium of form is not complete.[20]

In his 1960 paper, Hack describes a system that is in equilibrium even though it is developed on dissimilar rock type. The two rock types involved are quartzite and limestone with a gravel terrace developed at the base of quartzite hills. He points out that the terraces testify to the differences in resistance between the two formations and concludes that the terraces are part of the equilibrium between the two units.[21] Referring to a large region, the Appalachian region, within which diverse lithostratigraphic units are involved Hack states:

> In a landscape like that of the Appalachian region in which large areas are mutually adjusted, the diversity of form is largely the result of the differential erosion of rocks that yield to weathering in different ways. Such topography may be referred to as erosionally graded.[22]

Flint based on his study of landforms in Connecticut concluded that the area he studied was compatible with the theory of dynamic equilibrium as stated by Hack.[23] Meisler, from his study of the Lebanon Valley in Pennsylvania, reached a similar conclusion.[24]

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[20] Ibid., p. 17.

[21] Hack, "Interpretation," p. 94.

[22] Ibid., p. 89.

[23] Richard F. Flint, "Altitude, Lithology, and the Fall Zone in Connecticut," Journal of Geology, LXXI (November, 1963), 690.

[24] Harold Meisler, "Origin of Erosional Surfaces in the Lebanon Valley, Pennsylvania," The Geological Society of America Bulletin, LXXIII (September, 1962), 1071-82.

The influence of bedrock geology on stream equilibrium has been investigated, and it has been found that streams may reach a graded condition even though they traverse areas of diverse lithology. Mackin states

> . . . if the stream be graded across the barrier, differences in bedrock resistance have no direct influence on its slope; theoretically and actually, as indicated earlier, graded streams cross belts of such contrasted rock types as quartzite and shale without change in slope at the contacts.[25]

Wolman, from his study of equilibrium, concludes that Brandywine Creek is in equilibrium even though it crosses heterogeneous rocks.[26] Cherkauer in his study of ephemeral streams in southeastern Arizona concludes that the streams are adjusted to four major variables one of which is lithology.[27]

It is inferred from the works cited that equilibrium (or quasi-equilibrium) of topography as well as streams is possible if a balance has been achieved between the forces of erosion and the resistivity of the rock. Equilibrium can be achieved with diverse expressions of geometric forms. Differences in form elements may reflect differences in lithology but equilibrium among forms may also be present.

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[25]J. Hoover Mackin, "Concept of the Graded River," Bulletin of the Geological Society of America, LIX (May, 1948), 491.

[26]U.S., Department of Interior, Geological Survey, The Natural Channel of Brandywine Creek, Pennsylvania, by M. Gordon Wolman, United States Geological Survey Professional Paper 271 (Washington, D.C.: Government Printing Office, 1955), p. 3.

[27]Douglas S. Cherkauer, "Longitudinal Profiles of Ephemeral Streams in Southeastern Arizona," Geological Society of America Bulletin, LXXXIII (February, 1972), 364.

It is concluded that: (1) if areas of diverse lithologies such as the Appalachians have large areas in dynamic equilibrium, that in the areas isolated for study the drainage basins should have approximated a steady state, and (2) the predictive accuracy of the convergent mean model should not be significantly influenced by lithostratigraphic units in the study areas. If the convergent mean model predicts for those systems which develop within the constraints of equilibrium between economies of overland work and scale,[28] it should accurately predict for those landscapes in dynamic equilibrium regardless of the lithostratigraphic units on which they are developed.

Study Areas

Justification for Choosing Study Areas

Three areas (Areas I, II, and III) were chosen to test the null hypothesis (Figure 7). Areas I and III are located entirely within the West Gulf Coastal Plain. Area II is located primarily in the West Gulf Coastal Plain but extends into the Central Texas section of the Great Plains. These areas were chosen for the following reasons: (1) lithostratigraphic units have sufficient exposures to permit development of fifth order drainage basins on a single lithostratigraphic unit; (2) drainage basins can be isolated for analysis in which geological structures do not disturb the normal stratigraphic

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[28]Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Geological Society of America Bulletin, LXXX (January, 1969), 103.

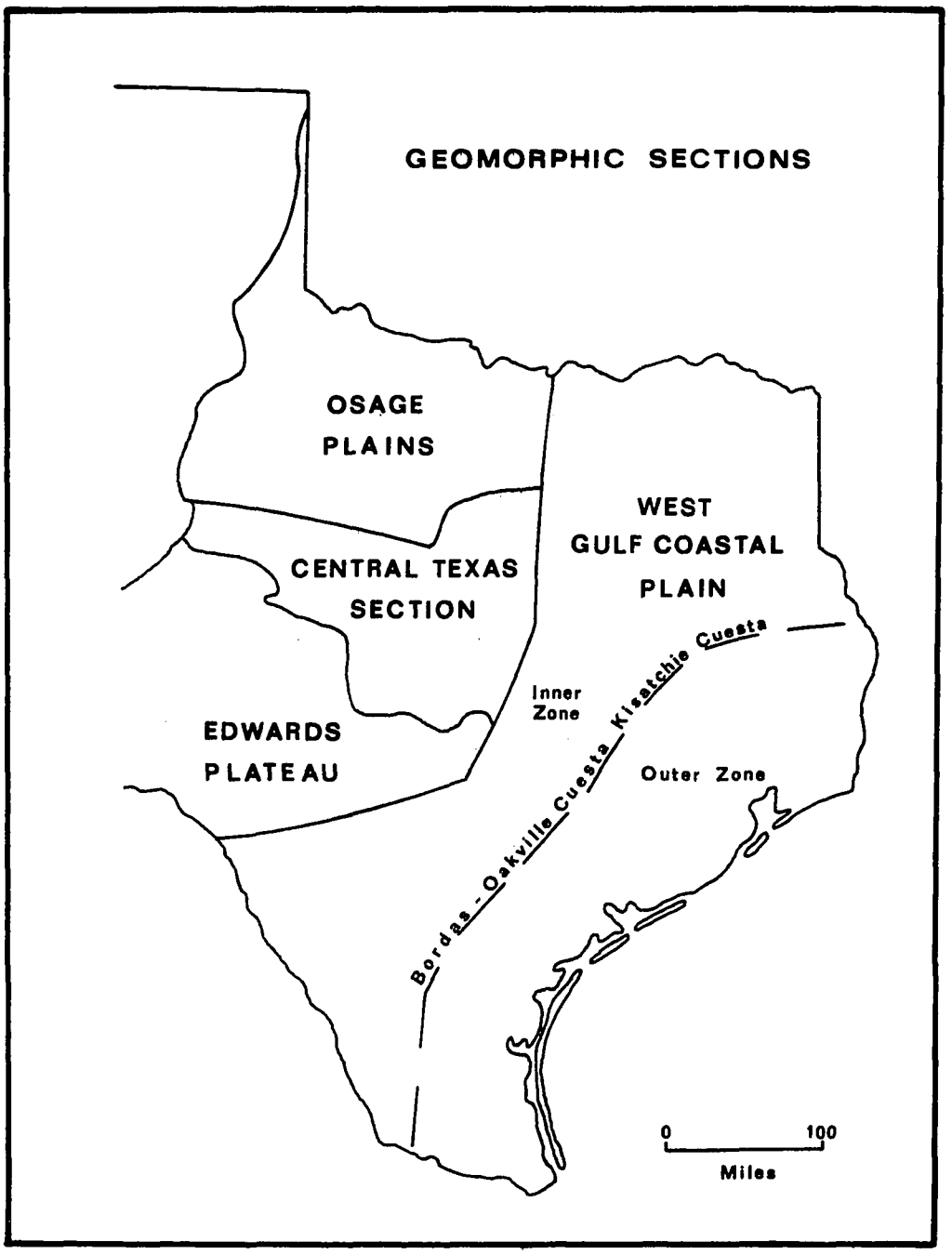

Fig. 7.--Geomorphic sections of Texas related to study

sequence; (3) climate within each area is similar according to the Köppen classification system; and (4) evidence indicates that the topography is in quasi-equilibrium.

Description of Study Areas

Evidence for Quasi-Equilibrium

Quasi-equilibrium in drainage basins is difficult to assess for the following reasons: (1) confusion of definition, (2) measuring difficulties, and (3) availability of data. However, two practical methods are inferred as measures of equilibrium. They are the hypsometric integral and the elongation ratio.

Elongation ratio.--The elongation ratio is defined as the ratio of basin diameter to maximum basin length,[29] and in areas in equilibrium a small range for basin elongation ratios has been found. Schumm found that for basins in the Perth Amboy area elongation ratios decreased to a constant of about 0.5 when 40 percent of basin mass was removed. He states that consistency of basin parameters, one of which is the elongation ratio, is evidence of steady state within the basins analyzed.[30] Consistency of the elongation ratio is also noted by Strahler who writes that the ratio ranges from 0.6 to 1.0 for a wide

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[29]Stanley A. Schumm, "Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey," Geological Society of America Bulletin, LXVII (May, 1956), 612.

[30]Ibid., p. 616.

variety of climatic and geologic types.[31] Based on these observations of consistency for the elongation ratio, it is inferred that if the drainage basins chosen for analysis in this study are in quasi-equilibrium that (1) the elongation ratio for individual basins should have small deviations from the area (Area I, II, and III) mean elongation ratio and (2) elongation ratios between the three study areas should not differ significantly.

The mean and standard deviation of the elongation ratio for each study area were computed (Appendix I). For each study area there was small deviation (Area I, .11; Area II, .10; and Area III, .13) from the mean which suggests that the drainage basins under consideration can be considered in quasi-equilibrium in terms of the elongation ratio. The nonparametric Kruskal-Wallis test was used to test for significance of difference for the elongation ratio for the three areas. The Kruskal-Wallis test was used instead of analysis of variance because results of Hartley's test for homogeneity of variance indicated that homogeneity of variance could not be assumed which is required for use of analysis of variance. The following null hypothesis was tested: There is not a significant difference in the elongation ratio between the three study areas. The null hypothesis could not be rejected at the .05 level of significance (Appendix I). Based on the Kruskal-Wallis test it was therefore concluded that there is

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[31]Arthur N. Strahler, "Quantitative Geomorphology of Drainage Basins and Channel Networks," in Handbook of Applied Hydrology: A Compendium of Water-Resources Technology, ed. by Ven Te Chow (New York: McGraw-Hill Book Company, 1964), pp. 4-51.

not a significant difference in the elongation ratio for the three study areas.

Elevation-relief ratio.--Strahler defines hypsometric integrals ranging from .35 to .60 as representing topography in equilibrium. Within these limits the curve represents topography that has attained a steady state.

> In this state, a system of channel slopes and valley-wall slopes has been developed which is most efficiently adapted to the reduction of the landmass with available erosional forces, balanced against the resistive forces of cohesion maintained by the bedrock, soil, and plant cover.[32]

Chorley concurs with Strahler but indicates that equilibrium ranges between hypsometric integrals of .20 and .80.[33] King assigns similar hypsometric integrals to equilibrium, but states that in maturity the hypsometric integral falls to about .50.[34]

Pike and Wilson demonstrate empirically and mathematically that the elevation-relief ratio and the hypsometric integral are identical.[35] They cite ease of computing the elevation-relief ratio as a

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[32]Arthur N. Strahler, "Hypsometric (Area-Altitude) Analysis of Erosional Topography," Geological Society of America Bulletin, LXIII (November, 1952), 1130. (Hereinafter referred to as "Hypsometric Analysis.")

[33]Chorley and Kennedy, Physical Geography: A Systems Approach, p. 229.

[34]Cuchlaine A. M. King, Techniques in Geomorphology (New York: St. Martin's Press, 1966), p. 247.

[35]Richard J. Pike and Stephen E. Wilson, "Elevation-Relief Ratio, Hypsometric Integral, and Geomorphic Area-Altitude Analysis," Geological Society of America Bulletin, LXXXII (April, 1971), 1080.

major advantage[36] and recommend a random sampling procedure to follow in determining mean basin elevation.[37] Their procedure for computing mean elevation was followed in this study. The elevation-relief ratio was derived from the following formula:[38]

$$E = \frac{\text{mean elevation-minimum elevation}}{\text{maximum elevation-minimum elevation}}$$

Elevation-relief values were computed for each basin (Appendix II). Elevation-relief values ranged from a low value of .3735 for basin three to a high value of .7808 for basin ten. Thus all basins are within the limits of equilibrium as defined by Chorley. Eight basins (basins five, ten, thirteen, twenty-six, thirty-four, forty-one, fifty-one, and fifty-two) exceed the upper limit of Strahler. The mean and standard deviation for each group was computed. Greatest deviation from the mean occurred for Area I (.1079) while the smallest standard deviation occurred for Area III (.0443). Standard deviation for Area II was .0624. The Kruskal-Wallis analysis of variance test was utilized to determine if there was a significant difference in the elevation-relief ratios between the three areas. The following hypothesis was tested: There is not a significant difference in the elevation-relief ratio between Areas I, II, and III. The null hypothesis could not be rejected at the .05 significance level (Appendix II).

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[36] Ibid., p. 1079.

[37] Ibid., p. 1081.

[38] Ibid., p. 1079.

Thus based on the Kruskal-Wallis analysis of variance it was concluded that there was not a significant difference in the elevation-relief ratio for the three study areas.

Based on the elevation-relief ratio it was concluded that the drainage basins in the three study areas are within the limits of equilibrium as outlined by Chorley. All but eight basins are within the equilibrium limits as outlined by Strahler. Analysis of the elevation-relief ratios and elongation ratios tend to confirm the hypothesis that the drainage basins are in a quasi-equilibrium.

Dimensional Parameters

The Kruskal-Wallis test was used to determine if the three study areas were similar in terms of dimensional parameters. In the steady state there is an adjustment between basin geometry and the mass and energy imposed on the system by the environment. Similarity of geometry between areas is not required, only adjustment of geometry within each basin to the mass and energy imposed upon it.[39, 40]

Drainage density, stream frequency, and basin area were computed for each stream (Appendix III). Mean and standard deviation for each of the dimensional parameters were computed for each area (Table 4). Within each area there was considerable deviation from the group mean basin area and stream frequency. Analysis of data indicated that there were large differences between the three areas in terms of three

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[39]Hack, "Interpretation," p. 89.

[40]Strahler, "Hypsometric Analysis," p. 1130.

TABLE 4

MEAN AND STANDARD DEVIATION FOR DRAINAGE DENSITY, STREAM FREQUENCY, AND BASIN AREA

	Area I		Area II		Area III	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Drainage density	4.12	1.04	5.59	1.48	6.20	.64
Stream frequency	18.24	11.69	34.24	16.21	37.27	13.78
Basin area	14.65	7.86	7.81	4.17	9.72	4.60

dimensional parameters. The Kruskal-Wallis analysis of variance was used to test for significance of difference (Appendix III). The following null hypotheses were tested:

1. There is not a significant difference in drainage density between the three study areas.

2. There is not a significant difference in stream frequency between the three study areas.

3. There is not a significant difference in basin area between the three study areas.

Each of the null hypotheses was rejected at the .05 level of significance. It was concluded that the areas differ significantly in terms of drainage density, stream frequency, and basin area.

However, these results do not indicate system disequilibrium because the equation $\phi[(HD)/\theta, QK_e] = 0$ requires that dimensional parameters adjust to the Horton number in order for equilibrium to exist. It is to be expected that as values for the Horton number vary or as the nature of the bedrock, soil, or vegetation vary the geometry number and variables related to it change.

Strahler writes that similarity among equilibrium hypsometric curves shows equilibrium is possible despite "great differences in relief, drainage density, climate, vegetation, soil and lithology. . . ."[41] Based on results of elevation-relief ratio and elongation ratio analysis it is inferred that quasi-equilibrium has been achieved

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[41] Ibid.

in the study areas although significant differences in basin areas, stream frequency, and drainage density occur when the three areas are compared. It is felt that differences in drainage density, stream frequency, and basin areas within the limits of quasi-equilibrium uniquely qualify these areas for assessing the influence of lithostratigraphic units on the predictive accuracy of the model. If the model is an equilibrium model, it must possess sufficient flexibility to predict the number of channels for basins in quasi-equilibrium even though differences exist in terms of drainage density, stream frequency, and basin areas.

Geology

Lithostratigraphic units.--The study areas in the West Gulf Coastal Plain and Central Texas section of the Great Plains, include units that range from the Comanchean Series, Cretaceous System (Paluxy Sand) to the Pliocene Series, Tertiary System (Goliad). Units are composed of clastic and nonclastic sediments that are usually lithologically transitional in nature ranging from relatively pure sands (Carrizo) through marls, calcareous marl, calcareous clay, and chalk (Austin Chalk) (Tables 5, 6, and 7). Units crop out in broad belts with outcrop width determined primarily by regional dip and thickness of the units. Thicknesses range from twenty to 1,500 feet.

Geomorphic Regions

West Gulf Coastal Plain.--The West Gulf Coastal Plain is a gently rolling plain that gradually slopes toward the Gulf of Mexico.

TABLE 5

AREA I--LITHOSTRATIGRAPHIC UNITS INCLUDED IN STUDY

Unit*	Dominant Lithology	Approximate Thickness	Classification			
			Group	Series	System	Era
Goliad Sand	sand, sandstone associated clay	500'	---	Pliocene	Tertiary	Cenozoic
Lagarto Clay	clay, sandy clay	1,500'	---	Miocene	Tertiary	Cenozoic
Oakville Sandstone	sand, sandstone associated clay	950'	---	Miocene	Tertiary	Cenozoic
Catahoula Tuff	tuffaceous clay	190' - 600'	---	Miocene?	Tertiary	Cenozoic
Yegua Formation	gypsiferous clay, sand	720' - 1,130'	Claiborne	Eocene	Tertiary	Cenozoic
Cook Mountain Formation	clay and marly sand	70'	Claiborne	Eocene	Tertiary	Cenozoic
Carrizo Sand	sand	75' - 200'	Wilcox	Eocene	Tertiary	Cenozoic
Sabinetown Formation	sand and clay	60' - 100'	Wilcox	Eocene	Tertiary	Cenozoic

*This is not a complete geologic column.

TABLE 6

AREA II--LITHOSTRATIGRAPHIC UNITS INCLUDED IN STUDY

Unit*	Dominant Lithology	Approximate Thickness	Classification			
			Group	Series	System	Era
Cook Mountain Formation	clay and marly sand	70'	Claiborne	Eocene	Tertiary	Cenozoic
Sparta Sand	sand, associated silt, clay	200'	Claiborne	Eocene	Tertiary	Cenozoic
Carrizo	sand	75' - 200'	Wilcox	Eocene	Tertiary	Cenozoic
Calvert Bluff Formation	mudstone associated sandstone	1,200'	Wilcox	Eocene	Tertiary	Cenozoic
Kemp Clay	clay, calcareous locally silty	80' - 200'	Taylor	Gulfian	Cretaceous	Mesozoic
Marlbrook Marl	marl	150' - 450'	Taylor	Gulfian	Cretaceous	Mesozoic
Pecan Gap Chalk	chalk grading upward to chalky marl	120'	Taylor	Gulfian	Cretaceous	Mesozoic
Wolfe City Formation	marl, sand sandstone	300'	Taylor	Gulfian	Cretaceous	Mesozoic
Ozan Formation	clay, calcareous	425'	Taylor	Gulfian	Cretaceous	Mesozoic

TABLE 6--Continued

Unit*	Dominant Lithology	Approximate Thickness	Classification			
			Group	Series	System	Era
Austin Chalk	chalk and marl	150' - 300'	Austin	Gulfian	Cretaceous	Mesozoic
Lake Waco Formation	limestone, and shale	25' - 60'	Eagle Ford	Gulfian	Cretaceous	Mesozoic
Woodbine Formation	sand, associated silt-clay	175'	Woodbine	Gulfian	Cretaceous	Mesozoic
Grayson Marl	clay associated siltstone	70' - 90'	Washita	Comanchean	Cretaceous	Mesozoic
Walnut Clay	clay, limestone, shale	125' - 175'	Fredericks-burg	Comanchean	Cretaceous	Mesozoic
Paluxy Sand	sand	70'	Fredericks-burg	Comanchean	Cretaceous	Mesozoic

*This is not a complete geologic column.

TABLE 7

AREA III--LITHOSTRATIGRAPHIC UNITS INCLUDED IN STUDY

Unit*	Dominant Lithology	Approximate Thickness	Classification			
			Group	Series	System	Era
Marlbrook Marl	marl	150' - 450'	Taylor	Gulfian	Cretaceous	Mesozoic
Wolfe City Formation	sand, and sandy marl	120'	Taylor	Gulfian	Cretaceous	Mesozoic
Annona Chalk	chalk, associated sand	450'	Taylor	Gulfian	Cretaceous	Mesozoic
Ozan Formation	clay, calcareous	425'	Taylor	Gulfian	Cretaceous	Mesozoic
Austin Chalk	chalk and marl	150' - 300'	Austin	Gulfian	Cretaceous	Mesozoic
Bonham Formation	marl and clay	375' - 530'	Austin	Gulfian	Cretaceous	Mesozoic
Blossom Sand	sand, calcareous	20' - 250'	Austin	Gulfian	Cretaceous	Mesozoic

*This is not a complete geologic column.

The topographic slope is less than the dip of the strata; therefore, successively younger strata crop out toward the Gulf Coast.[42] The plain is divided into two topographic types: (1) inner zone and (2) outer zone (Figure 7). The inner zone lies interior of a zone referred to as the Bordas-Oakville-Kisatchie Cuesta.[43] The inner zone, carved in older strata of higher altitude, is hilly and more broken than the outer zone. The inner zone is characterized by a series of cuestas developed on more resistant strata. The cuesta scarps face inland and undip.[44] The outer zone is a terraced, deltaic plain.[45]

Structure.--The dominant structural feature of the Gulf Coast is the Gulf Coast geosyncline. Bornhauser states:

> . . . all other structural types are subordinate to this feature, and their formation is directly or indirectly the result of the growth of the geosyncline. The structural history of the western Gulf Coast and adjoining parts of the Gulf of Mexico is, therefore, essentially the development of this geosyncline.[46]

The structure is essentially that of a homocline dipping gulfward. Subsidence of the structure occurred contemporaneous with

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[42]J. A. Udden, C. L. Baker, and Emile Rose, "Review of the Geology of Texas," Bulletin of The University of Texas, No. 44 (Austin: The Bureau of Economic Geology, 1916), p. 20.

[43]William D. Thornbury, Regional Geomorphology of the United States (New York: John Wiley and Sons, Inc., 1964), p. 64. (Hereinafter referred to as Regional Geomorphology.)

[44]Ibid., p. 65.

[45]Ibid., p. 64.

[46]Max Bornhauser, "Gulf Coast Tectonics," Bulletin of the American Association of Petroleum Geologists, XLII (February, 1958), 340.

tilting along the coastline and is reflected in the stratigraphy of the basin; that is, formations usually thicken gulfward. Locally, regional structural features alter the stratigraphy of the geosyncline. These features include: (1) Sabine Uplift, (2) East Texas Basin, (3) San Marcos Arch, and (4) Rio Grande Embayment[47] (Figure 8).

Three major zones of faulting occur in the Texas portion of the West Gulf Coastal Plain. From southwest to northeast they are: (1) Balcones, (2) Luling, and (3) Mexia. Of these three zones of faulting only the Balcones (Balcones Escarpment) has apparent expression in the landforms.[48] In addition to the three major faults, there are numerous minor faults.

Central Texas section--Great Plains.--Three parts of the Central Texas section of the Great Plains are included in this study: (1) Lampasas Cut Plain, (2) Western Cross Timbers (Paluxy Cross Timbers), and (3) Bosqueville Prairie (Figure 9).[49] These areas are developed on Comanchean Series Cretaceous System bedrock. They are separated from the Gulf Coastal Plain primarily because the bedrock is of the Comanchean Series in contrast to the Gulfian Series bedrock

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[47]J. A. Waters, P. W. McFarland, and J. W. Lea, "Geologic Framework of Gulf Coastal Plain of Texas," Bulletin of the American Association of Petroleum Geologists, XXXIX (September, 1955), 1823-24. (Hereinafter referred to as "Geologic Framework.")

[48]Thornbury, Regional Geomorphology, p. 64.

[49]U.S., Department of Interior, Geological Survey, Geography and Geology of the Black and Grand Prairies, Texas, by Robert T. Hill, Twenty-first Annual Report of the United States Geological Survey Part VII--Texas (Washington, D.C.: Government Printing Office, 1901), pp. 76-83. (Hereinafter referred to as Black and Grand Prairies.)

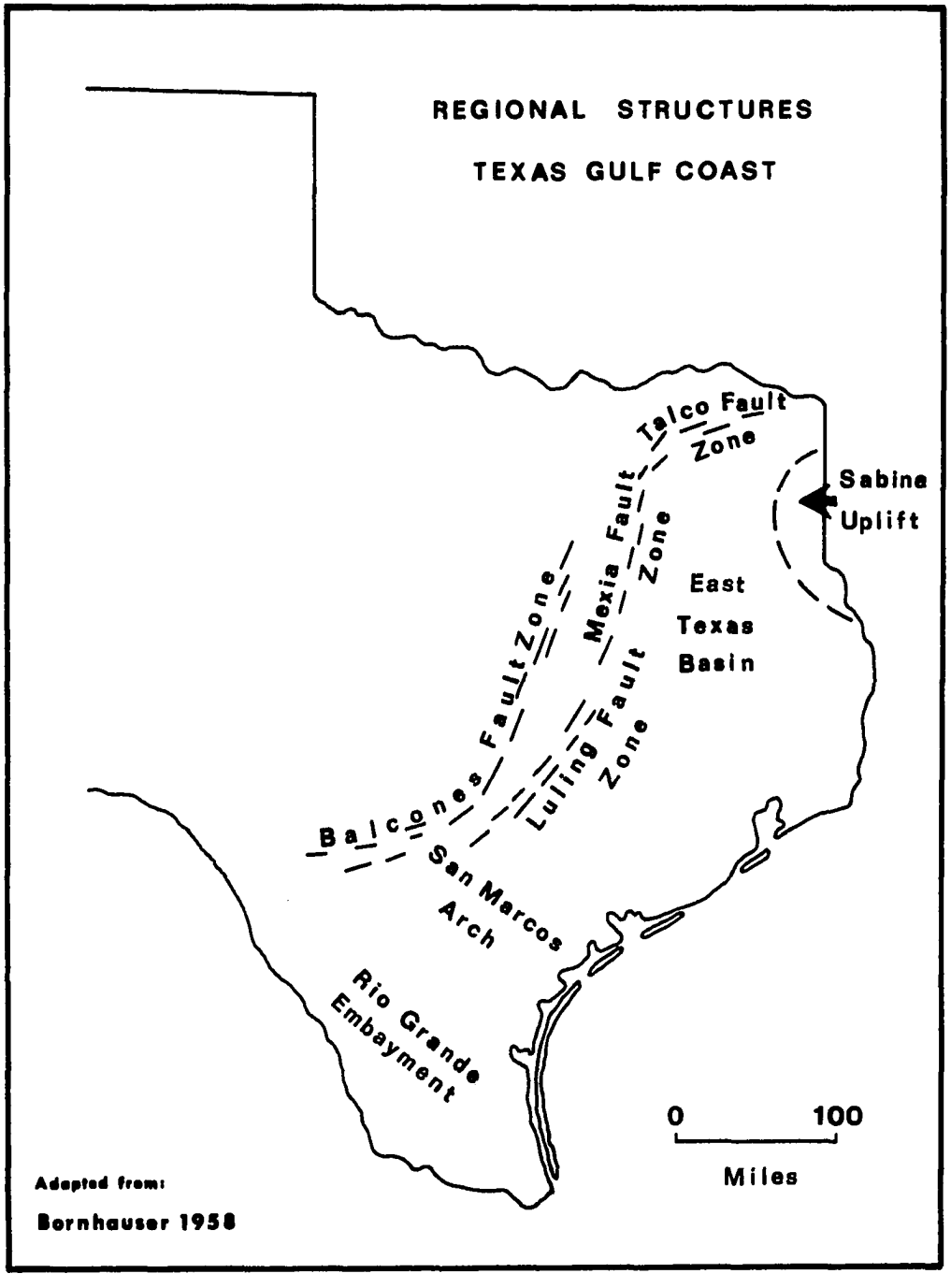

Fig. 8.--Regional structures of Texas Gulf Coastal Plain

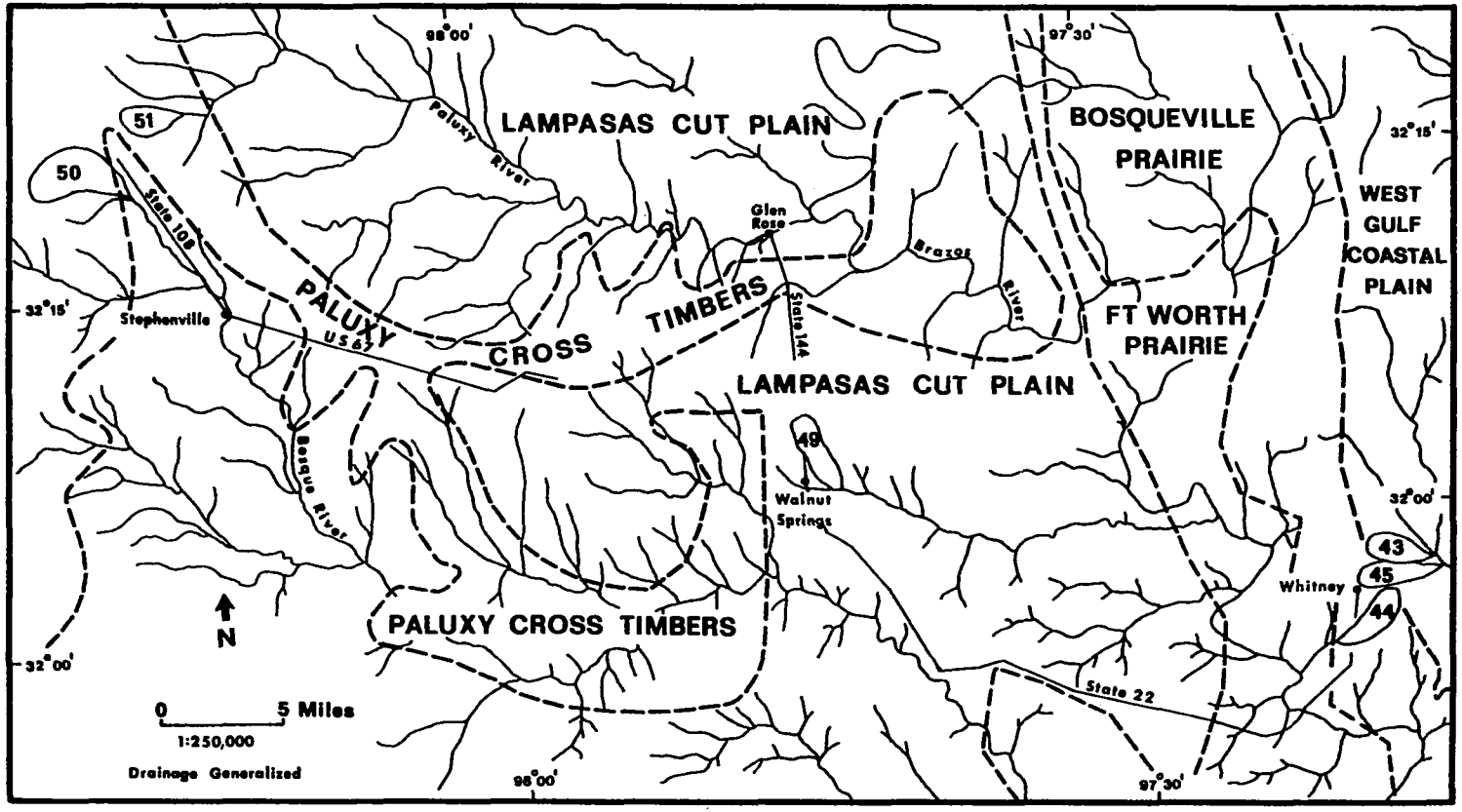

Fig. 9.--Central Texas Section of Study Area II and location of basins analyzed

of the adjacent West Gulf Coastal Plain. Southward, the Comanchean Series is separated from the Gulfian of the Gulf Coastal Plain by the Balcones fault system; however, in this region the boundary is not delineated by faulting. Justification for excluding this section from the Coastal Plain is based primarily on the greater resistivity of Comanchean rocks to erosion.[50]

Lampasas Cut Plain.--The Lampasas Cut Plain (included in the Comanche Plateau by Thornbury) is a dissected plateau with mesas and buttes capped by Edwards Limestone. The Edwards Limestone covered much of this region and was subsequently removed by erosion. Referring to the influence of the Edwards Limestone on the topographic forms in the region, Hill writes:

> This feature is so intimately related to and dependent upon the occurrence and erosion of one geologic formation--the Edwards Limestone--that it is difficult to describe it without constantly bearing in mind the vast extent of this formation. . . .[51]

He describes the region as a ". . . modified northern extension of the great Edwards Plateau."[52] The western border of the plain is 1,500 to 1,800 feet above sea level with elevations decreasing eastward. Local relief in the region reaches a maximum of 400 feet.[53]

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[50]Nevin M. Fenneman, Physiography of Eastern United States (New York: McGraw-Hill Book Company, Inc., 1938), p. 100.

[51]Hill, Black and Grand Prairies, p. 78.

[52]Ibid.

[53]Fenneman, Physiography of Eastern United States, p. 106.

Below the Edwards Cap, lower units of the Comanchean Series are exposed. Dominant among these formations is the Walnut Clay which yields a topography referred to by Hill as the Walnut Prairie.[54] In describing the Walnut Prairie Hill writes: "The Walnut Prairie usually occurs as benches, forming a shoulder immediately below the scarp rock of the summits of the Lampasas Plain, or as the surface uplands, from which the summit rock has been eroded."[55]

Western Cross Timbers.--The Western Cross Timbers are developed on sands of the Comanchean Series and are included as a subdivision of the Lampasas Cut Plain by Hill. In Texas the eastern portion of the Western Cross Timbers is referred to as the Paluxy Cross Timbers which are developed on the Paluxy Sand. The Paluxy Cross Timbers are separated from the western part of the Western Cross Timbers by the Glen Rose Prairie which is developed where the Glen Rose Formation crops out. Hill describes the Paluxy Cross Timbers as an area characterized by deep, sandy soils and stunted post-oak and black-jack timber.[56]

Bosqueville Prairie.--The Bosqueville Prairie is included in the Grand Prairies by Hill;[57] however, in this study it is included in the Central Texas section of the Great Plains. It is developed on the

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[54]Hill, Black and Grand Prairies, p. 81.

[55]Ibid.

[56]Ibid., p. 83.

[57]Ibid., p. 77.

Grayson Marl and yields a black waxy soil[58] that supports a mesquite and grass vegetation. It is characterized by flat topography with surface depressions locally referred to as "hog wallows."[59] Basin forty-four and a portion of basin forty-five in this study are located in this division.

Study Area I

Geology

Formations in this study area (Figure 10) range from the Sabinetown (Eocene) to the Goliad (Pliocene) (Table 5). The strike approximately parallels the coast, and the regional dip is one-half to one degree toward the Gulf of Mexico.[60] Lithologies represented by the units are clay, sand, sandstone, and tuffaceous clay. The three most distinctive units in terms of topographic expression are the Carrizo, Catahoula, and Oakville. The Carrizo and Oakville form cuestas which break the rolling terrain of this section of the coastal plain, and the Catahoula adjacent to major streams yields a badland type topography. Other units yield a gently rolling plain.

Pleistocene.--Pleistocene influence on drainage is evident throughout the area by the presence of gravels on hill crests and

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[58] Ibid.

[59] Ibid., p. 284.

[60] E. F. McBride, W. L. Lindemann, and P. S. Freeman, "Lithology and Petrology of the Gueydan (Catahoula) Formation in South Texas," Report of Investigations No. 63 (Austin: The Bureau of Economic Geology, 1968), p. 7.

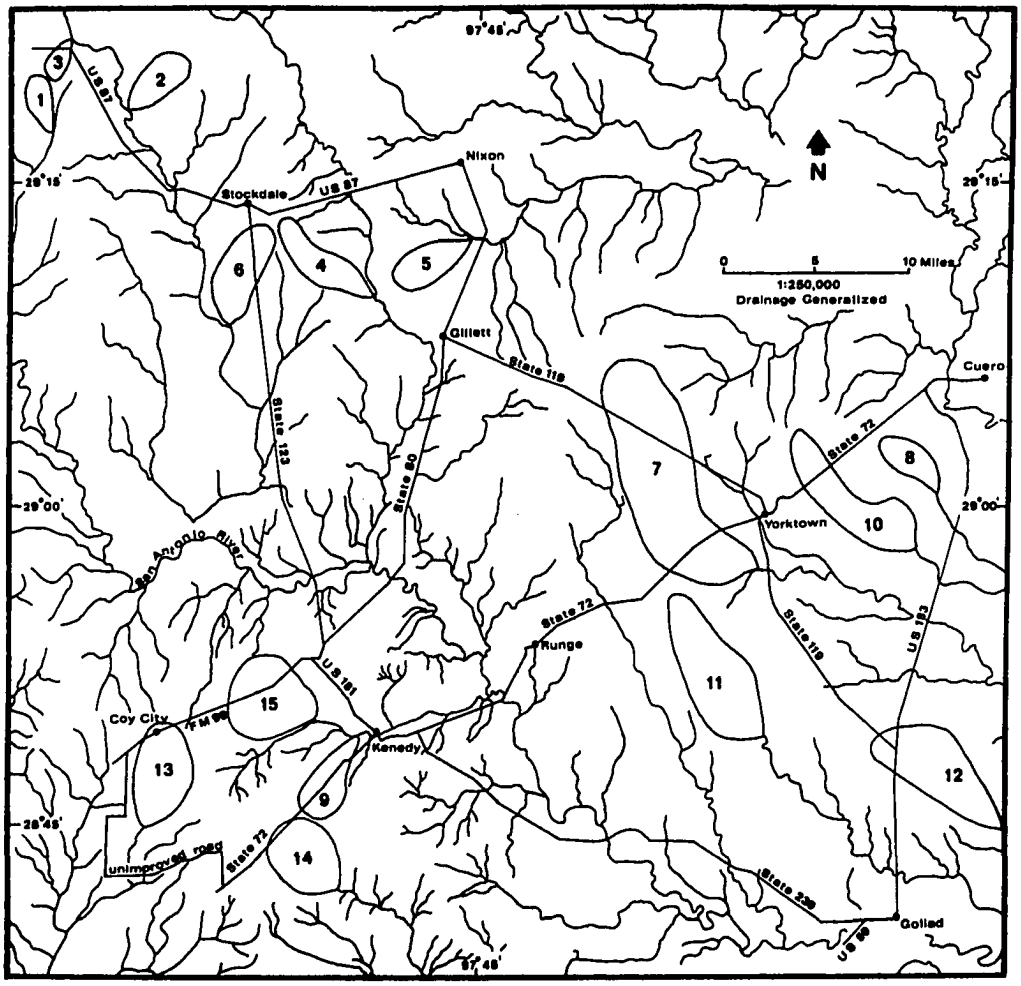

Fig. 10.--Study Area I and location of basins analyzed

terraces along streams and the coast. Development of coastal terraces as well as river terraces is evidence that major drainage had been established during the Pleistocene. Doering states that

> Pleistocene formations of the region consist of three types of deposits, the valley deposits made by the Pleistocene rivers along their interior courses, the deltaic deposits made by the rivers as they spread their sediments over the surface bordering the Pleistocene coast lines, and the shoreline deposits and features produced by wave action along the coast lines.[61]

Doering identified four terraces along the coast. He identified the Citronelle, which lies unconformably above the Goliad, as the oldest. In ascending order the following terraces were identified: Lissie, Oberlin, and Eunice. He dates the Citronelle as preglacial Pleistocene and assigns the Lissie, Oberlin, and Eunice to interglacial stages. Justification for his classification is based on the assumption that during glacial retreat sea levels rose and rivers filled their trenches and made coastal deposits. Such events occurred during Aftonian (Lissie terrace), Yarmouth (Oberlin terrace), and Sangamon (Eunice terrace) interglacial stages. During glacial advance it is assumed that sea levels fell and the rivers cut trenches in their valleys.[62]

Bernard, et al., recognize four terraces along the Texas coast which they identify as follows: Willis (oldest), Lessie, unnamed

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[61]John A. Doering, "Review of Quaternary Surface Formations of Gulf Coast Region," Bulletin of the American Association of Petroleum Geologists, XL (August, 1956), 1820.

[62]Ibid., pp. 1859-60.

terrace, and Beaumont (youngest).[63] Although their classification differs from that of Doering, they postulate an origin similar to that postulated by Doering. They interpret the Pleistocene coastal plain as a coalescing alluvial and deltaic plain deposited by major Pleistocene drainage entering the Gulf of Mexico during high sea level. They recognize equivalent inland extensions of the coastal terraces along the major rivers.[64]

Discontinuous deposits of cobble size gravel composed of flint, chert, and jasper are found on divides. The elevation of these gravels above present drainage suggests that they were not deposited by present drainage. They are interpreted as correlating with gravels identified as Uvalde Gravel in other areas of the Coastal Plain. In central Texas, Uvalde Gravels are interpreted as predating Pleistocene river terraces and are assigned a probable Miocene-Pliocene age.[65]

Drainage

The drainage pattern is dendritic to subdendritic and streams are primarily intermittent. Average drainage density for the basins analyzed is 4.11 (Figure 10). However, drainage density ranges from

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[63]H. A. Bernard, R. J. LeBlanc, and C. F. Major, "Recent and Pleistocene Geology of Southeast Texas," in Geology of the Gulf Coast and Central Texas and Guidebooks of Excursions, ed. by E. H. Rainwater and R. P. Zingula (Houston: Houston Geological Society, 1962), p. 172.

[64]Ibid., pp. 175-76.

[65]Clifford L. Byrd, "Origin and History of the Uvalde Gravels of Central Texas," Baylor Geological Studies No. 20 (Waco, Texas: The Baylor University Press, 1971), p. 23. (Hereinafter referred to as "Uvalde Gravels.")

2.75 for basin fourteen developed on the Oakville to 5.97 for basin fifteen developed on the Oakville (drainage density 6.08) and Catahoula (drainage density 5.87) (Appendix III).

Streams in this area flow into one of three perennial streams. However, only the San Antonio River crosses the area. From west to east the rivers are: (1) Atascosa, (2) San Antonio, and (3) Guadalupe (Figure 11). The San Antonio, Guadalupe, and the Nueces cross the Oakville escarpment which suggests that they may be consequent streams.[66] The Frio and Atascosa rivers join the Nueces River near the base of the Oakville Escarpment. The Nueces River crosses the escarpment.

Climate

Homogeneity of climate for this region varies with the classification used. The climate is classified as humid subtropical when the Köppen system and its various modified forms are used.[67, 68] However, according to the Thornthwaite classification the area is in two climatic types: (1) dry subhumid mesothermal, and (2) semiarid mesothermal[69] (Figure 12).

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[66]Waters, McFarland, and Lea, "Geologic Framework," p. 1823.

[67]Richard J. Russell, "Climates of Texas," Annals of the Association of American Geographers, XXXV (June, 1945), 40-43.

[68]Glenn T. Trewartha, An Introduction to Weather and Climate (2d ed.; New York: McGraw-Hill Book Company, Inc., 1943), Plate 1.

[69]W. H. Alexander, Jr., and D. E. White, "Ground-Water Resources of Atascosa and Frio Counties, Texas," Texas Water Development Board Report 32 (Austin: Texas Water Development Board, 1966), p. 13. (Hereinafter referred to as "Ground-Water Resources.")

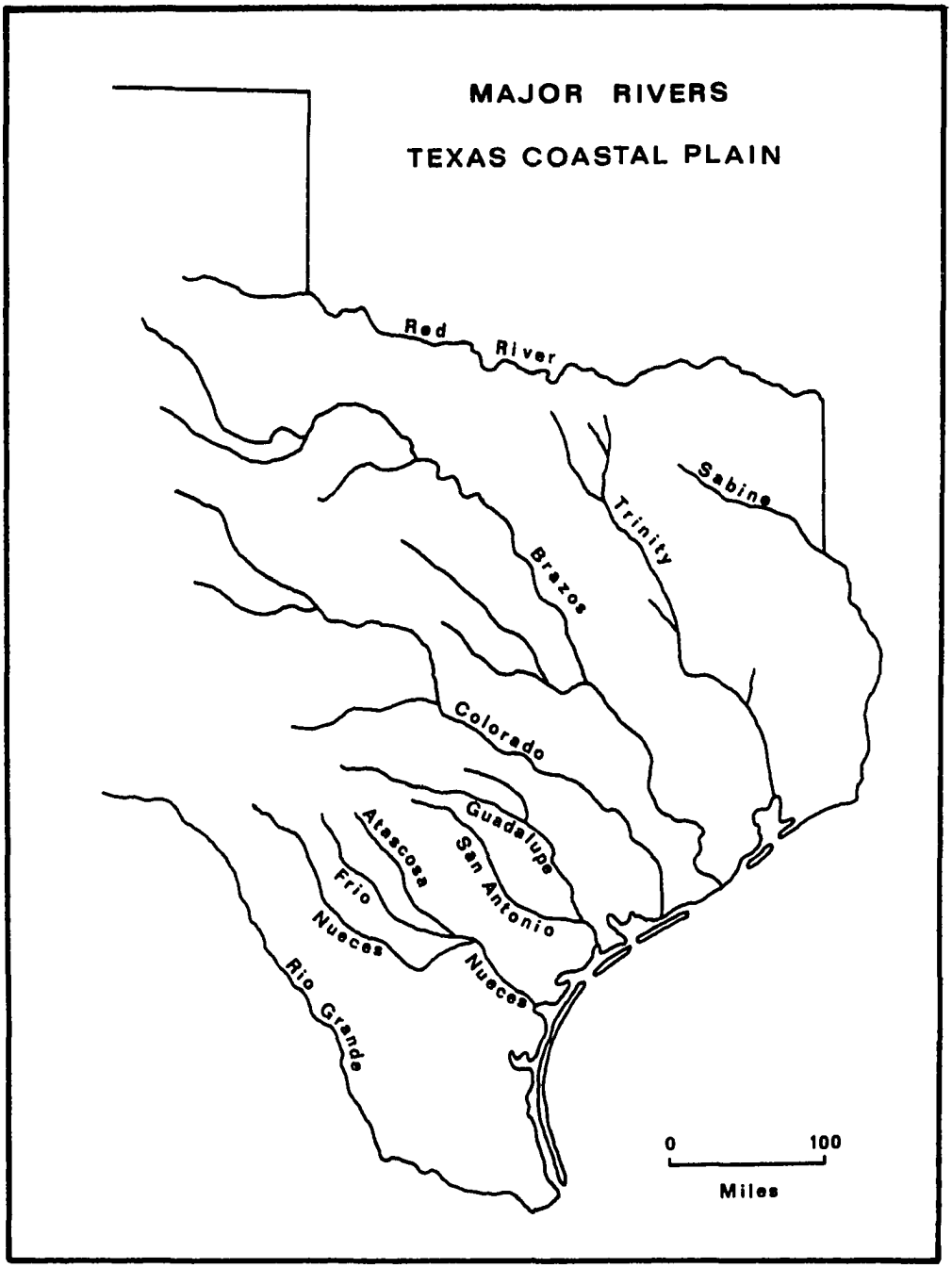

Fig. 11.--Major rivers of Texas Gulf Coastal Plain

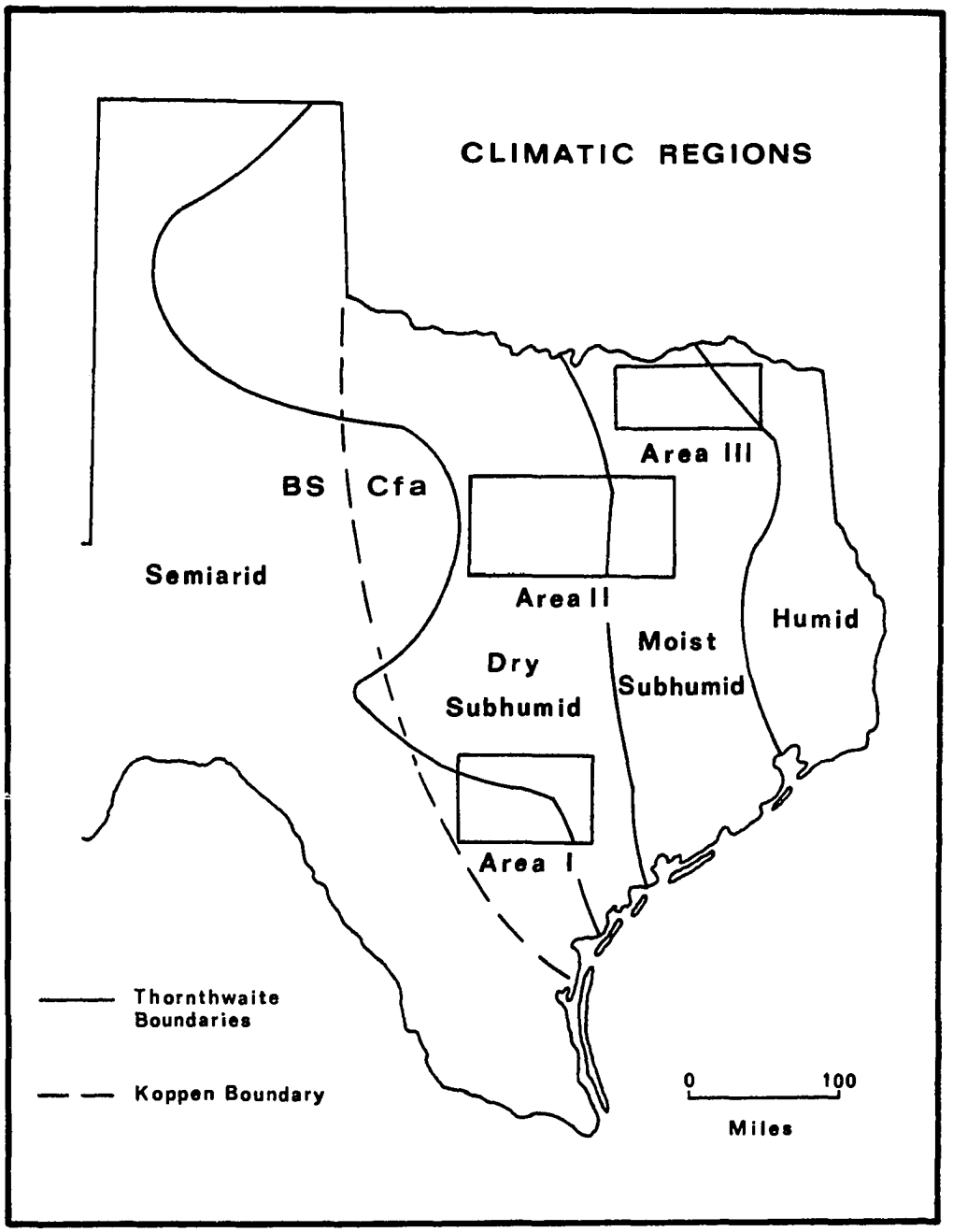

Fig. 12.--Thornthwaite and Köppen climatic classifications (Thornthwaite classification modified from Alexander and White, p. 13; Köppen classification modified from Russell, 1945, p. 43).

Within the study area (Area I) average annual precipitation ranges from thirty-six inches in the east to twenty-six inches in the west.[70] Precipitation maximums usually occur in May and September which coincide with periods of maximum stream flow. Average annual potential evapotranspiration ranges from forty-five inches in the east to forty-seven inches in the west.[71] However, winters are characterized by a water surplus and summers by water deficit.[72] During summer months ephemeral streams are dry with only through streams flowing throughout the year.

Study Area II

Streams isolated for analysis in this area are in two geomorphic regions: (1) West Gulf Coastal Plain and (2) Central Texas section of the Great Plains (Figures 9, 13, and 14). The study area includes lithostratigraphic units that range from the Paluxy Sand (Comanchean Cretaceous) to the Cook Mountain (Eocene) (Table 6). Formations strike in general north-northeast and dip approximately one degree east-southeast. Regional stratigraphy has been disturbed by

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[70]John T. Carr, Jr., "The Climate and Physiography of Texas," Texas Water Development Board Report 53 (Austin: Texas Water Development Board, 1967), p. 4. (Hereinafter referred to as "Climate and Physiography.")

[71]John T. Carr, Jr., "Texas Droughts: Causes, Classification and Prediction," Texas Water Development Board Report 30 (Austin: Texas Water Development Board, 1966), p. 13. (Hereinafter referred to as "Texas Droughts.")

[72]Carr, "Climate and Physiography," p. 18.

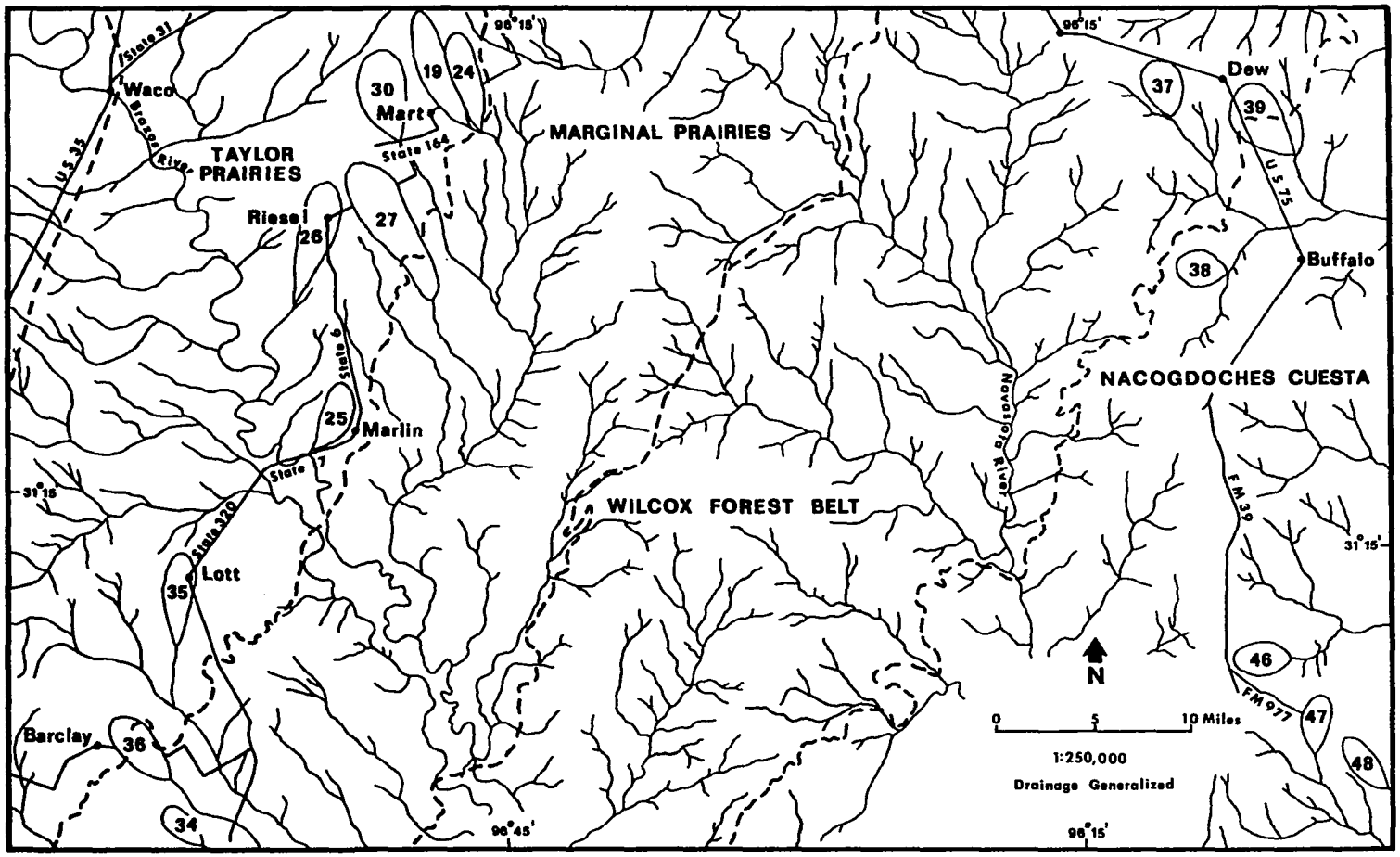

Fig. 13.--Southeast portion of Study Area II and location of basins analyzed

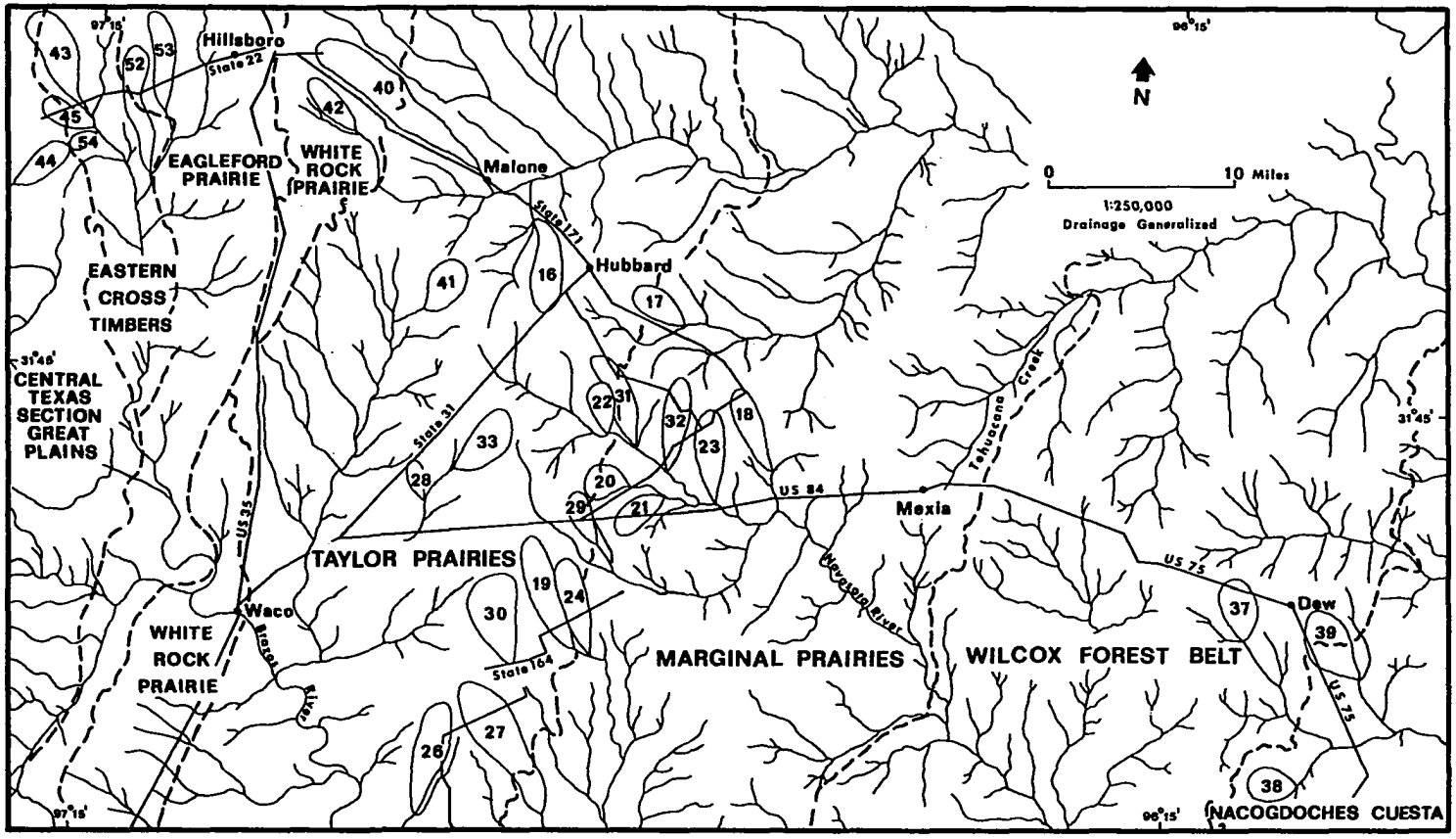

Fig. 14.--Northeast portion of Study Area II and location of basins analyzed

two zones of faulting, the Balcones and Mexia fault trends. However, drainage basins analyzed do not occur in areas of mapped fault trends.

Central Texas Section

Three lithostratigraphic units in Study Area II are in the Central Texas section of the Great Plains. These units are the Paluxy Sand, Walnut Clay, and Grayson Marl. The Paluxy Sand yields a distinctive topography and vegetation that is referred to as the Paluxy Cross Timbers (Figure 9). The second unit in the Central Texas section, the Walnut Clay, is in the Lampasas Cut Plain. The Walnut Clay supports a distinctive rolling topography and consists of ". . . alternating clay, nodular marly limestone, crystalline limestone, and massive shell beds . . ." in the type area.[73] The drainage systems analyzed in this study were developed on limestone units of the Walnut. The third unit is the Grayson Marl which yields a rolling topography and supports mesquite vegetation.

West Gulf Coastal Plain

Transition from the Central Texas section of the Great Plains in this area is marked by the contact of Gulfian and Comanchean Cretaceous rocks. Rocks of the Comanchean are characterized by a dissected topography in contrast to the rolling plains of the Coastal Plain.[74]

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[73]Johnnie B. Brown, "The Role of Geology in a Unified Conservation Program, Flat Top Ranch, Bosque County, Texas," Baylor Geological Studies Bulletin No. 5 (Waco, Texas: The Baylor University Press, 1963), p. 10.

[74]Thornbury, Regional Geomorphology, p. 62.

However, the transition between the two types of topography is gradational in this area in contrast to the well-defined escarpment between the two rock series and physiographic provinces south of Austin where displacement along the Balcones fault system forms a distinct break in the topography. The Balcones fault system traverses this area; however, north of approximately latitude thirty-one degrees (Temple 31°06'N) it does not form a distinct fault scarp.[75]

The topography in Area II east of Waco is classified into the following divisions: (1) White Rock Prairie, (2) Taylor Prairie, (3) Marginal Prairies, (4) Wilcox Forest Belt, and (5) Nacogdoches Cuesta (Figures 13 and 14). The White Rock Prairie is developed on the Austin Chalk and is bounded by an escarpment on the east. The streams are more deeply incised than those of the Taylor Prairies to the east where the topography is gently rolling and where the lithostratigraphic units are masked by a deep topsoil. In the Taylor Prairie the most distinctive unit in terms of surface expression is the Wolfe City Sand which yields a sandy soil and a scrub oak vegetation. Other units in the Taylor Prairies are marl, mudstone, and clay that are usually calcareous. The Pecan Gap Chalk, included in the Taylor Prairies, is a chalk in the lower part and grades upward to a chalky marl.[76]

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[75]Fenneman, Physiography of Eastern United States, p. 100.

[76]Arthur O. Beall, Jr., "Stratigraphy of the Taylor Formation (Upper Cretaceous), East-Central Texas," Baylor Geological Studies Bulletin No. 6 (Waco, Texas: The Baylor University Press, 1968), p. 20.

Immediately east of the Taylor Prairies are the Marginal Prairies. This division is on the uppermost Cretaceous and Midway (Eocene) bedrock. There is little topographic change from the Taylor Prairies to this division except for a slight increase in relief for the latter.[77] The Mexia fault zone traverses the Marginal Prairies; therefore, no drainage basins were chosen from this division.

East of the Marginal Prairies is the Wilcox Forest Belt developed on formations of the Wilcox Group. Elevations range from 450-500 feet and the surface is greatly dissected and in places hilly.[78]

Beyond the Wilcox Forest Belt is the Nacogdoches Cuesta which is one of the major cuestas in the Gulf Coastal Plain. The cuesta is composed of rock units of the Claiborne Group of the Eocene Series. In this study the Carrizo (Wilcox) is included as part of the cuesta as its topographic expression is similar to that of the units included in the cuesta. Southeast of the Nacogdoches Cuesta is the Yegua Prairie which is a gently rolling prairie.

Pleistocene

Evidence indicates that major drainage systems were well established in this area during the Pleistocene. Five terraces have been identified along the Brazos River, the major stream flowing through

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[77]Fenneman, Physiography of Eastern United States, pp. 108-9.

[78]U.S., Department of Interior, Geological Survey, Geology of the Coastal Plain of Texas West of Brazos River, by Alexander Deussen, United States Geological Survey Professional Paper 126 (Washington, D.C.: Government Printing Office, 1924), p. 11.

the region.[79] The deposits have been dated as Pleistocene and interpreted as evidence that during the Pleistocene valley deepening was a dominant feature of the river upstream from Waco.[80]

In addition to the Pleistocene gravels along the Brazos River, high level gravels are present. These gravels are identified as Uvalde Gravel and traced to a source region in the High Plains. They are interpreted as having been deposited by drainage systems that predate present drainage. Two types of evidence are cited for postulating deposition by previous drainage: (1) location of gravels on topographic highs and (2) large size of gravels. The size of the gravel exceeds that of gravel transported by present drainage systems.[81] Dating Uvalde Gravels has been difficult because of lack of fossils; however, it is assigned to Late Tertiary or Early Pleistocene.[82]

Based on gravels in the area, it is inferred that present drainage represents a system phase in drainage that was established at least in the Pleistocene and was preceded by an earlier system or systems in Early Pleistocene or Late Tertiary. The late Tertiary-Pleistocene drainage history of Area II was probably somewhat similar to that of Area I.

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[79]Fred L. Stricklin, "Degradational Stream Deposits of the Brazos River, Central Texas," Geological Society of America Bulletin, LXXII (January, 1961), 26.

[80]Ibid., p. 19.

[81]Byrd, "Uvalde Gravels," p. 5.

[82]Ibid., p. 29.

Drainage

Present drainage systems are arranged in dendritic to subdendritic patterns. Streams, except for through streams, are intermittent. Streams in the West Gulf Coast Plain portion of the area are usually separated by broad, gently sloping divides whereas in the Great Plains section divides are more pronounced as they are usually capped by resistant rock units. Drainage density ranges from 3.32 for basin thirty developed on the Pecan Gap Chalk (drainage density 2.98) and Wolfe City Sand (drainage density 3.66) to 10.55 for basin fifty-one developed on the Paluxy Sand (Appendix III). Mean drainage density for drainage basins analyzed in the area is 5.59.

Climate

This area is within the humid subtropical climate as classified according to the Köppen system. However, according to the Thornthwaite classification the western two-thirds of the area is in the dry subtropical type, and the eastern one-third is in the moist subtropical type[83, 84] (Figure 12).

Average annual precipitation ranges from forty inches in the eastern portion of the area to twenty-eight inches in the west.[85] Maximum precipitation usually occurs in May and September.[86] Average

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[83]Russell, "Climates of Texas," pp. 40-43.

[84]Alexander and White, "Ground-Water Resources," p. 13.

[85]Carr, "Texas Droughts," p. 13.

[86]Carr, "Climate and Physiography," p. 6.

annual potential evapotranspiration ranges from forty-two inches in the southeast to thirty-nine inches in the northwest.[87] Winters are characterized by a water surplus and summers by a deficit. Stream flow data for the North Bosque River, located in the northwestern quadrant of the area, reflect periods of maximum precipitation. Peak flows for the Bosque occur in April-May and September-October with minimum flow in August.[88] Ephemeral streams flow only after periods of heavy rainfall and are usually dry in summer.

Study Area III

Geology

Study Area III is south of the Red River in the northern part of the West Gulf Coastal Plain. Formations in the central and eastern portion of the area strike in general east-northeast and dip south-southeast at angles ranging from one-half to one degree. However, in the western part of the region the strike changes to north-northeast and the dip changes to east-southeast.

Lithostratigraphic units are of the Gulfian Series Cretaceous System (Table 7) and range from the Blossom Sand Austin Group to the Wolfe City Formation Taylor Group. Lithologies represented are marl, chalk, and sand.

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[87]Carr, "Texas Droughts," p. 13.

[88]U.S., Department of Interior, Geological Survey, The National Atlas of the United States of America (Washington, D.C.: Government Printing Office, 1970), p. 120.

Pleistocene

Pleistocene deposits have been identified along drainage channels in the study area which suggests that major drainage existed during the Pleistocene. Five fluviatile terraces have been identified near the Red River that have been dated as: (1) post-Bradyan Wisconsinan, (2) pre-Bradyan Wisconsinan, (3) Illinoian, (4) Kansan, and (5) Nebraskan.[89] Gravel terraces along tributary streams have been tentatively correlated with Pleistocene-Recent gravels in other areas of the Gulf Coastal Plain. It was suggested that these gravels were deposited under conditions of large stream volume, flash flood, and brief transport during a time of high precipitation.[90]

High level gravels characteristic of Study Areas I and II have not been identified in this area. Based on available data it is concluded that major drainage was well developed during the Pleistocene.

Drainage

Drainage is generally dendritic to subdendritic; however, some streams follow the strike of the formations and show a trellis pattern. The latter were not included in the study. Streams are intermittent flowing only after periods of precipitation and are generally separated by broad divides. Drainage density for streams included in this area

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[89] Geologic Atlas of Texas, Texarkana Sheet, Virgil E. Barnes, Project Director (Austin: Bureau of Economic Geology, 1966), p. 1.

[90] Donald H. Lokke and Millard D. Brent, "Pleistocene-Recent Chalk Gravel Terraces, Fannin County, Texas," The Compass of Sigma Gamma Epsilon, XLIII (January, 1966), 138-40.

(Figure 15) range from 4.09 for basin fifty-seven developed on the Bonham Formation (drainage density 4.71) and Blossom Sand (drainage density 3.47) to 9.03 for basin sixty-two developed on the Wolfe City Formation. Mean drainage density for the basins measured was 6.20. This was the largest mean for the three study areas.

Climate

This area is within the limits of the humid subtropical climate of the Köppen system; however, according to the Thornthwaite classification two climatic types are represented: (1) moist subhumid and (2) humid[91] (Figure 12). The largest portion of the area is in the moist subhumid type. The humid type is found in the eastern part of the region.

Average annual precipitation ranges from forty-six inches in the eastern portion of the area to thirty-six inches in the west.[92] Maximum precipitation usually occurs in May and September; however, precipitation is rather evenly distributed throughout the year. Average annual evapotranspiration is approximately thirty-nine inches. There is normally a surplus of water in winter and a deficit in summer.[93] During the summer period of water deficit streams are dry.

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[91]Alexander and White, "Ground-Water Resources," p. 13.

[92]Carr, "Climate and Physiography," p. 6.

[93]Ibid., p. 18.

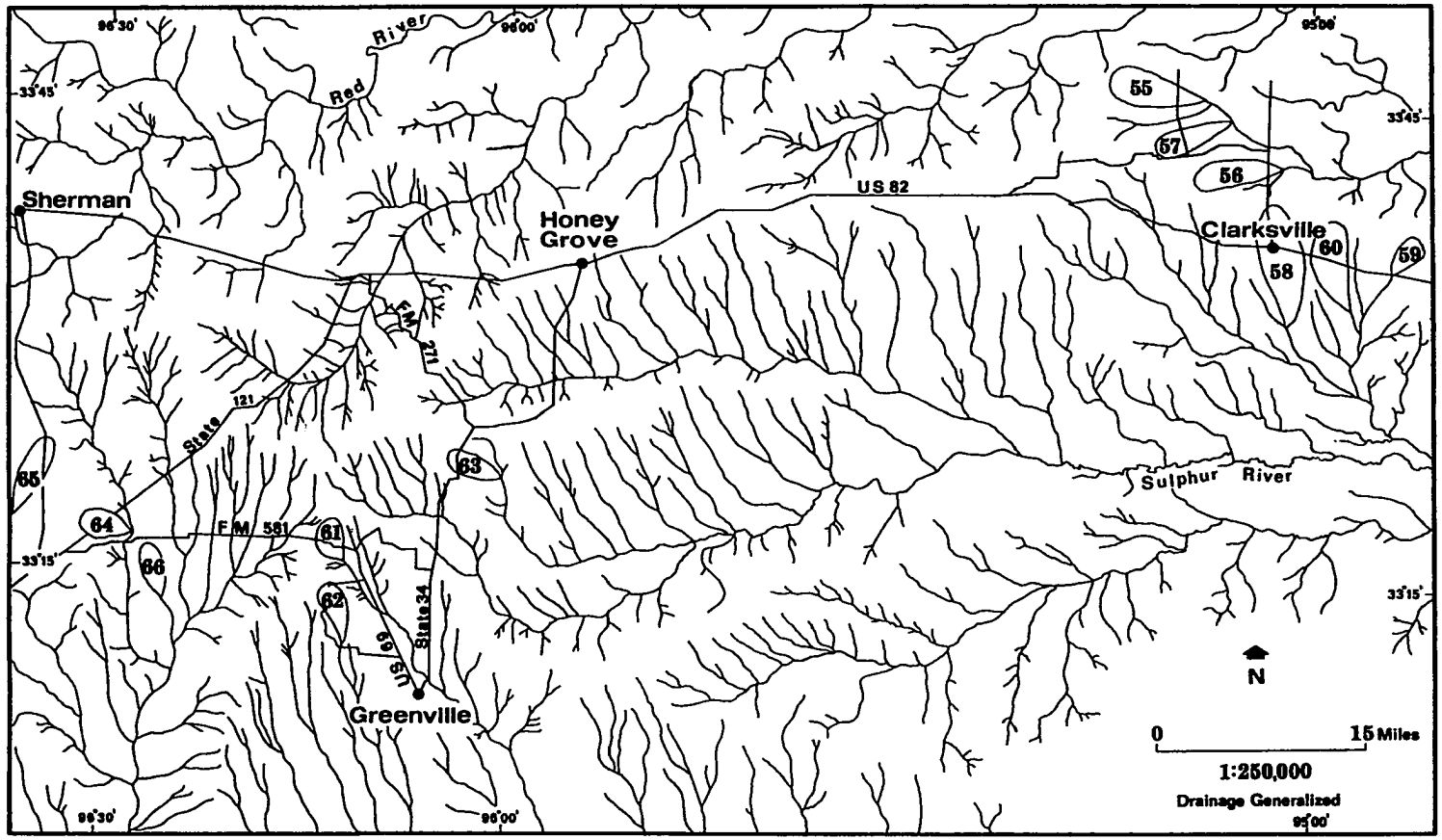

Fig. 15.--Location of basins analyzed in Study Area III

CHAPTER IV

NUMERICAL ANALYSIS

Method of Testing Research Hypothesis

The research hypothesis is tested by three statistical tests: (1) Kolmogrov-Smirnov test, (2) Mann-Whitney U test, and (3) analysis of regression slope values. For each of the twenty-two sets of three drainage systems the three tests are carried out for each drainage basin. The purposes of these tests are: (1) to determine if there is a significant difference between the number of observed channels (basins) and the number of channels (basins) predicted by the model for each drainage system, and (2) to determine if the model predicts better for basins on one lithostratigraphic unit than for basins on two lithostratigraphic units. Computed values for the Kolmogrov-Smirnov test and the analysis of regression slope values were inspected to determine if the value nearest the rejection level occurred for the drainage system developed on two lithostratigraphic units or for the two drainage systems developed on one lithostratigraphic unit. Under the restraints of climate and geological structure stated for each of the three study areas (Area I, Area II, and Area III), it was theorized that if lithostratigraphic units in the study areas significantly influence the predictive accuracy of the model, that the drainage basin on two lithostratigraphic units in each

set should show either: (1) a significant difference between observed and model predicted data or (2) a computed value nearer the rejection level (for the Kolmogrov-Smirnov test or for the test of regression slope values) than the two basins on one lithostratigraphic unit. In addition to these tests Spearman rank correlation was used to test for association between computed values near the rejection level for the significance tests and the following: (1) drainage density, (2) stream frequency, (3) elevation-relief ratio, and (4) circular shape.

Rationale for Using Spearman Rank Correlation

Spearman rank correlation analysis was used in this study in a preliminary attempt to determine if there was an association between predictive accuracy of the model and the following: (1) lithostratigraphic units in a drainage basin which have large differences in drainage density, (2) lithostratigraphic units in a drainage basin which have large differences in stream frequency, (3) deviation of drainage basin elevation-relief ratio from the area mean elevation-relief ratio, and (4) deviation of basin shape from circular.

Spearman rank correlation was used instead of the more powerful product moment correlation because plots of variables to be tested against values for the Kolmogrov-Smirnov test and the regression slope test failed to show linearity. In addition, the assumptions of normality of data, necessary for comparison of product moment correlation values to table values for hypothesis testing, could not be made for the data in this study.

Doornkamp and King successfully utilized Spearman rank correlation in their study of drainage basins in Ghana and concluded that Spearman rank correlation was the preferred test. They found that results of Spearman rank correlation and product moment correlation were similar for the areas studied.[1]

Rationale for Correlation Variables

Drainage Density

Drainage density was chosen as a morphometric parameter to test for an association with the computed values of the significance tests. Choice of drainage density was based on the assumption that one measure of the influence of lithostratigraphic units on drainage development is drainage density.[2] Drainage density, one of the most dependent variables,[3] is related to variables such as surface slope,[4] evapotranspiration,[5] and infiltration capacity.[6] It was therefore

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[1]John C. Doornkamp and Cuchlaine A. M. King, Numerical Analysis in Geomorphology: An Introduction (New York: St. Martin's Press, 1971), p. 51. (Hereinafter referred to as Numerical Analysis.)

[2]Mark A. Melton, "Control of Topographic Texture by Climate, Lithology, and Surface Properties," Geological Society of America Bulletin, LXVII (December, 1962), 1720-21. (Hereinafter referred to as "Topographic Texture.")

[3]Richard J. Chorley and Barbara A. Kennedy, Physical Geography: A Systems Approach (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1971), p. 63. (Hereinafter referred to as Physical Geography.)

[4]Doornkamp and King, Numerical Analysis, p. 50.

[5]Melton, "Topographic Texture," pp. 1720-21.

[6]Chorley and Kennedy, Physical Geography, p. 129.

assumed that for drainage basins on two lithostratigraphic units that differences in drainage density between lithostratigraphic units in a basin were one indication of uniqueness of lithology. This supposition is substantiated by Melton who states that surface properties control texture, but that surface properties are themselves controlled by climate, lithology, and history.[7] Doornkamp and King in their study of drainage basins in Ghana write: "Drainage density is frequently dependent on the bedrock over which it has developed. . . ."[8]

In this study, differences in drainage density between two lithostratigraphic units in a single drainage basin are compared with predictive accuracy of the model. This is carried out to assess if there is a possible correlation between differences in drainage density and the ability of the model to predict. Drainage density is computed as follows: $\frac{\Sigma L_u}{A}$ where L_u = channel length of all orders, and A = area.

Stream Frequency

Stream frequency is a distinct measure of basin geometry and is usually correlated with drainage density.[9] It is defined as: $\frac{\Sigma N_u}{A}$ where N_u = number of channels, and A = basin area. By definition it is a measure of the number of channels or basins per area; therefore, it was assumed that for the basins developed on two

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[7]Melton, "Topographic Texture," pp. 1720-21.

[8]Doornkamp and King, Numerical Analysis, p. 38.

[9]Chorley and Kennedy, Physical Geography, p. 281.

lithostratigraphic units that differences in the number of channels or basins per unit was a measure of uniqueness of the unit. Thus, it was decided to determine if the model predicted better for those basins on units with small differences in stream frequencies than for those basins with large differences in stream frequencies.

Circular Shape

It was theorized that there was a possible association between basin shape and the predictive accuracy of the model. This was based on the premise that, as the model is based on a mixed hexagonal progression, there should be a relationship between hexagonal shape and predictive accuracy of the model. The hexagon is four-fifths as efficient as the circle in terms of distance from center and perimeter.[10] It was thus inferred that as basins approach circular shape they approach the hexagon in terms of perimeter and radius.

In this study shape was measured in terms of the elongation ratio as developed by Schumm.[11] It was computed as follows: $\left\{2 \cdot \sqrt{\frac{A}{\pi}}\right\} / L$ where A = basin area, and L = length of major axis. Circular basins have a computed value of one. Deviation from circular was computed by subtracting the elongation ratio of each basin from one. This value was tested by the Spearman rank correlation test to

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[10]Peter Haggett and Richard J. Chorley, Network Analysis in Geography (New York: St. Martin's Press, 1970), p. 51.

[11]Stanley A. Schumm, "Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey," Geological Society of America Bulletin, LXVII (May, 1956), 621.

determine if there was an association between deviation from circular and predictive accuracy of the model.

Elevation-Relief Ratio

The elevation-relief ratio was computed to determine if there was an association between deviation of the elevation-relief ratio of each basin from the area mean elevation-relief ratio and predictive accuracy of the model. Values derived for the elevation-relief ratio have been equated to values for the hypsometric integral.[12] Strahler, based on comparison of hypsometric curves to actual drainage basins and correlation analysis of basin parameters (basin height, slope steepness, stream gradient, drainage density) with hypsometric integrals, concludes hypsometric values ranging from 35 percent to 60 percent represent topographic forms in equilibrium.[13] As Woldenberg postulates that his model is an equilibrium model, it was theorized that there might be an association between deviation of basin elevation-relief ratios from the mean of the area in which they are located and predictive accuracy of the model. Association was measured by means of Spearman rank correlation.

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[12]Richard J. Pike and Stephen E. Wilson, "Elevation-Relief Ratio, Hypsometric Integral, and Geomorphic Area-Altitude Analysis," Geological Society of America Bulletin, LXXXII (April, 1971), 1080. (Hereinafter referred to as "Elevation-Relief Ratio.")

[13]Arthur N. Strahler, "Hypsometric (Area-Altitude) Analysis of Erosional Topography," Geological Society of America Bulletin, LXIII (November, 1952), 1130.

The elevation-relief ratio was computed by the following formula:[14]

$$\text{elevation-relief ratio} = \frac{\text{mean elevation-minimum elevation}}{\text{maximum elevation-minimum elevation}}$$

Kolmogrov-Smirnov Test

The Kolmogrov-Smirnov test was chosen to test the research hypothesis because it is a nonparametric test appropriate for small samples.[15] As the test is nonparametric, no assumptions are necessary concerning normality of data. For the data under consideration normality could not be assumed. The Kolmogrov-Smirnov test was chosen instead of the usually considered more powerful chi square test because the chi square test requires a minimum frequency of five in each group.[16] In the fluvial systems analyzed there are fewer than five channels in all fourth and fifth orders and in systems nineteen, twenty-nine, and thirty-five fewer than five in the third order (Appendix IV).

The Kolmogrov-Smirnov test is designed to test if two samples come from the same population, and Champion cites its applicability for determining if theoretical distributions are different from

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[14] Ibid., p. 1079.

[15] Dean J. Champion, Basic Statistics for Social Research (Scranton, Pa.: Chandler Publishing Company, 1970), p. 159.

[16] John P. Cole and Cuchlaine A. M. King, Quantitative Geography: Techniques and Theories in Geography (New York: John Wiley and Sons, Inc., 1968), p. 129.

observed distributions.[17] The test is accomplished by determining if there is a significant difference in the maximum vertical deviation between two sample cumulative frequency distribution graphs (Figure 16).[18] In this study the two sample distributions were: (1) number of channels observed per order and (2) number of channels predicted per order by the model.

Computation of Kolmogrov-Smirnov Test

The method used in computing the Kolmogrov-Smirnov test is similar to that described by Miller and Kahn.[19] The percentage of channels in each order was determined for the observed and predicted data. The percentages per order for observed data were accumulated from first to fifth order. The same procedure was followed for the number of streams predicted per order by the model (Table 8). Difference in cumulative percent per order between observed and model data was determined. The maximum per order difference between cumulative percent observed and predicted was isolated for comparison with table values at the .05 significance level. In order to enter the table an N value was determined by the following method:

$$N = \frac{n_1 n_2}{(n_1 + n_2)}$$

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[17] Champion, Basic Statistics for Social Research, p. 159.

[18] Robert L. Miller and James Steven Kahn, Statistical Analysis in the Geological Sciences (New York: John Wiley and Sons, Inc., 1962), p. 464.

[19] Ibid., pp. 464-67.

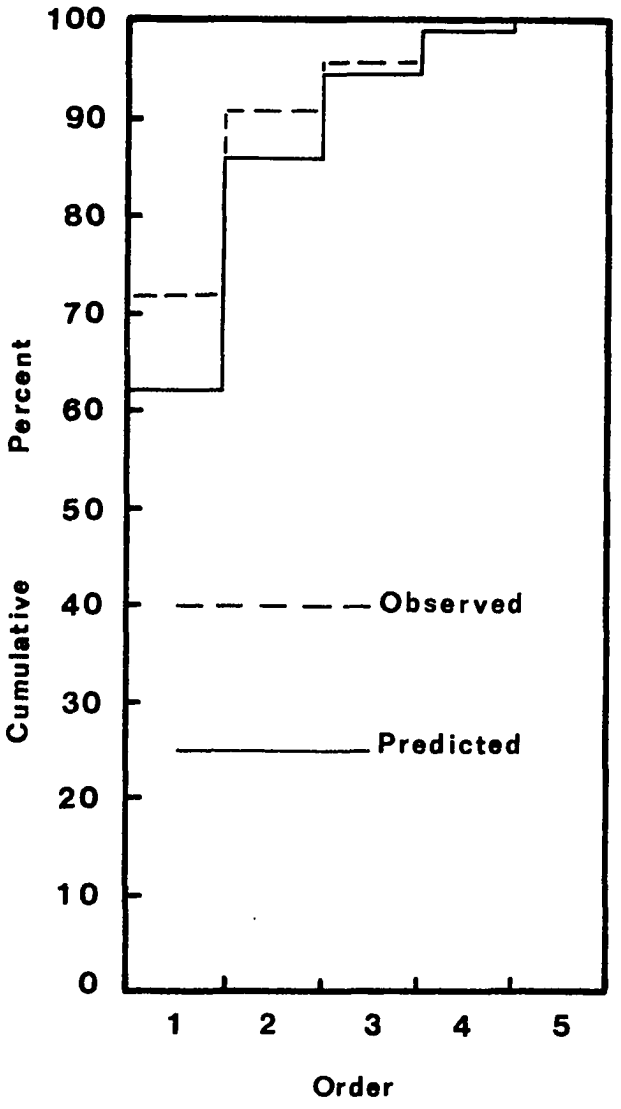

Fig. 16.--Kolmogrov-Smirnov Graph Basin 19

TABLE 8

KOLMOGROV-SMIRNOV TEST COMPUTED FOR BASIN SIXTEEN

Order	1	2	3	4	5
Observed Percent	74.80314	19.42254	04.724400	00.78740	00.26246
Predicted Percent	74.41854	19.26811	05.11842	00.92819	00.26672
Cumulative Observed Percent (1)	74.80314	94.22568	98.95008	99.73748	99.99994
Cumulative Predicted Percent (2)	74.41854	93.68665	98.80507	99.73326	99.99998
Difference 1-2	00.38460	00.53903	00.14501	00.00422	00.00004

where n_1 = total number of observed channels
n_2 = total number of predicted channels.[20]

Two-tailed table values were used in order that critical regions on both ends of the normal curve could be used for testing the hypothesis. For N values exceeding thirty-five, the level of significance was determined by a method described by Champion:

$\frac{1.36}{\sqrt{N}}$ where $N = \frac{n_1 n_2}{(n_1 + n_2)}$; where n_1 = total number of observed channels and n_2 = number of predicted channels.[21]

Results of Kolmogrov-Smirnov Test I

The null hypothesis tested was as follows: In the study areas there is a significant difference in the accuracy with which the convergent mean model predicts the number of channels per order for fluvial systems developed on two lithostratigraphic units as compared with those developed on one lithostratigraphic unit. Based on the Kolmogrov-Smirnov test the null hypothesis was rejected at the .05 confidence level. For each of the sixty-six streams the computed value neither equaled nor exceeded the rejection level (Appendix V). It was inferred from this test that for the streams analyzed lithostratigraphic units do not significantly influence the predictive accuracy of the model. Under the restraints of homogeneous geological structure and climate in each study area, if lithostratigraphic units significantly affected the ability of the model to predict, those

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[20] Ibid., p. 467.

[21] Champion, Basic Statistics for Social Research, p. 275.

fluvial systems developed on two lithostratigraphic units should have shown a significant difference between the predicted and observed data.

Even though results of this test permitted rejecting the null hypothesis with considerable confidence, further analysis of computed values was warranted in order to determine if lithostratigraphic units influenced, though not significantly, the predictive ability of the model. This analysis was in three parts. First, maximum computed percent difference between model and observed data for each set of three drainage basins was analyzed to determine if the lowest range between computed value and rejection level occurred for the drainage basin on two lithostratigraphic units. Secondly, maximum difference between cumulative percent observed and predicted was analyzed to determine if the largest difference between cumulative percent observed and predicted occurred for the drainage basin developed on two lithostratigraphic units. This analysis was made without regard to rejection level. The third part of the analysis involved correlation analysis to determine if there was an association between small ranges of the computed value from the rejection level and the following: (1) drainage density, (2) stream frequency, (3) elevation-relief ratio, and (4) elongation ratio.

Sets Approaching Rejection Level

In twelve of the twenty-two sets the smallest range between the computed value and rejection level occurred for the basin developed on two lithostratigraphic units (Table 9).

TABLE 9

SETS IN WHICH BASIN ON TWO LITHOSTRATIGRAPHIC UNITS IS NEAREST SIGNIFICANCE LEVEL

Set	Stream	Computed Kolmogrov-Smirnov Value	Significance Level
2	4	.012	.080
3	7	.052	.115
4	11	.008	.108
5	15	.046	.115
8	24	.033	.115
10	30	.027	.114
11	31	.015	.112
12	36	.016	.102
14	40	.038	.096
17	50	.014	.089
20	60	.016	.073
21	63	.019	.093

Analysis of Deviation from Rejection Level

Spearman rank correlation was employed to determine if there was an association between those drainage basins for which the Kolmogrov-Smirnov value approached the rejection level and drainage density, stream frequency, elevation-relief ratio, and basin circularity.

Spearman Rank Correlation--Drainage Density

It was theorized that those drainage systems developed on two lithostratigraphic units with large differences in drainage density were associated with those drainage systems whose computed value for the Kolmogrov-Smirnov test approached the rejection level (Table 10). The null hypothesis was as follows: For the drainage basins analyzed, there is not a significant correlation between large differences in drainage density and Kolmogrov-Smirnov values that approach the rejection level. The null hypothesis could not be rejected at the .05 significance level (Appendix VI). For the drainage basins on two formations there was not a significant correlation between large differences in drainage density and Kolmogrov-Smirnov values that approached the rejection level.

Spearman Rank Correlation--Stream Frequency

It was theorized that those drainage systems developed on two lithostratigraphic units with large differences in stream frequencies should be drainage basins whose computed value for the Kolmogrov-Smirnov test approach the rejection level (Table 11). The following

TABLE 10

DIFFERENCE IN DRAINAGE DENSITY BETWEEN TWO LITHOSTRATIGRAPHIC UNITS FOR BASINS ON TWO LITHOSTRATIGRAPHIC UNITS

Set	Stream	Lithostratigraphic Units	Drainage Density	Difference in Drainage Density
1	1	Sabinetown	3.24	
		Carrizo Sand	3.51	.27
2	4	Yegua Formation	3.81	
		Cook Mountain	4.38	.57
3	7	Oakville Sandstone	2.82	
		Lagarto Clay	3.25	.43
4	11	Lagarto Clay	4.02	
		Goliad Sand	3.73	.29
5	15	Catahoula	5.87	
		Oakville Sandstone	6.08	.21
6	17	Wolfe City Formation	5.09	
		Marlbrook Marl	4.82	.27
7	19	Pecan Gap Chalk	3.38	
		Marlbrook Marl	3.93	.55
8	24	Pecan Gap Chalk	3.69	
		Marlbrook Marl	4.19	.50
9	27	Pecan Gap Chalk	3.60	
		Wolfe City Formation	6.13	2.53
10	30	Pecan Gap Chalk	2.98	
		Wolfe City Formation	3.66	.68
11	31	Wolfe City Formation	6.04	
		Ozan Formation	4.90	1.14
12	36	Kemp Clay	5.07	
		Pecan Gap Chalk	4.69	.38
13	39	Carrizo Sand	6.37	
		Calvert Bluff Formation	6.19	.18
14	40	Austin Chalk	3.38	
		Ozan Formation	4.54	1.16
15	45	Grayson Marl	6.54	
		Woodbine Formation	5.47	1.07
16	47	Sparta Sand	5.56	
		Cook Mountain	5.12	.44
17	50	Paluxy Sand	5.30	
		Walnut Clay	7.13	1.83
18	52	Lake Waco Formation	3.58	
		Woodbine Formation	5.32	1.74
19	57	Bonham Formation	4.71	
		Blossom Sand	3.47	1.24

TABLE 10--Continued

Set	Stream	Lithostratigraphic Units	Drainage Density	Difference in Drainage Density
20	60	Annona Chalk	5.50	
		Marlbrook Marl	7.39	1.89
21	63	Wolfe City Formation	7.54	
		Ozan Formation	5.29	2.25
22	64	Ozan Formation	7.63	
		Austin Chalk	6.37	1.26

TABLE 11

DIFFERENCE IN STREAM FREQUENCY BETWEEN TWO LITHOSTRATIGRAPHIC UNITS FOR BASINS ON TWO LITHOSTRATIGRAPHIC UNITS

Set	Stream	Lithostratigraphic Units	Stream Frequency	Difference in Stream Frequency
1	1	Sabinetown	12.84	
		Carrizo Sand	13.11	.27
2	4	Yegua Formation	14.42	
		Cook Mountain	6.48	7.94
3	7	Oakville Sandstone	7.13	
		Lagarto Clay	8.82	1.69
4	11	Lagarto Clay	14.92	
		Goliad Sand	15.52	.60
5	15	Catahoula	50.13	
		Oakville Sandstone	43.98	6.15
6	17	Wolfe City Formation	30.85	
		Marlbrook Marl	16.09	14.76
7	19	Pecan Gap Chalk	16.31	
		Marlbrook Marl	16.71	.40
8	24	Pecan Gap Chalk	13.97	
		Marlbrook Marl	17.80	3.83
9	27	Pecan Gap Chalk	13.51	
		Wolfe City Formation	23.47	9.96
10	30	Pecan Gap Chalk	12.53	
		Wolfe City Formation	14.69	2.16
11	31	Wolfe City Formation	34.92	
		Ozan Formation	26.50	8.42
12	36	Kemp Clay	27.13	
		Pecan Gap Chalk	31.78	4.65
13	39	Carrizo Sand	51.84	
		Calvert Bluff Formation	45.55	3.14
14	40	Austin Chalk	14.72	
		Ozan Formation	21.57	6.85
15	45	Grayson Marl	38.75	
		Woodbine Formation	26.19	12.56
16	47	Sparta Sand	30.06	
		Cook Mountain	19.86	10.20
17	50	Paluxy Sand	35.99	
		Walnut Clay	39.50	3.51
18	52	Lake Waco Formation	14.94	
		Woodbine Formation	33.05	18.11
19	57	Bonham Formation	19.81	
		Blossom Sand	17.54	2.27

TABLE 11--Continued

Set	Stream	Lithostratigraphic Units	Stream Frequency	Difference in Stream Frequency
20	60	Annona Chalk	27.96	
		Marlbrook Marl	39.64	11.68
21	63	Wolfe City Formation	58.89	
		Ozan Formation	29.74	13.58
22	64	Ozan Formation	50.99	
		Austin Chalk	38.00	12.99

null hypothesis was stated: For the drainage basins analyzed, there is not a significant correlation between large differences in stream frequencies between the two lithostratigraphic units in a drainage basin and Kolmogrov-Smirnov values that approach the rejection level. The null hypothesis could not be rejected at the .05 significance level (Appendix VI).

Spearman Rank Correlation--Elevation-Relief Ratio

It was theorized that there was an association between large deviations from the mean elevation-relief ratio and computed Kolmogrov-Smirnov values that approach the rejection level. For this test deviation of the elevation-relief ratio for each drainage basin was computed and subtracted from the mean elevation-relief ratio for its area (Appendix VI). These values were tested by the Spearman rank correlation test. The following null hypothesis was stated: There is not a significant correlation between deviation of the elevation-relief ratio for each basin from the area mean elevation-relief ratio and deviation of the Kolmogrov-Smirnov value from the rejection level. The null hypothesis could not be rejected at the .05 significance level (Appendix VI).

Spearman Rank Correlation--Basin Circularity

It was theorized that there was an association between deviation of basin shape from circular and Kolmogrov-Smirnov values that approach the rejection level. In order to test this hypothesis, the value for the elongation ratio for each basin was subtracted from one

which is the value attained for the elongation ratio for circular basins (Appendix VI). The following null hypothesis was tested: There is not a significant correlation between large deviations from circular and Kolmogrov-Smirnov values that approach the rejection level. The null hypothesis could not be rejected at the .05 level of significance (Appendix VI).

Analysis of Difference in Percent Observed and Predicted Per Order

In this analysis differences between percentage channels (basins) observed and predicted per order were evaluated. Data for this analysis was from the Kolmogrov-Smirnov analysis, but differed from the previous analysis in that percentage difference was analyzed without reference to rejection levels.

In ten of the twenty-two sets, the largest difference between the cumulative observed and cumulative predicted occurred for the fluvial system developed on two lithostratigraphic units (Table 12). Five of these sets (sets three, eight, eleven, fourteen, and twenty-one) were sets in which the computed value for the fluvial system on two lithostratigraphic units most closely approached the rejection level. The two groups do not coincide because of differences in N values which are used to enter tables at the proper significance level.

The question arises as to whether or not there is a significant association between difference in predicted and observed percent and the following: (1) drainage density, (2) stream frequency, (3) elevation-relief ratio, and (4) circularity as measured by the

TABLE 12

BASINS IN WHICH THE LARGEST DIFFERENCE BETWEEN CUMULATIVE OBSERVED AND PREDICTED OCCURRED FOR STREAM ON TWO FORMATIONS

Set	Stream
3	7
7	19
8	24
9	27
11	31
14	40
15	45
16	47
19	57
21	63

elongation ratio. In order to assess if an association between these variables and difference between observed and predicted existed, the Spearman rho was computed.

Spearman Rank Correlation--Drainage Density

It was theorized that there was an association between the predictive accuracy of the model and drainage density. It was thought that difference in drainage density between two adjacent lithostratigraphic units was one method of assessing the influence of lithostratigraphic units on drainage morphology. The twenty-two drainage basins on two lithostratigraphic units were isolated for analysis. For each of the twenty-two basins, drainage density was computed for each lithostratigraphic unit. Differences in drainage density between the two lithostratigraphic units in each set were computed (Table 10). It was hypothesized: As the difference in drainage density between two lithostratigraphic units increases, the percentage difference between observed and predicted percent increases. The following null hypothesis was formulated: There is not a significant correlation between increases in differences in drainage density and increases in differences between percent observed and predicted. The Spearman rho value was computed (Appendix VI) as a result of which the null hypothesis could not be rejected at the .05 level of significance. It was thus inferred that there was not a significant association between large differences in drainage density and large differences in cumulative observed and predicted percent.

Spearman Rank Correlation--Stream Frequency

A test of association similar to that for difference in drainage density was computed for stream frequency. It was hypothesized: As the difference in stream frequency between two lithostratigraphic units in a drainage system increases, the difference in cumulative observed and predicted percent increases. The following null hypothesis was stated: There is not a significant correlation between differences in stream frequencies for two lithostratigraphic units in a drainage basin and increases in differences in percentage observed channels and percentage predicted channels. The null hypothesis could not be rejected at the .05 significance level (Appendix VI). Results of the test indicated that there was not a significant correlation between large differences in stream frequency and large differences in observed and predicted percent for the twenty-two streams on two lithostratigraphic units.

Spearman Rank Correlation--Elevation-Relief Ratio

It was theorized that there was a significant correlation between the elevation-relief ratio and large differences in the cumulative observed and predicted percentages. The elevation-relief ratio yields a value that has been equated to the hypsometric value.[22] It was therefore postulated that because the model is postulated to be an equilibrium model that there was a possible association between the predictive accuracy of the model and deviation of drainage basin

[22]Pike and Wilson, "Elevation-Relief Ratio," p. 1080.

elevation-relief ratio from the mean elevation-relief ratio of the area in which it was located. It was hypothesized that as the elevation-relief ratio deviates from the mean of its group that the difference between the cumulative observed and predicted percent increases. To test if a significant association exists, the elevation-relief ratio for each drainage basin was subtracted from the mean elevation-relief ratio for the area in which it was located (Appendix VI). The following null hypothesis was tested: For the drainage basins under consideration there is not a significant correlation between large deviations of basin elevation-relief ratio from the mean of its group and large differences in the percent of channels observed and predicted per order by the model. The null hypothesis could not be rejected at the .05 level of significance (Appendix VI).

Spearman Rank Correlation--Elongation Ratio

It was theorized that there was an association between deviation from circular shape and differences in percentage predicted and observed. As the hexagon is four-fifths as efficient as the circle in terms of perimeter and distance from center,[23] it was hypothesized that as basins deviated from circular shape, as measured by the elongation ratio, the percentage difference between the cumulative observed and predicted number of channels increased. In order to test this hypothesis the computed value for the elongation ratio was subtracted from one (Appendix I). For the elongation ratio, a basin with a value

[23]Haggett and Chorley, Network Analysis in Geography, p. 51.

of one is considered circular. The Spearman rho was computed to determine, if as basin shape deviates from one (circular), the difference between cumulative observed and predicted percent increases. The following null hypothesis was stated: There is not a significant correlation between large deviations from the elongation ratio and large differences in the cumulative observed and predicted channels per order. The null hypothesis was rejected at the .05 level of significance (Appendix VI). Results of this test indicate that there is a weak association between deviation from circular shape and large differences in the percentage observed and predicted channels per order.

Allometry--Kolmogrov-Smirnov Values

It was theorized that there was a relationship between allometry and the predictive accuracy of the model. Strahler writes that a log-log relationship between cumulative stream length plotted against mean basin area is evidence for an allometric relationship between these variables. In this study evidence for allometric relationships was assessed by the manner described by Strahler. For each drainage system, cumulative mean channel length was plotted against mean basin area per order. For the sixty-six streams analyzed in this study there was a log-log relationship between cumulative stream length and mean basin area with small deviation of data points from the least squares regression line (Appendix VIII).

Allometry--Kolmogrov-Smirnov
Values Near Rejection Level

Those sets for which the computed Kolmogrov-Smirnov value most closely approached the rejection level for the drainage system on two formations were isolated for comparison with their respective allometric graphs. In only three sets (set two, set four, and set twenty-one) (Appendix VIII) did Kolmogrov-Smirnov values near the rejection level coincide with allometric graphs with largest scatter of data points from the least squares line. In nine of the twelve sets greatest scatter occurred for the two streams whose computed Kolmogrov-Smirnov value was farthest from the rejection level (Table 13). Thus, there is no apparent association between scatter from the least squares line for the allometric graphs and predictive accuracy of the model. However, this conclusion should be viewed with caution as the scatter of data points for each of the sixty-six allometric graphs is small. If the scatter of data points had been greater for the allometric graphs and thus clearly indicated lack of a log-log relationship, perhaps there would have been a better association between predictive accuracy of the model and the log-log relationship of the allometric graphs.

Allometry--Cumulative Percent
Predicted and Observed

An analysis similar to that just described was carried out to determine if there was an association between scatter of points from the least squares regression line for the allometric graphs and poor

TABLE 13

SETS IN WHICH KOLMOGROV-SMIRNOV VALUE NEAR SIGNIFICANCE LEVEL AND GREATEST SCATTER OF DATA POINTS FOR ALLOMETRIC GRAPHS OCCUR FOR THE CORRESPONDING STREAMS ON TWO UNITS

Sets with Stream on Two Units Having Kolmogrov-Smirnov Value Near Rejection Level		Corresponding Sets with Greatest Scatter of Data Points for Allometric Graphs for Stream on Two Units	
Set	Stream	Set	Stream
2	4	2	4
3	7		
4	11	4	11
5	15		
8	24		
10	30		
11	31		
12	36		
14	40		
17	50		
20	60		
21	63	21	63

prediction by the model as measured by difference in cumulative percent predicted per order and cumulative percent observed per order. Data for this analysis are from the Kolmogrov-Smirnov Test I; however, cumulative percent per order is analyzed without regard to rejection level. The ten sets of three drainage systems for which the greatest difference between cumulative observed and predicted percent per order occurred for the drainage system on two lithostratigraphic units were isolated for analysis. For only three sets (set three, set seven, and set twenty-one) did the basin with greatest difference between cumulative observed and predicted percent coincide with the basin whose allometric graph showed greatest scatter of data points from the least squares regression line. Results of this analysis indicated that for the sets analyzed there was little association between observed and predicted percent per order and scatter of points from the least squares regression line for the allometric graphs. As cited previously, caution is warranted in viewing these results because in each drainage system, there was a log-log relationship between cumulative stream length and mean basin area with little scatter of data points from the least squares regression line.

Kolmogrov-Smirnov Test I--Lithostratigraphic Units

Computed Value--Rejection Level

Deviation of computed Kolmogrov-Smirnov values from the rejection level was analyzed to determine if there was a particular lithostratigraphic unit associated with basins on two units for which the

model predicted poorly. This analysis was difficult because the various lithostratigraphic units were not each involved in the same number of sets (Table 14). Of the twenty-four lithostratigraphic units involved in this study, only the Wolfe City Formation and Pecan Gap Chalk were involved in five sets. The next highest in occurrence were the Marlbrook Marl and Ozan Formation. They were each involved in four sets. Other lithostratigraphic units were in one or two sets. However, it should be noted that for three of the five sets in which the Pecan Gap Chalk occurred the Kolmogrov-Smirnov value most closely approached the rejection level for the basin on two units. In these three sets, the Pecan Gap Chalk was one unit in sets which included the following units: Marlbrook Marl (set eight), Wolfe City Formation (set ten), and Kemp Clay (set twelve). The two sets in which the Pecan Gap occurred and where the computed Kolmogrov-Smirnov value most closely approached the rejection level for a drainage system other than the one on two units were: set seven (units: Pecan Gap Chalk--Marlbrook Marl), set nine (units: Pecan Gap Chalk--Wolfe City Formation). Because sets eight and ten and sets seven and nine contained the same lithostratigraphic units, it is doubtful if nearness of the Kolmogrov-Smirnov value to the rejection level can be attributed to inherent characteristics of the Pecan Gap Chalk.

In three of the five sets in which the Wolfe City Formation occurred the Kolmogrov-Smirnov value most closely approached the rejection level for the basin on two lithostratigraphic units. The Wolfe City Formation was a lithostratigraphic unit in sets which

TABLE 14

LITHOSTRATIGRAPHIC UNITS IN EACH SET

1	Sabinetown Formation--Carrizo Sand
2	Yegua Formation--Cook Mountain Formation
3	Oakville Sandstone--Lagarto Clay
4	Lagarto Clay--Goliad Sand
5	Catahoula Tuff--Oakville Sandstone
6	Wolfe City Formation--Marlbrook Marl
7	Pecan Gap Chalk--Marlbrook Marl
8	Pecan Gap Chalk--Marlbrook Marl
9	Pecan Gap Chalk--Wolfe City Formation
10	Pecan Gap Chalk--Wolfe City Formation
11	Wolfe City Formation--Ozan Formation
12	Kemp Clay--Pecan Gap Chalk
13	Carrizo Sand--Calvert Bluff Formation
14	Austin Chalk--Ozan Formation
15	Grayson Marl--Woodbine Formation
16	Sparta Sand--Cook Mountain Formation
17	Paluxy Sand--Walnut Clay
18	Lake Waco Formation--Woodbine Formation
19	Bonham Formation--Blossom Sand
20	Annona Chalk--Marlbrook Marl
21	Wolfe City Formation--Ozan Formation
22	Austin Chalk--Ozan Formation

included the following lithostratigraphic units: Marlbrook Marl (set six), Pecan Gap Chalk (sets nine and ten), Ozan Formation (sets eleven and twenty-one). Of these five sets the Kolmogrov-Smirnov value showed least deviation from the rejection level for: set ten (units: Pecan Gap Chalk, Wolfe City Formation), set eleven (units: Wolfe City Formation, Ozan Formation), and set twenty-one (Wolfe City Formation, Ozan Formation). It should be pointed out that the Wolfe City Formation and Ozan Formation were combined in only two sets, and in these sets the largest computed Kolmogrov-Smirnov value occurred for the basins on two lithostratigraphic units. In both sets the difference in drainage density between the two units exceeded one, with the Wolfe City Formation having the higher drainage density. However, it is doubtful that the small range of the computed value from the rejection level can be attributed to difference in drainage density as Spearman Rank correlation indicates that, when all streams on two lithostratigraphic units are considered, there is not a significant correlation between differences in drainage density and computed Kolmogrov-Smirnov values near the rejection level.

In three of the four sets in which the Ozan Formation occurred the Kolmogrov-Smirnov value most closely approached the rejection level for the basin on two lithostratigraphic units. The Ozan Formation was one of two units which included the following lithostratigraphic units: Wolfe City Formation (set eleven), Austin Chalk (set fourteen), and Wolfe City Formation (set twenty-one). In set twenty-two the computed Kolmogrov-Smirnov value nearest the rejection level

did not occur for the basin on two units. In this set the two lithostratigraphic units involved were the Austin Chalk and Ozan Formation. It should be noted that the Austin Chalk and Ozan Formation were in set fourteen in which the computed Kolmogrov-Smirnov value most closely approached the rejection level for the stream on two units.

The Marlbrook Marl was a unit in the following sets: set six (units: Wolfe City Formation--Marlbrook Marl), set seven (units: Pecan Gap Chalk--Marlbrook Marl), set eight (units: Pecan Gap Chalk--Marlbrook Marl), and set twenty (units: Annona Chalk--Marlbrook Marl). In two of these sets (set eight and set twenty) the computed Kolmogrov-Smirnov value was nearest the rejection level for the drainage basin developed on two units.

Difference in Cumulative Observed and Predicted Percent

Lithostratigraphic units involved in sets in which the largest difference in cumulative observed and predicted number of channels occurred for the drainage basin developed on two units were isolated for analysis. In this analysis cumulative percentages were derived from Kolmogrov-Smirnov test I; however, cumulative percentages were considered without regard to rejection level. In ten of the twenty-two sets of three streams the largest difference between cumulative observed and predicted percent occurred for the drainage basin developed on two lithostratigraphic units (Table 15).

In three of the five sets in which the Pecan Gap Chalk was involved, the largest difference between observed and predicted

TABLE 15

TEN SETS AND LITHOSTRATIGRAPHIC UNITS FOR WHICH LARGEST DIFFERENCE BETWEEN PERCENT OBSERVED AND PREDICTED OCCURRED FOR THE BASIN ON TWO FORMATIONS

Set	Stream	
3	7	Oakville Sandstone--Lagarto Clay
7	19	Pecan Gap Chalk--Marlbrook Marl
8	24	Pecan Gap Chalk--Marlbrook Marl
9	27	Pecan Gap Chalk--Wolfe City Formation
11	31	Wolfe City Formation--Ozan Formation
14	40	Austin Chalk--Ozan Formation
15	45	Grayson Marl--Woodbine Formation
16	47	Sparta Sand--Cook Mountain Formation
19	57	Bonham Formation--Blossom Sand
21	63	Wolfe City Formation--Ozan Formation

percent occurred for the drainage basin on two units. These sets were: set seven (units: Pecan Gap Chalk, Marlbrook Marl), set eight (units: Pecan Gap Chalk, Marlbrook Marl), and set nine (Pecan Gap Chalk, Wolfe City Formation). The Pecan Gap Chalk was a lithostratigraphic unit in sets ten and twelve, and in these two sets the largest difference between cumulative observed and predicted percent did not occur for the drainage basins on two lithostratigraphic units. In set ten the Pecan Gap Chalk was combined with the Wolfe City Formation and in set twelve the Pecan Gap Chalk was combined with the Kemp Clay. It should be noted that in both sets nine and ten the Pecan Gap Chalk and Wolfe City Formation were in combination, and that in set ten the largest difference between cumulative predicted and observed percent did not occur for the drainage system on two units.

In three of the five sets in which the Wolfe City Formation was involved the largest difference occurred for the stream on two units. The three sets were: set nine (units: Pecan Gap Chalk, Wolfe City Formation), set eleven (units: Wolfe City Formation, Ozan Formation), and set twenty-one (units: Wolfe City Formation, Ozan Formation). The two sets in which the Wolfe City Formation occurred and for which the largest difference in cumulative percent observed and predicted did not occur for the drainage basins on two lithostratigraphic units were: set six (units: Wolfe City Formation, Marlbrook Marl) and set ten (Pecan Gap Chalk, Wolfe City Formation). In set nine the largest cumulative difference between percentage observed and predicted occurred for the basin on two units (Wolfe City Formation,

Pecan Gap Chalk), whereas in set ten where the Pecan Gap Chalk and Wolfe City Formation were combined the largest difference did not occur for the basin with two units. In the two sets where the Wolfe City Formation and Ozan Formation were combined the largest difference occurred for the basin developed on two lithostratigraphic units.

In three out of the four sets in which the Ozan Formation occurred, the largest difference occurred for the fluvial systems developed on two units. Two of the sets with highest difference between percentage observed and predicted were sets eleven and twenty-one where the Ozan Formation was combined with the Wolfe City Formation. The third set where the largest difference between percentage observed and predicted occurred for the drainage system on two lithostratigraphic units was set fourteen in which the Wolfe City Formation was combined with the Austin Chalk. In set twenty-two the Ozan Formation was combined with the Austin Chalk, but in this set the greatest difference between percentage observed and predicted did not occur for the drainage basin developed on two units.

The Marlbrook Marl formed a unit in four sets. Two of the four sets (sets seven and eight) were sets with the largest difference between cumulative percentage observed and predicted occurring for the stream developed on two units. In both of these sets (sets seven and eight) the Marlbrook Marl was combined with the Pecan Gap Chalk. In the two sets (sets six and twenty) in which the Marlbrook Marl was involved and where the largest differences between percentage observed and predicted did not occur for the drainage basin on two units, the

Marlbrook Marl was in combination with the Wolfe City Formation (set six) and the Annona Chalk (set twenty).

Conclusion Kolmogrov-Smirnov Test--
Lithostratigraphic Units

Analysis of units other than the Pecan Gap Chalk, Wolfe City Formation, Marlbrook Marl, and Ozan Formation becomes meaningless as all other units were involved in only one or two sets. However, it should be noted that the two sets in which the Oakville Sandstone and Lagarto Clay were each involved, the poorest prediction of the model, as measured by nearness of the computed Kolmogrov-Smirnov value to the rejection level, occurred for the drainage system on two units.

Isolation of particular lithostratigraphic units that influenced the predictive accuracy of the model was not permitted by this study. Evaluation of the influence of a particular lithostratigraphic unit on the predictive accuracy of the model would require a research design in which a given unit is tested in numerous sets. Isolation of the influence of a single unit was not the purpose of the research under consideration. However, based on analysis of lithostratigraphic units involved, it is concluded that further analysis of the impact of the following units warrants consideration in subsequent studies. The units are: Pecan Gap Chalk, Wolfe City Formation, Ozan Formation, Lagarto Clay, and Oakville Sandstone.

Kolmogrov-Smirnov Values--Basin Areas

In four of the five sets in Area I, the computed Kolmogrov-Smirnov values nearest the rejection level occurred for the drainage system on two lithostratigraphic units. It was observed that mean basin area for Area I was larger than the mean for Areas II and III. It was, therefore, theorized that there was a possible association between basin area and the predictive accuracy of the model. To test this hypothesis, the Spearman rank correlation test was employed to determine if there was a significant association between Kolmogrov-Smirnov values near the rejection level and large basin areas. For the sixty-six streams analyzed there was not a significant association between large basin areas and Kolmogrov-Smirnov values that approached the rejection level (Appendix VII).

The Spearman rank correlation test was carried out in order to determine if there was an association between large differences between cumulative percent observed and predicted per order and large basin areas. At the .05 level of significance, for the sixty-six streams in this study there was not a significant correlation between large differences in cumulative percent channels observed and predicted per order and large basin areas (Appendix VII).

Kolmogrov-Smirnov Test II

Woldenberg[24] and Berry[25] equate the log-normal distribution to steady state. Woldenberg postulates that the linear relationship of stream numbers (logarithmic) plotted against stream order (arithmetic) is actually a logarithmic relationship and therefore represents a steady state. Woldenberg proposes the general hypothesis that "the power function relationships in rivers, which have been called allometric growth, derive from approximate geometric progressions in the size of hexagonal basins."[26] Woldenberg proposes that the convergent mean model is an equilibrium model that replicates natural basins.[27] Based on these premises, it was hypothesized that those drainage systems for which there were large deviations of data points from the least squares regression line (the observed number of channels logarithmetically plotted against arithmetically plotted stream order) coincide with those drainage systems for which there was maximum

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[24]Michael J. Woldenberg, "Horton's Laws Justified in Terms of Allometric Growth and Steady State in Open Systems," Geological Society of America Bulletin, LXXVII (April, 1966), 431-34.

[25]Brian J. L. Berry, "Cities as Systems within Systems of Cities," The Regional Science Association Papers, XIII (1964), 149.

[26]Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Geological Society of America Bulletin, LXXX (January, 1969), 109.

[27]Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Harvard Papers in Theoretical Geography, No. 13, Office of Naval Research Tech. Report, Proj. N.R. 389-147, Harvard University, 1968, p. 38.

deviation between model and observed data. The Kolmogrov-Smirnov test was used to test this hypothesis.[28]

The purpose of the Kolmogrov-Smirnov test was twofold: (1) to determine if there was a significant deviation of the data points from the regression line; (2) to determine if those basins which have computed values that approach the significance level for Kolmogrov-Smirnov Test II were basins for which values for Kolmogrov-Smirnov Test I approached the rejection level.

Results of Kolmogrov-Smirnov Test II

In order to determine if there was a significant deviation of the observed data points from the least squares line, the following hypothesis was formulated: Data points do not significantly deviate from the least squares line. Null hypothesis: Data points significantly deviate from the least squares regression line. Based on the Kolmogrov-Smirnov test, the null hypothesis was rejected for each of the sixty-six fluvial systems at the .05 level of significance (Appendix IX). It was concluded that for the sixty-six drainage basins there was not a significant deviation of data points from the least squares regression line.

Comparison of nearness of computed values to the rejection level for Kolmogrov-Smirnov Test II to the nearness of computed values to the rejection level for Kolmogrov-Smirnov Test I showed that in

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[28]The Kolmogrov-Smirnov test of this hypothesis is referred to as Kolmogrov-Smirnov Test II to distinguish it from the previous Kolmogrov-Smirnov test referred to as Kolmogrov-Smirnov Test I.

sixteen of the twenty-two sets computed values near the rejection level occurred for the same basins for Kolmogrov-Smirnov Tests I and II (Table 16). Spearman rank correlation was used to determine if, when all sixty-six streams are considered, there is a correlation between small deviations for computed values from the rejection level for Kolmogrov-Smirnov Test I and Kolmogrov-Smirnov Test II. To carry out this test, the following research hypothesis was formulated: There is a significant correlation between small deviations of computed values from the rejection level for Kolmogrov-Smirnov Tests I and II. The null hypothesis was as follows: There is not a significant correlation between small deviations of computed Kolmogrov-Smirnov values from the rejection level for Kolmogrov-Smirnov Tests I and II. Based on Spearman rank correlation analysis the null hypothesis was rejected at the .05 significance level (Appendix X).

As a result of this analysis, it was concluded that as data points for fluvial systems deviate from the least squares line that the predictive accuracy of the model decreases. This suggests that as the number of channels per order plotted against order deviate from a log-normal relationship that the predictive accuracy of the model tends to decrease. If a log-log relationship represents steady state, and if a semi-log relationship of channels per order plotted against order is actually a log-log relationship, it is suggested that the predictive accuracy of the model decreases as the drainage systems deviate from the steady state as measured by the log-normal distribution of the number of channels plotted against order.

TABLE 16

SETS IN WHICH THE COMPUTED VALUES NEAR THE SIGNIFICANCE LEVEL FOR KOLMOGROV-SMIRNOV TESTS I AND II OCCUR FOR THE SAME STREAM

Set	Stream
2	4
3	7
4	11
5	15
6	16
7	21
8	25
10	30
12	36
14	40
15	44
17	50
18	53
19	55
20	60
21	63

Results of the above analysis raised the question of whether or not there is justification for inferring that the model predicts better for those basins in which there are small deviations of observed data points from the least squares regression line. Deviations from the rejection level for Kolmogrov-Smirnov Test II were analyzed. In this analysis, large deviations of computed values from the rejection level were examined because large deviations from the rejection level are a measure of goodness of fit of model and observed data. In sixteen of the twenty-two sets of three basins, the largest deviation of computed Kolmogrov-Smirnov values from the rejection level for Kolmogrov-Smirnov Tests I and II occurred for the same drainage basins (Table 17). It should be noted that these sixteen sets are not necessarily the same sixteen sets as those cited previously. Spearman rank correlation was used to determine if there was a correlation between large deviations from the rejection level for computed values for Kolmogrov-Smirnov Tests I and II. The null hypothesis of no significant correlation was rejected at the .05 level of significance (Appendix X). It was thus inferred that for the drainage basins analyzed that, as the data points for the graphs of number of channels plotted against order approached the least squares line, the model predicts better. Stated in terms of Woldenberg's definition of steady state, it can be inferred that for the basins analyzed the model predicts better for those drainage basins in which graphs of the number of channels plotted against order approach a steady state graph.

TABLE 17

SETS IN WHICH THE COMPUTED VALUES WITH GREATEST DEVIATION FROM SIGNIFICANCE LEVEL FOR KOLMOGROV-SMIRNOV TESTS I AND II OCCUR FOR THE SAME STREAM

Set	Stream
1	3
2	5
3	8
5	14
6	18
8	22
10	29
11	32
12	35
13	38
14	41
15	45
17	49
18	52
20	59
21	62

Sum of Channels Observed and Predicted for Each Basin

It was hypothesized that if lithostratigraphic units in the study areas significantly influence the predictive accuracy of the model, that when the sum of the observed channels and the sum of the predicted channels for each drainage basin are considered that the percentage deviation between the sum of the predicted and the sum of the observed should be larger for those drainage basins developed on two lithostratigraphic units than those developed on one lithostratigraphic unit. In order to test this hypothesis the number of observed channels and the number of predicted channels for each drainage basin were summed. The difference between these values was determined by subtraction. The percent by which the model value deviated from the observed data was determined by dividing the difference between the sum of the predicted and the sum of the observed by the sum of the observed channels (Appendix XI). The following formula was followed:

$$O - P = d$$

$$\frac{d}{O} \times 100 = d^1$$

where:

$O = \Sigma$ of observed channels

$P = \Sigma$ of predicted channels

d = deviation of P from 0

d^1 = percent deviation of model

Mann-Whitney U Test

The Mann-Whitney test was chosen to test this hypothesis because it is a nonparametric test and as such does not require normal data.[29] For the data tested, the assumption of normality was unwarranted. The Mann-Whitney U test is designed to test for a significance of difference between two ranked samples. It should be noted that when the computed value for the Mann-Whitney test was compared with table values that a different procedure was followed than for the Kolmogrov-Smirnov test. In order to reject the null hypothesis, when the Mann-Whitney test is used, the computed value must be equal to or smaller than the table value.[30]

In order to test the research hypothesis, the following null hypothesis was stated: There is not a significant difference between the percent deviation of total predicted from total observed for the forty-four basins on one lithostratigraphic unit as compared to the twenty-two basins on two lithostratigraphic units. Based on results of the Mann-Whitney test the null hypothesis could not be rejected at the .05 level of significance (Appendix XI). As a result of this test, it was concluded that when the percentage deviation of the total number of channels observed and predicted are considered, there is not a significant difference in the accuracy with which the model predicts for those basins on one unit as compared to those basins on two units.

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[29]Champion, Basic Statistics for Social Research, p. 176.

[30]Ibid., p. 178.

Spearman Rank Correlation--Total Observed--Predicted

Spearman rank correlation was employed to determine if there was a significant association between large percentage deviation between the sum of the predicted channels and the sum of the observed channels and the following: (1) large differences in drainage density and stream frequency between lithostratigraphic units in basins with two lithostratigraphic units, (2) elevation-relief ratio, and (3) basin circularity.

Drainage Density--Stream Frequency

It was hypothesized that those drainage basins developed on two lithostratigraphic units having large differences in drainage density should be associated with those drainage basins with large percentage differences between the sum of the channels predicted by the model and the sum of the channels observed. To test this hypothesis, the twenty-two drainage basins on two units were isolated. Differences in drainage density and stream frequency between the two lithostratigraphic units were determined. The following null hypothesis was formulated: For the twenty-two drainage basins analyzed, there is not a significant correlation between large differences in drainage density and large percentage differences between the total number of channels predicted for the drainage basin and the total number of channels observed for the drainage system. Based on results of the Spearman rank correlation test, the null hypothesis could not be rejected at the .05 level of significance (Appendix XII).

In the stream frequency analysis, the following null hypothesis was tested: For the twenty-two drainage basins developed on two units, there is a significant correlation between large differences in stream frequency between two units in a drainage basin and large percentage differences between the sum of the channels predicted for the drainage basin and the sum of the channels observed for the drainage basin. As a result of the Spearman rank correlation test, the null hypothesis could not be rejected at the .05 level of significance (Appendix XII).

It was concluded that for the twenty-two basins analyzed, there was not a significant association between large differences in drainage density and stream frequency between two units in a drainage basin and the predictive accuracy of the model as measured by the percentage difference between the sum of the predicted and the sum of the observed channels.

Spearman Rank Correlation--
Elevation-Relief Ratio

It was hypothesized that the model predicted with greater accuracy for those drainage basins with small deviations from the group mean elevation-relief ratio. In order to test this hypothesis, the mean elevation-relief ratio was computed for Areas I, II, and III. The group mean was computed by summing the elevation-relief values for each drainage basin and dividing by the number of drainage basins in each group. The elevation-relief ratio of each basin was subtracted from its area mean to determine the deviation of its elevation-relief

ratio from the area mean. To test the hypothesis, the following null hypothesis was stated: There is not a significant correlation between large deviations from the group mean elevation-relief ratio and large percentage differences between the sum of the channels predicted by the model and the sum of the channels observed for each drainage basin. As a result of the Spearman rank correlation test, the null hypothesis could not be rejected at the .05 significance level (Appendix XII). It was therefore concluded that there was not a significant association between deviation of the elevation-relief ratio from the group mean and predictive accuracy of the model as measured by the percentage difference between the sum of the predicted and the sum of the observed channels per drainage basin.

Spearman Rank Correlation--Basin Circularity

It was hypothesized that there was an association between circular form and predictive accuracy of the model as measured by the percentage difference between the sum of the predicted and the sum of the observed channels per drainage basin. This hypothesis was based on the premise that the hexagon is four-fifths as efficient as the circle in terms of radius and perimeter.[31] Therefore, it was hypothesized that as basins approach a circular form they resemble the hexagon in terms of perimeter and radius. The following research hypothesis was formulated: There is a significant correlation between large deviations from circular form (as measured by the elongation ratio) and

[31]Haggett and Chorley, Network Analysis in Geography, p. 51.

large percentage differences between the sum of the predicted and the sum of the observed channels per drainage basin. The following null hypothesis was stated: There is not a significant correlation between large deviations from circular form and large percentage differences between the sum of the predicted and the sum of the observed channels per drainage basin. Based on the Spearman rank correlation test, the null hypothesis could not be rejected at the .05 level of significance (Appendix XII). Thus, as a result of Spearman rank correlation, it was concluded that there was not a significant association between deviation from circular shape as measured by the elongation ratio and predictive accuracy of the model as determined by the percentage difference between the sum of the channels predicted by the model and the sum of the channels observed for each drainage basin.

Allometry--Total Predicted-Observed

The six sets in which the largest percentage deviation of the sum of predicted from the sum of observed occurred for the basin on two lithostratigraphic units were isolated for analysis. The sets involved in this analysis were: set two (units: Yegua Formation--Cook Mountain Formation), set three (units: Oakville Sandstone--Lagarto Clay), set six (units: Wolfe City Formation--Marlbrook Marl), set twelve (units: Kemp Clay--Pecan Gap Chalk), set seventeen (units: Paluxy Sand--Walnut Clay), and set nineteen (units: Bonham Formation--Blossom Sand). Only in set two did largest deviation of data points from the allometric graph regression line occur for the drainage basin on two lithostratigraphic units (drainage basin four). This suggests

that there is little if any relationship between the graphs of allometric relationships and predictive accuracy of the model as measured by percentage deviation of the sum of the predicted number of channels per basin and the sum of the observed channels per basin.

Analysis of Regression Slope Values

It was hypothesized that if lithostratigraphic units in the study areas significantly influence the predictive accuracy of the model, the slope of the regression line for the observed data and the slope of the regression line for the predicted data should differ significantly for those drainage basins developed on two lithostratigraphic units. Because the antilog of the slope value (b value) of the regression line approximates the mean bifurcation ratio for the drainage system,[32] the above hypothesis can be restated in terms of the bifurcation ratio (Appendix XIII). If lithostratigraphic units in the study area significantly influence the predictive accuracy of the model, the mean bifurcation ratio of the observed data and the mean bifurcation ratio for the predicted data should differ significantly.

The following null hypothesis was stated: For each drainage basin, there is not a significant difference between the slope of the regression line for the observed data and the slope of the regression line of the predicted data (Appendix XIII). The null hypothesis could not be rejected at the .05 level of significance (Appendix XIII). For

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[32] James C. Maxwell, "The Bifurcation Ratio in Horton's Law of Stream Numbers," Transactions American Geophysical Union, XXXVI (June, 1955), 520.

the sixty-six streams analyzed there was not a significant difference in the slope values of the regression lines whether the drainage basins were developed on one or two lithostratigraphic units. Each of the twenty-two sets of three drainage basins were analyzed to determine if the largest computed[33] value for the regression line analysis occurred for the drainage basin on two units or if the largest values occurred for the stream on one unit. Of the twenty-two sets under consideration, the largest value for the regression analysis occurred for the drainage basin on two units in only five sets.

The sets in which the largest computed value for the regression analysis occurred for the stream on two units were: set seven (units: Pecan Gap Chalk--Marlbrook Marl), set nine (units: Pecan Gap Chalk--Wolfe City Formation), set thirteen (units: Carrizo Sand--Calvert Bluff Formation), set fifteen (units: Grayson Marl--Woodbine Formation), and set eighteen (units: Lake Waco Formation--Woodbine Formation). Only two lithostratigraphic units (Pecan Gap Chalk and Woodbine Formation) were involved in more than two drainage basins in which the largest computed value was for the drainage basin on two lithostratigraphic units.

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[33]For the regression slope analysis a method was employed that is described by Crow, Maxfield, and Davis. Edwin L. Crow, Frances A. Davis, and Margaret W. Maxfield, Statistics Manual (New York: Dover Publications, Inc., 1960), pp. 160-63.

Spearman Rank Correlation--Drainage Density--Stream Frequency

Spearman rank correlation was used to determine if there was an association between large computed values for the regression analysis and large differences in drainage density and stream frequency between two units combined in a drainage basin. It was theorized that two measures of difference in lithology were drainage density and stream frequency. Based on this premise, it was hypothesized that those drainage basins on two lithostratigraphic units which have large differences in drainage density should coincide with those drainage basins with large computed values for the regression analysis. In order to test this hypothesis, the twenty-two drainage basins on two units were isolated for analysis. Difference in drainage density and stream frequency for each lithostratigraphic unit combined in a drainage basin was determined. The following null hypothesis was tested: For the twenty-two drainage basins on two lithostratigraphic units, there is not a significant correlation between large differences in drainage density and large computed values for the regression analysis. Based on the Spearman rank correlation test, the null hypothesis could not be rejected at the .05 significance level (Appendix XIV). Thus, it was concluded that there was not a significant correlation between large differences in drainage density and large computed values for the regression analysis.

The second null hypothesis tested was as follows: For the twenty-two drainage basins on two lithostratigraphic units, there is

not a significant correlation between large differences in stream frequency between two lithostratigraphic units in a drainage basin and large computed values for the regression analysis. Based on the Spearman rank correlation test, the null hypothesis could not be rejected at the .05 level of significance (Appendix XIV). Thus, it was concluded that there was not a significant correlation between large differences in stream frequency between two units in a drainage basin and large computed values for the regression analysis.

Elevation-Relief Ratio--Basin Circularity

Two additional morphometric parameters were tested for correlation with large computed values for the regression analysis test. They were elevation-relief ratio and basin circularity. These parameters do not directly assess the influence of lithostratigraphic units on the model, but they were isolated for analysis because each is a measure of a variable considered to be pertinent to the model (see pages 100-102).

It was hypothesized that the model should predict with greater accuracy for those drainage basins with small deviations from the area mean elevation-relief ratio. To test this hypothesis, the mean elevation-relief value was computed for each area. The deviation of each basin's elevation-relief ratio was computed by subtracting each basin's elevation-relief ratio from the mean of the area in which it was located. This procedure was followed for each of the three areas. It was hypothesized that there was a significant correlation between

large deviations from the area mean elevation-relief ratio and large computed values for the regression analysis. The following null hypothesis was formulated: There is not a significant correlation between large deviations from the area mean elevation-relief ratio and large computed values for the regression slope analysis. Based on Spearman rank correlation analysis, the null hypothesis could not be rejected at the .05 significance level (Appendix XIV). Thus, it was concluded that there is not a significant correlation between large deviations from the area mean elevation-relief ratio and large computed values for the regression analysis. Results were similar for each area.

It was hypothesized that there was a significant correlation between circular shape and predictive accuracy of the model. This was based on the premise that the hexagon is four-fifths as efficient as the circle in terms of radius and perimeter.[34] It was theorized that basins approaching circular shape resemble the hexagon in terms of perimeter and radius. The following research hypothesis was formulated: There is a significant correlation between large deviations from circular shape as measured by the elongation ratio and large computed values for the regression slope analysis. The null hypothesis was as follows: There is not a significant correlation between large deviation from circular shape as measured by the elongation ratio and large values for the regression slope analysis. The null hypothesis could not be rejected at the .05 significance level (Appendix XIV).

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[34]Haggett and Chorley, Network Analysis in Geography, p. 51.

In this test deviation from circular form was determined by computing the elongation ratio for each drainage basin. A computed value of one for the elongation ratio represents circular form; therefore, the computed elongation ratio for each drainage basin was subtracted from one to determine deviation from circular.

Regression Analysis Values--Allometric Graphs

The five sets in which the greatest computed value for the regression slope (b value) analysis occurred for basins on two units were isolated for comparison with the allometric graphs. In only one of the five sets, set seven, did the greatest deviation from the regression line for the allometric graph coincide with the basin on two lithostratigraphic units. In set eighteen the greatest deviation of a single point from the regression line occurred for the drainage system on two lithostratigraphic units (drainage basin fifty-two). However, the two drainage basins in this set developed on one unit have two points each of which deviate from the regression line (Appendix VIII). Based on this analysis there appears to be little association between the deviation of data points from the regression line for the allometric graphs and large computed values for the slope analysis of the regression lines.

CHAPTER V

INTERPRETATION OF RESULTS

Statistical Tests

Based on three statistical tests (Kolmogrov-Smirnov, Mann-Whitney U test, and analysis of regression slope values) it is concluded that for the basins analyzed lithostratigraphic units do not significantly influence the predictive accuracy of the convergent mean model when basins on two lithostratigraphic units are compared to basins on one lithostratigraphic unit (Appendixes V, XI, and XIII). It should be noted that in twelve of the twenty-two basin sets the computed value nearest the rejection level for the Kolmogrov-Smirnov test occurred for the basin on two lithostratigraphic units. Thus, for 54.54 percent of the basin sets lithostratigraphic units appear to influence, though not significantly, the predictive accuracy of the model. Analysis of computed values for the Kolmogrov-Smirnov test, without regard to rejection levels, shows that in ten of the twenty-two sets (45.45 percent) the largest computed value (difference between cumulative percent predicted and percent observed channels per order) occurred for the basin on two lithostratigraphic units. These analyses indicate that lithostratigraphic units influence, though not at a statistically significant level, the predictive accuracy of the model.

Analysis of computed values for the regression slope analysis does not indicate a similar influence of lithology. For only five sets did the computed value nearest the rejection level occur for the basin on two lithostratigraphic units. Therefore, when this test is considered the influence of lithostratigraphic units on the model is negligible. Differences between results of the two tests may be related to characteristics of the tests. The Kolmogrov-Smirnov test is a graph test that tests for significance of difference between two cumulative frequency distribution graphs. In order to test hypotheses, maximum difference between cumulative observed and predicted channels per order is compared to table values. It is felt that this procedure tends to bias the test as it is used in this study. For fifty-one of the sixty-six basins, maximum difference between cumulative percent observed and predicted occurred at the first order and these channels were the most difficult to identify. Although extreme care was used in identifying first order channels, greatest chance for measurement error was at the first order. In contrast, analysis of regression slope values involved a test for significance of difference between slope values for two least squares regression lines. As a consequence, it was not influenced to as great an extent by frequency of channels at a particular order.

Interpretation of Correlation Analysis

Drainage Density and Stream Frequency

Lack of significant correlation between measures of accuracy of prediction of the convergent mean model and large differences in drainage density and large differences in stream frequency between lithostratigraphic units combined in drainage basins is interpreted as evidence that these variables do not significantly influence the predictive accuracy of the model. These results as well as the large range of drainage densities and stream frequencies indicate that the model has sufficient flexibility to replicate (within the limits of statistical significance) the number of channels per order for fluvial systems within a wide range of drainage densities and stream frequencies.

Elevation-Relief Ratio

Absence of significant correlation between measures of accuracy of prediction and deviation of elevation-relief ratios from the mean elevation-relief ratios, suggests that within the range of elevation-relief ratios represented the predictive accuracy of the model is not significantly influenced by deviation of basin elevation-relief ratio from the area mean elevation-relief ratio. Elevation-relief ratios lie within the limits of equilibrium for hypsometric values (equated to elevation-relief values) as outlined by Chorley; all but eight basins are within the limits of equilibrium hypsometric values as defined by Strahler. It is therefore inferred that the

basins analyzed are in quasi-equilibrium; consequently, deviation of predicted data from observed data is not significantly related to deviation of elevation-relief ratios from area means. It may be that deviations are random occurrences within the limits of quasi-equilibrium. It is recommended that in future studies the influence of equilibrium, as measured by the elevation-relief ratio, on the model be measured where elevation-relief ratios clearly indicate disequilibrium.

Elongation Ratio

Results of rank correlation analysis of predictive accuracy of the model and deviation of basin elongation ratios from one (unity) indicates lack of significant correlation in all but one correlation test. Small standard deviation of elongation ratios from area mean elongation ratios and lack of significant difference (Kruskal-Wallis test, Appendix I) of elongation ratios between the three areas may be interpreted as evidence for equilibrium for the areas. This may account for absence of significant correlation in all but one of the correlation tests.

A significant correlation was found between large deviations of cumulative percent observed from cumulative percent predicted per order and deviation of elongation ratios from an index of one. This correlation is viewed with caution because other correlation analyses failed to show a significant correlation. However, it cannot be disregarded. The data probably do not justify inferring that predictive

accuracy of the model is related to shape, but it does indicate that influence of the elongation ratio on the predictive accuracy of the model warrants consideration in subsequent studies. Analysis of basins in which there is considerable variation of elongation ratios from regional mean elongation ratios is recommended; basin shape could be critical as the model is based on a particular form, the hexagon.

Kolmogrov-Smirnov Test II

The Kolmogrov-Smirnov test (referred to as Kolmogrov-Smirnov Test II) was used to test for significant deviation of data points from the least squares regression line for the graphs of channel frequency plotted against channel order. It was theorized that if the model is an equilibrium model there should be a significant correlation between predictive accuracy of the model and small deviation of data points from the least squares regression lines. In conjunction with this test, Spearman rank correlation was used to determine if there was a significant correlation between deviation of data points from the regression line and predictive accuracy of the convergent mean model. Results of these tests are interpreted as evidence that (1) the basins analyzed have attained a quasi-equilibrium within the limits of steady state as defined by Woldenberg and Berry; and (2) as data points approach the least squares regression line (that is, approach a steady state as defined by Woldenberg and Berry) the predictive accuracy of the model increases.

Conclusions

Lithology

Data from this study corroborate the research hypothesis that lithostratigraphic units in the study areas do not significantly influence the predictive accuracy of the model. For the study areas it is inferred that the restraint of the model to areas of homogeneous lithology, as defined by the lithostratigraphic unit, is unwarranted.

Lack of correlation between poor prediction of the convergent mean model and variables analyzed implies that deviation of observed from predicted data may be a random occurrence within the limits of quasi-equilibrium. Evidence indicates that the drainage basins have, through the interaction of variables, adjusted to differences in lithology and have reached a quasi-equilibrium. Analysis of stream frequency and drainage density indicates that differences in form are present. However, in light of data obtained from the elongation ratio, elevation-relief ratio, and regression analysis (Kolmogrov-Smirnov Test II) these differences are interpreted as reflecting differences in reaction of the rock to the forces of erosion rather than indicating disequilibrium. In this regard, Hack postulates that in areas where the topography is adjusted, that is in equilibrium, differences in form occur which he interprets as reflecting differences in resistance to erosion.[1]

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[1]John T. Hack, "Interpretation of Erosional Topography in Humid Temperate Regions," American Journal of Science, CCLVII-A (Bradley Volume, 1960), 89.

The influence of equilibrium as well as lithology on the model warrants consideration in other areas before resolution of the problem of the influence of lithology on the model is permitted and before postulating a model restraint in terms of lithology is justified.

Model

General Hypothesis

This study supports the convergent mean model; however, the static nature of the data analyzed does not permit direct evaluation of the general hypothesis proposed by Woldenberg (". . . the power function relationships in rivers which have been called allometric growth derive from approximate geometric progressions in the size of hexagonal basins.")[2] Evidences for allometric or power function relationships are present within the basins studied. However, to infer that these power function relationships are a result of allometric growth would be speculative at this time.[3] Resolution of the question of an underlying growth mechanism awaits further research. Until more evidences for allometric growth are available perhaps the general hypothesis could be more judiciously stated as follows: The power function

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[2]Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Geological Society of America Bulletin, LXXX (January, 1969), 104.

[3]For a discussion of the difficulties in applying the concept of allometric growth to geomorphology see M. P. Mosley and R. S. Parker, "Allometric Growth: A Useful Concept in Geomorphology?" Geological Society of America Bulletin, LXXXIII (December, 1972), 3669-74.

relationships in rivers derive from approximate geometric progressions in the size of hexagonal basins.

Bifurcation Ratios

In addition, comparison of bifurcation ratios produced by the model with observed bifurcation ratios shows a goodness of fit that supports the deterministic model. Woldenberg states that ". . . if the convergent mean model is accepted, one must reject the idea that bifurcation ratios, and by inference other similar ratios, can be constant."[4] Flexibility of bifurcation ratios between orders within drainage basins is permitted by the model and is cited by Woldenberg as an advantage of the deterministic model. Comparison of model and observed data in this study shows that while replicating mean bifurcation ratios (within limits of statistical significance) adequate flexibility is permitted by the model to produce between order bifurcation ratios that are similar to observed between order bifurcation ratios. This implies that the power function relationships (bifurcation ratios) of the basins analyzed are approximated by the power function relationships generated from the mixed hexagonal progression of the convergent mean model.

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[4]Michael J. Woldenberg, "Spatial Order in Fluvial Systems: Horton's Laws Derived from Mixed Hexagonal Hierarchies of Drainage Basin Areas," Harvard Papers in Theoretical Geography, No. 13 (Office of Naval Research Tech. Report, Proj. N.R. 389-147, Harvard University, 1968), 36.

Systems Analogy

Data for the basins analyzed support the hypothesis that the convergent mean model originally developed for urban systems is applicable to fluvial systems. Consequently, at the topologic level of resolution it appears that fluvial and urban systems (central place systems) are similar hierarchical systems. Both systems appear to possess form functional relationships expressed by the allometric law ($y = ax^b$). The form functional relationship in fluvial systems may represent a least work equilibrium as inferred by Woldenberg and Berry[5] and Nordbeck[6] for urban systems, and the equilibrium may be analogous to the optimal (cost minimizing) principle inferred for biological systems.[7]

Topological Randomness

Further, goodness of fit of model data and observed data for the basins studied is evidence that for these basins randomness in terms of stream frequency per order is accounted for by the convergent mean model. Consequently, randomness in terms of the law of proportionate effect (implicit in the model) appears to be adequate to

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[5]Michael J. Woldenberg and Brian J. L. Berry, "Rivers and Central Places: Analogous Systems?" Journal of Regional Science, VII (Winter, 1967), 129-39.

[6]Stig Nordbeck, "The Law of Allometric Growth," Michigan Inter-University Community of Mathematical Geographers Discussion Paper, No. 7, June, 1965, pp. 1-28.

[7]Robert Rosen, Optimality Principles in Biology (New York: Plenum Press, 1967), pp. 106-7.

account for the topologic development of the drainage networks analyzed. Although resolution of the apparent conflict between the deterministic convergent mean model and stochastic models is not permitted by this study, data do support the deterministic model proposed by Woldenberg.

APPENDIX I

ELONGATION RATIO

ELONGATION RATIO

Drainage Basin	Elongation Ratio	Elongation Ratio--1
1	.78	.22
2	.65	.35
3	.50	.50
4	.54	.46
5	.80	.20
6	.55	.45
7	.59	.41
8	.76	.24
9	.77	.23
10	.76	.24
11	.73	.27
12	.58	.42
13	.72	.28
14	.93	.07
15	.68	.32
16	.59	.41
17	.56	.44
18	.55	.45
19	.51	.49
20	.79	.21
21	.67	.33

Drainage Basin	Elongation Ratio	Elongation Ratio--1
22	.66	.34
23	.57	.43
24	.46	.54
25	.64	.36
26	.60	.40
27	.55	.45
28	.70	.30
29	.63	.37
30	.56	.44
31	.64	.36
32	.84	.16
33	.71	.29
34	.59	.41
35	.51	.49
36	.59	.41
37	.73	.27
38	.84	.16
39	.40	.60
40	.47	.53
41	.74	.26
42	.76	.24
43	.57	.43

Drainage Basin	Elongation Ratio	Elongation Ratio--1
44	.75	.25
45	.64	.36
46	.75	.25
47	.51	.49
48	.69	.31
49	.49	.51
50	.61	.39
51	.79	.21
52	.45	.55
53	.64	.36
54	.55	.45
55	.71	.29
56	.48	.52
57	.72	.28
58	.87	.13
59	.69	.31
60	.51	.49
61	.62	.38
62	.69	.31
63	.86	.14
64	.43	.57
65	.52	.48

Drainage Basin	Elongation Ratio	Elongation Ratio--1
66	.62	.38

Formula used to compute elongation ratio:

$$\left[2 \cdot \sqrt{\frac{A}{\pi}}\right] \Big/ L$$

where:

A = basin area

L = length of major axis

A computed value of 1.00 equals a circular basin.

MEAN AND STANDARD DEVIATION ELONGATION RATIO

	Mean	Standard Deviation
Area I	.68	.11
Area II	.62	.10
Area III	.64	.13

Formulas:

Mean

$$\bar{x} = \frac{\Sigma X_i}{N}$$

$\bar{x}$ = mean

ΣX_i = sum of scores

N = total number of scores

Standard Deviation

$$= \sqrt{\frac{\Sigma x^2}{N}}$$

ΣX = sum of square of the deviations from mean

N = total number of scores

KRUSKAL-WALLIS TEST

Elongation Ratio

Formula:

$$H = \frac{12}{N(N+1)} \left(\frac{\Sigma R_i^2}{N_i} \right) - [3(N+1)]$$

where:

N = total number in k samples

N_i = number in ith sample

ΣR_i = sum of ranks for ith sample

where:

$N = 66$

$N_i = 15, 39, 12$

$\Sigma R_i = 390, 1414, 407$

$$H = \frac{12}{66(66+1)} \left[\frac{(390)^2}{15} + \frac{(1414)^2}{39} + \frac{(407)^2}{12} \right] - [3(66+1)]$$

$$= \frac{12}{4422} \left(\frac{152100}{15} + \frac{1999396}{39} + \frac{165649}{12} \right) - 201$$

$$= .00271(10140 + 51266.56 + 13804.08) - 201$$

$$H = 2.81$$

Table value at two degrees of freedom and .05 significance level = 5.991

Ho

There is not a significant difference in the elongation ratios between areas I, II, III.

Results: Cannot reject null hypothesis (Ho)

APPENDIX II

ELEVATION-RELIEF RATIO

ELEVATION-RELIEF RATIO

Stream	Elevation-Relief Ratio	Stream	Elevation-Relief Ratio
1	42.10	22	50.09
2	47.20	23	54.78
3	37.35	24	51.58
4	42.50	25	53.99
5	63.20	26	62.06
6	49.60	27	48.23
7	46.67	28	51.06
8	51.20	29	54.29
9	52.54	30	56.20
10	78.08	31	49.00
11	50.21	32	52.58
12	59.71	33	51.47
13	72.84	34	65.19
14	54.30	35	52.80
15	55.94	36	52.25
16	51.40	37	57.62
17	50.56	38	52.61
18	44.47	39	47.91
19	55.50	40	39.78
20	49.96	41	65.86
21	50.77	42	52.79

Stream	Elevation-Relief Ratio	Stream	Elevation-Relief Ratio
43	57.50	55	56.84
44	46.86	56	56.95
45	43.40	57	47.94
46	51.47	58	44.93
47	49.12	59	53.53
48	52.36	60	55.63
49	38.56	61	52.78
50	41.23	62	53.65
51	65.65	63	45.87
52	62.33	64	56.27
53	55.81	65	55.93
54	52.36	66	59.16

Formula used to compute elevation-relief ratio:

$$\text{elevation-relief ratio} = \frac{\text{mean elevation - minimum elevation}}{\text{maximum elevation - minimum elevation}}$$

MEAN AND STANDARD DEVIATION ELEVATION-RELIEF RATIO

	Mean	Standard Deviation
Area I	53.56	10.79
Area II	52.34	6.24
Area III	53.29	4.43

Formulas:

Mean

$$\bar{x} = \frac{\Sigma X_i}{N}$$

$\bar{x}$ = mean

ΣX_i = sum of scores

N = total number of scores

Standard Deviation

$$= \sqrt{\frac{\Sigma X^2}{N}}$$

ΣX = sum of squares of deviations from mean

N = total number of scores

KRUSKAL-WALLIS TEST

Elevation-Relief Ratio

Formula:

$$H = \frac{12}{N(N+1)} \left(\frac{\Sigma R_i 2}{N_i} \right) - [3(N+1)]$$

where:

N = total number of k samples

N_i = number in ith sample

ΣR_i = sum of ranks for ith sample

where:

$N = 66$

$N_i = 15, 39, 12$

$\Sigma R_i = 525, 1345, 340$

$$H = \frac{12}{66(66+1)} \left(\frac{525^2}{15} + \frac{1345^2}{39} + \frac{340^2}{12} \right) - [(3)(66+1)]$$

$$= \frac{12}{4422} \left(\frac{275625}{15} + \frac{1809025}{39} + \frac{115600}{12} \right) - 201$$

$$= .0027137(18375 + 46385.25 + 9633.33) - 201$$

$$= .88$$

Table value at two degrees of freedom and .05 significance level = 5.991

Ho

There is not a significant difference in the elevation-relief ratios between areas I, II, III.

Results: Cannot reject the null hypothesis (Ho)

APPENDIX III

DRAINAGE DENSITY, STREAM FREQUENCY, AND BASIN AREA

DRAINAGE DENSITY

Basin	Drainage Density	Basin	Drainage Density
1	3.37	22	4.53
2	3.02	23	5.33
3	4.94	24	3.94
4	4.09	25	6.49
5	4.20	26	5.37
6	6.01	27	4.86
7	3.02	28	6.56
8	3.80	29	4.72
9	4.73	30	3.32
10	3.28	31	5.47
11	3.87	32	6.90
12	5.50	33	8.50
13	3.26	34	4.66
14	2.75	35	5.10
15	5.97	36	4.88
16	8.22	37	6.46
17	4.95	38	7.40
18	4.71	39	6.28
19	3.65	40	3.96
20	4.61	41	4.58
21	6.51	42	5.29

Basin	Drainage Density	Basin	Drainage Density
43	6.86	55	4.87
44	6.50	56	6.35
45	6.00	57	4.09
46	3.89	58	6.75
47	5.34	59	5.99
48	3.87	60	6.44
49	5.54	61	6.06
50	6.21	62	9.03
51	10.55	63	6.41
52	4.45	64	7.00
53	4.34	65	5.30
54	7.33	66	6.17

MEAN AND STANDARD DEVIATION DRAINAGE DENSITY

	Mean	Standard Deviation
Area I	4.12	1.04
Area II	5.59	1.48
Area III	6.20	.64

Formulas:

Mean

$$\bar{x} = \frac{\Sigma X_i}{N}$$

$\bar{x}$ = mean

ΣX_i = sum of scores

N = total number of scores

Standard Deviation

$$= \sqrt{\frac{\Sigma X^2}{N}}$$

ΣX = sum of squares of deviations from mean

N = total number of scores

KRUSKAL-WALLIS TEST

Drainage Density

Formula:

$$H = \frac{12}{N(N+1)} \left(\frac{\Sigma R_i^2}{N_i} \right) - [3(N+1)]$$

where:

N = total number of k samples

N_i = number in ith sample

ΣR_i = sum of ranks for ith sample

where:

$N = 66$

$N_i = 15, 39, 12$

$\Sigma R_i = 565504, 1425636, 68121$

$$H = \frac{12}{66(66+1)} \left[\frac{(752)^2}{15} + \frac{(1194)^2}{39} + \frac{(261)^2}{12} \right] - [(3)(66+1)]$$

$$= \frac{12}{4422} \left[\frac{565504}{15} + \frac{1425636}{39} + \frac{68121}{12} \right] - 201$$

$$= .0027137(37700.26 + 36554.76 + 5676.75) - 201$$

$$H = 15.91$$

Table value at two degrees of freedom and .05 significance level = 5.991

Ho

There is not a significant difference in drainage density between areas I, II, and III.

Results: Reject null hypothesis (Ho)

STREAM FREQUENCY

Basin	Stream Frequency	Basin	Stream Frequency
1	12.97	22	36.36
2	12.62	23	26.54
3	27.94	24	15.88
4	10.45	25	46.93
5	15.84	26	30.52
6	39.75	27	18.49
7	7.97	28	35.19
8	13.14	29	22.22
9	28.21	30	13.61
10	8.23	31	30.71
11	15.22	32	39.51
12	17.20	33	58.33
13	10.42	34	26.30
14	6.61	35	29.06
15	47.05	36	29.45
16	82.11	37	53.52
17	14.76	38	61.72
18	18.59	39	48.69
19	16.51	40	18.14
20	26.85	41	21.68
21	33.02	42	24.90

Basin	Stream Frequency	Basin	Stream Frequency
43	44.57	55	22.04
44	49.35	56	33.66
45	32.47	57	18.67
46	42.60	58	44.01
47	24.96	59	27.54
48	18.70	60	33.80
49	23.60	61	34.55
50	37.74	62	73.14
51	75.11	63	43.31
52	23.99	64	44.49
53	19.75	65	27.38
54	54.46	66	44.73

MEAN AND STANDARD DEVIATION STREAM FREQUENCY

	Mean	Standard Deviation
Area I	18.24	11.69
Area II	34.24	16.21
Area III	37.27	13.78

Formulas:

Mean

$$\bar{x} = \frac{\Sigma X_i}{N}$$

$\bar{x}$ = mean

ΣX_i = sum of scores

N = total number of scores

Standard Deviation

$$= \sqrt{\frac{\Sigma X^2}{N}}$$

ΣX = sum of square of the deviations from mean

N = total number of scores

KRUSKAL-WALLIS TEST

Stream Frequency

Formula:

$$H = \frac{12}{N(N+1)} \left(\frac{\Sigma R_i^2}{N_i} \right) - [3(N+1)]$$

where:

N = total number of k samples

N_i = number in ith sample

ΣR_i = sum of ranks for ith sample

where:

$N = 66$

$N_i = 15, 39, 12$

$\Sigma R_i = 759, 1157, 295$

$$H = \frac{12}{66(66+1)} \left[\frac{(759)^2}{15} + \frac{(1157)^2}{39} + \frac{(295)^2}{12} \right] - [3(66+1)]$$

$$= \frac{12}{4422} \left(\frac{576081}{15} + \frac{1338649}{39} + \frac{87025}{12} \right) - 201$$

$$= .0027137(38405.4 + 34324.33 + 7252.08) - 201$$

$$H = 16.046$$

Table value at two degrees of freedom and .05 significance level = 5.991

Ho

There is not a significant difference in stream frequency between area I, II, and III.

Results: Reject null hypothesis (Ho)

BASIN AREAS

(Square Miles)

Basin	Area	Basin	Area
1	14.75	22	3.63
2	14.65	23	6.48
3	2.72	24	9.56
4	23.34	25	6.03
5	10.10	26	11.40
6	8.20	27	9.45
7	33.84	28	8.07
8	16.59	29	3.33
9	8.72	30	20.90
10	23.32	31	9.59
11	21.20	32	4.15
12	11.86	33	6.24
13	8.63	34	7.83
14	16.03	35	4.30
15	5.91	36	11.61
16	4.64	37	8.65
17	8.35	38	3.37
18	7.10	39	8.68
19	5.19	40	21.21
20	5.92	41	9.04
21	4.30	42	8.23

Basin	Area	Basin	Area
43	4.42	55	14.06
44	4.66	56	6.03
45	4.65	57	10.11
46	6.76	58	9.52
47	7.19	59	6.28
48	7.11	60	21.26
49	5.72	61	7.38
50	12.26	62	2.83
51	4.20	63	7.57
52	11.25	64	8.72
53	15.79	65	13.84
54	3.58	66	9.12

MEAN AND STANDARD DEVIATION BASIN AREAS

	Mean	Standard Deviation
Area I	14.65	7.86
Area II	7.81	4.17
Area III	9.72	4.60

Formulas:

Mean

$$\bar{x} = \frac{\Sigma X_i}{N}$$

$\bar{x}$ = mean

ΣX_i = sum of scores

N = total number of scores

Standard Deviation

$$= \sqrt{\frac{\Sigma X^2}{N}}$$

ΣX = sum of squares of the deviations from mean

N = total number of scores

KRUSKAL-WALLIS TEST

Basin Areas

Formula:

$$H = \frac{12}{N(N+1)} \left(\frac{\Sigma R_i^2}{N_i} \right) - [3(N+1)]$$

where:

N = total number in k samples

N_i = number in ith sample

ΣR_i = sum of ranks for ith sample

where:

$N = 66$

$N_i = 15, 39, 12$

$\Sigma R_i = 301, 1550, 366$

$$H = \frac{12}{66(66+1)} \left[\frac{(301)^2}{15} + \frac{(1550)^2}{39} + \frac{(366)^2}{12} \right] - (3)(66+1)$$

$$= \frac{12}{4422} \left(\frac{90601}{15} + \frac{2402500}{39} + \frac{133956}{12} \right) - 201$$

$$= .0027137(6040.06 + 61602.56 + 11163.00) - 201$$

$$H = 12.85$$

Table value at two degrees of freedom and .05 significance level = 5.991

Ho

There is not a significant difference in basin areas between areas I, II, and III.

Results: Reject null hypothesis (Ho)

APPENDIX IV

CONVERGENT MEAN MODELS AND BASIN IDENTIFICATION

METHOD OF COMPUTING MODELS

Hexagon groups: Consecutive numbers from mixed hexagonal progression at bases 3, 4, 7 (see pages 28-29)

X = Numbers from hexagonal groups

$$\text{Arithmetic mean} = \frac{\Sigma X}{N}.$$

$$\text{Geometric mean} = \frac{\text{Log } X_1 + \text{Log } X_2 + \text{Log } X_3}{N} \ . \ . \ .$$

$$\text{Convergent mean} = \frac{\text{Arithmetic mean} + \text{geometric mean}}{2}$$

Basin 1

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	144	81, 243	140.29	162	151.14
2	37	16, 27, 49, 64	34.11	39	36.55
3	7	7, 9	7.93	8	7.96
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 2

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	134	81, 243	140.29	162	151.14
2	41	16, 27, 49, 64	34.11	39	36.55
3	7	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 3

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	52	49, 64	56	56.5	56.25
2	16	16, 27	20.78	21.5	21.14
3	5	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 4

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	502	243, 256, 343 729, 1024	436.94	519	477.97
2	77	49, 64, 81	63.33	64.66	63.99
3	14	7, 9, 16, 27	12.84	14.75	13.79
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 5

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	122	64, 81, 243	108	129.33	118.66
2	27	16, 27, 49	27.66	30.66	29.16
3	8	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 6

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	231	243, 256	249.41	249.5	249.45
2	74	64, 81	71.99	72.5	72.24
3	17	7, 9, 16, 27, 49	16.78	21.60	19.19
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 7

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	197	243, 256	249.41	249.5	249.45
2	51	16, 27, 49, 64, 81	40.55	47.4	43.97
3	7	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 8

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	156	81, 243	140.29	162	151.14
2	47	27, 49, 64	43.91	46.66	45.28
3	11	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 9

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	183	81, 243, 256	171.43	193.33	182.38
2	47	27, 49, 64	43.91	46.66	45.28
3	12	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 10

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	142	81, 243	140.29	162	151.14
2	38	16, 27, 49, 64	34.11	39	36.55
3	9	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 11

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	241	243, 256	249.41	249.5	249.45
2	56	27, 49, 64, 81	51.17	55.25	53.21
3	10	7, 9, 16	10.02	10.66	10.34
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 12

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	153	64, 81, 243, 256	134	161	147.5
2	37	27, 49	36.37	38	37.18
3	10	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 13

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	66	49, 64, 81	63.33	64.66	63.99
2	15	16, 27	20.78	21.5	21.14
3	6	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 14

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	74	49, 64, 81	63.33	64.66	63.99
2	22	16, 27	20.78	21.5	21.14
3	7	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 15

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	202	81, 243, 256, 343	203.89	230.75	217.32
2	56	27, 49, 64	43.91	46.66	45.28
3	12	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 16

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	285	243, 256, 343	277.36	280.66	279.01
2	74	64, 81	71.99	72.5	72.24
3	18	7, 9, 16, 27, 49	16.78	21.6	19.19
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 17

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	154	81, 243	140.29	162	151.14
2	40	16, 27, 49, 64	34.11	39	36.55
3	8	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 18

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	97	49, 64, 81, 243	88.63	109.25	98.94
2	26	16, 27	20.78	21.5	21.14
3	6	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 19

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	60	49, 64	56	56.5	56.25
2	16	16, 27	20.78	21.5	21.14
3	4	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 20

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	116	64, 81, 243	108	129.33	118.66
2	32	16, 27, 49	27.66	30.66	29.16
3	8	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 21

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	93	64, 81, 243	108	129.33	118.66
2	37	16, 27, 49	27.66	30.66	29.16
3	9	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 22

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	96	64, 81, 243	108	129.33	118.66
2	28	16, 27, 49	27.66	30.66	29.16
3	5	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 23

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	128	64, 81, 243	108	129.33	118.66
2	35	16, 27, 49	27.66	30.66	29.16
3	6	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 24

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	113	64, 81, 243	108	129.33	118.66
2	24	16, 27, 49	27.66	30.66	29.16
3	6	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 25

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	211	81, 243, 256, 343	203.89	230.75	217.32
2	57	27, 49, 64	43.91	46.66	45.28
3	11	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 26

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	259	243, 256	249.4	249.5	249.45
2	71	49, 64, 81	63.33	64.66	63.99
3	14	7, 9, 16, 27	12.84	14.75	13.79
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 27

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	134	64, 81, 243, 256	134	161	147.5
2	40	16, 27, 49	27.66	30.66	29.16
3	9	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 28

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	218	81, 243, 256, 343	203.89	230.75	217.32
2	53	27, 49, 64	43.91	46.66	45.28
3	9	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 29

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	52	49, 64	56	56.5	56.25
2	15	16, 27	20.78	21.5	21.14
3	4	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 30

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	217	81, 243, 256, 343	203.89	230.75	217.32
2	53	27, 49, 64	43.91	46.66	45.28
3	12	7, 9, 16	10.02	10.66	10.34
4	4	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 31

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	225	81, 243, 256, 343	203.89	230.75	217.32
2	58	49, 64	56	56.5	56.25
3	11	7, 9, 16, 27	12.84	14.75	13.79
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 32

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	120	64, 81, 243	108	129.33	118.66
2	33	16, 27, 49	27.66	30.66	29.16
3	8	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 33

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	292	243, 256, 343	277.36	280.66	279.01
2	58	27, 49, 64, 81	51.17	55.25	53.21
3	10	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 34

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	155	81, 243	140.29	162	151.14
2	39	16, 27, 49, 64	34.11	39	36.55
3	8	7, 9	7.93	8	7.96
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 35

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	96	49, 64, 81, 243	88.63	109.25	98.94
2	22	16, 27	20.78	21.5	21.14
3	4	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 36

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	267	81, 243, 256, 343, 729	263.06	330.4	296.73
2	58	49, 64	56	56.5	56.25
3	13	7, 9, 16, 27	12.84	14.75	13.79
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 37

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	357	243, 256, 343, 729	353.15	392.75	372.95
2	83	64, 81	71.99	72.5	72.24
3	18	7, 9, 16, 27, 49	16.78	21.6	19.19
4	4	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 38

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	152	81, 243	140.29	162	151.14
2	43	27, 49, 64	43.91	46.66	45.28
3	9	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 39

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	298	256, 343	296.32	299.5	297.91
2	91	49, 64, 81, 243	88.63	109.25	98.94
3	22	16, 27	20.78	21.5	21.14
4	7	3, 4, 7, 9	5.24	5.75	5.49
5	1	1, 1, 1	1	1	1

Basin 40

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	324	256, 343	296.32	299.5	297.91
2	70	27, 49, 64, 81, 243	69.88	92.8	81.34
3	11	7, 9, 16	10.02	10.66	10.34
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 41

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	140	81, 243	140.29	162	151.14
2	43	27, 49, 64	43.91	46.66	45.28
3	9	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 42

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	161	81, 243	140.29	162	151.14
2	33	16, 27, 49, 64	34.11	39	36.55
3	8	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 43

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	147	81, 243	140.29	162	151.14
2	39	16, 27, 49, 64	34.11	39	36.55
3	8	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 44

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	176	64, 81, 243, 256, 343	161.71	197.4	179.55
2	38	27, 49	36.37	38	37.18
3	11	7, 9, 16	10.02	10.66	10.34
4	4	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 45

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	95	49, 64, 81, 243	88.63	109.25	98.94
2	28	16, 27	20.78	21.15	21.14
3	6	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 46

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	212	81, 243, 256, 343	203.89	230.75	217.32
2	58	49, 64	56	56.5	56.25
3	14	7, 9, 16, 27	12.84	14.75	13.79
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 47

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	121	64, 81, 243	108	129.33	118.66
2	31	16, 27, 49	27.66	30.66	29.16
3	5	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 48

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	102	49, 64, 81, 243	88.63	109.25	98.94
2	22	16, 27	20.78	21.5	21.14
3	6	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 49

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	94	49, 64, 81, 243	88.63	109.25	98.94
2	31	16, 27	20.78	21.5	21.14
3	7	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 50

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	361	243, 256, 343, 729	353.15	392.75	372.95
2	82	64, 81	71.99	72.5	72.24
3	16	7, 9, 16, 27, 49	16.78	21.60	19.19
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 51

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	246	243, 256	249.41	249.5	249.45
2	57	27, 49, 64, 81	51.17	55.25	53.21
3	11	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 52

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	161	81, 243	140.29	162	151.14
2	38	16, 27, 49, 64	34.11	39	36.55
3	7	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 53

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	243	243, 256	249.41	249.5	249.45
2	56	27, 49, 64, 81	51.17	55.25	53.21
3	10	7, 9, 16	10.02	10.66	10.34
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 54

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	135	81, 243	140.29	162	151.14
2	43	27, 49, 64	43.91	46.66	45.28
3	11	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 55

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	242	243, 256	249.41	249.5	249.45
2	55	27, 49, 64, 81	51.57	55.25	53.21
3	10	7, 9, 16	10.02	10.66	10.34
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 56

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	144	81, 243	140.29	162	151.14
2	48	27, 49, 64	43.91	46.66	45.28
3	8	7, 9, 16	10.02	10.66	10.34
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 57

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	135	81, 243	140.29	162	151.14
2	37	16, 27, 49, 64	34.11	39	36.55
3	8	7, 9	7.93	8	7.96
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 58

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	327	256, 343	296.32	299.5	297.91
2	75	27, 49, 64, 81, 243	69.88	92.8	81.34
3	13	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 59

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	133	64, 81, 243	108	129.33	118.66
2	29	16, 27, 49	27.66	30.66	29.16
3	8	7, 9	7.93	8	7.96
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 60

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	527	256, 343, 729, 1024	505.98	588	546.99
2	124	64, 81, 243	108	129.33	118.66
3	24	7, 9, 16, 27, 49	16.78	21.60	19.19
4	2	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 61

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	188	81, 243, 256	171.43	193.33	182.38
2	51	27, 49, 64	43.91	46.66	45.28
3	12	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 62

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	150	64, 81, 243, 256	134	161	147.5
2	41	27, 49	36.37	38	37.18
3	12	7, 9, 16	10.02	10.66	10.34
4	3	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 63

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	208	81, 243, 256, 343	203.89	230.75	217.32
2	59	49, 64	56	56.5	56.25
3	15	7, 9, 16, 27	12.84	14.75	13.79
4	4	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 64

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	285	243, 256, 343	277.36	280.66	279.01
2	66	64, 81	71.99	72.5	72.24
3	20	7, 9, 16, 27, 49	16.78	21.60	19.19
4	4	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 65

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	278	243, 256, 343	277.36	280.66	279.01
2	76	64, 81	71.99	72.5	72.24
3	20	7, 9, 16, 27, 49	16.78	21.60	19.19
4	4	3, 4	3.46	3.5	3.48
5	1	1, 1, 1	1	1	1

Basin 66

Stream Data		Model			
Order	Number of Streams	Hexagon Groups	Geo-metric Mean	Arith-metic Mean	Con-vergent Mean
1	307	256, 343	296.32	299.5	297.91
2	78	49, 64, 81, 243	88.63	109.25	98.94
3	17	9, 16, 27	15.72	17.33	16.52
4	5	3, 4, 7	4.37	4.66	4.51
5	1	1, 1, 1	1	1	1

BASIN IDENTIFICATION

Stream Number	Stream Name	Quadrangle
1	Kicaster Creek	La Vernia S.W.
2	Tributary of Cibolo Creek	La Vernia, New Berlin
3	Tributary of Dry Hollow Creek	La Vernia
4	Dry Creek	Gillette, Kosciusko, Stockdale
5	Shockley Creek	Gillette
6	Wallace Creek	Stockdale
7	Fifteen Mile Creek	Yorktown East, Yorktown West, New Davy, Blackwell Lake
8	Five Mile Creek, Three Mile Creek	Meyersville, Blackwell Lake, Cuero
9	Panther Creek	Lenz, Monteola
10	Twelve Mile Creek, Shilow Creek	Yorktown East, Blackwell Lake
11	Manahuilla Creek	Yorktown West, Runge S.W.
12	Perdido Creek	Weesatche, Ander
13	Not Named	Coy City
14	Medio Creek	Monteola
15	Turkey Creek	Karnes City, Lenz
16	Post Oak Creek	Hubbard
17	North Fork	Coolidge, Hubbard
18	Not Named	Coolidge, Echols
19	Hogpen Creek	Mart

Stream Number	Stream Name	Quadrangle
20	Mustang Creek	Prairie Hill
21	Tributary of Mustang Creek	Echols
22	Tributary of Navasota River	Hubbard, Prairie Hill
23	Pin Oak Creek	Echols
24	Tributary of Cottonwood Creek	Prairie Hill, Mart
25	Bean Branch	Marlin
26	Sandy Creek	Riesel, Elk
27	Brushy Creek	Riesel, Otto, Mart, Elk
28	Salt Creek	Axtell, Prairie Hill
29	Tributary of Broad Creek	Prairie Hill
30	Big Creek	Elk, Mart, Prairie Hill
31	Wolfe Creek	Penelope
32	Not Named	Penelope
33	Williams Creek	Axtell, Prairie Hill, Penelope
34	Dry Hollow Creek	Westphalia, Yarreltown
35	Cactus Creek	Lott
36	Little Pond Creek	Westphalia
37	Linn Creek	Dew
38	Nanny Branch	Donie
39	Brown's Creek	Lanely, Dew
40	Bynum Creek	Hillsboro East, Abbott, Malone, Whitney

Stream Number	Stream Name	Quadrangle
41	Tehuacana Creek	Penelope
42	Ash Creek	Abbott
43	Not Named	Whitney
44	Whiterock Creek	Whitney
45	Not Named	Blanton
46	Boggy Creek	Spring Seat, Margie
47	Carryall Creek	Hilltop Lakes
48	Riley Creek	Leona S.W., Normangee
49	Steele Creek	Walnut Springs
50	North Bosque River	Blanton, Huckabay
51	North Paluxy River	Huckabay, Knob Hill
52	Jack's Branch	Hillsboro West, Peoria
53	Hackberry Creek	Itasca, Hillsboro West
54	Not Named	Whitney, Peoria
55	Pecan Bayou	Woodland, Manchester
56	Campground Bayou	Dimple, Bagwell
57	Blanton Creek	Bagwell
58	Langford Creek	Dimple, Clarksville
59	West Fork Harris Creek	Avery
60	Jake Creek, Young Creek	Annona, White Rock, Dimple
61	Sabine River	Celeste
62	East Caddo Creek	Greenville N.W.

Stream Number	Stream Name	Quadrangle
63	Middle Sulphur River	Gober
64	Stiff Creek	Anna, McKinney East, Culleoka
65	Hurricane Creek	Anna, Van Alystine
66	Harrington Creek[1]	Culleoka, Blue Ridge[2]

[1]For streams exceeding fifth order, headwater tributaries were analyzed.

[2]All maps United States Geological Survey Topographic Maps at a scale of 1:24,000.

LINEAR REGRESSION

Semi-logarithmic Regression Equation

$$\log y = \log a + (\log b)X$$

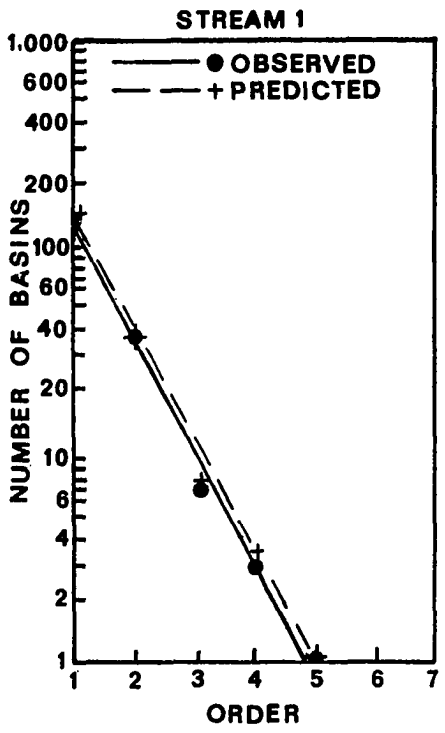
normal equation $\Sigma \log Y = \log a\, N + \log b\, \Sigma X$

$$x \cdot \log Y = \log a\, \Sigma X + \log b\, \Sigma X^2$$

by solving simultaneously

$$\log a = \frac{(\Sigma \log Y)(\Sigma X^2) - (\Sigma X)(\Sigma X \cdot \log Y)}{(N)(\Sigma X^2) - (\Sigma X)^2}$$

$$\log b = \frac{N(\Sigma X \cdot \log Y) - (\Sigma X)(\Sigma \log Y)}{N(\Sigma X^2) - (\Sigma X)^2}$$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100
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40
20
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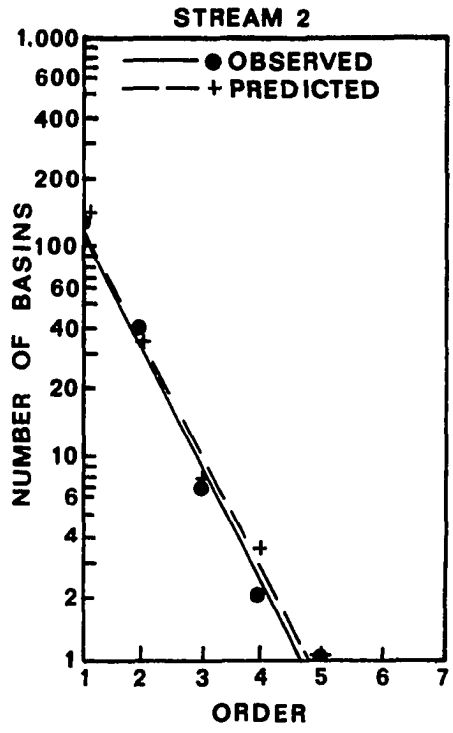
6
4
2
1
1 2 3 4 5 6 7
ORDER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PREDICTED
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20
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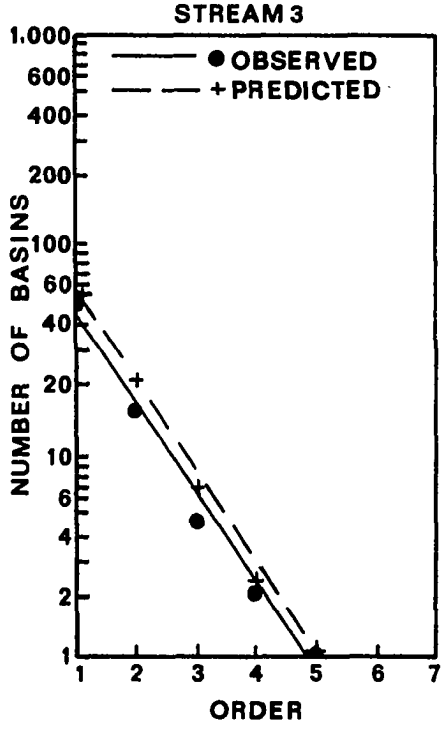
6
4
2
1
1 2 3 4 5 6 7
ORDER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100
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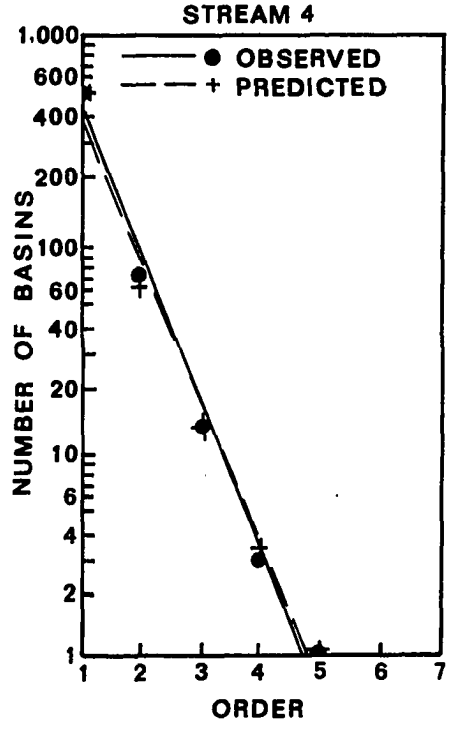
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER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20
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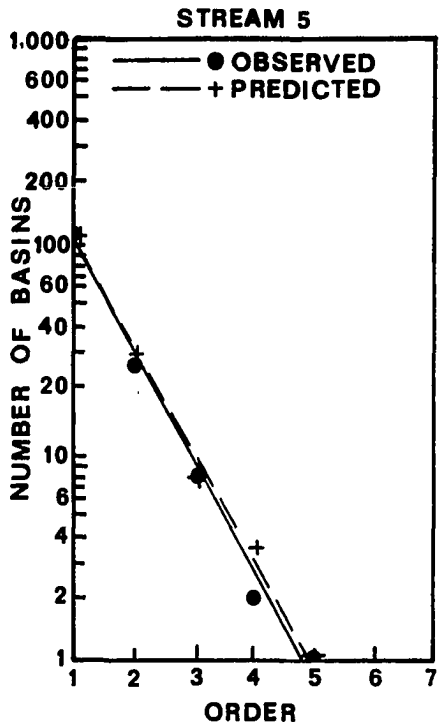
6
4
2
1
1 2 3 4 5 6 7
ORDER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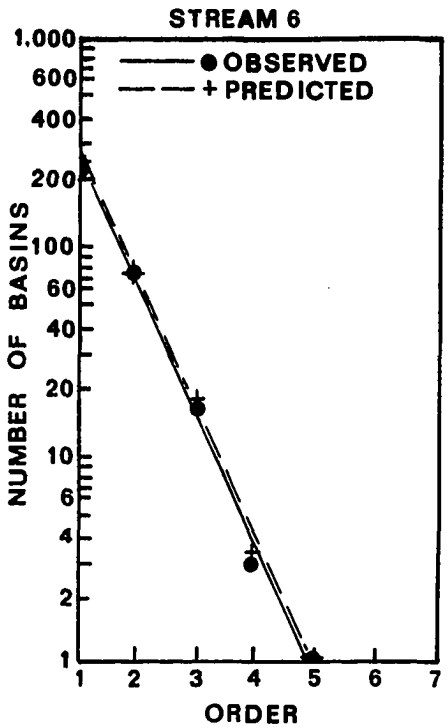
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER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PREDICTED
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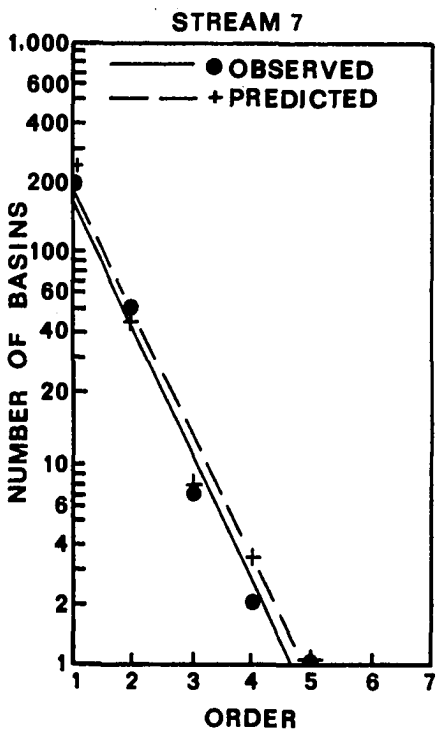
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER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PREDICTED
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200
100
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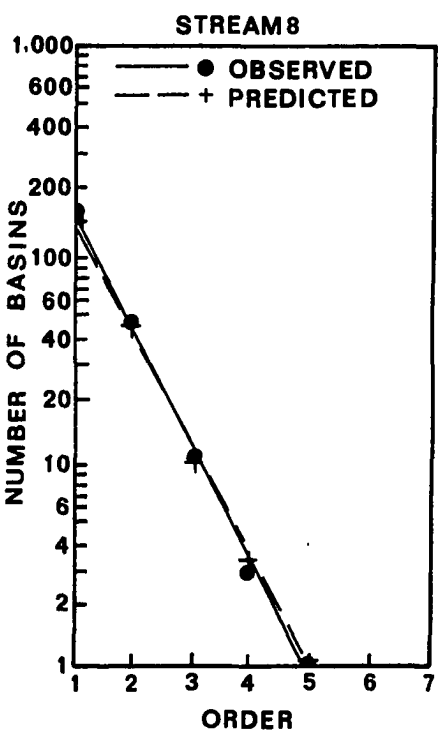
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER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PREDICTED
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40
20
10
6
4
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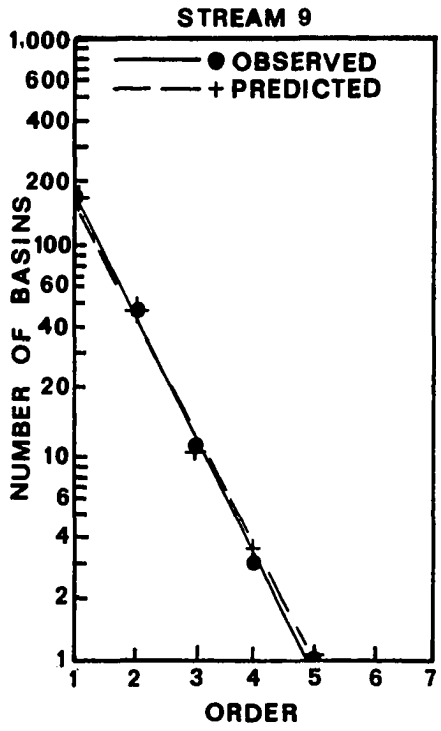
1
1 2 3 4 5 6 7
ORDER


STREAM 9
● OBSERVED
+ PREDICTED
NUMBER OF BASINS
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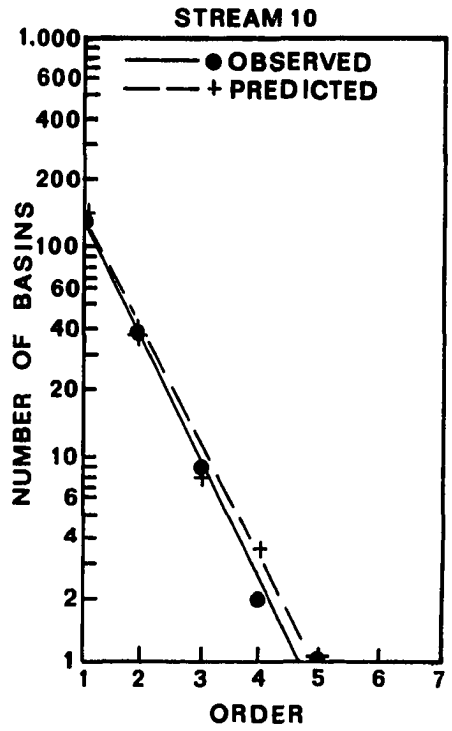
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER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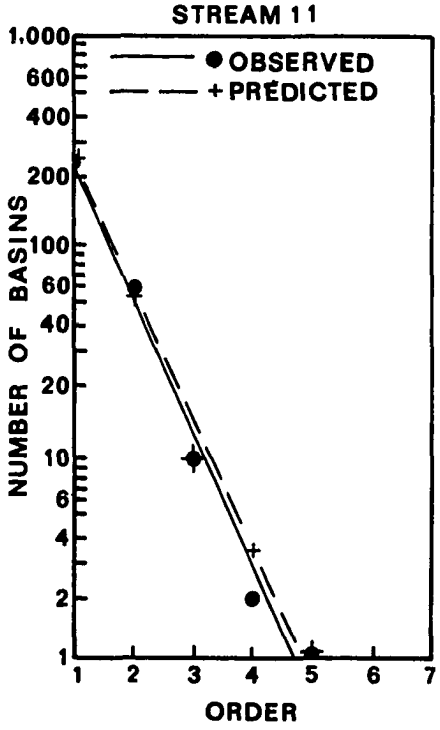
1 2 3 4 5 6 7
ORDER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+ PREDICTED
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200
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20
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6
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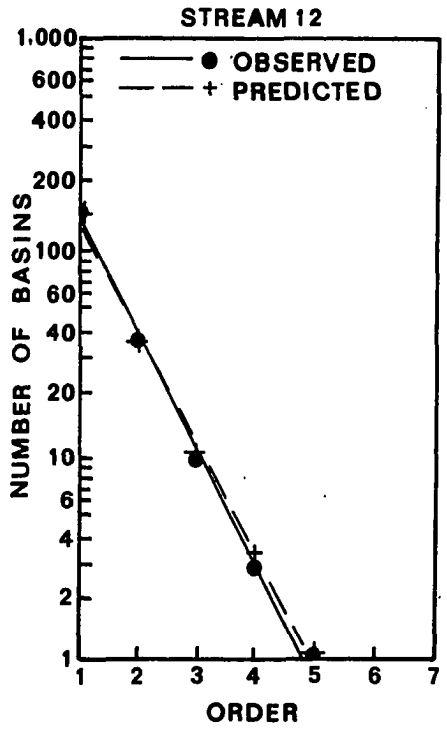
1
1 2 3 4 5 6 7
ORDER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20
10
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2
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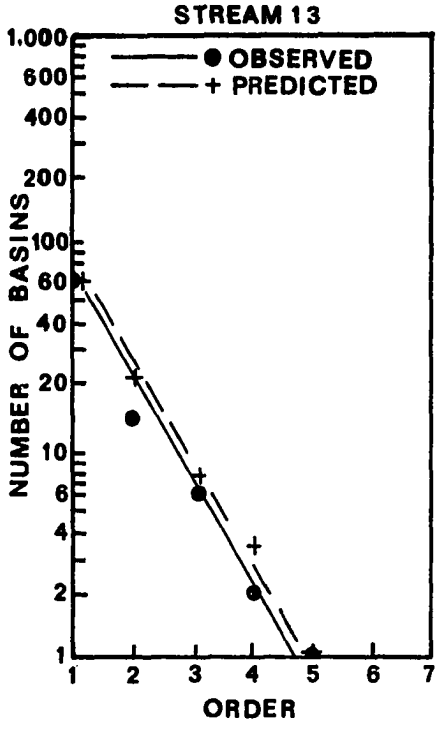
1 2 3 4 5 6 7
ORDER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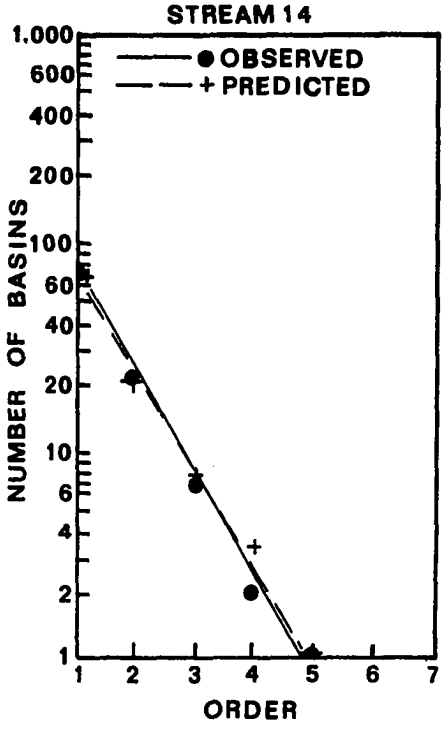
ORDER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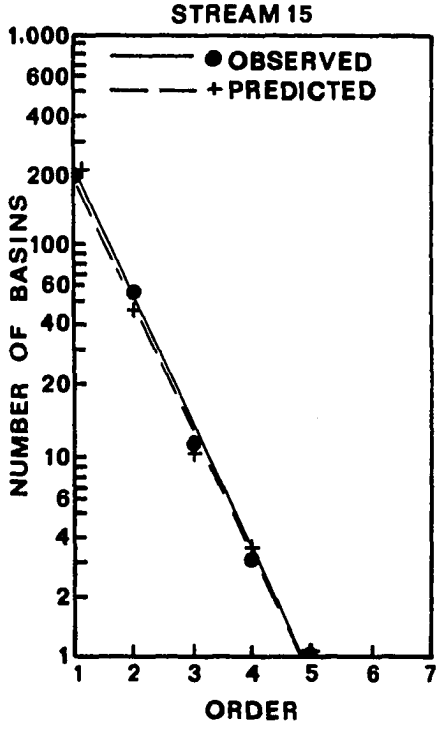
ORDER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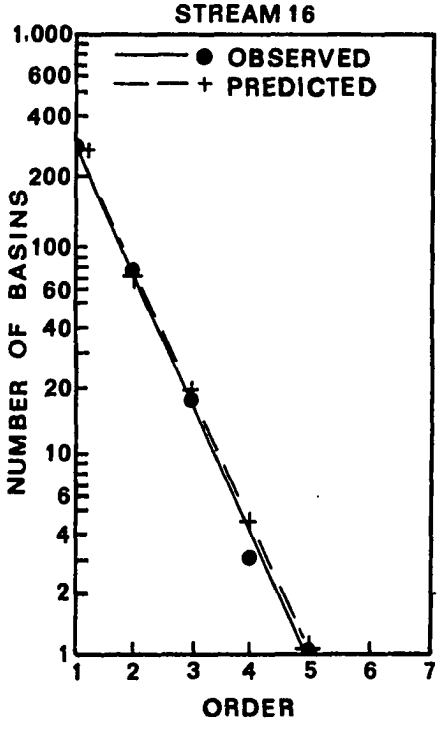
ORDER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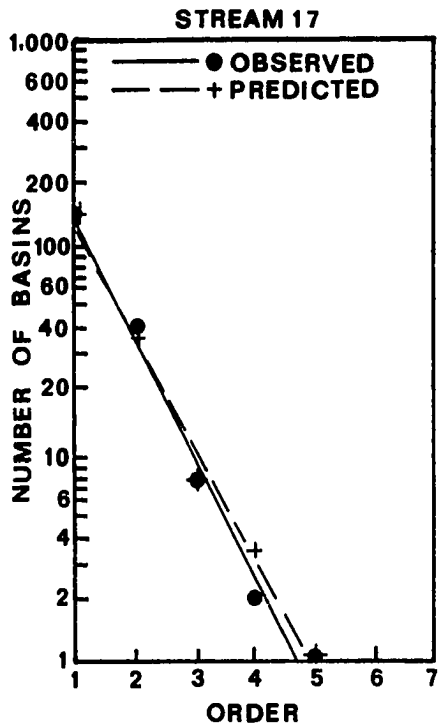
ORDER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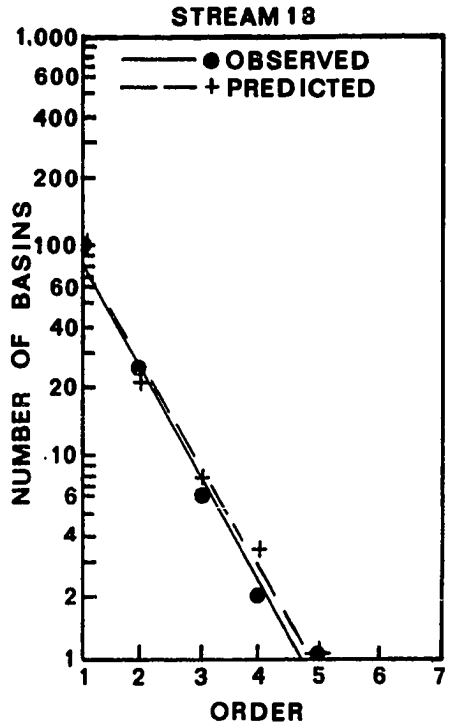
1 2 3 4 5 6 7
ORDER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200
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6
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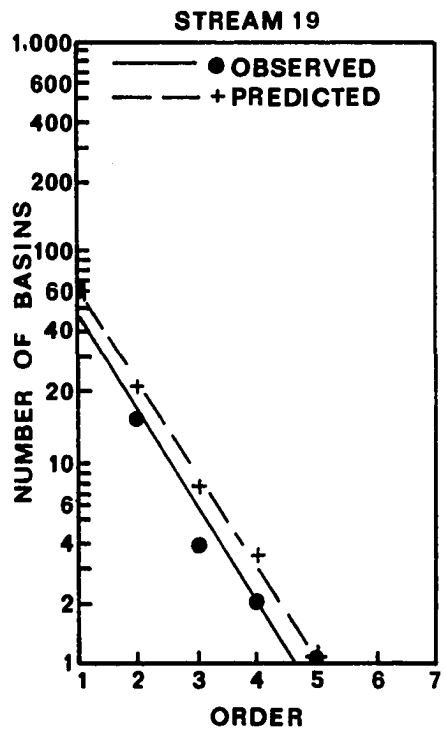
2
1
1 2 3 4 5 6 7
ORDER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20
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6
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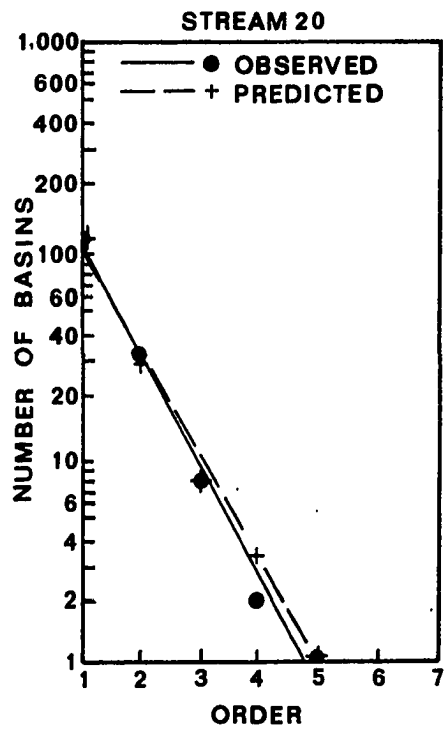
1
1 2 3 4 5 6 7
ORDER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6
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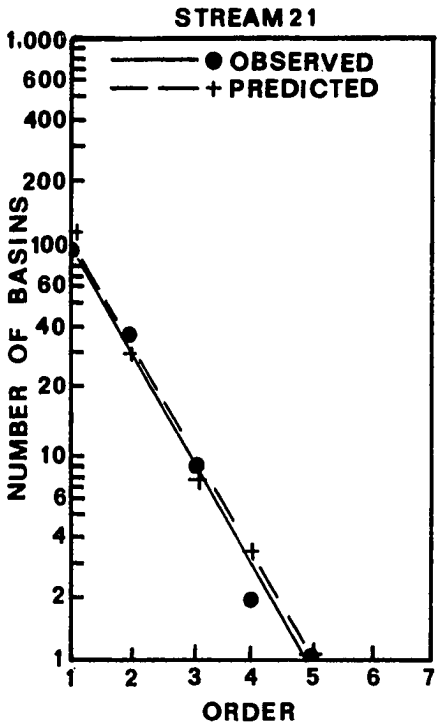
1
1 2 3 4 5 6 7
ORDER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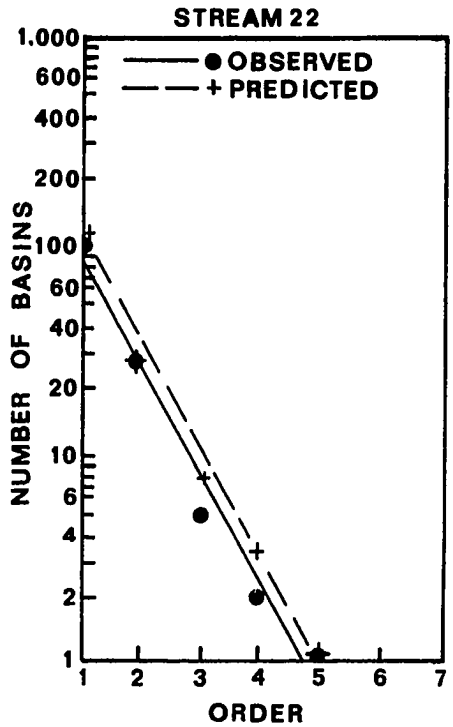
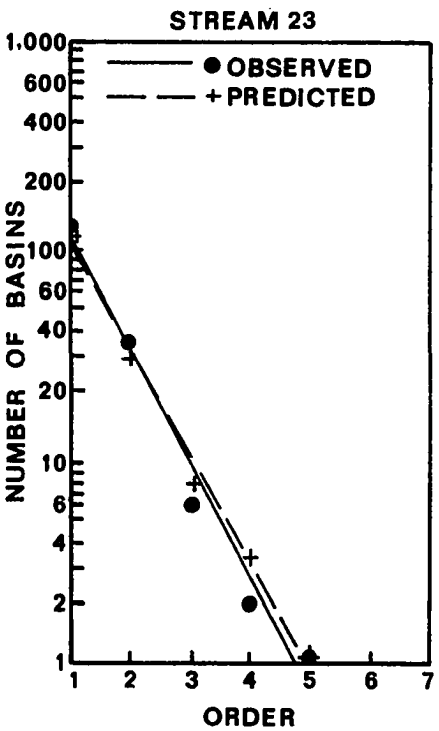
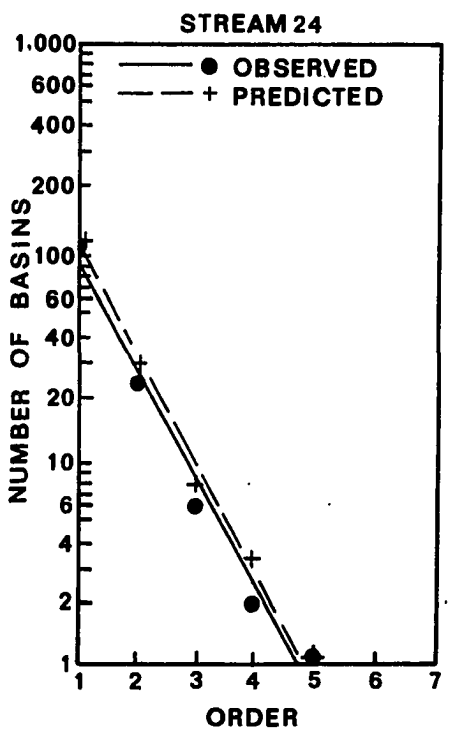
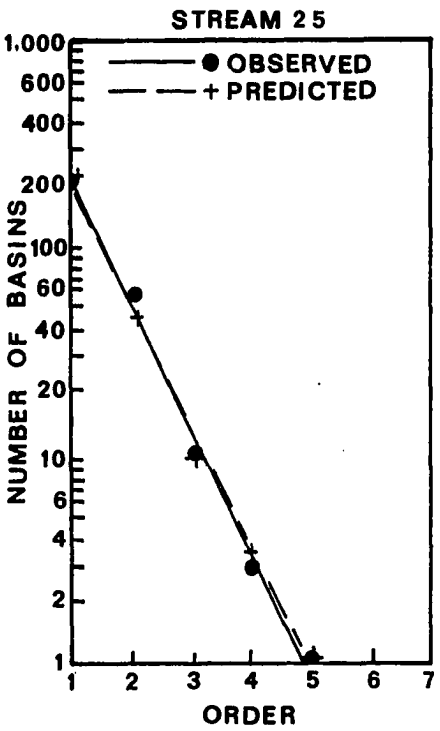
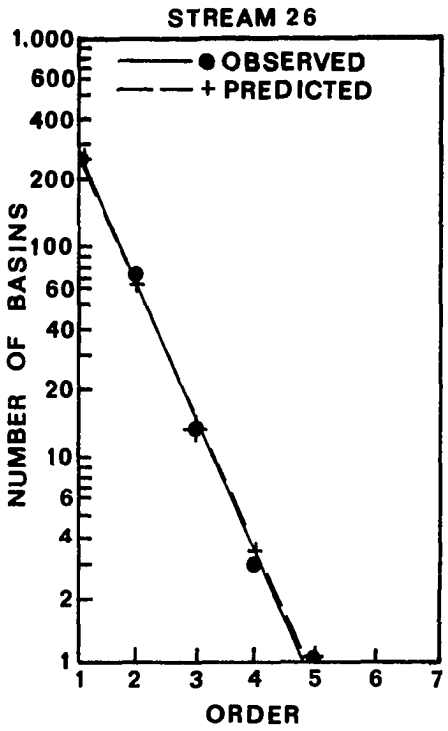
4
2
1
1 2 3 4 5 6 7

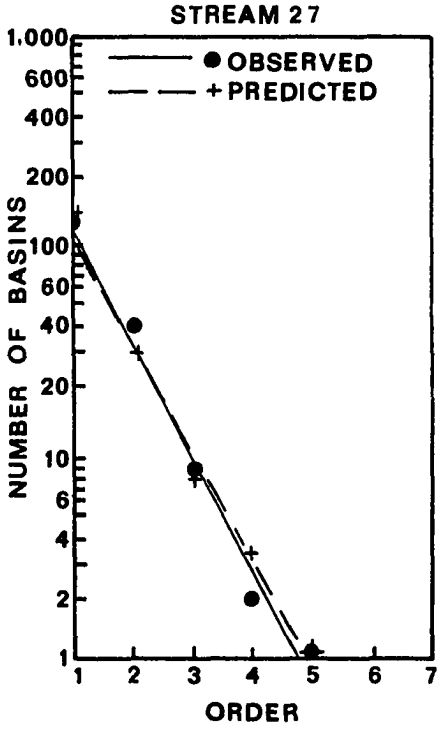

STREAM 22
OBSERVED
PREDICTED
NUMBER OF BASINS
ORDER
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7

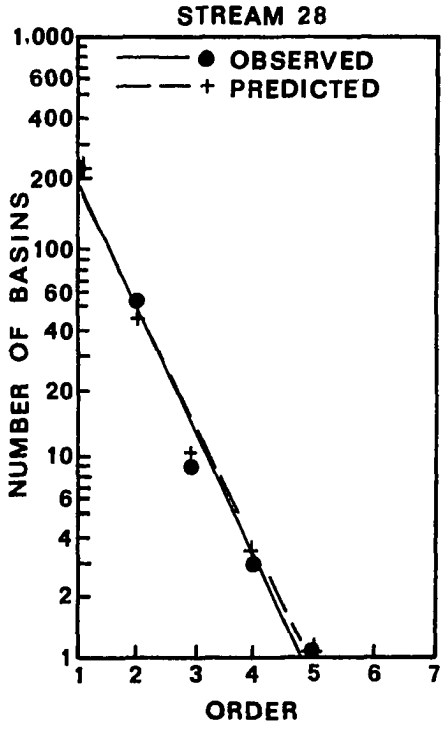

STREAM 23
OBSERVED
PREDICTED
NUMBER OF BASINS
ORDER
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7

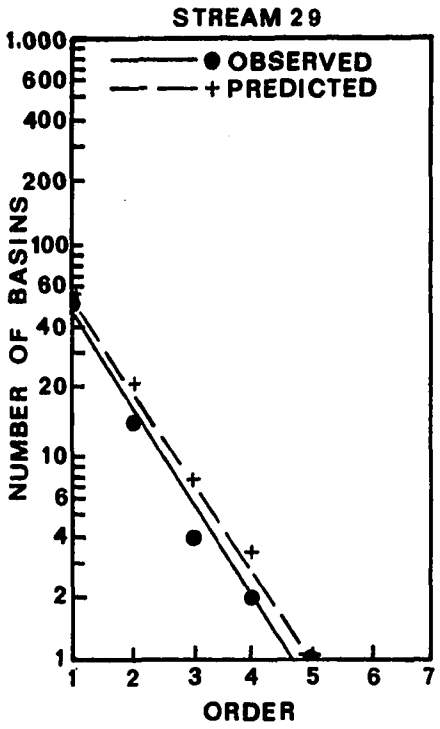

STREAM 24
OBSERVED
PREDICTED
NUMBER OF BASINS
ORDER
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7

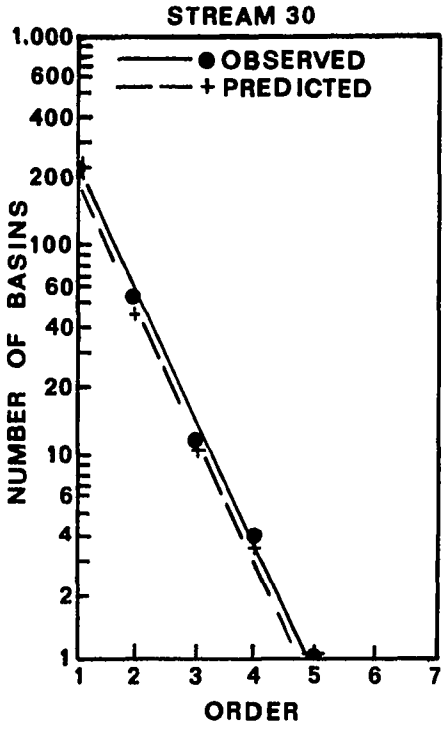

STREAM 25
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

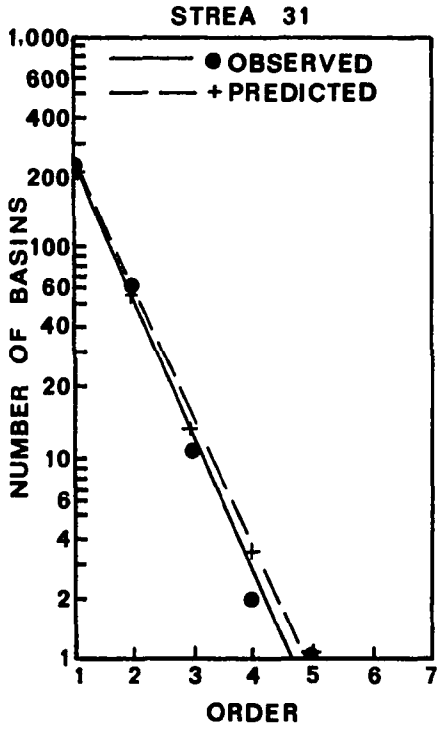

STREAM 26
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

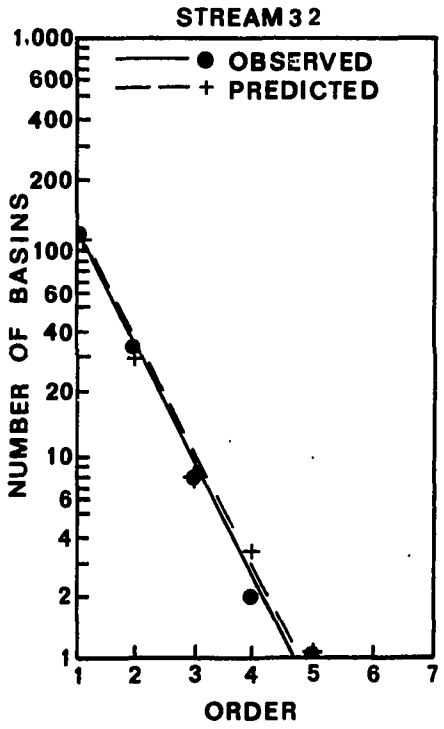

STREAM 27
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

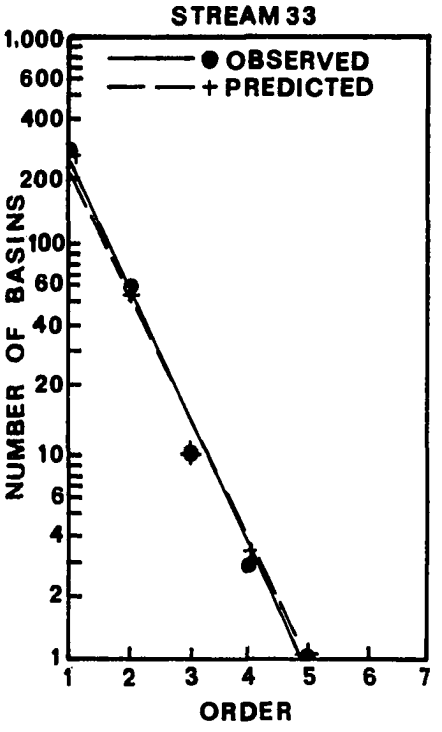

STREAM 28
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

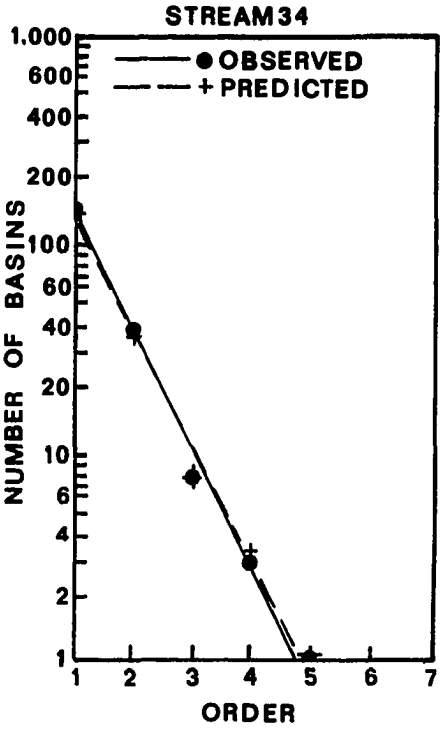

STREAM 29
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

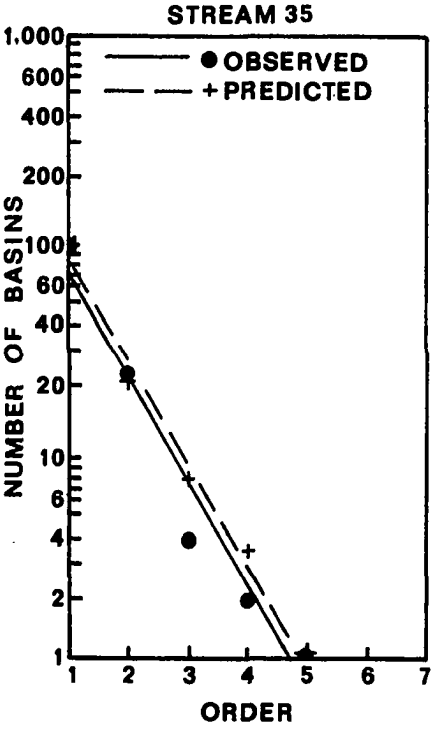

STREAM 30
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

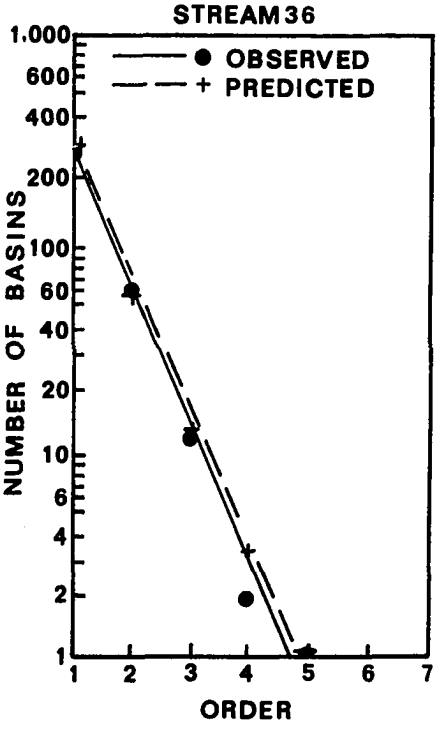

STREA 31
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

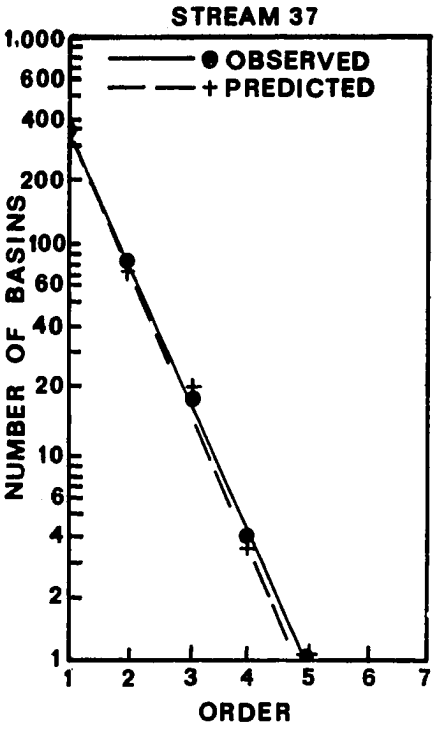

STREAM 32
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

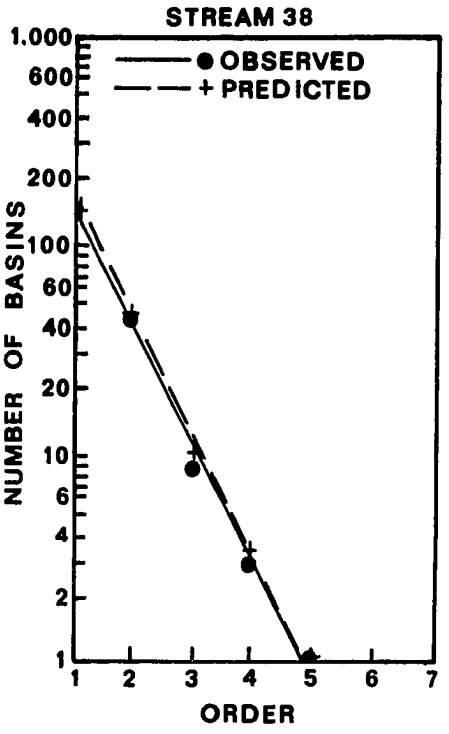

STREAM 33
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

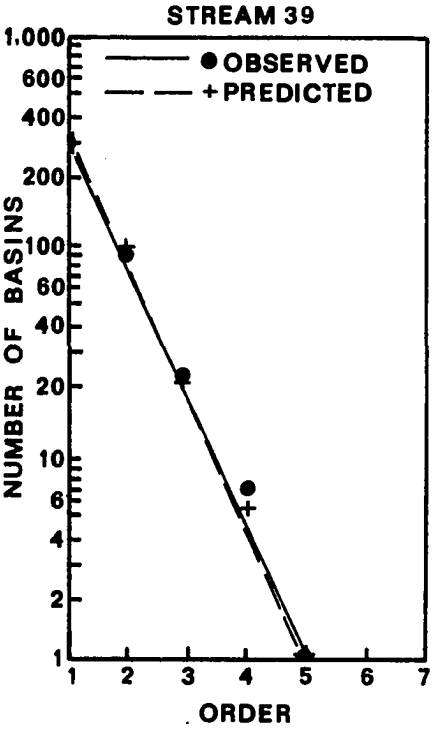

STREAM 34
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

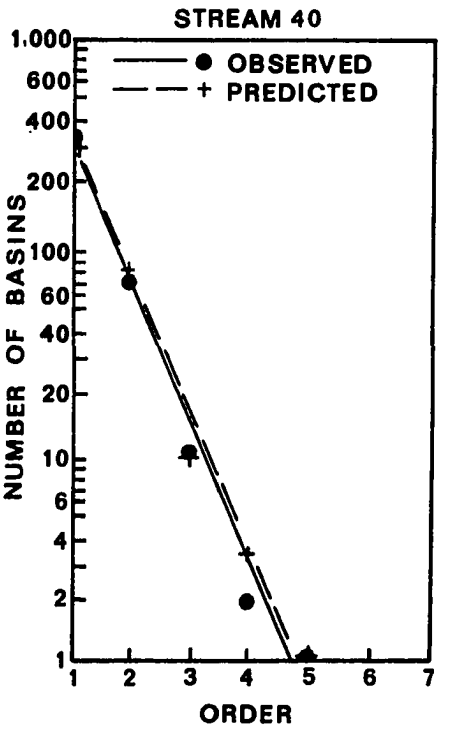

STREAM 35
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

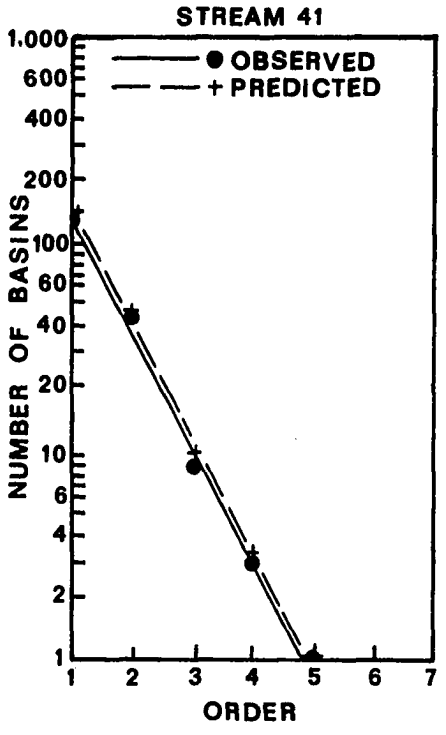

STREAM 36
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

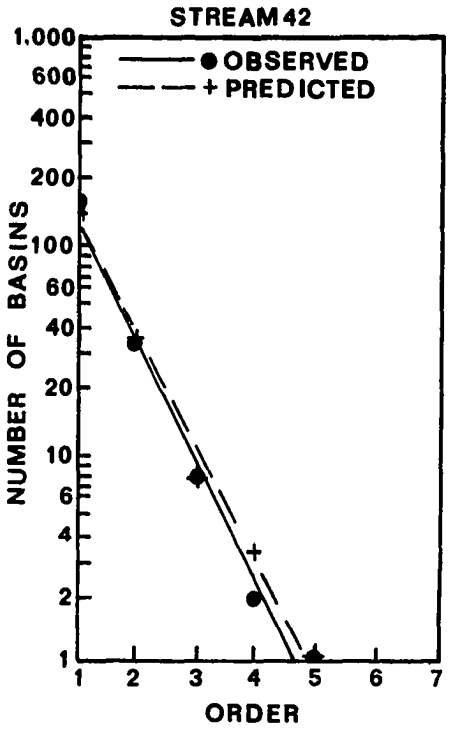

STREAM 37
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

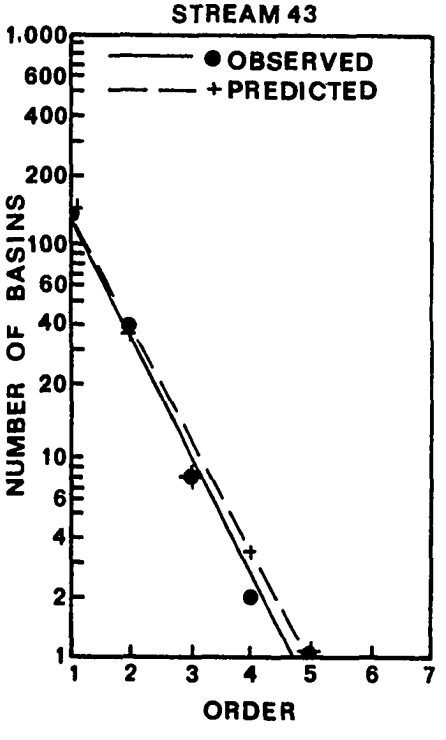

STREAM 38
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

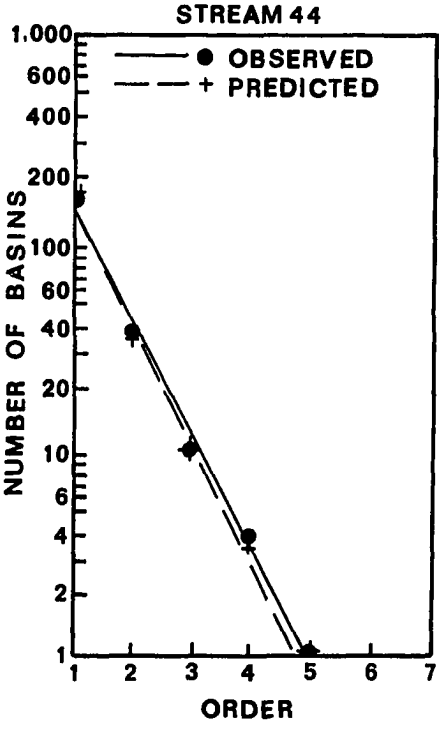

STREAM 39
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

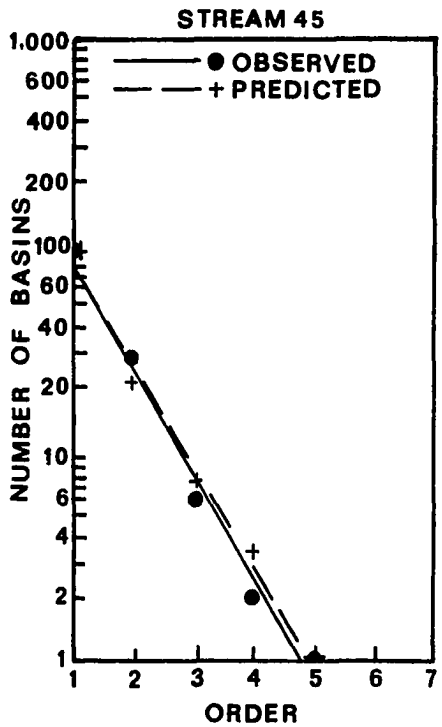

STREAM 40
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

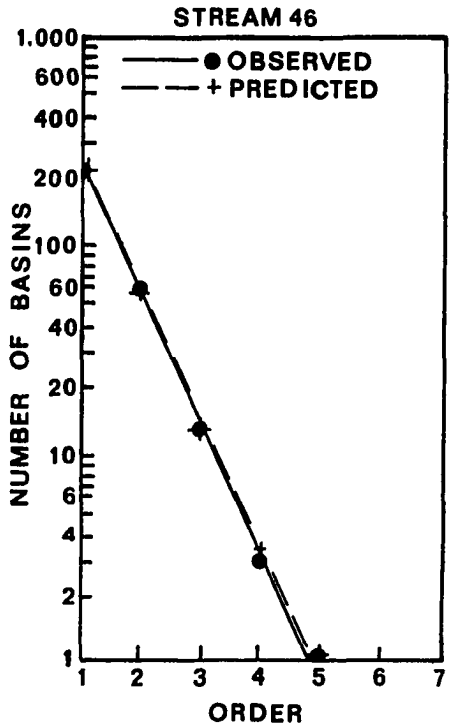

STREAM 41
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

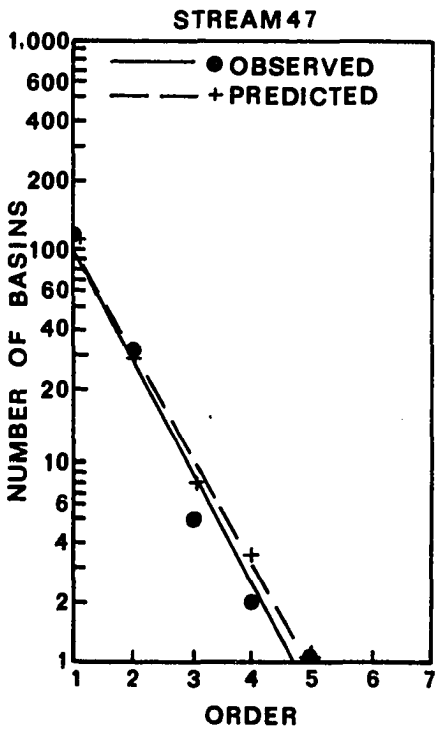

STREAM 42
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

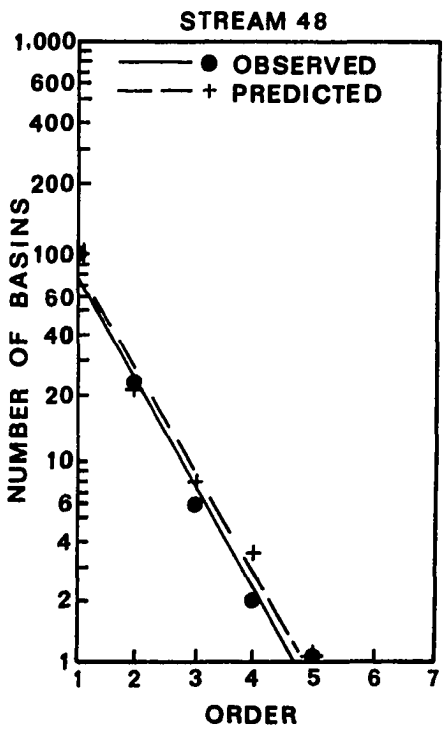

STREAM 43
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

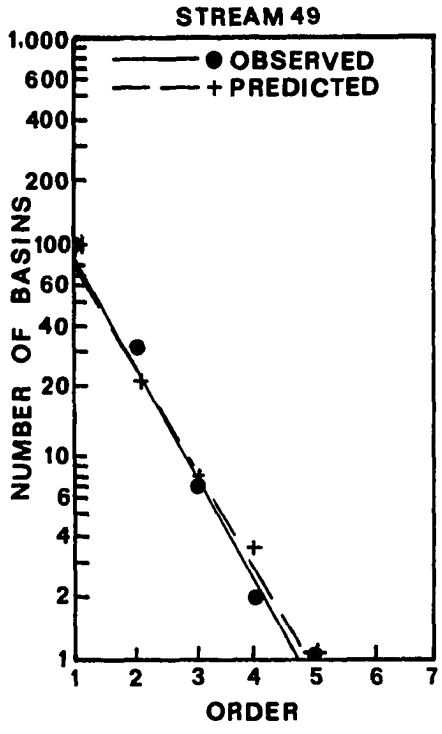

STREAM 44
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

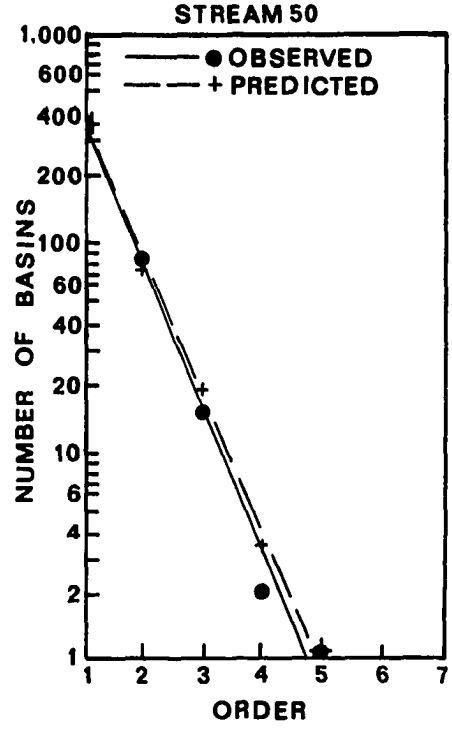

STREAM 45
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

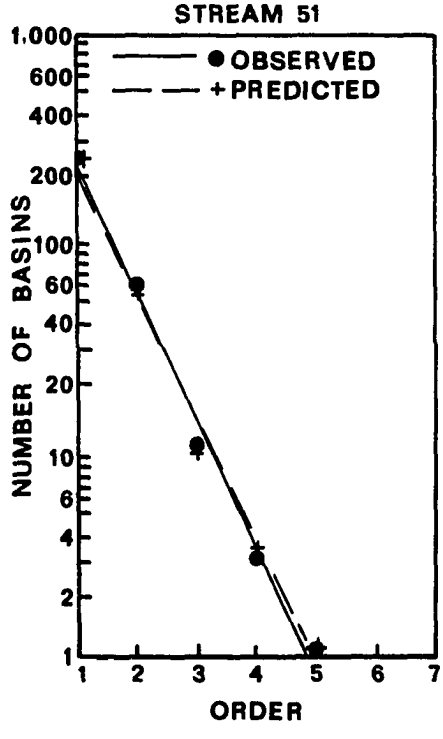

STREAM 46
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

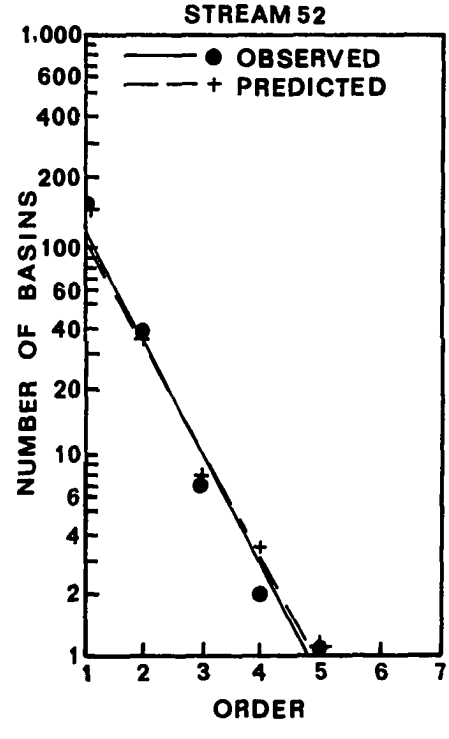

STREAM 47
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

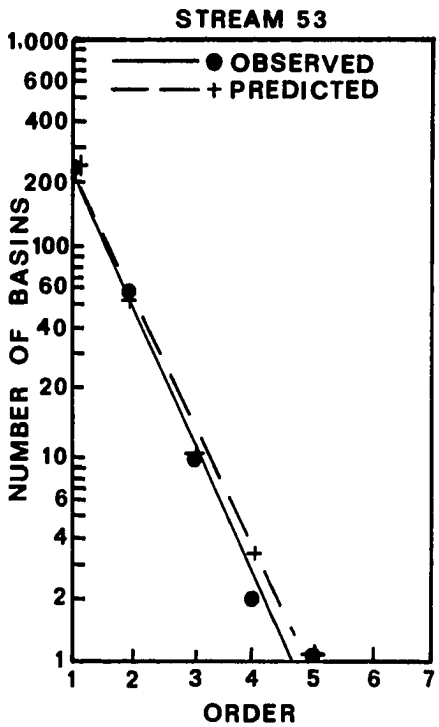

STREAM 48
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

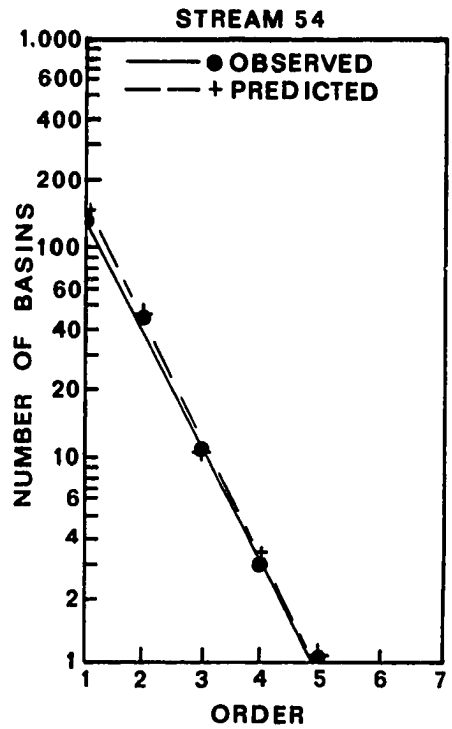

STREAM 49
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

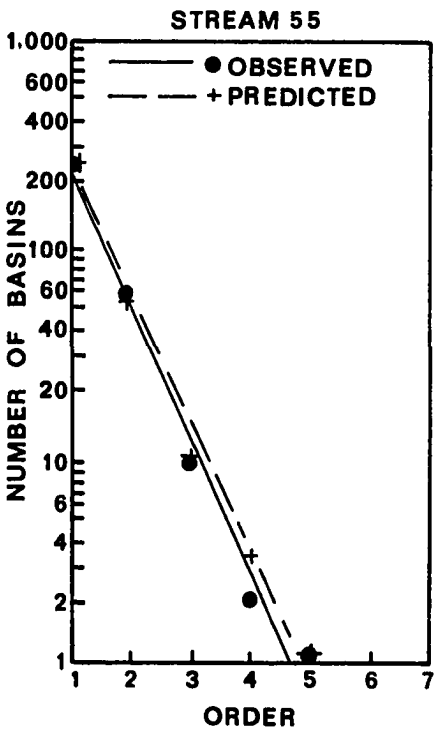

STREAM 50
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

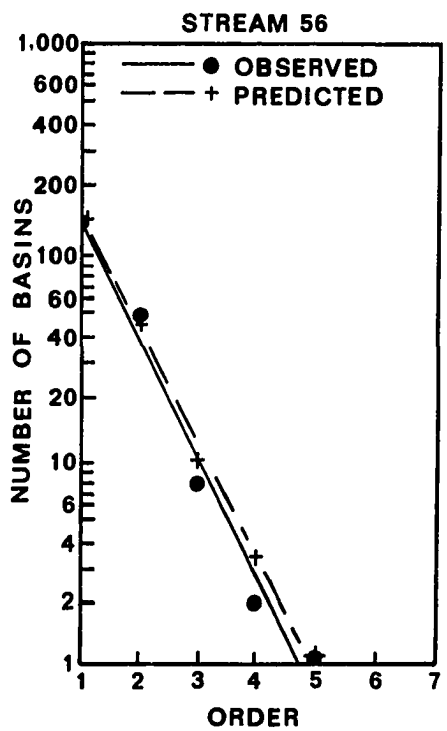

STREAM 51
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

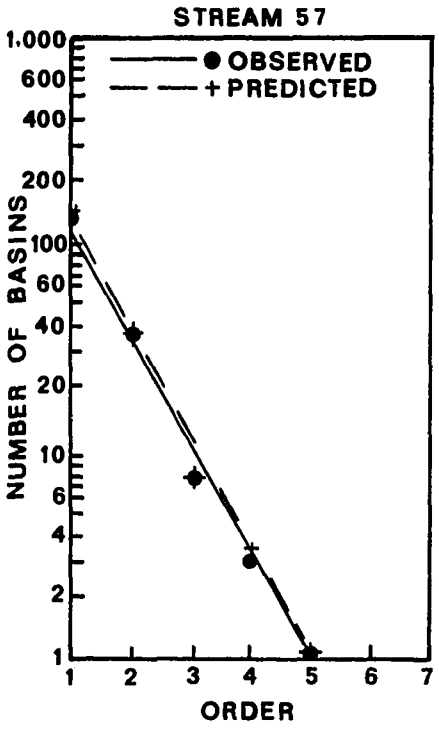

STREAM 52
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

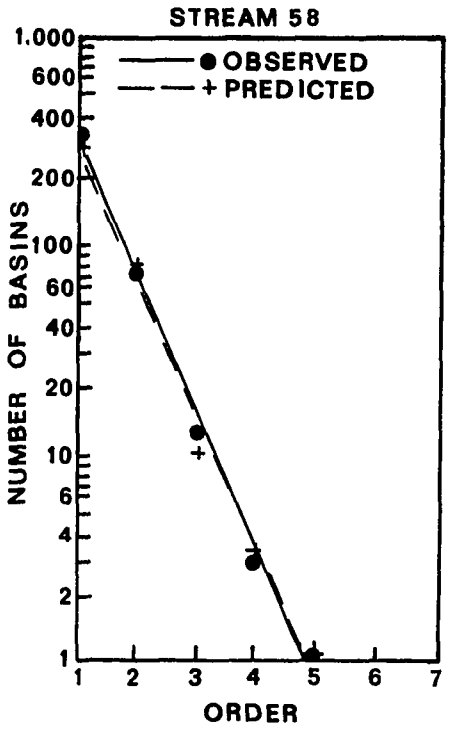

STREAM 53
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

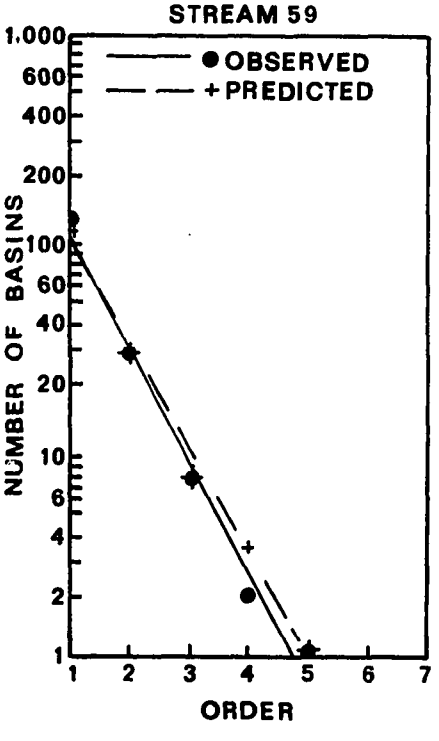

STREAM 54
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

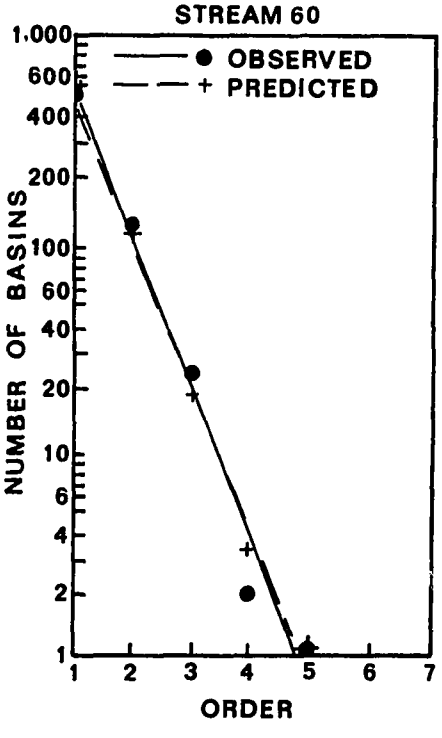

STREAM 55
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

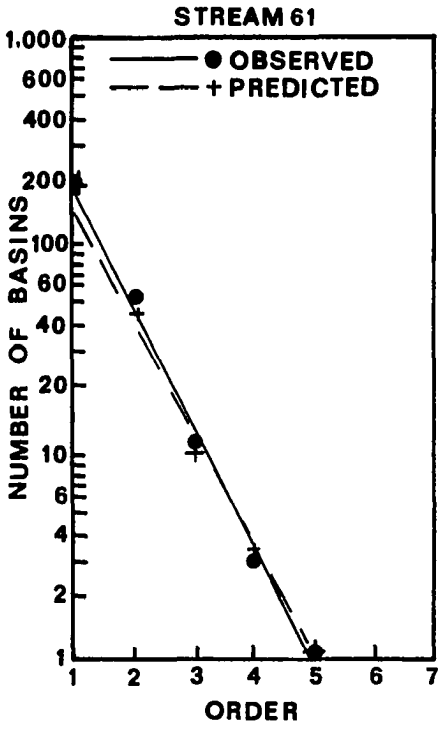

STREAM 56
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

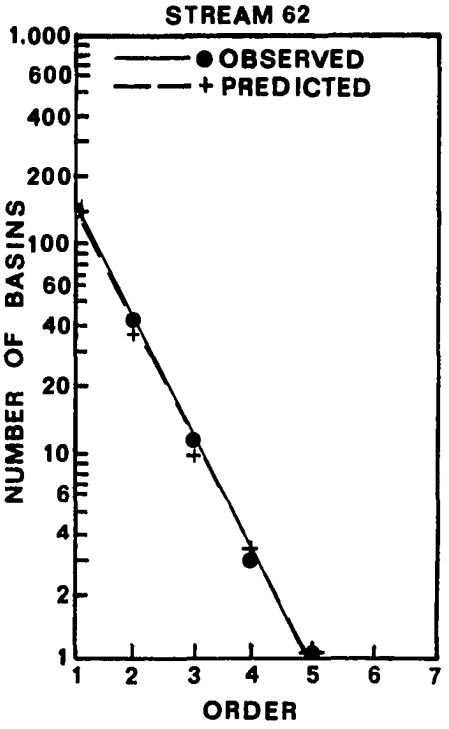

STREAM 57
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

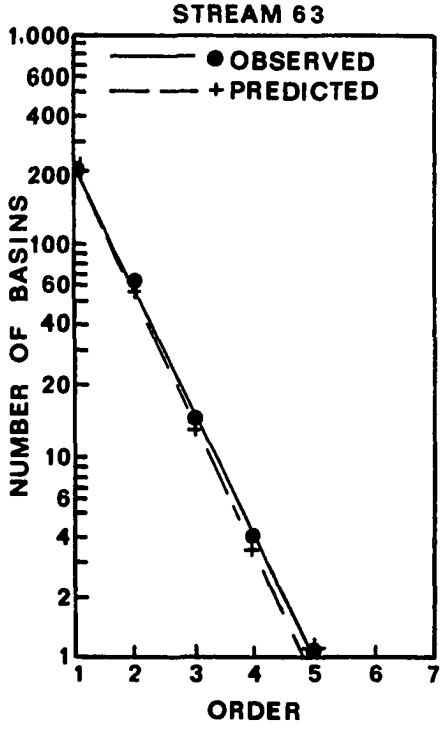

STREAM 58
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

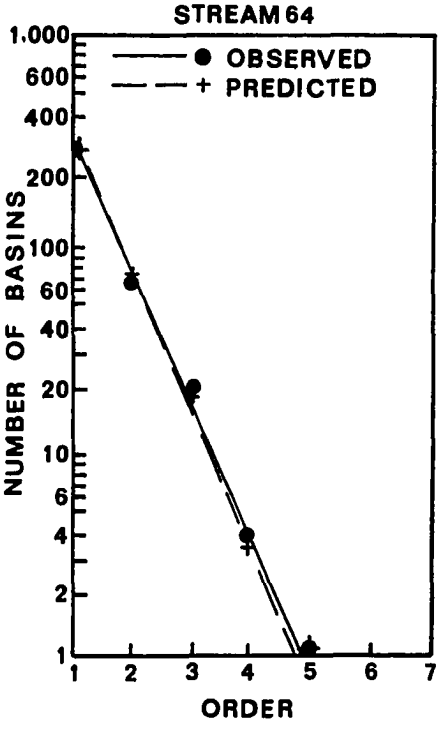

STREAM 59
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

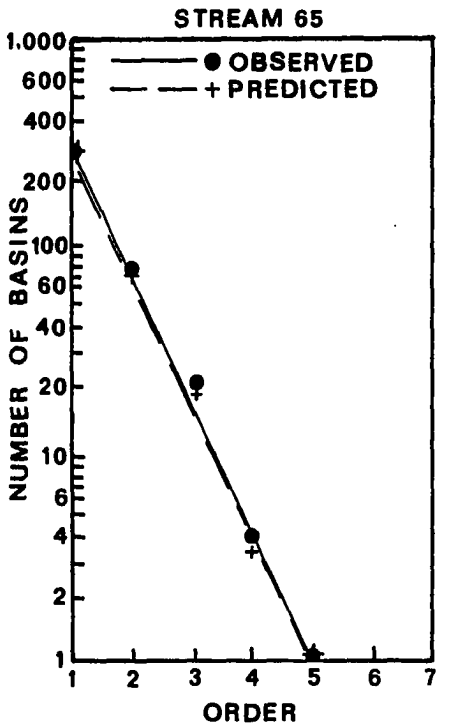

STREAM 60
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

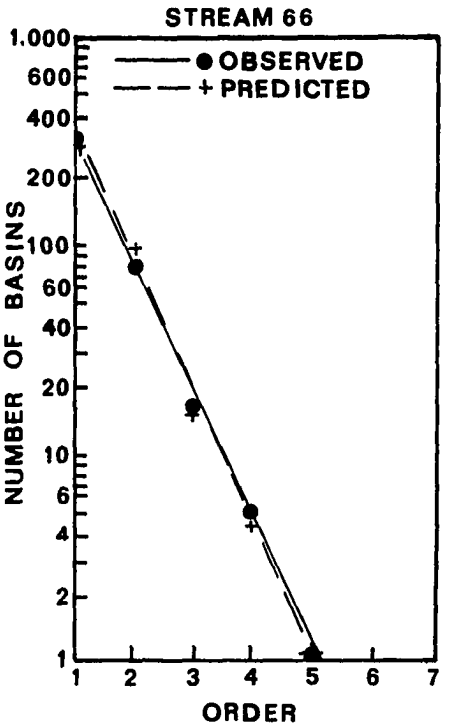

STREAM 61
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

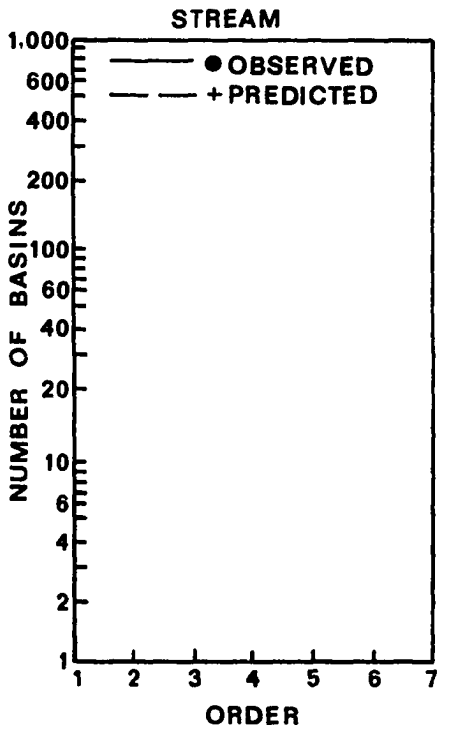

STREAM 62
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

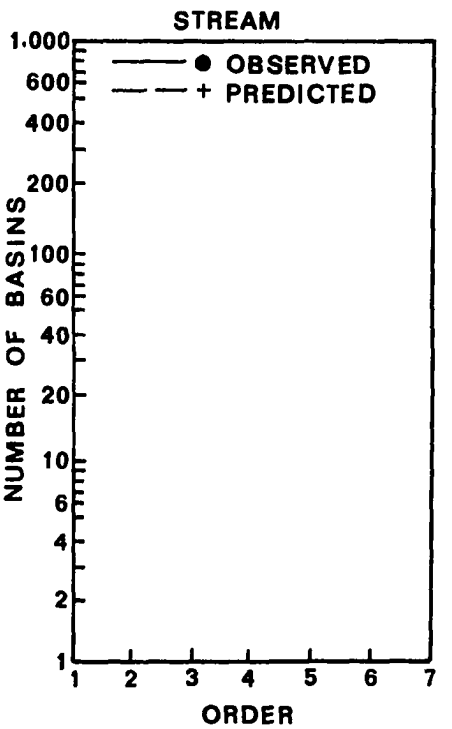

STREAM 63
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER


STREAM 64
OBSERVED
+ PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER


STREAM 65
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER


STREAM 66
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER


STREAM
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER


STREAM
OBSERVED
PREDICTED
NUMBER OF BASINS
1,000
600
400
200
100
60
40
20
10
6
4
2
1
1 2 3 4 5 6 7
ORDER

REGRESSION EQUATIONS

Basin Number		
1	Observed	$\log y = 2.63209 + (9.45922 - 10)x$
	Predicted	$\log y = 2.65097 + (9.46199 - 10)x$
2	Observed	$\log y = 2.64699 + (9.44340 - 10)x$
	Predicted	$\log y = 2.65097 + (9.46199 - 10)x$
3	Observed	$\log y = 2.08455 + (9.56649 - 10)x$
	Predicted	$\log y = 2.18867 + (9.57162 - 10)x$
4	Observed	$\log y = 3.28532 + (9.31892 - 10)x$
	Predicted	$\log y = 3.22033 + (9.33767 - 10)x$
5	Observed	$\log y = 2.53528 + (9.46969 - 10)x$
	Predicted	$\log y = 2.51786 + (9.49282 - 10)x$
6	Observed	$\log y = 3.02388 + (9.38807 - 10)x$
	Predicted	$\log y = 3.04943 + (9.38888 - 10)x$
7	Observed	$\log y = 2.82827 + (9.40045 - 10)x$
	Predicted	$\log y = 2.86519 + (9.41045 - 10)x$
8	Observed	$\log y = 2.75111 + (9.44188 - 10)x$
	Predicted	$\log y = 2.72020 + (9.45269 - 10)x$
9	Observed	$\log y = 2.81413 + (9.42801 - 10)x$
	Predicted	$\log y = 2.78548 + (9.43637 - 10)x$
10	Observed	$\log y = 2.67246 + (9.44167 - 10)x$
	Predicted	$\log y = 2.65097 + (9.46199 - 10)x$
11	Observed	$\log y = 2.94960 + (9.37888 - 10)x$
	Predicted	$\log y = 2.92932 + (9.40216 - 10)x$

Basin Number		
12	Observed	$\log y = 2.68414 + (9.45395 - 10)x$
	Predicted	$\log y = 2.66893 + (9.46337 - 10)x$
13	Observed	$\log y = 2.32779 + (9.51310 - 10)x$
	Predicted	$\log y = 2.38487 + (9.52257 - 10)x$
14	Observed	$\log y = 2.30551 + (9.52201 - 10)x$
	Predicted	$\log y = 2.23347 + (9.56043 - 10)x$
15	Observed	$\log y = 2.88649 + (9.41182 - 10)x$
	Predicted	$\log y = 2.84637 + (9.42115 - 10)x$
16	Observed	$\log y = 3.10183 + (9.36982 - 10)x$
	Predicted	$\log y = 3.08834 + (9.37916 - 10)x$
17	Observed	$\log y = 2.70156 + (9.43239 - 10)x$
	Predicted	$\log y = 2.65097 + (9.46199 - 10)x$
18	Observed	$\log y = 2.42243 + (9.49125 - 10)x$
	Predicted	$\log y = 2.38487 + (9.52257 - 10)x$
19	Observed	$\log y = 2.11489 + (9.55406 - 10)x$
	Predicted	$\log y = 2.18867 + (9.57162 - 10)x$
20	Observed	$\log y = 2.55465 + (9.46670 - 10)x$
	Predicted	$\log y = 2.51786 + (9.49282 - 10)x$
21	Observed	$\log y = 2.51963 + (9.47959 - 10)x$
	Predicted	$\log y = 2.51786 + (9.49282 - 10)x$
22	Observed	$\log y = 2.41909 + (9.48893 - 10)x$
	Predicted	$\log y = 2.51786 + (9.49282 - 10)x$

Basin Number		
23	Observed	log y = 2.58333 + (9.45425 - 10)x
	Predicted	log y = 2.51786 + (9.49282 - 10)x
24	Observed	log y = 2.45809 + (9.48147 - 10)x
	Predicted	log y = 2.51786 + (9.49282 - 10)x
25	Observed	log y = 2.89793 + (9.40727 - 10)x
	Predicted	log y = 2.84637 + (9.42115 - 10)x
26	Observed	log y = 3.03778 + (9.37993 - 10)x
	Predicted	log y = 2.99439 + (9.39415 - 10)x
27	Observed	log y = 2.66345 + (9.44448 - 10)x
	Predicted	log y = 2.59345 + (9.47392 - 10)x
28	Observed	log y = 2.87603 + (9.40759 - 10)x
	Predicted	log y = 2.84637 + (9.42115 - 10)x
29	Observed	log y = 2.05116 + (9.56929 - 10)x
	Predicted	log y = 2.18867 + (9.57162 - 10)x
30	Observed	log y = 2.88693 + (9.42049 - 10)x
	Predicted	log y = 2.84637 + (9.42115 - 10)x
31	Observed	log y = 2.94163 + (9.38332 - 10)x
	Predicted	log y = 2.91849 + (9.41173 - 10)x
32	Observed	log y = 2.57311 + (9.46242 - 10)x
	Predicted	log y = 2.51786 + (9.49282 - 10)x
33	Observed	log y = 3.00631 + (9.37829 - 10)x
	Predicted	log y = 2.96823 + (9.39244 - 10)x

Basin Number		
34	Observed	log y = 2.68070 + (9.45054 - 10)x
	Predicted	log y = 2.65097 + (9.46199 - 10)x
35	Observed	log y = 2.34734 + (9.49941 - 10)x
	Predicted	log y = 2.38487 + (9.52257 - 10)x
36	Observed	log y = 3.01561 + (9.36846 - 10)x
	Predicted	log y = 3.02670 + (9.38467 - 10)x
37	Observed	log y = 3.19252 + (9.35776 - 10)x
	Predicted	log y = 3.18916 + (9.35395 - 10)x
38	Observed	log y = 2.70534 + (9.44800 - 10)x
	Predicted	log y = 2.72020 + (9.45269 - 10)x
39	Observed	log y = 3.14286 + (9.39376 - 10)x
	Predicted	log y = 3.16801 + (9.37960 - 10)x
40	Observed	log y = 3.10915 + (9.34348 - 10)x
	Predicted	log y = 3.08316 + (9.36831 - 10)x
41	Observed	log y = 2.67677 + (9.45514 - 10)x
	Predicted	log y = 2.72020 + (9.45269 - 10)x
42	Observed	log y = 2.67523 + (9.43689 - 10)x
	Predicted	log y = 2.65097 + (9.46199 - 10)x
43	Observed	log y = 2.67990 + (9.43753 - 10)x
	Predicted	log y = 2.65097 + (9.46199 - 10)x
44	Observed	log y = 2.73437 + (9.45313 - 10)x
	Predicted	log y = 2.73724 + (9.44629 - 10)x

Basin Number		
45	Observed	log y = 2.43128 + (9.48984 - 10)x
	Predicted	log y = 2.38487 + (9.52257 - 10)x
46	Observed	log y = 2.92429 + (9.40610 - 10)x
	Predicted	log y = 2.91849 + (9.41173 - 10)x
47	Observed	log y = 2.52160 + (9.46441 - 10)x
	Predicted	log y = 2.51786 + (9.49282 - 10)x
48	Observed	log y = 2.40362 + (9.49414 - 10)x
	Predicted	log y = 2.38487 + (9.52257 - 10)x
49	Observed	log y = 2.46310 + (9.48634 - 10)x
	Predicted	log y = 2.38487 + (9.52257 - 10)x
50	Observed	log y = 3.21363 + (9.32722 - 10)x
	Predicted	log y = 3.18916 + (9.35395 - 10)x
51	Observed	log y = 2.95125 + (9.39394 - 10)x
	Predicted	log y = 2.92932 + (9.40216 - 10)x
52	Observed	log y = 2.69426 + (9.43076 - 10)x
	Predicted	log y = 2.65097 + (9.46199 - 10)x
53	Observed	log y = 2.95247 + (9.37816 - 10)x
	Predicted	log y = 2.92932 + (9.40216 - 10)x
54	Observed	log y = 2.68156 + (9.45830 - 10)x
	Predicted	log y = 2.72020 + (9.45269 - 10)x
55	Observed	log y = 2.94713 + (9.37930 - 10)x
	Predicted	log y = 2.92932 + (9.40216 - 10)x

Basin Number		
56	Observed	log y = 2.71782 + (9.43031 - 10)x
	Predicted	log y = 2.72020 + (9.45269 - 10)x
57	Observed	log y = 2.62127 + (9.46483 - 10)x
	Predicted	log y = 2.65097 + (9.46199 - 10)x
58	Observed	log y = 3.12424 + (9.35730 - 10)x
	Predicted	log y = 3.08316 + (9.36831 - 10)x
59	Observed	log y = 2.58079 + (9.45909 - 10)x
	Predicted	log y = 2.51786 + (9.49282 - 10)x
60	Observed	log y = 3.47010 + (9.27640 - 10)x
	Predicted	log y = 3.42999 + (9.29913 - 10)x
61	Observed	log y = 2.84123 + (9.42212 - 10)x
	Predicted	log y = 2.78548 + (9.43637 - 10)x
62	Observed	log y = 2.71539 + (9.45122 - 10)x
	Predicted	log y = 2.66893 + (9.46337 - 10)x
63	Observed	log y = 2.91489 + (9.41951 - 10)x
	Predicted	log y = 2.91849 + (9.41173 - 10)x
64	Observed	log y = 3.07364 + (9.38728 - 10)x
	Predicted	log y = 3.08834 + (9.37916 - 10)x
65	Observed	log y = 3.09564 + (9.38332 - 10)x
	Predicted	log y = 3.08834 + (9.37916 - 10)x
66	Observed	log y = 3.11195 + (9.38326 - 10)x
	Predicted	log y = 3.15514 + (9.37106 - 10)x

APPENDIX V

KOLMOGROV-SMIRNOV TEST I

KOLMOGROV-SMIRNOV TEST I

Basin Number	Computed Value	N Value	Table Value
1	.0052	97.99	.137
2	- .0308	96.13	.138
3	.0580	41.16	.212
4	- .0122	289.01	.080
5	.0220	80.06	.152
6	.0137	167.70	.105
7	- .0520	139.94	.115
8	.0028	107.28	.131
9	- .0082	122.11	.123
10	- .0156	97.99	.137
11	- .0082	156.84	.108
12	.0106	100.86	.135
13	.0736	46.81	.198
14	.0422	50.80	.191
15	- .0461	137.84	.115
16	.0053	188.96	.098
17	.0085	101.26	.135
18	.0256	66.12	.167
19	.0967	43.14	.207
20	- .0108	79.81	.152
21	- .0854	75.28	.156
22	.0170	72.38	.160

Basin Number	Computed Value	N Value	Table Value
23	.0252	82.96	.149
24	.0335	76.39	.155
25	- .0377	140.09	.114
26	- .0077	169.82	.104
27	- .0595	93.76	.140
28	- .0157	140.33	.114
29	.0765	40.57	.213
30	- .0272	141.06	.114
31	.0154	147.19	.112
32	.0105	81.05	.151
33	.0017	177.67	.102
34	.0039	101.51	.135
35	.0378	64.32	.169
36	- .0162	177.74	.102
37	- .0243	232.95	.089
38	.0152	104.80	.132
39	.0093	210.85	.093
40	.0381	200.45	.096
41	.0038	101.66	.134
42	.0301	101.26	.135
43	- .0090	99.27	.136
44	- .0102	115.38	.126

Basin Number	Computed Value	N Value	Table Value
45	- .0269	66.12	.167
46	- .0085	144.95	.113
47	.0276	80.06	.152
48	.0262	66.37	.167
49	- .0503	66.87	.166
50	- .0140	232.70	.089
51	- .0121	158.80	.107
52	.0151	102.23	.134
53	- .0068	157.35	.108
54	- .0160	101.39	.135
55	- .0050	156.84	.108
56	.0159	103.51	.133
57	- .0215	95.86	.138
58	.0244	203.07	.095
59	.0283	83.19	.149
60	- .0162	341.80	.073
61	- .0148	124.29	.122
62	- .0147	101.59	.135
63	- .0199	144.69	.113
64	.0137	187.72	.099
65	- .0106	188.47	.099
66	.0412	206.68	.094

N values were determined by the following formula:

$$N = \frac{n_1 n_2}{(n_2 + n_2)}$$

where:

n_1 = total observed channels

n_2 = total predicted channels

Table values for N exceeding thirty-five were determined by the following formula:

$$\frac{1.36}{\sqrt{N}}$$

where:

$$N = \frac{n_1 n_2}{(n_1 + n_2)}$$

APPENDIX VI

SPEARMAN RANK CORRELATION--LARGE COMPUTED KOLMOGROV-SMIRNOV I VALUES

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Kolmogrov-Smirnov I Values and Difference in Drainage Density

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank value one (Kolmogrov-Smirnov value) and rank value two (difference in drainage density)

N = number in sample

$\Sigma D^2 = 1353.75$

N = 22

$$rs = 1 - \frac{(6)(1353.75)}{22(22^2 - 1)}$$

$$rs = 1 - \frac{8122.50}{10626}$$

rs = .24

Table value at .05 level of significance at N = 22 = .428 (two-tailed test)

Ho

There is not a significant correlation between large computed values for Kolmogrov-Smirnov Test I and large differences in drainage density for the twenty-two drainage basins developed on two litho-stratigraphic units.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Computed Kolmogrov-Smirnov I Values Near Significance Level and Difference in Drainage Density

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to tables

D = difference between rank one (Kolmogrov-Smirnov values near rejection level) and rank two (difference in stream frequency)

N = number in sample

$\Sigma D^2 = 2160.50$

N = 22

$$rs = 1 - \frac{(6)(2160.50)}{22(484 - 1)}$$

$$rs = 1 - \frac{12963}{10626}$$

$$rs = -.21993$$

Table value at .05 level of significance at N = 22 = .428 (two-tailed test)

Ho

There is not a significant correlation between Kolmogrov-Smirnov values near the rejection level and large differences in drainage density.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Kolmogrov-Smirnov I Values and Stream Frequency

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to tables

D = difference between rank value one (Kolmogrov-Smirnov value) and rank value two (difference in stream frequency)

N = number in sample

$\Sigma D^2 = 1745.25$

N = 22

$$rs = 1 - \frac{(6)(1745.25)}{22(22^2 - 1)}$$

$$rs = 1 - \frac{10471.5}{10626}$$

rs = .014

Table value at .05 level of significance at N = 22 = .428 (two-tailed test)

Ho

There is not a significant correlation between large computed values for Kolmogrov-Smirnov Test I and large differences in stream frequency for the twenty-two drainage basins developed on two litho-stratigraphic units.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Computed Kolmogrov-Smirnov I Values Near Significance Level and Difference in Stream Frequency

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to tables

D = difference between rank one (Kolmogrov-Smirnov values near rejection level) and rank two (difference in stream frequency)

N = number in sample

$\Sigma D^2 = 1792$

N = 22

$$rs = 1 - \frac{(6)(1792)}{(22)(484 - 1)}$$

$$rs = 1 - \frac{10752}{10626}$$

$$rs = - .0118$$

Table value at .05 level of significance at N = 22 = .428 (two-tailed test)

Ho

There is not a significant correlation between Kolmogrov-Smirnov values near the rejection level and large differences in stream frequency.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Deviations from Circular Shape (Elongation Ratio) and Large Kolmogrov-Smirnov I Values

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed values to compare to tables

D = difference between rank one (large Kolmogrov-Smirnov values) and rank two (large deviations from circular shape, elongation ratio minus one)

N = number in sample

$\Sigma D^2 = 31768.00$

N = 66

$$rs = 1 - \frac{(6)(31768)}{(66)(66^2 - 1)}$$

$$rs = 1 - \frac{190608}{287430}$$

rs = .3368

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z tables

$$z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{65}}$$

$$S = \frac{1}{8.0623}$$

$$S = .1240$$

$$z = \frac{.3368542}{.1240340}$$

$$z = 2.7158$$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large deviations from circular (computed value for elongation ratio minus one) and large computed values for the Kolmogrov-Smirnov test.

Results: Reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Deviations from Circular Shape (Elongation Ratio) and Kolmogrov-Smirnov Values Near Rejection Level

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to tables

D = difference between rank one (Kolmogrov-Smirnov values near rejection level) and rank two (large deviations from circular shape, elongation ratio-one)

N = number in sample

N = 66

$\Sigma D^2 = 41068.75$

$$rs = 1 - \frac{(6)(41068.75)}{(66)(4356 - 1)}$$

$$rs = 1 - \frac{246412.50}{287430}$$

rs = .1427

Compute Z value ($Z = {}^{r}s/S$) and compare to Z tables

$$z = {}^{r}s/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{65}}$$

$$S = \frac{1}{8.0623}$$

$$S = .1240$$

$$z = \frac{.1427044}{.1240340}$$

$$z = 1.1505$$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large deviations from circular (computed value for elongation ratio minus one) and Kolmogrov-Smirnov values near the rejection level.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Kolmogrov-Smirnov Test I and Large Deviations from Area I Mean Elevation-Relief Ratio

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (large Kolmogrov-Smirnov values) and rank two (large deviations from Area I mean elevation-relief value)

N = number in sample

$\Sigma D^2 = 522.50$

N = 15

$$rs = 1 - \frac{(6)(522.50)}{15(15^2 - 1)}$$

$$rs = 1 - \frac{3135}{3360}$$

rs = .0670

Table value at .05 level of significance at N = 15 = .52 (two-tailed test)

Ho

There is not a significant correlation between large computed values for the Kolmogrov-Smirnov Test I and large deviations from Area I mean elevation-relief value.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Kolmogrov-Smirnov Values Near the Rejection Level and Large Deviations of Elevation-Relief Ratios from Area I Mean

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (Kolmogrov-Smirnov values near rejection level) and rank two (large deviations from Area I mean elevation-relief value)

N = number in sample

$\Sigma D^2 = 403.50$

N = 15

$$rs = 1 - \frac{(6)(403.50)}{15(15^2 - 1)}$$

$$rs = 1 - \frac{2421}{3360}$$

rs = .2795

Table value at .05 level of significance at N = 15 = .52 (two-tailed test)

Ho

There is not a significant correlation between Kolmogrov-Smirnov values near the rejection level and large deviations of the elevation-relief value from Area I mean.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Kolmogrov-Smirnov Test I and Large Deviations from Area II Mean Elevation-Relief Value

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (large Kolmogrov-Smirnov values) and rank two (large deviations from Area II mean elevation-relief value)

N = number in sample

$\Sigma D^2 = 10294$

N = 39

$$rs = 1 - \frac{(6)(10294)}{39(39^2 - 1)}$$

$$rs = 1 - \frac{61764}{59280}$$

$$rs = -.0419$$

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z table

$$z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{38}}$$

$$S = \frac{1}{6.1644}$$

$$S = .1622$$

$$z = \frac{-.04190}{.1622}$$

$$z = -.258$$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large values for the Kolmogrov-Smirnov Test I and large deviations from Area II mean elevation-relief value.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Kolmogrov-Smirnov Values Near Rejection Level and Large Deviations from Area II Mean Elevation-Relief Value

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(D^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (Kolmogrov-Smirnov Values near rejection level) and rank two (large deviations from Area II mean elevation-relief value)

N = number in sample

$\Sigma D^2 = 10415$

N = 39

$$rs = 1 - \frac{(6)(10415)}{39(39^2 - 1)}$$

$$rs = 1 - \frac{62490}{59280}$$

$$rs = -.05414$$

Compute Z value ($Z = r_{s/S}$) and compare to Z tables

$$Z = r_{s/S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{39 - 1}}$$

$$S = \frac{1}{6.1644}$$

$$S = .16222$$

$$Z = - \frac{.05414}{.16222}$$

$$Z = - .33374$$

Table value at .05 significance level 1.96

Ho

There is not a significant correlation between Kolmogrov-Smirnov values near the rejection level and large deviations of elevation-relief values from Area II mean elevation-relief value.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Kolmogrov-Smirnov Test I and Large Deviations from Area III Mean Elevation-Relief Value

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (large Kolmogrov-Smirnov values) and rank two (large deviations from Area III mean elevation-relief ratio)

N = number in sample

$\Sigma D^2 = 198$

N = 12

$$rs = 1 - \frac{(6)(198)}{(12)(12^2 - 1)}$$

$$rs = 1 - \frac{1188}{1716}$$

rs = .3077

Table value at .05 significance level, two-tailed test = .591

Ho

There is not a significant correlation between large values for the Kolmogrov-Smirnov Test I and large deviations from Area III mean elevation-relief value.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Kolmogrov-Smirnov Values Near Rejection Level and Large Deviations from Area III Mean Elevation-Relief Value

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(D^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (Kolmogrov-Smirnov value near rejection level) and rank two (large deviations from Area III mean elevation-relief value)

N = number in sample

$\Sigma D^2 = 384$

N = 12

$$rs = 1 - \frac{(6)(384)}{(12)(144 - 1)}$$

$$rs = 1 - \frac{2304}{1716}$$

$$rs = -.3426$$

Table value at .05 significance level, two-tailed test = .591

Ho

There is not a significant correlation between Kolmogrov-Smirnov I values near the rejection level and large deviations from Area III mean elevation-relief value.

Results: Cannot reject null hypothesis (Ho)

APPENDIX VII

SPEARMAN RANK CORRELATION--LARGE COMPUTED KOLMOGROV-SMIRNOV I VALUES--BASIN AREAS

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Kolmogrov-Smirnov Test I and Large Basin Areas

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (large Kolmogrov-Smirnov values) and rank two (large basin areas)

N = number in sample

$\Sigma D^2 = 41018.59$

N = 66

$$rs = 1 - \frac{(6)(41018.59)}{66(66^2 - 1)}$$

$$rs = 1 - \frac{246111.54}{287430}$$

rs = .1437514

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z tables

$$z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{N}}$$

$$S = \frac{1}{\sqrt{66 - 1}}$$

$$S = \frac{1}{8.0623}$$

$$S = .1240340$$

$$z = \frac{.1437514}{.1240340}$$

$$z = 1.1589$$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large computed values for Kolmogrov-Smirnov Test I and large basin areas.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Kolmogrov-Smirnov Values Near Significance Level and Large Basin Areas

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (Kolmogrov-Smirnov values near rejection level) and rank two (large basin areas)

N = number in sample

$\Sigma D^2 = 53969.25$

N = 66

$$rs = 1 - \frac{(6)(53969.25)}{(66)(4356 - 1)}$$

$$rs = 1 - \frac{323815.50}{287430}$$

$$rs = - .1265890$$

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z tables

$$z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{66 - 1}}$$

$$S = \frac{1}{8.0623}$$

$$S = .1240340$$

$$z = - \frac{.1265890}{.1240340}$$

$$z = - 1.020$$

Table value at .05 level of significance 1.96

Ho

There is not a significant correlation between Kolmogrov-Smirnov values near the significance level and large basin areas.

Results: Cannot reject null hypothesis (Ho)

APPENDIX VIII

LOG-LOG REGRESSION

LOG-LOG REGRESSION

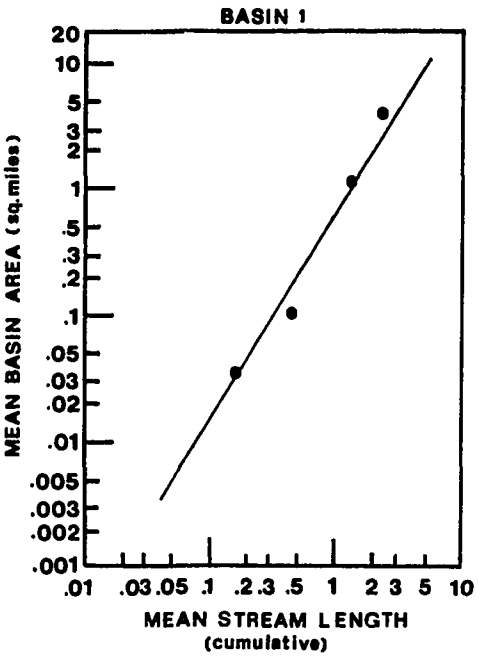
Log-Log Regression Equation

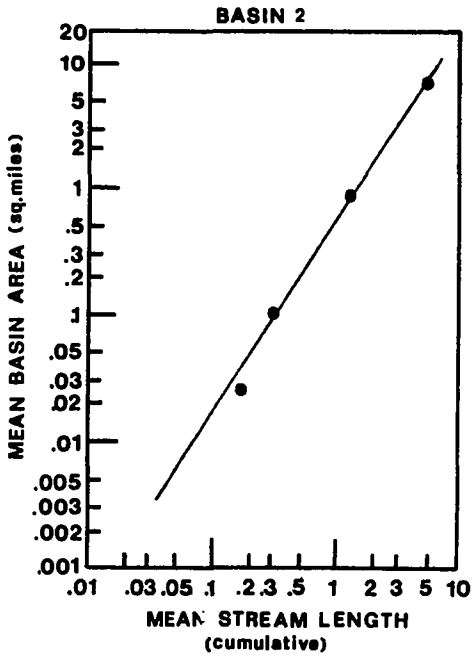
$$\text{Log } Y = A_o + A_1 \log X$$

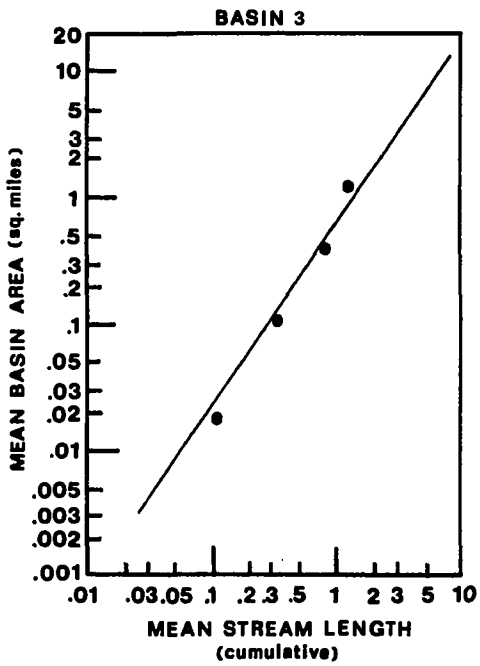
Normal Equations

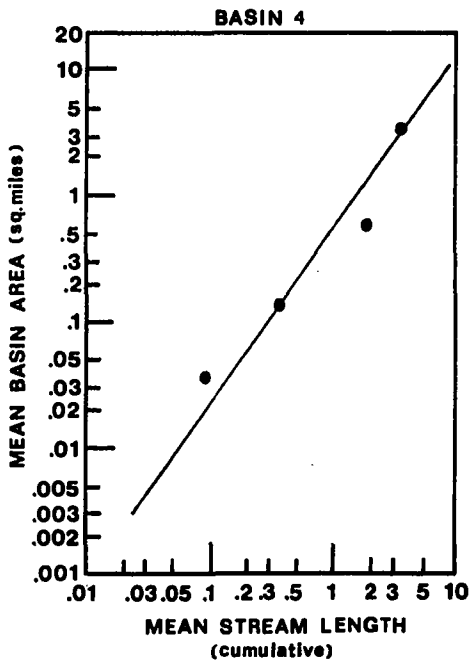
$$A_o = \frac{(\Sigma \log Y)(\Sigma \log^2 X) - (\Sigma \log X)(\Sigma \log X \cdot \log Y)}{N(\Sigma \log^2 X) - (\Sigma \log X)^2}$$

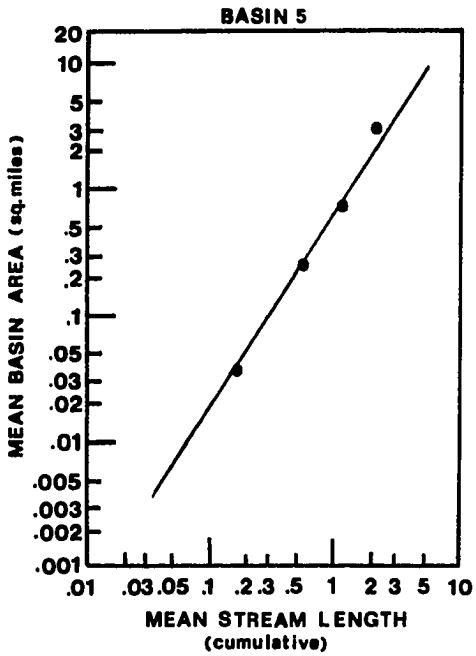
$$A_1 = \frac{N(\Sigma \log X \cdot \log Y) - (\Sigma \log X)(\Sigma \log Y)}{N(\Sigma \log^2 X) - (\Sigma \log X)^2}$$

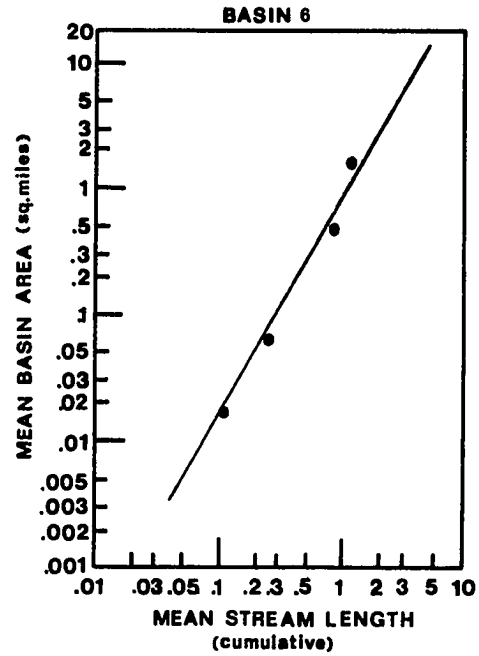

BASIN 1
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

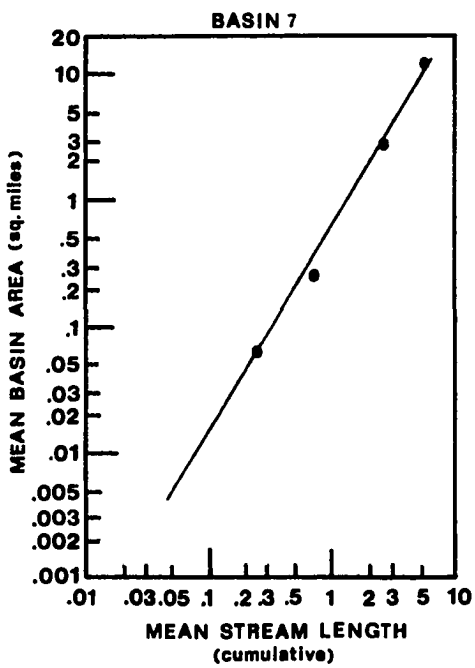

BASIN 2
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

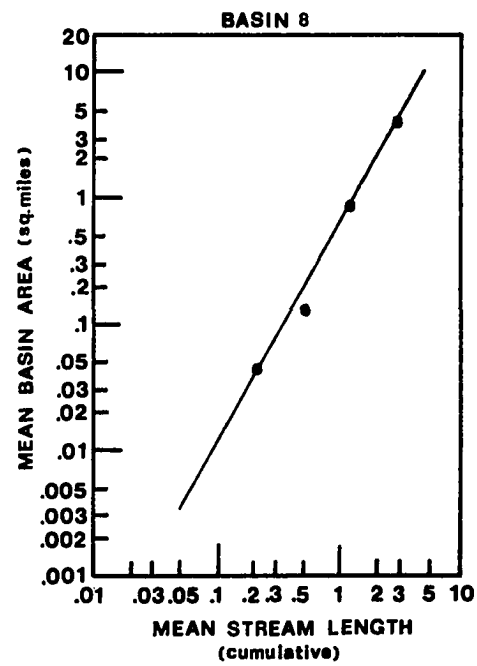

BASIN 3
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

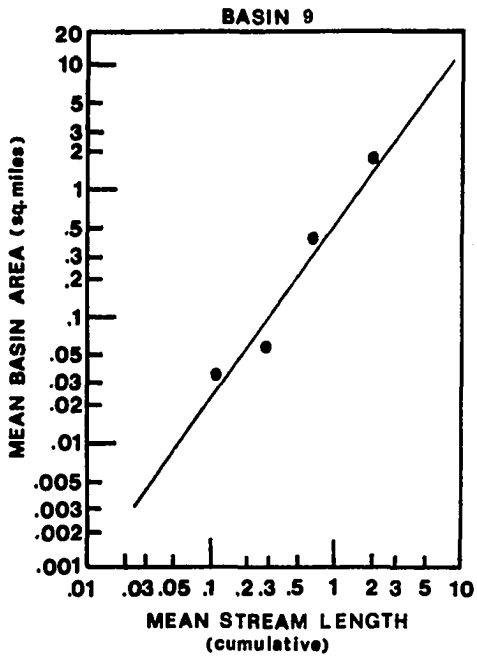

BASIN 4
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

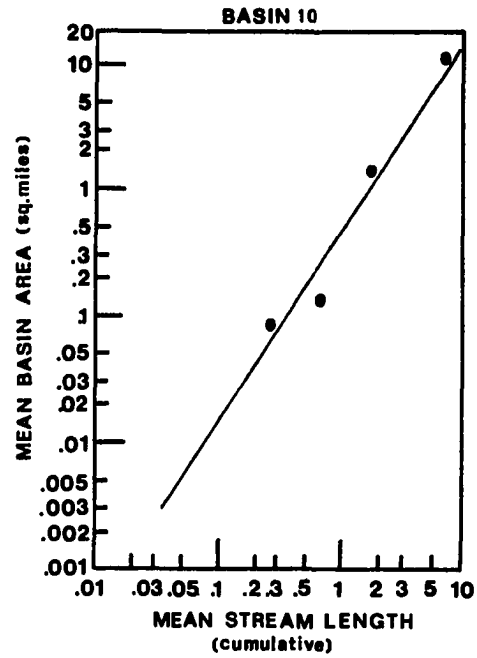

BASIN 5
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

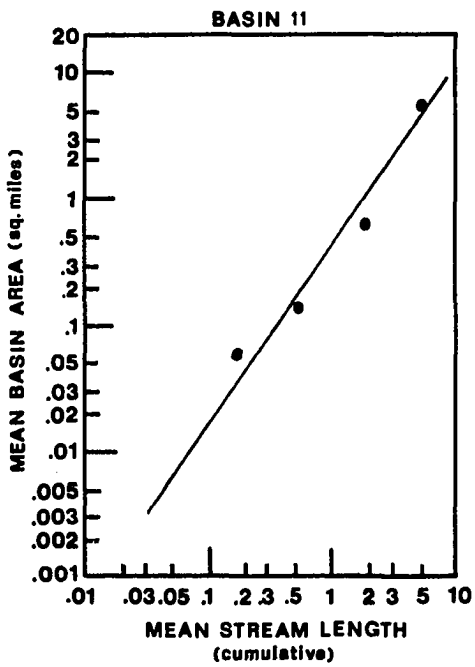

BASIN 6
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

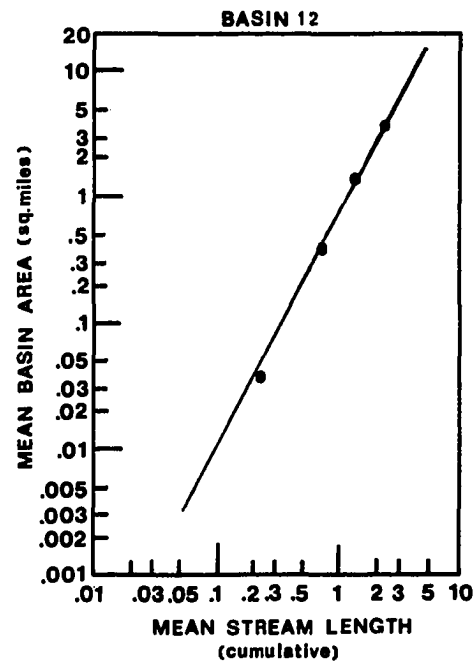

BASIN 7
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

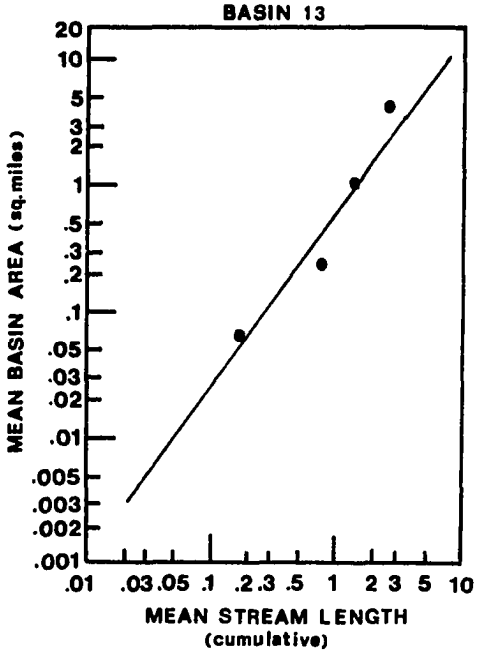

BASIN 8
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

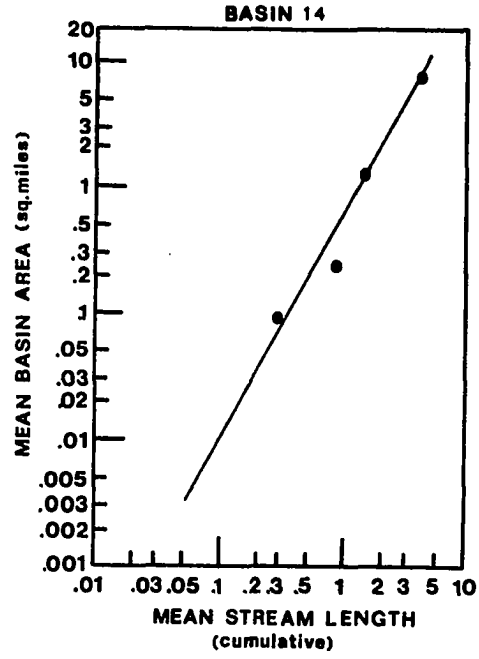

BASIN 9
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

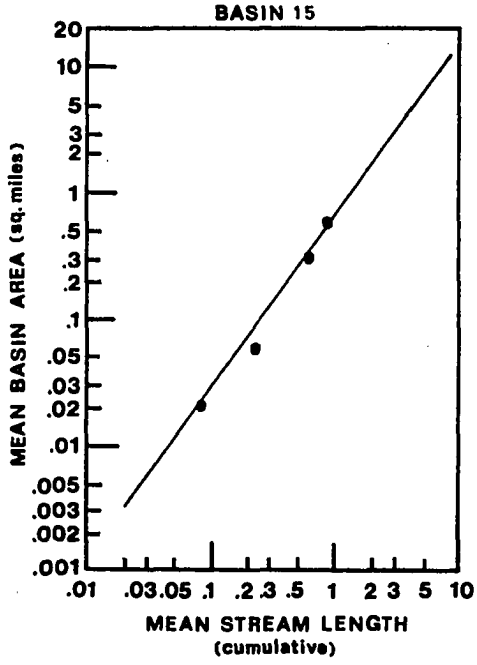

BASIN 10
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

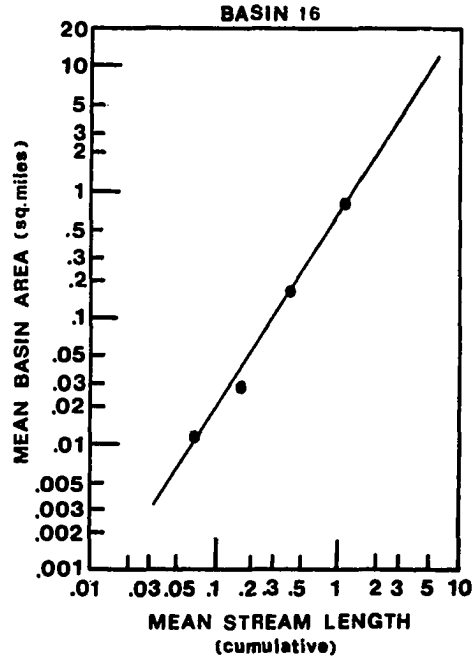

BASIN 11
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

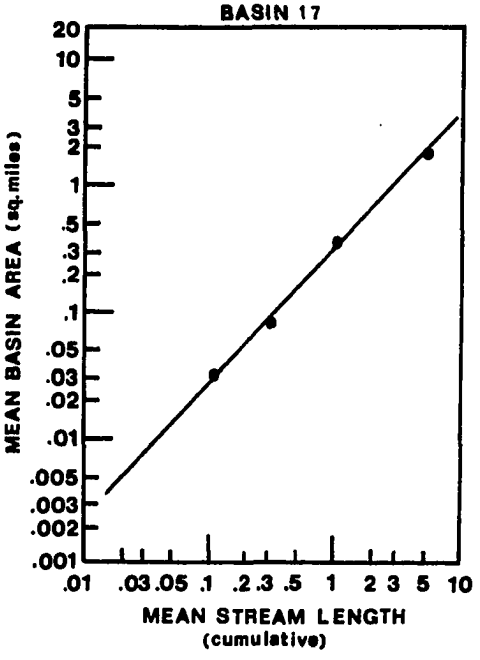

BASIN 12
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

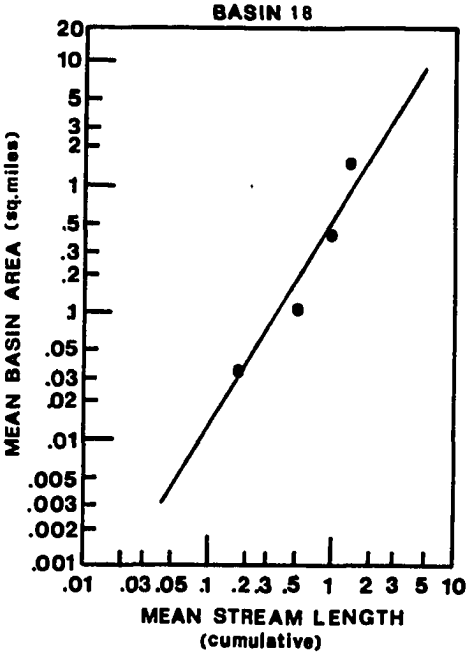

BASIN 13
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

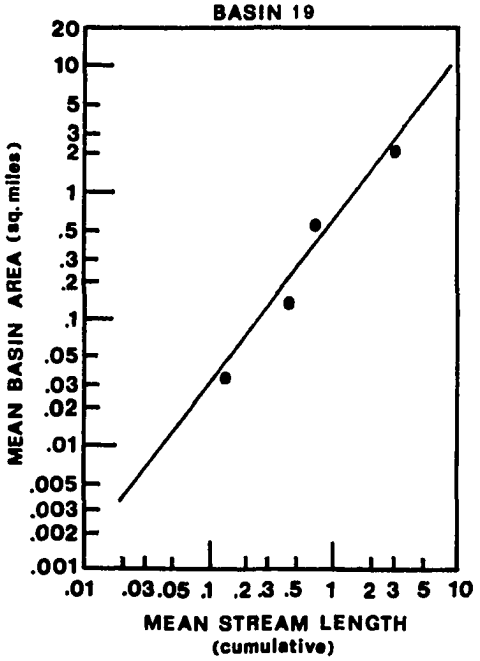

BASIN 14
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

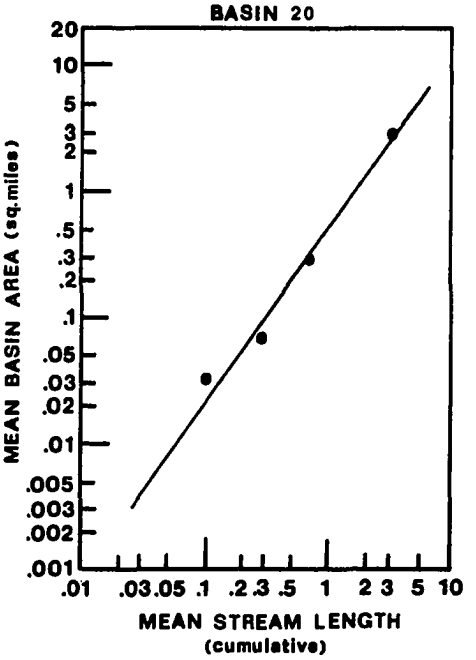

BASIN 15
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

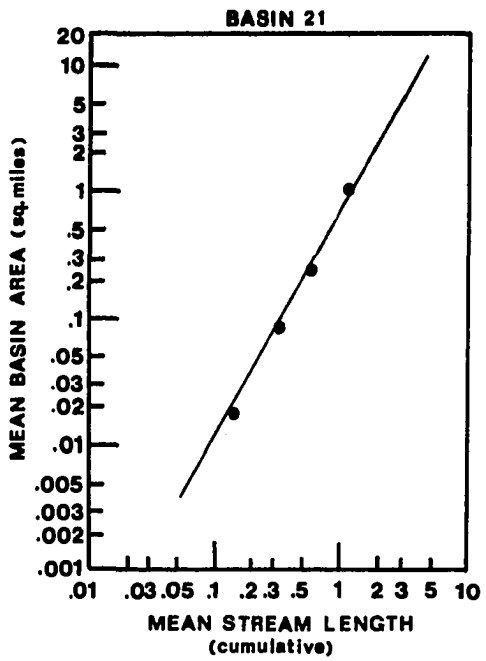

BASIN 16
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

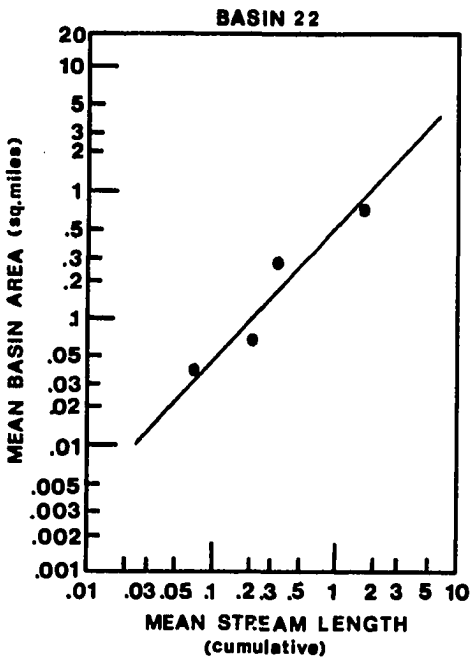

BASIN 17
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

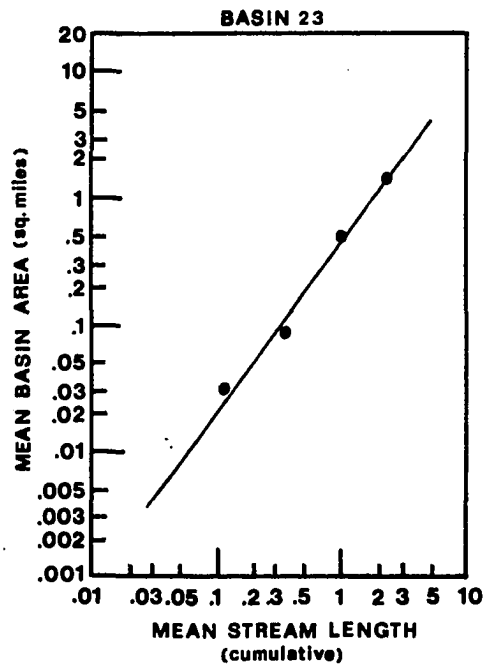

BASIN 18
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

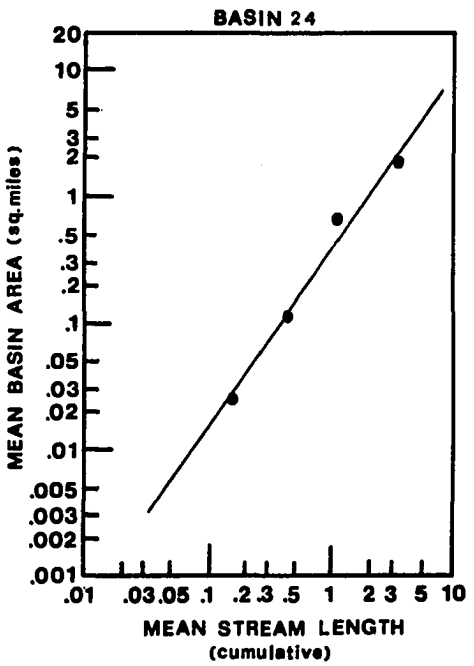

BASIN 19
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

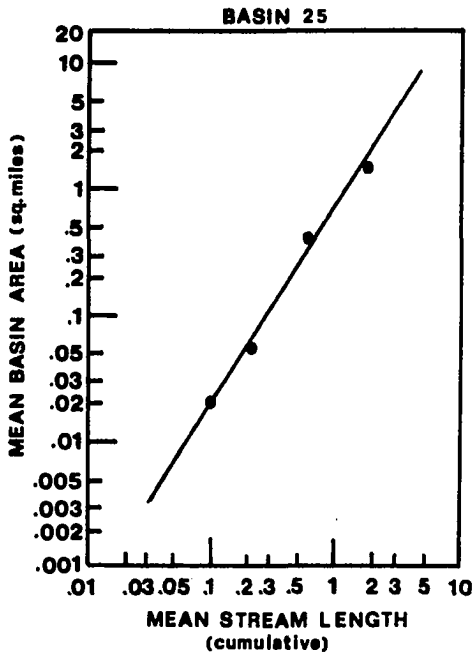

BASIN 20
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

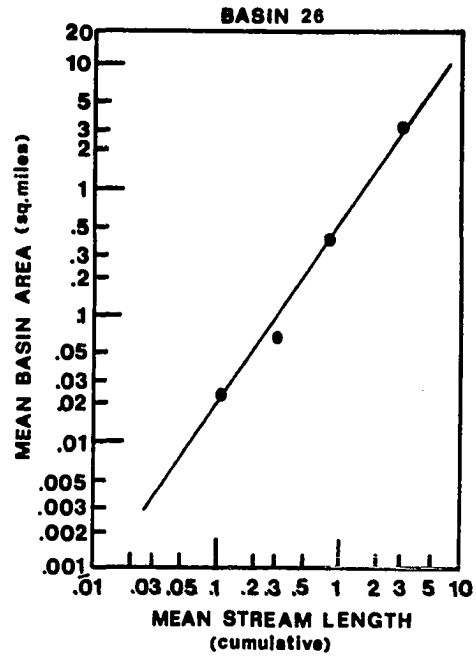

BASIN 21
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

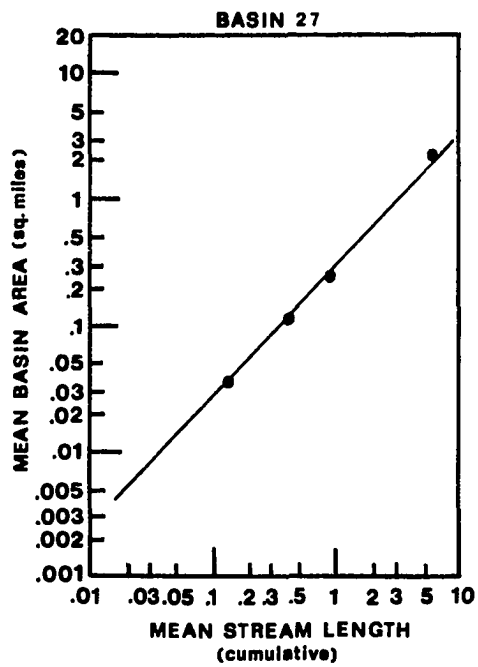

BASIN 22
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

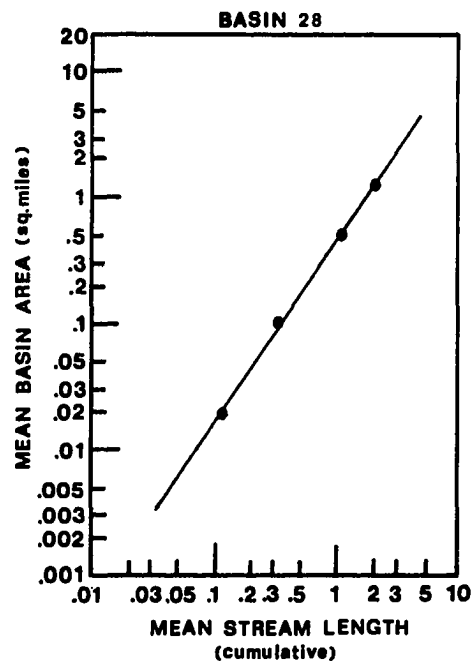

BASIN 23
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

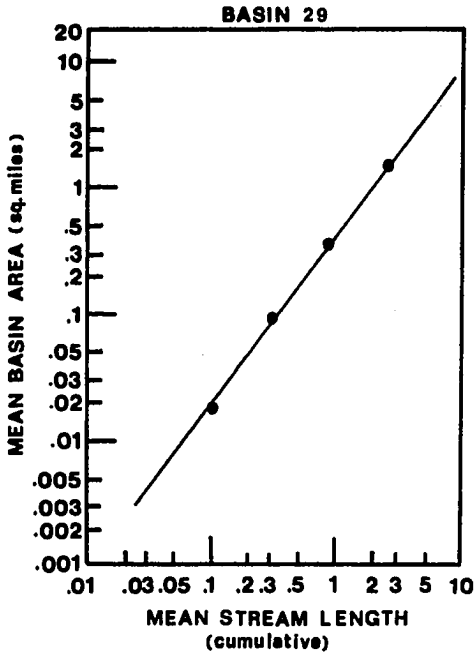

BASIN 24
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

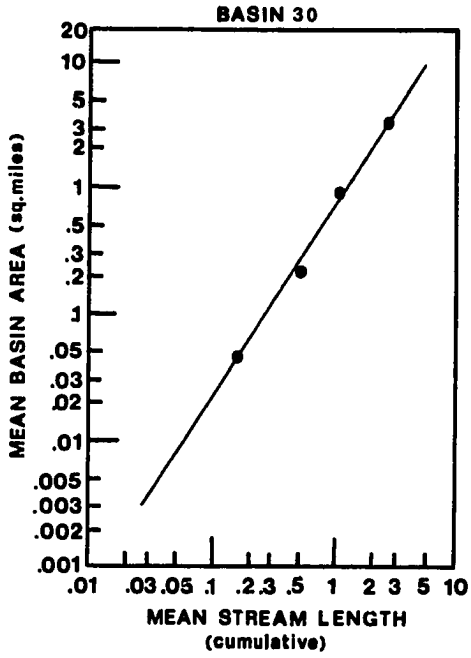

BASIN 25
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

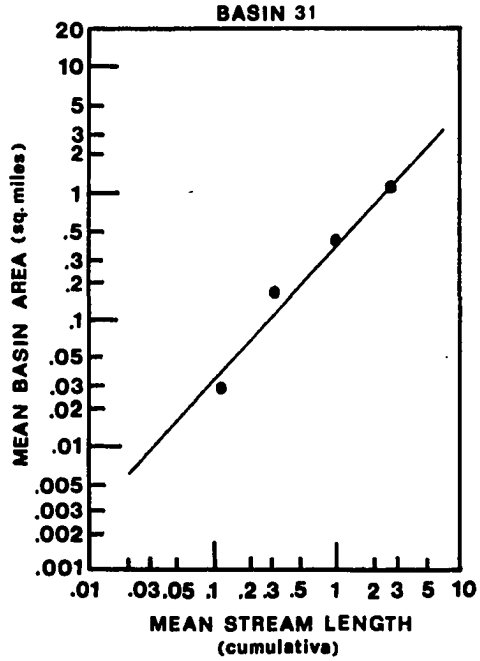

BASIN 26
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

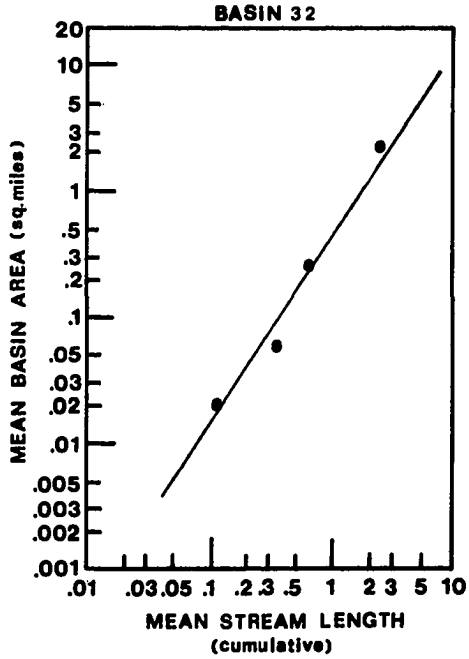

BASIN 27
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

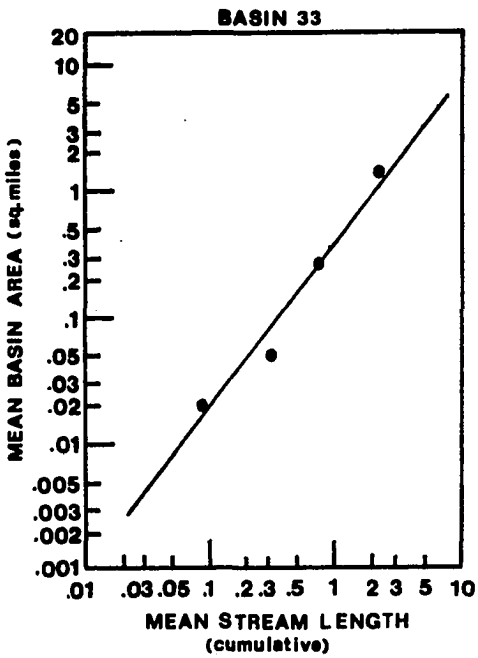

BASIN 28
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

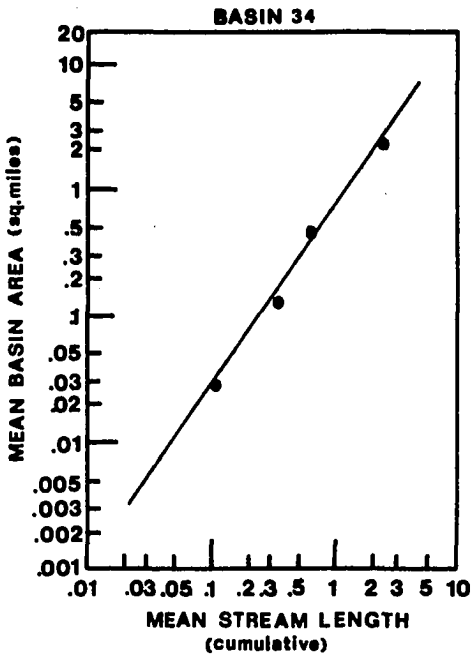

BASIN 29
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

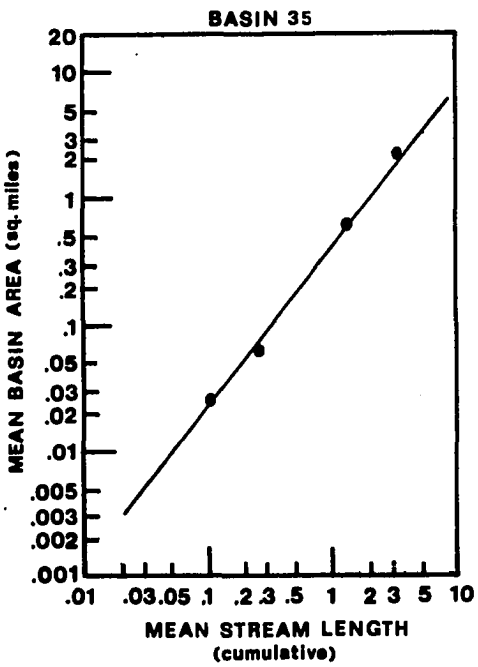

BASIN 30
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

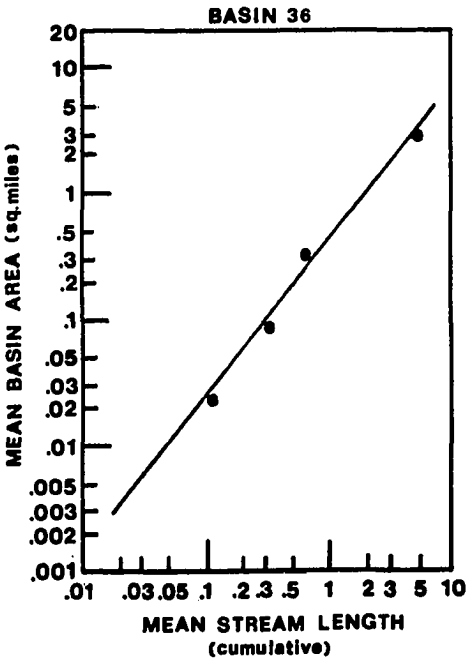

BASIN 31
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

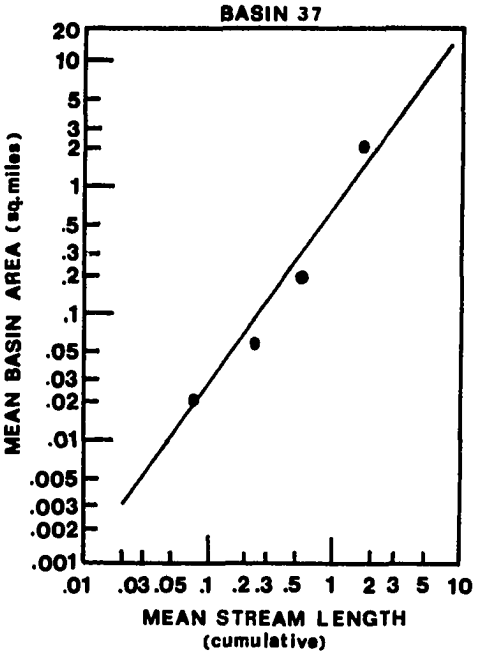

BASIN 32
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

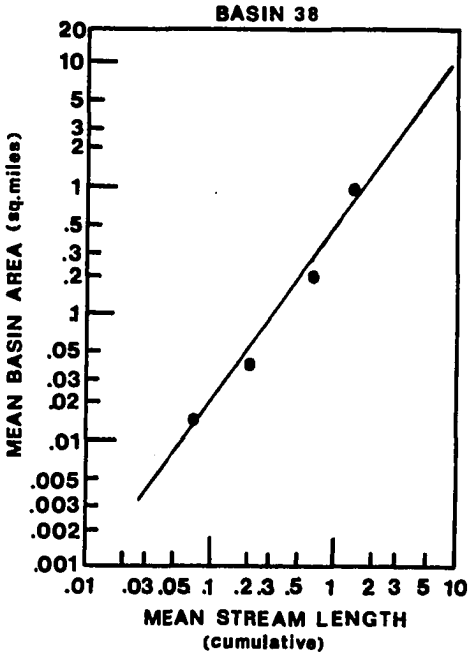

BASIN 33
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

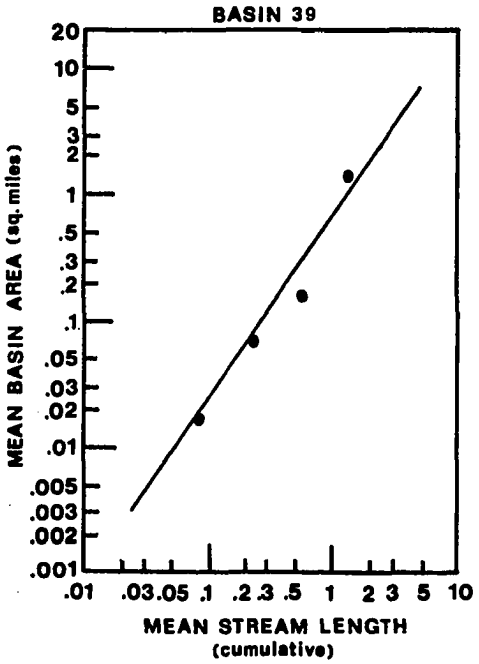

BASIN 34
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

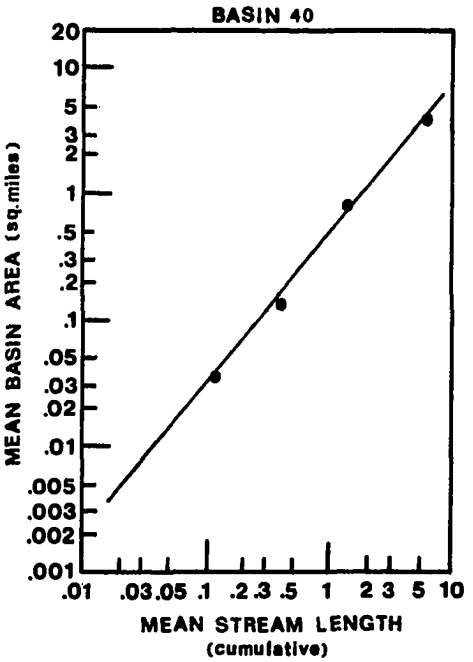

BASIN 35
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

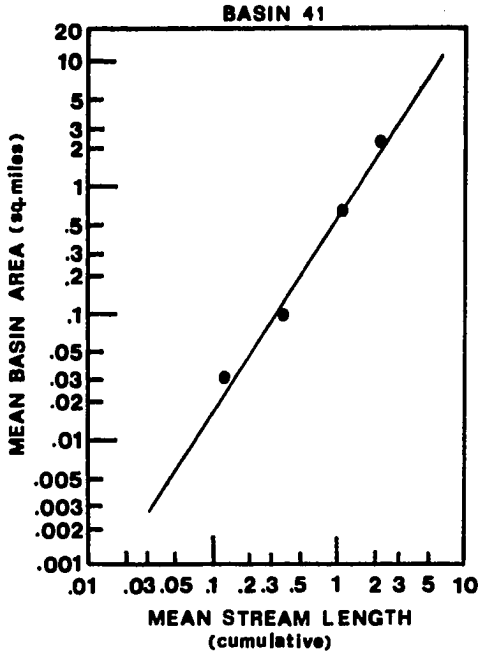

BASIN 36
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

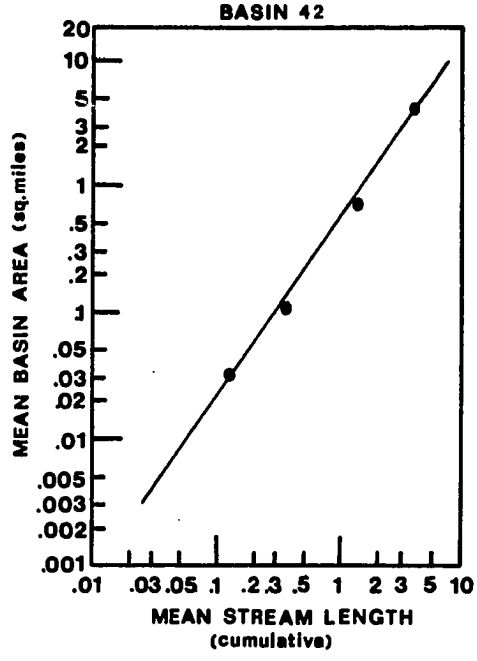

BASIN 37
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

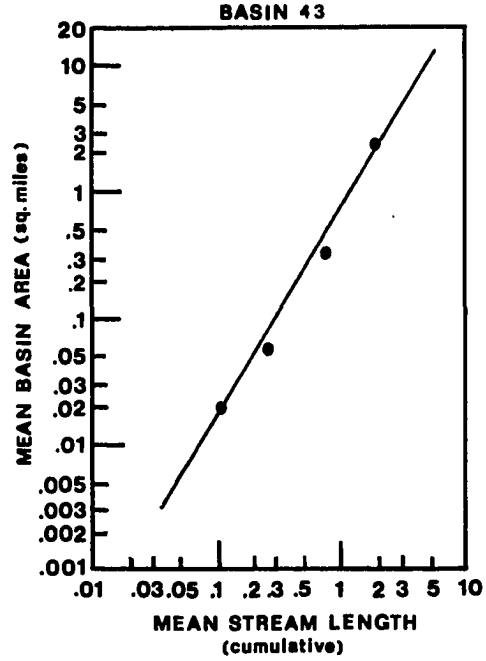

BASIN 38
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

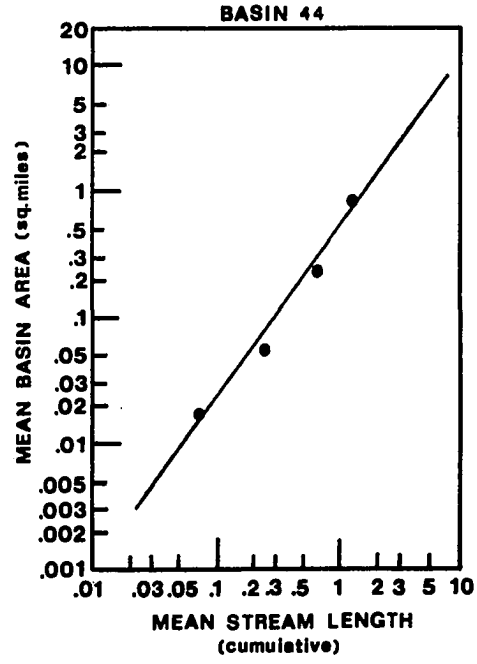

BASIN 39
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

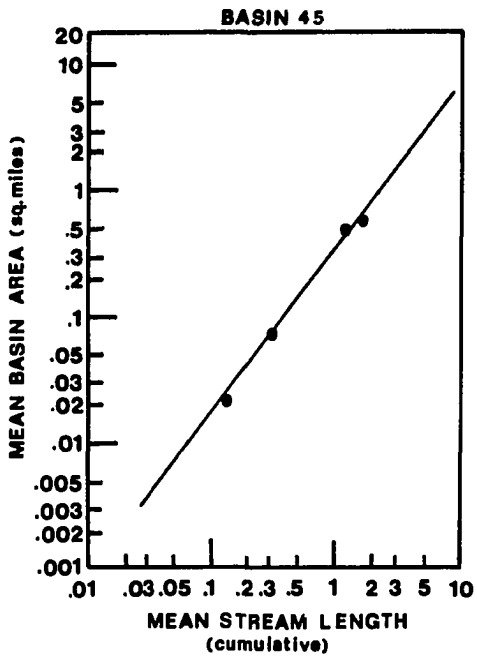

BASIN 40
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

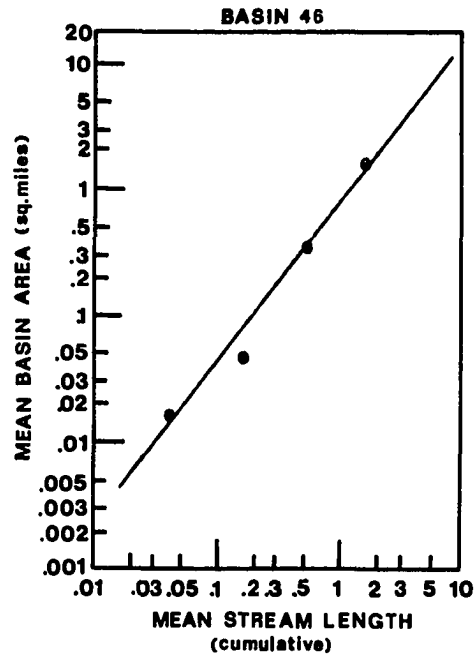

BASIN 41
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

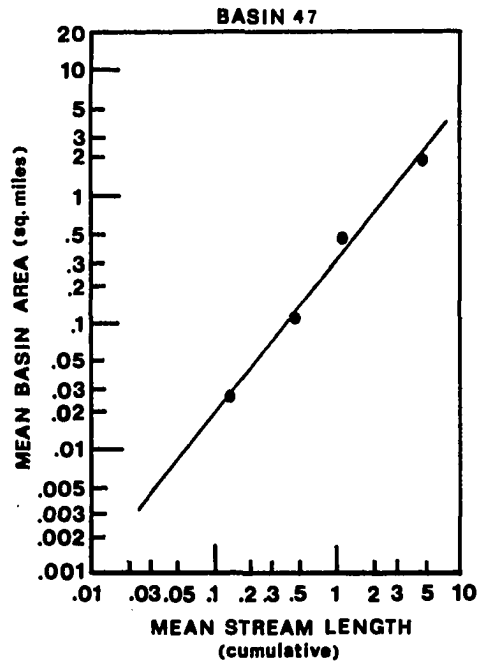

BASIN 42
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

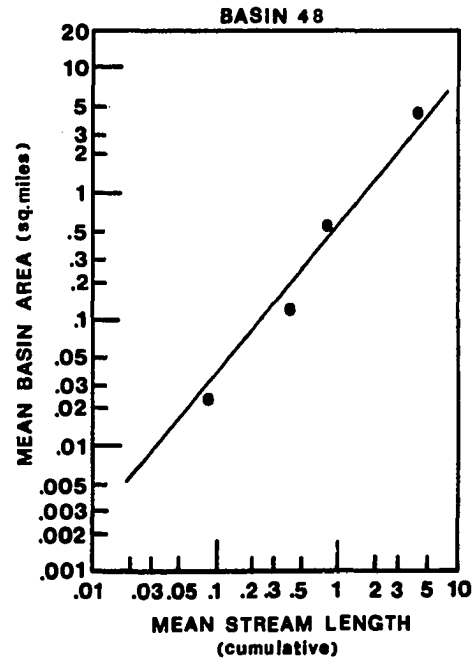

BASIN 43
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

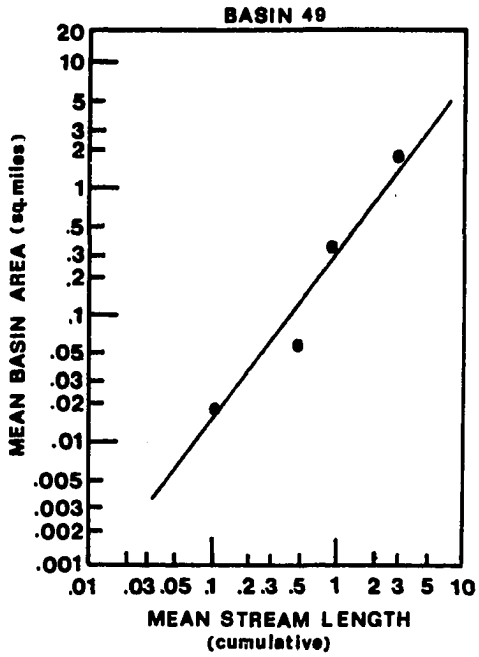

BASIN 44
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

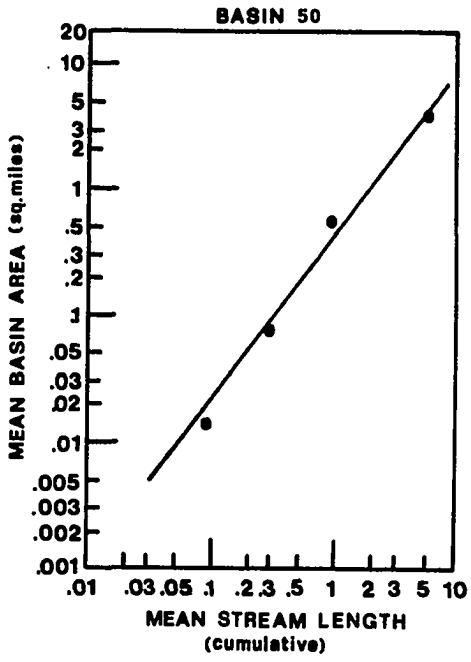

BASIN 45
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

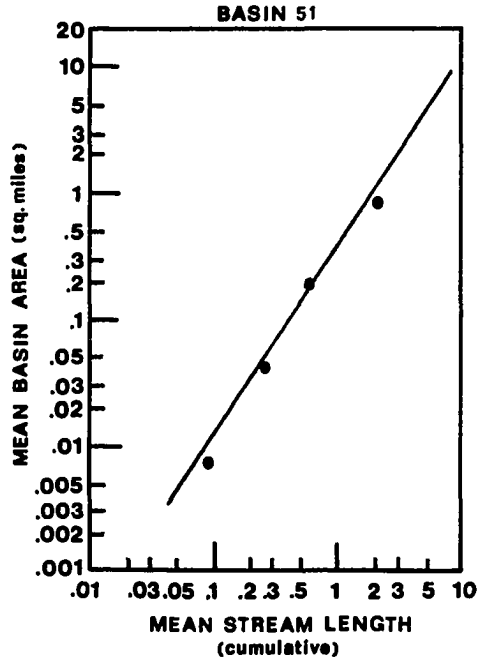

BASIN 46
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

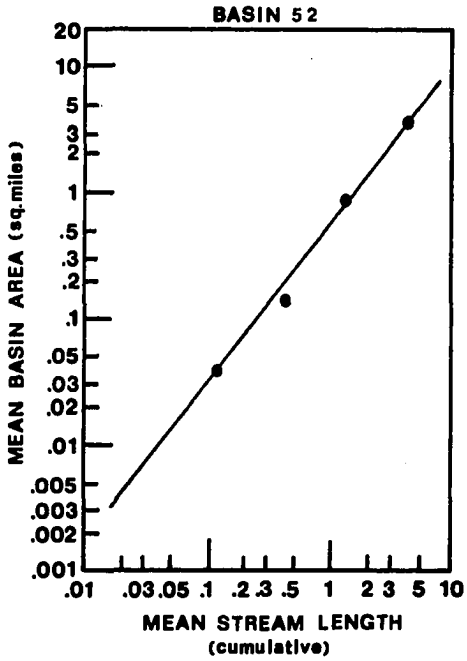

BASIN 47
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

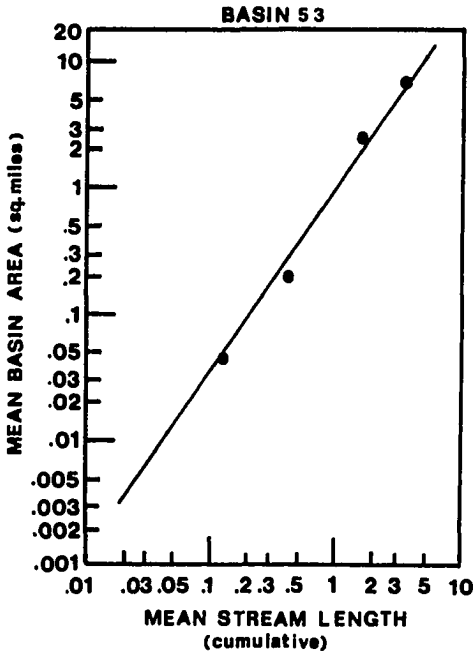

BASIN 48
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

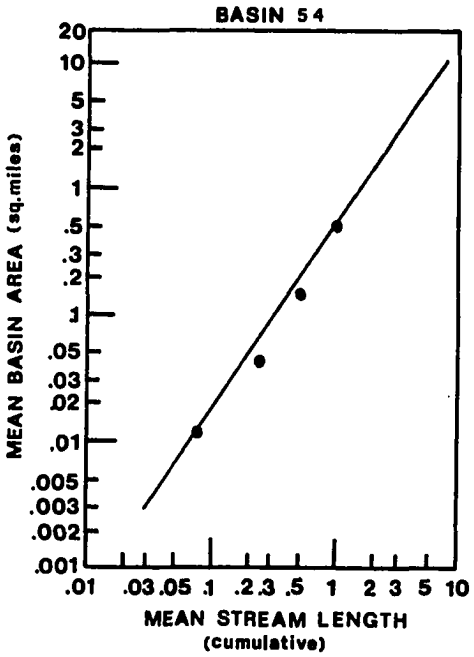

BASIN 49
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

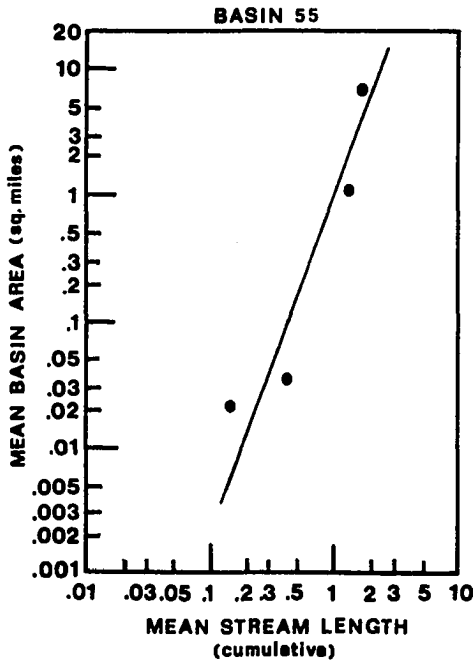

BASIN 50
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

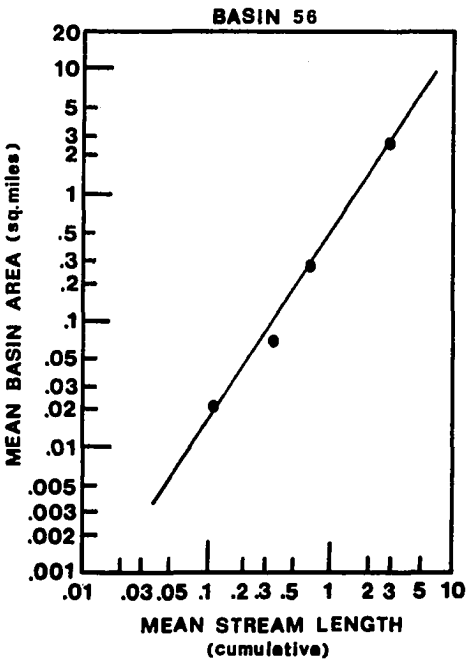

BASIN 51
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

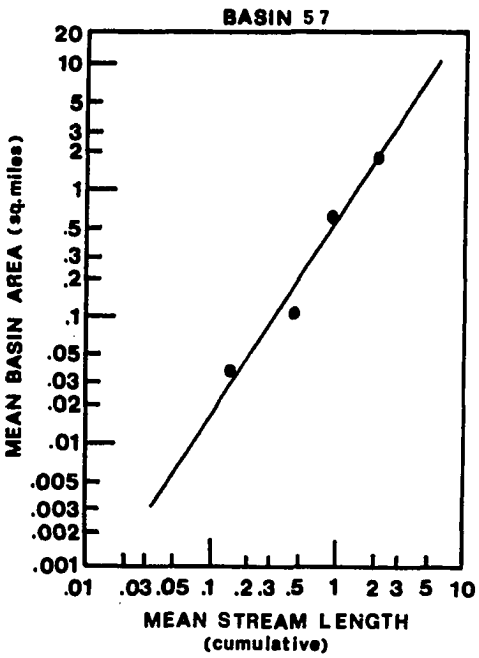

BASIN 52
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

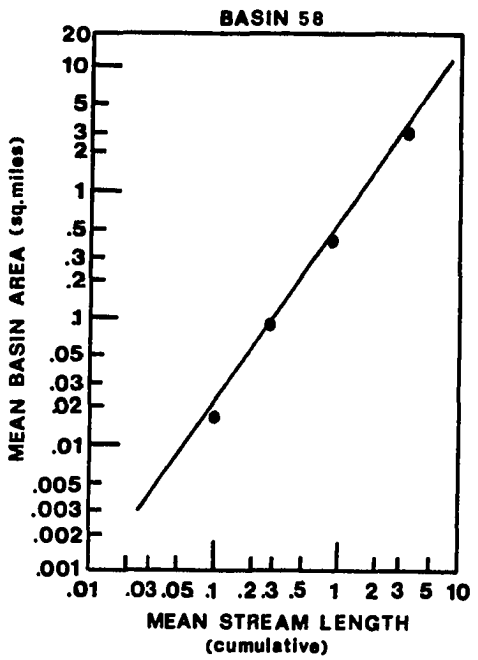

BASIN 53
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

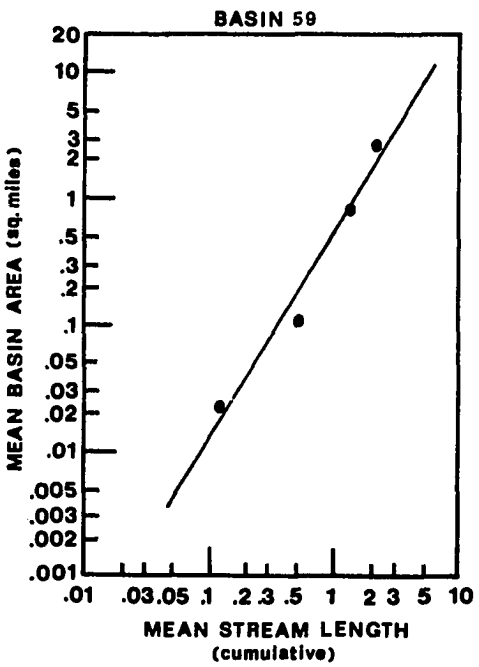

BASIN 54
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

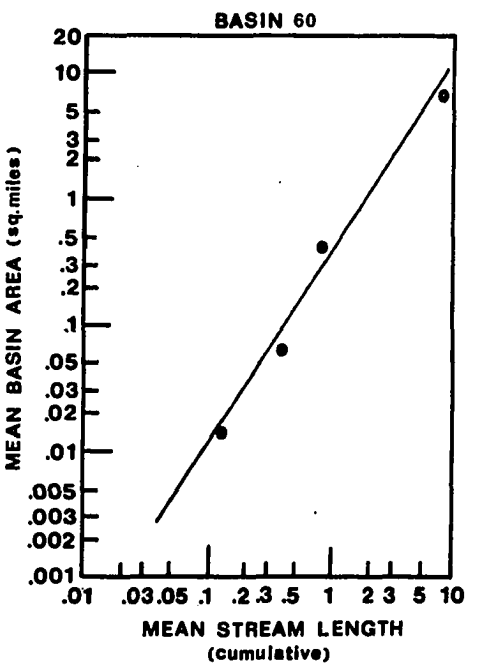

BASIN 55
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

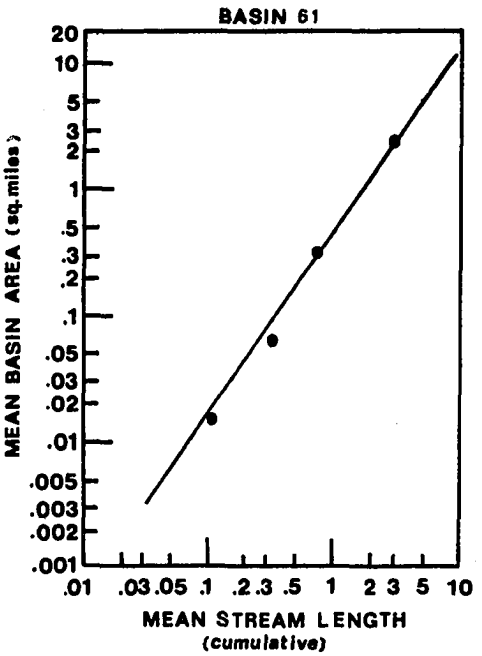

BASIN 56
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

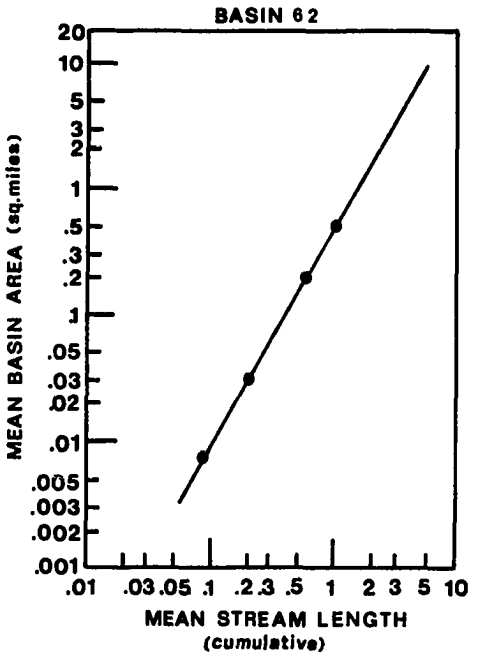

BASIN 57
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

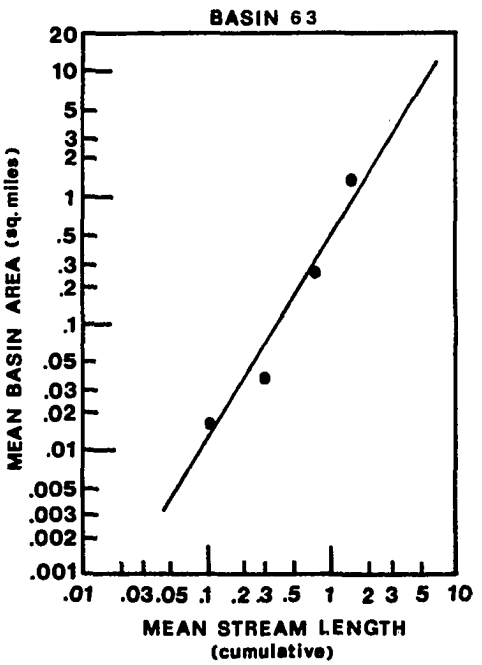

BASIN 58
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

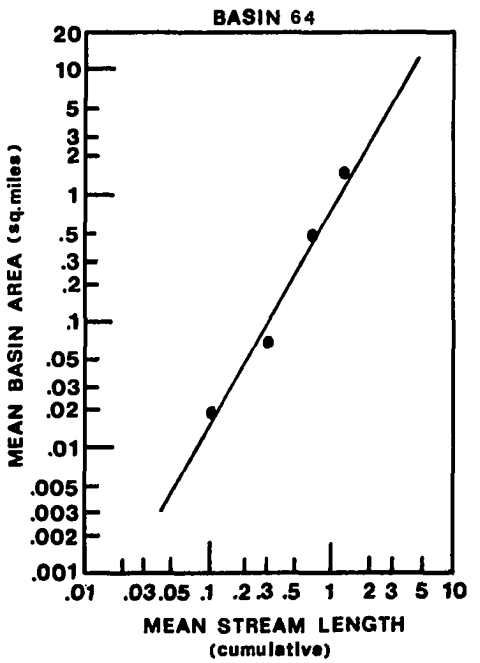

BASIN 59
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

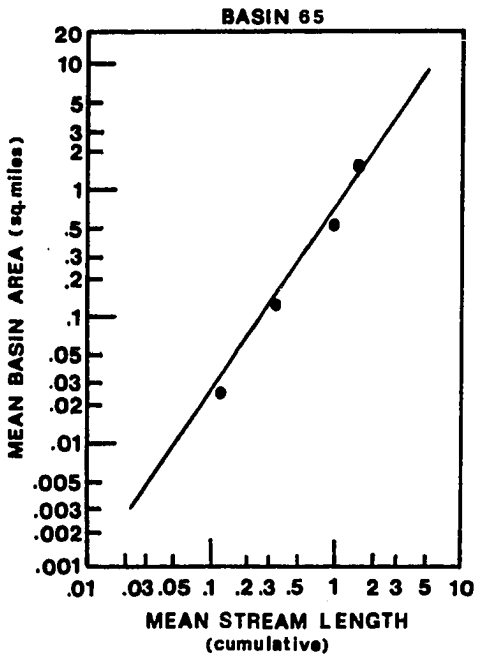

BASIN 60
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

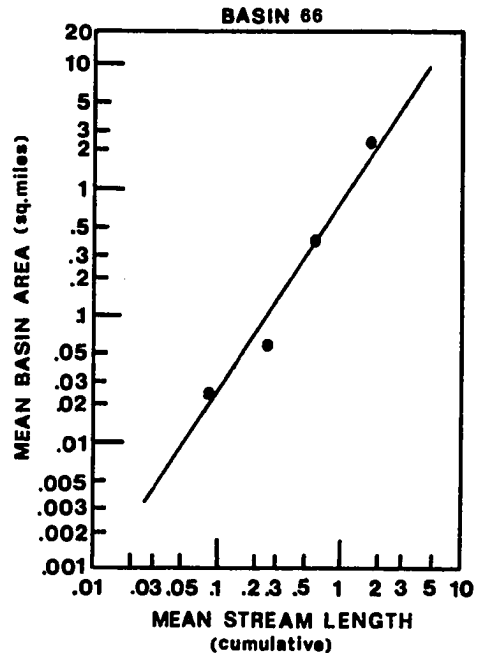

BASIN 61
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

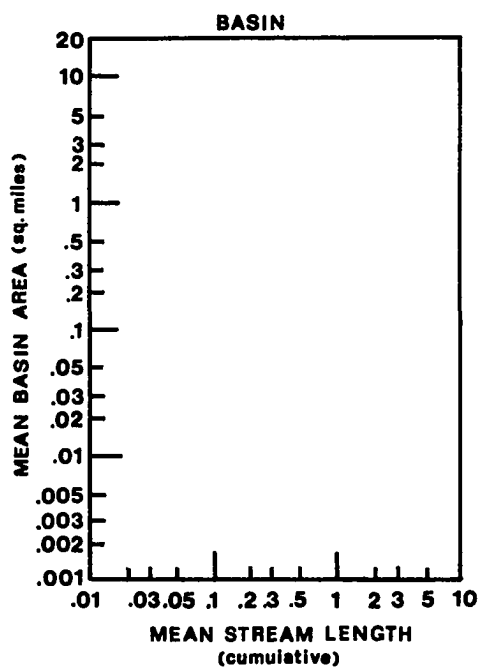

BASIN 62
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

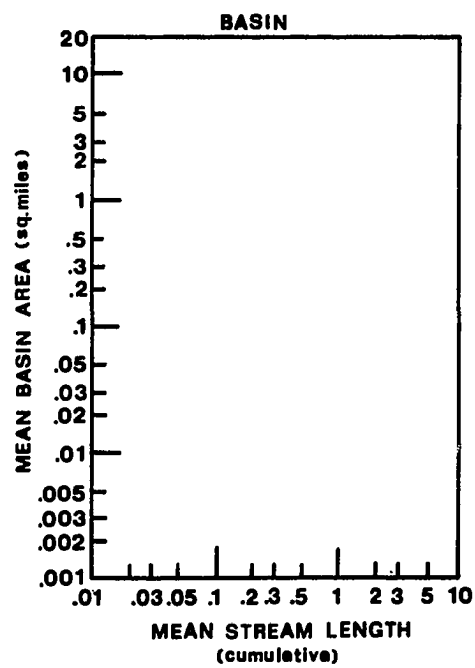

BASIN 63
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)


BASIN 64
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)


BASIN 65
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)


BASIN 66
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)


BASIN
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)


BASIN
MEAN BASIN AREA (sq.miles)
20
10
5
3
2
1
.5
.3
.2
.1
.05
.03
.02
.01
.005
.003
.002
.001
.01 .03 .05 .1 .2 .3 .5 1 2 3 5 10
MEAN STREAM LENGTH
(cumulative)

REGRESSION EQUATIONS

Basin Number	
1	log Y = - 0.22238 + 1.83314 log X
2	log Y = - 0.25491 + 1.64479 log X
3	log Y = - 0.20164 + 1.62734 log X
4	log Y = - 0.30196 + 1.18039 log X
5	log Y = - 0.17052 + 1.67454 log X
6	log Y = - 0.04963 + 1.78131 log X
7	log Y = - 0.26056 + 1.72198 log X
8	log Y = - 0.26039 + 1.75552 log X
9	log Y = - 0.22970 + 1.42400 log X
10	log Y = - 0.33825 + 1.60065 log X
11	log Y = - 0.37562 + 1.31403 log X
12	log Y = - 0.15144 + 1.90304 log X
13	log Y = - 0.19717 + 1.52036 log X
14	log Y = - 0.23660 + 1.77828 log X
15	log Y = - 0.24075 + 1.40305 log X
16	log Y = - 0.21624 + 1.60306 log X
17	log Y = - 0.49321 + 1.08659 log X
18	log Y = - 0.24820 + 1.76979 log X
19	log Y = - 0.28854 + 1.34501 log X
20	log Y = - 0.31230 + 1.35543 log X
21	log Y = - 0.19804 + 1.91073 log X
22	log Y = - 0.34324 + 0.97359 log X

Basin Number	
23	log Y = - 0.33659 + 1.36235 log X
24	log Y = - 0.43462 + 1.40530 log X
25	log Y = - 0.16193 + 1.52305 log X
26	log Y = - 0.27466 + 1.49980 log X
27	log Y = - 0.54242 + 1.09616 log X
28	log Y = - 0.37099 + 1.43007 log X
29	log Y = - 0.38163 + 1.36929 log X
30	log Y = - 0.16884 + 1.53535 log X
31	log Y = - 0.40126 + 1.10255 log X
32	log Y = - 0.37573 + 1.52337 log X
33	log Y = - 0.41285 + 1.36288 log X
34	log Y = - 0.15083 + 1.43646 log X
35	log Y = - 0.39433 + 1.30924 log X
36	log Y = - 0.41539 + 1.27565 log X
37	log Y = - 0.20633 + 1.45960 log X
38	log Y = - 0.33748 + 1.41780 log X
39	log Y = - 0.18241 + 1.51134 log X
40	log Y = - 0.36282 + 1.22940 log X
41	log Y = - 0.22835 + 1.53885 log X
42	log Y = - 0.29663 + 1.43073 log X
43	log Y = - 0.21325 + 1.64795 log X
44	log Y = - 0.35279 + 1.36216 log X

Basin Number	
45	log Y = - 0.48707 + 1.36588 log X
46	log Y = - 0.13215 + 1.27049 log X
47	log Y = - 0.52005 + 1.25142 log X
48	log Y = - 0.32482 + 1.30747 log X
49	log Y = - 0.51044 + 1.39036 log X
50	log Y = - 0.35118 + 1.40517 log X
51	log Y = - 0.48176 + 1.53612 log X
52	log Y = - 0.26084 + 1.31043 log X
53	log Y = - 0.02806 + 1.57190 log X
54	log Y = - 0.34361 + 1.52560 log X
55	log Y = - 0.10925 + 2.25992 log X
56	log Y = - 0.34312 + 1.53926 log X
57	log Y = - 0.27700 + 1.53122 log X
58	log Y = - 0.30961 + 1.40183 log X
59	log Y = - 0.28126 + 1.61169 log X
60	log Y = - 0.48984 + 1.47560 log X
61	log Y = - 0.36639 + 1.53583 log X
62	log Y = - 0.33323 + 1.66614 log X
63	log Y = - 0.31020 + 1.67402 log X
64	log Y = - 0.11965 + 1.75679 log X
65	log Y = - 0.17660 + 1.56010 log X
66	log Y = - 0.11528 + 1.55798 log X

APPENDIX IX

KOLMOGROV-SMIRNOV TEST II

KOLMOGROV-SMIRNOV TEST II

Basin Number	Computed Value	N Value	Table Value
1	.0279	91.06	.142
2	- .0134	88.80	.144
3	- .0308	36.65	.224
4	.0457	274.51	.082
5	.0454	75.69	.156
6	- .0521	166.79	.105
7	- .0267	120.68	.123
8	- .0151	108.24	.130
9	- .0087	121.07	.123
10	- .0125	92.90	.141
11	.0101	147.27	.112
12	.0254	98.87	.136
13	.0654	48.01	.196
14	- .0217	51.63	.189
15	- .0111	135.43	.116
16	- .0222	191.94	.098
17	.0124	97.78	.137
18	.0305	62.58	.171
19	.0581	38.78	.218
20	- .0151	76.84	.155
21	- .0552	71.23	.161
22	.0208	62.09	.172

Basin Number	Computed Value	N Value	Table Value
23	.0173	80.91	.151
24	.0631	67.37	.165
25	- .0078	138.48	.115
26	- .0210	173.04	.103
27	- .0127	91.15	.142
28	.0164	135.24	.117
29	.0486	34.97	.230
30	.0130	140.48	.114
31	- .0083	143.88	.113
32	- .0147	79.16	.152
33	.0355	169.93	.104
34	.0344	98.40	.137
35	.0670	56.49	.181
36	.0106	164.19	.106
37	- .0049	230.65	.089
38	- .0105	101.37	.135
39	- .0419	218.54	.092
40	.0095	192.48	.098
41	- .0110	96.32	.138
42	.0489	95.43	.139
43	.0103	94.26	.140
44	.0477	111.02	.129

Basin Number	Computed Value	N Value	Table Value
45	- .0186	63.09	.171
46	- .0152	143.75	.113
47	.0347	73.82	.158
48	.0640	71.59	.160
49	- .0174	65.82	.167
50	- .0103	225.79	.090
51	.0153	152.86	.110
52	.0302	97.57	.137
53	.0112	148.06	.111
54	- .0221	97.08	.138
55	- .0136	146.93	.112
56	- .0304	98.88	.136
57	.0153	88.89	.144
58	.0056	202.66	.095
59	.0453	81.51	.150
60	- .0364	341.55	.073
61	- .0084	126.01	.121
62	- .0100	102.82	.134
63	- .0135	144.87	.113
64	- .0078	189.46	.098
65	- .0254	193.88	.097
66	- .0065	205.01	.095

N values were determined by the following formula:

$$N = \frac{n_1 n_2}{(n_1 + n_2)}$$

where:

n_1 = total observed channels

n_2 = total predicted channels

Table value for N exceeding thirty-five were determined by the following formula:

$$\frac{1.36}{\sqrt{N}}$$

where:

$$N = \frac{n_1 n_2}{(n_1 + n_2)}$$

APPENDIX X

SPEARMAN RANK CORRELATION--KOLMOGROV-SMIRNOV TESTS I AND II

SPEARMAN RANK CORRELATION

Correlation Test for Large Deviations from Significance Level for Kolmogrov-Smirnov Tests I and II

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (deviation of Kolmogrov-Smirnov II value from significance level) and rank two (deviation of Kolmogrov-Smirnov I value from significance level)

N = number in sample

$\Sigma D^2 = 9992.25$

N = 66

$$rs = 1 - \frac{(6)(9992.25)}{(66)(66^2 - 1)}$$

$$rs = 1 - \frac{59953.50}{287430}$$

rs = .7914154

Compute Z value ($Z = r_{s/S}$) and compare to Z tables

$z = r_{s/S}$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{66 - 1}}$$

$$S = \frac{1}{8.0623}$$

$$S = .1240340$$

$$z = \frac{.7914154}{.1240340}$$

$$z = 6.3806327$$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large deviations from significance level for Kolmogrov-Smirnov Test I and II.

Results: Reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Small Deviations from Significance Level for Kolmogrov-Smirnov Tests I and II

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (deviation of Kolmogrov-Smirnov II value from significance level) and rank two (deviation of Kolmogrov-Smirnov I value from significance level)

N = number in sample

$\Sigma D^2 = 10038.25$

N = 66

$$rs = 1 - \frac{(6)(10038.25)}{(66)(4356 - 1)}$$

$$rs = 1 - \frac{60229.5}{287430}$$

rs = .7904551

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z tables

$$Z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{66 - 1}}$$

$$S = \frac{1}{8.0623}$$

$$S = .1240340$$

$$z = \frac{.7904551}{.1240340}$$

$$z = 6.3728904$$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between small deviations from significance level for Kolmogrov-Smirnov Tests I and II.

Results: Reject null hypothesis (Ho)

APPENDIX XI

PERCENTAGE DIFFERENCE BETWEEN SUM OF OBSERVED AND PREDICTED CHANNELS--MANN-WHITNEY U TEST

PERCENTAGE DIFFERENCE BETWEEN SUM OF OBSERVED CHANNELS AND SUM OF PREDICTED CHANNELS FOR EACH DRAINAGE BASIN

Basin	Sum of Observed	Sum of Predicted	Percent Predicted Deviates from Observed
1	192	200.13	4.23
2	185	200.13	8.17
3	76	89.83	18.19
4	597	560.23	6.15
5	160	160.26	.16
6	326	345.36	5.93
7	258	305.86	18.50
8	218	211.24	3.10
9	246	242.48	1.43
10	192	200.13	4.23
11	310	317.48	2.41
12	204	199.50	2.20
13	90	97.57	8.41
14	106	97.57	7.95
15	274	277.42	1.24
16	381	374.92	1.59
17	205	200.13	2.37
18	132	132.52	.39
19	83	89.83	8.22
20	159	160.26	.79

Basin	Sum of Observed	Sum of Predicted	Percent Predicted Deviates from Observed
21	142	160.26	12.85
22	132	160.26	21.40
23	172	160.26	6.82
24	146	160.26	9.76
25	283	277.42	1.97
26	348	331.69	4.68
27	186	189.10	1.66
28	284	277.42	2.31
29	74	89.83	21.39
30	287	277.42	3.33
31	297	291.84	1.73
32	164	160.26	2.28
33	364	347.04	4.65
34	206	200.13	2.84
35	125	132.52	6.01
36	341	371.25	8.87
37	463	468.86	1.26
38	208	211.24	1.55
39	419	424.47	1.30
40	408	394.07	3.41
41	196	211.24	7.77
42	205	200.13	2.37

Basin	Sum of Observed	Sum of Predicted	Percent Predicted Deviates from Observed
43	197	200.13	1.58
44	230	231.55	.67
45	132	132.52	.39
46	288	291.84	1.33
47	160	160.26	.16
48	133	132.52	.34
49	135	132.52	1.83
50	462	468.86	1.91
51	318	317.48	.16
52	209	200.13	4.24
53	312	317.48	1.75
54	195	211.24	8.32
55	310	317.48	2.41
56	203	211.24	4.05
57	184	200.13	8.76
58	419	394.07	5.94
59	173	160.26	12.74
60	678	689.32	11.32
61	255	242.48	12.52
62	207	199.50	7.50
63	287	291.84	4.84
64	376	374.92	1.08

Basin	Sum of Observed	Sum of Predicted	Percent Predicted Deviates from Observed
65	379	374.92	4.08
66	408	418.88	10.88

FORMULA USED TO COMPUTE PERCENTAGE DIFFERENCE BETWEEN SUM OF OBSERVED CHANNELS AND SUM OF PREDICTED CHANNELS FOR EACH DRAINAGE BASIN

$$O - p = d$$

$$\frac{d}{o} \times 100 = d'$$

$O = \Sigma$ of observed channels

$p = \Sigma$ of predicted channels

d = deviation of p from O

d' = percent deviation of model

MANN-WHITNEY U TEST

Percentage Difference Between Sum of Observed Channels and the Sum of the Predicted Channels for Basins on Two Lithostratigraphic Units as Compared to Those on One Lithostratigraphic Unit

Formula for Mann-Whitney U Test:

$$U_1 = n_1\, n_2 + \frac{n_1\,(n_1 + 1)}{2} - R_1$$

$$U_2 = n_1\, n_2 + \frac{n_2\,(n_2 + 1)}{2} - R_2$$

n_1 = number in sample one

n_2 = number in sample two

1) $$U_1 = n_1\, n_2 + \frac{n_1\,(n_1 + 1)}{2} - R_1$$

$n_1 = 22,\ n_2 = 44,\ R_1 = 727$

$$U_1 = (22)\,(44) + \frac{(22)\,(22 + 1)}{2} - 727$$

$$U_1 = 968 + \frac{506}{2} - 727$$

$$U_1 = 491$$

2) $$U_2 = n_1\, n_2 + \frac{n_2\,(n_2 + 1)}{2} - R_2$$

$n_1 = 22,\ n_2 = 44,\ R_2 = 1483$

$$U_2 = (22)\,(44) + \frac{(44)\,(44 + 1)}{2} - 1483$$

$$U_2 = 968 + \frac{1980}{2} - 1483$$

$$U_2 = 475$$

3) Compute Z value and compare to z tables

$$Z = \frac{U - \frac{n_1\ n_2}{2}}{\sqrt{\frac{(n_1\ n_2)\ (n_1 + n_2 + 1)}{2}}}$$

U = 491 (use larger U value from (1) and (2)

$n_1 = 22,\ n_2 = 44$

$$Z = \frac{491 - \frac{(22)\ (44)}{2}}{\sqrt{\frac{[(22)\ (44)]\ [22 + 44 + 1]}{2}}}$$

$$Z = \frac{7}{\sqrt{32428}}$$

Z = .03887

Table value at .05 significance level = 1.96; for Mann-Whitney U Test a Z table value equal to or larger than 1.96 is required to reject the null hypothesis (Ho)

Ho

There is not a significant difference between the percent deviation of total predicted from total observed channels for each of the forty-four basins on one lithostratigraphic unit as compared to each of the twenty-two basins on two lithostratigraphic units.

Results: Cannot reject null hypothesis (Ho)

APPENDIX XII

SPEARMAN RANK CORRELATION--PERCENT DIFFERENCE BETWEEN SUM OF OBSERVED AND PREDICTED

SPEARMAN RANK CORRELATION

Correlation Test for Percent Deviation of Total Predicted Channels from Total Observed Channels for Each Basin and Difference in Drainage Density

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank value one (percent deviation of total predicted from total observed) and rank two (difference in drainage density)

N = number in sample

$\Sigma D^2 = 1796.50$

N = 22

$$rs = 1 - \frac{(6)\ (1796.50)}{(22)\ (22^2 - 1)}$$

$$rs = 1 - \frac{10779}{10626}$$

$$rs = -\ .01439$$

Table value at .05 level of significance N = 22 = .428 (two-tailed test)

Ho

There is not a significant correlation between large deviations of total predicted from total observed channels for each basin and large differences in drainage density for the twenty-two basins developed on two lithostratigraphic units.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Percent Deviation of Total Predicted Channels from Total Observed Channels for Each Basin and Difference in Stream Frequency

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank value one (percent deviation of total predicted from total observed) and rank two (difference in stream frequency)

N = number in sample

$\Sigma D^2 = 1946$

N = 22

$$rs = 1 - \frac{(6)\ (1946)}{(22)\ (483)}$$

$$rs = 1 - \frac{11676}{10626}$$

$$rs = -\ .0988$$

Table value at .05 level of significance N = 22 = .428 (two-tailed test)

Ho

There is not a significant correlation between large percentage deviations of total predicted from total observed channels for each basin and large differences in stream frequency for the twenty-two basins developed on two lithostratigraphic units.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Percent Deviation of Total Predicted Channels from Total Observed Channels for Each Basin and Large Deviations from Area I Mean Elevation-Relief Ratio

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (percent deviation of total predicted from total observed) and rank two (large deviations from Area I mean elevation-relief ratio)

N = number in sample

$\Sigma D^2 = 306.50$

N = 15

$$rs = \frac{(6)\ (306.50)}{(15)\ (15^2 - 1)}$$

$$rs = 1 - \frac{1839}{3360}$$

rs = .4527

Table value at .05 level of significance at N = 15 = .52 (two-tailed test)

Ho

There is not a significant correlation between large percentage deviations of total predicted from total observed channels for each drainage basin and large deviations from Area I mean elevation-relief ratio.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Percent Deviation of Total Predicted Channels from Total Observed Channels for Each Basin and Large Deviations from Area II Mean Elevation-Relief Ratio

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (percentage deviation of total predicted from total observed) and rank two (large deviations from Area II mean elevation-relief ratio)

N = number in sample

$\Sigma D^2 = 9450.50$

N = 39

$$rs = 1 - \frac{(6)\ (9450.50)}{(39)\ (39^2 - 1)}$$

$$rs = 1 - \frac{56703}{59280}$$

rs = .0435

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z tables

$$Z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{39 - 1}}$$

$S = .1622$

$$Z = \frac{.0435}{.1622}$$

$Z = .2681$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large percentage deviations of total predicted from total observed channels for each drainage basin and large deviations from Area II mean elevation-relief value.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Percent Deviation of Total Predicted Channels from Total Observed Channels for Each Basin and Large Deviations from Area III Mean Elevation-Relief Ratio

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (percentage deviation of total predicted from total observed) and rank two (large deviations from Area III mean elevation-relief value)

N = number in sample

$\Sigma D^2 = 398$

N = 12

$$rs = 1 - \frac{(6)\ (398)}{(12)\ (12^2 - 1)}$$

$$rs = 1 - \frac{2388}{1716}$$

$$rs = -\ .3916$$

Table value at .05 significance level N = 12 = .591

Ho

There is not a significant correlation between large percentage deviations of total predicted from total observed channels for each drainage basin and large deviations from Area III mean elevation-relief value.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Deviations from Circular Shape (Elongation Ratio Minus One) and Large Percent Deviation of Total Predicted Channels from Total Observed Channels for Each Basin

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (percentage deviation of total predicted from total observed) and rank two (large deviations from circular shape, elongation ratio minus one)

N = number in sample

$\Sigma D^2 = 36899.5$

N = 66

$$rs = 1 - \frac{(6)\ (36899.5)}{(66)\ (66^2 - 1)}$$

$$rs = 1 - \frac{221397}{287430}$$

rs = .229736

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z tables

$$Z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{66 - 1}}$$

$$S = \frac{1}{8.0623}$$

$$S = .1240340$$

$$Z = \frac{.229736}{.1240340}$$

$$Z = 1.8522$$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large deviations from circular shape (computed value for elongation ratio minus one) and large percentage deviations of total predicted from total observed channels for each drainage basin.

Results: Cannot reject null hypothesis (Ho)

APPENDIX XIII

REGRESSION SLOPE ANALYSIS

FORMULA FOR REGRESSION SLOPE ANALYSIS

1) $$S^2x_i = \frac{n_i\ (\Sigma X_i^2) - (\Sigma X_i)^2}{n_i\ (n_i - 1)}$$

2) $$S^2 \log\ y_i = \frac{n_i\ \Sigma\ (\log\ y_i)^2 - (\Sigma\ \log\ y_i)^2}{N_i\ (n - 1)}$$

3) $$S^2 \log\ y_i/X = \frac{n_i - 1}{n_i - 2}\ (S^2\ \log\ y_i - b_i^2 S^2_{xi})$$

4) $$S'^2 \log\ y/X = \frac{n - 2\ S^2\ \log\ y_i/X + (n_2 - 2)\ S'\ \log\ y_2/X}{n_1 + n_2 - 4}$$

5) $$S'^2 b_i = \frac{S'^2\ \log\ y/X}{(n_1 - 1)\ (SX_i^2)}$$

6) $$S^2\ b_1 - b_2 = S'^2_{b_1} + S'^2_{b_2}$$

7) $$\sqrt{S'^2_{b_1} + S'^2_{b_2}}$$

8) $$t_o = \frac{b_1 - b_2}{\sqrt{S'^2_{b_1} + S'^2_{b_2}}}$$

X = stream order

y = number of channels per order

b_1 = slope value for observed data regression line

b_2 = slope value for predicted data regression line

Compare computed value to t table

Degrees of freedom = $n_1 + n_2 - 4$

TEST FOR SIGNIFICANT DIFFERENCE
REGRESSION SLOPE VALUES

Drainage Basin	Computed Value	Drainage Basin	Computed Value
1	- .00492	22	- .00829
2	- .03146	23	- .07370
3	- .02408	24	- .02367
4	- .01758	25	- .01929
5	- .04655	26	- .01736
6	- .00100	27	- .05178
7	- .01317	28	- .01882
8	- .01790	29	- .01106
9	- .01276	30	- .00095
10	- .03431	31	- .03632
11	- .02873	32	- .05984
12	- .01662	33	- .01706
13	- .04466	34	- .01985
14	- .12509	35	- .05655
15	- .01311	36	- .01879
16	- .01075	37	.00405
17	- .04865	38	- .00790
18	- .07500	39	.01721
19	- .07347	40	- .02614
20	- .05212	41	.00420
21	- .02750	42	- .04176

Drainage Basin	Computed Value	Drainage Basin	Computed Value
43	- .04078	55	- .02824
44	.01145	56	- .03571
45	- .07796	57	.00512
46	- .00763	58	- .01200
47	- .05585	59	- .06564
48	- .06873	60	- .01803
49	- .08535	61	- .02141
50	- .02641	62	- .02130
51	- .01055	63	.01092
52	- .05102	64	.00975
53	- .02957	65	.00494
54	.00972	66	.01422

Table value at .05 confidence level = 3.707

Ho

For each drainage basin there is not a significant difference between the slope of the regression line for the observed data and the slope of the regression line for the predicted data.

Results: For each of the sixty-six drainage basins the null hypothesis (Ho) cannot be rejected.

BASIN BIFURCATION RATIOS

(Antilog of b Value of Regression Line)

Drainage Basin	Observed Bifurcation Ratio	Predicted Bifurcation Ratio
1	3.47	3.45
2	3.60	3.45
3	2.71	2.68
4	4.79	4.59
5	3.39	3.21
6	4.09	4.08
7	3.97	3.88
8	3.61	3.52
9	3.73	3.66
10	3.61	3.45
11	4.17	3.96
12	3.51	3.44
13	2.82	2.75
14	3.00	2.75
15	3.87	3.79
16	4.27	4.17
17	3.69	3.45
18	3.22	3.00
19	2.79	2.68
20	3.41	3.21

Drainage Basin	Observed Bifurcation Ratio	Predicted Bifurcation Ratio
21	3.31	3.21
22	3.24	3.21
23	3.51	3.21
24	3.30	3.21
25	3.91	3.79
26	4.16	4.03
27	3.59	3.35
28	3.91	3.79
29	2.69	2.68
30	3.79	3.79
31	4.13	3.87
32	3.44	3.21
33	4.18	4.05
34	3.54	3.61
35	3.16	3.00
36	4.28	4.12
37	4.38	4.42
38	3.56	3.52
39	4.03	4.17
40	4.53	4.28
41	3.50	3.52

Drainage Basin	Observed Bifurcation Ratio	Predicted Bifurcation Ratio
42	3.65	3.45
43	3.65	3.45
44	3.52	3.57
45	3.23	3.00
46	3.92	3.87
47	3.43	3.21
48	3.20	3.00
49	3.26	3.00
50	4.70	4.42
51	4.03	3.96
52	3.70	3.45
53	4.18	3.96
54	3.48	3.52
55	4.17	3.96
56	3.71	3.52
57	3.42	3.45
58	4.39	4.28
59	3.47	3.21
60	5.29	5.02
61	3.78	3.66
62	3.53	3.44

Drainage Basin	Observed Bifurcation Ratio	Predicted Bifurcation Ratio
63	3.80	3.87
64	4.09	4.17
65	4.13	4.17
66	4.13	4.25

BIFURCATION RATIOS

Basin Number 1

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.89	4.13
2		
	5.28	4.59
3		
	2.33	2.28
4		
	3.00	3.48
5		

Basin Number 2

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.26	4.13
2		
	5.85	4.59
3		
	3.50	2.28
4		
	2.00	3.48
5		

Basin Number 3

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.25	2.66
2		
	3.20	2.65
3		
	2.50	2.28
4		
	2.00	3.48
5		

Basin Number 4

Bifurcation Ratio		
Order	Observed	Predicted
1		
	6.51	7.46
2		
	5.50	4.64
3		
	4.66	3.96
4		
	3.00	3.48
5		

Basin Number 5

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.51	4.06
2		
	3.37	3.66
3		
	4.00	2.28
4		
	2.00	3.48
5		

Basin Number 6

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.12	3.45
2		
	4.35	3.76
3		
	5.66	5.51
4		
	3.00	3.48
5		

Basin Number 7

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.86	5.67
2		
	7.28	5.52
3		
	3.50	2.28
4		
	2.00	3.48
5		

Basin Number 8

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.31	3.33
2		
	4.27	4.37
3		
	3.66	2.97
4		
	3.00	3.48
5		

Basin Number 9

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.89	4.02
2		
	3.91	4.37
3		
	4.00	2.97
4		
	3.00	3.48
5		

Basin Number 10

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.73	4.13
2		
	4.22	4.59
3		
	4.50	2.28
4		
	2.00	3.48
5		

Basin Number 11

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.30	4.68
2		
	5.60	5.14
3		
	5.00	2.97
4		
	2.00	3.48
5		

Basin Number 12

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.13	3.96
2		
	3.70	3.59
3		
	3.33	2.97
4		
	3.00	3.48
5		

Basin Number 13

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.40	3.02
2		
	2.50	2.65
3		
	3.30	2.28
4		
	2.00	3.48
5		

Basin Number 14

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.36	3.02
2		
	3.14	2.65
3		
	3.50	2.28
4		
	2.00	3.48
5		

Basin Number 15

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.60	4.79
2		
	4.66	4.37
3		
	4.00	2.97
4		
	3.00	3.48
5		

Basin Number 16

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.85	3.86
2		
	4.11	3.76
3		
	6.00	5.51
4		
	3.00	3.48
5		

Basin Number 17

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.85	4.13
2		
	5.00	4.59
3		
	4.00	2.28
4		
	2.00	3.48
5		

Basin Number 18

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.73	4.68
2		
	4.33	2.65
3		
	3.00	2.28
4		
	2.00	3.48
5		

Basin Number 19

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.75	2.66
2		
	4.00	2.65
3		
	2.00	2.28
4		
	2.00	3.48
5		

Basin Number 20

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.62	4.06
2		
	4.00	3.66
3		
	4.00	2.28
4		
	2.00	3.48
5		

Basin Number 21

Bifurcation Ratio		
Order	Observed	Predicted
1		
	2.51	4.06
2		
	4.11	3.66
3		
	4.50	2.28
4		
	2.00	3.48
5		

Basin Number 22

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.42	4.06
2		
	5.60	3.66
3		
	2.50	2.28
4		
	2.00	3.48
5		

Basin Number 23

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.65	4.06
2		
	5.83	3.66
3		
	3.00	2.28
4		
	2.00	3.48
5		

Basin Number 24

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.70	4.06
2		
	4.00	3.66
3		
	3.00	2.28
4		
	2.00	3.48
5		

Basin Number 25

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.70	4.79
2		
	5.18	4.37
3		
	3.66	2.97
4		
	3.00	3.48
5		

Basin Number 26

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.64	3.89
2		
	5.07	4.64
3		
	4.66	3.96
4		
	3.00	3.48
5		

Basin Number 27

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.35	5.05
2		
	4.44	3.66
3		
	4.50	2.28
4		
	2.00	3.48
5		

Basin Number 28

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.11	4.79
2		
	5.88	4.37
3		
	3.00	2.97
4		
	3.00	3.48
5		

Basin Number 29

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.46	2.66
2		
	3.75	2.65
3		
	2.00	2.28
4		
	2.00	3.48
5		

Basin Number 30

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.09	4.79
2		
	4.41	4.37
3		
	3.00	2.97
4		
	4.00	3.48
5		

Basin Number 31

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.87	3.86
2		
	5.27	4.07
3		
	5.50	3.96
4		
	2.00	3.48
5		

Basin Number 32

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.63	4.06
2		
	4.12	3.66
3		
	4.00	2.28
4		
	2.00	3.48
5		

Basin Number 33

Bifurcation Ratio		
Order	Observed	Predicted
1		
	5.03	5.24
2		
	5.80	5.14
3		
	3.33	2.97
4		
	3.00	3.48
5		

Basin Number 34

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.97	4.13
2		
	4.87	4.59
3		
	2.66	2.28
4		
	3.00	3.48
5		

Basin Number 35

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.36	4.68
2		
	5.50	2.65
3		
	2.00	2.28
4		
	2.00	3.48
5		

Basin Number 36

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.60	5.27
2		
	4.46	4.07
3		
	6.50	3.96
4		
	2.00	3.48
5		

Basin Number 37

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.30	5.16
2		
	4.61	3.76
3		
	4.50	5.51
4		
	4.00	3.48
5		

Basin Number 38

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.53	3.33
2		
	4.77	4.37
3		
	3.00	2.97
4		
	3.00	3.48
5		

Basin Number 39

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.27	3.01
2		
	4.13	4.68
3		
	3.14	3.85
4		
	7.00	5.47
5		

Basin Number 40

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.62	3.66
2		
	6.36	7.86
3		
	5.50	2.97
4		
	2.00	3.48
5		

Basin Number 41

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.25	3.33
2		
	4.77	4.37
3		
	3.00	2.97
4		
	3.00	3.48
5		

Basin Number 42

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.87	4.13
2		
	4.12	4.59
3		
	4.00	2.28
4		
	2.00	3.48
5		

Basin Number 43

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.76	4.13
2		
	4.87	4.59
3		
	4.00	2.28
4		
	2.00	3.48
5		

Basin Number 44

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.63	4.82
2		
	3.45	3.59
3		
	2.75	2.97
4		
	4.00	3.48
5		

Basin Number 45

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.39	4.68
2		
	4.66	2.65
3		
	3.00	2.28
4		
	2.00	3.48
5		

Basin Number 46

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.65	3.86
2		
	4.14	4.07
3		
	4.66	3.96
4		
	3.00	3.48
5		

Basin Number 47

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.90	4.06
2		
	6.20	3.66
3		
	2.50	2.28
4		
	2.00	3.48
5		

Basin Number 48

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.63	4.68
2		
	3.66	2.65
3		
	3.00	2.28
4		
	2.00	3.48
5		

Basin Number 49

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.03	4.68
2		
	4.42	2.65
3		
	3.50	2.28
4		
	2.00	3.48
5		

Basin Number 50

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.40	5.16
2		
	5.12	3.76
3		
	8.00	5.51
4		
	2.00	3.48
5		

Basin Number 51

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.31	4.68
2		
	5.18	5.14
3		
	3.66	2.97
4		
	3.00	3.48
5		

Basin Number 52

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.23	4.13
2		
	5.42	4.59
3		
	3.50	2.28
4		
	2.00	3.48
5		

Basin Number 53

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.33	4.68
2		
	5.60	5.14
3		
	5.00	2.97
4		
	2.00	3.48
5		

Basin Number 54

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.13	3.33
2		
	3.90	4.37
3		
	3.66	2.97
4		
	3.00	3.48
5		

Basin Number 55

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.40	4.68
2		
	5.50	5.14
3		
	5.00	2.97
4		
	2.00	3.48
5		

Basin Number 56

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.00	3.33
2		
	6.00	4.37
3		
	4.00	2.97
4		
	2.00	3.48
5		

Basin Number 57

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.64	4.13
2		
	4.62	4.59
3		
	2.66	2.28
4		
	3.00	3.48
5		

Basin Number 58

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.36	3.66
2		
	5.76	7.86
3		
	4.33	2.97
4		
	3.00	3.48
5		

Basin Number 59

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.58	4.06
2		
	3.62	3.66
3		
	4.00	2.28
4		
	2.00	3.48
5		

Basin Number 60

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.25	4.60
2		
	5.16	6.18
3		
	12.00	5.51
4		
	2.00	3.48
5		

Basin Number 61

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.68	4.02
2		
	4.25	4.37
3		
	4.00	2.97
4		
	3.00	3.48
5		

Basin Number 62

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.65	3.96
2		
	3.41	3.59
3		
	4.00	2.97
4		
	3.00	3.48
5		

Basin Number 63

Bifurcation Ratio		
Order	Observed	Predicted
1		
	3.52	3.86
2		
	3.93	4.07
3		
	3.75	3.96
4		
	4.00	3.48
5		

Basin Number 64

Bifurcation Ratio		
Order	Observed	Predicted
1		
	4.31	3.86
2		
	3.30	3.76
3		
	5.00	5.51
4		
	4.00	3.48
5		

Basin Number 65			Basin Number 66		
Bifurcation Ratio			Bifurcation Ratio		
Order	Observed	Predicted	Order	Observed	Predicted
1			1		
	3.65	3.86		3.93	3.01
2			2		
	3.80	3.76		4.58	5.98
3			3		
	5.00	5.51		3.40	3.66
4			4		
	4.00	3.48		5.00	4.51
5			5		

APPENDIX XIV

SPEARMAN RANK CORRELATION--COMPUTED VALUES

FOR REGRESSION SLOPE ANALYSIS

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Regression Slope Analysis and Large Differences in Drainage Density for Those Basins on Two Lithostratigraphic Units

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (computed value for regression slope analysis) and rank two (difference in drainage density)

N = number in sample

$\Sigma D^2 = 1575.50$

N = 22

$$rs = 1 - \frac{(6)\ (1575.50)}{(22)\ (22^2 - 1)}$$

$$rs = 1 - \frac{9453}{10626}$$

rs = .1104

Table value at .05 level of significance N = 22 = .428 (two-tailed test)

Ho

For the twenty-two drainage basins on two lithostratigraphic units, there is not a significant correlation between large differences in drainage density and large computed values for the regression analysis.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Regression Slope Analysis and Large Differences in Stream Frequency for Those Basins on Two Lithostratigraphic Units

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (computed value for regression analysis) and rank two (difference in stream frequency)

N = number in sample

$\Sigma D^2 = 1349$

N = 22

$$rs = 1 - \frac{(6)\ (1349)}{(22)\ (22^2 - 1)}$$

$$rs = 1 - \frac{8094}{10626}$$

rs = .2383

Table value at .05 level of significance N = 22 = .428 (two-tailed test)

Ho

For the twenty-two drainage basins on two lithostratigraphic units there is not a significant correlation between large differences in stream frequency between two units in a drainage basin and large computed values for the regression slope analysis.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Regression Slope Analysis and Large Deviations from Area I Mean Elevation-Relief Ratio

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (computed value for regression analysis) and rank two (deviations from Area I mean elevation-relief ratio)

N = number in sample

$\Sigma D^2 = 456$

N = 15

$$rs = 1 - \frac{(6)\ (456)}{(15)\ (15^2 - 1)}$$

$$rs = 1 - \frac{2736}{3360}$$

rs = .1857

Table value at .05 level of significance N = 15 = .52

Ho

There is not a significant correlation between large deviations from Area I mean elevation-relief ratio and large computed values for the regression slope analysis.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Regression Slope Analysis and Large Deviations from Area II Mean Elevation-Relief Ratio

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (computed value for regression analysis) and rank two (deviations from Area II mean elevation-relief ratio)

N = number in sample

$\Sigma D^2 = 8716$

N = 39

$$rs = 1 - \frac{(6)\ (8716)}{(39)\ (39^2 - 1)}$$

$$rs = 1 - \frac{52292}{59280}$$

rs = .1178

Compute Z value ($Z = {}^{r_s}/_{S}$) and compare to Z tables

$$Z = {}^{r_s}/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{39 - 1}}$$

$S = .1622217$

$$Z = \frac{.1178813}{.1622217}$$

$Z = .7266$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large deviations from the Area II mean elevation-relief ratio and large computed values for the regression slope analysis.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Regression Slope Analysis and Large Deviations from Area III Mean Elevation-Relief Ratio

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (computed value for regression analysis) and rank two (deviations from Area III mean elevation-relief ratio)

N = number in sample

$\Sigma D^2 = 410$

N = 12

$$rs = 1 - \frac{(6)\ (410)}{(12)\ (144 - 1)}$$

$$rs = 1 - \frac{2460}{1716}$$

$$rs = -\ .4335$$

Table value at .05 level of significance N = 12 = .591

Ho

There is not a significant correlation between large deviations from Area III mean elevation-relief ratio and large computed values for the regression slope analysis.

Results: Cannot reject null hypothesis (Ho)

SPEARMAN RANK CORRELATION

Correlation Test for Large Computed Values for Regression Slope Analysis and Large Deviations from Circular Shape (Elongation Ratio Minus One)

Formula for Spearman rho:

$$rs = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

rs = computed value to compare to table

D = difference between rank one (computed value for regression analysis) and rank two (deviations from circular shape, elongation ratio minus one)

N = number in sample

$\Sigma D^2 = 48444.71$

N = 66

$$rs = 1 - \frac{(6)\ (48444.71)}{(66)\ (66^2 - 1)}$$

$$rs = 1 - \frac{290668.26}{287430}$$

rs = - .0112

Compute Z value ($Z = {}^{rs}/_{S}$) and compare to Z tables

$$Z = {}^{rs}/_{S}$$

$$S = \frac{1}{\sqrt{N - 1}}$$

$$S = \frac{1}{\sqrt{66 - 1}}$$

$S = .1240340$

$$Z = - \frac{.0112662}{.1240340}$$

$Z = - .0908$

Table value at .05 significance level = 1.96

Ho

There is not a significant correlation between large deviations from circular shape as measured by the elongation ratio and large values for the regression slope analysis.

Results: Cannot reject null hypothesis (Ho)

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