# Parameter Measurement in Fluvial Morphology

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*Abstract*

Because of the quantitative significance of stream order, an accurate, ordered drainage map has become a base for much research in fluvial morphology. These maps are often prepared from U. S. Geological Survey 1:24,000 topographic maps and doubt is created about their usefulness as sources of primary data. This study indicates that blue lines of such topographic maps represent third- and fourth-order streams. Even interpretation of topographic maps by Strahler's method of "V's" does not necessarily result in an accurate drainage map. Relief, age, and geology appear to control the quality of drainage maps which are produced. The relative relief of apparent first-order streams may be used to predict the quality of a drainage map which will be produced from a topographic quadrangle and permits classifications of these quadrangles as excellent, marginal, and unacceptable.

## Introduction

For nearly 25 years attempts to quantitatively define river systems and landforms derived from their development have stemmed from Horton's concept of an ordered stream system (3). The advantage of stream order, in a given physiographic region, is its relation to the number, average lengths, gradients, drainage area, and perhaps discharge of stream segments of varying size. A modification of Horton's work whereby the smallest stream tributaries are assigned the lowest order was introduced by Strahler (8) and resulted in the system of stream order which is widely used today. An example of a stream ordered according to Strahler's system is shown in Figure 1. Because of stream order's quantitative significance, an accurate, ordered drainage map has become a base from which research into fluvial processes normally begins.

The results of any research are no better than the quality of original input data, and this is especially true in the study of stream patterns, geometry, and mechanics. Here the raw data generally involve measurement of the number, length, and gradient of stream segments; width, depth, and velocity of water in the channel; and area, main stream length, and shape of the drainage basin. If these parameters are measured and mapped in the field the quality of the data is generally excellent. Unfortunately, few researchers have time or money to devote to this procedurally difficult type of data collection, resulting in the use of topographic maps as a major source of original data for studies in fluvial morphology.

The purpose of this paper is to examine the problems involved in obtaining an accurately ordered drainage map from commonly available U.S.G.S. topographic maps. This study was sponsored by the Purdue University Water Resources Research Center, Office of Water Resources Research, but this paper has not had the benefit of its review. The author also acknowledges the assistance of Dr. W. N. Melhorn and

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## Measurement from Maps

In the field, first-order stream channels (defined as the smallest unbranched tributaries of a river system) are easily recognized resulting in the production of a very accurate drainage map. The U.S.G.S. topographic maps on which many studies rely, however, do not generally show all stream channels. Apparent first-order stream segments identified from these maps thus become functions of map scale and the type of map interpretation employed, and in the published literature may not represent from article to article, the same size stream channel. As a result, parameters such as average length may be correlated with stream orders which are incorrectly numbered.

Because of this common practice of compiling stream data directly from topographic maps, much effort has been devoted to determining the validity of ordering streams from the various types of maps commonly available. Morisawa (5) concluded that U.S.G.S. topographic maps scaled 1:62,500 are not reliable for measuring drainage basin characteristics other than area. She also stated that data on numbers and lengths of stream segments show great variation when taken from maps. Coates (2), in working with streams in southern Indiana, found that on U.S.G.S. maps scaled 1:24,000 first- and second-order streams were rarely shown and that most channels interpreted as first-order were actually third-order. Strahler (9) proposed an improvement in interpreting topographic maps, by adding to those stream channels shown in blue, segments where "V's" in contour lines indicate that valleys are present. This method greatly aids in adding otherwise overlooked stream segments to the drainage net, but produces an uncertainty as to the size of the smallest segment now shown.

Because of the ever increasing need for basic data, some researchers have ignored published warnings about the questionable validity of a drainage map prepared from topographic maps. One example is provided by Stall and Fok (7) who ordered drainage basins from U.S.G.S. topographic maps scaled 1:62,500 without interpretation by the method of "V's." Their correlation of discharge, drainage basin area, length, and slope which they ascribe to low order segments must conservatively belong to fourth- and fifth-order streams. Although some authors merely bypass the question of their data's validity, Scheidegger (6) suggested what the techniques of other investigators appear implicitly to assume; that if, for instance, second-order streams are treated as first-order streams because of map inaccuracy the results obtained in a study are proportional to the parameters of the actual stream system. If this is true, after a field check the values of the actual system may be obtained from the study by using Horton's law of drainage composition or some other mathematical tool of extrapolation.

## Objectives of this Study

Publication of the *Atlas of County Drainage Maps for Indiana* in July, 1959, permits large areal studies of stream ordering to be conducted while maintaining a high level of confidence in the data (1). These maps were prepared by the staff of the airphoto laboratory of the Engineering Experiment Station at Purdue University from 1940 A.A.A. aerial photographs. Depending on the time of year that photographs were taken these maps are estimated to show an average of 90% of all existing stream channels (R. D. Miles, personal communication). A field check in the vicinity of Tippecanoe County demonstrated that these maps show almost all first-order segments. Those stream channels not shown appeared young, probably having developed since the date of photography.

Using these maps as a base, a study was conducted to answer the following questions about drainage maps prepared from U.S.G.S. topographic maps scaled 1:24,000 with 10-foot contour interval:

1) What portion of a drainage basin and what order stream segments are actually shown by the blue lines of these maps?

2) What increase in accuracy is obtained by interpreting these maps using Strahler's method of "V's"?

3) Are drainage maps produced by analysis of data in the above two cases proportional to the actual stream net, and if not, what effect do lost segments have on ordering the basin?

4) Does accuracy of these maps vary with location in the state of Indiana?

## Procedure

Drainage basins up to sixth-order in size were selected randomly from the different physiographic provinces of the state (4). Topographic maps for these basins were obtained and drainage maps were produced, initially by tracing only those streams shown by solid or dashed blue lines, and secondly by adding all stream segments which could be recognized using the method of "V's." Experiments with different operators indicated that more than a general knowledge of topographic maps was required to apply the method of "V's" and that some practice was necessary before any operator made the best, consistent use of this method. Once familiar with the method, however, different operators could produce reasonably identical maps of the same drainage basin.

Once the two tracings were prepared they were ordered and compared with an ordered base map taken from the *Atlas of County Drainage Maps*. The data for this segment-to-segment comparison was punched on IBM cards and analyzed by a CDC 6500 computer.

TABLE 1. *Percent stream segments shown on maps of Tipton Till Plain.*

| True Strahler Stream Order Taken from Air Photo Maps | Stream Order Data Taken from 1/24000 USGS Maps Using only Stream Segments Shown by Blue Lines | | | | | Stream Order Data Taken from 1/24000 USGS Maps Using the Method of V's | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Percent of Stream Segments on USGS Maps | Apparent Order by Percent of Those Segments Appearing on Maps | | | | Percent of Stream Segments on USGS Maps | Apparent Order by Percent of Those Segments Appearing on Maps | | | |
| | | 1 | 2 | 3 | 4 | | 1 | 2 | 3 | 4 |
| 1 | 1.0 | 100 | 0 | 0 | 0 | 19.0 | 100 | 0 | 0 | 0 |
| 2 | 4.2 | 96 | 3 | 0 | 0 | 48.0 | 65 | 35 | 0 | 0 |
| 3 | 33.9 | 85 | 14 | 0 | 0 | 91.0 | 34 | 54 | 2 | 0 |
| 4 | 90.0 | 48 | 48 | 4 | 0 | 100.0 | 14 | 15 | 50 | 21 |

TABLE 2. *Accuracy of U.S.G.S. maps according to physiographic province.*

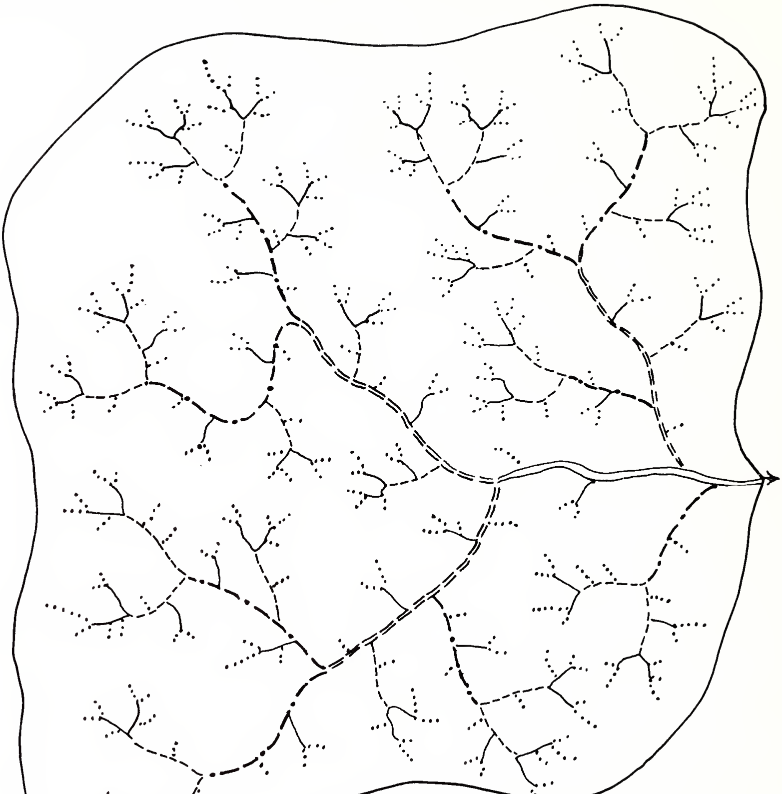
| Physiographic Province | Range of General Relief | Geology | Percent of Various Segments Shown on Map | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 |
| Crawford Upland | 220-350 | Mississippian SS, LS, SH | 98 | 100 | 100 | 100 |
| Norman Upland | 170-260 | Mississippian SS, SH | 97 | 100 | 100 | 100 |
| Dearborn Upland | 120-250 | Ordovician LS | 97 | 100 | 100 | 100 |
| Scottsburg Lowland | 100-150 | Devonian & Mississippian SH | 89 | 96 | 100 | 100 |
| Muscatatuck Slope | 100-150 | Silurian LS | 79 | 90 | 100 | 100 |
| Wabash Lowland | 100-150 | Pennsylvanian SH, SS | 67 | 90 | 99 | 100 |
| Tipton Till Plain | 100-150 | Glacial Till | 19 | 48 | 91 | 100 |
| Lake and Moraine | 80-120 | Fluvial Glacial | 15 | 45 | 100 | 100 |
| Mitchell Plain | Underground Drainage | | — | — | — | — |
| Indiana | All Provinces Using Only the Blue Lines | | 2 | 5 | 35 | 93 |

## Results of Computer Analysis

The percentage of each order of stream segments shown by blue lines on the topographic maps was found to be about the same for all physiographic provinces of the state (see "Indiana" in Table 2). Table 1 shows results for basins from the Tipton Till Plain. These findings agree well with those of Coates (2) as almost no first- and second-order streams are shown. From one-third to one-half of the third-order segments appear and almost all fourth-order segments, are shown. As the breakdown into apparent order indicates, nearly all third-order streams and one-half of the fourth-order streams would be classed as first-order if only blue lines were used to construct a drainage map. Of 4,498 segments from various basins used in this analysis, only 153 or about 4% of all segments were shown in blue on the 1:24,000 U.S.G.S. topographic maps.

An increase in the number of stream segments located using the 1:24,000 U.S.G.S. topographic maps was found to be significant in every physiographic province if interpretation by Strahler's (9) method of "V's" was employed. Table 1 shows that in the Tipton Till Plain about ⅕ of the first-order, ½ of the second-order, and almost all of the third-order channels are shown. The proportion of total segments shown increased from 4% to 28% in this province, whereas in other physiographic provinces of the state the method of "V's" resulted in almost 100% recovery of all stream segments. Even in areas where this method proved most successful, however, it still contained two major uncertainties. First, the correct length of an added segment was always in doubt, commonly by a factor many times the contour interval. Second, many segments were recognized whose point of junction with other channels was uncertain, which ultimately could result in incorrect ordering of the stream net.

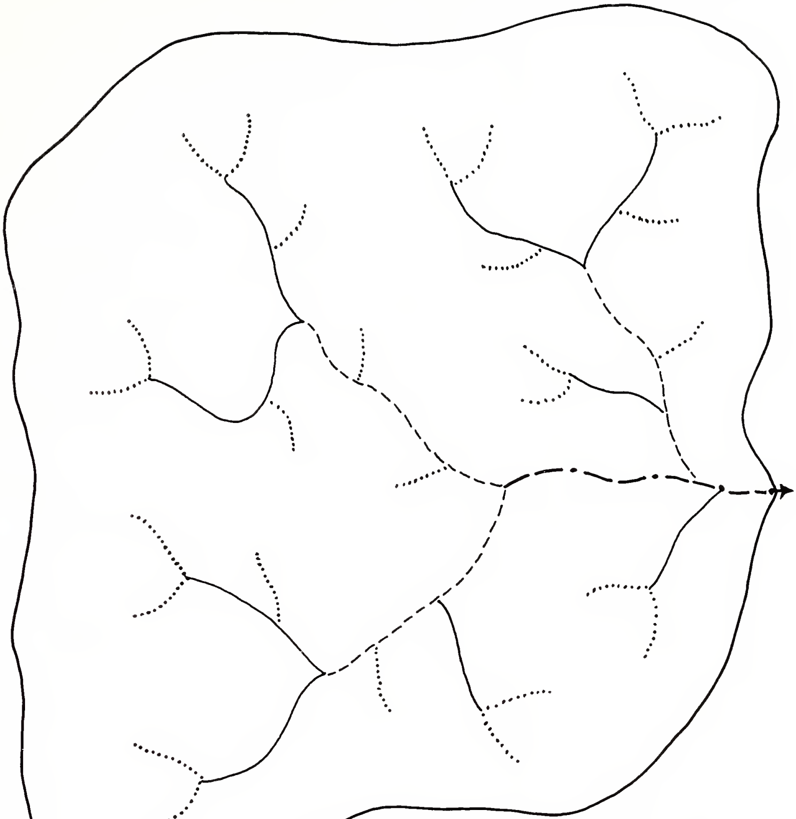
In provinces where almost all stream segments in a basin are obtained using the method of "V's," only the uncertainty of junction




| Us | | N | L | Us | | N | L |
|---|---|---|---|---|---|---|---|
| 1 | ····· | 236 | .2 | 4 | ▬ ▬• | 9 | 1.6 |
| 2 | —— | 81 | .4 | 5 | = = = | 3 | 2.6 |
| 3 | - - - | 27 | .8 | 6 | ══ | 1 | — |

FIGURE 1. *Hypothetical stream.*

locations will cause lack of proportionality between actual and traced stream nets. However, if a portion of segments is missed, either because of the map or inaccurate procedures used in tracing a stream net, the ordered stream system which results will be in no way proportional to the real stream system. To emphasize this point, consider the stream system shown in Figure 1. It has a perfect bifurcation ratio (R) of three, and the numbers (N) and average lengths (L) for the various orders are indicated. Figure 2 is the same drainage basin without first- and second-order segments. This remains a reasonable representation of the original basin and provides an example of the stream net which some researchers assume is obtained by ordering stream systems from large-scale topographic maps. The bifurcation ratio is unaltered and



| Us | | N | L | Us | | N | L |
|---|---|---|---|---|---|---|---|
| 1 | ····· | 27 | .8 | 3 | - - - | 3 | 2.6 |
| 2 | —— | 9 | 1.6 | 4 | —·—· | 1 | — |

FIGURE 2. *Hypothetical stream without 1st and 2nd orders.*

after a field check the laws of drainage composition would allow calculation of the numbers and average lengths of stream orders not shown by this map.

Figure 3, however, shows what actually happens when a stream net is ordered directly from the blue lines of a U.S.G.S. topographic map scaled 1:24,000. Since approximately only ⅓ of the third-order stream segments are shown, the ordered basin is no longer proportional to the real stream net. The bifurcation ratio is altered and the average segment lengths become distorted. It is impossible to extrapolate the properties of the original stream net from this ordered basin. Using the data for the Tipton Till Plain, Figure 4 shows a theoretical drainage map produced from a U.S.G.S. topographic map using the method of "V's." It shows more segments than the stream net in Figure 3, but the

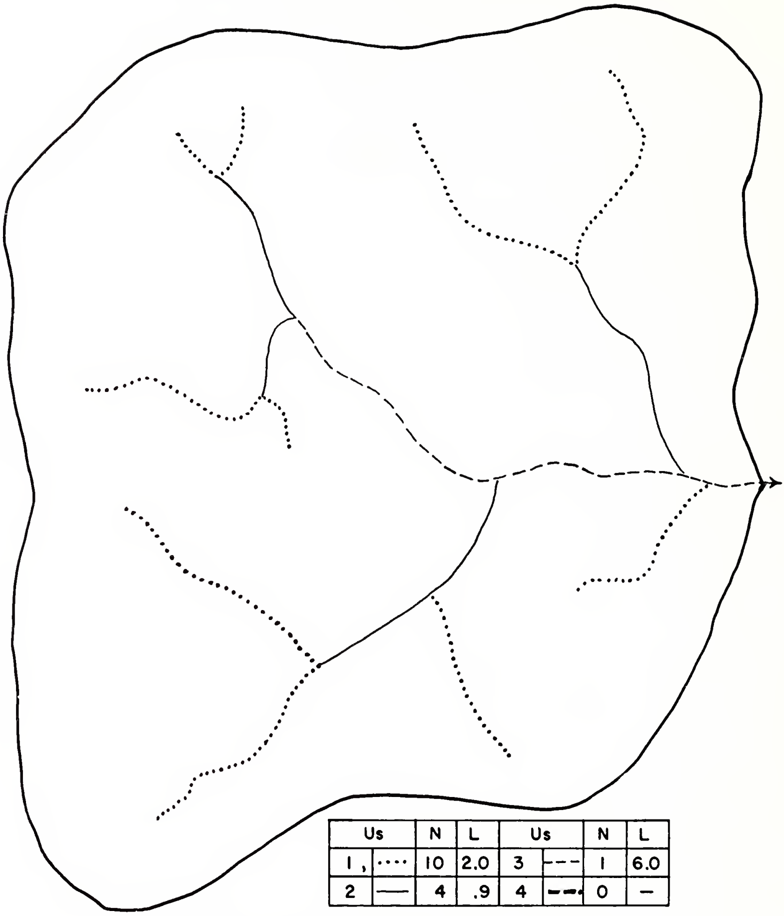
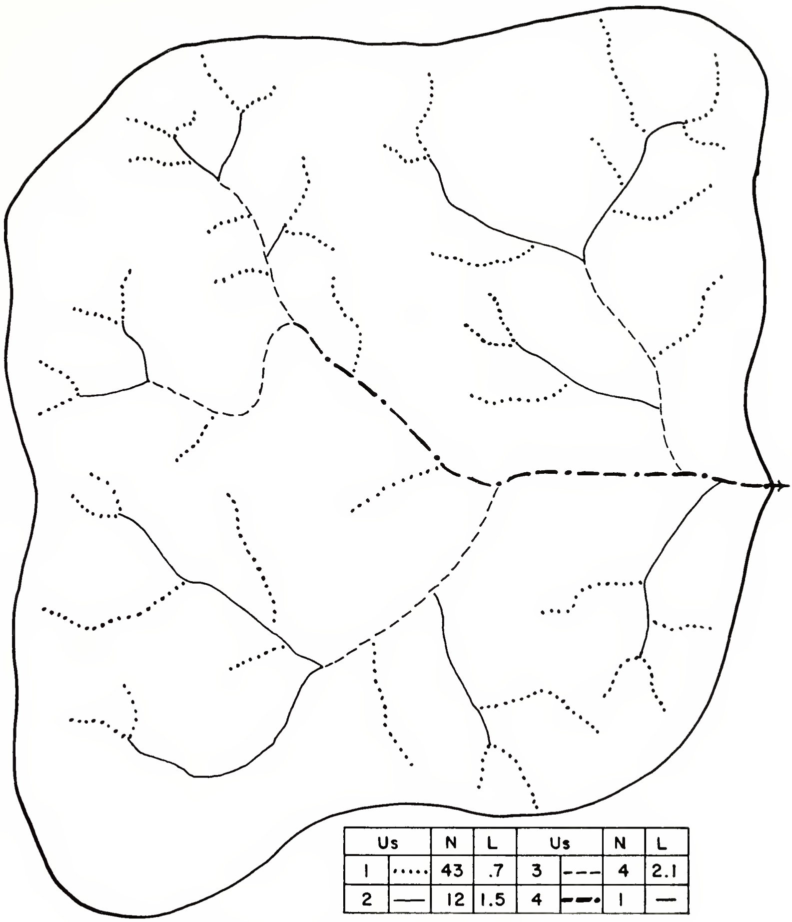



FIGURE 3. *Stream as it might appear on USGS map.*

bifurcation ratio is still altered and the measurement of average lengths is meaningless.

The ability of interpretation using the method of "V's" to add segments to the blue lines of topographic maps was found to vary considerably depending on location in the state. This variability appears to be a function of 1) basin relief, 2) age of development of topography and 3) geology. Basin relief (the difference in elevation from the drainage divide to the mouth of the stream) is an indication of slope. The greater the slope the more contour lines a given length of stream crosses and thus the easier it is to map. As the length of time during which the topography has been evolving increases, low order streams develop more distinct channels, commonly rectangular in shape, resulting in more distinct "V's" in the contour lines. Geology effects resistance



| Us | | N | L | Us | | N | L |
|---|---|---|---|---|---|---|---|
| 1 | ····· | 43 | .7 | 3 | - - - | 4 | 2.1 |
| 2 | — | 12 | 1.5 | 4 | ━━• | 1 | — |

FIGURE 4. *Stream as it might be mapped using method of V's.*

to erosion and thus controls the rate of gully development. Some geological materials are characterized by shallow channels whereas others possess steep, deep channels more likely to produce pronounced "V's" in contour lines.

Because physiographic divisions of the state reflect differences in relief, age, and geology some generalizations about the topographic maps covering these areas may be made. Table 2 lists the divisions and indicates the percent of various order streams which would likely be obtained by interpreting a 1:24,000 U.S.G.S. topographic map using Strahler's (9) method of "V's." This table intends to show only average conditions and because of variations within any province it should not be used as an accurate guide for all topographic quadrangles within this physiographic division. No data were taken for the Mitchell Plain because drainage in that province is essentially underground. Data for the Lake and Moraine Province are poor and inconclusive because of extensive development of ditch systems over most of the area, which are mapped in detail as cultural features on U.S.G.S. quadrangles.

## Estimation of Map Accuracy

As most first- and second-order streams are tributary to third-order segments, and because they account for the majority of those segments not shown on the topographic maps, a method to estimate their presence or absence was sought. It has been demonstrated that the smallest dashed, blue lines on a U.S.G.S. quadrangle represent third- and fourth-order channels and that relief is of prime importance in the ability to interpret a map using the method of "V's." Thus, the average relative relief of apparent first-order streams was compared with the quality of interpretation using the method of "V's." Ten apparent first-order segments were chosen from a basin (or quadrangle if the basin was small) and their relative relief calculated. Highest and lowest

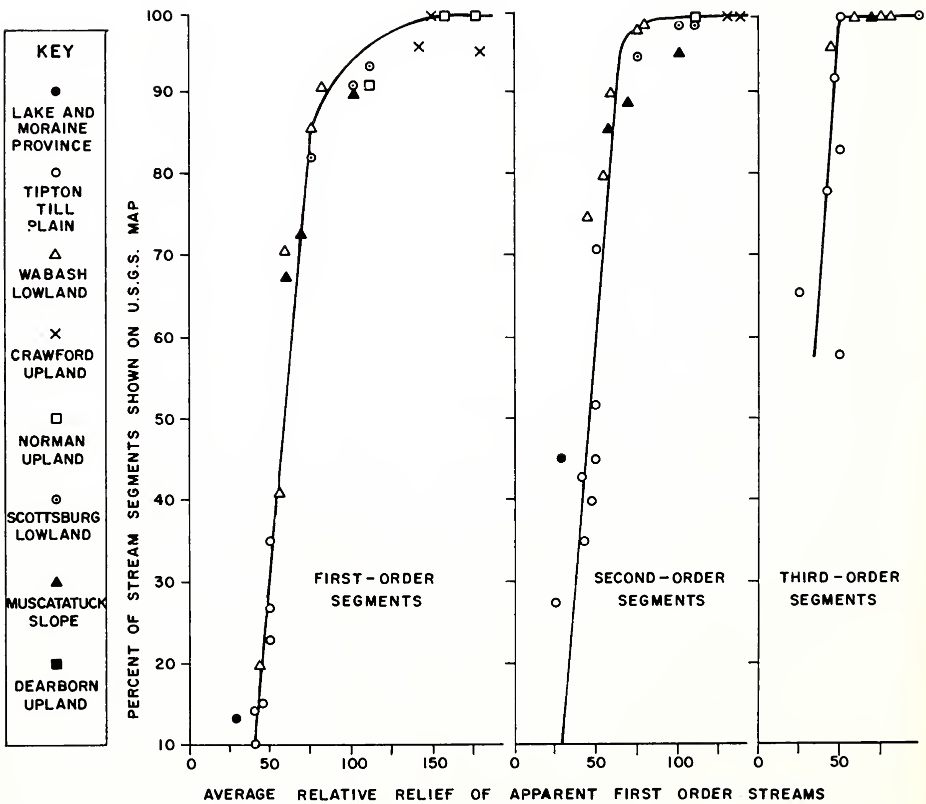



FIGURE 5. *Plot of average relative relief versus percent of streams.*

values were discarded and the average relative relief of the eight remaining segments was plotted against the percent of first-, second-, and third-order segments shown on the map. Results as shown in Figure 5 indicate that the average relative relief provides a good estimate of the accuracy of a single U.S.G.S. quadrangle map.

Average relative relief of apparent first-order streams has been used to divide U.S.G.S. quadrangles into three separate classes; excellent, marginal, and unacceptable. Quadrangles with an average relative relief of 150 feet or more are excellent, showing all stream segments of all orders, and may be used with confidence to produce an accurate drainage map. Quadrangles with an average relative relief less than 80 feet are unacceptable because they fail to show first-, second-, and some third-order segments, making any drainage map produced from them unproportional and unreliable.

If average relative relief is between 80 and 150 feet the topographic map is marginal as a base for production of an accurate drainage map. Assuming random failure to detect "lost" stream segments the minimum acceptable omission of first-order streams may be calculated using the formula

$$\left(1 - \frac{2}{R}\right) \bullet (100) \text{ where } R = \text{bifurcation ratio}$$

and is compared to the probable percentage of first-order streams as obtained from Figure 5 after calculating the average relative relief. If enough first-order segments are shown the quadrangle should produce a drainage map proportional with the real system. If R is not known it is recommended that three be used because it is the worst possible value.

## Conclusions

Unless drainage maps are produced by field mapping or from interpretation of large-scale aerial photographs their reliability as accurate models of the real stream net must be initially questioned. No acceptable drainage map can be made from a U.S.G.S. topographic map scaled 1:62,500 without considerable field verification. If drainage maps are traced from 1:24,000 U.S.G.S. topographic maps, using only the streams shown by blue lines, the apparent first-order segments actually will represent third- and fourth-order streams. If these quadrangles are interpreted using the method of "V's" uncertainty about order, length, and junction location of added segments is introduced.

The quality of interpretation by the method of "V's" varies as a function of 1) basin relief, 2) age of topography, and 3) geology. An approximate guide to the quality of a drainage map produced from a given topographic map is thus the physiographic province from which it comes. It has been demonstrated that the average relative relief of apparent first-order stream segments shown by blue lines can be used to predict the quality of a topographic map for use in preparing an accurate drainage map. Based on this average relative relief the

1:24,000 U.S.G.S. topographic maps for Indiana may be classed as excellent, marginal, and unacceptable.

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