CHANNEL SLOPE-AN INDEX OF WATERSHED CHARACTERISTICS

by

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ABSTRACT

Channel slope is related to unit discharge in eastern Colorado and western Nebraska. Channel slope can be estimated from parameters of area, drainage density, infiltration, location and precipitation. Measurements of these watershed characteristics can be used to estimate the similarity of physical and runoff characteristics between watersheds.

INTRODUCTION

Knowledge of the degree of similarity or difference in runoff characteristics between watersheds is of value to the design engineer faced with the problem of estimating magnitude and frequency of peak rates of runoff from ungaged watersheds for the design of drainage structures. As part of a study of peak rates of runoff in semi-arid areas, a study was made of channel slope as an index of watershed characteristics.

WATERSHED SLOPE

Work by Benson [1959] indicated that channel slope showed considerable promise as a factor for explaining variation in peak rates of runoff from New England watersheds. Various methods of measuring slope of watershed were studied in order to find a slope parameter which was simple to determine and also highly correlated with unit discharge (Q_{10}/A, peak rates of runoff in cfs per square mile having a ten-year recurrence interval). After consideration of a number of different methods of determining slope, three were considered to be sufficiently simple to compute to warrant detailed correlation studies with unit discharge. They were:

1. Main channel slope S
2. Overland slope S_{LS}
3. Oblique overland slope S_{OO}

Definition sketches for each of these methods of slope measurement are given in Fig. 1.

The methods for determining each of these values of slope are as follows:

Main channel slope, S ,

Find the slopes in feet per mile between the gaging station and the respective points 0.1, 0.2, 0.3.....1.0 times the length from the construction site (the assumed location of the drainage structure to be constructed) to the headwaters.

Overland slope, S_{LS} ,

1. Along the stream, find the 0.25L, 0.50L, and 0.75L points from the construction site.
2. Draw an elevation contour through each point to the boundary limits of the watershed.
3. Find points on these contours midway between the main channel and the watershed boundary.

4. Measure the slopes in feet per mile between these midpoints and the next point downstream found from step 1, that is, measure along the dashed lines as shown in Fig. 1b.

Oblique overland slope, S_{OO},

1. Follow steps 1-3 as for determination of overland slope.
2. Measure the slopes in feet per mile between the midpoints on the contour of 0.25L, 0.50L, 0.75L, and the construction site, that is, measure along the dashed lines shown in Fig. 1c.

These slopes were measured as the difference in elevation in feet divided by the length in miles between the indicated points.

The slopes as computed by these three methods, and values of unit discharge, are given in Table 1.

TABLE I. SLOPES OF SIXTEEN WATERSHEDS, BASED ON THREE TECHNIQUES, AND VALUES OF UNIT DISCHARGE (VALUES OF SLOPE ARE IN FEET PER MILE).

Watershed	Q_{10}* / A	Channel Slope, S										Overland Slope, S_{LS}					Oblique Overland Slope, S		
		0.1L	0.2L	0.3L	0.4L	0.5L	0.6L	0.7L	0.8L	0.9L	1.0L	0.25L	0.50L	0.75L	1.0L	Total	0.25L	0.50L	0.75L
Fountain Creek at Pueblo, Colo.	17.6	29.4	27.2	26.0	25.7	26.5	27.5	29.0	31.3	32.7	39.7	35.2	45.4	70.8	102.7	63.5	35.2	34.9	39.7
Apishapa River near Fowler, Colo.	13.3	15.3	17.8	22.1	22.4	23.9	24.2	26.0	30.2	37.3	92.5	28.4	55.2	44.0	137.0	66.1	28.4	35.5	71.5
Timpas Creek near Rocky Ford, Colo.	21.0	2.2	19.6	23.2	22.8	22.8	26.5	26.1	28.0	29.2	32.8	28.0	31.0	46.7	49.7	38.9	28.0	28.2	34.2
Blue Creek near Lewellen, Nebr.	2.2	10.2	10.7	10.9	11.1	13.4	13.6	12.9	12.8	12.3	14.0	28.4	113.2	54.6	28.7	56.3	28.4	26.2	25.2
Birdwood Creek near Hershey, Nebr.	3.9	6.7	10.0	10.0	10.0	9.4	9.5	9.1	10.0	10.4	13.3	23.5	75.5	16.9	34.2	37.5	23.5	21.7	26.2
Cherry Creek near Franktown, Colo.	37.2	115.3	86.5	70.5	62.5	56.9	53.8	51.6	51.9	51.3	53.9	143.0	62.4	49.6	63.1	79.5	143.0	80.9	65.2
Cherry Creek near Melvin, Colo.	31.4	30.7	31.9	31.4	32.5	44.8	44.0	43.8	44.8	45.0	47.2	56.3	81.7	53.3	54.1	61.4	56.3	52.7	48.6
Lodgepole Creek at Bushnell, Nebr.	5.4	35.1	31.4	25.9	24.7	23.6	24.1	24.8	25.5	30.3	41.8	32.2	28.0	40.6	56.2	39.3	32.2	30.8	32.0
North Fork Republican River	10.8	23.8	21.8	19.8	18.9	18.3	17.2	18.7	19.9	19.9	22.2	37.9	129.4	67.5	43.6	69.5	37.9	33.1	41.6
Buffalo Creek near Haigler, Nebr.	5.3	4.8	14.4	16.0	16.8	18.3	21.7	25.4	26.5	27.8	29.8	34.8	112.7	90.0	45.9	70.7	34.8	54.8	39.0
Rock Creek at Parks, Nebr.	4.9	10.0	12.5	13.3	12.5	13.0	12.5	12.9	12.5	16.7	20.0	28.0	160.0	35.7	9.6	58.3	28.0	27.1	27.8
Frenchman Creek at Culbertson, Nebr.	29.2	9.2	9.2	8.0	10.6	11.3	11.9	12.3	12.3	12.5	12.5	20.9	16.8	17.3	14.5	17.4	20.9	14.6	14.9
White River at Crawford, Nebr.	4.3	17.9	21.4	25.0	28.6	32.8	37.5	37.2	36.6	37.7	43.6	45.1	91.3	43.0	60.8	60.0	45.1	76.7	96.9
Niobrara River above Box Butte, Res.	1.1	10.9	10.4	10.5	10.6	10.7	10.4	10.7	10.7	11.3	12.5	24.9	85.8	19.7	24.9	38.8	24.9	24.2	16.2
Pumpkin Creek near Bridgeport, Nebr.	0.7	9.4	13.1	12.5	12.7	13.5	13.5	13.4	13.9	14.4	16.0	25.9	39.9	44.0	37.2	36.7	25.9	26.6	27.4
Landsman Creek near Hale, Colo.	11.2	20.4	18.4	19.8	18.9	19.0	19.8	20.1	20.4	19.7	17.8	39.8	24.2	40.1	26.4	32.6	39.8	20.8	23.9

*Unit discharge, cfs/sq. mi., based on 10-year peak flow and contributing area.

Correlation Between Slope and Unit Discharge

Correlation coefficients were computed between various measures of slope and unit discharge for the watersheds shown in Table 1. The results are given in Table 2.

TABLE 2. CORRELATION COEFFICIENTS BETWEEN MEASURES OF SLOPE AND UNIT DISCHARGE (Q_{10}/A)

Position	Channel Slope S	Overland Slope S_{LS}	Oblique Overland Slope S_{OO}
0.2L	.793***		
0.25L		.783**	.783***
0.4L	.888***		
0.5L	.918***	-.130	.653**
0.6L	.915***		
0.7L	.903***		
0.75L		.883***	.533*
0.8L	.908***		
0.9L	.870***		
1.0L	.597*		

* Significant at .05 level
** Significant at .01 level
***Significant at .001 level

From this study, it was concluded that the main channel slope, S, was best correlated to unit discharge, and that the channel slope measured between the construction site and any position between 0.4L and 0.9L gave approximately the same degree of correlation with unit discharge.

Watershed Characteristics as a Similarity Test

A method was sought to determine whether a particular watershed under consideration could be considered similar to other watersheds in the study region. The ideal procedure to follow would be to relate various physical characteristics of watersheds to discharge. However, because only limited discharge data were available, it was necessary to relate the watershed characteristics to a parameter (related to discharge) which could be obtained from a large number of watersheds in the region studied. From the watershed slope study, $S_{.9L}$ (the slope measured between the construction site and a point 9/10 of the length from the construction site to the headwaters) was such a parameter. Hence, the procedure followed was to select a large sample of ungaged watersheds and search for typical relationships of physical characteristics that could be related to $S_{0.9L}$, which in turn could be expected to be related to discharge. This procedure permitted examination and analysis of a much larger sample of data than would have been possible from analysis of gaged watersheds only.

An attempt was made to relate the slope parameter $S_{0.9L}$ to the following independent variables:

Contributing area (A).--The contributing areas, in square miles, for the watersheds studied, were determined from topographic maps. Non-contributing areas were defined as those in which the water contributed to lakes, ponds, or reservoirs.

Total channel length (ΣL).--Total channel length, in miles, was used as a measure of drainage density. The values of ΣL were obtained by measuring the total length of the blue lines (solid and dashed) in the watershed on the 1:250,000 scale maps of the area prepared by the U.S. Geological Survey.

Soil infiltration index (I).--The soil infiltration indices were calculated from the modified soil map as shown in Fig. 2. The indices range from unity for a clay soil to 15 for a sandy soil. The definition and computation procedure for determining "I" is presented in the Appendix.

Location parameter (L_L).--This parameter was defined as the difference in degrees between the longitude and the latitude at the centroid of the watershed. Watersheds were grouped in the class intervals 59 to 66 degrees.

Precipitation parameter (P_{10}).--The 24-hour amount of precipitation having a ten-year recurrence interval (P_{10}) nearest the centroid of watershed. The isohyetal map of P_{10} values is shown in Fig. 3.

Zone of environment.--Eastern Colorado was divided into three zones of environment on the basis of principal drainage basins. These zones are:

1. Upper Republican River Basin
2. Arkansas River Basin
3. South Platte River Basin

After the correlation analysis, it was found that watersheds of South Platte River Basin near the Front Range having a slope greater than 22 feet per mile needed to be adjusted to be comparable to the other areas. The adjustment equation is $S_{0.9L}^{*} = 2.3\, S_{0.9L} - 28.8$.

Fifty-two (52) ungaged watersheds in eastern Colorado were used as the dependent sample to derive the relation for estimating $S_{0.9L}$ from A , ΣL , I , and P_{10} by coaxial graphical correlation as shown in Fig. 4. An independent sample of 18 ungaged watersheds was used as a check.

Figure 5 shows the cumulative relative frequency of error of estimate, which is defined by $\text{Percent error} = \frac{S_{estimated} - S_{actual}}{S_{estimated}} \times 100$, for Fig. 4. Approximately 67 per cent of the cases gave errors less than 23 per cent for the dependent sample, and 67 per cent of the cases in the independent sample gave errors less than 18 per cent.

These results indicate that the parameter $S_{0.9L}$ can be estimated with acceptable accuracy ("acceptable accuracy" for field design purpose is defined as at least 67 per cent of the sample having a departure of less than 25 per cent from the fitted regression) from the given watershed characteristics. Furthermore, success in estimating $S_{0.9L}$ from the watershed characteristics suggest that the relation shown in Fig. 4 can serve as a test for determining whether or not the runoff characteristics of a particular watershed are similar to other watersheds in the region for which more complete data may be available. This assumption is supported by the fact that the factors used to estimate $S_{0.9L}$ from Fig. 4 (drainage area, drainage density, soil infiltration characteristics, location, and precipitation) are all factors which reasonably could be expected to influence peak rates of runoff. Hence, if two ungaged watersheds under consideration are found to be similar on the basis of the aforementioned characteristics, it is reasonable to expect that runoff characteristics would also be similar.

This leads to the criterion for determining the degree of similarity of watersheds. If the estimated $S_{0.9L}$ from Fig. 4 does not depart from the measured value of $S_{0.9L}$ by more than 25 per cent of the estimated value, the watershed under consideration may be regarded as similar to those used to derive Fig. 4.

Procedure for Determination of Degree of Similarity

The procedure for determining whether or not a particular watershed is similar to those used to derive Fig. 4 is as follows:

1. Determine from topographic maps (scale 1:250,000) prepared by the U.S. Geological Survey, the following:

   A — Contributing area in square miles

   ΣL — Total length of channel in miles, including tributaries in the watershed, represented by the blue lines on the U.S. Geological Survey maps of scale 1:250,000.

   L_L — Location, longitude minus latitude of the centroid of the watershed.

2. Determine the soil infiltration index, I, from Fig. 2.
3. Determine the precipitation parameter, P_{10}, from Fig. 3.
4. With these parameters, enter Fig. 4 and obtain an estimate of $S_{0.9L}$. If the watershed is in the South Platte Basin and the estimate of $S_{0.9L}$ exceeds 22 feet per mile, determine an adjusted value of the estimate, $S_{0.9L}*$, by the empirical relation,

   $$S_{0.9L}* = 2.3S_{0.9L} - 28.8.$$

5. Measure the actual $S_{0.9L}$ from topographic maps or from a site survey.
6. Compute the per cent of error.

$$\text{Per cent error} = \frac{S_{0.9L_{est.}} - S_{0.9L_{actual}}}{S_{0.9L_{est.}}} \times 100$$

7. Accept the watershed as being similar to those used to derive Fig. 4 if the per cent of error of estimate does not exceed 25 per cent.

CONCLUSIONS

1. The channel slopes measured between the construction site and any position between 0.4 and 0.9 of main channel length is significantly correlated with unit discharge (Q_{10}/A) for watersheds in eastern Colorado and western Nebraska.
2. In eastern Colorado and western Nebraska, the channel slope, $S_{0.9L}$, can be estimated from contributing area, drainage density, soil infiltration characteristics, location, and precipitation. A comparison of the actual slope with the slope computed from these parameters can be used to estimate a measure of the similarity of physical and runoff characteristics between watersheds.

APPENDIX

Definition and Computation of Soil Infiltration Index "I"

The infiltration index follows the soil classification system of the Soil Conservation Service as follows:

Group A - (Lowest runofff potential) Includes deep sands with very little silt andclay, also deep, rapidly permeable loess.

Group B - Mostly sandy soils less deep than A and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.

Group C - Comprises shallow soils and soils containing considerable clay and colloid, though less than those of Group B. The group has below average infiltration after pre-saturation.

Group D - (Highest runoff potential) Include mostly clays of high swelling per cent, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface.

These soil groups were assigned index numbers related to infiltration as follows:

Group A - Index Number 16 (highest infiltration rate)

Group B - Index Number 8

Group C - Index Number 4

Group D - Index Number 1 (lowest infiltration rate)

The procedure followed in determining a soil index for a particular soil type (2, 3, 4 and 5) is illustrated in the following example:

Soil type - Anselmo - Keith - Bush

from the hydrologic groupings of soil series, Anselmo is in Group A which gives an indes number of 16; Keith is in Group B, which gives an index number of 8; and Bush is in Group B which also gives an index number of 8. The assigned soil index "I" of this group is

$$I = \frac{(16 + 8 + 8)}{3} = 10.67$$

This procedure was followed to obtain soil infiltration indices for the study area. The results are shown in Fig. 2.

To determine the soil index, "I" , for a particular watershed, the watershed is plotted on the modified soils map shown in Fig. 2. The percentage of the total area of the watershed with each soil index value is then determined. The soil index for the entire watershed is then the summation of the products of the percentages and the index for each group included in the watershed.

ACKNOWLEDGMENTS

The work reported herein was supported jointly by the U.S. Bureau of Public Roads, Hydraulic Research Division, Carl F. Izzard, Chief; and the Colorado Department of Highways, Mark U. Watrous, Chief Engineer.

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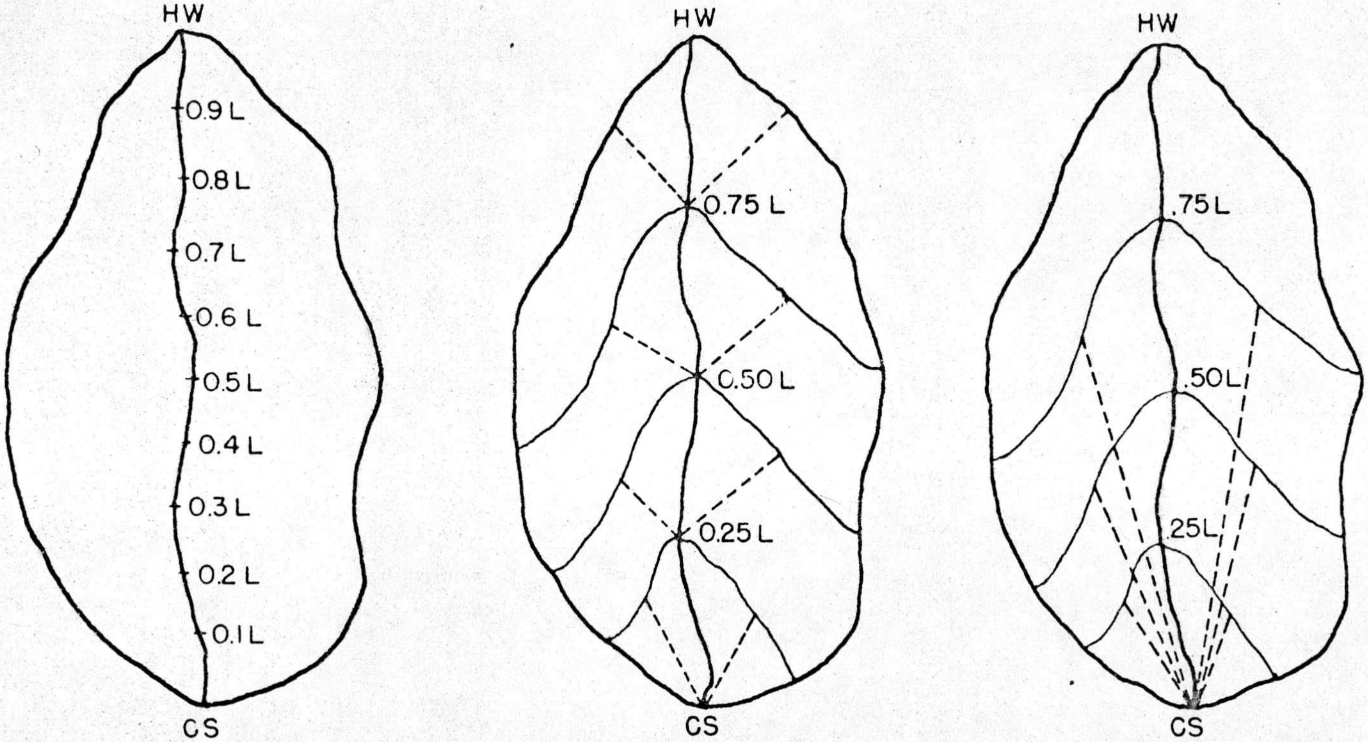
LIST OF FIGURES



(a) Main Channel Slope, S (b) Overland Slope, S_{LS} (c) Oblique Overland Slope, S_{OO}

CS Construction Site

HW Head Water

L Main Channel Length

Fig 1

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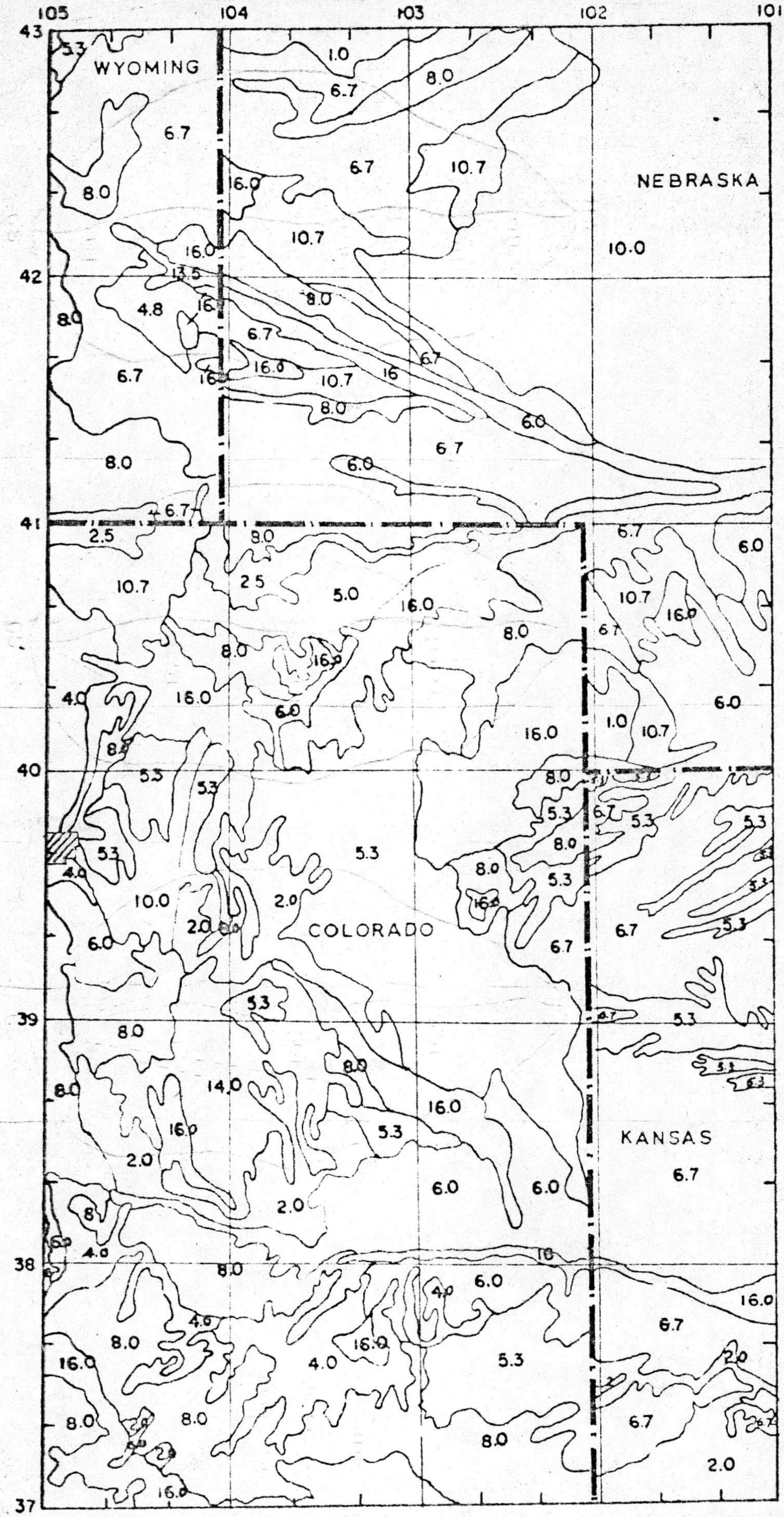

Fig. 2. Soil infiltration indicies for study area based on an arbitrary numbering scale of 16 for high infiltration rates (sandy soils) and unity for low infiltration rates (clay soils).

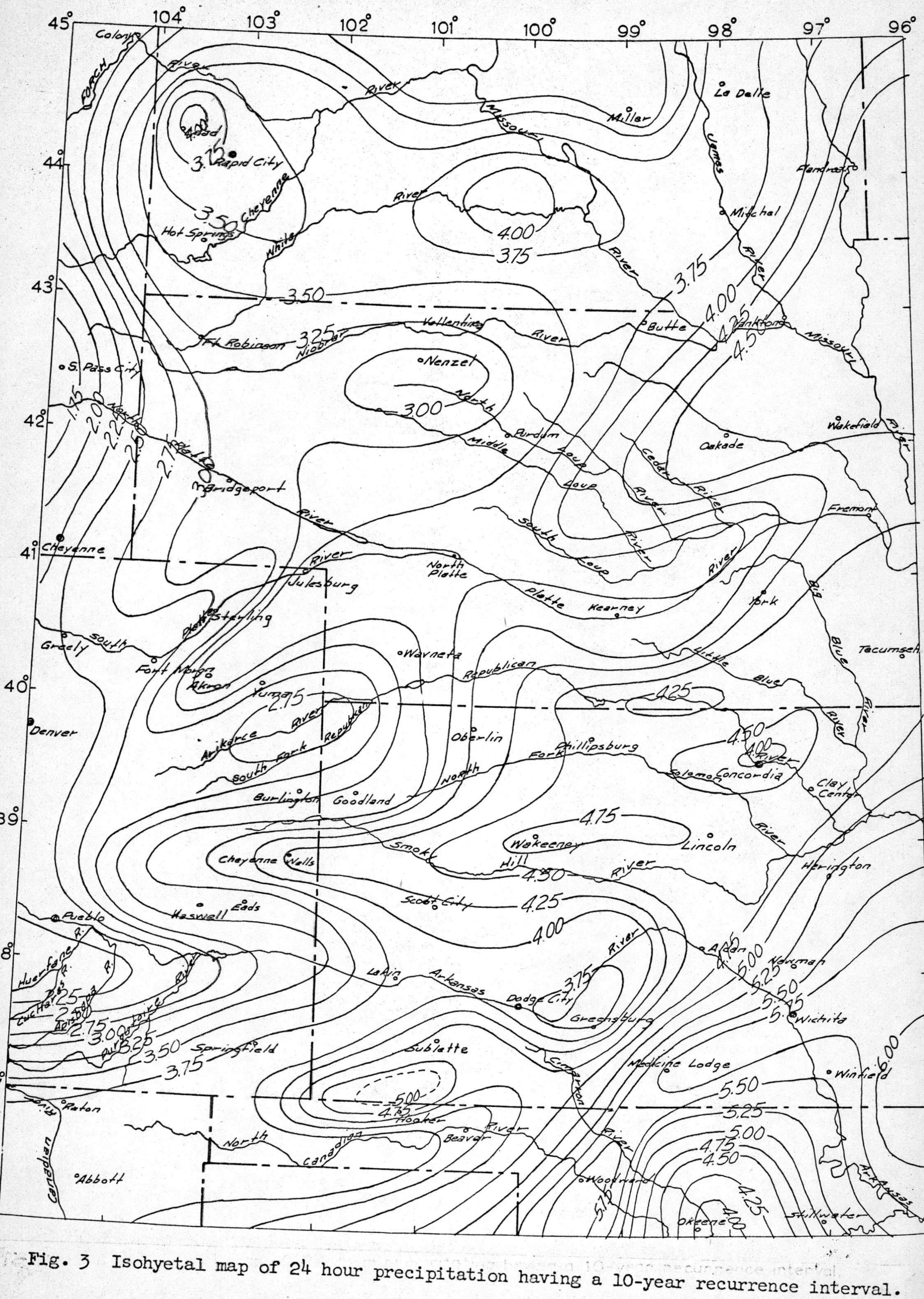

Fig. 3 Isohyetal map of 24 hour precipitation having a 10-year recurrence interval.

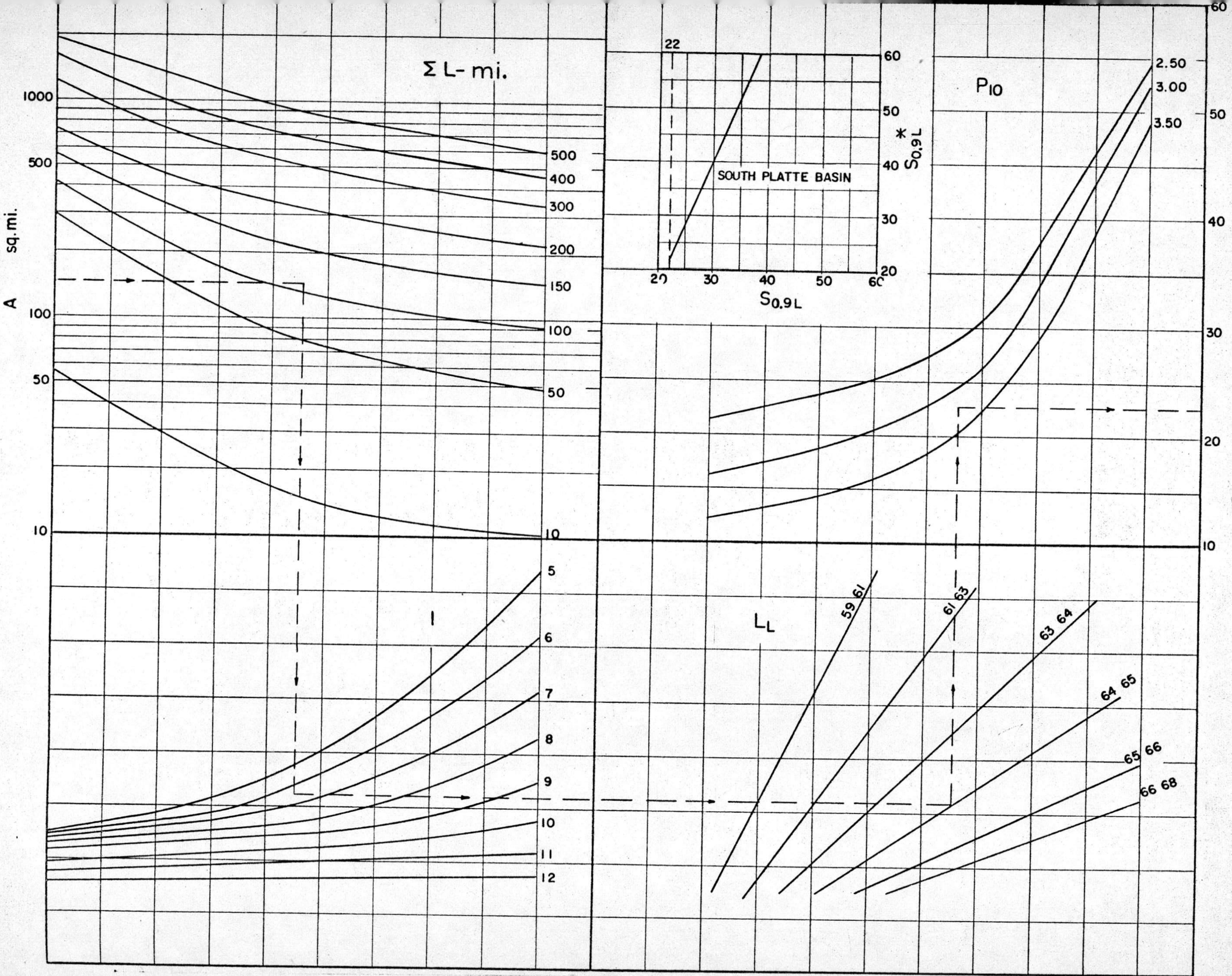

Fig. 4. Relations for estimating $S_{0.9L}$ from A , ΣL , I , L_L , and P_{10} .

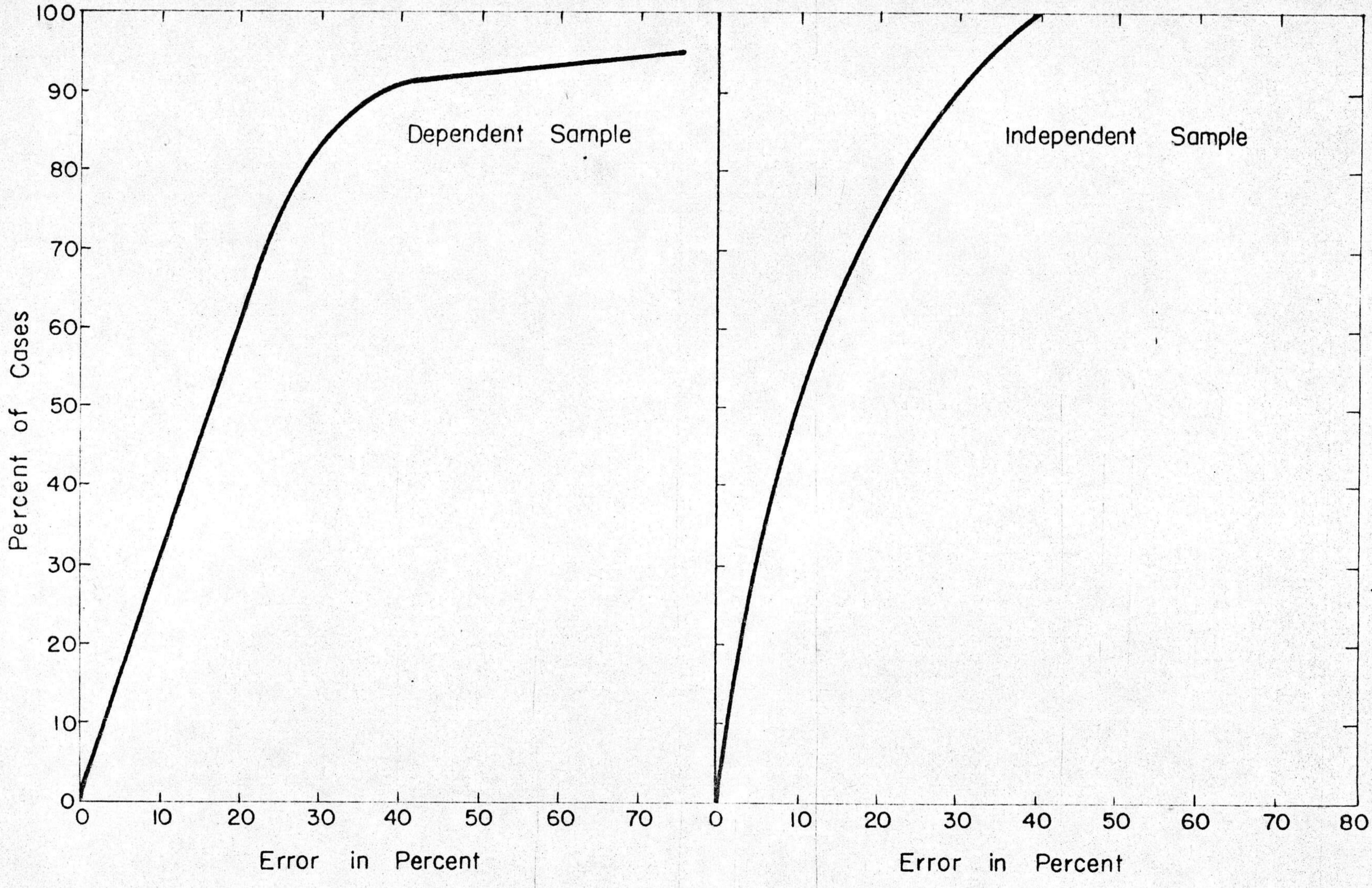

FIG. 5
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