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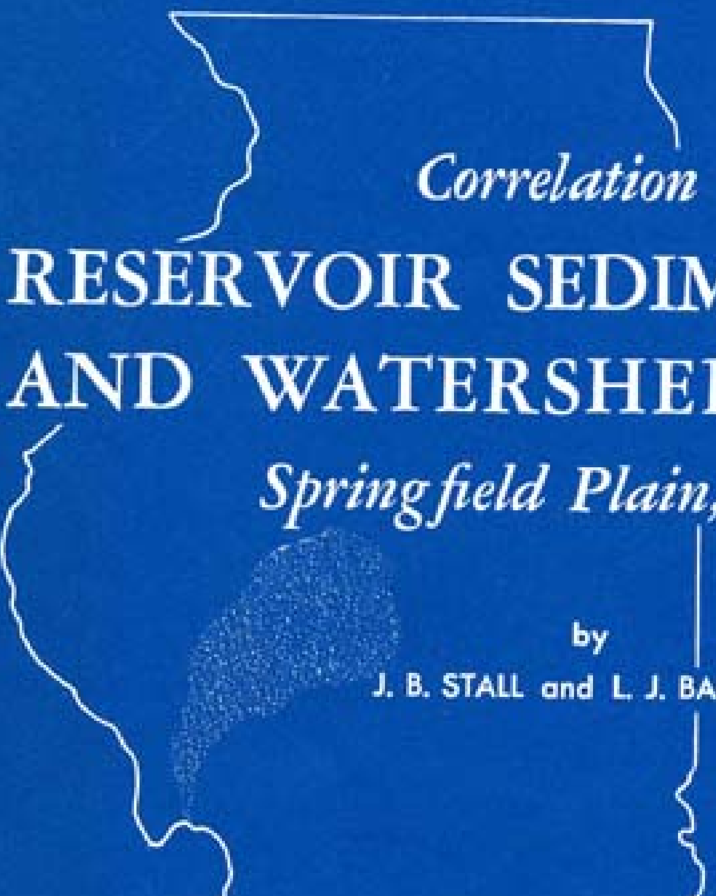

Correlation of

RESERVOIR SEDIMENTATION AND WATERSHED FACTORS

Springfield Plain, Illinois

by

J. B. STALL and L. J. BARTELLI

ILLINOIS STATE WATER SURVEY
WILLIAM C. ACKERMANN, Chief

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CORRELATION OF RESERVOIR SEDIMENTATION AND WATERSHED FACTORS

SPRINGFIELD PLAIN, ILLINOIS

by J. B. STALL and L J. BARTELLI

A Cooperative Study by Illinois State Water Survey, U. S. Department of Agriculture Soil Conservation Service and Agricultural Research Service, and Illinois Agricultural Experiment Station

STATE WATER SURVEY DIVISION
WILLIAM C. ACKERMANN, Chief

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CORRELATION OF RESERVOIR SEDIMENTATION AND WATERSHED FACTORS

Springfield Plain, Illinois

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ABSTRACT

Lake sedimentation data and watershed factors are correlated utilizing results on 20 lakes varying in original capacity from 3.7 to 61,309 acre-feet and having watersheds from 0.09 to 258 square miles. All watersheds are located within the deep loess soils of the Springfield Plain physiographic area in west-central Illinois, and the conclusions reached in this study apply to this area only.

Thirteen lake and watershed variables were tested by multiple correlation analysis for their significance in determining the rate at which sediment is deposited in a lake. Those variables significant at the 10 percent level, or having significance that could probably be reproduced on the average in 9 of 10 new sets of data, were retained as important. Nine different equations are presented which contain from one to six independent variables, having varying accuracies in determining the dependent sediment deposition.

The most accurate, Equation 6, allows computation of the sediment deposition within 50 percent confidence limits of +8.2 tons per acre and 95 percent limits of 25.6 tons per acre. Included in Equation 6 are: a slope factor, age, gross erosion, capacity-inflow ratio, non-incised channel density, and a watershed shape factor. All equations are applicable to a range of sediment deposition from 3 to 102 tons per acre.

INTRODUCTION

Acknowledgment

The study reported here was conducted cooperatively by four agencies: the Illinois State Water Survey, the Illinois Agricultural Experiment Station, and the Soil Conservation Service and Agricultural Research Service of the United States Department of Agriculture. This cooperative study program of reservoir sedimentation problems in Illinois was begun in 1936 for the following purposes: to develop for Illinois the relation of sediment yield to watershed characteristics, to determine the effect of conservation practices on reservoir sedimentation, and to establish the relation of reservoir sedimentation to reservoir and sediment characteristics. Mr. L. C. Gottschalk, Soil Conservation Service, was active in the conception, planning, and conduct of the current study. H. G. Heinemann and L. M. Glymph, Agricultural Research Service, furnished technical advice during the study. S. W. Melsted, Illinois Agricultural Experiment Station, supervised the physical analyses of the reservoir sediment samples obtained. C. E. Downey, Soil Conservation Service, carried out the major amount of the watershed soil mapping. J. C. Neill, Illinois State Water Survey, served as consultant to the authors in the statistical phases of the study. Most of the statistical computation was accomplished by the University of Illinois digital computer, the Illiac.

Study Area

The area studied in the current investigation was chosen on the basis of the needs for sediment information of the cooperating agencies at the time the investigation of this study area was planned in 1949. The study area is located in the northwestern portion of the Springfield Plain physiographic region as delineated by Leighton, Ekblaw and Horberg.[1] The location of this Study Area No. 1, is shown in Figure 1. These authors describe the region as including the level portion of the Illinoian drift sheet in central and south central Illinois. They characterize this division as a flat plain with a low and broad moraine. The drainage systems are well developed, the uplands are low with respect to master streams, and the valleys are relatively shallow. Most of the principal streams have low gradients and occupy broad alluviated terraced valleys. The Illinoian drift is covered by a blanket of loess varying from more than 200 inches along the northern and western edges of the study area to 75 to 100 inches along the southern and eastern edges as described by Smith.[2]

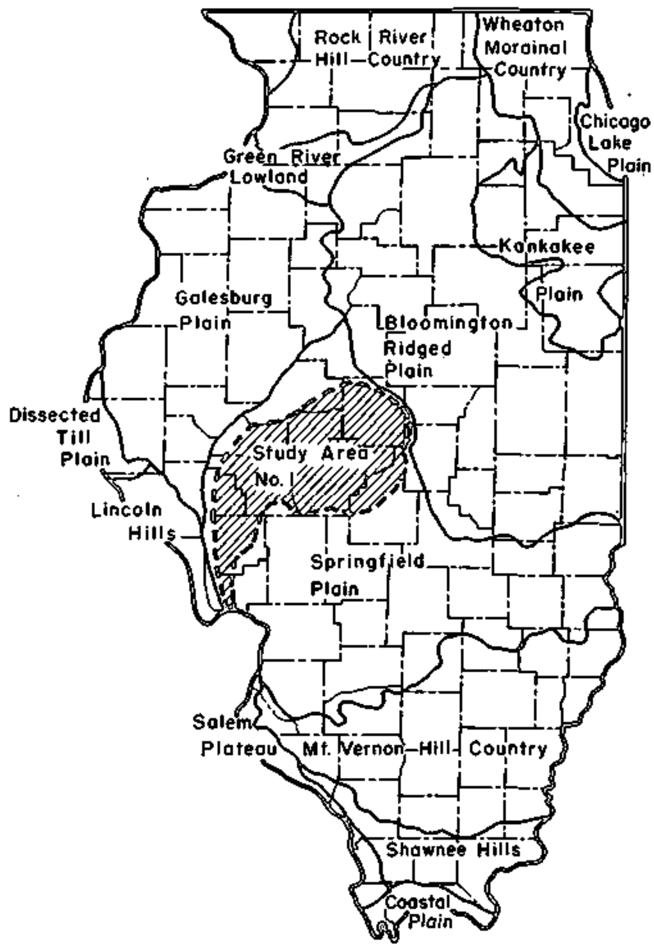

FIGURE 1 PHYSIOGRAPHIC DIVISIONS OF ILLINOIS (AFTER LEIGHTON) SHOWING STUDY AREA NO. 1 LOCATION

The soils are predominantly formed from loess and are classified in soil associations "K" and "L" as delineated by the Illinois Agricultural Experiment Station.(3) The soils in association K are predominately in the Bolivia-Ipava group which are dark colored, moderately permeable, and developed under the influence of prairie vegetation. The Alma-Bogota-Hickory soils associated in the L association are somewhat more leached and lighter colored on the surface due to the influence of a natural timber vegetation.

Data are available on 20 lakes in this study area. These lakes and their watersheds vary considerably in size, watershed characteristics, and intensity of cultivation and yet they are considered typical of this region. The locations of these 20 lakes are shown in Figure 2.

LAKE DATA

Table 1 contains a summary of the physical and sedimentation data on the lakes studied. With the exception of Lakes No. 2, 8, 9 and 10, complete summaries of survey results have been published by the Interagency Committee on Water Resources'.'0

Columns 1 and 2 identify each lake by number and lake owner, respectively. In most cases the lakes are owned by either a municipality or an individual.

Column 3 gives the age of the lakes in years at the time each was surveyed during the period 1950-1954. At the bottom of column 3, it will be noted that the maximum age was 55 years and that the

TABLE 1
LAKE DATA

1 Ident. No.	2 Owner	3 Age Yrs.	4 Orig. Surface Area Acres	5 Orig. Capacity Acre Feet	6 Sediment Acre Feet	7 Average Annual Loss of Capacity Percent	8 No. of Sediment Samples	9 Avg. Sp. Wt. of Sediment Lbs/cu.ft.	10 Average Sediment Deposition Tons/Acre	11 Orig. Capacity Inflow Ratio
Variable Symbol		A							P	I
1.	D. Cole	28.0	6.3	67.2	10.5	0.56	11	61.8	99	0.61
2.	Elliot Bank	52.0	6.3	47.1	11.5	0.47	9	45.9	59	0.32
3.	Woodbine C.C.	26.0	6.0	58.5	15.1	0.99	12	54.5	91	0.37
4.	Franklin C.C.	47.0	23.0	328.3	27.6	0.18	13	40.4	92	1.55
5.	Roodhouse	35.0	7.5	61.6	7.7	0.36	9	53.8	32	0.29
6	H. Ashauer	13.0	4.9	18.3	8.9	3.73	4	64.1	37	0.06
7	N. Anderson	43.0	20.0	260.7	35.1	0.31	15	50.2	100	0.88
8	F. Reilly	12.0	1.2	4.2	2.9	5.67	1	58.1	8	0.01
9	Virginia	17.0	18.7	154.0	38.0	1.50	12	65.3	102	0.40
10	C.B. & Q. R.R.	50.0	5.0	31.7	16.3	1.03	7	55.1	36	0.06
11	Whitehall	55.0	34.0	459.3	51.6	0.20	12	51.1	98	1.01
12	Waverly	13.8	49.0	308.3	69.7	1.64	12	54.1	14	0.07
13	Jacksonville	12.0	469.0	7058.0	184.0	0.22	10	39.7	29	1.35
14	Mauv. Terre	31.0	245.0	1820.0	605.0	1.07	15	50.9	29	0.12
15	J. Langdon	45.0	6.3	56.8	12.0	0.47	11	36.6	43	0.34
16	H. Seely	50.0	1.5	3.7	1.5	0.84	7	71.5	42	0.09
17	L. Schmidt	9.0	3.0	6.0	2.6	4.80	8	58.4	4	0.01
18	Morgan	52.0	18.2	126.0	53.0	0.87	9	47.7	32	0.10
19	J. Sudduth	45.0	41.0	181.8	66.5	0.81	13	54.6	36	0.09
20	Springfield	14.6	4234.4	61309.0	2659.0	0.30	10	42.6	3	0.41
=	Minimum	9.0	1.5	3.7	1.5	0.18	1	36.6	3	0.01
	Maximum	55.0	4234.4	61309.0	2659.0	5.67	15	71.5	102	1.55

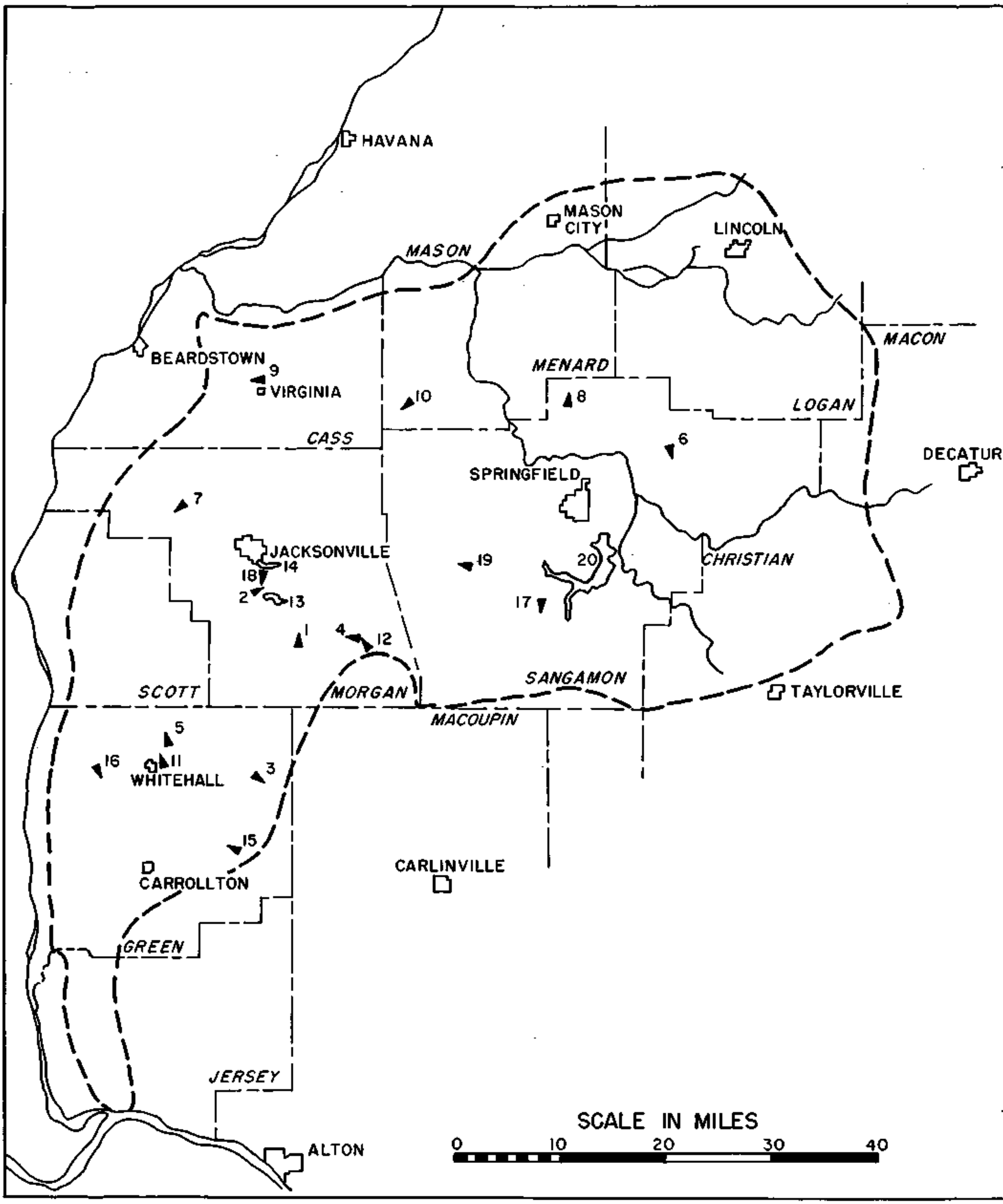

FIGURE 2 STUDY AREA NO. 1 SHOWING LOCATIONS OF 20 LAKES SURVEYED

FIGURE 3 USE OF PISTON-TYPE SEDIMENT SAMPLER

minimum age was 9 years. The designation "A" shown at the head of column 3 indicates that this factor, the age of the reservoir, entered into the regression equations described later.

Column 4 shows the original surface area of the lake in acres. Column 5 shows the original storage capacity of the lake in acre feet.

Column 6 shows the total volume of sediment deposited in the lake in acre-feet. This figure was determined by the detailed sedimentation survey of each reservoir, utilizing methods developed by the Soil Conservation Service and described by Eakin[5] and Gottschalk.[6]

Column 7 shows the average annual loss of storage capacity in percent.

Column 8 gives the number of sediment samples obtained from each lake. These samples were obtained at a maximum depth of two feet below the top of the sediment by use of a thin-wall, core type sampler 1-3/8 inches in diameter. This sediment sampler is illustrated in Figure 3. The specific weight of each sample was adjusted to represent the specific weight of the sediment at the midpoint of the sediment column at that location. The authors feel that this best reflects the mean specific weight of the entire thickness of sediment.

Column 9 shows the average specific weight of the sediment in the lake. Specific weight is the dry weight of solids per unit volume of the water-sediment mixture; it is expressed in pounds per cubic foot. The figures in column 9 are the weighted average of the specific weights of sediment deposited in the various segments of the lake.

TABLE 2
Watershed Data

Ident. No.	12 Land Drainage Area	13	14 Gross Erosion	15 Channel Density Ft/Acre	16	17	18 Slope 3rd Order Streams	19 Direct Tributary Drainage Area	20 Relief Ratio
	Sq. Mi.	Acres	Tons Acre/Yr.	Incised	Non-incised	Total	Ft/Mile	Acres	$X10^4$
Variable Symbol			E		C		S	D	
1	0.22	142	4.3	16.9	18.5	35.4	129	29.5	108
2	0.31	195	2.2	5.3	20.6	25.9	69	42.8	82
3	0.32	204	5.6	11.6	25.9	37.5	87	42.0	107
4	0.41	265	2.5	28.0	11.6	39.6	103	28.3	90
5	0.44	282	3.7	14.8	41.2	56.0	58	85.5	98
6	0.52	334	6.7	0.0	34.9	34.9	34	97.8	83
7	0.60	384	4.5	14.8	23.3	38.1	87	60.1	144
8	0.67	427	3.4	4.2	28.5	32.7	32	196.4	95
9	0.83	530	8.6	17.0	42.9	59.9	82	44.5	90
10	0.84	538	4.5	4.8	31.7	36.5	39	22.1	56
11	0.92	587	3.1	26.4	26.4	52.8	59	156.7	133
12	9.16	5865	2.6	9.1	16.0	25.1	103	2632.0	43
13	10.00	6411	2.4	4.2	22.5	26.7	34	1650.0	46
14	32.20	20606	3.4	7.1	21.0	28.1	34	5181.0	28
15	0.35	223	0.6	9.0	18.4	27.4	71	43.7	81
16	0.09	58	0.5	0.0	9.0	9.0	38	11.7	112
17	1.30	834	0.7	4.5	9.0	13.5	19	378.9	29
18	2.72	1742	1.9	4.5	11.6	16.1	34	303.2	137
19	3.42	2191	1.3	4.5	9.0	18.0	12	566.2	24
20	258.00	165376	3.3	38.3	24.8	63.1	12	26173.8	19
Min.	0.09	58	0.5	0.0	9.0	9.0	12	11.7	19
Max.	258.00	165376	8.6	38.3	42.9	63.1	129	26173.8	144

Column 10 shows the average sediment deposition in the lake, expressed in tons per acre of watershed. In this case the total tons of sediment deposited in the lake have been divided by the watershed land area. This value of sediment deposited in the lake has been labelled "P" and used throughout the remainder of this study as the dependent variable in the regression analyses.

The capacity-inflow ratio of each lake at the time of its construction is shown in column 11. This was utilized as variable "I" in the regression analysis. This is the ratio of the capacity of the lake at the time of construction to the mean annual inflow. Inflow was determined by utilizing records of streamflow of the Macoupin Creek near Kane[7] and the South Fork of the Sangamon River near Kincaid.[7] Both of these basins are virtually adjacent to the study area on the south. Flow records from the gage nearest to the lake were used to compute the inflow to each lake. The Macoupin Creek record covered the years 1922 to the present except for the period 1934-1940. The Sangamon record covered 1918 to the present except for the year 1928, 1931, and 1934-1944. The missing records were synthesized using the stream gage record of the LaMoine River near Ripley[7] (1934 to the present) which is located just north of the study area.

The ages of the lakes surveyed varied from 9 to 55 years. For the lakes built in 1918 or later near the Sangamon River, or 1934 or later near Macoupin Creek, the actual inflow for the sedimentation period of the lake was utilized to compute the capacity-inflow ratio. For lakes constructed prior to these dates, the mean flow for the entire period of record prior to 1954 was utilized.

The capacity-inflow ratio was included in this analysis due to its influence on the trap efficiency of the reservoir. Its relationship with trap efficiency has been shown by Brune.[8]

WATERSHED DATA

Watershed information utilized in this study is shown in Table 2 which contains both physical data determined by field survey and computed information as described below.

The first column gives the lake identification number. Column 12 gives the total land drainage area in square miles and column 13 shows the same drainage area expressed in acres.

Column 14 gives the rate of gross erosion on the watershed in tons per acre per year. This value was computed by the method of Van Doren and Bartelli.[9] This method utilizes soil group, slope, and erosion data developed from field surveys, and land use data as derived from township census reports. Gross erosion represents the average annual soil loss from sheet erosion based on a normal distribution of rainfall. In only one of the lakes studied, No. 9, was gully erosion considered significant. In this case, all gullies were mapped, and the measured quantity of gully erosion is included in the values shown in column 14. Gross erosion was utilized as variable "E" in the regression.

Figure 4 illustrates the type of soil information used to compute soil loss. A soil map of the watershed of Lake No. 7 is shown. The map designations contain three symbols which show soil group, slope and erosion. For example, the area labelled 3E2 denotes soil group No. 3 having an E slope and "2" erosion. Slopes vary from A through E as the steepness increases, and erosion varies from 0 through 3 according to the inches of soil removed. The land use is designated on the map as L, cultivated land; F, forest land; H, farmyard; and P, pasture.

The utilization of this map to make the actual computations of soil loss according to the Van Doren and Bartelli method is shown in Table 3. The resulting value of 4.5 tons per acre per year appears also in Table 2, column 14, opposite Lake No. 7.

Column 15 of Table 2 gives the incised channel density in feet per acre, and column 16 the non-incised channel density in feet per acre, "C" in the regression. Column 17 is the total of columns 15 and 16. The mapping of these two different types of channels was accomplished as a part of the watershed soil survey. An incised channel is one in which the flow of water is sharply cut into the earth, characterized by steep side banks regardless of size of channel. It is illustrated in Figure 5. The non-incised channel is a drainageway, between two slopes, in which water must collect and flow away; there is no incision into the earth and yet a definite drainageway is present. Such a channel is pictured in Figure 6.

In column 18 of Table 2 is shown the mean slope of third-order streams of the particular watershed in question expressed in feet per mile. Horton[10] devised a method of study of the relationships involved in stream systems. Strahler[11] has discussed these relationships and other authors in the field of sedimentation have utilized these parameters successfully. In the watersheds under study, field surveys were made to measure the slopes of a number of the representative channels of each

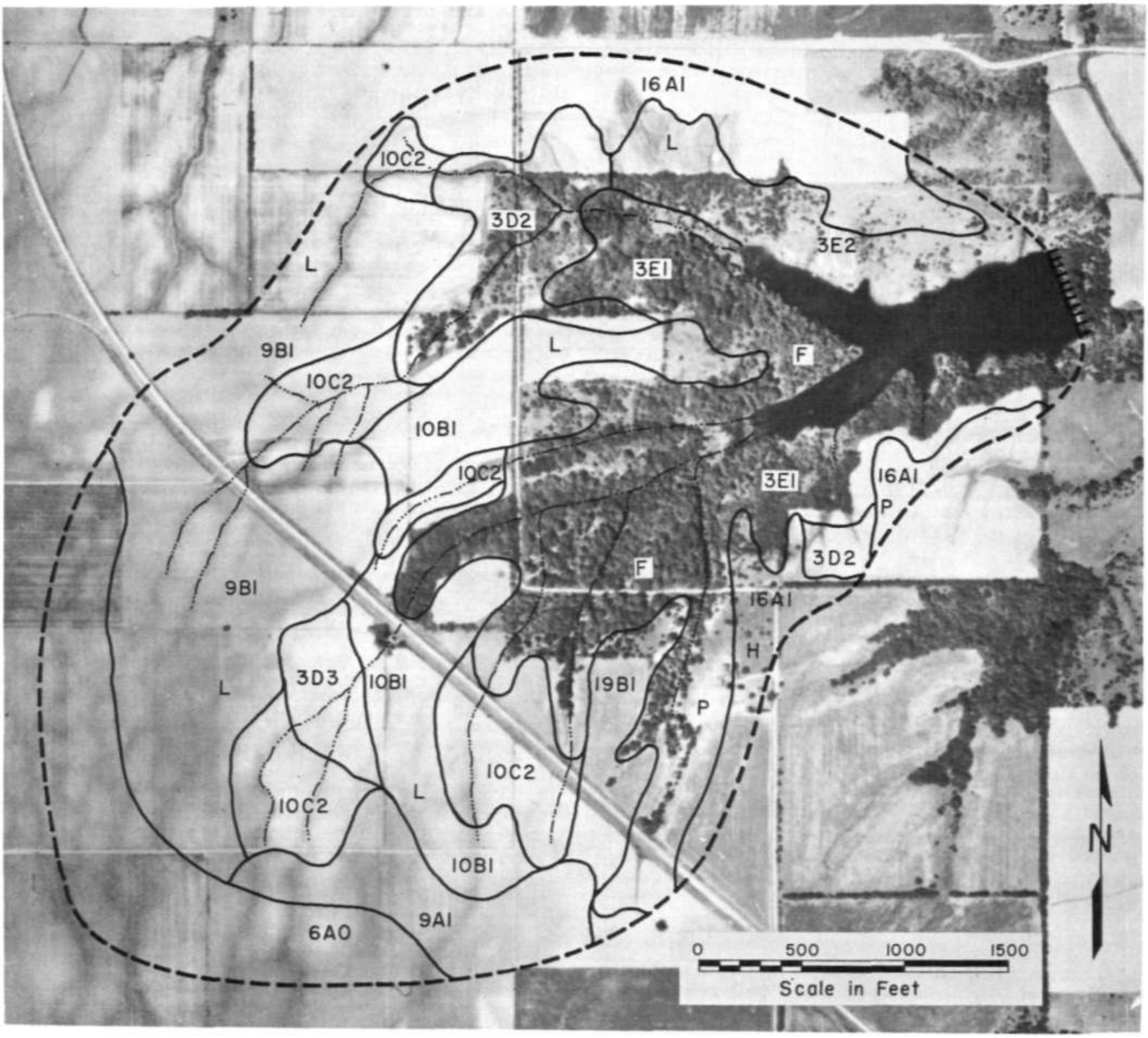

FIGURE 4 SOIL SURVEY MAP OF WATERSHED OF LAKE NO. 7; EXPLANATION OF SOIL DESIGNATIONS GIVEN ON PAGE 9

FIGURE 5 TYPICAL INCISED CHANNEL

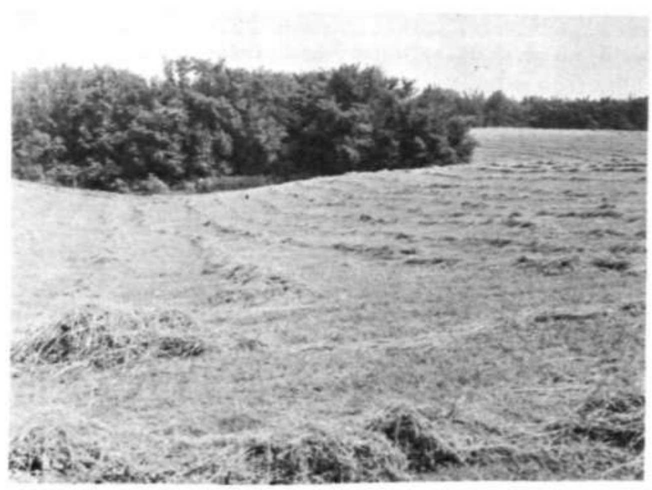

FIGURE 6 TYPICAL NON-INCISED CHANNEL

order. The stream systems in these twenty watersheds were assigned orders and the general relationships devised by Horton were verified.

Figure 7 is a map of the watershed of Lake No. 6 illustrating the Horton ordering system as revised by Strahler. Each unbranched tributary is considered a first-order stream and has been labelled "1" in Figure 7. A stream formed by the confluence of two first-order streams is considered a second-order stream. These have each been labelled "2" in Figure 7. At the point where two second-order streams combine, a third-order stream is formed. There occurs a single third-order stream in Figure 7 and it is labelled "3".

Horton[10] has shown a semi-logarithmic relation to exist between the mean slopes of streams of the various orders. This relation was generally verified in the twenty watersheds of Study Area

TABLE 3

Sample Computation of Gross Erosion (E), Watershed of Lake No. 7

Slope Length = 200 Feet
Mean Rotation 1909-1945 = 1-1-0

Soil Designation	Area Acres	Soil Rainfall and Rotation Factor	Cropping Practice Factor (Continuous Corn, No practices equals 100)	Average Soil Loss Tons/Year
Cultivated Land				
16A1	25.0	.56	2	28
3E2	5.0	.58	98	284
3D2	2.0	.58	53	61
3E1	6.4	.48	98	301
3D3	5.5	.67	53	195
10B1	1.2	.48	4	2
10C2	39.6	.48	18	437
9A1	38.1	0	0	0
6A0	60.8	0	0	0
9B1	81.4	.40	12	391
Forest Land				
3D2	19.0	.30	1	6
3E1	74.6	.30	1	22
Farmyard				
16A1	0.8	0	0	0
Pasture Land				
16A1	6.6	.50	1	3
3E2	14.0	.50	1	7
3D3	4.0	.50	1	2
Totals	384.			1739

Mean Soil Loss or Gross Erosion

$$E = \frac{1739 \text{ Tons/Year}}{384 \text{ Acres}} = 4.5 \frac{\text{Tons}}{(\text{Acre})\ (\text{Year})}$$

TABLE 4

Slope of Streams in Drainage Area of Lake No. 6

Stream Order	Number of Streams	Mean Slope Feet/Mile
1	34	145
2	8	68
3	1	34

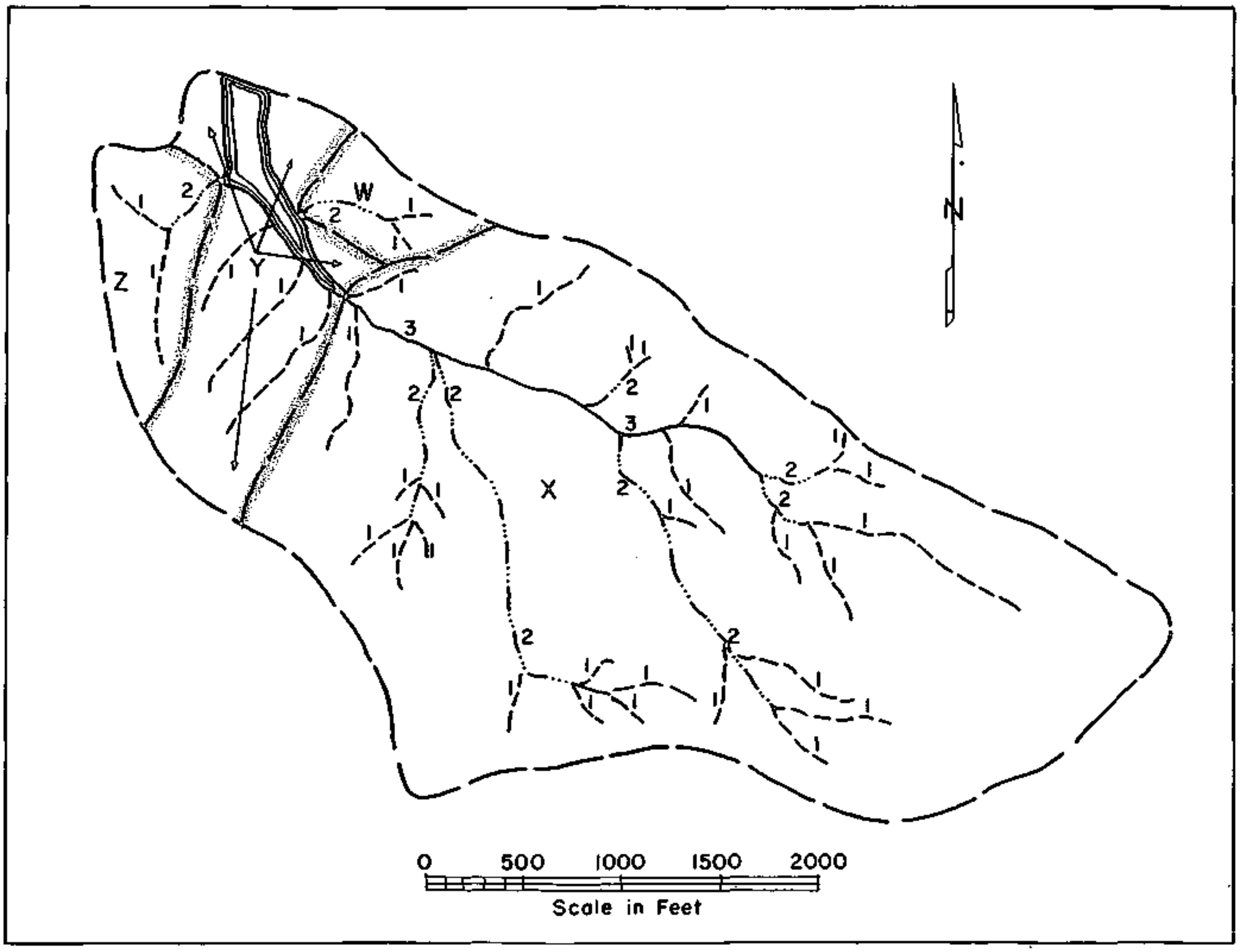

FIGURE 7 STREAM SYSTEM OF LAKE NO. 6 WATERSHED SHOWING HORTON ORDER NUMBERS AND FOUR DIRECT SUBBASINS

No. 1. An example of this relation is shown by the data for Lake No. 6 contained in Table 4. The semi-log plot of these data is illustrated in Figure 8.

Preliminary plots showed the importance of these slope factors in this sedimentation study. The slope of the third-order stream as shown in column 18 of Table 2 was utilized as one of the independent variables "S" in the regression study. The slope of the first-order streams showed significance equal to that of the third order. It is probable that the slope of any of the other stream orders would have equal significance. The slope of third-order streams was used in the regression since it was believed easier to determine than the slope of lower orders.

Column 19 in Table 2 lists values of mean direct tributary drainage area D in acres. This figure is an expression devised by the authors to represent the effect of drainage area conformation and distribution of the tributaries. To obtain this value all of the streams which empty directly into the lake were taken as separate watersheds and these averaged by stream orders as described below. The use of such a parameter as D was based fundamentally on the studies of Horton.[10]

He revealed that a number of important physiographic factors were related to the stream orders. In addition to the slope, as discussed above and

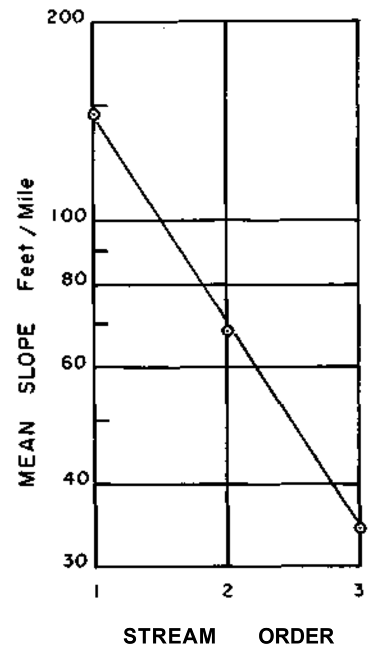

FIGURE 8 SLOPES OF STREAM ORDERS FOR WATERSHED OF LAKE NO. 6

shown in Figure 8; Horton showed that: (1) the number of streams, and (2) the average length of streams were related to stream order. For example, the first-order streams in a basin are the most numerous; there occur fewer second-order

TABLE 5

Sample Computation of Mean Direct Tributary Drainage Area (D) for Lake No. 6

(See map in Figure 7)

Designated Area on Map	Number of Tributaries	Land Area in Acres	Mean Area in Acres
First-Order Tributaries			
Y	3	39.9	13.3
Second-Order Tributaries			
W	1	10.2	
Z	1	18.0	
	2	28.2	14.1
Third-Order Tributaries			
X	1	266.1	266.1
			293.5

Mean

$$D = \frac{293.5 \text{ Acres}}{3 \text{ Orders}} = 97.8 \text{ Acres}$$

streams and fewer yet third-order streams. The general relation is similar to that shown in Figure 8 for slope and stream order.

Horton showed also that the average length of second-order streams is greater than that of first-order streams. Third-order streams are shown to have greater average length than second-order streams, etc.

Since average stream length increases with stream order it was believed by the present authors that drainage area would also increase with stream order. The present authors, in an effort to devise a single parameter to represent drainage area conformation and the distribution of tributaries, decided to test a variable which represented the size of the drainage areas of the tributaries emptying directly into the lake. This variable, D, the mean direct tributary drainage area was the result.

A watershed with many tributaries emptying directly into the lake has a small mean direct tributary drainage area while a watershed of the same actual area with only one principal tributary has a large value. An example of the computation procedure for the mean direct tributary drainage area for Lake No. 6 is shown in Table 5 and is illustrated on the map in Figure 7.

In the map in Figure 7 the area labelled Y is drained by three first-order tributaries emptying directly into the lake. All other parts of the reservoir watershed are drained by tributaries having a higher order than "first." Table 5 shows that the area Y of Figure 7 has a land area of 39.9 acres. This 39.9 acres divided by the three tributaries gives a mean area of 13.3 acres served by each first-order tributary emptying directly into the lake.

In Figure 7 areas labelled W and Z are drained by second-order tributaries emptying directly into the lake. Table 5 shows that the mean of these two areas is 14.1 acres. Figure 7 shows that the area labelled X is served by a single third-order stream emptying directly into the lake. Table 5 shows the area X to be 266.1 acres.

At the bottom of Table 5 a mean is calculated of the right column of the table which contains the mean areas drained by each order tributary. This value of 97.8 acres is called D, the mean direct tributary drainage area.

In column 20 of Table 2 is shown the relief ratio. The ratio is dimensionless and the values in column 20 have been multiplied by 10^4. This variable was tested in the regression but not found to be significant. It represents the relief of the watershed land area and was obtained by the following equation.

$$\frac{R}{L} = \frac{M_e - J_e}{F}$$

in which $\frac{R}{L}$ = Relief Ratio

M_e = Maximum watershed land elevation

J_e = Lake spillway crest elevation

and F = Distance from head of lake to watershed divide

ANALYSIS OF DATA

Approach

The multiple regression method was used in the current study after a number of preliminary graphical analyses were made. It is most applicable to this type of problem and has been successfully used by others and explained by Anderson.[12] The value of this statistical device is that it furnishes a means of testing. The values and limitations of such an approach are well described by Mood.[13] In the end, the statistical manipulations must be considered as evidence and not proof of any physical relationships. They must be interpreted in the light of the observations and must be accepted as being completely empirical in nature.

In the present study the sediment deposited in the lake per unit of drainage area as shown in column 10 of Table 1 was utilized as the dependent variable.

Regressions

Regression analyses were run on more than fifty combinations of thirteen independent variables in an effort to determine the combinations that best correlated with the dependent variable P. Some of the results are summarized in Table 6. This table shows the efficiency of these nine regression equations in computing the dependent sediment variable, P.

The first entry in Table 6 has no equation number but shows the standard error or standard deviation about the mean of the twenty observed values of P. The confidence limits shown reveal the accuracy with which P could be predicted from the observations of P itself, without correlations with any of the independent variables.

In Table 6, Equation 1 contains one independent variable, S, mean slope of third-order streams. The correlation coefficient R is .705, and the coefficient of determination R^2 is .50. This means that 50 percent of the variations in the dependent variable, P, can be accounted for by variations in S. The next column shows that this regression is based on 18 degrees of freedom, meaning that the variables involved had 18 chances to operate independently in the determination of the dependent

TABLE 6

Efficiency of Regression Equations

Equation Number	Dependent Variable	Independent Variables	Multiple Correlation Coefficient R	Coefficient of Determination R^2	Degrees of Freedom	Standard Error Tons/Acre	Confidence Limits ±50 Percent Tons/Acre	Confidence Limits ±95 Percent Tons/Acre
--	P		--	--	19	33.9	23.4	70.9
(1)	P	S	.705	.50	18	24.1	16.6	50.5
(2)	P	S A	.769	.59	17	21.7	15.0	47.5
(3)	P	S A E	.868	.75	16	16.8	11.6	35.7
(4)	P	S A E I	.913	.83	15	13.8	9.5	29.4
(5)	P	S A E I C	.931	.87	14	12.4	8.6	26.7
(6)	P	S A E I C Log D	.937	.88	13	11.8	8.2	25.6
(7)	P	A E	.722	.52	17	23.5	16.2	49.6
(8)	P	E R	.701	.49	17	24.2	16.7	51.0
(9)	P	A E I	.849	.72	16	17.9	12.4	38.0

Legend

P = Sediment Deposition, Tons/Acre

S = Mean Slope of Third-Order Streams, Feet/Mile

A = Age, Years

E = Gross Erosion, Tons/Acre/Year

I = Capacity/Inflow Ratio, Ratio

C = Density of Non-Incised Channels, Feet/Acre

D = Mean Direct Tributary Drainage Area, Acres

TABLE 7

Regression Equations

Equation	Equation Number
$P = +7.5 + 0.74\ S$	(1)
$P = -11.5 + 0.70\ S + 0.65\ A$	(2)
$P = -39.3 + 0.54\ S + 1.00\ A + 7.7\ E$	(3)
$P = -40.7 + 0.41\ S + 0.94\ A + 8.0\ E + 24.0\ I$	(4)
$P = -29.4 + 0.35\ S + 0.97\ A + 12.6\ E + 24.4\ I - 1.07\ C$	(5)
$P = +3.9 + 0.25\ S + 0.74\ A + 12.2\ E + 26.9\ I - 1.16\ C - 8.21\ Log\ D$	(6)
$P = 27.5 + 1.25\ A + 11.0\ E$	(7)
$P = +8.3 + 7.3\ E + 41.4\ I$	(8)
$P = -33.8 + 1.08\ A + 10.3\ E + 35.0\ I$	(9)

variable. The term, degrees of freedom, has been discussed by Ezekial.[14] The standard error of this regression equation is shown to be 24.1 tons per acre. The confidence limits are such that in utilizing the equation to compute an unknown value of P, in 50 percent of the cases, the actual sediment deposition would probably be within ±16.6 tons per acre of the computed value. Similarly, in 95 percent of the cases, the sediment deposition would be within ±50.5 tons per acre.

In Table 6 Equation 2 is more efficient than Equation 1. In this case the age of the lake was added to the regression equation. Similarly Equations 3, 4, 5 and 6 show an increase in efficiency. In each of these six equations, the addition of another independent variable was tested and found statistically significant at the ten percent level. This means that it is to be expected that in repeating the experiment the importance of the addition of this particular variable could probably be established again in 90 out of 100 cases. The authors have chosen the ten percent level of significance as a minimum level for judging whether a variable is retained or rejected. Equation 6 is the most efficient equation in Table 6 having R = .937 and 95 percent confidence limits equal to +25.6 tons per acre.

It will be noted that Equation 6 in Table 6 contains the logarithm of D, the mean direct tributary drainage area. Preliminary plots of the isolated effects of various independent variables on the dependent variable indicated that the logarithmic values of D were more closely correlated with the dependent variable, P, than were the plain values of D. Also the statistical regression showed that the logarithm of D would increase the efficiency of the regression over that of Equation 5. The plain values of D would not increase the efficiency of the equation. In the case of every variable tested, a regression was run to check the arithmetic, semi-log, and log-log correlation with the dependent variable P. This case of D in Equation 6 was the only one in which the plain arithmetic or straight-line correlation did not prove best.

Table 6 shows that a slope factor, S, the mean slope of the third-order streams is the most efficient single factor in computing sediment production P. Next in importance come age, gross erosion, capacity-inflow ratio, density of non-incised channels and the logarithm of the mean direct tributary drainage area. Equations 7, 8, and 9 have been included in Table 6 in the belief that they might be useful in cases where S, C or D cannot be easily determined.

Table 7 contains the actual Equations 1 through 9. These equations are all valid for use in Study Area No. 1 and can be used to compute the sediment deposition with the confidence limits shown in Table 6.

Most Efficient Equation

In Table 8 are presented statistical data on the most efficient regression devised in the current study, Equation 6. All of the six independent variables in this equation have been found significant at the 10 percent level. As Table 8 shows, the partial regression coefficient for each of these independent variables is more than 1.7 times its own standard error.

The variable S has the highest simple correlation with the dependent variable P. The multiple regression system will, however, isolate the influence of each independent variable on the dependent by "taking out" the effects of other variables. The result is a partial correlation of each independent variable with the dependent. This "pure" relation (as determined by this set of observations) is shown by the partial correlation value in Table 8. Here the gross erosion E has the highest partial correlation with sediment deposition.

The beta coefficients in Table 8 represent the change expected in the dependent variable caused by a change of one standard error in the independent variable. Beta coefficients have been explained in an understandable manner by Arkin and Colton.[15]

TABLE 8

Statistical Data on Most Efficient Regression, Equation 6

Partial Regression Coefficient b	Variable Symbol	Variable Name	Variable Units	Standard Error, Sb of Partial Regression Coefficient	Ratio b/Sb	Correlation with Dependent Variable P: Simple	Correlation with Dependent Variable P: Partial	Beta Co-efficient
	P equals	Sediment Deposition	Tons/Acre					
+0.25	S	Mean Slope of Third-Order Streams	Feet/Mile	0.13	2.0	+.71	+.48	+.24
+0.74	A	Age	Years	0.25	2.9	+.38	+.63	+.35
+12.2	E	Gross Erosion	Tons/Acre/Year	3.0	4.1	+.45	+.75	+.72
+26.9	I	Capacity/Inflow	Ratio	7.9	3.4	+.55	+.69	+.35
-1.16	C	Density, Non-incised channels	Feet/Acre	0.55	2.1	+.18	-.50	-.34
-8.21	Log D	Mean Direct Tributary Drainage Area	Log (Acres)	4.90	1.7	-.60	-.42	-.21
	+3.9	(Constant)						

RESULTS

Importance of Variables

In Equation 6 the isolated effect that each independent variable has on the dependent variable can be shown by utilizing the observations. Observed values of all independent variables except one are substituted into Equation 6. These are used to adjust the observed value of P, the dependent variable. The effects of these independent variables are thus "taken out" of P and the adjusted P can be plotted versus the remaining independent variable to show the isolated relation. This manipulation has been carried out for each variable in Equation 6. The plotted results are shown in Figures 9 through 14. In each plot the slope of the line denoting the relation is equal to the partial regression coefficient, b, shown in Table 8 and the standard deviation of the plotted points is equal to the standard error S_b shown in Table 8.

The plotted graphs in Figures 9 through 14 show graphically the strength of the relation that each independent variable in Equation 6 has with the sediment deposition, P. As stated earlier the over-all importance of each relation has been proved by its statistical significance at the 10 percent level. The relative importance of the variables can be noted from comparison of these plots as well as by reference to the statistical data shown in Table 8. In each plot the deviations from the partial regression line represent the effects of unknown or unmeasured variables.

Figure 9 shows the effect of the mean slope of third-order streams, S, on sediment deposition, P. As the slope factor increases more sediment is delivered to the lake. This seems reasonable since the ability of a stream to transport sediment is known to be a function of flow velocity which in turn is a function of the stream gradient or slope.

Figure 10 shows that as a lake increases in age, more sediment per unit of drainage area is deposited in the lake. This is to be expected since a lake normally collects more sediment as it increases in age.

In Figure 11 the sediment deposited in the lake per unit of drainage area is seen to increase as the gross erosion, E, increases. In the cases of rapid erosion on a drainage area, more soil is available for transport downstream to the lake; consequently, more sediment is deposited in the lake.

The variable I, capacity-inflow ratio, is shown

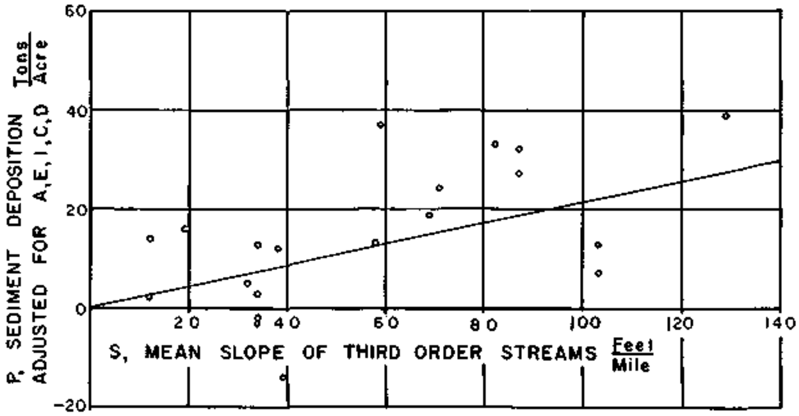

FIGURE 9 EFFECT OF SLOPE FACTOR ON SEDIMENT DEPOSITION

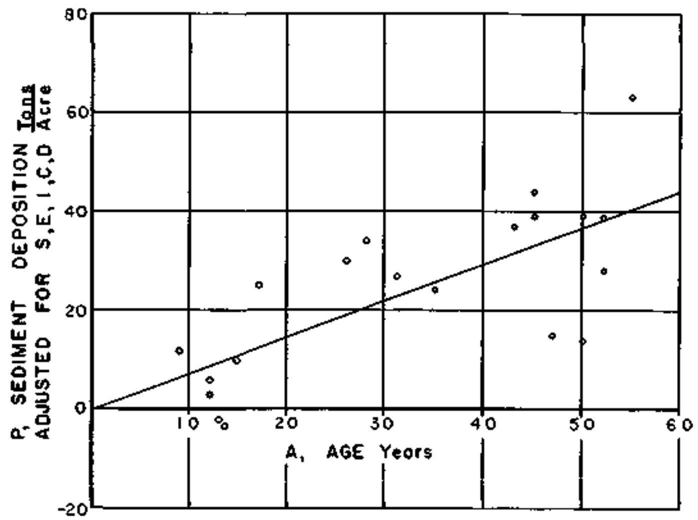

FIGURE 10 EFFECT OF AGE ON SEDIMENT DEPOSITION

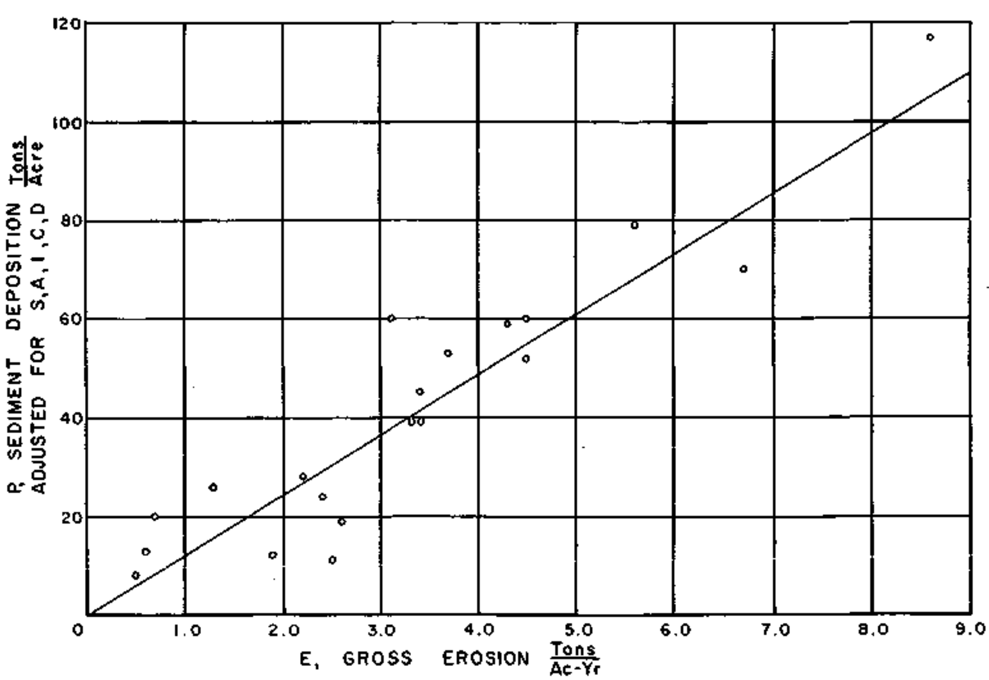

FIGURE 11 EFFECT OF WATERSHED GROSS EROSION ON SEDIMENT DEPOSITION

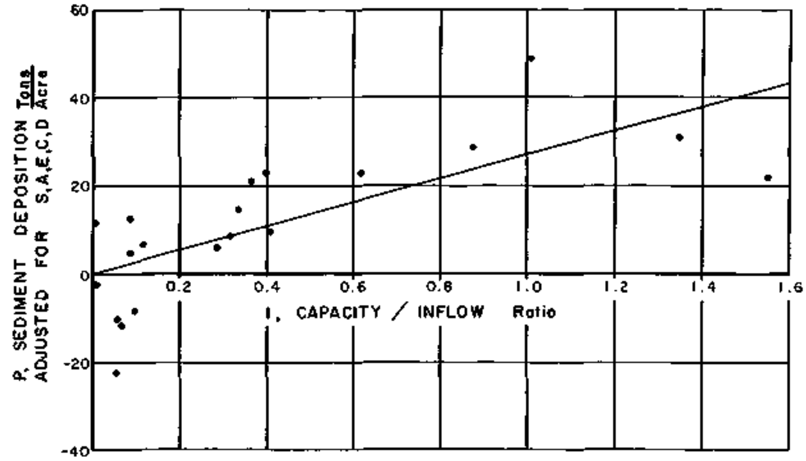

FIGURE 12 EFFECT OF CAPACITY-INFLOW RATIO ON SEDIMENT DEPOSITION

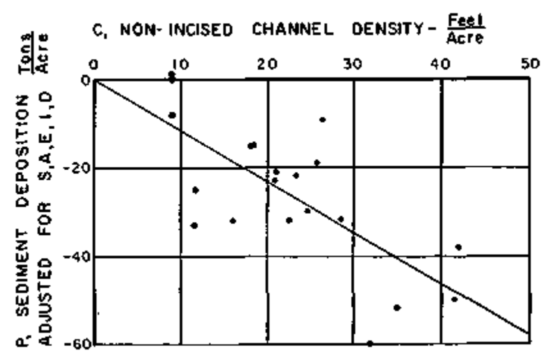

FIGURE 13 EFFECT OF NON-INCISED CHANNEL DENSITY
ON SEDIMENT DEPOSITION

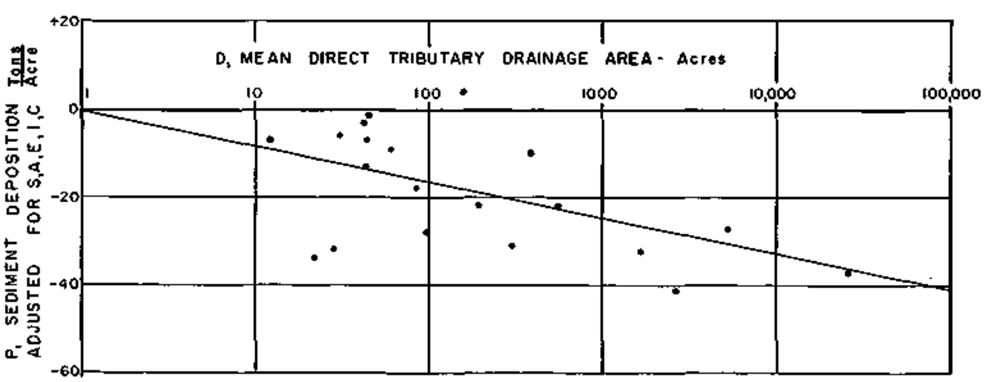

FIGURE 14 EFFECT OF WATERSHED SHAPE FACTOR D ON SEDIMENT DEPOSITION

in Figure 12 to have a direct relation to the dependent variable, P. As the capacity-inflow ratio increases the sediment deposited in the lake also increases. This ratio amounts to the lake capacity divided by the average annual inflow. The numerical unit of this "ratio" is actually years and it is thus an indication of detention time within the lake. In a lake with a large detention time it is natural to assume that more sediment will be deposited than in a lake with a short detention time, and thus the sediment rate will be greater in the former. The value of the I ratio reflects this increase in the trap efficiency of the lake. This relation has been shown also by earlier authors such as Brune.[8]

Variable C, the non-incised channel density, shows some strength as an independent variable. Its effect on the dependent sediment variable is shown in Figure 13 to be negative. It is believed that the inverse relation which this factor shows with the dependent variable indicates that this type of non-incised channel represents an opportunity for upland sediment deposition and that the importance of this type of channel deserves further study.

Variable D, the mean direct tributary drainage area, is shown in Figure 14 to have an inverse relation with P. This would seem to show that if the drainage area consists of a number of small subwatersheds draining directly into the lake, higher rates of sediment deposition could be expected. This is believed a reasonable theory and tends to confirm the use of such a "shape" factor as a parameter for measurement of this effect. The relation of this variable to sediment deposition is semi-logarithmic as shown by the use of the logarithm of D in Equation 6 as discussed earlier.

Conclusions

1. Equation 6, the most accurate regression resulting from the current study contains six independent factors. The slope of third-order streams, age, gross erosion, capacity-inflow ratio, non-incised channel density, and a watershed shape factor are combined to explain 88 percent of the variations in the sediment deposited in a lake. In utilizing this equation, the sediment deposition can be computed within +8.2 tons per acre 50 percent of the time and within +25.6 tons per acre 95 percent of the time. The equation was devised for the deep loess soils of the Springfield Plain physiographic area of western Illinois and these confidence limits apply to this region only.

2. Eight other equations utilizing from 1 to 5 independent variables are presented in Table 7 and can be utilized within this study area with the confidence limits shown.

3. The mean slope of the third-order streams of the watershed was the single variable which was strongest in determining sediment production. In Equation 6, the most efficient regression, the watershed gross erosion was the strongest of six independent variables in determining sediment deposition.

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