SEDIMENT DISTRIBUTION IN SMALL FLOODWATER-RETARDING RESERVOIRS

in the Missouri Basin Loess Hills

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Prepared by
Soil and Water Conservation Research Division
Agricultural Research Service
in cooperation with the
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SEDIMENT DISTRIBUTION IN SMALL FLOODWATER-RETARDING RESERVOIRS IN THE MISSOURI BASIN LOESS HILLS

Herman G. Heinemann[1]

INTRODUCTION

The distribution of sediment that accumulates in a proposed floodwater-retarding reservoir has long been a problem in planning and design. If one knew how the sediment would be distributed, he could better determine the crest elevation of the principal spillway and the required capacities of the various storage pools.

The Bureau of Reclamation, U. S. Department of the Interior, has made a number of studies of the sediment distribution in large reservoirs. However, very little work has been done on small ones.

This report discusses recent research on the sediment distribution in small conservation reservoirs in the loessial hills area of the Missouri River Basin. The findings of this report can be considered directly applicable on Public Law 566 reservoirs, because of the similarity in the characteristics of these reservoirs to those of floodwater-retarding structures built under this Law[2].

By graphical and multiple regression analysis, a method is derived for predicting sediment distribution and the minimum elevation of the principal spillway with respect to sediment accumulation. Most of the significant watershed, reservoir, and structural parameters that are believed to influence the mode of sediment distribution were considered in this study. However, since adequate data were not available for all, some parameters were eliminated from further consideration in this study.

It should be pointed out that some of the parameters not included herein and also those that do not appear statistically significant in this particular study area may be highly significant in other areas. It also should be emphasized that this material applies only to floodwater-retarding structures in the Missouri River Basin loess hills. The findings should not be applied to reservoirs having values for important parameters in excess of the variables used in this study to develop the prediction equation nor to reservoirs in different physiographic areas which have not been studied.

The loessial hills area of the Missouri River Basin lies mainly in western Iowa and eastern Nebraska. Gottschalk and Brune (6)[3] describes this area in considerable detail.

PROCEDURE

All available field notes concerning the ponds and reservoirs were obtained from the Milwaukee office of the Engineering and Watershed Planning Unit, Soil Conservation Service, U.S.D.A. Information was also received from other Soil Conservation Service offices and the Iowa State University. The writer also made a field trip to inspect each of these ponds and reservoirs and to obtain additional field data.

The first step in the use of these data was to review all the available information. This included checking the computations for determining the reservoir capacities by Eakin's (2) range method. When minor errors were uncovered, they were disregarded, and the information was left unaltered. However, when major differences developed, an attempt was made to resolve them and use the correct capacities. If the differences could not be resolved, the pond and its data were eliminated from further study. The location of the remaining 23 ponds or reservoirs finally selected is shown in figure 1. In some cases data are available for more than one sedimentation survey of a particular reservoir, resulting in a total of 34 sedimentation surveys for consideration in the analyses.

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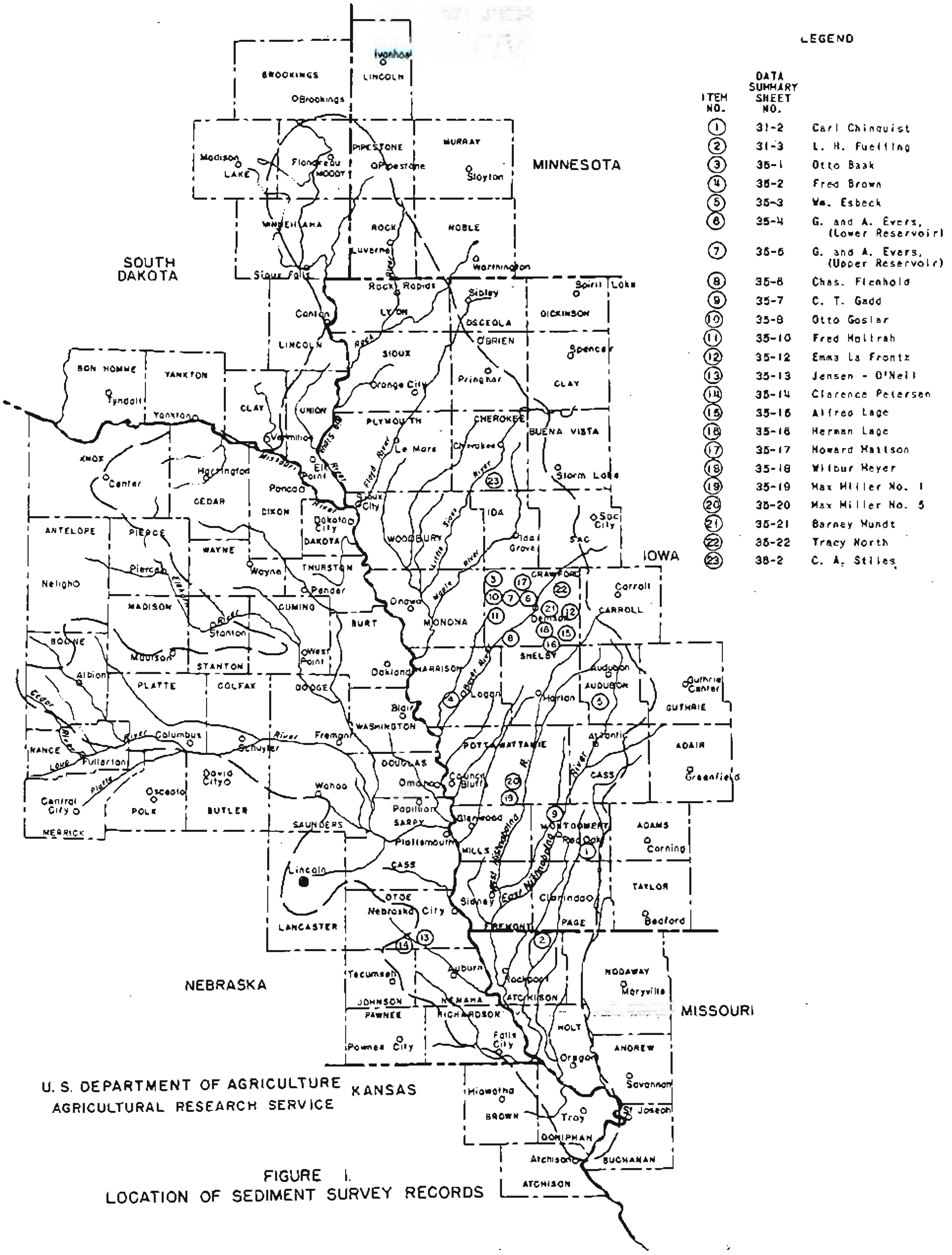
[2] Watershed Protection and Flood Prevention Act - 83d Cong.; 68 Stat. 666.

[3] Numbers in parentheses refer to Literature Cited at end of this report.



LEGEND

ITEM NO.	DATA SUMMARY SHEET NO.	
①	31-2	Carl Chinquist
②	31-3	L. H. Fuelling
③	35-1	Otto Baak
④	35-2	Fred Brown
⑤	35-3	Wm. Esbeck
⑥	35-4	G. and A. Evers, (Lower Reservoir)
⑦	35-5	G. and A. Evers, (Upper Reservoir)
⑧	35-6	Chas. Flenhold
⑨	35-7	C. T. Gadd
⑩	35-8	Otto Goslar
⑪	35-10	Fred Holtrah
⑫	35-12	Emma La Frontz
⑬	35-13	Jensen - O'Neil
⑭	35-14	Clarence Petersen
⑮	35-15	Alfred Lage
⑯	35-16	Herman Lage
⑰	35-17	Howard Mattson
⑱	35-18	Wilbur Meyer
⑲	35-19	Max Miller No. 1
⑳	35-20	Max Miller No. 5
(21)	35-21	Barney Mundt
(22)	35-22	Tracy North
(23)	38-2	C. A. Stiles

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FIGURE 1.
LOCATION OF SEDIMENT SURVEY RECORDS

The plotting of the cross sections from the original survey notes was checked in every instance, and these cross sections then used to develop a contour map for each survey of each pond or reservoir. Using data from these maps and the modified prismoidal formula $\left[V = \frac{L}{3}(A + \sqrt{AB} + B)\right]$

where: V = volume in acre feet
L = Contour interval in feet
A = Area of lower contour in acres
B = Area of upper contour in acres, reservoir capacities were calculated for each survey, following the procedure described by Gottschalk (5). The accumulated capacities computed from this method were adjusted to agree with the capacities as determined by the range method. This adjustment was made for the capacity below the principal spillway (drop inlet), as well as the capacity between the two spillways or above the principal spillway. The modified prismoidal method capacities were adjusted to the range method capacities because the original surveys were made for the range method of computations. A sample of the modified prismoidal method of calculation and the adjustments is shown in table 1.

This table shows the method used on the G. & A. Evers (lower) pond No. 35-4. Columns 1 through 7 and 10 through 13 show the calculations of remaining capacity using the modified prismoidal method. Columns 8 and 14 show the adjustments to make these capacities coincide with those determined by the range method at the two spillways. The capacity values 6.63, 28.26, 1.26, and 20.96 were obtained from the range method computations. The adjustment factors were always applied to the Volume Between Contours "V" (col. 6 or 12). The Accumulated Sediment Volume is the difference between the two Adjusted Accumulated Capacity values. The last column shows the status of storage depletion, progressing from the original bottom of reservoir. It is column 15 divided by column 8.

Sedimentation Information Curves

Tables similar to table 1 were prepared for each pond and results were utilized in plotting sedimentation and capacity curves. Depths, capacities, sediment volumes, and storage depletion information were plotted in percentages so that the curves on one pond could be compared with those of another. A set of the following three curves was prepared on a single sheet of graph paper for each of the ponds.

A. Original stage-capacity showing the capacities at the date of construction.

B. Sediment distribution developed from the changes in reservoir capacities between the time of construction and sedimentation surveys.

C. Storage depletion shown as capacity replaced by sediment.

A set of these curves provides a great deal of information on the sedimentation history and distribution in the reservoir. Pond No. 35-4 is again used as an example (see figure 2).

The original stage-capacity curve shows, as an example, that about 20 percent or 5.65 ac.-ft. of the original capacity were located in the bottom 50 percent or 7.5 ft. of the reservoir. Of course, the more horizontal a segment of this curve is, the more capacity there is available within the given segment of depth.

The sediment distribution curve shows the location of trapped sediment in the reservoir as of the date of the sedimentation survey - April 1949. This shows, as an example, that about 73 percent of the sediment in the reservoir is located below the principal spillway. The flatter segments indicate the elevations between which the highest percentages of the sediment have been deposited. Only 10 percent of the sediment is located in the upper 32.5 percent of the reservoir.

COMPUTATIONS OF: G.&A. EVERS, Lower 35-4 ~ Remaining Capacities ~ TABLE I

Sediment Distribution Project ~ Missouri Basin Loess Hills ~ Sedimentation Section – Lincoln, Neb.

	ORIGINAL SURVEY 12/1938								1st SURVEY 4/1949							
Elev. ft	Diff. in Elev. (L)	% of Total Depth	Contour Area "A" (Acres)	Contour Area "B" (Acres)	Volume Between Contours (A.F.)(V)	Accum. Capacity (A.F.)	Adj. Accum Cap A.F.	Cap. in %	Contour Area "A" (Acres)	Contour Area "B" (Acres)	Volume Between Contours (A.F.)(V)	Accum. Cap. (A.F.)	Adj. Accum Cap (A.F.)	Accum. Sediment Volume (A.F.)	% Total Sediment 1949	% Accum Orig Cap Occupied by Sed.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
91.8		0.00	0													
	0.2				0.007											
92		1.33	0.106	0.106		0.007	0.01	0.04						0.01	0.01	100.00
	2.0				0.516											
94		14.67	0.450	0.450		0.523	0.51	1.80						0.51	6.99	100.00
	2.0				1.209											
96		28.00	0.774	0.774		1.732	1.68	5.94						1.68	23.01	100.00
	2.0				2.051											
98		41.34	1.299	1.299		3.783	3.66	12.95						3.66	50.14	100.00
	2.0				3.074											
98.4									0			0				
	0.6										0.089					
99									0.445	0.445		0.089	0.14			
	1.0										0.718					
100		54.67	1.788	1.788		6.857	6.63	23.46	1.031	1.031		0.807	1.26	5.37	73.56	81.00
	2.0				4.480						3.321					
102		68.00	2.725	2.725		11.337	11.11	39.31	2.383	2.383		4.128	4.51	6.60	90.41	59.41
	2.0				6.119						5.768					
104		81.34	3.407	3.407		17.456	17.23	60.97	3.416	3.416		9.896	10.16	7.07	96.85	41.03
	2.0				7.549						7.559					
106		94.67	4.155	4.155		25.005	24.78	87.69	4.155	4.155		17.455	17.56	7.22	98.90	29.14
	0.8				3.474						3.474					
106.8		100.00		4.532		28.479	28.26	100.00		4.532		20.929	20.96	7.30	100.00	25.85

Formula Used: $V = \frac{L}{3}(A + \sqrt{AB} + B)$

Adjustment Factors:

$\frac{6.63}{6.857} = 0.96689$

$\frac{28.26 - 6.63}{28.479 - 6.857} = \frac{21.63}{21.622} = 1.00036$

$\frac{1.26}{0.807} = 1.56133$

$\frac{20.96 - 1.26}{20.929 - 0.807} = \frac{19.70}{20,122} = 0.97902$

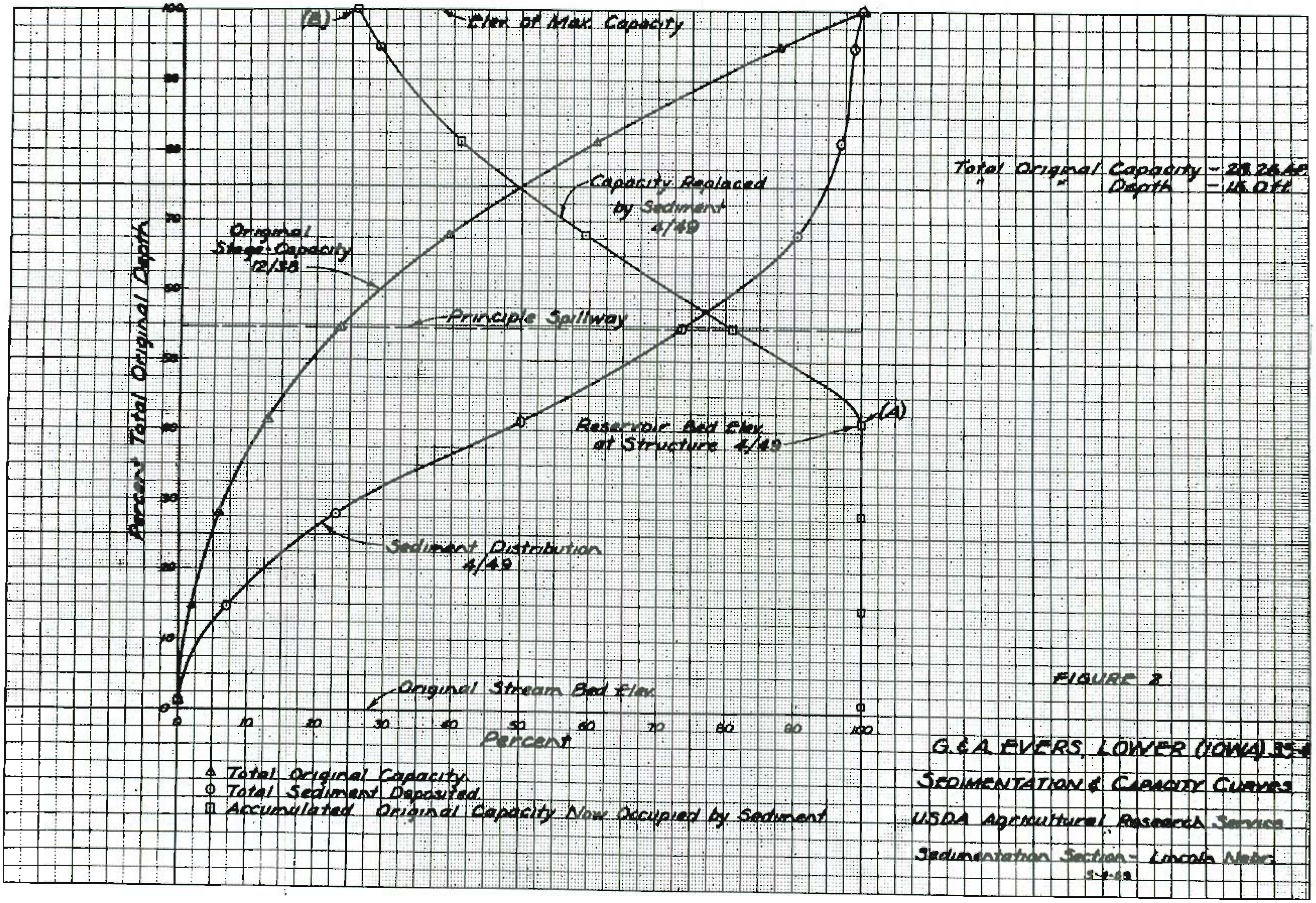

FIGURE 2

G. & A. EVERS, LOWER (IOWA) 35-

SEDIMENTATION & CAPACITY CURVES

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5-4-53

The capacity replaced by sediment curve shows, in effect, the percent of storage depletion up to a given elevation. In this pond, 100 percent of the storage in the bottom 41 percent of the reservoir depth was depleted by sediment as of the survey date. This means that the bottom of the reservoir is now 41 percent x 15 feet or over 6 feet higher than it was originally. The total capacity lost to the elevation of maximum capacity is about 26 percent.

If the original stage-capacity and capacity replaced by sediment curves are available, the sediment distribution can be computed. If the original stage-capacity and sediment distribution curves are available, plus the total sediment volume, the capacity replaced by sediment can be computed. If more than one sedimentation survey was made on a pond, additional sediment distribution and capacity replaced by sediment curves were plotted for the additional surveys. Figures 6 to 28, inclusive, in the appendix show the 23 sets of curves for the ponds studied.

Data Tables

An attempt to obtain a quantitative value or measure of every sedimentation, reservoir, and watershed parameter believed to have an effect on sediment distribution was not completely successful. Considerable information, however, was collected or computed and recorded in appendix tables 6-1 to 6, inclusive.

Reservoir Capacity and Sediment Information

The data summary sheet referred to in column 1 of Table 6-1 is the Reservoir Sedimentation Data Summary Sheet compiled by the member agencies of the Subcommittee on Sedimentation, Federal Inter-Agency River Basin Committee (4). Column 9 includes the total storage capacity at the date being considered up to the elevation of maximum capacity. In this report, this is the elevation of the emergency spillway or of the critical storage elevation when there is no emergency spillway. Column 12 of this same table is the percentage of the total available storage capacity that is located above the principal spillway or between spillways. Column 16 is not adjusted for trap efficiency, nor is the negligible amount of sediment which is located above the elevation of maximum capacity included at any time.

Reservoir Data

Column 18 is the surface area at the elevation of maximum capacity. The length of reservoir, column 19, was determined by measurement on the contour map of the distance from the dam up the valley to the most distant point at the elevation of maximum capacity.

Column 20 is the slope of the plottings on log-log paper of the original depth versus capacity. It is a topography factor. It can be determined for a reservoir site as follows:

a. Using log-log paper, plot the reservoir depths as the ordinates (Y axis) versus the reservoir capacities as the abscissas (X axis).

b. Draw a straight line through these points.

c. Determine the slope of the line using a scale rather than reading measurements in log units. The slope is the "n" value.

This parameter was originally used by Sutherland (11) to type reservoirs as to shape. The Sedimentation Section (9), Borland and Miller (1), and Van't Hul (12) of the Bureau of

Reclamation used this factor in their work on distribution of sediment. They classify reservoirs as follows:

"n" Value	Reservoir type	Standard classification
0.22 to 0.28	Lake	I
.28 to .40	Floodplain-foothill	II
.40 to .67	Hill	III
.67 to 1.00	Gorge	IV

Column 21, reservoir shape factor, is the circularity factor developed by Miller (8). He defines it as the ratio of basin area to the area of a circle having the same perimeter. He states that "A circle provides maximum area with minimum perimeter whereas a long, narrow drainage basin will have a large perimeter but a small area. An index of drainage basin circularity affords a quantitative basis for comparison of the form of basins . . ." Melton (7) also discusses this factor. In this column, however, the factor designates the circularity of the water surface in the reservoir at the elevation of maximum capacity.

Column 22 does not include the reservoir area. It is the net sediment contributing area. The capacity-watershed ratio, column 23, is for the entire storage, not that between spillways or above the principal spillway alone. The area described in column 22 was used in this ratio. Column 24 is the lowest reservoir elevation given in the reservoir sedimentation survey field notes. Column 28, detention time, may not be a very reliable figure as several different methods were used in determining the values. It is the estimated length of time required to pass the runoff from a 50-year storm through the principal spillway. Although detention time is an important factor for small reservoirs in most areas, it is not too significant in this instance because of the highly flocculating nature of the sediment entering the reservoirs studied.

Watershed Data

Column 29, basin length, is the measured distance, on a drainage area map, from the dam up the valley to the most distant point. Column 30 is the circularity factor explained for column 21, except that in this column the factor designates the circularity of the entire drainage area. The area of the reservoir was included in the area of the watershed. Time of concentration, column 31, is the estimated time required for runoff to reach the reservoir area from that point in the watershed requiring the longest time. Because of changes between surveys in slopes, additions of terraces and diversions, this factor was not studied any further.

It was believed necessary to include parameters of rainfall or runoff to arrive at some indication of water stage in these small reservoirs. Runoff, however, was deleted from further consideration after inspection of available records on small watersheds in this area. Adequate precipitation records are available for this area so these were scrutinized. For this study it was assumed that runoff does not take place until there has been at least a half inch of rainfall during the rainfall event. Column 32 is the total number of these events between the date of construction and the date of the last sedimentation survey. Column 33 is the total amount of precipitation occurring during those events which exceeded 0.5 inch during the period of study of the pond.

Analyses of Data

Two approaches were used in the analyses of the data. These are the graphical and statistical methods.

The graphical approach was used principally to determine the relationship between various parameters and also as an aid in determining their importance as independent variables. Approximately 35 such relationships were investigated. A few of these will be discussed later in this report.

Multiple regression methods were used to evaluate parameters that appeared to have an influence on the dependent variable. Ezekiel (3) and Snedecor (10) discuss these methods. Table 2 gives the values of the variables used in the multiple regression.

TABLE 2.--Variables considered in regression analyses.

Summary Sheet No.	Name	Date	Percent orig. res. depth filled with sediment	Total orig. storage depletion, percent	Orig. "n" value	Remaining storage capacity acre-feet	Sed. sample volume wt. pounds per cubic feet	Orig. C/W ratio acre feet per square mile
			Y	D	n	C	w	C/W
31-2	Chinquist	5/49	55.3	48.27	0.47	8.52	50.0	92.50
31-3	Fuelling	5/49	59.3	51.14	.37	33.50	62.9	65.93
35-1	Baak	4/49	36.5	25.12	.38	16.81	54.8	142.99
35-2	Brown	5/49	51.6	34.06	.49	15.12	63.8	236.39
35-3	Esbeck	5/49	51.3	43.68	.49	11.19	56.1	97.40
35-4	Evers, Lower	4/49	41.8	25.83	.41	20.96	68.4	217.38
35-5	Evers, Upper	4/49	71.6	63.50	.46	1.19	71.6	74.10
35-6	Fienhold	4/49	52.2	36.08	.47	17.45	63.1	64.24
35-7	Gadd	5/49	20.8	11.46	.49	12.82	63.0	183.30
35-7	do	6/52	32.3	17.27	.49	11.98	57.3	162.30
35-8	Goslar	3/49	30.5	13.81	.41	11.80	69.1	95.07
35-10	Hollrah	3/49	27.6	17.03	.42	31.14	57.6	172.90
35-12	LaFrontz	4/49	37.7	32.07	.44	10.38	56.4	100.50
35-12	do	7/53	51.5	38.02	.44	9.47	62.0	68.30
35-13	Jensen-O'Neil	11/48	23.8	24.28	.40	31.18	54.7	213.37
35-14	Peterson	11/48	56.9	55.04	.47	1.74	61.0	52.30
35-15	A. Lage	4/49	32.8	23.77	.42	8.56	54.0	58.80
35-15	do	6/52	46.3	36.42	.42	7.14	53.3	44.81
35-16	H. Lage	4/49	4.0	10.44	.62	10.81	55.1	335.28
35-16	do	6/52	13.2	25.77	.62	8.96	49.3	300.28
35-17	Mattson	4/49	33.9	23.60	.48	12.56	69.0	167.75
35-17	do	7/53	62.0	45.80	.48	8.91	87.1	128.16
35-18	Meyer	4/49	21.8	14.77	.37	37.33	58.0	149.49
35-18	do	6/52	39.4	20.94	.37	34.63	63.6	127.41
35-19	Miller No. 1	5/49	30.6	26.79	.51	35.75	64.9	223.99
35-19	do	6/52	41.8	34.26	.51	32.10	69.5	163.99
35-20	Miller No. 5	5/49	40.2	21.15	.42	41.94	69.2	233.99
35-20	do	6/52	41.0	22.81	.42	41.06	73.1	183.95
35-21	Mundt	4/49	40.0	28.04	.36	33.08	54.0	139.30
35-21	do	6/52	50.8	36.44	.36	29.22	53.3	100.24
35-22	North	3/49	25.4	17.68	.41	40.04	52.4	204.37
35-22	do	7/53	36.4	23.09	.41	37.41	56.5	168.24
36-2	Stiles	9/50	7.0	11.41	.43	69.10	47.3	136.34
36-2	do	2/53	10.2	13.20	.43	67.70	57.8	120.79

Since one of the primary reasons for needing information on sediment distribution is to aid in establishing the minimum elevation of the principal spillway, the dependent variable must provide a means of obtaining that elevation. In this study, the dependent variable is the rise in the original lowest reservoir bed elevation because of sediment accumulation and is expressed as the percent of the maximum original reservoir depth at the dam at the time of the sedimentation survey. This provides a basis for predicting the minimum elevation of the principal spillway at the end of the design life. The dependent variable "Y", percent original reservoir depth filled with sediment, was obtained from the capacity replaced by sediment curves of figures 6 to 28. This figure was read from the percent of total original depth ordinate at the highest point where capacity replaced by sediment was 100 percent.

The independent variable "D", total original storage depletion, is column 17 of table 6. It is the percent of the original reservoir capacity filled with sediment as of the date being considered. Variable "n" is the same as column 20 of table 6 and has been explained. Variable "C", total storage capacity, is the same as column 9.

Variable "w", sediment sample volume weight, is column 8 of table 6. It is the arithmetic average of the volume weights of sediment samples taken at the time of the sedimentation survey. These samples were obtained above and below the water level, throughout the sediment depth. The volume weight of incoming sediment is an important factor in the deposition location. The average volume weight of deposited sediment is usually increased with greater depth, and with repeated wetting and drying of sediment. Attempts were made to obtain data on other parameters of the sediment, such as mean particle size and particle size distribution, but they were not available.

Variable "C/W" is column 23 of table 6 and is expressed in acre feet per square mile. This parameter is the storage capacity divided by the contributing drainage area.

RESULTS

Regression Analyses

Regression analyses were run on 12 combinations of the 5 independent variables to determine the best combination for computing the dependent variable. Table 3 summarizes these regression equations and indicates the ability of each.

TABLE 3.--Efficiency of regression equations.

[Dependent variable: Y, percent of original reservoir depth filled with sediment. Independent variable: D, total original storage depletion, in percent; n, original "n" value; C, total storage capacity, in acre-feet; w, sediment sample volume weight, in lb. per cubic ft.; C/W, capacity watershed ratio, in acre-feet per square mile.]

Equation number	Dependent variable	Independent variable	Multiple correlation coefficient R	Coefficient of determination R^2	Degrees of freedom	Standard error of estimate
						Percent
1	Y	D	0.883	0.78	32	7.66
2	Y	D n	.909	.83	31	6.73
3	Y	D n C	.919	.84	30	6.34
4	Y	D n w	.942	.89	30	5.39
5	Y	D n C/W	.906	.82	30	6.83
6	Y	D C w	.907	.82	30	6.77
7	Y	D n C w	.953	.91	29	4.88
8	Y	D n C C/W	.918	.84	29	6.37
9	Y	D n w C/W	.940	.88	29	5.47
10	Y	D C w C/W	.919	.84	29	6.35
11	Y	n C w C/W	.758	.58	29	10.50
12	Y	D n C w C/W	.952	.91	28	4.95

Equation 1 in table 3 has but one independent variable, total original storage depletion in percent. The correlation coefficient, R, is 0.883 and the coefficient of determination, R^2, is 0.78. This is a high coefficeint and it means that storage depletion is a very important factor in predicting Y. In fact, 78 percent of the variations in Y are explained by variations in D. The degrees of freedom associated with this equation are 32. The last column shows that the standard error of estimate is 7.66 percent.

The other equations in table 3 have additional independent variables or combinations of them. These equations constitute an attempt to secure the best one for determining the dependent variable Y. The ability of each is shown, indicating little difference between 7 and 12. Equation 7 is the most efficient one, however, having $R^2 = 0.91$. It has one more degree of freedom and slightly better confidence limits than equation 12.

Table 4 shows 12 complete equations. All of them are valid and can be used to compute the dependent variable. However, equation 7 is the most desirable, as shown in table 3.

TABLE 4.--Regression equations.

Equation number	Equation
1	$Y = 7.12 + 1.06\ D$
2	$Y = 34.1 + 1.07\ D - 60.8\ n$
3	$Y = 50.0 + .957\ D - 79.8\ n - .183\ C$
4	$Y = 7.03 + .982\ D - 63.1\ n + .500\ w$
5	$Y = 34.2 + 1.09\ D - 65.4\ n + .008\ C/W$
6	$Y = -18.9 + .974\ D - .0263\ C + .483\ w$
7	$Y = 22.6 + .886\ D - 81.2\ n - .175\ C + .494\ w$
8	$Y = 51.9 + 1.00\ D - 92.7\ n - .199\ C + .020\ C/W$
9	$Y = 6.61 + .980\ D - 60.8\ n + .506\ w - .00403\ C/W$
10	$Y = -11.1 + .841\ D - .042\ C + .526\ w - .042\ C/W$
11	$Y = 37.7 - 54.8\ n - .392\ C + .763\ w - .086\ C/W$
12	$Y = 23.6 + .903\ D - 85.8\ n + .181\ C + .487\ w + .00711\ C/W$

Statistical data on the most efficient regression, equation 7, are presented in table 5. The equation itself is reproduced in the vertical in the first two columns. All four of the independent variables in this equation are significant at about the 1 percent level or less. This is determined from the ratio of b divided by Sb and a probability table on the distribution of t, such as found in Snedecor (10). The significance at the 1 percent level means that if additional reservoirs were studied independently, in 99 out of 100 cases it would be expected that the importance of each variable would again be established.

Variable D, total original storage depletion, has the highest simple correlation with the dependent variable Y. Variables C and w are next and about equal in importance. The simple correlation is a correlation between the dependent variable and the individual independent variable, with the influence of the other variables still present. In the partial correlation, the influence of each independent variable on the dependent is isolated by holding constant the effects of the other variables. This, therefore, is a measure of the relationship without the interaction of other variables. In this column, D again is most

TABLE 5.--Statistical data on most efficient regression, equation 7.

Partial regression coefficient b	Variable			Standard error, Sb of partial regression coefficient	Ratio b/Sb	Correlation with dependent variable Y		Beta Coefficient
	Symbol	Name	Units			Simple	Partial	
	Y equals	Orig. res. depth filled with sediment	Percent					
0.886	D	Total original storage depletion	Percent	0.0628	14.112	0.88	0.90	0.74
-81.2	n	Original "n" value	--	15.133	5.368	-.22	-.69	-.30
-.175	C	Total storage capacity	Acre-feet	.0638	2.749	-.46	-.43	-.18
.494	w	Sediment sample volume weight	Lb/Cu. Ft.	.1059	4.664	.45	.64	.25
	+22.6	(Constant)						

important, followed by n, w, and C in that order. The mathematical signs before the values in the simple and partial correlation columns indicate the slope of the curve showing how the dependent variable changes with increases in the independent variable. The beta coefficient is another measure of the value of each of the variables. It is a measure of the effect that one standard error in the independent variable will have on the dependent variable.

Using equation 7 and actual field data, the dependent variable, percent original reservoir depth filled with sediment, was computed. When this variable is converted from percent to feet, it establishes the minimum elevation of the principal spillway. This dependent variable was compared with the actual Y and the points plotted in figure 3. Departures of the points from the solid line are caused by other independent variables and parameters not included in the final equation.

Graphical

In addition to the above regression analyses which were used to derive an equation for establishing the minimum elevation of the principal spillway, several other relationships were found that are of value in this study on sediment distribution. Figure 4, remaining storage-depth ratio curve, shows the relationship between the percent of the total remaining storage that exists between spillways (column 12 of table 6) and a depth ratio of (principal spillway elevation minus lowest reservoir bed elevation) divided by (elevation of maximum capacity minus lowest reservoir bed elevation). Of course, this curve is not applicable when all of the remaining storage is located above the crest elevation of the principal spillway. The coefficient of determination, r^2, for this curve is 0.95. The equation is, Y = square root of (11,140 - 11,860X). An attempt was made to improve the determination for Y, percent of total remaining storage existing between spillways, by adding other independent variables and making a multiple regression analysis. This attempt was not successful.

As mentioned previously in the discussion of the sedimentation information curves, if the original stage-capacity and capacity replaced by sediment curves are available, the sediment distribution can be computed. In order to obtain a point for assistance in plotting the curved part of the capacity replaced by sediment curve, an effort was made to determine the midordinate of this curve. The length of a straight line between the reservoir bed elevation (at the time of the sedimentation survey) and the point at the elevation of maximum capacity (on the capacity replaced by sediment curve) were measured on figures 6 to 28. On figure 2, this is from point A to point B. The scale used for this measurement was the same as the scales used in these figures. The straight line was drawn in and a perpendicular line constructed at the midpoint. This perpendicular line was extended until it intersected the curved part of the capacity replaced by sediment curve. This perpendicular line (midordinate) was measured and assigned a positive sign if the midordinate extended to the left and below the straight line, and a negative sign if the midordinate extended to the right and above the straight line. A curve showing the relationship between the length of the straight line and the length of the midordinate is shown in figure 5. The equation of this curve is $Y = 0.002849X^{1.894} - 10$, and the coefficient of determination $r^2 = 0.77$. Attempts were made to improve the determination of the midordinate by adding other independent variables and making a multiple regression analysis. These attempts did not improve on the graphic solution shown in figure 5.

DISCUSSION

This is a study of a sediment distribution in some small reservoirs in the Missouri Basin loess hills. The study has been made to establish procedures for predicting (1) the elevation of sediment accumulation immediately upstream of a dam and (2) the distribution of sediment within the reservoir area.

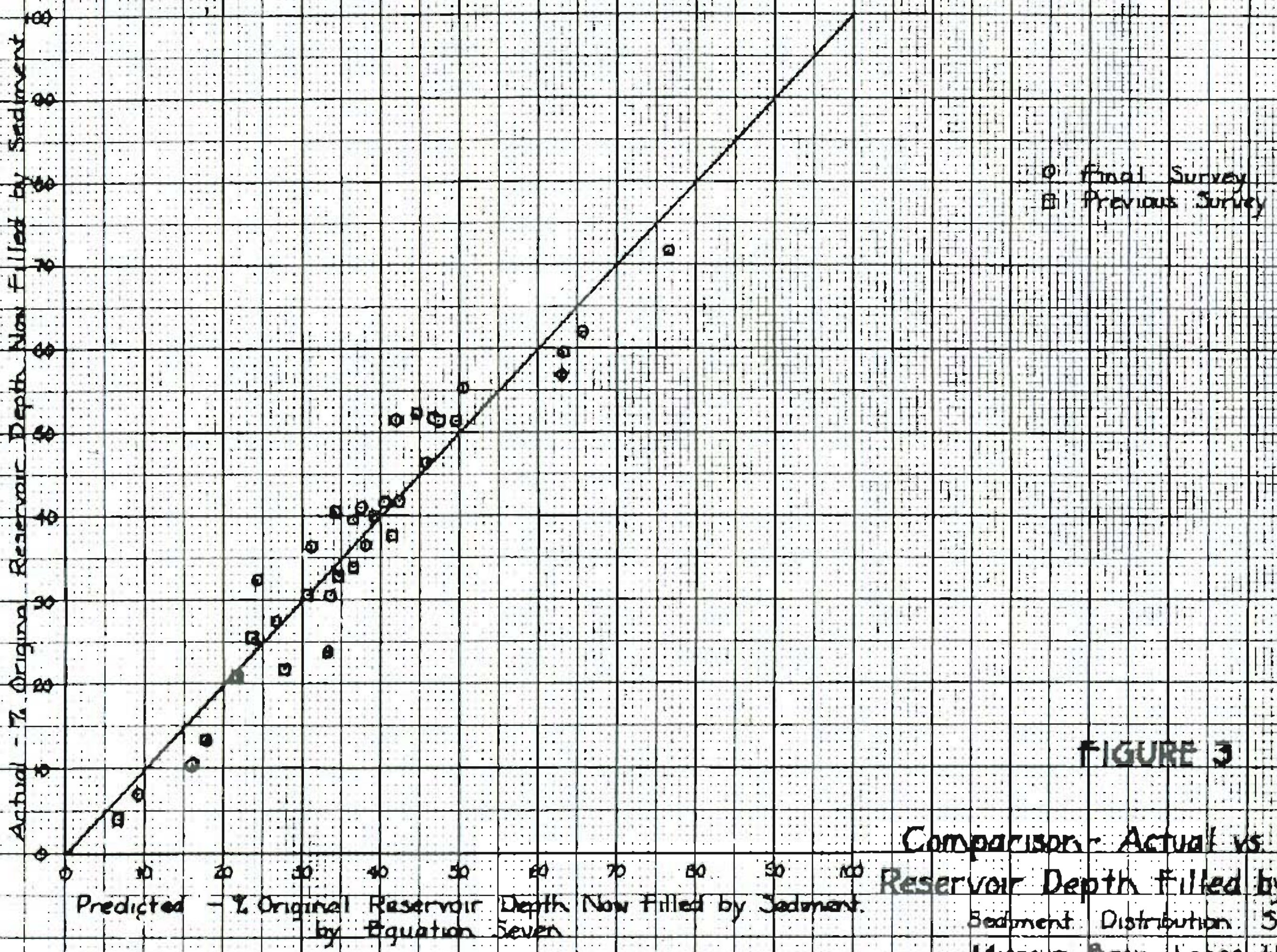

FIGURE 3

Comparison - Actual vs Predicted
Reservoir Depth Filled by Sediment
Sediment Distribution Study
Missouri Basin Loess Hills
Sedimentation Section - Lincoln, Nebr.
7-30-59 CLM

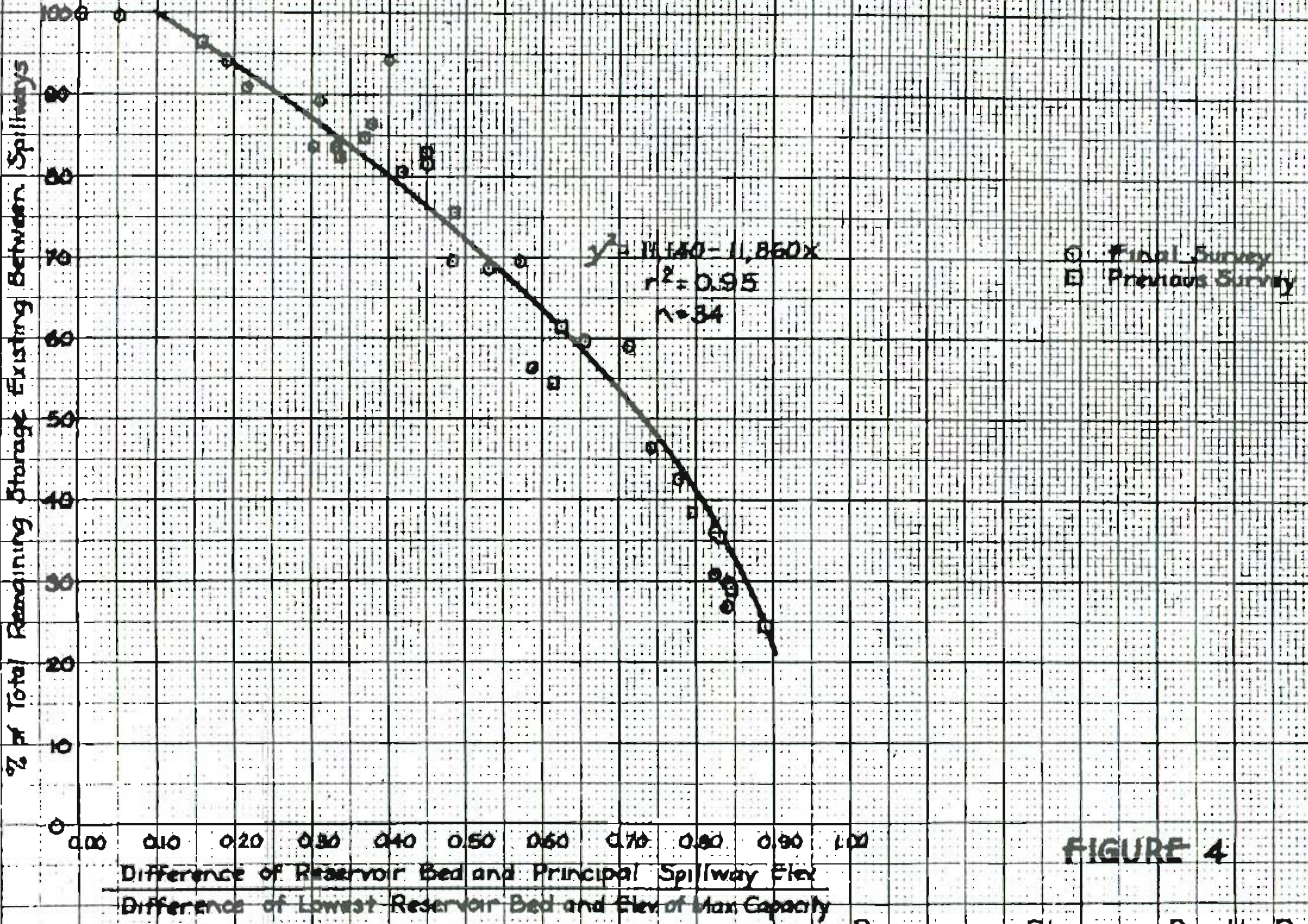

FIGURE 4

Remaining Storage - Depth Ratio Curve
Sediment Distribution Study
Missouri Basin Loess Hills
Sedimentation Section - Lincoln, Neb.
7-30-58 [illegible]

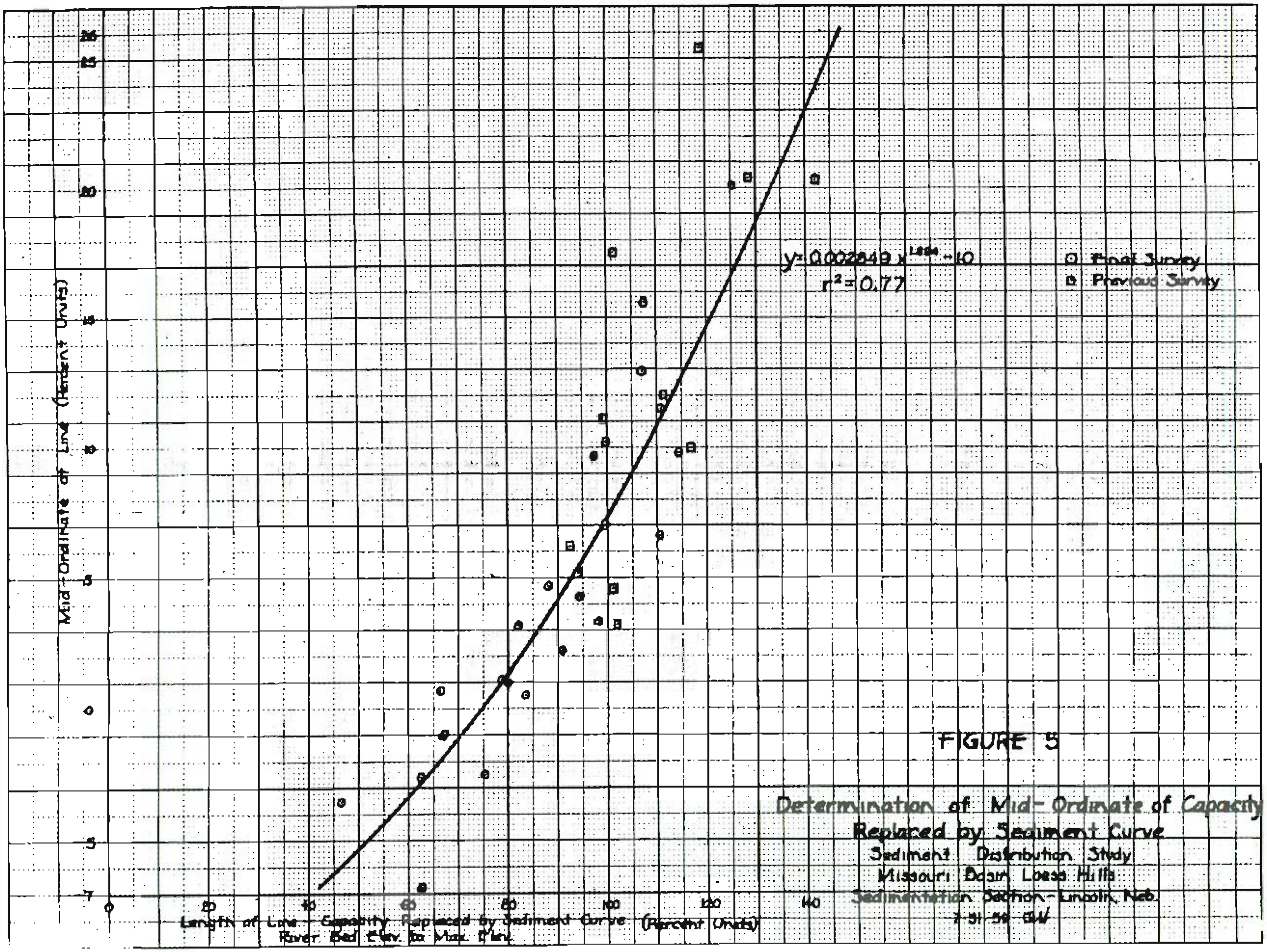

FIGURE 5

Determination of Mid-Ordinate of Capacity
Replaced by Sediment Curve
Sediment Distribution Study
Missouri Basin Loess Hills
Sedimentation Section - Lincoln, Neb.
7-31-56 GW

The data on the 23 ponds and reservoirs used in this study are believed to be generally good. The results, having been determined by accepted procedures, should then be very reliable within the stated limits for each solution.

Sedimentation Information Curves

The sedimentation information curves, figures 6 to 28, inclusive, are an excellent way to show the sediment history and distribution for a pond or reservoir. In these curves, original capacity, sediment distribution, and storage depletion are related to the original total depth with all values being converted to percent of total. With units in percent, the curves for one pond can be compared readily with those for another pond. It was hoped that a comparison of the shapes of these curves would provide a basis for separating the ponds into different groups, but no such basis was found.

A study of these curves reveal that the stage-capacity curves for all ponds are almost identical. There is very little difference between them probably because all ponds are located in one general problem area.

The sediment distribution curves are occasionally erratic at low degrees of storage depletion, but they usually become more uniform as additional sediment is deposited in the pond. As the pond fills up with sediment, this curve approaches the stage-capacity curve. Since the storage capacity at low elevations is restricted by the channel topography, the sediment volume at low elevations is also restricted. The sediment distribution curve at the lower elevations for later surveys always falls between the curve for earlier surveys and the stage-capacity curve. This is because the sediment at this elevation becomes a smaller percentage of the total. The sediment distribution curve is not affected abruptly at the principal spillway as was originally presumed. The flatter, more horizontal segments of these curves indicate the elevations between which the highest percentages of sediment are deposited. The more vertical segments indicate segments of lower percentages of sediment accumulation.

The capacity replaced by sediment curves, or storage depletion, show the percent of accumulated original capacity to any percent of depth, now occupied by sediment. The highest percent of depth, which has 100 percent of its capacity replaced by sediment, is the elevation of the stream bed or bottom of reservoir at the date of survey. As the reservoir fills up and storage depletion is greater, the reservoir bed elevation also increases. As this takes place, the distance on this curve between the reservoir bed and at 100 percent depth becomes shorter and the curve usually becomes straighter. It is believed that the curved portion of this curve can be drawn in sufficiently accurate if several points are provided.

As mentioned previously, the sediment distribution curve can be computed from the original stage-capacity and the capacity replaced by sediment curves. Use the formula, sediment distribution for a certain elevation = (value from stage-capacity curve at the elevation) x (value from capacity replaced by sediment curve at the elevation), ÷ by (total storage depletion). As an example, the sediment distribution at the 68 percent depth level on figure 2 would be $39.3 \times 59.4 \div 25.8$ or 90.5 percent.

Evaluation of Results

Data from the 34 sedimentation surveys were utilized in a multiple regression analysis to derive a method for estimating the rise in the lowest bed elevation of a floodwater-retarding reservoir due to sediment accumulation during a given period. The rise in the lowest reservoir bed elevation was expressed as the percent of the maximum original reservoir depth. Statistical data on the most efficient equation are given in table 5. The independent variables used in the equation are significant at about the one percent level, and the other tests also show that the variables are important. The coefficient of determination, R^2, for the equation is 0.91. A comparison of the actual values of the dependent variable with the computed or predicted values is shown in figure 3.

Many parameters were investigated for this study, each one of which could influence reservoir sediment deposition. Sufficient good data were not available for each item and, therefore, some were eliminated from further study. Nor did all of the parameters used in the regression analysis prove to be significant. (The data actually used in the statistical work were obtained from table 6 and figures 6 to 28 and are shown in table 2.) Some of the discarded parameters, as well as those which proved to be insignificant, however, may be the important variables in other areas of the country. Consequently, they need to be investigated further.

Relationships were also found (figures 4 and 5) that enable the drawing of capacity replaced by sediment curves. From these and other data, sediment distribution curves can be drawn.

Figure 4, remaining storage-depth ratio curve, also can be used to determine the portion of the total remaining storage that exists above the crest elevation of the principal spillway. The coefficient of determination, r^2, for this curve is 0.95, which indicates an excellent relationship. This curve cannot be used when all of the remaining storage is located above the principal spillway.

The plottings for figure 5, determination of midordinate of capacity replaced by sediment curve, show that this relationship is fairly good, the coefficient of determination being 0.77. However, when this is used with the curve described in the preceding paragraph, the results should be very good.

Application of Results

In the preceding material, an empirical procedure has been developed for determining the elevation to which sediment will accumulate immediately upstream from a floodwater-retarding structure. A procedure also has been developed for determining the distribution of sediment deposits within the reservoir created by this structure.

Assuming that the total initial reservoir capacity and stage-capacity curve have been established for such a structure and that the sediment deposition quantities and volume weight for a given design period have been determined by standard methods, these empirical procedures can be utilized in planning and/or design considerations:

a. Elevation of sediment accumulation immediately upstream from the structure--using the basic equation

$$Y = 22.6 + 0.886D - 81.2n - 0.175C + 0.494w$$

Where: Y = Percent of original reservoir depth filled with sediment.
D = Total original storage depletion in percent. This is for the end of the design period.
n = Original "n" value (slope on log-log paper of depth versus capacity).
C = Total storage capacity in acre feet. This is the estimated remaining capacity at the end of the design period.
w = Sediment sample volume dry weight in pounds per cubic feet

the percent of reservoir depth below which the initial capacity will be completely filled with sediment can be readily established. This is a guide to the minimum elevation at which the principal elevation should be placed.

b. Distribution of sediment within the reservoir--In the reservoir the sediment will encroach on the original capacity in amounts varying with elevation or stage. It may be desirable to estimate the amount of original storage depletion that is likely to occur at various reservoir elevations and time increments, particularly when more than one use for this storage capacity is involved. An approximation of this distribution can be obtained as follows:

1. Plot the original stage-capacity curve in percents, as in figure 2.

2. Plot the percent of total original depth filled with sediment as determined by the equation, for the storage depletion in which you are concerned. This is point A on figure 2.

3. Plot the storage depletion in which you are concerned at the elevation of maximum capacity. This is point B on figure 2.

4. Draw a straight line between the points (A) and (B) and find the midpoint. From the length of the straight line (using the same units of measurement) and figure 5, determine the length of the midordinate and plot it from the midpoint of the straight line. The length of the midordinate may be + or - , as described in the graphical section of this report.

5. Multiply original capacity by the storage depletion in percent and obtain the storage lost to sediment. Subtract this from the original capacity to obtain the storage capacity remaining. Using the percent of depth determined by the equation (point A of figure 2), compute the depth ratio needed in figure 4. From this ratio and figure 4 obtain the percent of the total remaining storage that exists between the spillways. This figure subtracted from 100 percent gives the percent of remaining storage located below the principal spillway. This value multiplied by the total reservoir capacity remaining (determined above) gives the acre feet capacity remaining below the principal spillway. Determine the original capacity below the principal spillway by multiplying the original capacity by the percent of the original storage below this spillway (from stage-capacity curve). Divide this original capacity into the capacity remaining (determined in the last step of the previous paragraph) to find the percent of the original storage below the principal spillway that remains. This percent subtracted from 100 percent gives the percent depletion up to the crest of the principal spillway. This computed point should be plotted at the elevation of the principal spillway. This point will be a more accurate one than that determined in step 4 and, therefore, should be given the most weight if these two points plot near each other.

6. Using the characteristic shapes of the capacity replaced by sediment curves of figures 6 to 28 as a guide and the four points established above, sketch in the capacity replaced by sediment curve.

7. Planimeter the total area above this curve and also the area outlined by this curve that is located above the elevation of the principal spillway. The percent of the total area that is located above the elevation of the spillway, determined in this manner, should approximate the percent as determined by using figure 4. This figure can only be used while capacity remains below the principal spillway. Adjust the sketched curve of step 6, if these percentage figures are far apart.

8. From this curve (step 7) capacity replaced by sediment, and the original stage-capacity curve (step 1) compute points for the sediment distribution curve. This can be done in accordance with the method described in the paragraph just prior to the section, ''Evaluation of Results.'' When sufficient points have been determined, draw in the sediment distribution curve.

SUMMARY

Considerable data were obtained on 23 small reservoirs in the Missouri Basin loess hills. Stage-capacity, capacity replaced by sediment, and sediment distribution curves were drawn for each. These curves are discussed in detail, compared with one another, and various findings pointed out.

After making numerous graphical analyses, the writer used the multiple regression method to develop an equation to predict the minimum elevation of the principal spillway for floodwarer-retarding structures. The variables used in this equation are (1) total original storage depletion, (2) original "n" value, (3) total storage capacity, and (4) sediment sample volume weight. Application of the results of the findings is suggested when sedimentation principles are the only criteria.

Curves are also presented and a description given for determining points and predicting the capacity replaced by sediment curve. A step-by-step procedure is then given for drawing a sediment distribution curve, using the capacity replaced by sediment and the original stage-capacity curves.

The material and results presented here have not been compared with or tried on the data from other areas. Therefore, these findings should be limited in application to floodwater-retarding structures in the Missouri Basin loess hills only. Furthermore, the limits of the data used in this report should be kept in mind. The material presented here should not be applied to structures having values for important parameters that are in excess of the data used herein. Additional studies are under way or planned to study sediment distribution relationships in other areas.

ACKNOWLEDGMENTS

The Soil Conservation Service, U. S. Department of Agriculture, and Iowa State University of Science and Technology were generous in their cooperation and assistance in providing the basic data. Messrs. W. J. Abrams, Paul Jacobson, and E. O. Schwab of the Soil Conservation Service were especially helpful.

Mr. Verne I. Dvorak, Hydraulic Engineer, Agricultural Research Service, directed the multiple regression analyses and provided other useful assistance whenever called upon. The writer is particularly indebted to him, and also to the University of Nebraska students employed by the Agricultural Research Service who did most of the computations.

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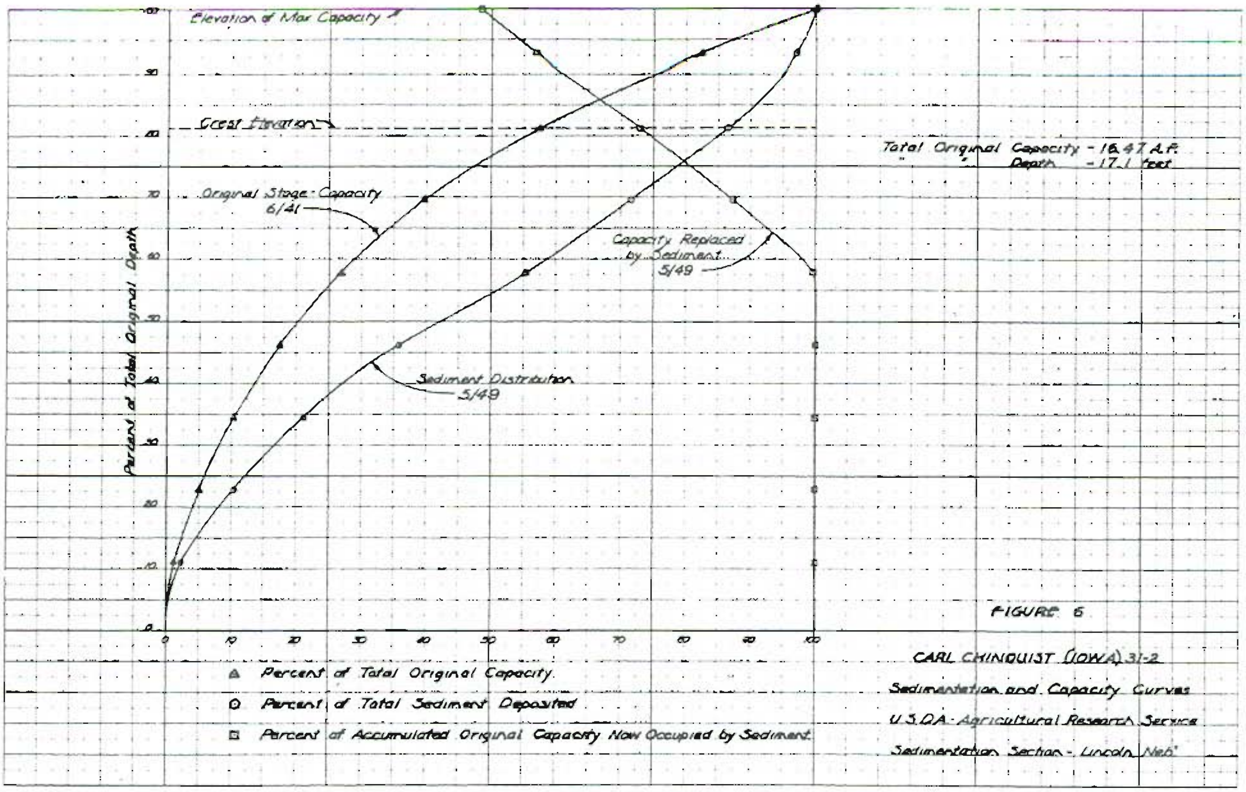


Total Original Capacity - 16.47 A.F.
" Depth - 17.1 feet

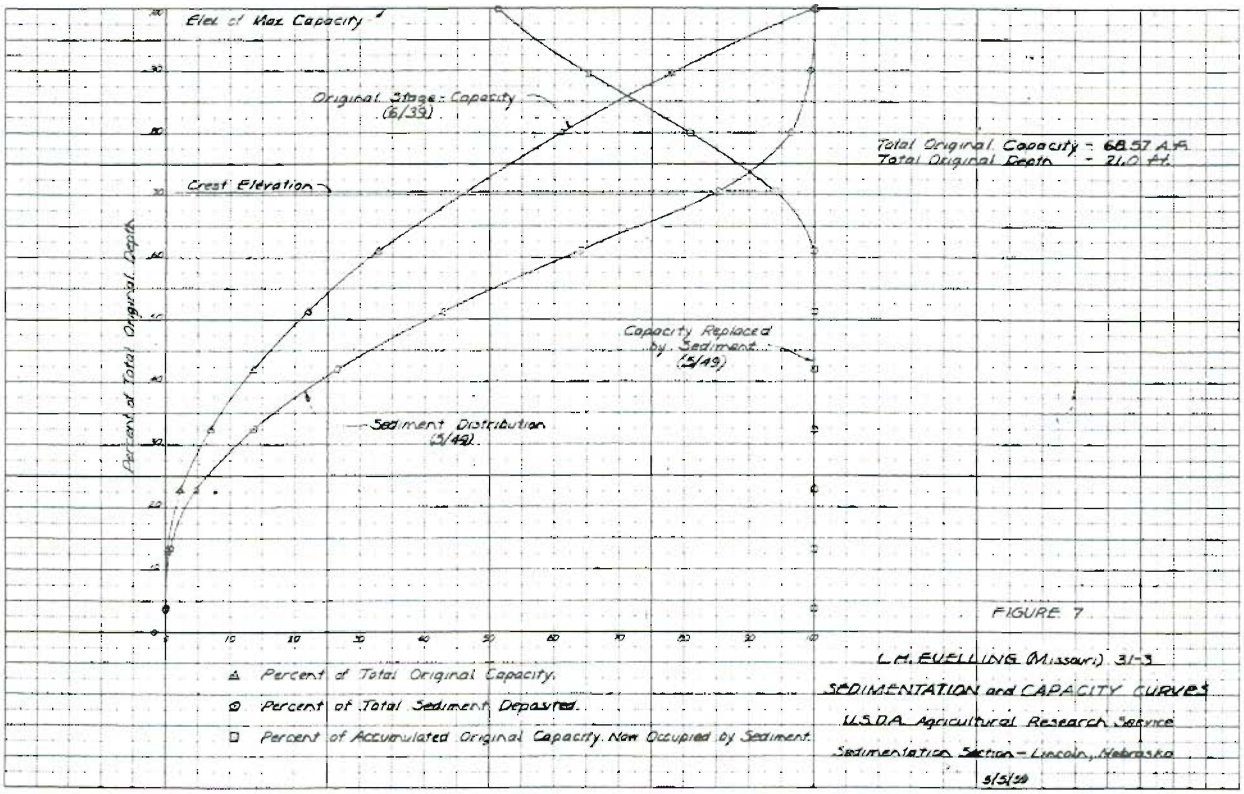
FIGURE 6

CARL CHINQUIST (IOWA) 31-2

Sedimentation and Capacity Curves

U.S.D.A.-Agricultural Research Service

Sedimentation Section - Lincoln, Neb.



Total Original Capacity - 68.57 A.F.
Total Original Depth - 21.0 ft.

FIGURE 7

L.H. EUELLING (Missouri) 31-3

SEDIMENTATION and CAPACITY CURVES

U.S.D.A. Agricultural Research Service

Sedimentation Section - Lincoln, Nebraska

5/5/59

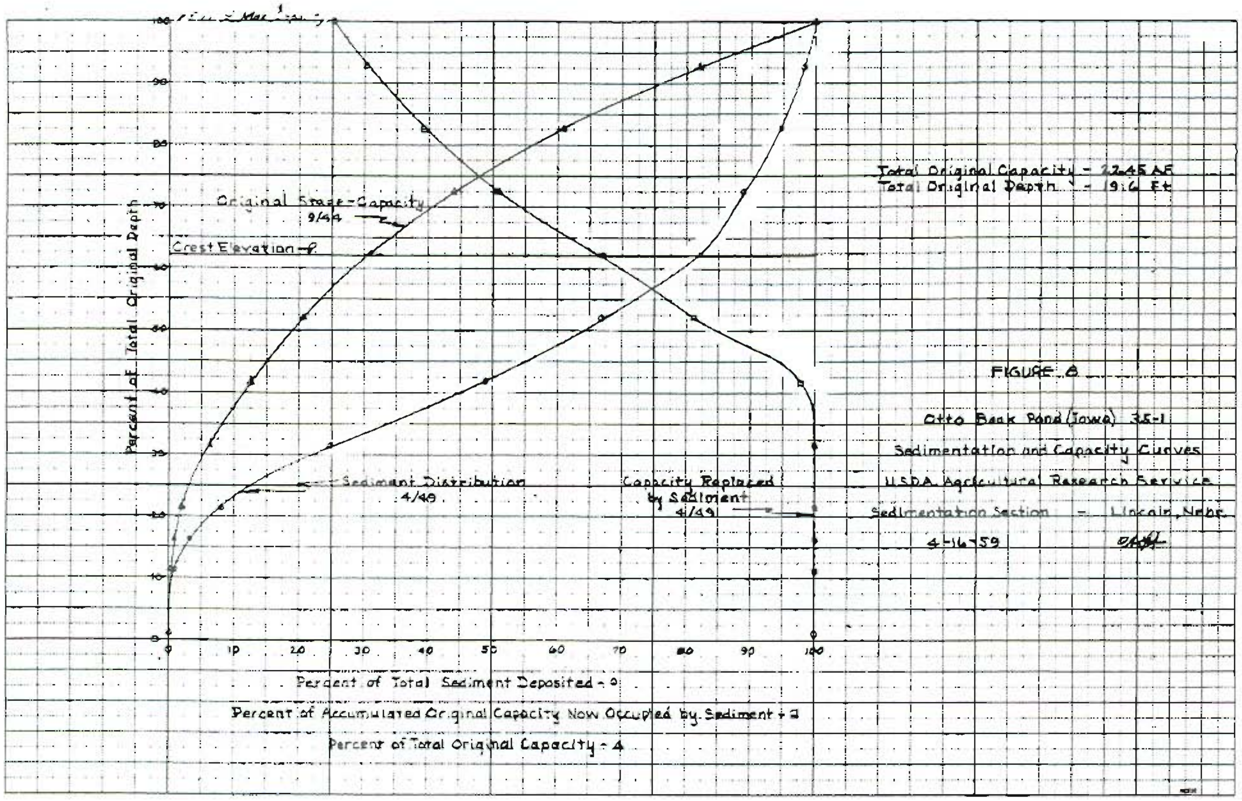


FIGURE 8

Otto Beak Pond (Iowa) 35-1

Sedimentation and Capacity Curves

U.S.D.A. Agricultural Research Service

Sedimentation Section - Lincoln, Nebr.

4-16-59

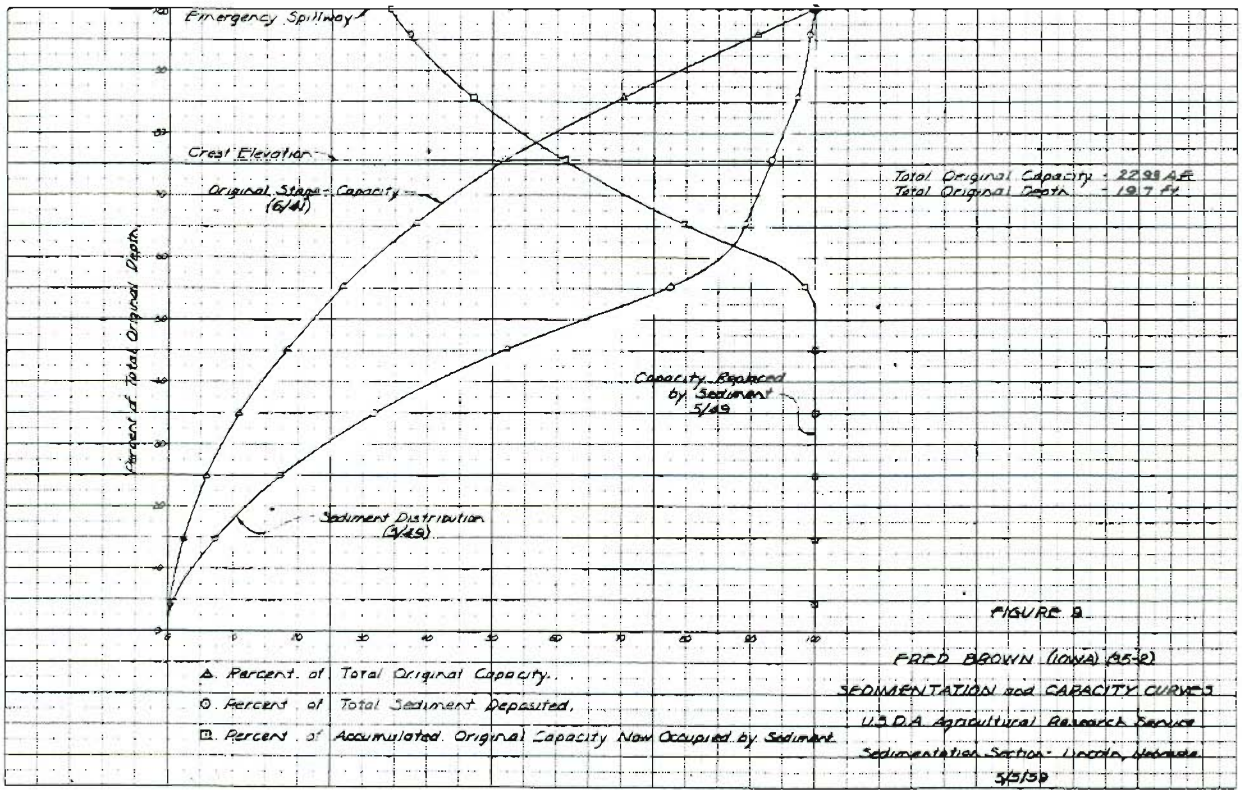


FIGURE 9

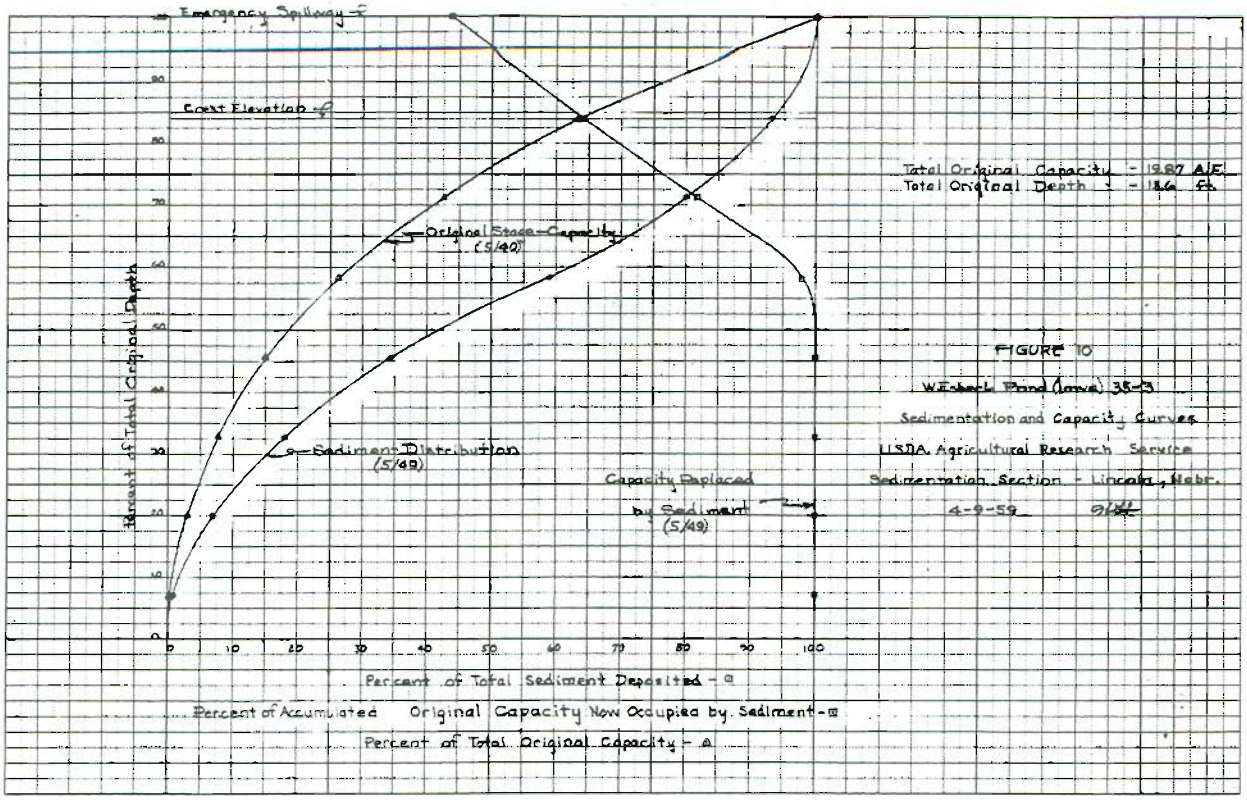
FRED BROWN (IOWA) (35-2)

SEDIMENTATION and CAPACITY CURVES

U.S.D.A. Agricultural Research Service

Sedimentation Section - Lincoln, Nebraska

5/5/59



Total Original Capacity - 19.87 A/F.
Total Original Depth - 18.6 ft.

FIGURE 10

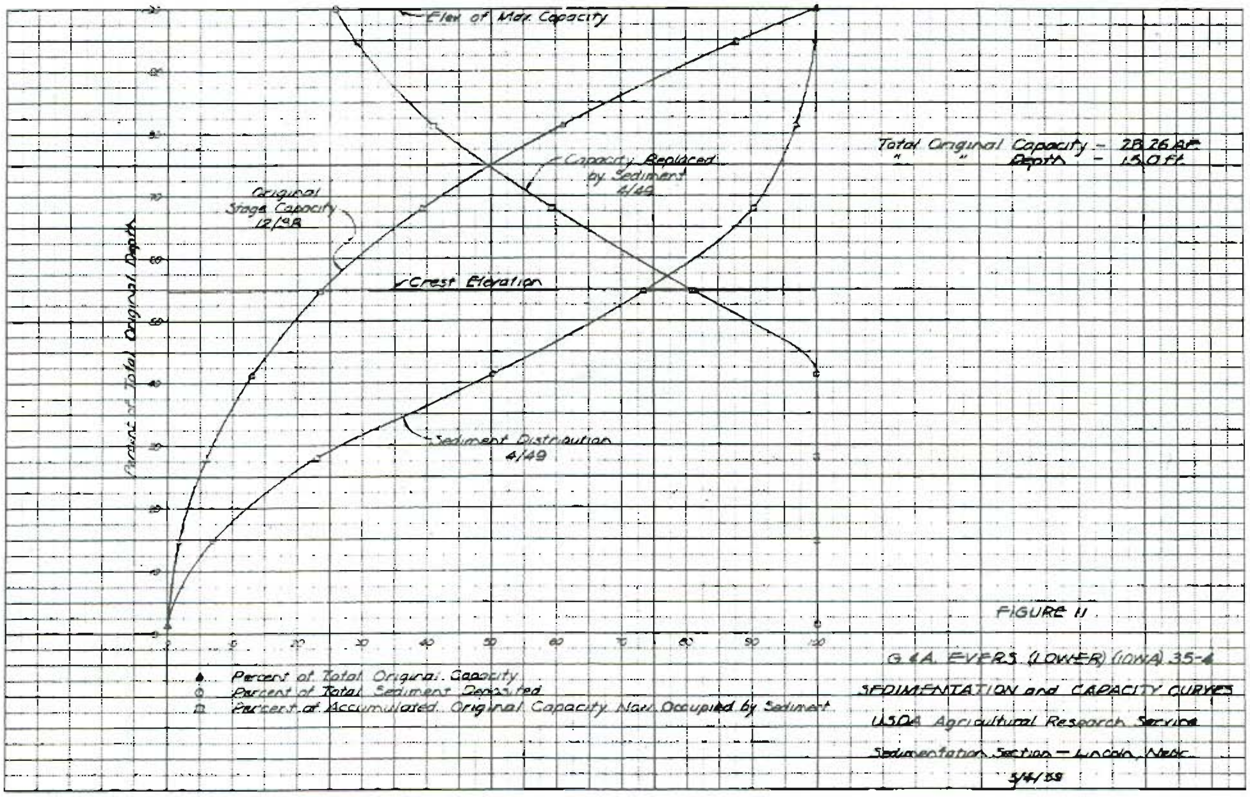
Wiesbeck Pond (Iowa) 35-3

Sedimentation and Capacity Curves

USDA Agricultural Research Service

Sedimentation Section - Lincoln, Nebr.

4-9-59 9144



Total Original Capacity - 28.26 AF
" " Depth - 15.0 Ft.

FIGURE 11

G & A. EVERS (LOWER) (IOWA) 35-4

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section - Lincoln, Nebr.

5/4/59

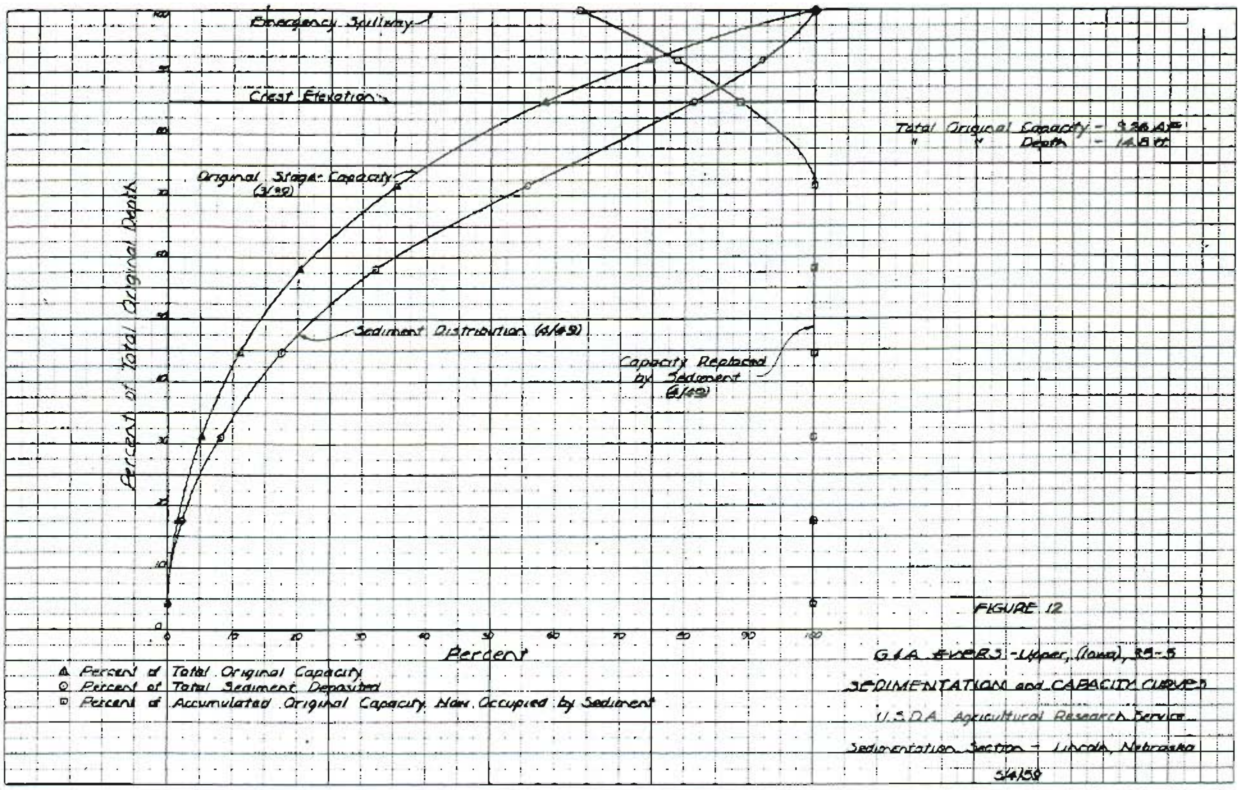


FIGURE 12

G & A EVERS - Upper, (Iowa), 35-5

SEDIMENTATION and CAPACITY CURVES

U.S.D.A. Agricultural Research Service

Sedimentation Section - Lincoln, Nebraska

5/4/59

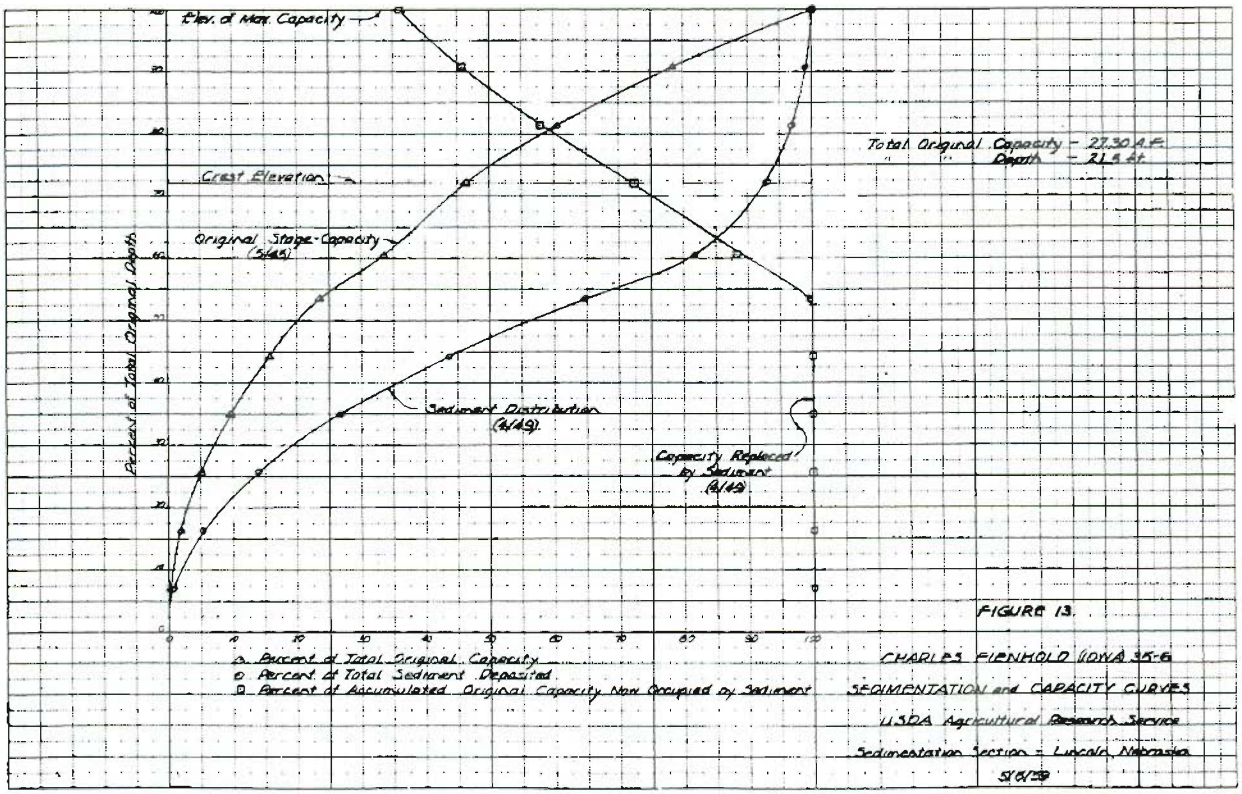


FIGURE 13

CHARLES FIENHOLD (IOWA) 35-6

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section - Lincoln, Nebraska

5/6/59

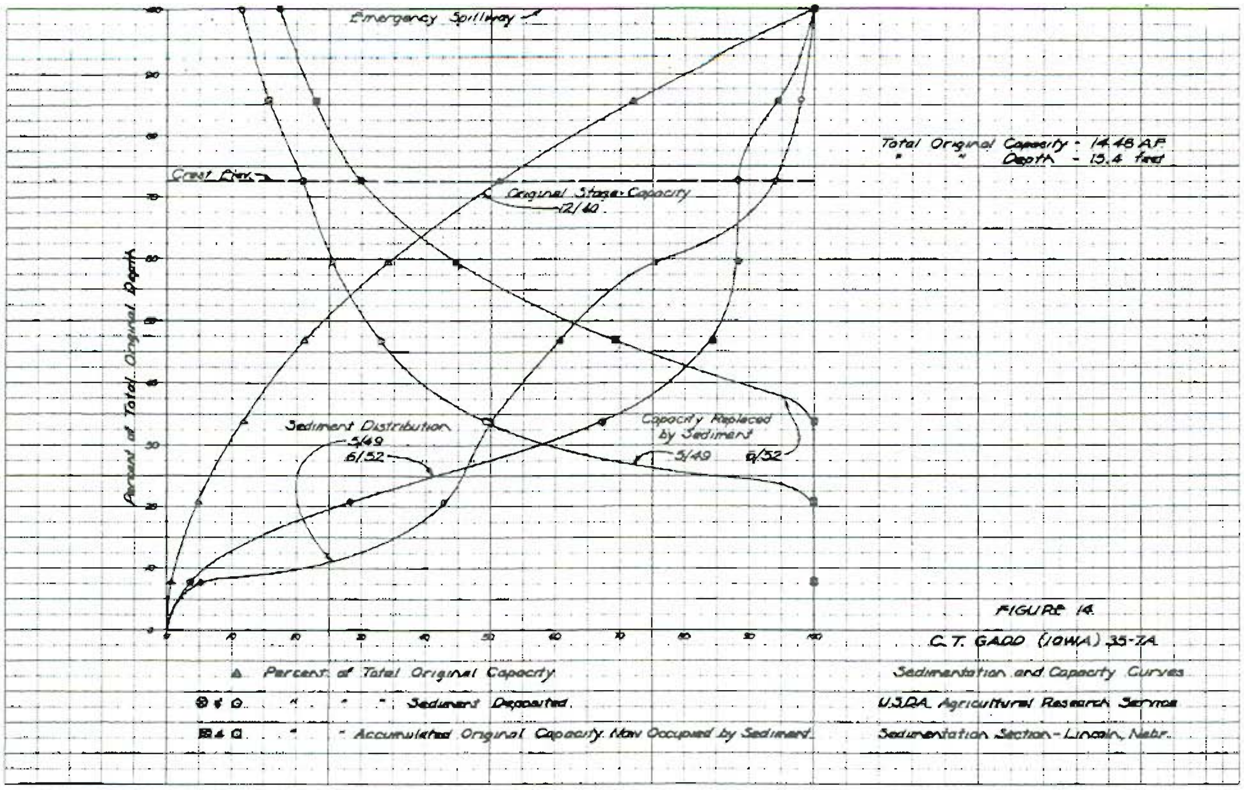


FIGURE 14

C.T. GADD (IOWA) 35-7A

Sedimentation and Capacity Curves

U.S.D.A. Agricultural Research Service

Sedimentation Section - Lincoln, Nebr.

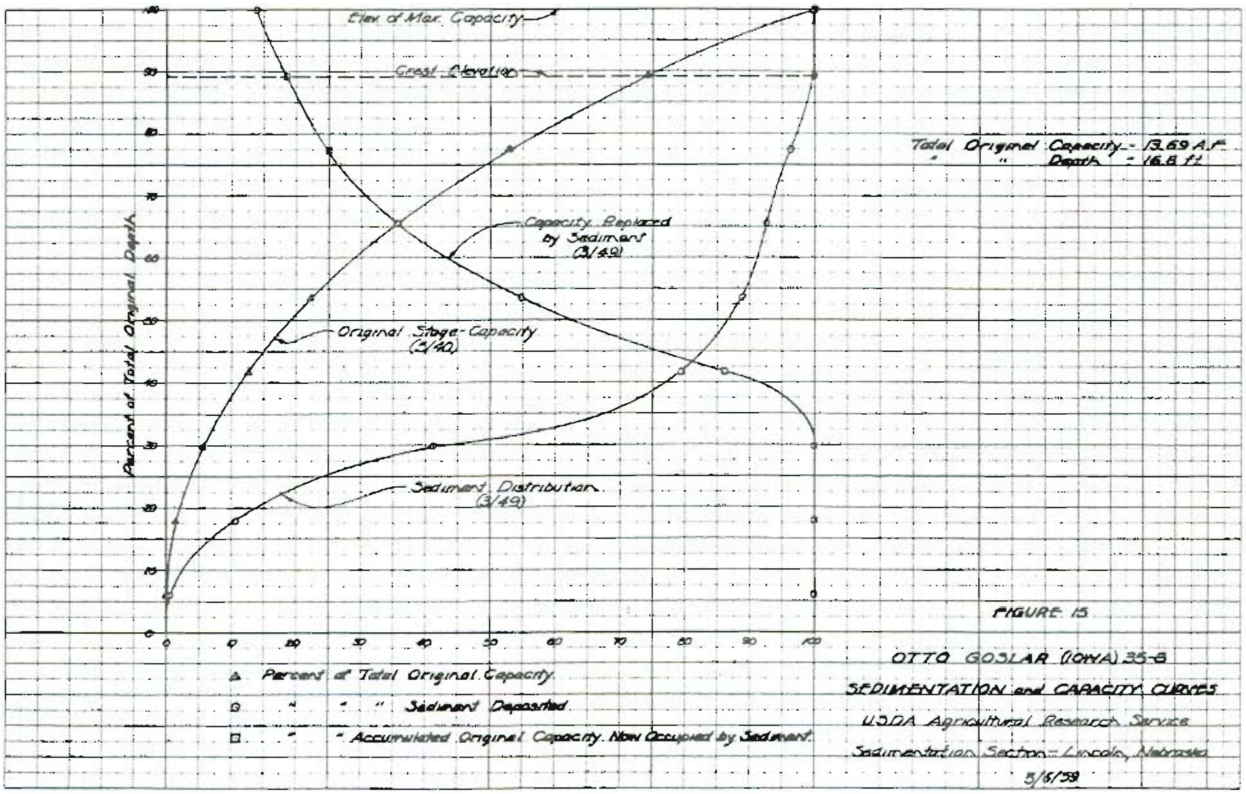


FIGURE 15

OTTO GOSLAR (IOWA) 35-6

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section - Lincoln, Nebraska

5/6/59

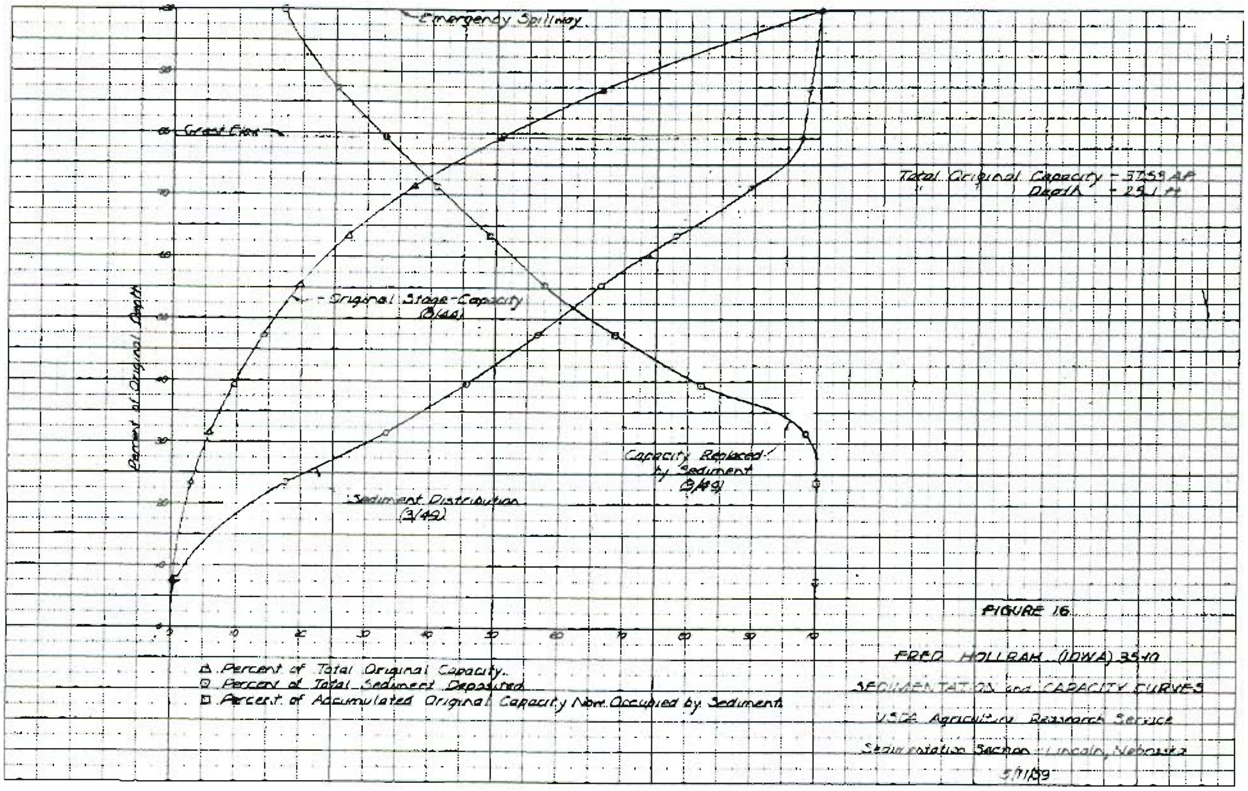


FIGURE 16.

FRED HOLLRAH (IOWA) 35-10

SEDIMENTATION and CAPACITY CURVES

U.S.D.A. Agricultural Research Service

Sedimentation Section - Lincoln, Nebraska

5/11/59

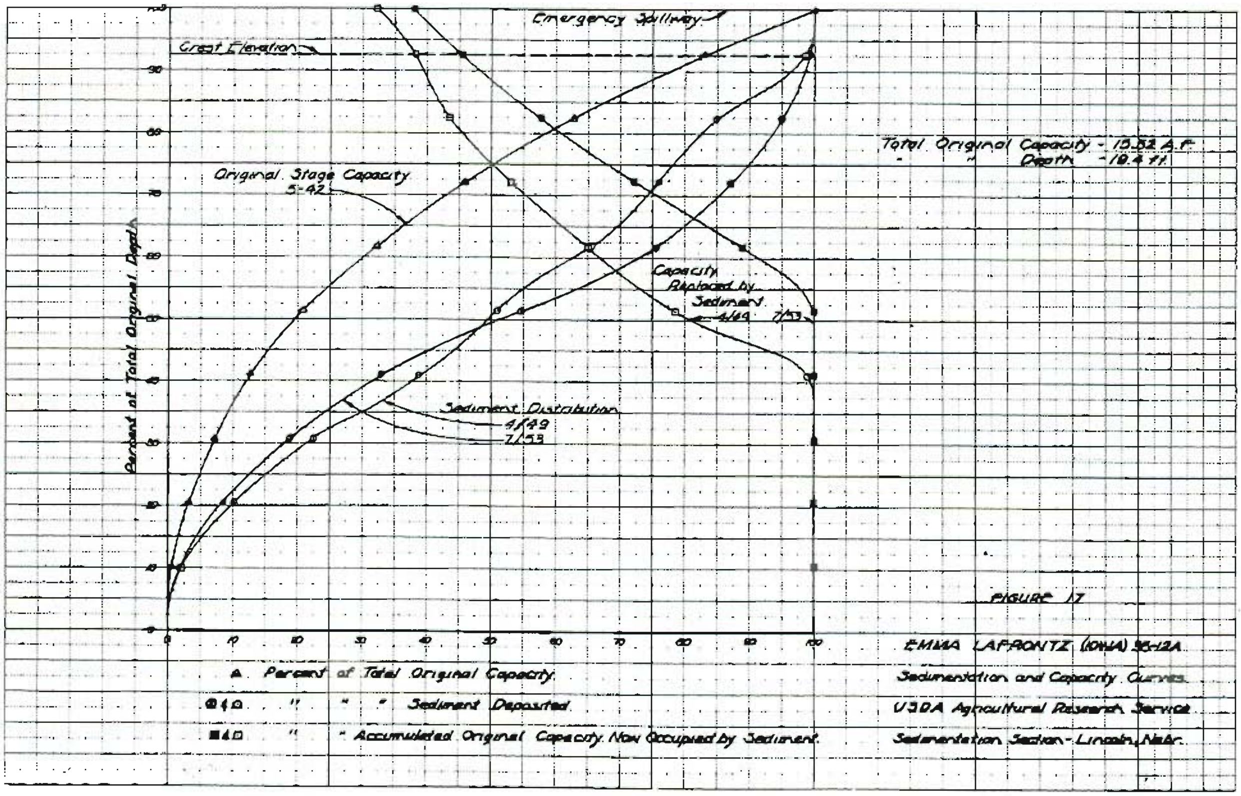


FIGURE 17

EMMA LAFRONTZ (IOWA) 35-12A

Sedimentation and Capacity Curves

USDA Agricultural Research Service

Sedimentation Section - Lincoln, Nebr.

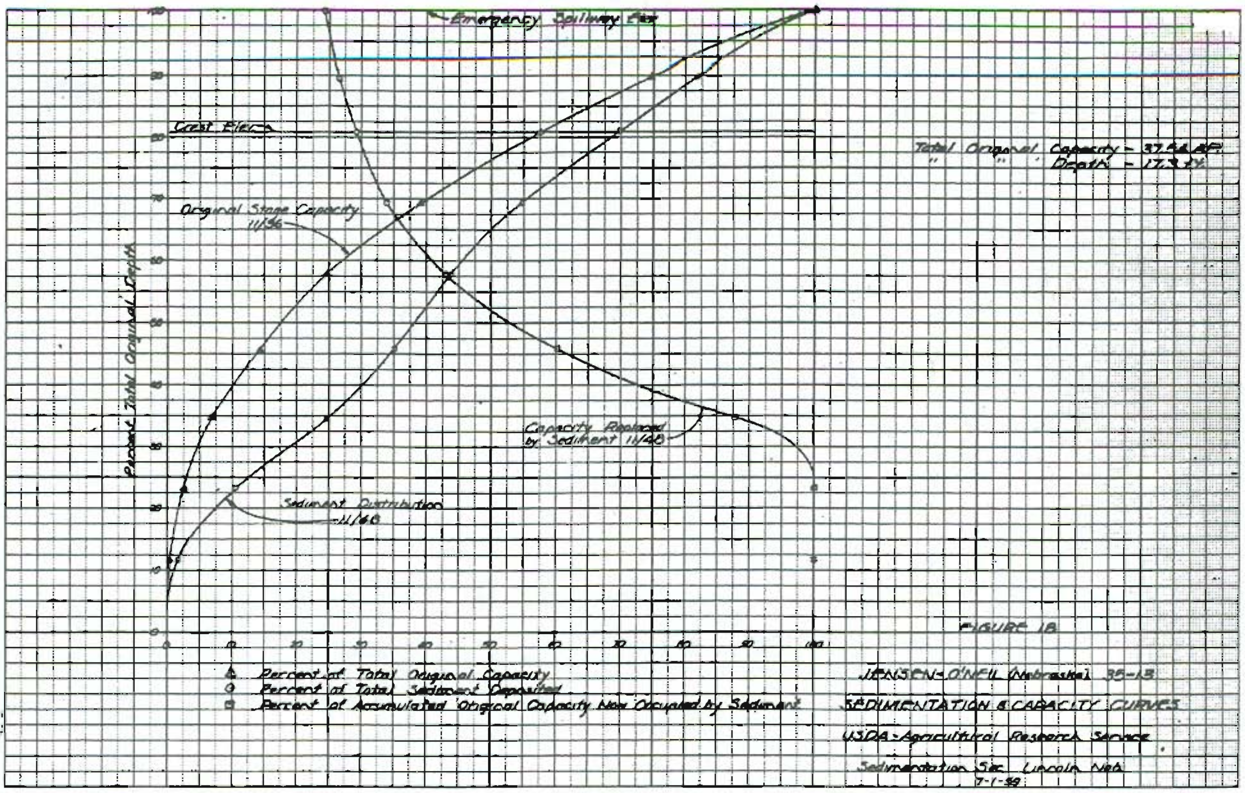


FIGURE 18

JENSEN-O'NEIL (Nebraska) 35-18

SEDIMENTATION & CAPACITY CURVES

USDA-Agricultural Research Service

Sedimentation Sec. Lincoln Neb.
7-1-59

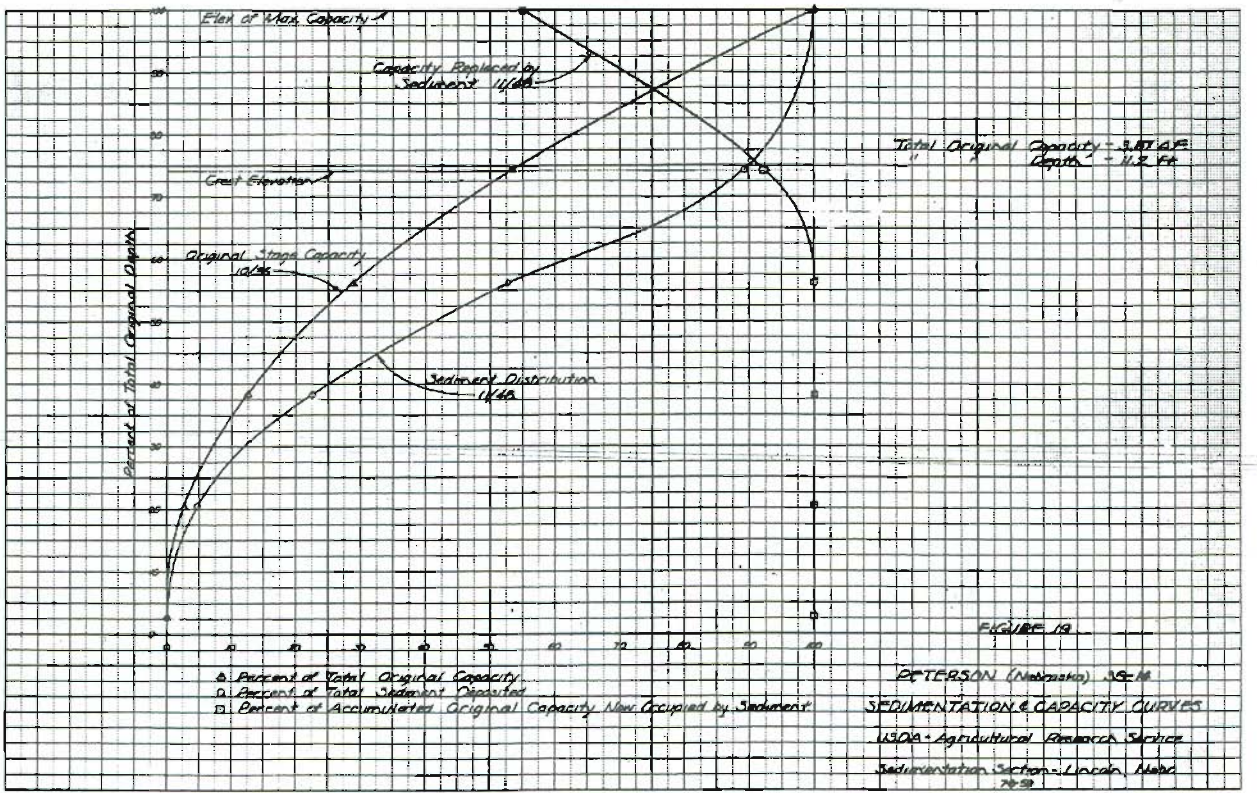


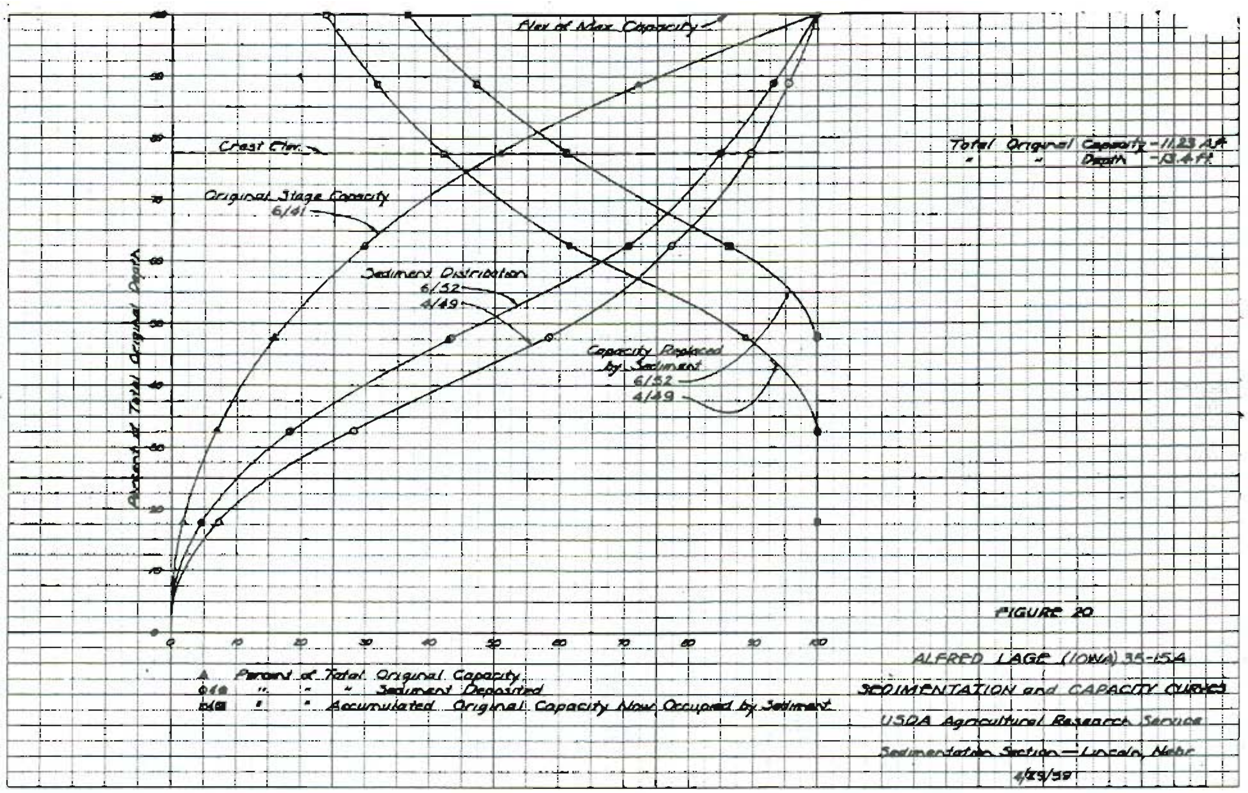
FIGURE 19

PETERSON (Nebraska) 35-14

SEDIMENTATION & CAPACITY CURVES

USDA-Agricultural Research Service

Sedimentation Section-Lincoln, Nebr.
7-1-59



Total Original Capacity - 11.23 A.F.
" " Depth - 13.4 Ft.

FIGURE 20

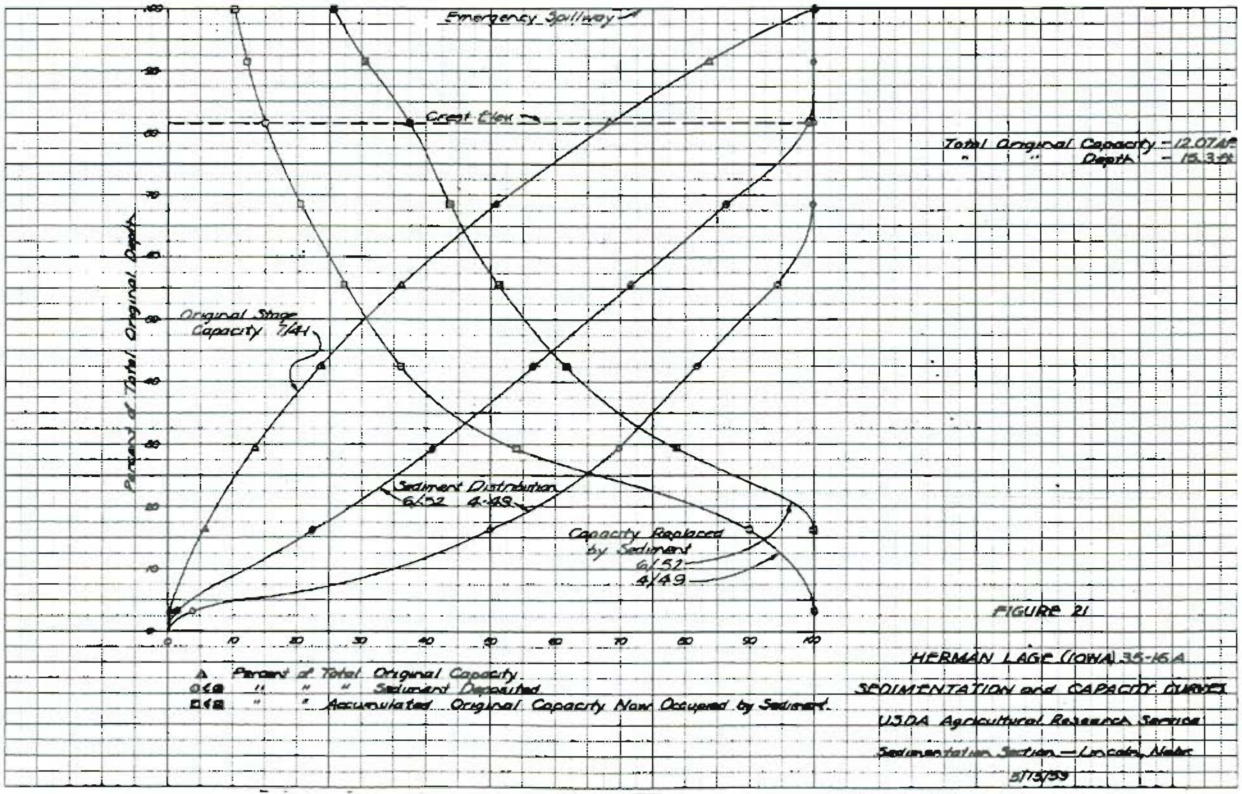
ALFRED LAGE (IOWA) 35-15A

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section — Lincoln, Nebr.

4/25/59



Total Original Capacity - 12.07 A.F.
" " Depth - 15.3 Ft.

FIGURE 21

HERMAN LAGE (IOWA) 35-16A

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section — Lincoln, Nebr.

5/13/59

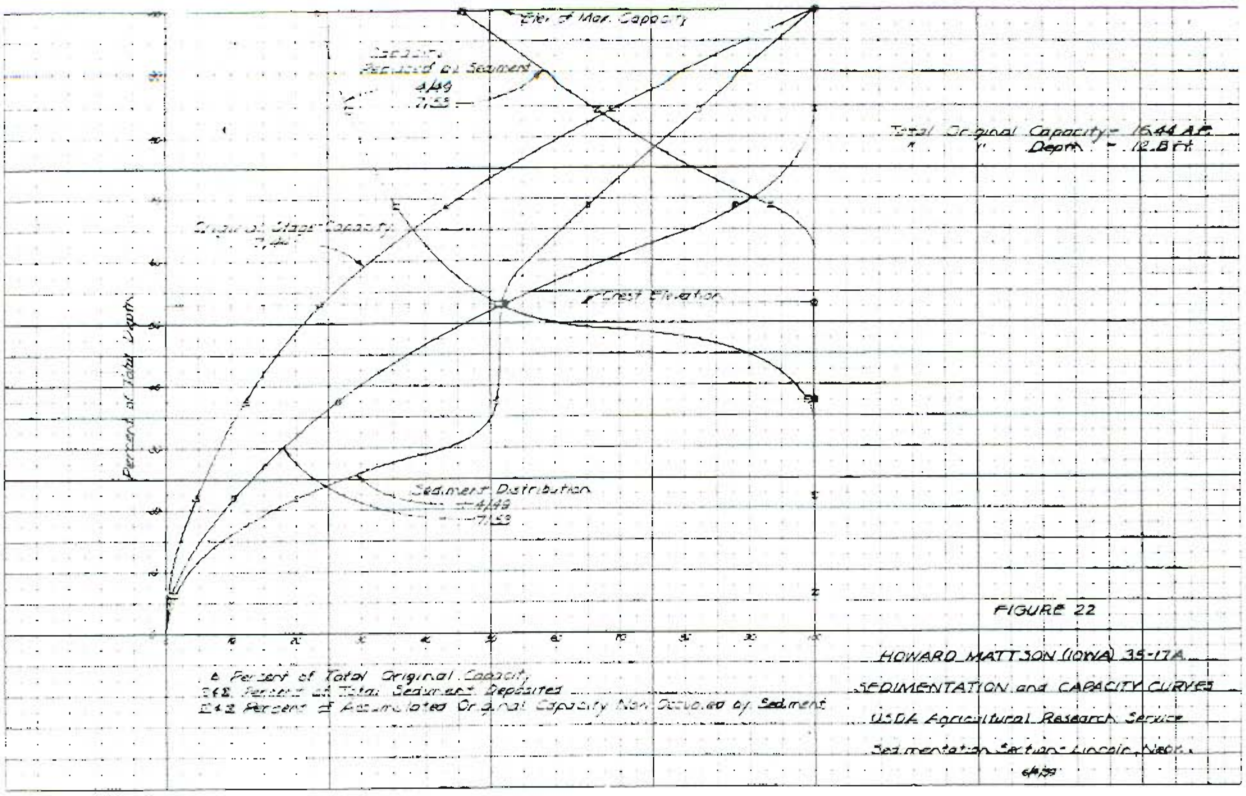


FIGURE 22

HOWARD MATTSON (IOWA) 35-17A

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section - Lincoln, Nebr.

6/59

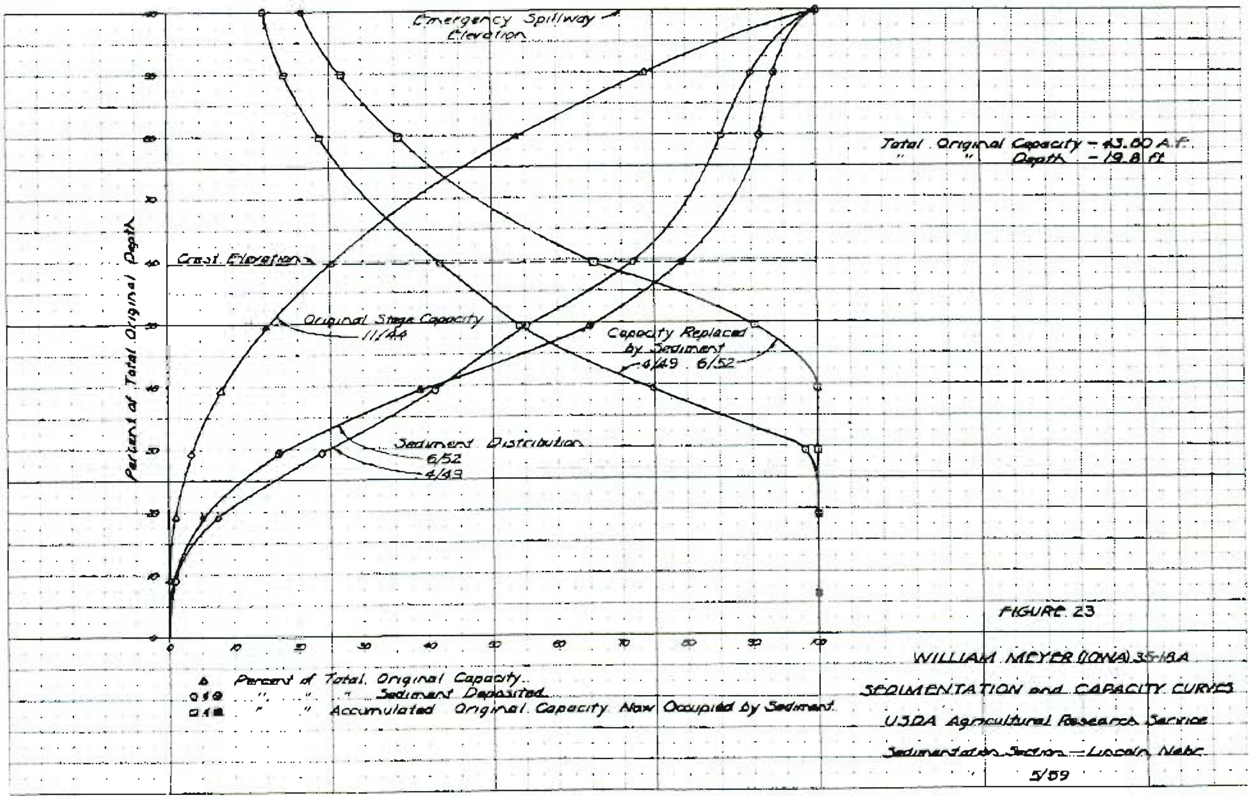


FIGURE 23

WILLIAM MEYER (IOWA) 35-18A

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section - Lincoln, Nebr.

5/59

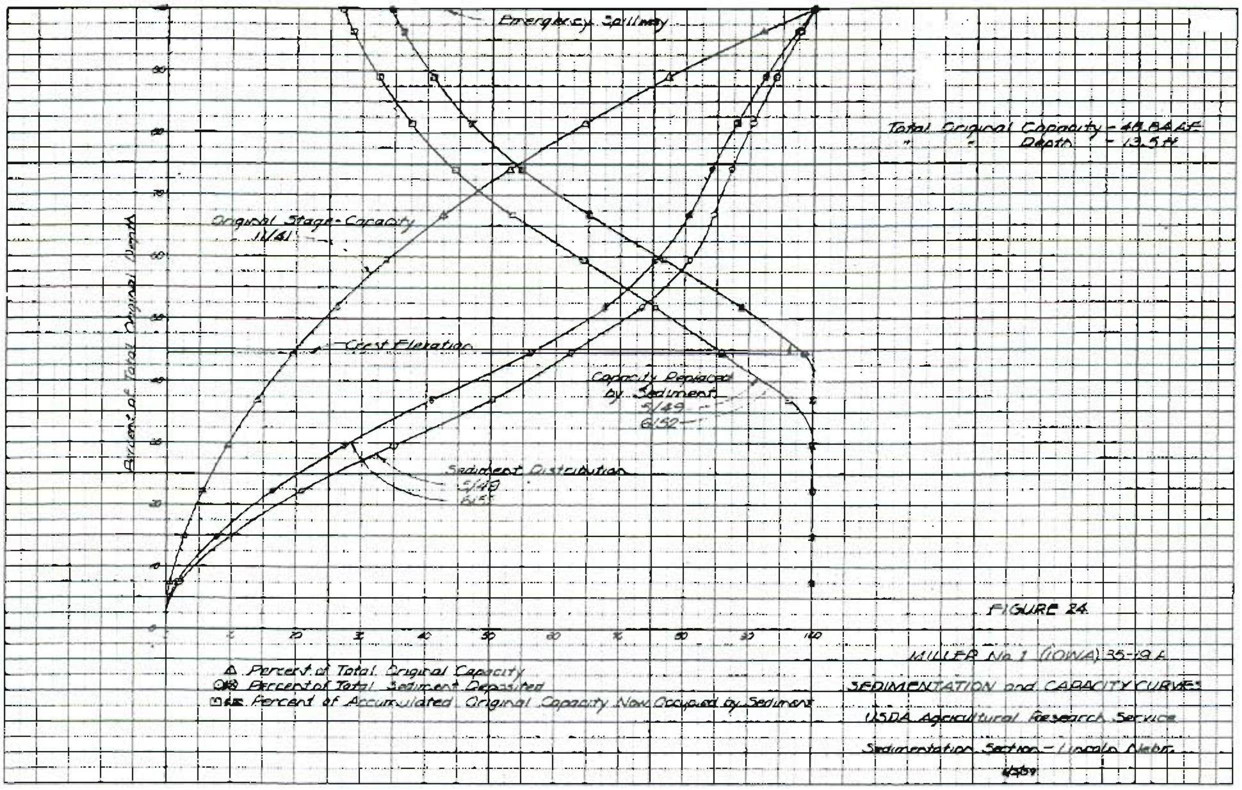


FIGURE 24

MILLER No 1 (IOWA) 35-19A

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section - Lincoln Nebr.

6/59

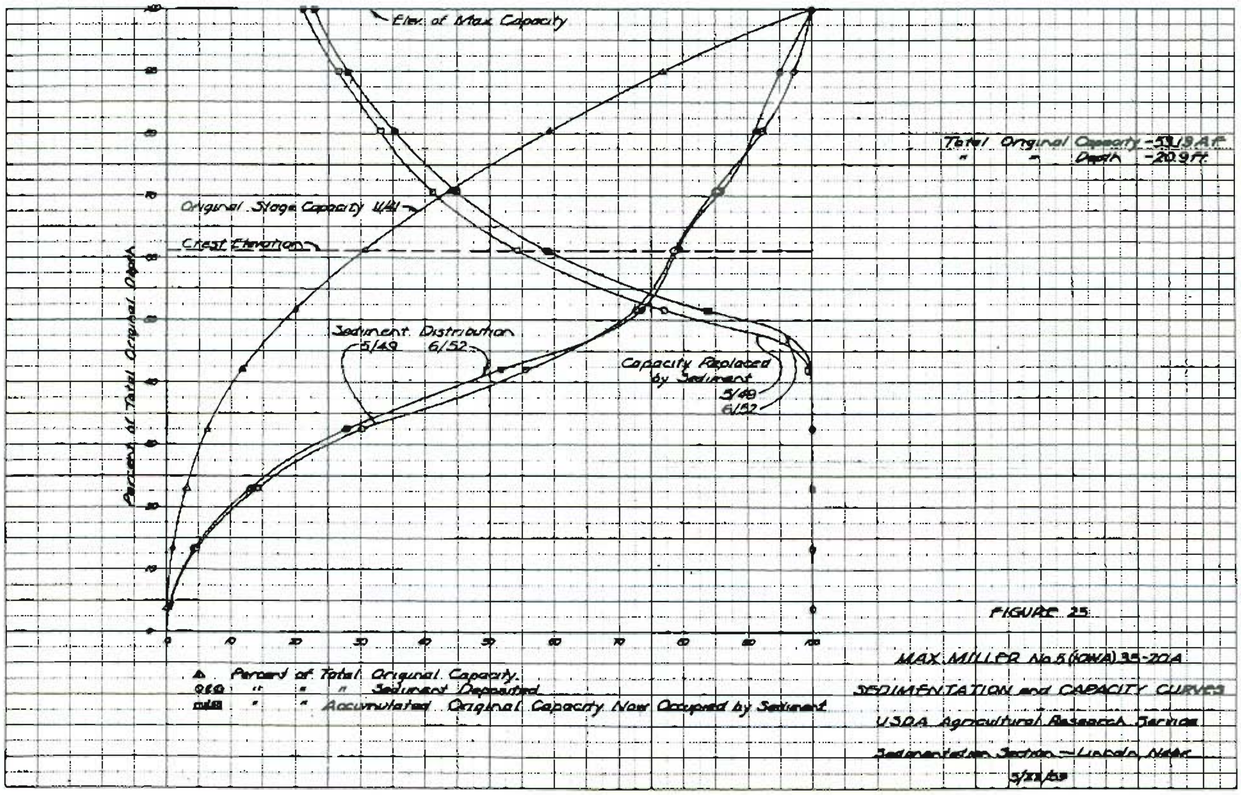


FIGURE 25

MAX MILLER No 5 (IOWA) 35-20A

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section - Lincoln Nebr.

5/22/53

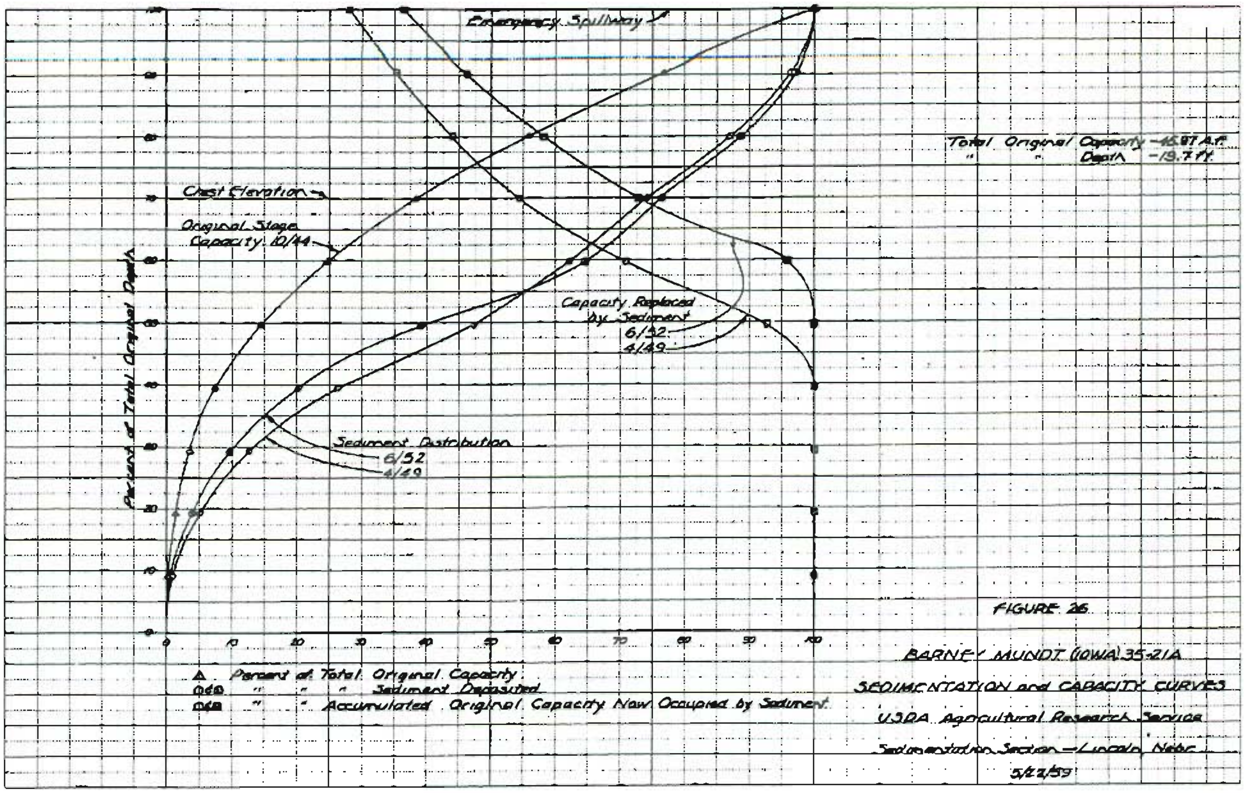


FIGURE 26.

BARNEY MUNDT (IOWA) 35-21A
SEDIMENTATION and CAPACITY CURVES
USDA Agricultural Research Service
Sedimentation Section — Lincoln, Nebr.
5/22/59

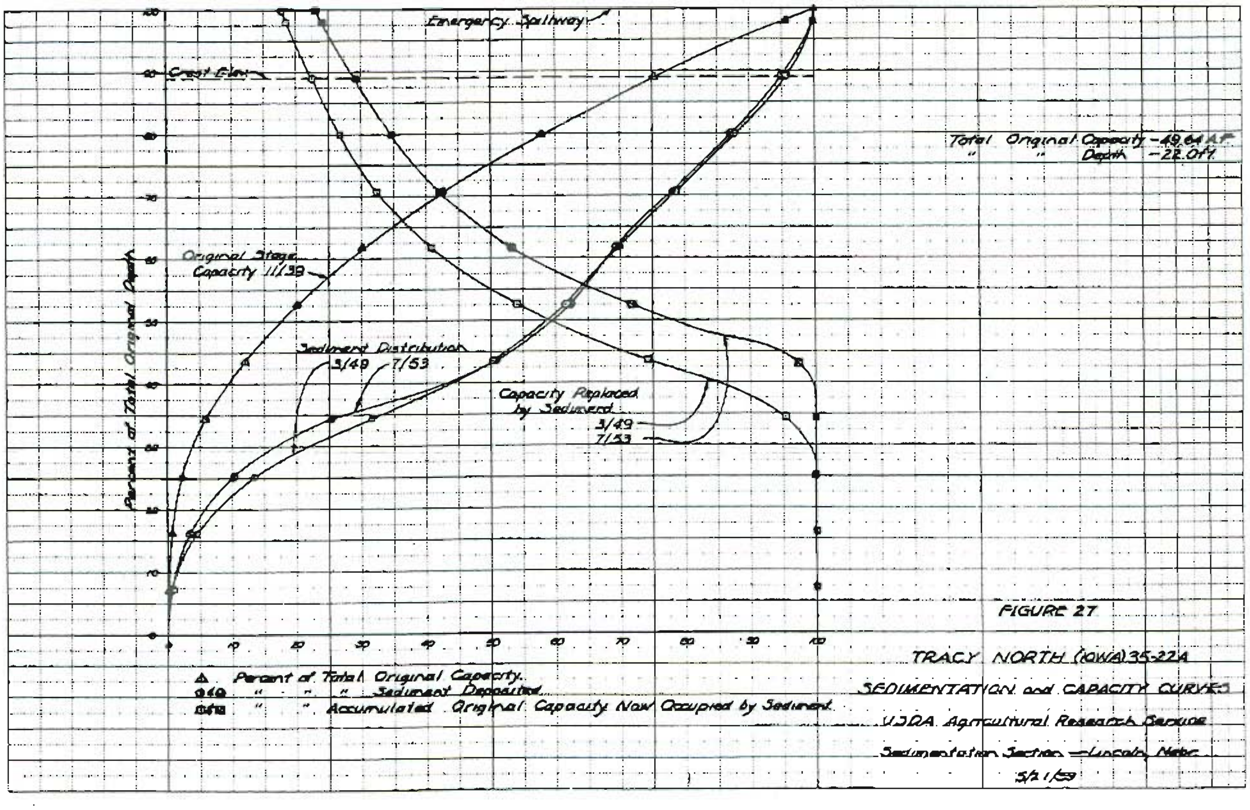


FIGURE 27

TRACY NORTH (IOWA) 35-22A
SEDIMENTATION and CAPACITY CURVES
USDA Agricultural Research Service
Sedimentation Section — Lincoln, Nebr.
5/21/59

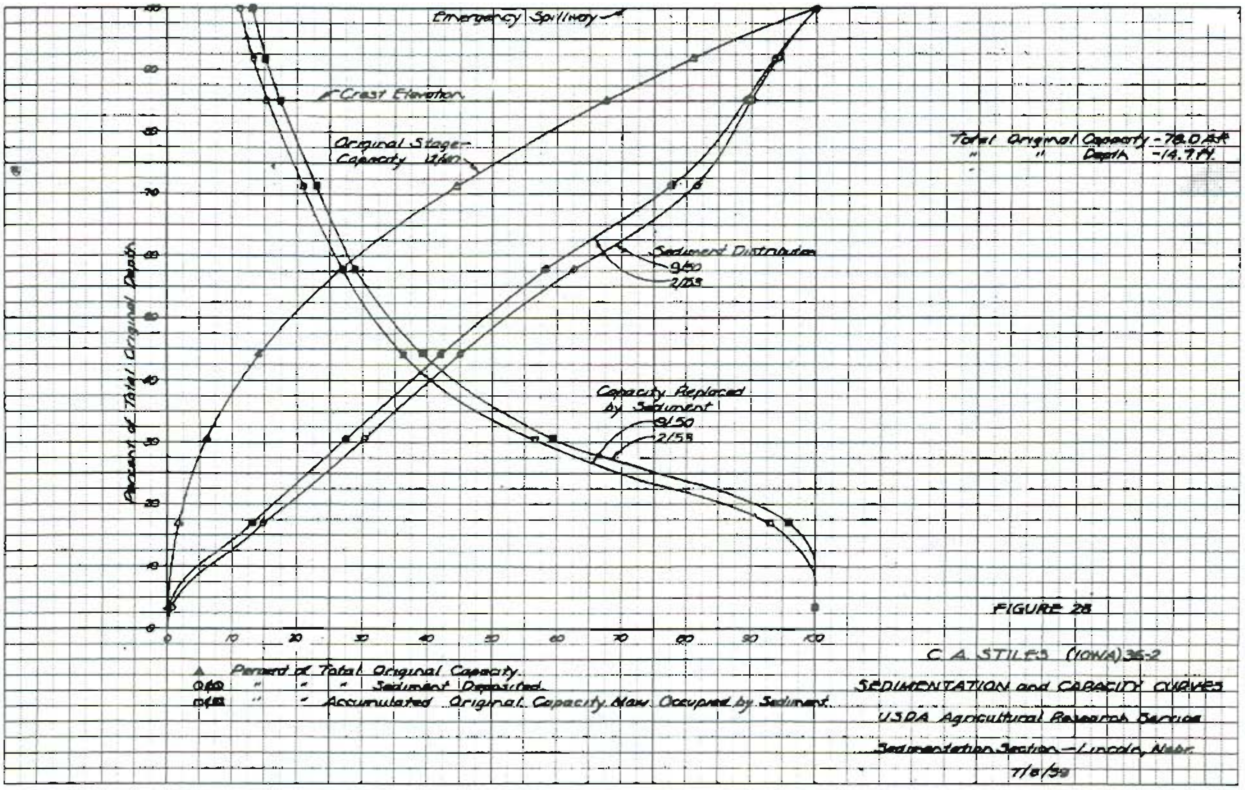


FIGURE 28

C. A. STILES (IOWA) 36-2

SEDIMENTATION and CAPACITY CURVES

USDA Agricultural Research Service

Sedimentation Section — Lincoln, Nebr.

7/8/59

COMPUTATIONS OF: Sediment Distribution Study
Reservoir Capacity and Sediment Information

TABLE 6-1

(1) Data Summary Sheet	(2) Name	(3) County	(4) Stream System	(5) Date of Survey (Mo.& Yr.)	(6) Period between Surveys (Years)	(7) Sed. Samples (No.)	(8) Sed. Sample Ave. Vol. Wt. (lb/ft³)	(9) Total Storage Capacity (AF)	(10) Remain Capacity Retent. Pool (AF)	(11) Remain. Capacity Detent. Pool (AF)	(12) Remain Storage between Spillways (%)	(13) Origin Storage Lost Retent. Pool (AF)	(14) Origin Storage Lost Detent. Pool (AF)	(15) Total Storage Capacity Lost (AF)	(16) Total Average Annual Capacity Lost (AF/mi.²/Yr)	(17) Total Origin Storage Depletion (%)
31-2	Carl	Montgomery	West	6/38	-	-	-	16.47	9.46	7.01	42.56	0	0	0	0	0
	Chinquest		Nodaway	5/49	10.9	3	50.0	8.52	2.59	5.93	69.60	6.87	1.08	7.95	4.10	48.27
31-3	L. H.	Atchison	Tarkio	7/39	-	-	-	68.57	31.80	36.77	53.62	0	0	0	0	0
	Fuelling	(Missouri)	Creek	5/49	9.8	3	62.9	33.50	1.93	31.57	94.24	29.87	5.20	35.07	3.44	51.14
35-1	Otto Bank	Crawford	Soldier	9/44	-	-	-	22.45	6.91	15.54	69.22	0	0	0	0	0
			River	4/49	4.6	3	54.8	16.81	2.28	14.53	86.44	4.63	1.01	5.64	7.81	25.12
35-2	Fred Brown	Harrison	Willow River	6/41	-	-	-	22.93	11.89	11.04	48.15	0	0	0	0	0
				5/49	7.9	3	63.8	15.12	4.61	10.51	69.51	7.28	0.53	7.81	10.19	34.06
35-3	Wm. Esbeck	Cass	Elkhorn	5/40	-	-	-	19.87	12.60	7.27	36.59	0	0	0	0	0
			Creek	5/49	9.0	3	56.1	11.19	4.51	6.68	59.70	8.09	0.59	8.68	4.73	43.68
35-4	G.& A. Evers	Crawford	Boyer River	12/38	-	-	-	28.26	6.63	21.63	76.54	0	0	0	0	0
	(Lower)			4/49	10.3	3	68.4	20.96	1.26	19.70	93.99	5.37	1.93	7.30	5.45	25.83
35-5	G.& A. Evers	Crawford	Boyer River	3/39	-	-	-	3.26	1.90	1.36	41.72	0	0	0	0	0
	(Upper)			4/49	10.1	3	71.6	1.19	0.22	0.97	81.51	1.66	0.39	2.07	4.66	63.50
35-6	Charles	Crawford	Boyer River	5/45	-	-	-	27.30	12.63	14.67	53.74	0	0	0	0	0
	Fienhold			4/49	3.9	3	63.1	17.45	3.48	13.97	80.06	9.15	0.70	9.85	5.94	36.08
35-7A	C. T. Gadd	Montgomery	East Mishna-	12/40	-	-	-	14.48	7.43	7.05	48.69	0	0	0	0	0
			botna River	5/49	8.4	3	63.0	12.82	5.87	6.95	54.21	1.56	0.10	1.66	2.50	11.46
				6/52	3.1	3	57.3	11.98	5.25	6.73	56.18	2.18	0.32	2.50	2.75	17.27

COMPUTATIONS OF: Sediment Distribution Study

TABLE 6-2

Reservoir Data													Watershed Data				
(1) Data Summary Sheet	(5) Date of Survey (Mo & Yr)	(18) Elev. of Max Capacity Area (Acres)	(19) Length of Reserv (ft)	(20) "n" Values (Slope on log log of Depth vs Cap.)	(21) Reserv Shape Factor	(22) Contrib Drainage Area (Sq Miles)	(23) Capacity Water-shed Ratio (af/mi²)	(24) River-bed Elev (ft)	(25) Primary Spillway Elev (ft)	(26) Elev of Max Capacity (ft)	(27) Size of Lower Spillway (Sq ft)	(28) Detention Time (Min)	(29) Basin Length (ft)	(30) Drainage Area Shape Factor	(31) Time of Concentration (Min.)	(32) Total No of Precip Events ≥0.50 in	(33) Total Precip for Events ≥0.50 in (Inches)
31-2	6/38	2.82	675	0.47	0.470	0.178	92.5	85.2	100.0	103.2	16	0	3700	0.532	15	235.3	241.3
	5/49	2.49					47.9	95.7	100.0	103.2							
31-3	7/39	7.76	3260	0.37	0.040	1.04	65.93	85.2	100.0	106.2	36	42	8900	0.598	43.0	227.3	246.0
	5/49	7.96					32.21	95.9	100.0	106.2							
35-1	9/44	3.17	700	0.38	0.459	0.157	142.99	87.8	100.0	107.4	4.91	432	3130	0.736	17.4	74.3	74.7
	4/49	3.17					107.07	95.5	100.0	107.4							
35-2	6/41	2.62	660	0.49	0.480	0.097	236.39	85.1	100.0	104.8	3.14	210	3100	0.645	10	145.1	146.8
	5/49	2.62					155.88	95.5	100.0	104.8							
35-3	5/40	3.37	380	0.49	0.399	0.204	97.40	86.9	100.0	102.5	30.0	0	3400	0.835	14.0	185.8	202.1
	5/49	3.37					54.85	95.2	100.0	102.5							
35-4	12/38	4.58	875	0.41	0.353	0.130	217.38	91.8	100.0	106.8	36.0	0	3200	0.468	12	190.8	194.8
	4/49	4.58					161.23	98.4	100.0	106.8							
35-5	3/39	.810	160	0.46	0.460	0.044	74.1	87.4	100.0	102.2	0.785	0	3170	0.918	12	190.0	196.1
	4/49	.798					27.0	98.2	100.0	102.2							
35-6	5/45	3.48	1405	0.47	0.070	0.425	64.24	84.5	100.0	106.0	36.0	0	4538	0.764	25.2	70.3	80.3
	4/49	3.48					41.1	95.7	100.0	106.0							
35-7A	12/40	2.09	550	0.49	0.383	0.079	183.3	88.8	100.0	104.2	1.23	384	2100	0.890	13.0	258.1	272.7
	5/49	2.09					162.3	93.3	100.0	104.2							
	6/52	2.09					151.6	94.0	100.0	104.2							

COMPUTATIONS OF: Sediment Distribution Study — TABLE 6-3

Reservoir Capacity and Sediment Information

(1) Data Summary Sheet	(2) Name	(3) County	(4) Stream System	(5) Date of Survey (Mo & Yr)	(6) Period between Surveys (Years)	(7) Sed. Samples (No.)	(8) Sed. Sample Ave. Vol. Wt. (lb/ft³)	(9) Total Storage Capacity (A.F.)	(10) Remain. Capacity Retent. Pool (A.F.)	(11) Remain. Capacity Detent. Pool (A.F.)	(12) Remain. Storage between Spillways (%)	(13) Origin. Storage Lost Retent. Pool (A.F.)	(14) Origin. Storage Lost Detent. Pool (A.F.)	(15) Total Storage Capacity Lost (A.F.)	(16) Total Average Annual Capacity Lost (A.F./mi²/yr)	(17) Total Origin. Storage Depletion (%)
35-8	Otto Goslar	Crawford	Middle	5/40	-	-	-	13.69	10.18	3.51	25.64	0	0	0	0	0
			Soldier Riv.	3/49	8.8	3	69.1	11.80	8.29	3.51	29.75	1.89	0	1.89	1.49	13.81
35-10	Fred Hollrah	Crawford	Willow Creek	8/44	-	-	-	37.53	18.98	18.55	49.42	0	0	0	0	0
				3/49	4.6	3	57.6	31.14	12.76	18.38	59.02	6.22	0.17	6.39	6.40	17.03
35-12A	Emma	Crawford	Boyer River	5/42	-	-	-	15.28	12.69	2.59	16.95	0	0	0	0	0
	LaFrontz			4/49	6.9	3	56.4	10.38	7.86	2.52	24.28	4.83	0.07	4.90	4.67	32.07
				7/53	4.2	3	62.0	9.47	6.93	2.54	26.82	5.76	0.05	5.81	3.44	38.02
35-13	Jensen-	Otoe	Little	11/36	-	-	-	41.18	23.68	17.50	42.50	0	0	0	0	0
	O'Neil	(Nebraska)	Nemaha	11/48	12.0	3	54.73	31.18	16.79	14.39	46.15	6.89	3.11	10.00	4.32	24.28
35-14	Peterson	Otoe	Little	10/36	-	-	-	3.87	2.06	1.81	46.77	0	0	0	0	0
		(Nebraska)	Nemaha	11/48	12.1	3	61.01	1.74	0.16	1.58	90.80	1.90	0.23	2.13	2.38	55.04
35-15A	Alfred Lage	Crawford	Elk Creek	6/41	-	-	-	11.23	5.70	5.53	49.24	0	0	0	0	0
				4/49	7.8	3	54.0	8.56	3.31	5.25	61.33	2.39	0.28	2.67	1.79	23.77
				6/52	3.2	2	53.3	7.14	2.23	4.91	68.77	3.47	0.62	4.09	1.95	36.42
35-16A	Herman Lage	Crawford	Elk Creek	7/41	-	-	-	12.07	8.24	3.83	31.73	0	0	0	0	0
				4/49	7.8	3	55.1	10.81	6.68	4.13	38.21	1.56	+0.30	1.26	4.48	10.44
				6/52	3.2	3	49.3	8.96	5.15	3.81	42.52	3.09	0.02	3.11	7.85	25.77
35-17A	Howard	Crawford	Boyer River	7/44	-	-	-	16.44	3.92	12.52	76.16	0	0	0	0	0
	Mattson			4/49	4.8	3	69.0	12.56	1.91	10.65	84.79	2.01	1.87	3.88	8.25	23.60
				7/53	4.2	3	87.1	8.91	0	8.91	100.0	3.92	3.61	7.53	8.54	45.80

COMPUTATIONS OF: Sediment Distribution Study

TABLE 6-4

Reservoir Data | Watershed Data

(1) Data Summary Sheet	(5) Date of Survey (Mo & Yr)	(18) Elev. of Max. Capacity Area (Acres)	(19) Length of Reserv. (ft)	(20) "n" Values (Slope on log log of Depth vs. Cap.)	(21) Reserv. Shape Factor	(22) Contrib. Drainage Area (Sq Miles)	(23) Capacity Water-shed Ratio (AF/Mi²)	(24) River-bed Elev. (ft)	(25) Primary Spillway Elev. (ft)	(26) Elev. of Max. Capacity (ft)	(27) Size of Lower Spillway (Sq. ft)	(28) Detention Time (Min)	(29) Basin Length (ft)	(30) Drainage Area Shape Factor	(31) Time of Concentration (Min)	(32) Total No of Precip Events ≥0.50 in	(33) Total Precip for Events ≥0.50 in (Inches)
35-8	5/40	2.19	470	0.41	0.330	0.144	95.07	85.0	100.0	101.8	17.5	0	2100	0.712	9.0	163.8	162.7
	3/49	2.19					81.94	90.3	100.0	101.8							
35-10	8/44	4.71	1170	0.42	0.232	0.217	172.9	80.1	100.0	105.2	7.07	148	5100	0.545	21	80.9	79.1
	3/49	4.71					143.5	87.1	100.0	105.2							
35-12A	5/42	2.07	420	0.44	0.390	0.152	100.5	82.0	100.0	101.4	7.07	0	2800	0.866	12.0	234.1	249.3
	4/49	2.04					68.3	88.7	100.0	101.4							
	7/53	2.04					62.3	92.6	100.0	101.4							
35-13	11/36	6.06	700	0.40	0.614	0.193	213.37	80.6	100.0	103.3	4	201	2970	0.604	15	238.6	245.5
	11/48	5.12					161.56	90.5	100.0	103.3	4						
35-14	10/36	0.83	275	0.47	0.601	0.074	52.30	91.7	100.0	102.9	4	28	1550	0.811	7.5	238.2	245.2
	11/48	0.82					23.51	99.2	100.0	102.9	4						
35-15A	6/41	2.35	860	0.42	0.160	0.191	58.80	89.6	100.0	103.0	25.0	0	3200	0.620	13.5	232.5	244.3
	4/49	2.31					44.81	95.0	100.0	103.0							
	6/52	2.31					37.38	96.6	100.0	103.0							
35-16A	7/41	1.63	420	0.62	0.503	0.036	335.28	87.5	100.0	102.8	0.54	321	1500	0.760	6.0	231.6	244.0
	4/49	1.63					300.28	89.1	100.0	102.8							
	6/52	1.63					248.89	90.2	100.0	102.8							
35-17A	7/44	2.72	400	0.48	0.302	0.098	167.75	93.2	100.0	106.0	9	150	2100	0.917	7.2	192.8	199.5
	4/49	2.72					128.16	96.5	100.0	106.0							
	7/53	2.72					90.92	100.7	100.0	106.0							