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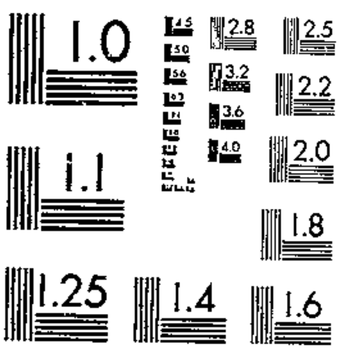

MICROCOPY RESOLUTION TEST CHART
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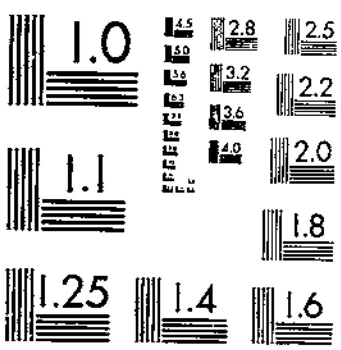

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SILTING OF RESERVOIRS

By

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Soil Conservation Service

Revised by

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Soil Conservation Service

United States Department of Agriculture, Washington, D. C.

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TECHNICAL BULLETIN No. 524 JULY 1936
REVISED AUGUST 1939

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

SILTING OF RESERVOIRS [1]

By HENRY M. EAKIN [2]

Head, Sedimentation Studies, Division of Research, Soil Conservation Service

Revised by CARL B. BROWN

Project Supervisor, Reservoir Investigations

CONTENTS

[1] Progress report on reservoir surveys and investigations by the Soil Conservation Service in 1934–36 with notes on previous investigations of reservoir silting made by other agencies. Revised to bring up to date information on reservoirs described in first edition. The author of the revision acknowledges the valuable assistance received from F. F. Barnes and G. A. Zwerner of the Section of Sedimentation Studies.

[2] Deceased, October 20, 1936.

INTRODUCTION

THE PROJECT

The inherent relation of silting of reservoirs to problems of erosion control led the Soil Conservation Service to institute in July 1934 the first attempt at a general Nation-wide investigation of the condition of American reservoirs with respect to reduction of storage by silting.

The ultimate objective of these studies is to accumulate information on the factors involved in the silting of reservoirs, including rates of silting, and to correlate the results with soil, slope, and climatic conditions and land use in watershed areas. It seems obvious that such a broad factual basis is necessary for sound determination of policy and practice of reservoir development and sediment control in the various sections of the country.

The work accomplished through 1936 under the project consisted of detailed surveys of sediment accumulation in representative reservoirs in the southeastern, south-central, and southwestern type areas, along with reconnaissance examinations of other reservoirs in the same regions incident to selection of more broadly significant cases for special study.

The direct objective of each detailed survey has been to determine the volume and distribution of sediment deposits accumulated in the reservoir during a known period of time, either the entire period of the reservoir's existence or a shorter period between an earlier survey and the current resurvey. From these data and those on tributary drainage basins the average annual rate of silting per unit of drainage area is derived as an important practical index to differences and changes in regional erosional conditions and expectancy of useful life of existing or contemplated reservoirs.

These studies have been continued over a period of 5 years, and at the date of revision of this bulletin (June 1939) a total of 76 surveys have been completed, of which 67 are original sedimentation surveys, 3 are sedimentation resurveys, and 6 are surveys of reservoir basins made prior to initial flooding to establish permanent range systems for future sediment measurements. In addition, reconnaissance investigations have been made on some 500 other reservoirs out of an estimated total of nearly 10,000 in the United States.

This bulletin was originally prepared with a view to giving a preliminary outline of the more important aspects of the problem of reservoir silting, to summarize the results of the more important investigations in this field previously made by other agencies, and to present the findings of the Soil Conservation Service studies during the fiscal year ended June 30, 1935.

This revised edition does not attempt to present, even in summary, most of the data collected during the succeeding 3 years. To accomplish this would require a bulletin several times the present size. This revision is devoted mainly to bringing information up to date on reservoirs described in the original edition. Detailed surveys have been made on six reservoirs previously described under reconnaissance investigations and a very brief discussion of these and a few others has been included in the appropriate place under detailed surveys. Further reconnaissance studies have been made on other reservoirs, and the results are given herein. Additional information on watershed characteristics has been added where available, and errors in fact and figures discovered since original publication have been corrected.

Table 13 includes not only the results of the surveys described in this bulletin but also pertinent data on all reservoirs surveyed through June 30, 1938. Advance reports on many of these additional reservoirs, containing information on the reservoir, its drainage basin, and sedimentation, have been mimeographed for circulation to cooperating technical workers for their information and criticism prior to final publication. Table 13 is inserted so that the summary data may be made more widely available for analysis and use by conservationists and engineers. Advance reports on most of the reservoirs not described in this bulletin can be furnished by the Soil Conservation Service on request.

ECONOMIC ASPECTS OF THE PROBLEM

The economic values involved in present and proposed reservoir developments are very large. They include not only investments in dams and basin lands of the reservoir properties themselves, but also the much larger values of appurtenant water supply and power facilities, industrial establishments, and irrigated-land resources and improvements.

A comprehensive inventory of the Nation's resources dependent upon water storage has never been made, but even rough calculations of Federal, State, municipal, and corporate expenditures for reservoir and auxiliary facilities and similar estimates of the aggregate value of dependent private holdings easily run to several billion dollars. All of these interests are bound together under the common menace of depletion of reservoir capacity by silting wherever accelerated erosion occurs.

It is true, of course, that some of these resources are less critically impaired by loss of reservoir storage than others. Power reservoirs, even when completely silted, still afford operating head for ordinary stream flow. Where stream flow is equable through the seasons, either naturally or by reason of regulation by other reservoirs in the same watershed, the injury from local reservoir silting may be almost negligible. In most cases, however, local storage is an important factor of power-plant operation in meeting daily and seasonal demands. The injury caused by silting increases with the dependence of the individual plant upon local storage, and this in many instances, particularly in more arid regions, has a critical relation to profitable power-plant operation.

In general, reservoir storage is vitally important to irrigation and municipal water-supply projects. In these, a depletion of storage by silting to bare equality with maximum seasonal or annual requirements puts the project in a precarious position, and any further depletion means actual deficiency, any degree of which is intolerable and must be covered by construction of additional storage facilities.

This leads to the question of values destroyed by reservoir silting. The view all too frequently held is that the destruction is to be measured by the cost of the original reservoir. This could be so only where additional storage could be developed indefinitely and at similar cost. There is, of course, an ultimate limit of feasible storage in every drainage basin. It is only natural that the initial reservoirs should be constructed at the most favorable and economic sites, and that substitute or supplementary storage facilities, to serve the same locality, are more costly. It is, therefore, probably correct to compute the more immediate harm of reservoir silting upon the basis of replacement rather than original storage costs and the ultimate harm in terms of the entire economic development dependent upon local water storage.

It is pertinent in this connection to consider the possibilities and relative costs of conservation of developed storage against depletion by silting.

In a few instances attempts have been made to vent sediment from a reservoir through outlet gates and conduits in the dam. The typical results shown after complete draw-down have been the cutting out by the normal river current of a new channel of rather deep and narrow cross section from the outlet in the dam to the previous head of backwater. The amount of sediment thus removed as shown by the volume of the channel has generally been only a small percentage of the total accumulation.

The proposal has been advanced, in view of the known tendencies toward underflow of heavily sediment-charged waters to the dam, that systematic venting of these sediment flows through properly arranged gates or conduits might be effective in removing a considerable proportion of the sediment load.

This proposal might be technically feasible, though its efficiency in removing a large percentage of the total sediment load is yet to be proved. However, it is open to grave objections in the problem of sediment disposal below the dam. The excess of sediment thus released periodically would seriously impair the utility of water below the dam, particularly for irrigation projects, adding to the cost of maintaining canals and field distribution systems.

Hydraulic dredging and mechanical removal of sediment would generally cost from 5 to 50 times as much as the original storage. This, of course, is prohibitive except for special-purpose dams where there is no alternative.

In certain instances the rate of storage depletion in reservoirs has been reduced by sediment detention in headwater and valley areas by engineering structures and vegetation screens. Such measures are admittedly temporary in nature and have the effect in general of building up alluvial deposits in valleys above the reservoir, thereby being of practical application only where such valley lands are comparatively worthless for other use.

In contrast with these inefficient or objectionable measures, the permanent reduction of sediment load in the contributing streams by means of erosion-control practices in the drainage basin has been repeatedly indicated as desirable and effective by experimental evidence. Erosion control not only has the effect of conserving lands in the drainage area, but is outstanding as the one fundamental and permanently practicable means of reducing the rate of reservoir silting. It inhibits primary production of debris and thus involves no progressive and ultimately embarrassing accumulations above, or troublesome sediment-laden discharge from the reservoir.

PHYSICAL ASPECTS OF THE PROBLEM

Practical understanding of the physical basis of the present-day sediment problem requires, first of all, a definite recognition of the dependence of silting upon erosion of directly tributary watershed areas and of the critical fact that rates of erosion are neither uniform nor fixed in different sections of the country, but are subject to material change under a civilized use and abuse of lands and various practical measures of erosion control. This is all too frequently a difficult advance in thought concerning erosion, particularly on the part of scientists and engineers who have studied erosion only from the viewpoint of primordial forces and processes of nature.

It is true, of course, that erosion has been active throughout geologic history in sculpturing and planating the lands of the earth, and that where man has least interfered with soil and vegetative conditions, erosional processes are still in force at primeval or geologically normal rates. It is also true that, elsewhere, man has materially changed natural erosional conditions by deforestation, agriculture, grazing, and fire so that erosion has been variously accelerated from moderate to truly catastrophic degrees.

On account of this historic change in erosional conditions over much of the country it is essential to draw a clear distinction between natural and man-induced erosion. This has been well done by erosion specialists through adoption of the terms "geologic norm" and "accelerated erosion" for succinct reference respectively to natural and man-induced phases of erosion. Under geologic norms, erosion was generally far less intense and more regular over broad type regions of climate, soil, and vegetative cover. Acceleration of erosion by human activities has greatly increased the average sediment production over large sections of the continent and has introduced erratic distribution of erosional intensities quite different from the corresponding prenomena of nature.

The original geologic norms of erosion in each type region of the country reflected the natural balance between opposite factors of (1) erosional attack, determined for the most part by amount and intensity of rainfall, and (2) resistance of the terrain to erosional attack, determined for the most part by vegetative protection of the soil.

The potentials of erosion were naturally stronger in regions of humid climate but were generally countered by heavy forest growth and other vegetation, so that erosion tended toward minimum rates and streams generally ran clear even in flood. Under more arid conditions, potentials of erosion were relatively weak, but were less effectively countered by natural vegetation, so that sediment production was relatively high and streams were generally more or less sediment laden. Human acceleration of erosion has affected both humid and arid sections of the country, but has been proportionately somewhat more effective in humid regions where human activities have destroyed the balance between stronger natural factors.

Acceleration of erosion in the humid sections of the country has been brought about most extensively by land clearing and clean cultivation of sloping lands occupied by deep soils. It has been for the most part in such regions of greater rainfall that an aggregate of approximately 100,000,000 acres of formerly tilled land has been washed and gullied to the point of agricultural abandonment, or so severely affected by sheet washing as to support only a submarginal type of agriculture; and an even greater area has been seriously affected within the geologically brief period of civilized occupation. Acceleration of erosion in the more arid sections of the country, though proportionally less than in the humid regions, has nevertheless involved extensive wastage of topsoil and catastrophic development of arroyos and gullies over widespread areas.

To appreciate the full import of human acceleration of erosion in relation to the silting problem of the present and future, it is necessary to recognize the progressive and cyclical aspects of the phenomenon of erosion rejuvenation. It is a basic physiographic principle that rejuvenated erosion tends to spread progressively upstream and upslope throughout the affected watershed area. Each gully and arroyo lowers the elevation of controlling base level and carries the menace of potential degradation in like measure to its entire drainage area.

The entrenchment of rejuvenated drainage courses extends progressively upstream through headward erosion, and each entrenched section of trunk and tributary stream entails additional sediment production through lateral planation of exposed banks and general slope readjustment. Acceleration of sediment production thus advances at increasing rates through a long period leading up to maturity of a new erosion cycle. The new erosion cycles that have been recently developed so extensively throughout the country as a result of human activity are mostly still in incipient and immature stages. It thus appears that the present-day rates of sediment production in many sections of the country, although now greater than those of the original geologic norms, may be destined to increase still further for a long time in the future unless countered by corrective interference with the inevitable progress of erosion through various measures already succeeding in, or under development for, erosion control. Natural revegetation will, of course, in time impede erosion on large areas of abandoned land, especially where fires are controlled.

PROCESSES OF RESERVOIR SILTING

The rate of sediment accumulation and forms of sediment distribution in a reservoir are determined largely by the volume and character of load carried into it by contributing streams. The transporting power of streams and the load they carry are, in turn, determined by the extent of the drainage area and erosional factors of climate, topographic relief, soils, vegetative cover, and land use. The total stream load derived from headwater sources is subject to variation, from time to time, by changes in factors controlling erosion, particularly through changes in extent and effectiveness of vegetative cover. The load at any given time is subject to change in character from place to place approaching the reservoir, through processes of wear of debris particles and exchange of material between load and alluvial environment in the course of travel, and to change in volume through processes of valley scour and deposition.

As a general rule, particularly where load includes a considerable proportion of coarse-grained material and the reservoir is frequently at full stage, the load of contributing streams is subject to radical reduction in both volume and average grain size through processes of valley aggradation above reservoir level. This process of load reduction tends to be still further augmented where such valley deposits come to support new vegetation that acts as a sediment screen by spreading and retarding stream flow. This process, like that of primary headwater erosion, is subject to change with time. Its characteristic trend is to become more and more effective with time and thus gradually to reduce the rate of silting of the reservoir proper.

This process is naturally a benefit to conservation of reservoir storage, but involves the possible ruin and sacrifice of riparian properties in the lower part of the affected valley. The deposits in the valley, due to this process that is attributable to the new base level created by the reservoir, tend to decrease in depth going up valley. Somewhat similar valley deposits may occur also as the result of accelerated headwater erosion, but the latter are generally characterized by decrease in depth of deposits going down valley. The possible use of this criterion to determine the origin of valley deposits, in many cases, may be of decisive economic importance.

The rate of reservoir silting is also subject to progressive reduction by escape of increasing amounts of debris over or through the dam as storage space is reduced by silting. This effect, however, is limited to the finest fractions of suspended load in all but the final stages of reservoir filling and so cannot enter with any great importance into the problem of major storage conservation.

The processes and forms of sediment accumulation strictly within the storage space of reservoirs are dependent primarily upon differences in settling rates and mass effects of different-sized fractions of stream-borne load.

The relatively coarse-grained materials, that are carried on or settle rapidly toward the bottom, tend to accumulate in the form of deltas where velocity slackens at the mouths of tributary streams. Such deposits, typically developed where there is little change in reservoir stage, are composed of characteristic bottom-set, fore-set, and top-set beds of conventional delta form, limited in areal extent and confined in the vertical to the higher levels of original storage.

The aggregate volume of delta deposits reflects the presence and amount of relatively coarse-grained debris in the total stream-borne load. If only coarse-grained materials are carried the deltas may truly represent the entire sedimentary accumulation. On the other hand, if no coarse-grained materials are carried by tributary streams, delta processes and features may be entirely lacking.

The processes and final forms of deltas are frequently complicated by changes in reservoir level. Such deposits formed at higher levels are subject to entrenchment and more or less complete removal at lower stages, the moved materials being redeposited in new delta features farther downstream and at lower elevation. The form of delta accumulations in reservoirs that vary in stage is thus subject to radical change from one time to another and the problem of comparative measurement of total delta volume by periodic resurveys is correspondingly complicated.

The building of deltas at the mouths of tributary streams is the most conspicuous and familiar phenomenon of reservoir silting and one that is all too frequently recognized to the exclusion of all others. There are, however, phenomena of distribution of finer-grained fractions of load within the storage space of reservoirs that are just as definite and important as those of delta building.

In contrast with the tendency of coarser debris to concentrate in limited higher areas of the reservoir, the finer-grained materials tend to spread broadly over the reservoir bottom and in many cases to accumulate selectively in the deeper portions of the basin. This tendency to concentrate beneath the deeper waters is due to the striking and widely prevalent phenomenon of underflow of heavier, silt-charged, inflowing waters beneath lighter, desilted waters already in storage. This is not a readily observable phenomenon and consequently it has not been broadly recognized in engineering literature. It is of signal importance to systematic silting studies in that the volume of finer-grained bottom-set beds, more frequently than otherwise, has been found to exceed the total volume of delta deposits and that, contrary to customary thought, the depletion of deeper reservoir storage space in the vicinity of the dam may not await the gradual approach of growing deltas but may, and in most cases does, begin at selective rates from the very beginning of storage.

In Elephant Butte Reservoir underflows of sediment-charged water, coming from flood flows on the Rio Puerco, and carrying as much as 15 percent of solid matter, have moved at the rate of over 2 feet per second, or about 1½ miles per hour. Muddy underflows in this reservoir have repeatedly extended to the dam and have caused muddy discharges through the outlet gates while the surface water of the lake was perfectly clear. The record includes a maximum period of 17 days of muddy discharge, from a superficially clear blue lake, in which the sediment content of the discharge reached a maximum of 6 percent by weight.

The same phenomenon has occurred in connection with the operation of other southwestern reservoirs that receive very muddy flood flows from tributary rivers. The resultant deposits in the deeper parts of the reservoirs tend to be extremely flat in both transverse and longitudinal profile and so to increase in thickness and in ratio to overlying water toward the dam. Similar features of silt distribution have been noted in reservoirs of the more humid sections of Texas and even in the very humid section of the southern Piedmont. This would appear to indicate that the phenomenon of underflow is not strictly limited to cases of extremely muddy inflow but is a general phenomenon of stratification of liquids of different density which tends to be expressed quite generally in reservoir silting wherever an effective difference in sediment content of inflowing and stored waters may occur.

Recognition of the importance of the widespread bottom-set beds in reservoirs and their careful measurement are essential to accurate studies of general rates of reservoir silting. In the course of the present project, cases have been found where previous oversight of this form of deposit in the main reservoir area above the dam introduced very large errors in computations of total sediment.

PREVIOUS INVESTIGATIONS

Published results of actual capacity surveys to determine rates of silting appear to be limited to some 40 American reservoirs. Of this number, 16 have been of basin type, with original capacities large enough to permit practically complete natural desilting of all inflowing water. The volumes of sediment per unit of drainage area found in reservoirs of this type, therefore, afford a practical index to comparative average rates of erosion in the respective watersheds during periods of record. The rest of the list of previously surveyed reservoirs have been more strictly of channel type, with relatively small storage in relation to inflow and, therefore, given to indeterminate wastage of sediment past the dam in time of flood. In these reservoirs the disclosed volumes of sediment represent unknown fractions of total sediment delivered from the corresponding watershed areas.

Owing to this basic difference in practical significance of their data, these two classes of reservoirs are treated separately in the following discussion of previous investigations.

BASIN RESERVOIRS

Table 1 presents a summary of data on basin reservoirs, including computations of average annual rate of sediment accumulation per 100 square miles of drainage area. This expression is essentially an index of comparative average erosional intensities in the directly tributary watershed area. Insofar as the local watershed is representative of average climatic and erosional conditions of a general region or erosion province, the determined rate of silting per unit of watershed area would appear applicable to watershed areas of other reservoirs or prospective reservoir sites. This suggests perhaps the most practicable method of evaluating probabilities of storage depletion and useful life in the absence of individual reservoir-sedimentation surveys or adequate sediment records on the streams involved.

TABLE 1.—*Silting records of reservoirs of higher capacity-inflow ratio*

Reservoir	Stream	Location	Period	Annual accumulation per 100 square miles of drainage	Average annual capacity loss	Original storage capacity per square mile of drainage
				Acre-feet	*Percent*	*Acre-feet*
White Rock	White Rock Creek	Dallas, Tex.	1923–28	119.0	0.69	183.2
			1910–35	109.0	.80	
Elephant Butte	Rio Grande	Hot Springs, N. Mex.	1915–25	88.1	.88	100.3
			1925–35	50.7	.51	
Roosevelt	Salt River	Roosevelt, Ariz.	1911–25	125.2	.44	284.3
Lake Michie	Flat River	Durham, N. C.	1926–30	17.6	.24	75.7
			1926–35	27.1	.36	
Gibraltar	Santa Ynez River	Santa Barbara, Calif.	1920–31	71.4	1.06	67.5
			1931–34	325.3	4.82	
			1934–36	138.7	2.06	
Lake Worth	West Fork Trinity River.	Fort Worth, Tex.	1915–28	57.1	2.26	25.3
Lake McMillan [1]	Pecos River	Carlsbad, N. Mex.	1894–1915	8.8	2.14	[2] 4.1
			1915–25	1.6	.38	
			1925–32	1.0	.31	
Zuni	Zuni River	Black Rock, N. Mex.	1906–17	95.8	3.03	[3] 31.6
			1917–27	121.0	3.83	
Sweetwater	Sweetwater River	Sunnyside, Calif.	1888–95	80.7	.90	[4] 121.1
			1895–1916	71.0	.65	
			1916–27	95.8	.56	
Lake Chabot	San Leandro Creek	Oakland, Calif.	1875–1923	171.0	.43	401.8
Cheoah	Little Tennessee River.	Fairfax, N. C.	1918–30	22.7	.88	25.7
Ocoee No. 1	Ocoee River	Parksville, Tenn.	1912–30	184.9	1.14	161.7
O'Shaughnessy	Scioto River	Columbus, Ohio	1925–34	11.4	.68	16.9
Pine Lake	Pine Creek	Hardin County, Iowa	1921–32	151.6	3.15	48.1
Muskingum College.	Small stream	New Concord, Ohio	1915–35	37.5	1.28	29.4

[1] Enlargements made in 1909, 1911, 1912, and 1915.
[2] Although the ratio between storage capacity and drainage area is low, the capacity-inflow ratio is high because of the low rainfall in this section.
[3] At contour 1,000.
[4] Original capacity increased in 1895 by raising dam 5 feet, and in 1911 by raising dam an additional 15 feet.

Five of the reservoirs listed in table 1 were resurveyed in 1935–36. Gibraltar, White Rock, and Lake Michie by the Soil Conservation Service, Elephant Butte by the Soil Conservation Service in cooperation with the United States Bureau of Reclamation, and Roosevelt by the Salt River Valley Water Users' Association. In each of these cases, except Roosevelt (see below), the 1935–36 as well as the earlier data are given.

BASIN RESERVOIRS RESURVEYED IN 1935–36

White Rock Reservoir

White Rock Reservoir is on White Rock Creek, about 4 miles northeast of the center of Dallas, Tex., and is described in detail on pages 78–82.

In 1923 the city engineer's office of Dallas made a detailed survey of the capacity of the reservoir (*16, pp. 89–90*).[3] In this survey an accurate base line was laid out along the dam and from it a triangulation system of 13 stations covering the lake was set up. A closed transverse was run around the lake connecting all triangulation stations, and nine ranges for sounding were laid out in this survey net. Location of soundings taken from a boat were determined by transit and stadia or by intersection angles from two transits. Soundings were usually taken at intervals of 400 feet except near the old channel where the interval was less. From these data a contour map on a scale of 200 feet to the inch with 2-foot contours was constructed. The capacity of the lake in 1923 was computed on the basis of this map to be 16,896 acre-feet up to the 138.5 contour and 19,535 acre-feet up to the 140.5 contour. The original survey data were too meager to draw trustworthy conclusions on the total extent of silting to that date. However, according to Taylor (*16, pp. 90–91*):

> Some general facts were ascertained. Where the side branches entered the lake through broad-mouthed sloughs, evidence of silt was obtained by the disappearance of the channel and the growth of some form of vegetation. At the upper end of the lake cattails, willows, and other forms of plants have sprung up and they serve to clog the current, retard the flow, and cause silt to be deposited. As soon as the vegetation disappears, there is a sudden dropping off in the lake, indicating that the silt is slowly creeping down the lake. At the upper end of the lake, the channel had become obliterated from the bridge to about 900 feet down, where it was again evident and distinct.
>
> Up to 1923, silt had amounted to a fraction of 1 percent of the original capacity.

In 1928 Taylor, with the aid of W. J. Powell and party, made new soundings on the ranges of 1923. The results are given in some detail in the publication cited above. The volume of fill over the 5-year period, derived from resounding, was 680 acre-feet. This represents a storage loss of 3.48 percent between 1923 and 1928.

It is to be noted in table 1 that these earlier surveys of White Rock Reservoir, by the municipal water department of Dallas in 1923 and by Taylor (*16, pp. 91–92*) in 1928, showed a rate of 119 acre-feet of sediment a year per 100 square miles of drainage area over the intervening 5-year period, whereas the 1935 resurvey indicates an average rate of 160 acre-feet a year over the whole 25-year period of the reservoir's existence.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 152.

It is believed that these discrepancies in rates are more apparent than real. From the records of the earlier surveys as given by Taylor (*16, p. 91*) silting up to 1923 "had amounted to a fraction of 1 percent of the original capacity," and in 1928 "no evidence of any silt was found at section 5–6 or between the section 5–6 and the dam." (Section 5–6 is about 2 miles above the dam.) This seems to indicate that the earlier surveys discovered and took into account only the sediment of the delta deposits, whereas the 1935 survey included both the delta deposits and widely distributed bottom-set clays and silts that were found to extend throughout the main reservoir area all the way to the dam. Since the average percentage rate of fill over the full 1910–35 period has been but slightly less than 1 percent a year it seems clearly impossible that total accumulation during the first 13 years up to 1923 could have been less than 1 percent of the original reservoir volume. Also, the deposition of bottom-set clays all the way to the dam must have begun with the original flooding of the reservoir. It would appear likely that the greater part of the deposits of this class that were found to contribute much to the total volume of sediment in 1935 were actually in place between section 5–6 and the dam at the time of the 1928 survey.

Elephant Butte Reservoir

Elephant Butte Reservoir is on the Rio Grande in southern New Mexico, about 130 miles above El Paso, Tex. A description of the reservoir and its drainage basin is given on pages 90–99 in connection with findings of the 1935 survey.

Various data have been presented concerning earlier rates of silting of this reservoir. As an original index to probabilities, Lawson (*10, p. 372*) stated in 1925: "The silt content of the discharge at San Marcial, as determined by samplings and later by reservoir soundings, is approximately 20,000 acre-feet per annum." Taylor (*16, p. 68*) cites reservoir surveys of 1916, 1920, and 1925, giving accumulation to 1925 as 231,735 acre-feet, to 1920 as 140,000 acre-feet, and the accumulation to 1916 as 90,858 acre-feet less than that to 1920, or 49,142 acre-feet.

At variance with the data given in his context, Taylor (*16, p. 68*) gives in a special tabulation of data for a 104-month period, presumably from December 1916 to August 1925, an increment of silt of 177,740 acre-feet. Stevens (*15, p. 210*) also refers to an increment of 178,000 acre-feet for a period of 8.67 years from 1916 to 1925 which would appear to be the same data, stated in round numbers and in years instead of months. The actual accumulation during this period would appear to have been 182,593 acre-feet according to the statements of Taylor instead of the smaller figures given in his table and by Stevens. Furthermore, Stevens (*15, p. 211*) gives the total accumulation to 1920 as 90,900 acre-feet, whereas Taylor (*16, p. 68*) states specifically that "there had been a total accumulation of 140,000 acre-feet up to the time of the 1920 survey." Stevens also gives the volume of total silt in 1925 as 178,000 acre-feet instead of the 231,735 acre-feet given by Taylor in his tabulation of 1925 conditions, which agrees with the actual records of the United States Bureau of Reclamation at El Paso.

Stevens (*15, p. 210*), using the figures of 178,000 acre-feet of silt in 8.67 years, gives the average annual rate from 1916 to 1925 as 20,500 acre-feet. If the larger figure of 182,593 acre-feet for the same period, derived from Taylor's statements, is used, an annual rate of 21,060 acre-feet is indicated. The total of 231,735 acre-feet for the entire early period, from beginning of storage to the 1925 survey, would give an average annual rate of 21,903 acre-feet.

Taking the latest period alone, from 1925 to 1935, the accumulation of 133,451 acre-feet in 9.67 years gives an annual rate of 13,801 acre-feet. Adding the later period to the earlier, the general average rate for the 20.25 years from 1915 to 1935 would be 18,033 acre-feet.

At slight variance with published data in the reports of Taylor and Stevens, table 2 has been arranged from the latest compilation of statistics made from the official records, both of past surveys and the 1935 cooperative survey, as given by L. R. Fiock,[4] superintendent of the Rio Grande Project, United States Bureau of Reclamation. This table should, therefore, be considered as the latest authentic information available.

TABLE 2.—*Capacity changes and silt accumulation of Elephant Butte Reservoir*[1]

Date of survey	Period covered	Time	Reservoir storage	Silt deposit	Cumulative total silt	Reservoir inflow	Average reservoir inflow per year	Percentage of silt inflow	Average silt per year
		Years	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Percent*	*Acre-feet*
1903-8[2]	Original survey		2,638,800						
1916	January 1915–December 1916	1.91	2,584,805	53,095	53,095	3,005,750	1,573,065	1.80	28,270
1920	December 1916–August 1920	3.67	2,498,850	86,015	140,010	5,188,810	1,413,845	1.66	23,437
1925	August 1920–August 1925	5.0	2,407,125	91,725	231,735	5,651,742	1,130,348	1.62	18,345
1935	August 1925–April 1935	9.67	2,273,674	133,451	365,186	8,252,048	853,428	1.62	13,801

[1] From official records of Bureau of Reclamation and 1935 cooperative survey.
[2] Survey of basin at intervals before completion of dam.

There is, of course, considerable uncertainty as to whether the capacity given for 1915 is correct, inasmuch as it is taken to be the same as that indicated by the original surveys of 1903 to 1908. Some deposition in the valley probably occurred during this interim. Erosion had been accelerated in many parts of the watershed by 1908, and the Rio Puerco, in particular, is known to have begun delivery of abnormal quantities of sediment to the trunk valley by that time.

With respect to the validity of the indicated falling off in rate of silting of the reservoir proper since 1925, it should be noted that silting in the valley above the head of the reservoir has increased greatly during the later period. Silting in valley and reservoir combined in the 1925–35 period would undoubtedly equal and probably exceed the earlier deposition in the reservoir alone.

Furthermore, only the original surveys of 1903 to 1908 and the latest survey of 1935 covered the entire reservoir area. The surveys of 1916, 1920, and 1925, as stated by Taylor (*16, p. 67*), were made only "of the upper portion of the reservoir, where practically all the

[4] Personal communication from L. R. Fiock, dated November 9, 1935.

silt is deposited * * *." In the survey of 1925, according to Fiock,[6] the actual silt survey did not extend into the lower reaches of the reservoir below elevation 4,330 (project datum). The actual field survey was conducted over the reservoir above this elevation only and a percentage applied to the original storage capacity of the lower reservoir volume, presumably to correct it to the 1925 conditions.

It seems probable from the foregoing statement of Taylor that the phenomenon of underflow of muddy flood waters and its importance to selective deposition in the deeper portions of the reservoir were not recognized and taken fully into account in connection with the earlier surveys. If so, it would appear natural for earlier computers to have underestimated the fill of the lower part of the reservoir and, by the same amount, to have derived less than actual total volumes of sediment.

It is perhaps significant of the correctness of this suggestion that the complete survey of 1935 showed 20 percent less volume of storage remaining below contour elevation 4,320 than was calculated in 1925 and that 53 percent of total sediment in 1935 is in the lower 50 percent of the original reservoir volume.

While none of the foregoing average annual rates of silting can be considered precise in an absolute sense, a certain consistency appears that permits little question as to the general magnitude of the processes involved.

Roosevelt Reservoir

Roosevelt Reservoir is about 55 miles in a direct line, or 80 miles by road, a little north of east from Phoenix, Ariz. The dam is at the junction of Salt River and Tonto Creek, and the lake extends up both valleys.

The dam is a stone masonry structure 284 feet high above foundation and 1,125 feet in total length at the top. The lake, at gate level, originally extended over 18,300 acres and had a storage capacity of 1,637,300 acre-feet.

The drainage area is 5,760 square miles. Much of the area is covered by highly erodible soils underlain by loosely consolidated alluvial deposits or disintegrated granites. The latter are particularly prolific sources of coarse-grained sediment under present erosion conditions. Grazing in the basin under arid conditions has generally reduced natural vegetal protection of soils and resulted in greatly accelerated sheet and gully erosion.

The dam was completed and dedicated March 18, 1911. Water storage dates from near the beginning of the same year. The age of the reservoir in 1935 was 24 years.

A resurvey of Roosevelt Reservoir was made in 1925 by the Salt River Valley Water Users' Association to determine the extent of silting up to that time. The survey showed a total accumulation of 101,000 acre-feet of sediment, predominantly of coarser-grained type in the delta areas at the lower ends of Salt River and Tonto Creek Valleys. This gives an average annual rate of accumulation of 7,214 acre-feet, or 125.2 acre-feet per 100 square miles of drainage area.

A report on similar investigations at Roosevelt Reservoir by the supervisor of Tonto National Forest in 1924–25 gave total silt 106,262

[6] Fiock, L. R. Official correspondence, 1935.

acre-feet, 86,796 acre-feet in the Salt River Valley, and 19,466 acre-feet in Tonto Valley. This gives a rate of 131.8 acre-feet a year per 100 square miles of drainage area.

In this connection the forest supervisor reported as follows:

> My silt depth measurements were ascertained from the 124-foot water level, as the lake receded, checking various levels with topography and known landmarks. After the low-water level was reached, soundings checked against topography were also made. From the 124-foot water level on both Salt River and Tonto, silt depths to both heads of the lake were estimated from exposed trees, topography, and known landmarks. * * * The silt beds uncovered by the rapid lowering of the lake in 1925 show a decided even level trend of silt surface with a slope downstream largely in keeping with the natural fall of the river. The silt has a tendency to deposit deeper in the center of the lake than at the edges, leaving a slight oval effect if a cross section were available. In Salt River the deposit gradually thickened to a point E (4.8 miles above the dam) from nothing at the head of the lake to perhaps more than 20 feet at E. Owing to the lake being narrow and the current greater at this point, silt again flattens out only to gain in thickness before another narrow channel is reached at the 45-foot water level. Silt again flattens out in the narrow channel to increase in thickness rapidly until the dam is reached, for against the face of the dam the silt attains a thickness of 55 feet.

The various stages and processes of silting of Roosevelt Reservoir described above are shown in detail in plates 1 to 3, for which the photographs were furnished by T. T. Swift, supervisor of the Tonto National Forest.

The 1935 resurvey of Roosevelt Reservoir by the Salt River Valley Water Users' Association, as reported by T. A. Hayden, hydraulic engineer at the interbureau conference at Apache Lodge, Ariz., June 8, 1935, showed the original maximum water storage of 1,637,300 acre-feet to have been reduced to 1,528,500 acre-feet in 1935, which gives a total sediment accumulation to 1935 of 108,800 acre-feet. Taking from the later figure the 101,000 acre-feet of sediment shown by the 1925 survey, there remains 7,800 acre-feet as the total accumulation in the last 10 years. This would be equivalent to 780 acre-feet a year, or 13.5 acre-feet a year per 100 square miles of drainage area, in contrast with the annual increment 7,214 acre-feet or 125.2 acre-feet a year per 100 square miles during the 14-year period prior to 1925. This is in contrast also with the corresponding rates of 43 and 69 acre-feet, respectively, coming from the neighboring Gila and Rio Grande watersheds. However, the 1935 resurvey of Roosevelt Reservoir would appear to have been made under exceptionally favorable circumstances, at a time of extremely low water when the bottom of the reservoir was dry except under a small pool immediately above the dam. This should have permitted direct examination and mapping of the sediment deposits to any desired standard of accuracy.

Lake Michie

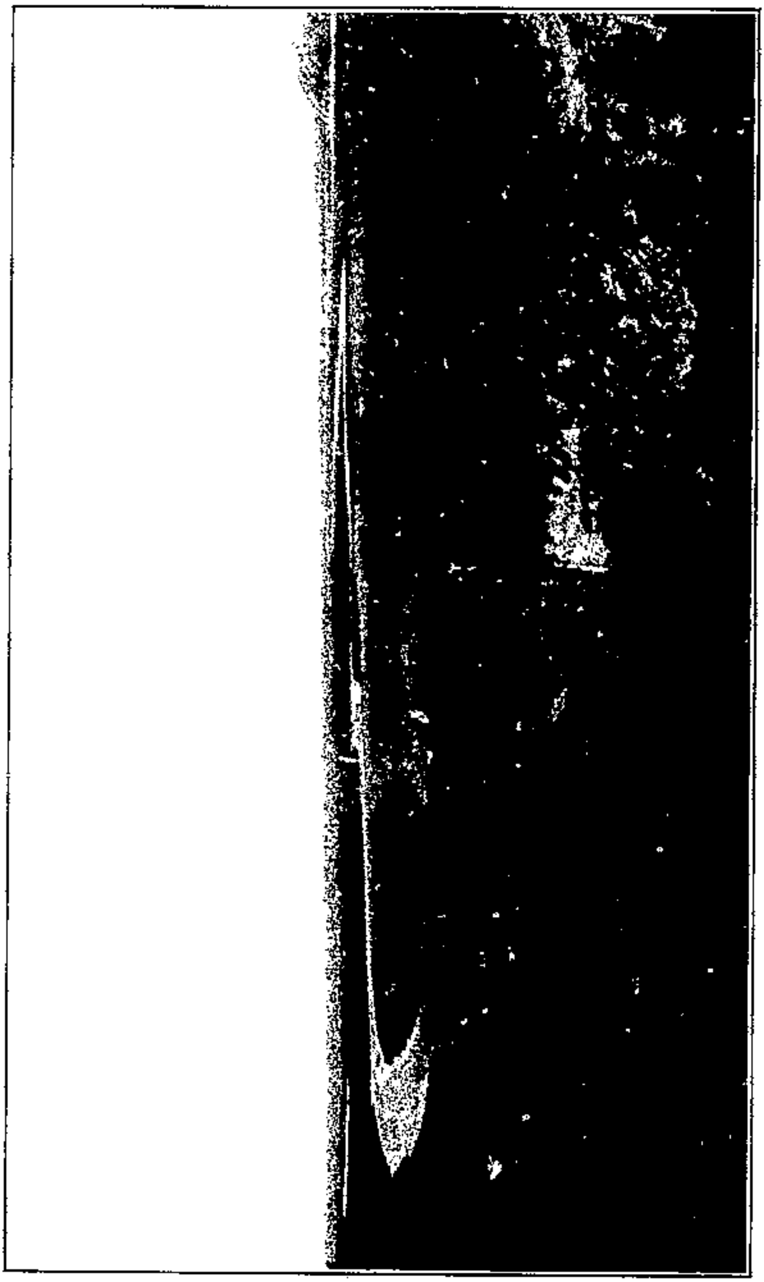
An earlier investigation of Lake Michie near Durham, N. C., covering the period 1926 to 1930, gave a rate of sediment production of 17.6 acre-feet per 100 square miles of drainage area as compared with a rate of 27.1 acre-feet determined by the 1935 resurvey by the Soil Conservation Service.

The earlier investigation was based upon comparative profile surveys of a number of ranges that were located and permanently marked prior to flooding of the reservoir basin. Of a whole series of

Roosevelt Reservoir, Salt River, Ariz.: *A*, Looking up Salt River arm at intermediate stage, showing high-water delta deposits entrenched and partly carried farther down in the reservoir by the stream. *B*, Successive stages of reexcavation of silt with falling stages of lake level; the silt is redeposited in deeper parts of the lake.

Roosevelt Reservoir, Salt River, Ariz.: A, Mud cracks on drying silt surface exposed by lake draw-down; background shows the great width and depth of mud fill. B, Intermediate delta being reexcavated and moved into deeper parts of lake.

Roosevelt Reservoir, Salt River, Ariz.: *A*, Remnant of fill held between branches of tree and indicating former height of sediment deposits. *B*, Sediment deposits around large cottonwood trees; trunks entirely buried, branches only showing above surface.



Lake McMillan, Pecos River, Carlsbad, N. Mex., under complete draw-down, September 1934. View upstream from dam, showing clay deposits, as much as 28 feet in depth, which form level to gently sloping plains over original topography of lake bottom. The left foreground is 9.7 feet higher than bottom sills of the outlet gates. Note fall of river from level of general fill approaching the outlet.

10 ranges thus located and surveyed in the fall of 1926, only the upper 5 ranges appear to have been resurveyed in October 1930 to give the data upon which the estimated rate of silting was based.

The 1935 resurvey of Lake Michie relocated 9 of the original ranges, 8 of which, together with some 24 new ranges, were used in determining the volume of sediment at that time. In this resurvey, chief reliance was placed upon direct measurements of sediment depths with special apparatus which is described in detail under the heading Range Method in the appendix.

In view of the facts that the 1935 resurvey covered all instead of only a part of the reservoir area, and that direct measurement of sediment depth gives more precise data than comparative range soundings alone, it is believed that the average rate of 27.1 acre-feet per 100 square miles of drainage is perhaps more truly significant of actual conditions of silting on Lake Michie than the lower figure referred to above.

The work and results of the 1935 resurvey of Lake Michie are described in detail in a later section of this report (pp. 31–35).

Gibraltar Reservoir

Gibraltar Reservoir is on the Santa Ynez River 4 miles north of Santa Barbara, Calif., for which it is a source of municipal water supply. A description of the dam and reservoir is given on page 113 with the discussion of the 1936 sedimentation survey by the Soil Conservation Service.

The drainage area, some 215 square miles in extent, is hilly to mountainous and is floored throughout with sedimentary formations that have formed deep and friable soils naturally protected against erosional attack by a cover of chaparral. Since the dam was completed in 1920, 11 fires have burned over different parts of the basin. In 1922, 8.8 square miles were burned over; in 1923, 64 square miles; in 1925, 14.3 square miles; in 1930, 1.2 square miles; in 1932, 19.9 square miles; and in 1933, 57.3 square miles, a total of 165.5 square miles, leaving only 49.9 square miles unburned.

Resurveys of the reservoir in 1931 and 1934 have shown progressive rates of silting corresponding with accelerated erosion increasing as additional areas of watershed were denuded of vegetal covering by fire. The data of these surveys, and also of the 1936 survey, revised somewhat as a result of the latest study, are given in table 3. The results of the 1936 survey indicate that there was a sharp decline in silting rate after 1934. This was due in large measure to a lower rate of inflow during the period 1934–36, and to the absence of fires.

Table 3.—*Progressive silting in Gibraltar Reservoir, Santa Barbara, Calif.*

Year	Lake area	Storage capacity	Time since preceding survey	Sediment accumulated in period	Average annual accumulation	Annual accumulation per 100 square miles of drainage	Average annual capacity loss
	Acres	*Acre-feet*	*Years*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Percent*
1920	325	14,500					
1931	283	12,608	11.75	1,802	153	71	1.06
1934	261	10,657	2.92	2,041	699	325	4.82
1936	256	10,180	1.58	471	208	130	2.06

BASIN RESERVOIRS WITH EARLIER RECORDS ONLY

Lake Worth

Lake Worth is on West Fork of the Trinity River, about 5 miles northwest of Fort Worth, Tex. The dam is an earth structure with concrete spillway, one-half mile long and 36 feet in maximum height above the old stream channel.

The reservoir was completed and storage began in the summer of 1915. A record of silting for a subsequent period of 13 years was established by a complete resurvey of the reservoir in 1928 by Dean T. U. Taylor of the University of Texas. According to Taylor (*16, p. 83*) the capacity was reduced by silting during this period from 47,177 acre-feet to 33,340 acre-feet or by a total sediment volume of 13,837 acre-feet.

The watershed is described by Taylor (*16, p. 82*) as follows:

> The watershed covers 1865 square miles of drainage area. The topography is rather rolling, perhaps one-third of it in cultivation, the rest being devoted to forestry and grazing purposes. A large part of the watershed area is composed of sandy soil and in some places reaches into the colloidal clays. The flood waters enter the Fort Worth Reservoir heavily charged with silt and of a chocolate or yellowish-brown color.

The mean annual rainfall at Fort Worth is 31.31 inches. The average reservoir inflow for the exact period of the silting record is unknown but is probably of the same order as the average of 211,800 acre-feet a year for a period of record from October 16, 1923, to September 30, 1930, cited by Stevens (*15, p. 213*). The maximum discharge during this period as reported by Stevens was 7,600 cubic feet per second on November 18, 1923.

In terms of sediment production from the watershed area above Lake Worth the total volume for the 13-year period determined by Taylor reduces to 57.1 acre-feet a year per 100 square miles of drainage area. (See footnote 33, page 145.)

The results of observations made in September 1934 and the probable effect of the construction of two large dams on the West Fork above Lake Worth are discussed on page 145.

Lake McMillan

Lake McMillan is on the Pecos River about 15 miles north of Carlsbad, N. Mex., and supplies water for the extensive irrigation project in the Pecos Valley below (pl. 4).

The dam is a rock-and-earth-fill structure with concrete spillway and a separate concrete structure with gate control for service outlet. The dam is 1,686 feet long and has a maximum height above original channel bottom of 52 feet.

A rather full record of the rates of silting in Lake McMillan has been established by repeated surveys of the reservoir by various agencies from time to time. Variations in rates of silting in the earlier part of this record are mainly a reflection of the general influence of an arid climate under which total rainfall is highly erratic from year to year. A notable falling off in the rate of silting of the reservoir proper during the latter part of the record points unmistakably to the influence of tamarisk or saltcedar growth in the valley at the head of the reservoir where it has greatly increased valley sedimentation above the lake level since 1915.

Table 4 presents the records of silting in Lake McMillan as given by Taylor (*16, p. 52*) for the periods up to 1925 and by the records of the United States Bureau of Reclamation for the 7-year period preceding the survey of 1932.

TABLE 4.—*Record of silting of Lake McMillan, Carlsbad, N. Mex., from 1893 to 1932*

Period covered	Length of period	Total sediment deposited	Deposits per year	Deposits per year per 100 square miles of drainage area
	Years	*Acre-feet*	*Acre-feet*	*Acre-feet*
1894-1904	10.42	18,000	1,730	7.80
1904-10	6.42	10,000	1,560	7.10
1910-15	4.58	13,400	2,920	13.30
1915-25	10.00	3,500	350	1.60
1925-32	7.00	1,500	215	.08

Table 4 is of particular interest in its reflection of the changing rate of valley sedimentation above the dam due to the accidental introduction and spreading of tamarisk or saltcedar growth.

The tamarisk, or so-called saltcedar, is a native tree of western Europe which grows as far east as the Himalayas. It is highly tolerant of saturated alkali soils and when once established appears to be very drought-resistant. In many sections of southwestern United States, including the Pecos Valley in the vicinity of Lake McMillan, it is self-propagating from seed which is spread by floods and which germinates selectively in the fresh sediment deposits near reservoir or river level.

Prior to 1912 the Pecos Valley above Lake McMillan was practically devoid of vegetation other than low-growing saltgrass. In the fall of 1912 the first few seedlings of saltcedar were observed on the mud flats at the head of the reservoir and along the Pecos River for several miles upstream, the seed presumably having come from parent trees planted a few years previously for ornamental purposes around certain home sites. By 1915 the seedlings had grown to heights of 3 to 5 feet and new seedlings had started over large additional areas. Since then the growth has become very dense over the whole upper end of the reservoir and along the river for some 200 miles upstream, generally forming impenetrable thickets and in places growing as high as 20 or 25 feet.

The general effect of this new vegetative development is, as indicated by table 4, a reduction in the average rate of silting from 1,882 to 294 acre-feet for the 22- and 17-year periods of record, respectively, before and after the 1915 survey. During the latter period the continuing increase in effectiveness of the growing vegetative screen is shown by a decrease in average rate from 350 to 215 acre-feet, comparing the 10-year period 1915–25 with the 7-year period 1925–32. In terms of sediment per unit of drainage area the last 7-year period indicates a falling off to the low figure of less than 1 acre-foot a year per 100 square miles of drainage area. The corresponding improvement in the outlook for the future useful life of the reservoir is, of course, at a sacrifice of any agricultural interests in the lower part of the valley above the reservoir. Fortunately, in this case, such lands had very little original value, so that the saving of reservoir storage from further depletion is almost completely a net economic gain.

The accidental development of the saltcedar screen at Lake McMillan serves as an important demonstration of the fact that new valley vegetation can induce a major change in the rate of reservoir silting. This would appear to point the way quite definitely to real possibilities of sediment control by vegetative means. Intentional use of vegetation to induce silting above the heads of reservoirs has not yet entered into reservoir practice. To develop such a practice by appropriate studies of available species and experimentation with appropriate supplemental engineering works would appear eminently justified by the magnitude and import of the present-day silting problem in the Southwest and in other localities where natural vegetation alone does not answer.

ZUNI RESERVOIR

Zuni Reservoir is on the Zuni River, a tributary of the Little Colorado at Black Rock, N. Mex. It supplies water for an average of about 1,500 acres of valley lands under the main irrigation project of the Zuni Indian Reservation. The average annual draft on the reservoir is about 4,500 acre-feet.

The reservoir as originally impounded in 1906 had a capacity of 15,811 acre-feet below spillway level at contour 1,000. By 1927, after 20 years use, silting had reduced this capacity to 4,256 acre-feet or just about the mean annual draft. By 1929 this had been further reduced to 3,652 acre-feet. By 1930 the capacity below spillway level at contour 998.3 was 2,600 acre-feet.

The record of silting of Zuni Reservoir is unique in that capacity surveys have been made almost every year since the beginning of storage in 1910. Table 5, kindly furnished by the Indian Irrigation Service, gives this record in detail up to 1929.

TABLE 5.—*Silting of Zuni Reservoir, 1906–29*

Year	Total silt deposit	Length of period	Silt deposit for period	Periodical run-off	Percentage of silt in run-off remaining in reservoir	At contour 990 [1]: Capacity	At contour 990 [1]: Percentage of original capacity	At contour 990 [1]: Percentage of original capacity lost per year	Present maximum at contour 1,000: Capacity	Present maximum at contour 1,000: Percentage of original capacity	Present maximum at contour 1,000: Percentage of original capacity lost per year
	Acre-feet	*Years*	*Acre-feet*	*Acre-feet*	*Percent*	*Acre-feet*	*Percent*	*Percent*	*Acre-feet*	*Percent*	*Percent*
1906				38,000	------	10,230	------	4.4	15,811	------	2.9
1907											
1908				18,110	------	------	------	4.4	------	------	2.9
1909						------		4.4			2.9
1910	1,804	4	1,804	21,630	3.20	8,409	82.30	8.8	14,007	88.4	5.7
1911	3,144	1½	1,340		6.40	7,069	69.20	8.8	12,667	80.0	5.6
1912				4,030			------	5.2		------	3.3
1913	4,200	2	1,056	10,330	7.30	6,013	58.80	5.2	11,611	73.4	3.3
1914				21,150	------	------	------	3.2	------	------	1.9

See footnotes at end of table.

TABLE 5.—*Silting of Zuni Reservoir, 1906-29*—Continued

Year	Total silt deposit	Length of period	Silt deposit for period	Periodical run-off	Percentage of silt in run-off remaining in reservoir	At contour 900 [1]			Present maximum at contour 1,000		
						Capacity	Percentage of original capacity	Percentage of original capacity lost per year	Capacity	Percentage of original capacity	Percentage of original capacity lost per year
	Acre-feet	*Years*	*Acre-feet*	*Acre-feet*	*Percent*	*Acre-feet*	*Percent*	*Percent*	*Acre-feet*	*Percent*	*Percent*
1915				54, 811				3. 2			1. 9
1916				146, 588				3. 2			1. 9
1917	5, 507	4	1, 307	3, 777	. 58	4, 706	46. 00	3. 2	10, 304	65. 8	1. 9
1918	6, 185	1	678	5, 323	12. 50	4, 028	39. 30	6. 7	9, 626	60. 8	5. 0
1919	7, 433	1	1, 248	46, 473	2. 66	2, 801	27. 30	12. 0	8, 202	53. 0	7. 8
1920	9, 296	1	1, 863	46, 711	4. 00	2, 503	24. 50	2. 8	7, 308	41. 3	11. 7
1921	10, 589	1	1, 291	6, 770	19. 00	1, 666	16. 28	8. 2	6, 114	38. 2	3. 1
1922				22, 723				2. 1			1. 9
1923	11, 271	2	684	20, 375	2. 90	1, 248	12. 10	2. 1	5, 430	34. 3	1. 9
1924	11, 388	1	117	8, 865	1. 30	1, 074	10. 50	1. 6	5, 313	33. 6	. 7
1925	11, 653	1	265	2, 645	1. 00	925	9. 04	1. 5	5, 048	31. 9	1. 7
1926	11, 839	1	186	4, 981	. 38	728	7. 11	1. 9	4, 802	30. 7	1. 2
1927	11, 940	1	606	16, 017	. 38	541	5. 29	1. 8	4, 256	26. 9	3. 8
1928	11, 555	1	(4)	55, 377	(5)	656	6. 40	(6)	4, 509	29. 9	(6)
1929	12, 066	1	511	38, 000	1. 34	145	1. 40	2. 1	3, 652	23. 1	3. 3

[1] Elevation 997, top of weir—gage 44.8; elevation 998.3, top of stop logs—gage 46.1; elevation 1,000—gage 47.8. Dam not yet high enough to carry water above 1,000.
[2] January 1908 to June 1910. [3] June 1910 to Jan. 1, 1912. [4] None. [5] Loss. [6] Gain.

It should be noted that the record subsequent to 1927 has been so complicated by extensive wastage of sediment over and through the dam and by sediment detention in tributary valleys above the head of the reservoir that it has no definite bearing on the general rates of erosion in the watershed. By 1928 the capacity had been so reduced that the exceptional floods of that year resulted in no net increment in reservoir sediment accumulation. In view of this feature of the record, data on only the period up to and including 1927 were included in table 1, giving average rates of sediment production in drainage areas above basin reservoirs.

This remarkable history of silting occurred despite protective works for sediment detention in the Nutria Valley section of the drainage basin, begun in 1922. This work has consisted of construction of two sediment-detention dams, one-quarter to one-half mile long and 11 and 14 feet in height, respectively, across Nutria Valley, 10 to 25 miles above the reservoir. A similar dam has been built on Horsehead Creek, 850 feet long, 36 feet in height above the arroyo bottom, and 11 feet above the general valley level. Each dam is equipped with a low-placed culvert to feed slowly into the lower valley waters stored below spillway level. They are both located at sites favorable for construction of a natural bedrock spillway through marginal uplands. Both dams have wide valleys upstream and will undoubtedly store immense volumes of sediment at a cost much less than the value of the reservoir-storage capacity they will conserve. In addition, they will afford considerable auxiliary water storage directly during the time they are being silted, and perhaps indirectly, underground, thereafter.

This highly commendable sediment-detention practice seems susceptible to greatly expanded application above the many major storage reservoirs that otherwise must face the certainty of unduly rapid extinction.

The capacity of Zuni Reservoir, 2,600 acre-feet below contour 998.3 in 1930, was enlarged in 1931 by sluicing sediment out of the reservoir through a new, improvised lower outlet gate. It was estimated at the time that some 500 acre-feet of sediment was wasted. Upon the basis of a resurvey in 1932, it appears that 628.8 acre-feet of sediment in all was actually evacuated as a result of this practice. This significant incident in the history of Zuni Reservoir is described in the following excerpt from a report of the acting supervising engineer, Indian Irrigation Service, under date of November 20, 1931:

Realizing that the reservoir would soon be filled with silt and its usefulness for irrigation purposes would be lost, authority was requested to use funds appropriated for the Zuni Project to install a larger gate in the gate tower of the Zuni dam. As originally constructed, there were three 14-inch gates installed in the tower. As silt and debris accumulated in the reservoir, two of these gates became clogged and efforts to clear them were unsuccessful. On July 1, 1931, the reservoir was at extremely low stages and steps were taken immediately to install a gate four feet by six feet. The elevation at which the gate was installed was 950 and the tunnel or conduit through the dam was six feet in diameter.

The work of making the opening was accomplished by the use of an air compressor and jack hammers. The size of the opening was outlined and the gate tower wall, which is 18 inches thick at the base, was gradually removed until only a thin shell remained. Holes were bored in the remaining section and ten charges of dynamite placed at different locations around the outline of the proposed opening and the charge set off by an electric detonator. The aperture made in the dam was not of the size originally intended, but resulted in an opening of about two feet by three feet. The edges of this opening were very ragged and did not allow a free flow of water and silt as would have resulted with a larger opening with smooth sides. However, immediately following the blast there was a flow of water about equal to the capacity of the tunnel, due to the pressure of some 40 feet of water. The water flowed for a few minutes, carrying approximately fifty percent of silt. A silt slide occurred, choking off the water entirely, and the silt continued to flow for about ten minutes. This was followed by another rush of water, heavily laden with silt, until the reservoir was practically empty. Silt again slid and choked off the water and flowed for approximately fifteen or twenty minutes, entirely filling the tunnel and sluiceway below. This was followed by a flow of water until the reservoir was empty. This was again followed by a flow of mud, and continued until the tunnel and sluiceway were entirely blocked. The tunnel and sluiceway remained blocked for about three days until the seepage in the tunnel completely saturated the silt, the silt in the sluiceway was removed by hydraulic methods, using 1½-inch pipe connected with the main water supply for the school.

During the first flood, the opening in the gate tower was completely closed with rock and debris and it was necessary to dislodge this by placing a charge of dynamite in the opening, at which time it was made larger.

Silt sluiced from the reservoir filled the canyon immediately below the sluiceway to a depth of three feet for a distance of 700 to 800 feet, gradually tapering from this depth to the grade of the river five miles below. Evidence of silt which has been removed from the reservoir is found at a distance of some forty to fifty miles below the dam. There seems to be no danger of filling the river bed to a depth which would cause overflow of the lands as during the rainy season there is usually sufficient water to carry the silt for a great distance and in turn will gradually be carried into the Little Colorado River. From a point immediately below the dam to the Zuni village, a distance of four miles, the banks of the river will average about ten feet deep.

Due to summer rains which followed immediately after the opening was made in the tower, the installation of the gate was delayed until October 15. While the rainfall on the watershed was somewhat below normal, the runoff was very gradual and materially aided in sluicing silt from the reservoir.

It was believed at first that one deep channel would be sluiced through the reservoir, the water flowing in the shortest distance from where it entered the reservoir to the point of discharge to the gate tower, but due perhaps to the gradual run-off, the water assumed three different courses; first, along the north side of the reservoir, thence through the center, and finally around the south side, taking the longest possible course. At extreme flood stages the water flowed in all three channels and at times covered practically the entire surface area of the reservoir, thus removing considerable silt from the entire area below contour 990 and on the south-center side of the reservoir from elevation 990 to 970.

The high rate of silting of Zuni Reservoir reflects an advanced stage of arroyo and gully development and severe sheet erosion in this general region. Deep arroyos are generally prevalent, wide in the lower valleys and relatively narrow, but even deeper in headwater basins. Gullies of the latter type 20 feet deep and only 5 or 6 feet wide have been noted. It is said that Indians now living recall the general absence of these erosional features at the time of their youth, indicating that the arroyos and gullies have developed almost entirely within the last 40 or 50 years. The trees of the Zuni Reservation also are said to have shown slower growth—narrower annual growth rings—for the last 50 years. It is probably significant that sheep raising was introduced about 50 years ago and large flocks have been grazed on the reservation continuously since that date.

Sweetwater Reservoir

Sweetwater Reservoir is on the Sweetwater River near Sunnyside, San Diego County, Calif. The dam was built in 1888 to a height of 70 feet above original river level and has since been raised, 5 feet in 1896 and 15 feet in 1915.

Capacity surveys of the reservoir were made from time to time up to 1927 to determine the condition of the reservoir with respect to silting. Table 6 shows the rates of silting for selected periods from 1888 to 1927 and the total cumulative effects of the process. This information is compiled from a tabulation of the Sweetwater Water Corporation.

Table 6.—*Rates of silting in Sweetwater Reservoir, Calif.*

Period	Spillway elevation above sea level	Time since preceding survey	Total accumulation during period [1]	Annual accumulation
	Feet	*Years*	*Acre-feet*	*Acre-feet*
1888–95	210.11	7	1,137	162
1895–1916	224.11	21	2,814	134
1916–27	230.11	11	1,903	173

[1] Accumulation below spillway elevation indicated for period. Sum does not equal total accumulation of 7,303 acre-feet below elevation 230.11 for entire period.

The watershed embraces an area of 181 square miles, composed for the most part of chaparral-covered mountain slopes but with some cleared land in the lower valleys. Rainfall is very irregular. Total inflow for the 39-year period, during which 7,303 acre-feet of sediment accumulated below elevation 230.11, amounted to 740,000 acre-feet of water, giving an average sediment content of 0.99 percent by volume. Inflow varied from an average of 1,032 acre-feet a year for the 9-year period 1895–1904 to 160,000 acre-feet for a 12-month period in 1915 and 1916.

The average sediment production from the watershed for the 39-year period of record, based on the total accumulation below spillway elevation 239.11 for the entire period, would appear to have been 103.5 acre-feet of sediment a year per 100 square miles of drainage area.

Lake Chabot

Lake Chabot is on San Leandro Creek near San Leandro, southeast of Oakland, Calif. The following notes are given by Stevens (*15, p. 214*):

> The drainage area [42 square miles in extent] is densely covered with brush and redwood. Capacity surveys referred to Spillway Gauge 83.5 are: For 1875, 17,000 acre-feet; for 1900, 15,500 acre-feet; for 1911, 13,800 acre-feet; and for 1923, 13,500 acre-feet.

Total inflow during the 48-year period of record, during which 3,500 acre-feet of sediment accumulated, was 854,000 acre-feet, giving an average sediment content of 0.41 percent by volume.

Computation of the average sediment production in the watershed, based on data given by Stevens (*15, p. 210*), show that the rate for the 48-year period of record was 174 acre-feet a year per 100 square miles of drainage area.

Guernsey Reservoir [6]

Guernsey Reservoir, which began storage in July 1927, is on the North Platte River about 2 miles northwest of Guernsey, Wyo. Its drainage area, excluding the 12,000 square miles above Pathfinder Reservoir, 150 miles upstream, is 4,200 square miles.

The dam, a gravel and rock-fill structure with a clay core wall, is 560 feet long and 105 feet in height above the stream bed. The reservoir formed by the dam is 13 miles long and has a surface area at spillway level (elevation 4,420) of 2,336 acres. The original storage capacity above the penstock inlet sill at elevation 4,360 was 71,060 acre-feet; and above the base of the Stoney gates in the spillway, at elevation 4,370, it was 67,570 acre-feet. The total original capacity, including live and dead storage, was computed as 74,260 acre-feet.

Sedimentation surveys of Guernsey Reservoir were made by the United States Bureau of Reclamation in 1929, 1931, 1933, 1935, and 1937. The progressive loss of capacity between elevations 4,370 and 4,420 is shown in table 7.

TABLE 7.—*Progressive silting in Guernsey Reservoir, Guernsey, Wyo.*

Year	Time since preceding survey	Sediment accumulated during period	Usable storage capacity	Year	Time since preceding survey	Sediment accumulated during period	Usable storage capacity
	Years	*Acre-feet*	*Acre-feet*		*Years*	*Acre-feet*	*Acre-feet*
1927			67,570	1933	2	2,400	59,170
1929	2	3,000	64,570	1935	2	1,870	57,300
1931	2	3,000	61,570	1937	2	2,690	54,610

According to table 7, the total loss of capacity above elevation 4,370 in 1937 was 12,960 acre-feet, or about 19 percent. At the time of the

[6] The data on this reservoir were supplied by the United States Bureau of Reclamation, in an unpublished report on sedimentation surveys of Guernsey Reservoir and in communications from the commissioner.

1937 sedimentation survey the total volume of sediment in both live and dead storage was determined to be 16,780 acre-feet. These figures indicate that 3,820 acre-feet of sediment had been deposited below elevation 4,370, displacing about 57 percent of the 6,690 acre-feet of essentially dead storage below this level.

As the period of storage up to the 1937 survey was 9.4 years, the average annual total accumulation in Guernsey Reservoir was 1,785 acre-feet. This is equivalent to an annual total capacity loss of 2.4 percent, and to a sediment production of 42.5 acre-feet per 100 square miles of drainage area.

Cheoah Reservoir

Cheoah Reservoir is on the Little Tennessee River 5 miles west of Fairfax, N. C. It is formed by a concrete arch-gravity dam 700 feet long and 180 feet in height above the stream bed. The dam was completed in 1919.

The original storage capacity was approximately 41,600 acre-feet. A survey to determine the amount of sediment in the upper 2½ miles of the reservoir was made by the Aluminum Co. of America in 1922 and a complete survey was made by the United States Army engineers in the fall of 1930. This latter survey showed 4,350 acre-feet of sediment deposited during the 11.83 years the reservoir had been in existence (*15, p. 210*).

The average sediment production from the 1,620 square miles in the drainage basin is computed as 22.7 acre-feet a year per 100 square miles of drainage area.

Ocoee No. 1 Reservoir

Ocoee No. 1 (Parksville) Reservoir is on the Ocoee River at Parksville, Tenn. It is formed by a concrete dam completed in 1912.

The drainage basin covers 600 square miles, of which 70 percent is in forest, but about 20 square miles are completely devoid of vegetation. This area contains the Ducktown mining district, where in former years the poisonous gases that came from roasting large quantities of sulphide ores in open heaps killed off the vegetation. As a result erosion is extremely severe and the area contributes a large amount of sediment to the Ocoee River.

The reservoir had an original capacity of approximately 97,000 acre-feet and an area of 2,000 acres. Surveys of the upstream half of the reservoir were made in 1917, 1921, and 1929 by the Tennessee Electric Power Co. A survey of the entire reservoir was made by the United States Army engineers in the fall of 1930. This survey showed a deposit of 20,800 acre-feet of sediment accumulated in the 18.75 years (*15, p. 210*).

The average annual sediment production of the watershed is computed as 185 acre-feet per 100 square miles of drainage area.

O'Shaughnessy Reservoir

O'Shaughnessy Reservoir is on the Scioto River 16 miles north of Columbus, Ohio. The dam, completed in the fall of 1925, is a concrete-masonry structure of the gravity overflow type, 1,750 feet long, including approaches. The crest of the spillway is 84 feet in height above the rock foundation. The reservoir has a surface area of 829 acres and a drainage area of 988 square miles.

A sedimentation survey of the reservoir was made in 1934 under the general supervision of C. E. Sherman, professor of civil engineering at Ohio State University. The original capacity of the reservoir was determined as 16,673 acre-feet. In the 9 years between the time the reservoir was completed and the survey 1,016 acre-feet of sediment, representing 6.1 percent of the original capacity, had accumulated (*4, pp. 511–512*). This gives an average annual rate of accumulation of 11.4 acre-feet of sediment per 100 square miles of drainage area.

Pine Lake

Pine Lake is on Pine Creek in Eldorado-Pine Creek State Park, Hardin County, Iowa. Water was first impounded in 1924 by a semicircular concrete spillway and bridge with earth embankments at either end. The reservoir, built for recreational purposes, had an original storage capacity of 738 acre-feet and a surface area of 65 acres.

A sedimentation survey of this reservoir was made during the winter of 1932, and a brief summary of the results, together with data on other southern Iowa reservoirs, were submitted by G. A. Marston as a thesis at the State University of Iowa. The records of the survey show 186 acre-feet of sediment, representing 25.2 percent of the original storage capacity, accumulated in the 8-year period.[7]

The average annual rate of sediment production from the drainage area of 15.34 square miles is determined as 151.6 acre-feet per 100 square miles of drainage area.

Muskingum College Reservoir

Muskingum College Reservoir is on a small stream on the campus of Muskingum College at New Concord, Ohio. It is approximately 0.94 acre in area and had an original storage capacity of about 9.41 acre-feet. The dam is of earth-fill type, 150 feet long, and was constructed in 1915.

A sedimentation survey was made in 1935 by R. H. Mitchell and G. Robert Hall, of Muskingum College. In a period of 20 years, from the date of construction to the time of survey, 2.36 acre-feet of sediment was deposited. This amounts to an average rate of sediment production of 37.5 acre-feet per year per 100 square miles of drainage area for the 0.32 square mile of watershed area.

CHANNEL AND OTHER RESERVOIRS OF SMALL CAPACITY-INFLOW RATIO

Table 8 lists the reservoirs of relatively low capacity-inflow ratio that have been studied in the past by various agencies with respect to rates of silting. The computations of original storage capacity per square mile of drainage area and average annual rates of silting expressed in acre-feet per 100 square miles of drainage area and in per-

[7] Marston, G. A. Sedimentation in southern Iowa reservoirs. Unpublished master's thesis, University of Iowa, 75 pp., 1933.

centage of original capacity are based for the most part upon Stevens' (*15, p. 210*) tabulation of records of American reservoirs for which amount of silting has been measured.

TABLE 8.—*Silting records of reservoirs of lower capacity-inflow ratio*

Reservoir	Stream	Location	Period	Original storage capacity per square mile of drainage	Annual accumulation per 100 square miles of drainage	Average annual capacity loss
				Acre-feet	*Acre-feet*	*Percent*
Coon Rapids Pond	Mississippi River	Anoka, Minn	1899–1931	0.4	0.4	1.08
New Lake Austin	Colorado River	Austin, Tex	1913–26	.8	6.1	7.35
Old Lake Austin	do	do	1893–1900	1.3	9.2	7.10
Lake Penick	Clear Fork, Brazos River.	Lueders, Tex	1920–27	1.4	6.1	4.47
La Grange	Tuolumne River	La Grange, Calif	1895–1931	1.6	3.6	2.31
Sterling Pool	Rock River	Sterling, Ill	1912–30	1.6	1.3	.82
Holtwood	Susquehanna River.	McCalls Ferry, Pa.	----------	2.1	2.7	1.32
Boysen	Bighorn River	Fremont County, Wyo.	1911–24	2.1	12.9	6.25
Schoolfield	Dan River	Danville, Va	1904–15	2.1	15.4	7.32
Keokuk	Mississippi River	Keokuk, Iowa	1891–1928	3.1	6.3	2.02
Furnish	Umatilla River	Pendleton, Oreg	1909–31	4.6	17.1	3.73
Loch Raven	Gunpowder River	Baltimore, Md	1880–1900	5.1	21.6	4.24
Lower Salt Creek	Salt Creek	Natrona County, Wyo.	1924–33	5.2	56.2	10.79
Hales Bar	Tennessee River	Guild, Tenn	1913–30	7.2	12.3	1.72
Buckhorn	Buckhorn River	Loveland, Colo	1907–25	9.2	24.2	2.64

The arrangement of table 8 in the order of increasing original storage capacity per square mile of drainage area brings out the general tendency of the annual sediment accumulation to increase as this ratio increases. The weight of evidence indicates that the larger the reservoir relative to the size of the drainage area the more complete the desilting of inflowing waters, and hence, in many cases, the greater the actual volume of sediment deposited.

On the other hand, the average annual depletion of storage capacity fails to show any definite relation to the ratio of capacity to drainage area (or inflow); but, taken as a whole, the reservoirs of lower capacity-inflow ratio listed in table 8 have a much greater annual capacity loss than the reservoirs of higher ratios listed in table 1. The absence of a definite relation between the capacity-inflow ratio and annual capacity loss among the reservoirs with a low ratio is believed to indicate the much greater effect of relatively small differences in run-off and factors affecting the rate of sediment production in their respective drainage areas. Such differences are reflected in the percentage of sediment bypassed through or over the dam, which varies greatly in different reservoirs with the volume of inflow and character and amount of sediment load, as well as with the length and shape of the reservoir. Reservoirs of this class are, therefore, in contrast with reservoirs of high capacity-inflow ratio, which afford nearly complete desilting under a wide range of inflow and sediment-load conditions—at least until they reach such an advanced stage of silting that they become more like the channel-type reservoirs. Thus reservoirs with low capacity-inflow ratio, while being more sensitive to differences in drainage-area characteristics, offer little or no index to these differences which are clearly reflected in basin-type reservoirs that retain most of the incoming sediment.

The principle of dependence of rate of silting upon the capacity of the reservoir has been recognized by Taylor (*16, p. 37*). After stating that "the silting of reservoirs is generally erratic and spasmodic and is confined to the flood periods," he proceeds with the development of a mathematical expression of companionate waning of capacity and rate of silting in reservoirs receiving discharge of alluvial streams. Based upon the assumption, made to simplify analysis, that silting is a regularly progressive phenomenon, his formula indicates progressive reduction in rates of silting as capacity is depleted.

The general validity of this principle is apparently supported even by the histories of some low capacity-inflow reservoirs, such as the two built successively at the same site on the Colorado River at Austin, Tex. The rates of silting above the old and new dams, respectively, have been computed as 9.2 and 6.1 acre-feet a year per 100 square miles of drainage area. The higher rates of silting in the old reservoir relate to the original and final capacities of 49,300 and 25,777 acre-feet from 1893 to 1900, compared with corresponding capacities of 32,029 and 1,477 acre-feet for the new reservoir from 1913 to 1926. The original capacity of the new reservoir was 65 percent and its rate of silting 67 percent of corresponding features of the old dam.

The final limiting condition approached by such companionate waning of capacity and rates of silting apparently must be a moderate residual capacity and zero rate of silting. The final capacity would be that of the volume of an adjusted alluvial flood channel through the filled reservoir, subject, perhaps, to temporary reduction by sedimentation in low-water season and restoration to the same general dimension with each succeeding flood. Under these conditions the low-water silting would be temporary and result in no permanent increase in sediment accumulation from flood to flood.

Inasmuch as the rates of silting of channel and other reservoirs of low capacity-inflow ratio relates to fractional desilting of inflowing water, each reservoir of its general class is more or less a law unto itself as to the relation of its life expectancy to past records. The data of periodic capacity surveys of these reservoirs are thus useful chiefly as a basis of individual forecast. However, in each case, they may be studied to advantage in relation to general land use and policy of erosion control, in the respective watershed areas. In final analysis, it appears that only through reduced production and delivery of erosional waste, particularly of coarser-grained nonsuspensible character, by improved land use and erosion control in the drainage basins of such reservoirs, can effective progress be made toward improving their condition and the prospects for longer periods of useful life.

RESERVOIR SURVEYS BY THE SOIL CONSERVATION SERVICE IN 1934–36 [8]

FIELD WORK

The general project of reservoir investigations was initiated by the Soil Conservation Service July 15, 1934, with instructions to H. M. Eakin to proceed with a general survey of previous work in this

[8] The results of work in 1936–38 on reservoirs described in the original edition are included in this revision. In addition, data on other reservoirs surveyed in 1936–38 are included in table 13.

field, with further development of the problem and optimum methods of study, and with selection and organization of personnel for at least three field parties to make detailed reservoir surveys in the southeastern, southern Great Plains, and southwestern type areas of the country. Subsequent extensions of the work to the northeastern and northwestern parts of the country were contemplated.

Under these instructions Eakin first made a general field reconnaissance of the three southerly type areas, visiting in all 87 reservoirs in North Carolina, South Carolina, Georgia, Alabama, Texas, New Mexico, Arizona, and California. In connection with this preliminary work, detailed studies were made of the municipal reservoirs of Greensboro and High Point, N. C., Spartanburg, S. C., and Rogers, Tex., and the methods and apparatus for direct measurement of sediment depth, that have been used extensively in subsequent work, were developed.

In this earlier reconnaissance work Eakin was assisted by L. M. Glymph, Jr., assistant agricultural engineer of the Spartanburg regional office, who was later assigned as assistant to Thomas L. Kesler, chief of the Great Plains party. The southeastern area was assigned to Carl B. Brown and D. Hoye Eargle, and the southwestern area to Raymond C. Becker and Fred E. Tardy, as chief of party and assistant, respectively, in each case. Each party was increased to six men by assignment of personnel from the various regional offices of the Service. These parties began work in their respective fields in late December in the southeast, and in early January in the Great Plains and southwest areas. The subsequent results achieved by each party appear in the accounts of detailed reservoir surveys in their respective areas up to July 1, 1936, as given in the following sections of this report.

The Elephant Butte survey was made with the cooperation of the United States Bureau of Reclamation, through the El Paso office in charge of Supt. L. R. Fiock. The field work was done under the direction of Herbert W. Yeo, of the Albuquerque regional office of the Soil Conservation Service.

In addition to this field program, an original capacity survey of Lake Mead, on the Colorado River, was undertaken by the Soil Conservation Service with the cooperation of the United States Bureau of Reclamation at Boulder City, Nev., Walker R. Young, construction engineer in charge; and of the Coast and Geodetic Survey, represented in the field by Gilbert R. Fish and Charles Pierce, in charge of vertical- and horizontal-control surveys, respectively. Detailed topographic mapping of certain flatter areas of the reservoir basin and other necessary observations, undertaken by Bureau of Reclamation personnel, were in charge of Engineer R. C. Thaxton, of that Bureau. The aerial photography, detailed control surveys, stereoplanigraphic contouring, and assemblage of the final complete map of the reservoir have been done under contract with a commercial concern. The maps have now been lithographed and work is proceeding on computation of the original capacity.

METHODS OF SURVEY

Surveying operations were designed and have been executed to attain two immediate objectives: (1) To measure as accurately as possible within reasonable time limitations the total volume of sediment accumulated to date, and to determine its distribution, its relation to capacity and age of the reservoir, and to size of drainage area; and (2) to establish a permanent system of monuments which future surveys may utilize from time to time for comparing variations in rates of silting as reflecting change in erosional conditions, either from human acceleration or from retardation through erosion control.

The plan of surveying is based on detailed and experimental work by Eakin during the summer of 1934, and was developed to a large extent during surveys of Spartanburg Reservoir in South Carolina, and High Point and Greensboro Reservoirs in North Carolina. The Instructions for Reservoir Sedimentation Surveys given in the Appendix are substantially the same as those issued to party chiefs when the present program of detailed surveys was inaugurated in January 1935. Minor modifications have been made from time to time to incorporate improvements developed by the field parties. The instructions have been rigorously followed except where unusual and unforeseen conditions demanded certain deviations. Each modification of procedure has served some desirable end, either to further increase the accuracy of results, to avoid duplication of work already done, or by justifiable short cuts to bring the survey within reasonable time limits. In no case, however, has accuracy of results been sacrificed to any other objective. In addition to the several improvements that have been incorporated in the general instructions, other special variations demanded by local conditions have in each instance been fully described in the individual project report under History of Survey.

Primary control by triangulation was established on more than half the lakes surveyed. On Elephant Butte Reservoir a triangulation system set up by the Bureau of Reclamation surveys of 1903, 1908, and 1916 was used in the present work, although many elevations were checked and adjusted by further accurate leveling. On Lloyd Shoals Reservoir, Lake Michie, and University Lake, the availability of adequate large-scale base maps made further control and shore-line mapping unnecessary. Sediment ranges on these lakes were located with reference to prominent contour irregularities, small tributary streams, and artificial landmarks. Being well monumented (pl. 5, *A*) the relocation of ranges with the large-scale maps on file in the Washington office of the Soil Conservation Service will present no difficulties.

Triangulation and stadia control, and shore-line mapping were part of the surveys of Lake Concord in North Carolina and Spartanburg Reservoir in South Carolina and all the projects in Texas and Oklahoma. On most of these lakes the delta areas were mapped with contours. On High Point Reservoir, N. C., control and ranges had been previously established by the United States Geological Survey with the cooperation of the project office of the Soil Conservation Service, and by the city of High Point.

Mapping scales have varied from 1 inch to 100 feet on Rogers Lake, 200 feet on Boomer, Michie, University, Concord, High Point, Spartanburg, and Greensboro, 300 feet on Guthrie, 400 feet on White Rock and Lloyd Shoals, to 1,000 feet on San Carlos, Elephant Butte, and Waco. Elevations were taken from water surface as a datum except at Elephant Butte, and have been referred to sea-level datum unless otherwise noted in the project reports. Soundings and sediment-depths measurements were taken at the intervals suggested in the general instructions, except on Boomer Lake, where sediment measurements were made with each sounding at intervals of 50 feet. It was desirable on this particular lake to attain exceptional detail because it lies within a soil conservation demonstration project.

All the surveys except San Carlos, Elephant Butte, Greensboro, Hodges, Gibraltar, and Rogers were made by the range cross-section method, in which volume is computed by the modified end-area formulas. On these six the existing sediment surface was mapped for comparison with original contours, and sediment volume was computed on the modified prismoidal formula from differences in area enclosed by the existing and original contours. The thickness of sediment in San Carlos and Elephant Butte Reservoirs was generally too great to measure with sampling apparatus.

On Elephant Butte the sediment surface, covering 21,800 acres, was mapped with 1-foot contours, the established triangulation system being used as a base. Contours above 4,330 were not remapped. San Carlos Reservoir was remapped up to contour 2,435, and to higher levels in several tributary valleys, from a triangulation system established with plane table and permanently marked with concrete monuments.

The sediment surface of Rogers Lake was mapped with 5-foot contours on a scale of 100 feet to the inch, and its original topography was reconstructed from auger borings made at selected spots, from spud measurements, and from careful mapping of the valley just below the dam. On Greensboro Reservoir the availability of accurate contour maps made the same procedure advisable, although the sediment blanket is relatively thin in the lower reaches of the lake.

Computations of original capacity and volume of sediment from data obtained by the range cross-section method have been made by the use of a formula especially derived to give the most probable values for these quantities when only these data were available. Cross sections of the sediment surface and old soil line are carefully plotted, and the area enclosed in each curve up to crest level is obtained by planimeter. The difference in area represents sediment. Surface area is planimetered from the base map. It is believed that in the present surveys, with ranges spaced at frequent intervals and at well-chosen locations, the limit of error is small and the large number of ranges tends to make errors compensating.

Computations based on difference between present topography and original topography have been made on the standard formula for computing volume of a cone or pyramid frustrum (*8, p. 18*). On Elephant Butte, however, the standard prismoidal formula: $V=\frac{1}{6}(A_1+A_2+4A_m)\,L$ had been used in former capacity computations, so for the sake of uniformity it was retained in making the present calculations. The difference in results obtained by the two prismoidal formulas has been shown by checking to be less than 1 percent. Special cases where two lake arms join to form a third and where a smaller arm enters a larger have been computed according to special formulas as set out in the appendix.

The development and use of the spud (see fig. 27, in Appendix) has been perhaps the most novel feature of these investigations. Devised from necessity, it has been employed regularly throughout these investigations as a means to obtain direct measurement of sediment depths where original valley depths are unknown. It is used in conjunction with soundings taken simultaneously at the same point. Thousands of measurements to date have proved the spud exceptionally efficient and trustworthy except where relatively coarse sand or gravel is encountered. Two sizes have been developed (pl. 5, *B*). The shorter spud is a case-hardened steel rod, similar to axle shafting, into which grooves have been machined at intervals of one-tenth of a foot. Each groove tapers outward from a maximum depth of one-quarter of an inch to zero at the rim of the next tenth above. This spud is 6 feet long and 1½ inches in diameter at the rim above each groove. At the top of the rod a hole has been drilled, through which a rope is attached. Another spud of similar design, 10 feet long and 1¼ inches in diameter, has been used to obtain deeper penetration. The short spud weighs 27 pounds, and the longer spud 43 pounds. In operation the spud is dropped from the side of the boat, and the attached rope is played out through the hands with only enough grip maintained to keep it in a vertical position when it hits the deposits. In sediment that has never been exposed to air, the spud seldom fails from its own weight to penetrate entirely through the deposit into old soil, even where the sediment depth is several feet greater than the length of the spud.

Soundings have been made with an 8-pound iron sounding weight [9] (pl. 5, *C*) attached to a copper-center sounding line graduated in feet. Tenths of a foot are estimated at the water line when the sounding weight rests on the sediment.

A transit, set up over one range end and oriented on the opposite end, is generally used for keeping the moving boat on line, but when surveying party personnel is limited targets are used (pl. 5, *D*).

In the Elephant Butte and San Carlos surveys a transit was used in conjunction with the plane table, the two being set up on adjacent triangulation stations. With the sounding boat moving at random, a cut-in line was drawn on the oriented plane table and the angle read from a known bearing on the transit to each point of sounding. The bearings were later plotted on the plane-table sheet, where their intersections with the cut-in lines definitely established points of sounding.

In the more common range cross-section surveys the range is mapped on the plane-table sheet and a cut-in station is established, usually by stadia, at a convenient point where suitable cut-in angles may be obtained. The plane table is then moved to this point, oriented by backsight, and, as the boat is directed along the range by the transit man, a cut-in line is drawn to each point of sounding to intersect the range line and establish accurately the location of sounding.

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[9] In later surveys a 5-pound conical aluminum sounding weight was adopted.

A, Permanent monument marking range end, Lake Waco, Waco, Tex. *B*, Ten-foot and six-foot sediment-sampling spuds. *C*, Close-up view of six-foot sediment-sampling spud and sounding weight. *D*, Five-foot targets marking range line for sounding, White Rock Reservoir, Dallas, Tex.

SURVEYS IN SOUTHEASTERN UNITED STATES

LAKE MICHIE[10]

General Information

Location: State—North Carolina. County—Durham. Distance and direction from nearest city: 13 miles northeast of Durham, N. C. Drainage and backwater: Flat River, a southeastward-flowing tributary of the Neuse River.

Ownership: City of Durham.

Purpose served: Municipal water supply and electric power development. Development of electric power is secondary to the reservoir's principal use in impounding water to assure a constant supply for the residents and industries of Durham. The city uses its own power, when available, for street lighting, schools, and other municipal purposes, but does not distribute it privately. The surplus power is sold to the Durham Public Service Co., a subsidiary of Cities Service Co. During dry seasons, usually from 3 to 6 months out of the year, the power plant is closed in order to conserve all water for municipal needs.

Description of dam: The dam is a reinforced concrete gravity-type structure with an earth-fill embankment on the east end, and has an over-all length of 1,000 feet. The concrete section of the dam is approximately 660 feet long and is buttressed against solid rock on the west side. The center spillway section is 580 feet long. The maximum height of the spillway section is 85 feet, and its elevation is 340 feet above mean sea level, as determined by a line of levels carried from a United States Geological Survey benchmark in Durham.

Date of completion: April 1926. Completely filled by December 31, 1926. Surveyed January 1935. Age at time of survey, 8.75 years.

Length of lake (original and at date of survey): 4.8 miles.

Area of lake at crest stage (original and at date of survey): 507 acres.

Storage capacity to crest level: Original, 12,671 acre-feet (4,128,845,350 gallons). At date of survey, 12,276 acre-feet (4,000,134,600 gallons). Loss, 395 acre-feet (128,710,750 gallons).

Former sedimentation surveys.—In 1926, before the reservoir began to fill, the water resources division of the North Carolina Department of Conservation and Development established 10 ranges for sediment-depth measurements at intervals across the main body of the lake and its arms. Profiles were obtained from levels run across these ranges, and the end points, usually 2 to 4 feet above crest level of the lake, were permanently marked by concrete monuments.

On October 1, 1930, profiles of the upper five ranges were reestablished by soundings, and on June 8, 1933, new profiles of the upper three ranges were again obtained.

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[10] The Soil Conservation Service wishes to acknowledge the generosity of the city of Durham in providing two boats and an outboard motor for use during the survey. Captain J. E. Michie, head of the city water department, and D. M. Williams, of the same department, who spent considerable time in locating old range monuments and giving information on the original survey, cooperated to the fullest extent. James Kellam, caretaker at the lake, was helpful in acting as pilot for the party. H. D. Panton, chief of the water resources division, North Carolina Department of Conservation and Development, aided by the loan of notes on previous silt measurements.

In the 1935 survey, sounding and direct sediment-depth measurements were made on all of these ranges except 1—1, which was above high water at the time and in a stretch of rapids, and 9—9, which could not be relocated.

The results shown by plotting the profiles of different dates on the same cross section are manifestly not dependable for revealing the true thickness of sediment. On all ranges except 1—1 and 2—2 direct sediment-depth measurements of this survey have shown from 0.1 to 4 feet of sediment distributed practically from crest line to crest line across the lake. Yet sounded profiles plotted over those of the original survey, using the same monuments, have in many places shown scour rather than fill, and in some places strikingly, as on ranges 6—6 and 7—7. The discrepancies are perhaps a result of inaccurate leveling or erroneous elevations assigned to the range monuments in the original survey. In the 1935 survey water level datum was used and soundings were made from a boat held very closely on the range line. Despite these precautions, sections indicated scour over almost the entire range 6—6, while direct measurements actually showed 0.1 to 1.7 feet of sediment. These results clearly demonstrate the advantage of direct sediment-depth measurements wherever they can be made.

Area of watershed.—167.5 square miles.

General character of watershed.—The drainage area of Flat River is a dissected plateau of undulating, gently rolling to strongly rolling, steep, and broken topography. A few isolated hills rise above the general level of the uplands. Flood plains along the streams are almost level and vary from a few feet to one-fourth mile wide. Surface drainage is complete over all the upland portions of the area and on many of the steeper slopes run-off is excessive and serious erosion has resulted. The general elevation of the country varies from 340 feet, crest level of the lake, to 650 feet near the stream headwaters. The valleys are generally 50 to 100 feet below the upland level. A recent conservation survey has shown that slopes of 0 to 3 percent cover 13.3 percent of the drainage area; slopes of 3 to 7 percent, 60.0 percent; slopes of 7 to 12 percent, 17.5 percent; and steeper slopes, 8.9 percent.

Lake Michie is in a narrow, entrenched valley underlain by ancient volcanic rocks and granite. It is less than 1 mile northwest of the Durham Basin, a topographic depression 50 to 100 feet lower than the general Piedmont level. This basin owes its origin to sandstone and shale of Triassic age which is less resistant to erosion than the bordering crystalline rocks. Streams flowing southeastward into it have cut relatively deep and narrow valleys for several miles through the bordering upland. It is in a valley of this type, where not only are slopes steep and rocky, but shoals are common, that Lake Michie is impounded.

Soils of the watershed are—

> dominantly light in color, ranging from light gray and pale yellow to reddish brown and brown. * * * they are deficient in organic matter. * * *
>
> Changes due to the influence of surface configuration and the action of rainfall are evident in many of the soils. Through erosion and gullying, which have in many places reached serious proportions, not only have the surface features been changed but also the soil texture itself. In places the sandy or silty surface material has been entirely removed, exposing the underlying

heavier material of the B horizon or the partly disintegrated rock. The results of erosion are particularly noticeable in areas of the Cecil, Georgeville, Appling, Iredell, and Wilkes soils (*9, p. 31*).

The conservation survey has shown that the relative areas of the principal soil series of the watershed are, in percentage, Appling 15.8 and Durham 1.2, derived from granite and gneiss; Georgeville 14.3, Herndon 19.7, Orange 11.2, and Alamance 5.5, from fine-grained tuff and volcanic slate; Davidson 2.4, Iredell 4.7, and Mecklenburg 4.3, from dark-colored basic rocks such as diorite, diabase, and gabbro; Helena 11.0 and Wilkes 1.2, derived from mixtures of the above types of rocks; and Congaree 1.1, and meadow soils 1.8 which are recent stream alluvium.

Land use in the watershed includes 35.5 percent of cropland, 2.8 idle land, 2.5 pasture, 58.6 woodland, and 0.6 percent in farmsteads and urban areas.

Corn is the largest crop of Person County, and probably of the watershed as a unit, in point of acreage. Tobacco, second in area, is the first in cash value, chiefly because the light, porous, friable soil is admirably adapted to its cultivation. Other crops in order of importance are hay and forage, wheat, oats, potatoes, vegetables, and fruits. Moderate sheet erosion, representing losses predominantly of 25 to 50 percent of topsoil, has been mapped on 76.4 percent of all land in the watershed. Very little land, however, has suffered extremely severe erosion.

Soil conservation measures have been introduced into the area only very recently. It is reported that the first practicable terracing was done in 1927.

Mean annual rainfall.—43.15 inches at Rougemont, Durham County.

Stream flow.—Stream-flow records [11] on the Flat River for the period 1925–33, taken at a station just above the head of backwater, reveal that the lowest mean monthly flow was 0.752 second-foot for September 1932; the highest mean monthly flow was 506 second-feet for October 1929; the lowest mean annual flow was 80.6 second-feet for 1930, and the highest 210 second-feet for 1929. Minimum daily flow for any month was 0.37 second-foot in September 1932, and the maximum for any month was 9,900 second-feet for October 1932. The lowest mean monthly flow per square mile was 0.005 second-foot in September 1932; the highest 3.37 second-feet in October 1929. The lowest average mean flow per square mile was 0.621 second-foot in 1926 and the highest was 1.4 second-feet in 1929. The lowest annual run-off on the drainage area was 7.2 inches in 1930 and the highest 19 inches in 1929.

Draft on municipal reservoir.—The daily draft for water supply of the city of Durham is approximately 5 million gallons. This represents an increase of approximately 2 million gallons since completion of the reservoir.

Power development.—The installed power equipment consists of three vertical waterwheel-driven units, generating 625 kilovolt-amperes each, a total of 1,875 kilovolt-amperes. In addition, two water-

[11] From files of North Carolina Department of Conservation and Development, Division of Water Resources and Engineering, Raleigh, N. C.

wheel-driven pumps rated at 250 horsepower each, operate independently to pump water to a storage basin near the city of Durham. A maximum of 2,400 horsepower is developed for electrical purposes. The operating head at crest stage is 80 feet.

Because of the dual purpose of this reservoir, the operating drawdown is not kept as a matter of separate record. However, the following departmental memorandum from the city water department to the city manager of Durham, dated September 7, 1932, is pertinent in this connection:

> We have today received a report from the engineer's office of the Department of Conservation and Development which shows that for the month of August the average flow of Flat River at the Lake head was 5.35 cubic feet per second. This is equivalent to 108.5 million gallons. In view of the fact that the small tributaries entering the lake were practically dry, this 108.5 million gallons can be considered as the entire stream flow. The weather report (also furnished by the Department of Conservation and Development) shows the evaporation as 6.24 inches. This we estimate as 56.1 million gallons, making the pumpage and evaporation 89.4 million gallons more than the total stream flow. Our present supply of impounded water would allow for similar draft for 22 months.

History of Survey

The survey of Lake Michie marked the first step in a comprehensive program of reservoir surveys throughout the country based on the work of H. M. Eakin during the summer of 1934. Here the personnel that have been responsible for carrying out this series of investigations received their initial training under Eakin's supervision. Carl B. Brown was appointed chief of party and D. Hoye Eargle, assistant chief of party at the beginning of this survey. Temporarily assisting were Thomas L. Kesler, later chief, and Louis M. Glymph, Jr., assistant chief of the Great Plains party, and Raymond C. Becker, later chief of the southwestern party.

Field work began on December 28, 1934. On January 9, the original personnel, with the exception of Brown and Eargle, left this project to organize additional field parties. Field work was completed on January 20, 1935, by the full southeastern party of six men.

Base maps of Lake Michie, made by transit traverse in 1924 on a scale of 200 feet to the inch, were available through the courtesy of the city of Durham, and were adopted as a base. They show the 340-foot (crest) contour and a 344-foot contour. Field operations involved establishing 32 ranges, which were tied together by stadia and adjusted to the original base. Planimeter work was done by the staff of the Soil Conservation Service office at High Point, N. C. Final computations and drafting were done by the southeastern party at a later date.

Sediment Deposits

The sediment has a remarkably uniform distribution from the head of Lake Michie to the dam. The delta is not pronounced and was not measured separately from the bottom-set clays of the lower part of the lake. The front of the delta, insofar as it can be determined, lies between ranges 38–39 and 40–41 where the sediment becomes very slightly coarser in texture. No sand as coarse as 1 millimeter in diameter was found in the new deposits of the lake. The maximum thickness of sediment occurs on range 40–41 where one penetration of 4.4 feet was obtained.

Shoals occur just at the head of backwater. At the time these were observed the stream was carrying an unusually small bottom load, including virtually no coarse sand. A range sounded just below the shoals showed as much as 0.2 foot of sediment at only one point.

For the most part sediment accumulating in the lake is the finest mud, and apparently settles slowly and comparatively uniformly over the entire lake basin. It remains in an oozy condition while under water and can be penetrated with ease. It is predominantly of a light chocolate brown to light or dark gray color.

A summary of pertinent data relative to Lake Michie (fig. 1) is contained in the following tabulation:

Summary of data on Lake Michie, Durham, N. C.

Age [1] ... years	8.75
Watershed area [2] ... square miles	167.5
Reservoir:	
Area at crest stage (original and at date of survey) ... acres	507
Original storage capacity to crest level ... acre-feet	12,671
Storage capacity at date of survey ... do	12,276
Original storage per square mile of drainage area [2] ... do	75.65
Storage per square mile of drainage area at date of survey [2] ... acre-feet	73.29
Sedimentation:	
Total sediment ... do	395
Annual accumulation per 100 square miles of drainage area ...	[3] 27.1
Average annual accumulation ... do	45.14
Annual accumulation per acre of drainage area ... cubic feet	[3] 18.43
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds ... tons	[3] 0.55
Depletion of storage:	
Loss of original capacity per year ... percent	0.36
Loss of original capacity to date of survey ... do	3.12

[1] Storage began in April 1926; survey was made in January 1935.

[2] Including area of lake.

[3] These figures are revised to exclude the lake area from the total area of the drainage basin and to conform with a revision of the watershed area based on a new map made since the first edition of this bulletin was published. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, based on a total drainage area of 170 square miles, including reservoir, are 26.55 acre-feet, 18.07 cubic feet, and 0.90 ton, respectively.

UNIVERSITY LAKE [12]

General Information

Location.—State—North Carolina. County—Orange. Distance and direction from nearest city: 2 miles southwest of Chapel Hill, N. C. Drainage and backwater: Morgan Creek, on which the dam is located, and its tributaries, Neville Creek on the west, and Price Creek on the south.

[12] The Service wishes to acknowledge the cooperation of the university consolidated service plants, through its director, J. S. Bennett, who kindly furnished maps and boats for the survey, and who supplied much of the general information concerning the lake. Pipe used to mark the range ends was furnished by the building department of the university. H. J. Bryson, State geologist and acting head of the water resources division of the North Carolina Department of Conservation and Development, furnished data on the stream flow of Morgan Creek and maps showing the location of ranges previously established by the water resources division.

Ownership.—The University of North Carolina, operated by the university consolidated service plants.

Purpose served.—Municipal water supply for Chapel Hill, Carrboro, and the University of North Carolina.

Description of dam.—The gravity-type reinforced concrete dam has a maximum height of 30 feet and a length of 380 feet. The elevation of the spillway is 347 feet above sea level, except for a middle section which is at an elevation of 346 feet. Since the water rarely fails to flow over the whole spillway, the upper elevation is considered crest level. Maximum thickness of the dam at the base is 75 feet.

A conduit for future water power development and a gate for lowering or draining the water in the lake are located in the segment of the dam nearest the pump house. According to J. S. Bennett, supervisor of utilities and auxiliary enterprises, University of North Carolina, this gate has been opened only once since the dam was built, for a few hours in May 1934.

Date of completion.—June 2, 1932, when the outlet to the lake was permanently closed. The lake was first filled to overflowing in December 1932. Surveyer April 1935. Age at date of survey, 2.9 years.

Length of lake (original and at date of survey, from dam to upper limit of backwater on each arm at crest stage).—Morgan Creek, 8,000 feet; Neville Creek, 6,800 feet.

Area of lake at crest stage (original and at date of survey).—219 acres.

Storage capacity to crest level.—Original, 1,915 acre-feet (624,002,750 gallons). At date of survey, 1,851 acre-feet (603,148,350 gallons). Loss: 64 acre-feet (20,854,400 gallons).

Former sedimentation surveys.—In 1932, before the lake was flooded, profiles of eight ranges, marked with concrete-filled tile monuments, were established at intervals across the lake basin by the North Carolina Department of Conservation and Development. Six of the eight ranges were sounded during the present survey for the first time, and the old soil profiles were found to check approximately with the original valley cross sections. The other two were not discovered until ranges were established in approximately the same positions.

Area of watershed.—30.6 square miles, of which Morgan and Neville Creeks drain about four-fifths, and Price and Mill Creeks, about one-fifth.

General character of the watershed.—Most of the watershed of University Lake is a rolling upland 400 to 500 feet above sea level, but contains occasional peaks, or monadnocks, several hundred feet higher. The topography is of two classes (1) gently to strongly rolling dissected peneplain, underlain mostly by slates, and (2) rolling, broken, and steep areas, underlain by granite. Valley sides have comparatively steep slopes near the streams, and the flood plains, 50 to 100 feet below the general level of the upland, are narrow (*18, pp. 5–6*). As shown by a recent conservation survey, slopes of 0 to 3 percent cover 7 percent of the drainage area; slopes of 3 to 7 percent, 40.7 percent; slopes of 7 to 12 percent, 30.2 percent; and slopes steeper than 12 percent, 22.1 percent.

The soils of the drainage area consist, in percentage, chiefly of Herndon 33.1, Georgeville 25.9, Helena 18.5, and Orange 12.6, with smaller areas of Wilkes 6.5, and Alamance 1.5. The narrow flood plains are Congaree silt loam and undifferentiated alluvial soils 1.9 percent.

Moderate to severe sheet erosion, representing losses of 50 to 75 percent of topsoil, has been mapped on 54.9 percent of all land in the drainage area. Moderate sheet erosion (25 to 50 percent of soil lost) has occurred on 10.2 percent, slight erosion on 15.1 percent, and severe to very severe erosion on 6.2 percent of the area. Only 11.8 percent has suffered little or no erosion. Accumulation of soil debris has taken place on 1.8 percent of the area.

Land use in the watershed includes 24.5 percent of cropland and 61.2 percent of woodland. Nine percent of the area is classed as idle land now suffering erosion or being gradually covered with a growth of young trees and a heavy growth of broomsedge. Only 5.3 percent of the area is in pasture, this commonly being abandoned farm land fenced in and covered with natural grasses. This pasture land is likewise being eroded to a noticeable extent. The forest trees are second-growth old field or shortleaf pine, various oaks, hickory, cedar, poplar, and dogwood.

Crops grown on the watershed of University Lake, in order of acreage, are corn, wheat, oats, cotton, and tobacco. Other crops grown in lesser amounts are hay (red clover, alfalfa, and millet), soybeans, peas, vegetables, sorghum, orchards, and vineyards.

Mean annual rainfall.—48.08 inches (*18, p. 6*). Records of the North Carolina Department of Conservation and Development for the period 1924–31, show that the mean annual discharge of Morgan Creek at the site of the dam varied from 18.8 to 61.1 second-feet. The maximum discharge of any month was 6,240 second-feet in August 1924, the minimum 0.47 second-foot in September 1925. The total depth of run-off varied from 9.40 inches in 1930 to 30.90 inches in 1924.

Draft on municipal reservoir.—Table 9 shows the gallons of water per month used from University Lake from January 1933 through March 1935.

TABLE 9.—*Water used from University Lake, N. C., from January 1933 to March 1935, inclusive*

Month	1933	1934	1935	Month	1933	1934	1935
	Gallons	*Gallons*	*Gallons*		*Gallons*	*Gallons*	*Gallons*
January	13,071,000	12,736,000	14,215,000	July	13,209,000	12,280,000	
February	11,808,000	12,721,000	13,238,000	August	9,791,000	11,500,000	
March	13,141,000	12,688,000	12,829,000	September	11,591,000	11,322,000	
April	12,279,000	13,282,000		October	14,575,000	14,766,000	
May	16,495,000	14,293,000		November	13,335,000	13,656,000	
June	14,550,000	12,277,000		December	11,016,000	11,888,000	

The seasons of greatest use, therefore, are late spring and early fall, mainly because of college consumption. The average consumption per month for April and May, and for October and November, of the little more than 2 years that water has been used from this lake, was nearly 14,100,000 gallons.

History of Survey

The sedimenation survey of University Lake was begun on April 23 and completed on April 27, 1935, by the southeastern sedimentation party. Arrangements for the survey, collection of general data, and the preliminary lay-out were made by Carl B. Brown, chief of the party. The remainder of the survey was carried out under the direction of D. Hoye Eargle, acting chief, who was also responsible for final computations and preparation of the detailed project report of which this is an abstract.

A total of 18 ranges, shown on the accompanying map, were established, sounded, and spudded. A scale of 200 feet to the inch was used in field mapping. Distances between ranges varied from 600 to 1,100 feet. Ranges were located on a previous base map in closely approximate positions by obtaining distances and directions to prominent irregularities in the contours, to small streams and to artificial landmarks. A variation in the usual spudding practice was necessary in the upper reaches of the deltas where the water was too shallow to permit entry of a boat. Here a line of levels was run across the range, and depth of sediment was measured with the spud by pushing it down to old soil from a standing position (pl. 6, *A*).

Elevations were taken from water surface, which remained constant during the survey.

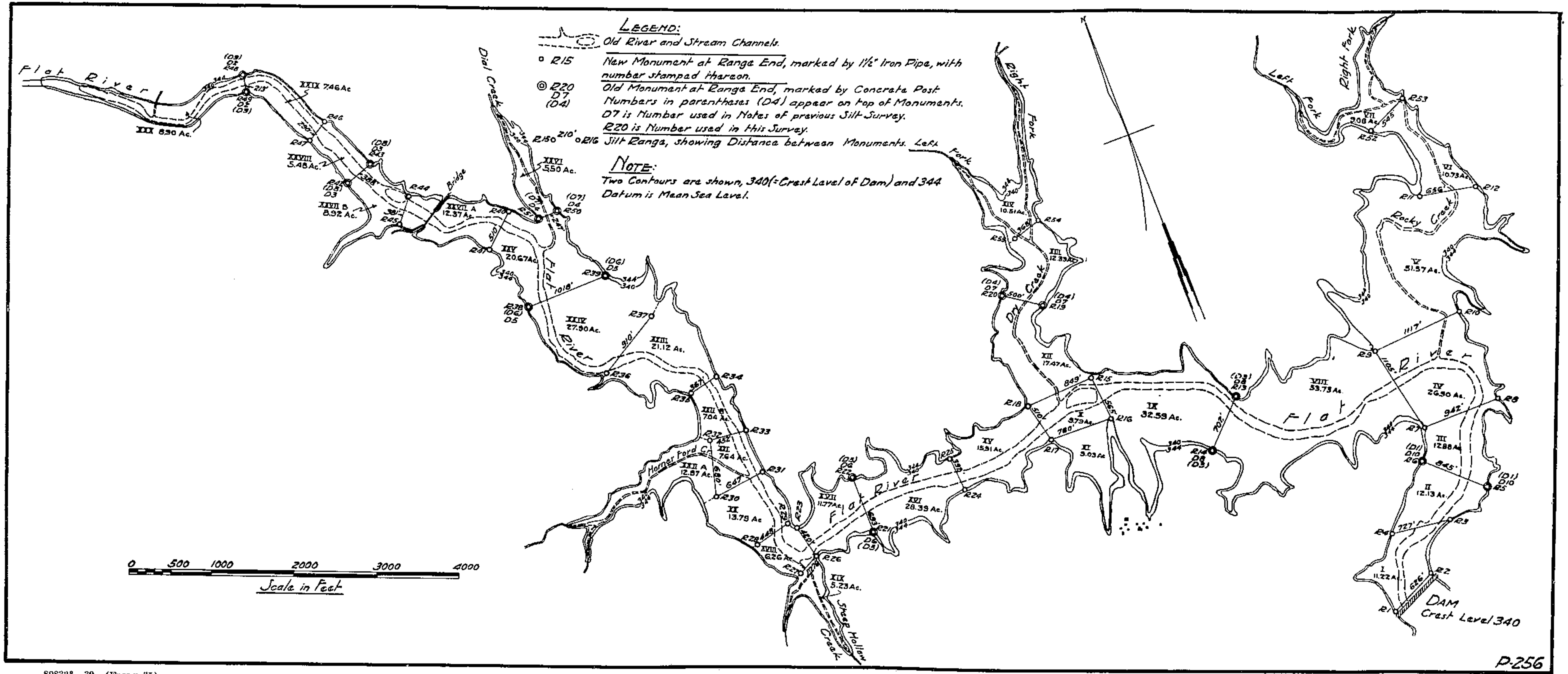
Computations of original capacity and volume of sediment were made with the formulas applicable to the range method of volume determination.

Sediment Deposits

A study of sedimentation in University Lake shows two classes of deposits: (1) A relatively thick accumulation of sediment, mostly sand, at or near the headwaters on each of the arms, and (2) a rather evenly spreading blanket, largely of fine mud, over the floor of the lake. Graphs drawn to give a visual interpretation of the depth ratio between sediment and water in each of the ranges show clearly the sudden decrease in proportion of sediment a short distance below the head of backwater where the fronts of the delta deposits are found. From the fronts of the deltas to the dam there is a rather constant depth ratio of sediment to water, decreasing only slightly toward the dam.

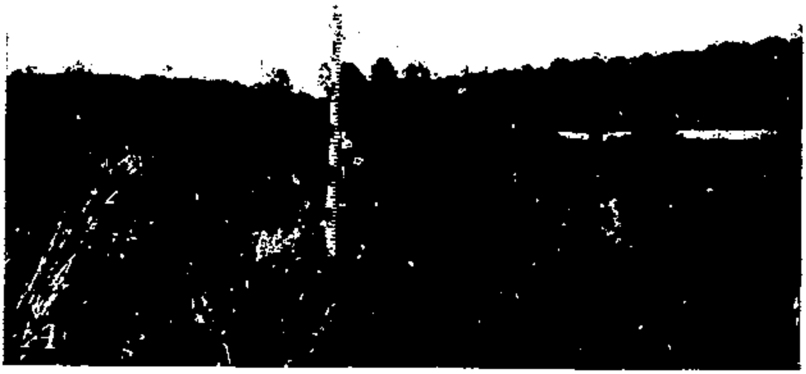
The front of a very young delta is well displayed on Price Creek above the mouth of Mill Creek, a small tributary. At this point Price Creek has filled the old channel with sand, beginning at the point where the velocity of the stream was checked when it entered the backwater of the lake. After the old channel had been filled for a short distance downstream, the current shifted at right angles and began to flow toward the flooded meadow or old flood plain, making an alluvial fan in that direction. The old soil of this flooded meadow was found to have many of the characteristics of reservoir fill. It was easily distinguishable, however, by the presence of roots of considerable size and by the fact that the new sediment, being a very recent and thin deposit, never exposed to air, was soft and oozy (pl. 6, *B*).

The sediment in the lake varies from coarse gravelly sand at the head of the delta to very fine mud a few hundred yards farther downstream.



80832°—39 (Face p. 35)

FIGURE 1.—Map of Lake Michie, Durham, N. C., resurveyed December 1934 to January 1935.



A, Pushing a spud down to old soil in delta area on Price Creek arm, University Lake, Chapel Hill, N. C. *B*, Sediment-covered flood plain at upper limit of backwater, Price Creek, University Lake, Chapel Hill, N. C.

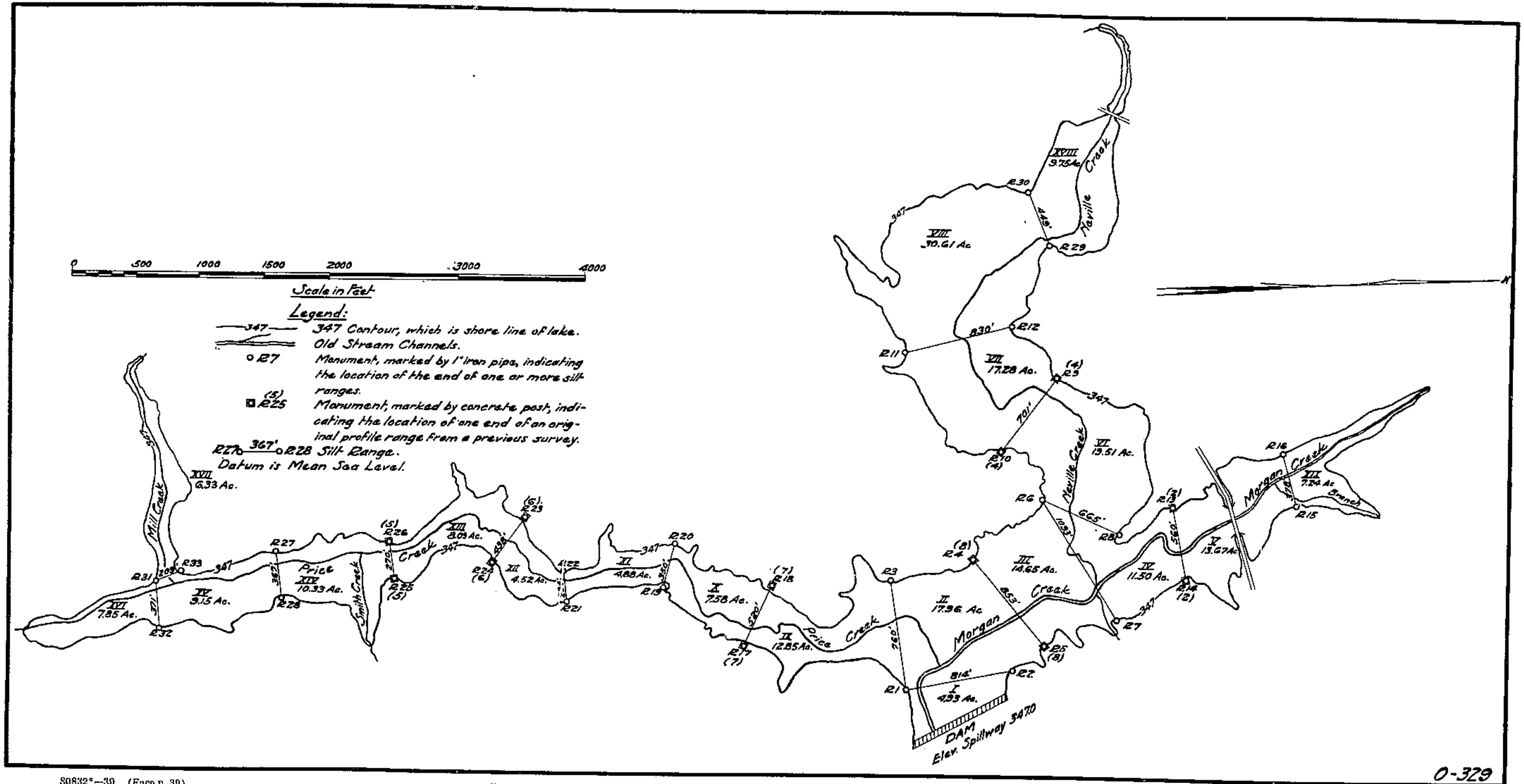


FIGURE 2.—Map of University Lake, Chapel Hill, N. C., and tributary streams, surveyed April 1935.

For a few hundred feet below the head of the delta on each arm the coarser material, mostly quartz sand, is confined to the channel. This material grades downstream and toward the sides through sandy silt to mud. A typical delta, rather flat on top and dropping suddenly beyond a rim at the outer edge of the fore-set beds, was noted only on Price Creek. On either side of this delta, which is in and near the original channel, very fine, soft mud was deposited over the old flood plain. On the other arms, into which larger streams enter, the sandy material has been swept farther down the channel and partly mixed with silt; it is now found in channel spuddings well below the limit of backwater. Near the upper end of backwater on Neville Creek a large quantity of leaves had accumulated along with the silt and sand. When the spud was pushed into this material, marsh gas was given off in such quantity that when lighted it burned for several seconds.

Downstream from the sandy deposits, a thin blanket of mud was found over the floor of the lake. This material is soft, oozy, little compacted, gray in color, and contains occasional leaf fragments. It varies in thickness from a foot or more in the old stream channel, where it is usually deepest, to zero near the shore. Its average depth over the old flood plain away from the main channel is only a few tenths of a foot.

A summary of pertinent data relative to University Lake (fig. 2) is contained in the following tabulation:

Summary of data on University Lake, Chapel Hill, N. C.

Age[1]	years	2.9
Watershed area[2]	square miles	30.6
Reservoir:		
Area at crest stage (original and at date of survey)	acres	219
Original storage capacity to crest level	acre-feet	1,915
Storage capacity at date of survey	do	1,851
Original storage per square mile of drainage area[2]	do	62.58
Storage per square mile of drainage area at date of survey[2]	do	60.49
Sedimentation:		
Total sediment	do	64
Average annual accumulation	do	21.92
Annual accumulation per 100 square miles of drainage area	do	[3]72.3
Annual accumulation per acre of drainage area	cubic feet	[3]49.23
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds	tons	[3]1.48
Depletion of storage:		
Loss of original capacity per year	percent	1.14
Loss of original capacity to date of survey	do	3.34

[1] Storage began June 2, 1932; average date of survey, Apr. 25, 1935.

[2] Including reservoir area.

[3] These figures are revised to exclude the lake area from the total area of the drainage basin and to conform with a revision of the watershed area based on a new map made since the first edition of this bulletin was published. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, based on a drainage area of 27 square miles, including reservoir, are 81.19 acre-feet, 55.26 cubic feet, and 2.76 tons, respectively.

GREENSBORO RESERVOIR

General Information

Location.—State—North Carolina. County—Guilford. Distance and direction from nearest city: 9 miles north of Greensboro, N. C. Drainage and backwater: Horsepen Creek and Reedy Fork.

Computations.[13]—Total clays over the reservoir area below the deltas, computed from map areas and direct sediment depth measurements have an aggregate volume of 137 acre-feet. The delta areas and adjacent mud flats are now filled approximately to crest level. Their maximum depth of fill is about 4 feet at the present delta fronts. Computed as thinning upstream to the line of intersection of crest level and original ground surface of the valley bottoms, their aggregate volume is 123 acre-feet. Combined bottom clays and delta deposits thus amount to a total of 260 acre-feet of sediment accumulation during a period of 11½ years of active storage.

A summary of pertinent data relative to Greensboro Municipal Reservoir (fig. 3) is contained in the following tabulation:

Summary of data on Greensboro Municipal Reservoir, Greensboro, N. C.

Age [1] .... years..	11.5
Watershed area [2] .... square miles..	74.1
Reservoir:	
Original area at crest stage .... acres..	450
Original storage capacity .... acre-feet..	2,870
Storage capacity at date of survey .... do....	2,610
Original storage per square mile of drainage area [2] .... do....	39.86
Storage per square mile of drainage area at date of survey [2] .. do....	35.22
Sedimentation:	
Delta deposits .... do....	123
Bottom-set beds .... do....	137
Total sediment .... do....	260
Average annual accumulation .... do....	23.4
Annual accumulation per 100 square miles of drainage area .. do. ..	[3] 32.3
Annual accumulation per acre of drainage area .... cubic feet..	[3] 22.46
Or, assuming 1 cubic foot of deposit weighs 60 pounds ...... tons.	[3] 0.67
Depletion of storage:	
Loss of original capacity per year .... percent..	0.79
Loss of original capacity to date of survey .... do....	9.06

[1] Storage began in February 1923; survey was made in August 1934.
[2] Including reservoir area.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin and to conform with a revision of the watershed area based on a new map made since the first edition of this bulletin was published. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, based on a total drainage area of 72 square miles, including reservoir, are 31.4 acre-feet, 21.4 cubic feet, and 1.07 tons, respectively.

HIGH POINT RESERVOIR

General Information

Location.—State—North Carolina. County—Guilford. Distance and direction from nearest city: 4½ miles northeast of High Point, N. C. Drainage and backwater: East Fork and West Fork of Deep River.

Ownership.—City of High Point.

Purpose served.—Municipal water supply.

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[13] It should be noted that the computation of sediment volumes was not based on planimeter measurements of original and new contours of the lake basin as required by instructions in the appendix for standard detailed surveys. The survey of Greensboro Reservoir was conducted by the late H. M. Eakin during the initial stage of the investigations under this project, when standard methods were just being developed and before the organization of survey parties. For this reason it is now considered, in the light of 4 years' experience in calculating sediment volumes, that the data on sedimentation in this reservoir are not so precise as those for later surveys. Nevertheless, such checks as are possible indicate the data are within reasonable limits of error, and are probably more accurate than data from most reservoir-silting surveys previously made in this country. (Note by author of revision.)

FIGURE 3
FOUND AT END
OF BULLETIN.

Description of dam.—The dam has a total length of 630 feet, of which the concrete ogee-shaped section in the center is 370 feet long. On the west is an earth-filled section with concrete core 190 feet long, and on the east is a similar section 70 feet long. The spillway is at an elevation of 748 feet above sea level, and 45 feet above the bed of the stream.

Date of completion.—January 1928. Surveyed August 1934 and April 1938. Age at date of each survey, 6.5 and 10.25 years, respectively.

Length of lake at spillway stage.—2.8 miles, including 2,200 feet of narrow ponded channel at the head.

Area of lake at spillway stage.—Original, 322 acres. At date of 1938 survey, 318 acres. Loss, 4 acres.

Storage capacity to crest level.—Original, 4,354 acre-feet (1,418,-750,900 gallons). At date of 1938 survey, 4,038 acre-feet (1,315,-782,300 gallons). Loss, 316 acre-feet (102,968,600 gallons).

Area of watershed.—62.8 square miles.

General character of watershed.—The headwater drainage area of the Deep River is a dissected plateau, 800 to 900 feet above sea level, with gently rolling to rolling, but in places steep or broken, topography. The interstream divides are usually smooth to gently rolling belts ½ to 3 miles wide. Level strips of bottom land are found along most of the streams.

In the Deep River soil conservation project area, of which the High Point Reservoir drainage basin constitutes the uppermost 40 percent, the proportionate areas of slope classes are as follows: 0- to 3-percent slopes, 4.7 percent; 3- to 7-percent slopes, 49.1 percent; 7- to 12-percent slopes, 32.5 percent; and steeper slopes, 13.7 percent. General observations suggest that the average slope of the High Point drainage area is slightly less than that of the project area as a whole.

The predominant upland soils belong to the Cecil and Appling series, derived mainly from granite and granite gneiss, but there are many smaller areas of Iredell and Davidson soils, derived from basic igneous rocks, and considerable areas of Wilkes soils, derived from complexly intermixed acidic and basic intrusives. Soils derived from basic rocks are especially prevalent in the southern and southeastern parts of the watershed.

The loose open texture of the soil is conducive to severe sheet and gully erosion in areas not protected by terracing and soil-binding crops. It was estimated in 1934 that 60 percent of the area had undergone moderate sheet erosion, and that perhaps 25 percent showed occasional gullies.

Approximately 42 percent of the land in the High Point drainage area was placed under cooperative agreement with the Soil Conservation Service before the project went on a maintenance basis in 1937. Soil conservation practices were instituted on virtually all the area under agreement in the period between the 1934 and 1937 sedimentation surveys. These two surveys thus afford an excellent opportunity to study the effect of soil conservation measures on the erosional output by comparing the rates of silting in the reservoir before and after erosion-control practices were inaugurated on a large part of the contributing drainage area.

The following figures, based on the 1935 United States census reports on the three townships that comprise the greater part of the watershed, represent the approximate division of the area according to land use: Forest, 35 percent; cultivated cropland, 30 percent; idle cropland, 12 percent; woodland pasture, 10 percent; cleared pasture, 6 percent; and miscellaneous, 7 percent. The principal crops and the proportion of the cultivated land devoted to each in 1934, according to estimates based on the census reports for the three townships were as follows: Corn, 31 percent; hay, 31 percent; grain, 22 percent; tobacco, 9 percent; and miscellaneous, 7 percent.

Mean annual rainfall.—Data on rainfall for stated periods are as follows: 1921–38 (17.25 years), 44.39 inches; 1928–34 (6.5 years), 47.87 inches; 1928–38 (10.25 years), 46.21 inches; and 1934–38 (3.7 years), 50.83 inches.

Draft on municipal reservoir.—The average daily draft from January 1, 1926, to November 30, 1929, is shown in table 10. The monthly draft from 1932 to 1935 ranged from approximately 57 million gallons in February 1933 to 87 million gallons in October 1934. A number of large industrial plants are supplied in addition to domestic consumption.

TABLE 10.—*Average daily draft on High Point Reservoir from January 1, 1926, to November 30, 1929, inclusive*

Year	Average daily consumption	Estimated population supplied	Daily per capita consumption	Year	Average daily consumption	Estimated population supplied	Daily per capita consumption
	Gallons		*Gallons*		*Gallons*		*Gallons*
1926	2,076,000	27,300	76	1928	2,236,166	31,300	72
1927	2,195,000	29,250	75	1929	2,274,000	33,300	68

HISTORY OF SURVEYS [11]

First sedimentation survey.—A survey of High Point Reservoir to determine the amount of sediment accumulation was begun early in July 1934 under the direction of E. D. Burchard, district engineer of the United States Geological Survey, Asheville, N. C. The initial plan of this survey was to relocate and sound 38 ranges across the reservoir that had been laid out and surveyed to determine profile elevations prior to completion of the dam. Since the original ranges had not been marked by permanent monuments, their positions could be reestablished only by rerunning the traverse lines of the earlier survey from the field-book records. Transit traverse lines were run for this purpose but, as shown by subsequent check in 1938, did not coincide at all points with the traverse system which included the original 38 ranges. This check of all previous engineering data available in 1938 showed numerous minor, but to a considerable extent cumulative, differences responsible for divergence of the earlier and later traverses in several parts of the lake. The check did indicate strongly that numerous ranges thought to be relocated precisely in 1934 were in slightly different positions from those of the original

[11] Rewritten by author of the revision.

survey made prior to 1928. Soundings taken on the ranges thus believed to be reestablished appeared to indicate silting on only 25 ranges, the other 13 showing larger cross-section areas than had been determined for them by the original survey. In view of the certainty, fully established by spudding operations later in 1934, that

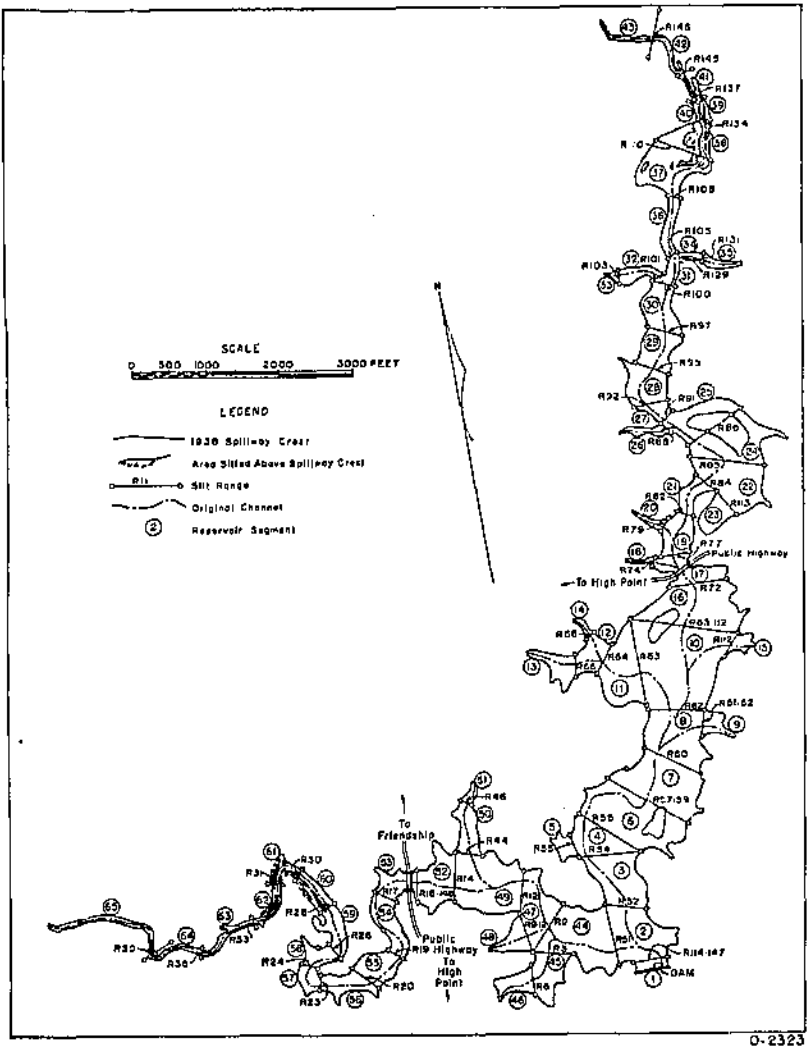


FIGURE 4.—Map of High Point, N. C., Municipal Reservoir and tributary streams resurveyed March–April 1938

silting had been general throughout the reservoir, the method of computing sediment volumes from differences in range cross-section areas from one survey to another was abandoned for all the segments, except in the more completely filled sections near the heads of the two principal arms.

In connection with the 1934 survey, in order to establish a basis for more accurate determinations of the amount of sediment by the sounding method in the future, all the relocated ranges and 106 additional ranges were permanently marked with concrete monuments.

At the time the sounding survey was being completed, August 15, 1934, the party was joined by H. M. Eakin and assistant, L. M. Glymph, Jr., and sediment-depth measurements on numerous range sections below the deltas were undertaken. This phase of the investigation was carried out by the use of a sediment-sampling spud described in the appendix. The final part of the survey was completed August 24, 1934.

The data obtained by the Geological Survey party in resounding original ranges at the heads of the two arms of the reservoir indicated consistent filling throughout the delta regions amounting to 104.5 acre-feet of delta deposits. The delta deposits consist for the most part of coarse to medium sand. Farther downstream the sands grade into silt and finer deposits along the channel, and the silt grades into clay in the lateral basin, the latter deposits partaking of the general character of the bottom-set clays found generally distributed throughout the lower reservoir basin.

In the main body of the reservoir, where the new deposits were thin, direct measurements of sediment depth with the sampling spud were made on many ranges, together with soundings of water depth at each point of observation.

In computing sediment volumes in the lower part of the lake from these data, the ratio of aggregate water and aggregate sediment depths on a range was applied in each case to mean depth of water on the range to derive average depth of sediment at the range locality. The means of average depths of sediment on adjacent ranges were taken to apply generally to intervening segments of the reservoir. The aggregate volume of bottom deposits for the whole reservoir below the delta areas thus computed was 142.5 acre-feet. This combined with delta deposits gave a total volume of 247 acre-feet of sediment accumulated in the reservoir during the 7 years of active storage.

Second sedimentation survey.—A second sedimentation survey of High Point Reservoir was made by a field party of the Section of Sedimentation Studies during the period March 11 to April 15, 1938, under the direction of Leland H. Barnes, chief of party.

Inasmuch as results from the 1934 survey were not obtained according to the standardized procedure outlined in the appendix, and this being the first reservoir-sedimentation survey in which the Soil Conservation Service participated, it was considered desirable to make a complete redetermination of original and present capacities.

The shore-line map used in the survey of 1934 was used as a base for the 1938 survey, but in the delta regions of both arms of the reservoir, 4.7 miles of original and existing shore line were remapped to obtain more detail than was shown by the original map.

During the course of the resurvey 55 ranges set by the United States Geological Survey in 1934 and 7 new ranges set out by this survey were sounded and spudded. Numerous ranges established in earlier surveys, but poorly located according to present standards, were not used in this survey. Range ends and cut-in stations were tied in by the use of plane table and telescopic alidade. In order to obtain more accurate existing and original profiles across each range, soundings and spuddings were taken at intervals of 20 to 30 feet by methods described in the appendix. Computations of original capacity and sediment volume were made by the use of the formula for range surveys.

All range ends are permanently marked with concrete markers for the purpose of resurveys; 96 range ends were marked by the Geological Survey in 1934 and 18 new markers were set by this survey.

Improvements in survey technique and methods of calculation since 1934 have permitted a more accurate determination of the original capacity. The 1938 survey has shown that the original capacity was 4,354 acre-feet, or 134 acre-feet more than was determined in 1934. The total sediment accumulated to 1938 was 316 acre-feet. It is considered that the previously determined sediment accumulation of 247 acre-feet to 1934 is very nearly correct, as it was computed from averages of direct sediment-depth measurements. The comparative data, therefore, indicate a marked falling off in the rate of sedimentation since 1934, a reduction of almost one-half in the annual rate of silting.

Inasmuch as the rainfall data given above show a higher average precipitation at High Point for the 4-year period 1934–38 than for the preceding 6-year period 1928–34, there is support for the belief that introduction of soil conservation practices in the drainage area has markedly reduced the rate of silting.

Sediment Deposits

The sediment of High Point Reservoir shows all gradations from coarse sand near the heads of both arms to fine, unctuous clay in the lower basins. The prevailing color is greenish buff, changing to grayish brown in the upper reaches. The organic content of the sediment appears to be low near the dam but increases considerably toward the head of each arm.

Both the west and north branches have distinct deltas near the head of backwater. The delta on the west branch extends downstream to about range 24, and that on the north branch ceases to be prominent at about range 108. Both delta areas are featured by lateral sedimentation resulting in an inward migration of the shore line and the formation of large bars both above and below crest level. Much storage capacity has been lost in these areas. In the course of the 1938 survey, many of the concrete markers set during the 1934 survey were found to have been covered by sediment to depths of as much as 5 inches. In addition, although the markers were originally set on the crest contour, they were found to be 3 to 6 feet from the present shore line. These above-crest deposits extend upstream for several hundred feet beyond the reservoir as well-defined natural levees. They rise above crest level as far down as range 110 on the north branch and to a point just below range 30 on the west branch. Below these points they continue as submerged bars which are in general immediately adjacent to the original stream channel and create longitudinal lagoonal areas at low-water stages.

The sediment grades laterally from coarse to medium sand in the channel and sandy silt in the bars to fine silt in the lagoonal areas. Fairly definite delta fronts occur on both arms. Practically all the sandy sediment in the reservoir is confined to the delta areas.

Sediment thicknesses decrease very gradually below the delta fronts, there being no apparent tendency for concentration of fine-grained material near the dam. The bulk of the deposit in these lower reaches is confined to the original stream channel, sediment thicknesses decreasing laterally toward the shores. Within the delta areas the longitudinal distribution of sediment is characterized by gradual increase in depth downstream, followed by a fairly abrupt decrease in the delta front. Laterally, on both sides of the channel, a sharp increase in thickness in the natural levees is followed by a gradual decrease across the lagoonal areas toward the shores.

Wave erosion, formerly of some importance as a source of sediment in the lower reaches of the reservoir, has been almost entirely eliminated within the past few years by the program of shore-line planting carried out by the local Soil Conservation Service demonstration project.

In view of the generally turbid condition of the lake waters and the almost constant discharge of such sediment-laden waters over the spillway, it is believed that a considerable proportion of the finer-grained sediment is being bypassed completely through the lake.

Distinctions between sediment and pre-lake bottom material were readily made, mainly on the basis of radical differences both in texture and degree of compaction. Three types of "old soil" occur: (1) Sandy clay loam, generally some shade of reddish brown but in places greenish gray, which occurs on the submerged valley sides; (2) dark-gray gritty silt loam with fairly high clay content, which occurs on the submerged flood plains and terraces; and (3) undifferentiated stream deposits, ranging from gray river silt to clean, washed sand and gravel, which occurs in the original stream channel.

A summary of pertinent data relative to High Point Reservoir (fig. 4) is contained in the following tabulation:

Summary of data on High Point Reservoir, High Point, N. C.

Age[1]:		
At date of first survey	years	6.5
At date of second survey	do	10.25
Watershed area[2]	square miles	62.8
Reservoir:		
Area at spillway stage:		
1928 (original)	acres	322
1938	do	318
Storage capacity to spillway level:		
1928	acre-feet	4,354
1934	do	4,107
1938	do	4,038
Storage per square mile of drainage area:[2]		
1928	do	69.33
1934	do	65.40
1938	do	64.30

[1] Storage began in January 1928; average date of first survey, August 1934; average date of second survey, April 1938.
[2] Including area of reservoir.

Summary of data on High Point Reservoir, High Point, N. C.—Continued

Sedimentation:		
Sediment volume:		
1934	acre-feet	247
1938	do	316
Accumulated during period 1934–38	do	69
Average annual accumulation:		
1928–34	do	38.0
1928–38	do	30.8
1934–38	do	18.4
Annual accumulation per 100 square miles of drainage area:[3]		
1928–34	acre-feet	61.0
1928–38	do	49.5
1934–38	do	29.5
Annual accumulation per acre of drainage area:[3]		
1928–34	cubic feet	41.51
	tons[4]	1.05
1928–38	cubic feet	33.68
	tons[4]	0.85
1934–38	cubic feet	20.10
	tons[4]	0.51
Depletion of storage:		
Annual loss of original capacity:		
1928–34	percent	0.87
1928–38	do	0.71
1934–38	do	0.42
Total loss of original capacity:		
1928–34	do	5.07
1928–38	do	7.26
1934–38	do	1.58

[3] Excluding area of reservoir.
[4] Based on an average dry weight of 50.6 pounds per cubic feet of sediment, as determined from 12 undisturbed samples.

LAKE CONCORD[15]

General Information

Location.—State—North Carolina. County—Cabarrus. Distance and direction from nearest city: 3 miles southeast of Kannapolis. Drainage and backwater: Chambers Branch and Rose Branch, tributaries of Coldwater Creek.

Ownership.—City of Concord.

Purpose served.—Municipal water supply.

Description of dam.—The dam is of earth-fill construction with a concrete apron on the upstream side. It is 479 feet long, 35 feet high, and 250 feet thick at the base. A concrete spillway on the west side of the dam is 60 feet wide, 150 feet long, and 5 feet lower than the top of the dam. A skimming wall 24 inches high is built into the spillway.

Date of completion.—March 1925. Completely filled March 1926. Surveyed May 1935. Age at date of survey: 10.2 years.

Length of lake at crest stage.—Original—on Chambers Branch, 4,350 feet; on Rose Branch, 4,380 feet. The two branches unite 1,500

[15] The Service is indebted to the city of Concord, through L. A. Fisher, superintendent of waterworks, for use of two boats and outboard motor, and for furnishing iron pipe to mark range ends. Mr. Fisher also supplied the original map of the lake and much valuable general information. C. H. Peck, warden of the lake since it was completed, assisted in several phases of the work and gave observations on silting which had come to his notice.

feet above the dam to form the main body of the lake. At date of survey—on Chambers Branch 4.900 feet; amount shortened 160 feet. On Rose Branch 4.130 feet; amount shortened 250 feet.

Area of lake at crest stage.—Original, 101 acres.

Storage capacity to crest level.—Original, 1,201 acre-feet, or 391,-345,850 gallons. At date of survey, 1,122 acre-feet, or 365,603,700 gallons. Loss, 79 acre-feet, or 25,742,150 gallons. Prior estimates according to L. A. Fisher, superintendent of the Concord City waterworks, placed the original capacity between 350 and 400 million gallons.

Area of watershed.—4.7 square miles (3,001 acres) as planimetered directly from aerial photographs without adjustment to a planimetric base.

General character of watershed: Topographically, the drainage basin is part of a broad rolling upland and has gentle to moderate slopes from divides to stream courses, and a total relief of about 150 feet. It is in typical piedmont country, underlain largely by coarse-grained granite, and to a lesser extent by rocks of basic composition, including diorite, gabbro, and diabase. Deep residual soils have been developed through long-continued weathering.

A detailed conservation survey of the watershed has shown the proportionate areas with slopes within stated limits to be as follows: 0- to 3-percent slopes, 6.8 percent; 3- to 7-percent slopes, 62.1 percent; 7- to 12-percent slopes, 18.6 percent; 12- to 15-percent slopes, 7.5 percent; and steeper slopes, 5.0 percent.

The soils of about two-thirds of the area are sandy loams of the Appling series, derived from granites and gneisses. The soils of the remaining third of the area include types of the Cecil, Durham, Helena, Iredell, Mecklenburg, and Wilkes series.

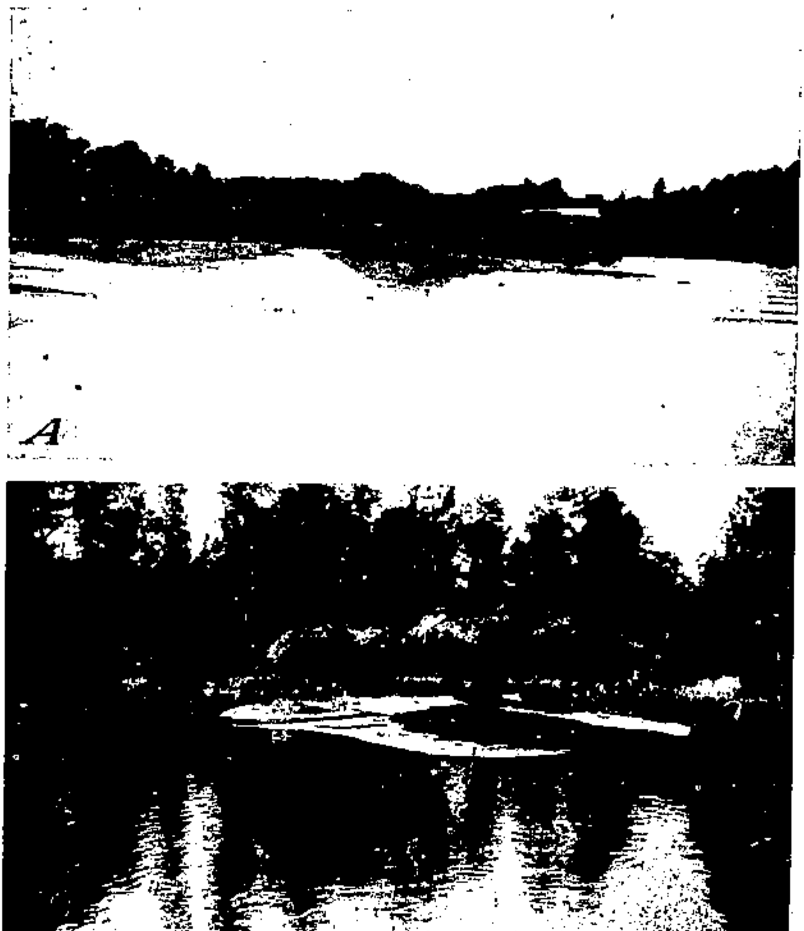
The conservation survey showed that accelerated erosion was apparently absent on only 0.2 percent of the drainage area; that deposition of recent alluvium and colluvium had occurred on 2.1 percent; and that slight erosion had affected 8.6 percent, moderate erosion 14.9 percent, moderate to severe erosion 52.2 percent, severe erosion 3.6 percent, and very severe erosion 4.0 percent. The remaining 14.4 percent consists of urban areas and farmsteads in which degrees of erosion were not differentiated.

Land use in the watershed is divided as follows: Cropland, 39 percent; woodland, 22 percent; idle, 21 percent; pasture, 4 percent; and urban areas and farmsteads, 14 percent. The urban area consists mainly of part of the industrial town of Kannapolis.

The principal crops are corn, cotton, wheat, oats, cowpeas, and tobacco (*1*). Smaller acreages are planted in sweetpotatoes, sorghum, peanuts, rye, gardens, and orchards. The dominant species of the woodland areas are various oaks, hickory, poplar, dogwood, and sweetgum.

Mean annual rainfall.—Approximately 48 inches.

Draft on municipal reservoir.—The normal supply for the city of Concord is 1,000,000 gallons a day. The heaviest demand comes in July when the average daily use exceeds 1,250,000 gallons.



Lake Concord, Concord, N. C.: *A*, Recent delta on Chambers Branch overgrown with marsh grass in background. *B*, Small sand delta on Second Branch.

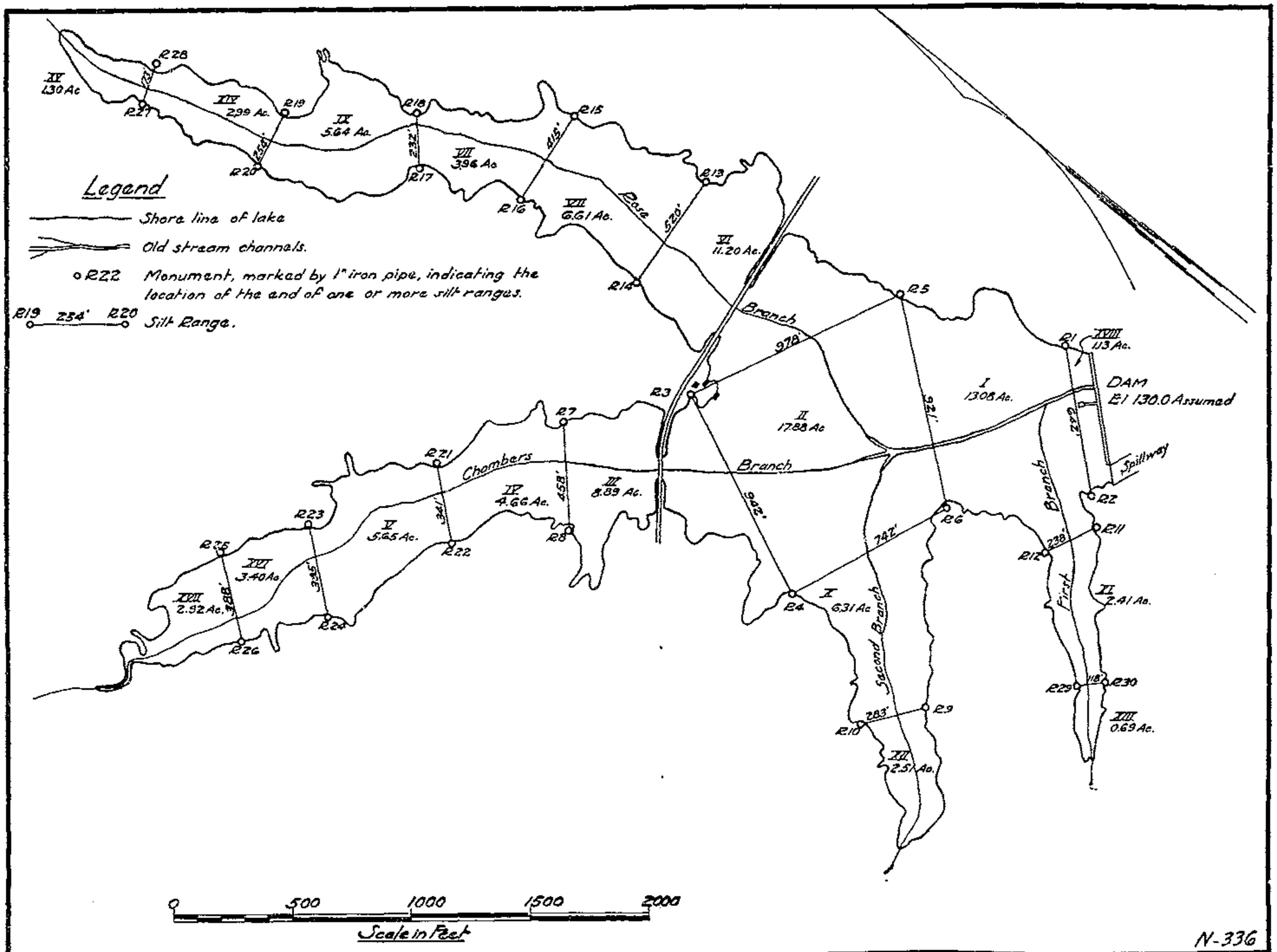


FIGURE 5.—Map of Lake Concord, Concord, N. C., surveyed in May 1935.

History of Survey

The survey of silting in Lake Concord was carried out between May 8 and May 17, 1935, by the southeastern sedimentation party under the direction of Carl B. Brown, chief of party. Most of the field work, computations, and preparation of the project report were under the immediate supervision of D. Hoye Eargle, acting chief of party, in the absence of Mr. Brown.

Field work involved mapping the shore line of the lake from control established by triangulation and stadia; and setting up, sounding, and spudding 18 cross-section ranges, the end points of which were permanently marked by numbered iron pipe. A mapping scale of 200 feet to the inch was used. Ranges were placed as nearly at right angles to the old stream channel as possible, and spaced at intervals ranging from 850 feet near the dam to 450 feet in the delta areas. Elevations were taken from the water surface by using an assumed datum of 730 feet for spillway crest. Soundings were taken at intervals of 20 to 30 feet, except near the old channels where the interval was shorter.

Computations were made on the formulas given in the Appendix under the heading, Range Method.

Sediment Deposits

Bottom-set beds cover by far the larger part of the lake, though on each arm fed by a small tributary, miniature deltas show all the typical characteristics of delta deposits. Bottom-set beds account for a volume of 72 acre-feet, while delta deposits amount to only 7 acre-feet, a ratio of about 10 to 1.

Bottom-set beds are composed of extremely fine-textured, soft, oozy gray mud containing some organic matter, mostly leaves, twigs, and small branches floated into the lake. With an increase in organic matter, such as occurs in the more sheltered bays, the mud assumes a darker color. Delta deposits are made up of coarse gravelly sand near the head of the delta, fine sand in the middle portions, and silty sand on the fore-set beds, grading into fine sandy silt at a distance of several hundred feet downstream. Typical alluvial features, such as spits, bars, and flat triangular-shaped fans nosing suddenly on the downstream end and often spread over the bordering flood plains, are characteristic features (pl. 7, *A* and *B*).

The average thickness of sediment decreases for several ranges downstream from the head of backwater, then levels off, and finally increases gradually near the dam. Such distribution indicates a slight tendency toward underflow of sediment-laden water toward the dam. Distribution from bank to bank along ranges shows an increase from zero near the banks to a foot or two in and near the old stream channel.

The average depth of sediment on Chambers Branch ranges from 2.25 feet in segment 16 to 0.5 foot in segment 2, and on Rose Branch, from 3.85 feet in segment 15 to 0.45 foot in segment 6.

A summary of pertinent data relative to Lake Concord (fig. 5) is contained in the following tabulation:

Summary of data Lake Concord, Concord, N. C.

Age[1] ...years	10.2
Watershed area[2] ...square miles	4.7
Reservoir:	
Original area at crest stage ...acres	101
Original storage capacity to crest level ...acre-feet	1,201
Storage capacity at date of survey ...do	1,122
Original storage per square mile of drainage area[3] ...do	255.53
Storage per square mile of drainage area at date of survey[3] ...do	238.72
Sedimentation:	
Delta deposits ...do	7
Bottom-set beds ...do	72
Total sediment ...do	79
Average annual accumulation ...do	7.75
Annual accumulation per 100 square miles of drainage area ...acre-feet	[3] 172
Annual accumulation per acre of drainage area ...cubic feet	[3] 117.14
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds ...tons	[3] 3.51
Depletion of storage:	
Loss of original capacity per year ...percent	0.65
Loss of original capacity to date of survey ...do	6.59

[1] Storage began in March 1925; survey was made in May 1935.
[2] Including reservoir area.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, computed by including the lake area, are 205.0 acre-feet, 139.53 cubic feet, and 6.98 tons, respectively.

SPARTANBURG RESERVOIR

General Information

Location.—State—South Carolina. County—Spartanburg. Distance and direction from nearest city: 13 miles due north of Spartanburg, S. C. Drainage and backwater: South Pacolet River.

Ownership.—City of Spartanburg.

Purpose served.—Municipal water supply.

Description of dam.—The dam is of the hollow, reinforced concrete type with full concrete apron, having an over-all length of 450 feet, of which 359 feet between buttresses is the spillway section. It has a height of 50 feet above normal water surface, and contains 7,200 cubic yards of concrete. Flashboards 3 feet high have been placed on the dam, which brings the elevation of crest level to 775.25 feet above sea level. The thickness of the dam at its base ranges from 50 to 108 feet.

Date of completion.—May 1926. Surveyed July 1934. Age at date of survey, 8.2 years.

Length of lake at crest stage.—Original, approximately 6 miles.

Area of lake at crest stage.—Original, 314 acres at elevation 775.

Storage capacity to crest level.—Original, 2,700 acre-feet (879,795,000 gallons). At date of survey, 2,237 acre-feet (728,926,450 gallons). Loss, 463 acre-feet (150,868,550 gallons).

Area of watershed.—91 square miles.

General character of watershed.—Spartanburg Reservoir is in the upper Piedmont not far from the front of the Blue Ridge. Topographically the district is a high plateau, intricately dissected by a well-defined stream system into a series of low smooth ridges, somewhat flattened on top where the original level of the plateau has been preserved, and broken along the edges. The interstream areas, 100 to 200 feet higher than the stream valleys, are gently rolling to undulating, becoming hilly and often severely gullied near the streams. According to a recent conservation survey, slopes of 0 to 3 percent cover 8.5 percent of the drainage area; slopes of 3 to 7 percent, 25.8 percent; slopes of 7 to 10 percent, 21.4 percent; slopes of 10 to 14 percent, 12.8 percent; and slopes over 15 percent, 31.5 percent.

The drainage basin is underlain by ancient gneisses and schists and occasional patches of granite and basic intrusives. The foundations of the dam are on a hard blue granite.

The soils of the county range from gray and brown to red, the prevailing color being red or reddish brown. Cecil soils occupy 75.8 percent of the entire drainage basin. Other soil series covering more than 1 percent of the drainage area are, in percentage, Appling 3.2, Edneyville 2.3, Porters 9, Worsham 1, and undifferentiated alluvium 5.5, representing mainly recent overwash of erosional debris.

Only 1.4 percent of the drainage area has undergone little or no erosion, whereas 6.7 percent, mostly bottom lands, has received recent accumulations. Slight erosion has affected 12.0 percent of the watershed; moderate erosion, 19.9 percent; moderate to severe erosion, 42.4 percent; and severe and very severe erosion, 17.2 percent; 0.4 percent is in still other classes.

Land use in the watershed includes 45.9 percent of cropland, 4 percent of idle land, 5 percent of pasture, and 45.1 percent of woodland. Cotton is the principal crop, occupying about twice as much acreage as any other. Corn, wheat, and oats are next in order of importance.

Mean annual rainfall.—47.56 inches at Spartanburg.

Evaporation.—The average annual evaporation from water surface is estimated to be 48 inches.

Draft on municipal reservoir.—The Spartanburg Reservoir, like Lake Michie, serves a dual purpose of municipal water supply and power development. Figures on draft, therefore, represent combined water supply and power development. The mean annual flow of the South Pacolet River is 127 second-feet. The maximum flow over the dam was 14,000 second-feet in August 1928.

Twice a year on an average, as much as 12 inches of water flows over the dam. This is equivalent to a flow of 1,200 second-feet.

The average draw-down of the water level is 3 feet below crest. The greatest draw-down occurs during the dry months, September, October, and November. The maximum draw-down is 15 feet, to elevation 760.

The daily average of water released, by months from July 1933 to June 1935, varied from a low of 51 second-feet in October 1933 to a high of 102.5 second-feet in August of that year; from a low of 76.6 second-feet in July 1934 to a high of 162.6 second-feet in April; from a low in June 1935 of 73 second-feet to a high of 151.8 second-feet in January 1935.

January, February, and March are the months of heaviest draft; and September, October, and November are months of lowest draft.

History and Method of Survey

The survey of Spartanburg Reservoir was begun July 23 and completed August 2, 1934. The party consisted of H. M. Eakin, L. M. Glymph, Jr., as assistant, and a number of rodmen and laborers furnished by the Spartanburg Regional Office as needed from time to time.

The work was greatly facilitated by the generous cooperation of Superintendent R. B. Sims and staff of the city water department, whose office furnished boat facilities, iron pipe for marking control stations and ranges and all available base maps and other records of the reservoir. It was also arranged to have employees at the dam take special gage readings on lake elevations during the progress of the survey.

Owing to lack of accuracy and detail in the original base maps and records that were available, it was found necessary to resurvey the entire reservoir and to resort to direct measurement of sediment depths with spud and soil auger to determine sediment volume and distribution.

The new map was made on a scale of 200 feet to the inch by plane table and stadia as a general basis for establishing sounding ranges and points of depth measurement. Some 38 ranges in all were located, sounded, spudded, and monumented for future resurveys with iron pipe.

Sediment Deposits[16]

In the direct measurements of sediment distribution over the main reservoir area below the deltas a close concordance was found between depths of water and sediment at the observation points on each range. Also the depth ratios of sediment to water were found to fall off progressively down the reservoir from its head toward the dam. Very little sediment was found between the crest-level contour 775 and contour 770, certainly not more than was compensated for by wave scour below high-water level. Of the 314 acres originally flooded at crest stage, 107 acres are thus eliminated from the calculation of total volume of sediment accumulated to the date of survey.

The original area between contours 770 and 760 amounted to 125 acres. Some 15 acres of this section are now occupied by delta deposits which were surveyed separately, leaving 110 acres of reservoir bottom in this depth range containing general clay deposits. The

[16] It will be noted from this section that the computation of sediment volumes in this reservoir was not based on planimeter measurements of plotted cross sections showing both original soil and sediment profiles along the ranges, nor were computations made according to the standard formula for determining volumes from range surveys as given in the Appendix. The survey was conducted by the late H. M. Eakin during the initial stage of the investigations under this project, and was the first reservoir on which the range method of survey was applied. The experience gained in making this survey, together with detailed studies on High Point and Greensboro Reservoirs, was the foundation for establishing the standard methods outlined in the Appendix. In the light of 4 years' subsequent experience in calculating sediment volumes, it is now considered that the data on sedimentation in this reservoir are not so precise as those for later surveys. Such checks as are possible, however, indicate that the data fall within reasonable limits of error, and are probably as accurate as data from most reservoir-silting surveys previously made in this country. (Note by author of revision.)

average of water-depth measurements within this area is 11.6 feet and the ratio of aggregate sediment to water depth 0.119, indicating an average depth of sediment over the 110 acres of 1.38 feet or a volume of 152 acre-feet.

The original area of reservoir bottom below contour 760 was 82 acres, none of which is encroached upon by delta deposits. The average of systematic water-depth measurements within this area is 24 feet and the ratio of aggregate sediment and water depths is 0.07, indicating an average depth of sediment of 1.68 feet or a volume of 137 acre-feet. Combining these volumes above and below the 760-foot contour gives a total volume of general bottom-set clays amounting to 289 acre-feet.

The delta area at the head of the reservoir is elongated in form, extending for 5,000 feet downstream from the original valley crossing of the 775-foot contour. The stream has filled in parts of original storage space along this reach, tending to reestablish a normal alluvial channel by building natural levee banks and bars attached to the original reservoir shore. These deposits increase in depth but vary in width downstream.

Table 11 gives the aggregate widths of deposits on successive cross sections at 200-foot intervals in the main delta area below Mary Foster Bridge.

TABLE 11.—*Aggregate widths of deposits on successive cross sections at 200-foot intervals in the main delta area below Mary Foster Bridge*

Range	Width	Range	Width	Range	Width	Range	Width
	Feet		*Feet*		*Feet*		*Feet*
1	0	7	85	13	120	19	90
2	50	8	70	14	45	20	100
3	140	9	85	15	30	21	170
4	200	10	155	16	40		
5	240	11	135	17	65	Total	2,140
6	50	12	180	18	60	Average	102

Borings and soundings were made in the delta area to determine maximum depths of deposit at positions corresponding with ranges 4, 5, 10, and 21 of table 11. The first three gave depths of 8.0, 9.2, and 9.4 feet, respectively, or an average depth of 8.8 feet. The last two gave depths of 12.8 and 12.0 feet, respectively, or an average of 12.4 feet in the lower end of the delta. The average depth of the five borings is 10.8 feet.

The thinning out of these deposits from maximum depths toward the original lake shore and in the area above Mary Foster Bridge indicates an average depth about half that of the maximum or 5 feet, approximately. This depth over an area 100 feet wide and 5,000 feet long gives an aggregate volume of some 57 acre-feet for the main South Pacolet River delta deposit.

Other deltas have been built into the reservoir at the mouths of local tributaries. Most of the lands surrounding the reservoir that are drained by these streams are undergoing cultivation and attendant accelerated erosion. Consequently many of the subordinate deltas have developed considerable volume.

The volume of each of these minor deltas as computed is limited to accretions below spillway-flashboard level, or elevation 775.25, United States Geological Survey datum. The volume thus delimited begins upstream at the intersection of this level with the original valley bottom. From this line downstream its top is a horizontal plane to the 775.25 contour on the present delta surface, and thence slopes with the surface of the deposit, first gently to the delta rim, and then more steeply to the toe of the frontal slope. Owing to controlled operation of the reservoir, with stage held close to elevation 772.0 at the top of the concrete spillway, there is little terracing of the delta surfaces and delta rims are generally at this elevation. To simplify computation of volumes the surface of the individual deposit is assumed to consist of two sloping planes, one from the upstream margin to the rim and the other from the rim to the toe, and the depth from the rim to the original valley floor is assumed to extend for the full width of the valley. This excludes a prism of material above the plane of the 775.25 contour, but compensates this more or less closely by exaggerating the area of the rim cross section. The form of the delta thus simplified is that of two wedges with their bases coincident on the rim cross section and thinning out in opposite directions, the valley wedge narrowing upstream and the fore-set prism widening out to the toe. The volumes of these prisms, if widths were constant throughout, would be one-half the product of base and length. To take into account actual differences in width more complex equations are necessary.

Designating rim depth as D, widths at the head, rim, and toe as $W1$, $W2$, and $W3$, and lengths of valley and fore-set prisms as $L1$ and $L2$, respectively, the volume of the valley prism becomes:

$$\frac{W2\,D\,L1}{2}-\frac{(W2-W1)\,D\,L1}{6}$$

and that of the fore-set prism becomes:

$$\frac{W2\,D\,L2}{2}+\frac{W3-W2\,D\,L2}{6}.$$

Owing to low slope of the fore-set beds there is usually little difference between $L1$ and $L2$. Also the spread of the fore-set prism compensates closely the taper of the valley prism.

It follows that a close approximation of the entire delta volume is represented in the product of the delta rim cross-section area and distance from the rim to the original valley position of contour 775.25. A more conservative result is obtained in the product of actual area of the valley prism and depth of deposit at the delta rim. The volumes of individual deltas are computed on this basis. Their combined volume, without allowance for numerous still smaller deltas, too tedious and unimportant to be surveyed, is 117 acre-feet. Adding to this figure the 57 acre-feet of the main South Pacolet delta at the head of the reservoir gives a total volume of 174 acre-feet of delta deposits.

A summary of pertinent data relative to Spartanburg Reservoir (fig. 6) is contained in the following tabulation:

FIGURE 6
FOUND AT END
OF BULLETIN.

Summary of data on Spartanburg Reservoir, Spartanburg, S. C.

Age [1]	years	8.2
Watershed area [2]	square miles	91.0
Reservoir:		
Original area at crest stage	acres	314
Original storage capacity	acre-feet	2,700
Storage capacity to crest level	do	2,237
Original storage per square mile of drainage area [3]	do	29.67
Storage per square mile of drainage area at date of survey [2]	do	24.58
Sedimentation:		
Delta deposits	do	174
Bottom-set beds	do	289
Total sediment	do	463
Average annual accumulation	do	56.5
Annual accumulation per 100 square miles of drainage area	do	[3] 62.0
Annual accumulation per acre of drainage area	cubic feet	[3] 42.23
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds	tons	[3] 1.27
Depletion of storage:		
Loss of original capacity per year	percent	2.09
Loss of original capacity to date of survey	do	17.15

[1] Storage began in May 1926; survey was made in July 1934.
[2] Including lake area.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin and to conform with a revision of the watershed area based on a new map made since the first edition of this bulletin was published. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, based on a total drainage area of 92 square miles including reservoir, are 61.6 acre-feet, 41.93 cubic feet, and 2.1 tons, respectively.

LLOYD SHOALS RESERVOIR [17]

General Information

Location.—State—Georgia. Counties—Jasper, Butts, and Newton. Distance and direction from nearest city: 8 miles east of Jackson, Ga. Drainage and backwater: Ocmulgee River, and its tributaries, the Alcovy, South, and Yellow Rivers, and Tussahaw Creek.

Ownership.—Georgia Power Co., a subsidiary of Commonwealth & Southern Corporation, New York, N. Y.

Purpose served.—Hydroelectric power development.

Description of dam.—The Jackson Dam [18] is a gravity-type structure, constructed of cyclopean-concrete masonry with a concrete powerhouse built into the west end. It is 1,750 feet long, 100 feet high, and 85 to 96 feet thick at the base. The spillway on top of the dam is 728 feet long. A center section of the spillway, 420 feet long, 180 feet from the east end and 128 feet from the west end, is 3 feet lower than the rest of the spillway. In the lower section, 42 flashboards, 5 feet high and 10 feet long, and in the higher sections 30 flashboards, 2 feet high and 10 feet long, and 1 flashboard 1 foot high and 8 feet long, have been erected.

The elevation of the middle section of spillway is 525 feet, the upper section 528 feet, and top of the flashboards, or crest level, 530 feet above sea level. The flashboards trip automatically when the water rises to elevation 530.50. The tailrace of the dam is at an elevation of 425 feet.

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[17] The Service received fullest cooperation from the Georgia Power Co., which supplied boats and motors for use in the survey. B. F. Sinclair, chief engineer of the company, arranged for photostating and use of the base maps, and supplied important data on the reservoir. J. K. Sitton, superintendent of the power plant, was helpful in supplying local information and in other ways.
[18] Local name.

Date of completion.—December 1910. Completely filled May 1911. Age at date of survey, 24.3 years.

Length of lake at crest stage.—Original—dam to head of backwater on South River, 12.5 miles; to head of backwater on Yellow River, 10.7 miles; to junction of South and Yellow Rivers, 6.1 miles; to head of backwater of Alcovy River, 10.4 miles; to junction of Alcovy River, 4.1 miles; to head of Tussahaw Creek, 7.6 miles; and to junction of Tussahaw Creek, 2.6 miles.

Area of lake at crest stage.—4,537 acres at 530 contour, planimetered from original base maps. Previous estimates by the power company give the area at the 530 contour as 4,752 acres.

Storage capacity to crest level.—Original, 112,538 acre-feet. At date of survey, 98,578 acre-feet. Loss, 13,960 acre-feet.

Area of watershed.—1,414 square miles.

General character of watershed.—The watershed above Jackson Dam lies wholly in the Piedmont province. It is typically a broad rolling peneplain with even skyline, though actually dissected by an intricate and complete system of drainage. Occasional isolated hills and mountains occur, the most notable of which is the famous Stone Mountain, near Decatur, Ga. The topography is purely erosional, and consists of broad undulating to gently rolling divides which slope more steeply near to the stream courses. The main river valleys are 100 to 200 feet below the major divides. Along the valleys, especially that of the Ocmulgee, slopes are often steep, rocky, and thoroughly dissected. Smaller streams are commonly 50 to 75 feet below the local divides, and their valley slopes are longer, more rounded, and more gentle. Gullies, intermittent streams, and even spring-fed streams extend far back into the divides and around these headwaters the land is likewise more broken and eroded. Flat strips of bottom lands are found along most of the drainage courses, ranging in width from a few feet on the small streams to more than half a mile on the Ocmulgee.

According to a recent conservation survey, slopes of 0 to 3 percent cover 9.1 percent of the drainage area; slopes of 3 to 7 percent, 39.4 percent; slopes of 7 to 12 percent, 32.9 percent; slopes of 12 to 15 percent, 8.2 percent; and slopes over 15 percent, 10.4 percent.

The watershed is underlain entirely by ancient crystalline rocks, gneisses, schists, and numerous areas of granite, and many smaller areas of basic igneous and metamorphic rocks. Among the most widespread formations are the Carolina (acidic) gneiss, the Roan (basic) gneiss, and the Lithonia granite.

The principal soil series in the watershed are, in percentage, as shown by the conservation survey, Cecil 52.7, Appling 16.8, Louisburg 10, Lloyd 5.9, and Madison 3. The Cecil and Appling series are derived from acidic crystalline rocks, which are predominant in the drainage area. Congaree 0.8 percent, and meadow soils or undifferentiated alluvium 6.4 percent, commonly occur as strips along major streams, the latter type representing mainly areas of recent overwash resulting from soil erosion on the slopes.

Residual soils of the upland are deeply weathered, often loose textured, and subject to severe erosion where they have been stripped of the natural vegetative cover. Lack of erosion-control measures has resulted in severe sheet erosion and serious gullying in all parts of the watershed. Only 0.6 percent of the total area is unaffected by soil erosion; in contrast, 9.7 percent has undergone slight erosion; 26.5 percent, moderate erosion; 39.9 percent, moderate to severe erosion; 9.4 percent, severe erosion, representing a loss of more than 75 percent of topsoil; and 6.1 percent is classed as very severely eroded, which includes areas having lost all topsoil and a part of the subsoil. The severity of erosion and the continuing high losses of soil are shown by the heavy load of suspended matter carried in most of the streams, whose water has almost continuously a reddish-brown appearance.

Land use in the watershed includes 40.8 percent of cropland, 10.9 percent of idle land usually undergoing serious erosion, 5.3 percent of pasture, 41 percent of woodland, and 2 percent of farmsteads and urban areas. The principal crop is cotton, which far outranks any other, both in acreage planted and in cash value. Corn and oats are next in order of importance. Cowpeas, alfalfa, hay, wheat, rye, vegetables, and fruits are raised less extensively.

Mean annual rainfall.—Annual rainfall at the nearest points of record has ranged as follows: At Griffin, Ga., driest year (1904), 32.91 inches; wettest year (1906), 53.68 inches; mean, 49.23 inches. At Covington, Ga., driest year (1904), 32.50 inches; wettest year (1900), 67.31 inches; mean, 47.84 inches. At Monticello, Ga., driest year (1904), 35.55 inches; wettest year (1906), 60.95 inches; mean, 49.99 inches.

Power development.—The installed power equipment consists of six horizontal-type turbines, four of 39-inch diameter, and two of 42-inch diameter, with a capacity of 5,500 horsepower each at full gate. They are connected to six horizontal-type Westinghouse generators of 3,000 kilovolt-amperes each. The total wheel capacity at full gate is 33,000 horsepower, but as the wheels give a higher efficiency and are subject to better control at a normal three-quarter gate opening, the average rating of the plant is 24,000 horsepower. The installed generator capacity is 18,000 kilovolt-amperes.

The operating head is 83 to 104 feet. At spillway elevation (530 feet) it is 102.8 feet with full load.

The upper 20 feet of the reservoir, between the 510 and 530 contours, is considered as storage. It gave an original available storage of about 3 billion cubic feet, or 68,870 acre-feet. The maximum drawdown is slightly over 15 feet during dry summers.

History of Survey

Field work for the survey of Lloyd Shoals Reservoir was begun February 4 and completed April 13, 1935, by the southeastern sedimentation party under the direction of Carl B. Brown, chief of party.

Photostats of original maps of the reservoir basin, made in 1907 by an engineering firm on a scale of 400 feet to the inch, were available through the courtesy of the Georgia Power Co. Four contours, 530 (crest), 525, 515, and 505, are shown on these maps.

A total of 132 ranges was established and marked by numbered iron pipe. Ranges were connected by triangulation and stadia traverse from the dam to the junction of the Ocmulgee and Alcovy Rivers. Above this point range ends were located with reference to natural features of topography and artificial landmarks. They were not tied together in view of the character of the lake's long winding arms, wooded terrain, and other natural obstacles which would have interposed a serious time limitation on other work of the survey. It is believed that ranges have been established and plotted on the large scale base maps with sufficient accuracy for easy relocation.

Ranges were sounded and spudded in the lower part of the lake, in accordance with the general instructions outlined in the appendix. In the lower part of the delta area a new sediment-sampling apparatus was devised for the purpose of obtaining deeper penetrations. A 2-foot wooden section of spud was machine-grooved from a 2- by 2-inch oak strip, and was jammed securely into a 1¼-inch section of pipe which was coupled to a 5-foot section of 1-inch pipe. Available with this were 45 additional feet of 1-inch pipe in 5-foot sections with couplings, together with an auger handle. Working from a flat-bottomed scow anchored securely at both ends, the spud was pushed down into the sediment, additional sections of pipe being added as needed. The original bottom was recognized readily by added resistance to downward pressure. The pipe spud could usually be pushed less than a foot into old soil. Penetrations to a depth of 23 feet of sediment were measured by this method.

In the upper part of the delta areas, considerable sediment occurs above crest level as overbank deposits accumulated during flood periods. All the delta area that is usually above water is covered by a thick growth of willows, beach, sycamore, ash, and small underbrush, much of it 15 to 20 years old. In these areas range lines across the delta were necessarily chopped out. Profiles were established by stadia, except in the narrow channel of the present stream, which was sounded. Attempts were made at several points to reach old soil by auger borings, but only sand was penetrated. Apparently the character of old soil is so similar to the present deposits that no distinction could be recognized. Failure of borings made it necessary to construct original cross-section profiles from the contour maps. These, of course, are generalized by lack of more closely spaced contours than 10 feet, yet the relative accuracy is probably as great as could have been attained with the few borings that time would have permitted, considering the extent of the delta areas.

Computations and drafting were done by the field party. Part of the planimeter work was done in the Washington office and part in the field. All computations were based on the range formulas given in the Appendix.

Sediment Deposits

The two classes of sediment, delta deposits, and bottom-set clays, that accumulate typically in southeastern reservoirs, are quite distinct both in character and occurrence at Lloyd Shoals. Delta deposits, resulting from impounding of this reservoir, actually extend several miles above the head of backwater on the South and Yellow Rivers because of banking up of sediment or development of top-set beds as the rivers have tended to flatten their gradient to a normal profile of equilibrium. For computing loss of reservoir capacity, however, it was necessary to disregard the above-crest deposits and consider the delta as that body of sediment beginning at the head of backwater, extending downstream with low gradient for several miles to the delta rim, and finally nosing steeply to the toe of the fore-set beds, where it merges with the bottom-set clays of the main lake basin. Bottom-set beds cover the entire floor of the lake below the deltas, except for a narrow strip around the shore line from which they have been washed into deeper water during periods of seasonal draw-down. In any cross section, deposits are thicker in the deeper parts, especially near the old stream channel. This may be partly a result of underflow of heavily sediment-laden waters toward the dam, although variation on the cross section appears to be closely proportional to the depth of the overlying column of water from which the sediment could settle.

Deltas

Nearly the entire surface of the deltas is above water during more or less frequent periods of draw-down, of which the last prior to the survey was in the fall and winter of 1934. Exposure to air and sun rapidly dewaters the silt, causing it to compact into an extremely tight and sticky deposit. Once this condition is attained, the sediment will never return to its original loosely coherent state despite long-continued flooding. The spud can be pushed into such compacted sediment only a foot or two at most, which is seldom sufficient to reach old soil. The sediment has, in fact, all the coherence and plasticity characteristic of the finest-textured loams of the section.

The fine to sandy silt of the delta, usually dark gray in color, contains leaf and stem fragments, while the old soil, at the few places where it was observed, has a bluish-gray cast and contains numerous rootlets. The presence of rootlets alone, however, is misleading, because fast-growing willows of the delta region spread their rootlets almost as widely as they occur in the old soil. The presence of sand was likewise an uncertain criterion, for the deltas are made up characteristically of alternating layers of sand and silt. The doubtful distinction in color afforded virtually the only basis for distinguishing delta deposits from old soil, but since it was seldom possible to penetrate through the new deposits either with spud or auger, this distinction was relatively unimportant.

The South and Yellow Rivers are comparable in size, the deltas are connected for a short distance below their junction, and numerous features are common to each, while the two differ in several respects from the Alcovy and Tussahaw. Therefore, the first two arms are treated together, and the last two separately.

South and Yellow Rivers.—The deltas of the South and Yellow Rivers may be separated for description into three longitudinal segments, merging uniformly and almost imperceptibly into each other.

The upper division, while extending some distance above the original head of backwater, maintains its distinctive character for 1¼ miles below the head of backwater on the South River, and 1½ miles on the Yellow River. It is differentiated from the lower segments chiefly by the fact that backwater at crest stage is confined to the original stream channel, or to a channel of comparable size. The river current is noticeable to a casual observer even at high-water stage. Shoals of bare rock were discovered by spudding at a number of places in the channel, even though the lake was then at crest-level stage. Fine to medium-grained sand is the typical sediment. Natural levees along the channel banks, formed by the rivers in their continuous process of adjusting channel capacity to load and rate of flow, are a marked characteristic. Behind them are miniature lagoons partly filled with silt, although in places covered by extensive sand flats deposited during flood stage when water level of this stretch rises several feet above normal. Since the levees average about 5 feet higher than crest near the head of backwater, a rise of this magnitude is required for overflow and deposition of sand. Behind the depressions against the original valley sides are remnants of an older flood plain, or terrace, nearly 5 feet higher than the present levees. This terrace extends for long stretches as a pronounced bench 10 to 25 feet wide. According to local testimony, the river has risen above normal stage to the level of this bench, or approximately 10 feet, in recent years during major floods.

Sand is deposited in large quantities as bars in the river channel during high reservoir stages. As this takes place the levees are shifted toward the valley sides to bring the river cross section into adjustment with load and rate of flow. With subsequent draw-down the sand bars are moved downstream by the current, and deposition takes place on the channel side of the levees. The consequent alternation of shallowing and widening with deepening and narrowing is not an orderly repetition but is dependent on several independent factors, namely, inflow, load, and service requirements on the reservoir reflected in draw-down.

Sand deposited by flood waters on the back side of the levees is seldom disturbed except during rare recurrence of extremely high water. Such deposits, however, are often of considerable size; one contains over 20 acre-feet, all above crest level, though more than one-half mile below the original head of backwater and entirely within the original basin.

Farther downstream, in the second delta segment, the terrace and present flood plain gradually merge and pass below crest level. The channel is still well defined, though at spillway stage water covers large parts of the lagoons behind low levees. These depressions are seldom more than 3 feet deep measured from crest elevation.

Sediment of the levees consists of alternating layers of sand and silt ranging usually from 6 inches to 3 feet in thickness. It is well exposed in drainage ditches cut from the overbank depressions into the channel, and has also been explored to depths of 10 feet by auger borings. In the channel, sand alone is found, while in the irregular bays back of the levees, silt and organic matter constitute the principal accumulation. Some sand as well as silt is being brought into the bays from small tributary streams, and in places flood waters have deposited sandy alluvial fans, especially where the flood plains or shallow bays are near crest level. The deeper bays are fed through levee openings when the water is at spillway stage. Once the sediment-laden water has flowed into the depressions it practically stagnates, and most of the suspended load settles out. During the course of this survey, the water rose from a maximum draw-down of 15 feet to 6 inches above crest level, then dropped 2 feet. Actual measurement showed that during the course of this rise one-tenth foot of extremely fine silt was deposited over bays where the water depth was only 1 to 3 feet.

The middle segment of the deltas supports a heavy growth of willows, beech, and other water-loving trees as much as 15 inches in diameter, as well as a dense undergrowth of brush, shrubs, and briers. The smaller growth is partially cleared at intervals by the power company, but despite this, much decaying organic matter is continually added to the sediment accumulation of the bays.

The lower segment of the deltas extends from about 3 miles to 5 miles below the head of backwater on the South River, and from 3½ to 5 miles on the Yellow River. In this stretch the deltas are entirely below water at spillway stage; that is, the water extends from bank to bank of the original valley, though during maximum draw-down all but the channel is exposed. The deposits are a mixture of fine sand and silt. They thicken toward the rim of the delta, which begins about 1,000 feet below the junction of the South and Yellow Rivers, where in one place an accumulation of 23 feet was measured. Thick sediment continues for several thousand feet downstream, but the deposits become less sandy, grading through sandy silt to fine mud devoid of all grit.

Alcovy River.—Shoals occurring just at the head of backwater on the Alcovy River have a fall of 45 feet in 1,200 feet. Immediately below them the force of rushing water keeps the channel free of sediment, but several hundred feet downstream sand has accumulated in such quantity that the course of the channel has been entirely changed. An island covered with a considerable growth of trees now exists near the center of the old channel.

A few hundred feet farther downstream the above-crest deposits disappear, and water at spillway level covers all the original valley. The deposits grade rapidly from sand through sandy silt to fine silt, and at a distance of 2 miles below the shoals consist wholly of bottom-set clays. A considerably smaller depth ratio of sediment to water was found on the Alcovy River than on the South and Yellow Rivers.

Tussahaw Creek.—The delta of Tussahaw Creek is the shortest and most regular of any on the four major arms of the lake. The rim of the fore-set beds lies between ranges 38—39 and 224—225, about 8,500 feet below the head of backwater. Soundings show a marked difference in average depth between these two ranges. Spud penetrations were easily obtained on all points on the lower range (38—39), while complete penetration could not be obtained on the upper range. This indicates a very distinct and sharply nosing delta front.

Bottom-Set Beds

Bottom-set beds cover the entire floor of the lake below the delta areas except for the narrow strip alongshore from which they have been washed into deeper water. These deposits, where they have been continually covered by water, are composed of very fine soft, oozy mud containing occasional leaf and stem fragments. They are readily distinguishable from old soil, which is usually residual from granite and therefore contains unassorted sand and clay. Old soil contains numerous rootlets, is much darker in color, and is far more sticky and compacted than the silt.

On the Ocmulgee, sediment between range 65—66, 1,000 feet below the junction of the South and Yellow Rivers, and the dam is classed as silt. It varies in depth from a maximum of 14.8 feet on range 65—66 to 3.7 feet on range 1—2, just above the dam. The deepest silt is almost invariably found in the old stream channel, a result perhaps partly of underflow of silt-laden water.

On the Alcovy River, the upper limit of bottom-set beds is on range 128—129, 2 miles below the head of backwater, where the last sand-free silt was penetrated. However, the front of the delta is less distinct on this arm and much fine sand may have been carried down into the predominantly silt deposits. The maximum thickness of sediment, 6.3 feet on range 128—129, is considerably less than at the same relative position on the Ocmulgee.

The old soil of the wide Alcovy flood plain is largely a tight blue clay, contrasting with the sandy soil along the narrower flood plains of the Ocmulgee. This fact suggests that in the past, as at present, the Alcovy deposited a greater proportion of finer sediment than the Ocmulgee.

The upper limit of bottom-set beds on Tussahaw Creek was definitely located between ranges 38—39 and 224—225, 8,500 feet below the head of backwater. The maximum depth of sediment measured on the lower range (38—39) was 5.8 feet.

A summary of pertinent data relative to Lloyd Shoals Reservoir (fig. 7) is contained in the following tabulation:

Summary of data on Lloyd Shoals Reservoir, Jackson, Ga.

Age [1]	years	24.3
Watershed area [3]	square miles	1,414
Reservoir:		
Original area at crest stage	acres	4,537
Original storage capacity to crest level	acre-feet	112,538
Storage capacity at date of survey	do	98,578
Original storage per square mile of drainage area [2]	do	79.59
Storage per square mile of drainage area at date of survey [2]	do	69.72
Sedimentation:		
Total sediment	do	13,960
Average annual accumulation	do	574
Annual accumulation per 100 square miles of drainage area	acre-feet	[3] 40.8
Annual accumulation per acre of watershed	cubic feet	[3] 27.76
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds	tons	[3] 0.83
Depletion of storage:		
Loss of original capacity per year	percent	0.51
Loss of original capacity to date of survey	do	12.40

[1] Storage began in December 1910; survey was made in March 1935.

[2] Including reservoir area.

[3] These figures are revised to exclude the lake area from the total area of the drainage basin and to conform with a revision of the watershed area based on a new map made since the first edition of this bulletin was published. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, based on a total drainage area of 1,375 square miles, including reservoir, are 41.73 acre-feet, 28.40 cubic feet, and 1.42 tons, respectively.

HIGH ROCK RESERVOIR

High Rock Reservoir is impounded by a dam on the Yadkin River, 14 miles southeast of Salisbury, N. C. It is a hydroelectric power development owned and operated by the Carolina Aluminum Co. The power plant consists of three units which develop a total of 44,100 horsepower.

FIGURE 7
FOUND AT END
OF BULLETIN.

The dam is a gravity-type concrete structure 60 feet high and 920 feet long, including the Stoney-type floodgates on top and the powerhouse at the east end. Crest level, determined by the tops of the gates, is 624.1 feet above mean sea level. When storage began in 1927 the area of the reservoir at crest stage was 15,886 acres and the total storage capacity was 289,432 acre-feet, but at the time of survey in 1935 silting had reduced the area to approximately 15,833 acres, a loss of 53 acres, and the capacity to 275,516 acre-feet. Backwater extends 23 miles up the Yadkin River from the dam.

The drainage basin above High Rock Dam is 3,930 square miles in area, of which about 30 percent, mainly in the Blue Ridge province, is mountainous and the remaining 70 percent has the rolling topography and moderate relief typical of the Piedmont of North Carolina. The soils in general are highly erodible, and sheet and gully erosion have wasted vast quantities of topsoil in areas that are or have been cultivated. These areas, lying chiefly in the Piedmont section, comprise more than 40 percent of the total drainage area. The mountain section is largely forested. The average annual rainfall is 47.78 inches.

The sedimentation survey of High Rock Reservoir, made during the summer of 1935, revealed a total deposit of 13,916 acre-feet of sediment, ranging from gravel and coarse sand in the upper reaches to fine-grained unctuous mud in the lower basin. Considerable organic matter, chiefly leaves, is included.

The average sediment depth varied considerably in the upper reaches of the reservoir, but in general increased from the head of backwater to a point 6 miles downstream, where it reached a maximum of about 5 feet. From this point downstream it ranged from 3 to 5 feet for the first 5 miles and then decreased gradually and uniformly to 0.6 foot within a mile of the dam, but increased again to nearly 2 feet just above the dam. This distribution shows that the most rapid sediment accumulation is occurring just below the narrow upper section of the reservoir in which all but the main channel is drained during periods of draw-down, and which is subject to the scouring action of periodic floods.[10]

The quantitative results of the survey of High Rock Reservoir are summarized in the following tabulation:

Summary of data on High Rock Reservoir, Salisbury, N. C.

Age[1]	years	7.8
Watershed area[2]	square miles	3,930
Reservoir:		
Original area at crest stage	acres	15,886
Area at crest stage at date of survey	do	15,833
Original storage capacity	acre-feet	289,432
Storage capacity at date of survey	do	275,516
Original storage per square mile of drainage area[2]	do	73.65
Storage per square mile of drainage area at date of survey[2]	do	70.11

[1] Storage began November 1927; average date of sediment measurements, September 1935.
[2] Including reservoir area.

[10] More complete information on this reservoir is given by D. Hoye Eargle in the *Advance report on the sedimentation survey of High Rock Reservoir, Salisbury, North Carolina.* U. S. Soil Conserv. Serv. SS-10, February 1937. (Mimeographed.)

Summary of data on High Rock Reservoir, Salisbury, N. C.—Continued

Sedimentation:	
Total sediment ... acre-feet	13,916
Average annual accumulation ... do	1,784
Annual accumulation per 100 square miles drainage area [3] ... do	45.7
Annual accumulation per acre of drainage area [3] ... cubic feet	31.10
Or, assuming 1 cubic foot of deposit weighs 60 pounds ... tons	0.93
Depletion of storage:	
Loss of original capacity per year ... percent	0.62
Loss of original capacity to date of survey ... do	4.81

[3] Excluding reservoir area.

LAY RESERVOIR

Lay Reservoir is impounded by a dam on the Coosa River about 12 miles northeast of Clanton, Ala., and 50 miles southeast of Birmingham. It is a hydroectric power development owned and operated by the Alabama Power Co. The power plant consists of six units which develop 116,000 horsepower.

The dam is a gravity-type cyclopean-concrete masonry structure 77 feet high and 1,543 feet long, including the modified Stoney floodgates on top and the powerhouse built into the west end. At the time of construction in 1913, the area of the reservoir at crest stage was 6,698 acres and the total storage capacity was 156,525 acre-feet. At the time of survey in 1936 silting had not appreciably reduced the area but had decreased the capacity to 138,520 acre-feet. The reservoir has an average width of 2,000 feet and extends 24 miles up the Coosa River from the dam.

The drainage basin above Lay Dam is 9,087 square miles in area. It lies mainly in the Valley and Ridge province, characterized by long parallel ridges and somewhat wider valleys, but overlaps slightly into the moderately dissected Appalachian plateaus on the west and the lower rolling Piedmont on the east. A wide variety of soil types has been developed chiefly from limestone and shale and to a lesser extent from granitic and various metamorphic rocks. Under the impetus of unwise farming practices and deforestation, sheet and gully erosion have progressed until one-half to three-fourths of the area has undergone moderate to severe erosion, and probably one-fourth of the area has lost 75 to 100 percent of its topsoil. The mean annual rainfall for the area as a whole is about 54 inches.

The sedimentation survey of Lay Reservoir, made during parts of the period January 27 to July 24, 1936, revealed a 22-year accumulation of 18,005 acre-feet of sediment, representing a total capacity loss of 11.5 percent. The sediment consists chiefly of fine even-textured medium-brown silt but includes minor amounts of sand and vegetal material. The average sediment depth in general increases downstream, averaging less than 1 foot in the upper 10 miles of backwater, 2 to 4 feet in the next 8 miles, and 4 to 6 feet in the lower 6 miles. This concentration of sediment toward the dam is largely the result of three factors, namely, (1) the predominance of fine, easily transported silt and clay in the incoming sediment load, (2) a low capacity-inflow ratio, resulting in the continuous passage of large volumes of water through the reservoir, and (3) the narrow, constricted basin, which maintains strong currents far down the reservoir.[20]

The quantitative results of the survey of Lay Reservoir are summarized in the following tabulation:

Summary of data on Lay Reservoir, Clanton, Ala.

Age [1]	years	22.3
Watershed area [2]	square miles	9,087
Reservoir:		
Original area at crest stage	acres	6,698
Area at crest stage at date of survey	do	6,698
Original storage capacity	acre-feet	156,525
Storage capacity at date of survey	do	138,520
Original storage per square mile of drainage area [2]	do	17.23
Storage per square mile of drainage area at date of survey [2]	do	15.24
Sedimentation:		
Total sediment	do	18,005
Average annual accumulation	do	807
Annual accumulation per 100 square miles drainage area [3]	do	8.9
Annual accumulation per acre of drainage area [3]	cubic feet	6.05
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds	tons	0.18
Depletion of storage:		
Loss of original capacity per year	percent	0.52
Loss of original capacity to date of survey	do	11.50

[1] Storage began December 1913; average date of survey, May 1936.
[2] Including area of reservoir.
[3] Excluding area of reservoir.

SURVEYS IN SOUTH-CENTRAL UNITED STATES

ROGERS MUNICIPAL RESERVOIR

General Information

Location.—State—Texas. County.—Bell. Distance and direction from nearest city: 4 miles southwest of Rogers, Tex. Drainage and backwater: Eastern tributary of the Little River.

Ownership.—City of Rogers.

Purpose served.—Municipal water supply.

Description of dam.—The dam is of earth-fill construction, 700 feet long and 22 feet high. The spillway consists of a concrete overflow box in the reservoir, connected with a tunnel leading through the dam.

Date of completion.—September 1922. Surveyed September 1934. Age at date of survey, 12 years.

Length of lake at crest stage.—Original, 2,000 feet. At date of survey, 1,600 feet. Amount shortened, 400 feet.

Area of lake at crest stage.—Original, 23.1 acres. At date of survey, 21.8 acres. Loss, 1.3 acres.

Storage capacity to crest level.—Original, 164 acre-feet (53,439,400 gallons). At date of survey, 126.5 acre-feet (41,220,025 gallons). Loss, 37.5 acre-feet (12,219,375 gallons).

Area of watershed.—350 acres, or 0.55 square mile.

[20] More complete information on this reservoir is given by F. F. Barnes in the *Advance report on the sedimentation survey of Lay Reservoir, Clanton, Alabama.* U. S. Soil Conserv. Serv. SS-13, May 1937. (Mimeographed.)

General character of watershed.—Rogers Reservoir, on the headwaters of an eastern tributary of the Little River, is the smallest lake surveyed during the present investigations. It was selected for special study as a possibly significant check on rates of debris production from the blackland soils of Texas, which are notably erodible under current agricultural practice. Also, the relations of storage capacity to drainage area exemplify on a small scale an important general characteristic of the large reservoirs of the Southwest; that is, a capacity large enough to store the larger part of a year's run-off and hold it long enough for practically complete clarification, in the intervals between flood flows, of muddy water from intermittent tributary streams.

The drainage basin, 350 acres in extent, is floored throughout with the typical deep, highly granular and porous, limy soils of the Texas Black Belt. All of it has been cultivated in the past and much of it is still under the plow, with furrows run straight, regardless of ground slope. Slopes of 4 to 10 percent are common along the valley sides. Farther back toward the divides the slopes are less steep, and the divides are practically level. These lands throughout the drainage area have suffered serious sheet erosion and in many places have been severely gullied (pl. 8, *A*).

Mean annual rainfall.—Approximately 35 inches.

Draft on municipal reservoir.—The daily draft on Rogers Lake for municipal water supply, allowing 100 gallons daily per inhabitant, is about 108,000 gallons.

History of Survey

The survey of Rogers Lake was made in September 1934 by H. M. Eakin and assistants. It included contour mapping of both original and present topography of the flooded area below spillway level, on a scale of 100 feet to the inch and with a contour interval of 2 feet. An assumed datum of 100 feet was used for the spillway elevation.

The original topography was determined by soundings and borings through new sediment deposits to the underlying original soils, supplemented by detailed mapping of the unaltered topography immediately below the dam.

Sediment Deposits

Contour mapping of Rogers Lake indicated an original reservoir capacity of 164 acre-feet and a present capacity of 126.5 acre-feet, or a total sediment accumulation of 37.5 acre-feet in 12 years. The area of the lake at spillway level has been reduced from 23.1 to 21.8 acres, chiefly by formation of a delta in the main valley head of the reservoir (pl. 8, *B* and *C*). The maximum depth of sediment is about 6 feet in the deeper part of the original basin just above the dam. The depth of water has been reduced here from about 18 feet to 12 feet at spillway crest stage.

The general distribution of sediment at different levels of the original pond is shown in figure 8. It may be observed that the capacity curve has retained much the same form it had at the start, but has lifted rather uniformly in elevation, the lowermost areas of stor-

A, Characteristic erosion of blacklands, Rogers, Tex. Gullies are developing where plow rows run with the slope. B, Municipal Reservoir, Rogers, Tex., located in cultivated "Blacklands" region, filling at an exorbitant rate of 19 tons a year per acre of drainage area. Lake stage 5.6 feet below crest level. Note new vegetation on fill at high-water level in middle distance. C, Detail of new vegetation on fill at high-water level at Municipal Reservoir, Rogers, Tex.

age being completely eliminated. This is emphasized in figure 9, which shows the proportional reduction in storage capacity at different levels.

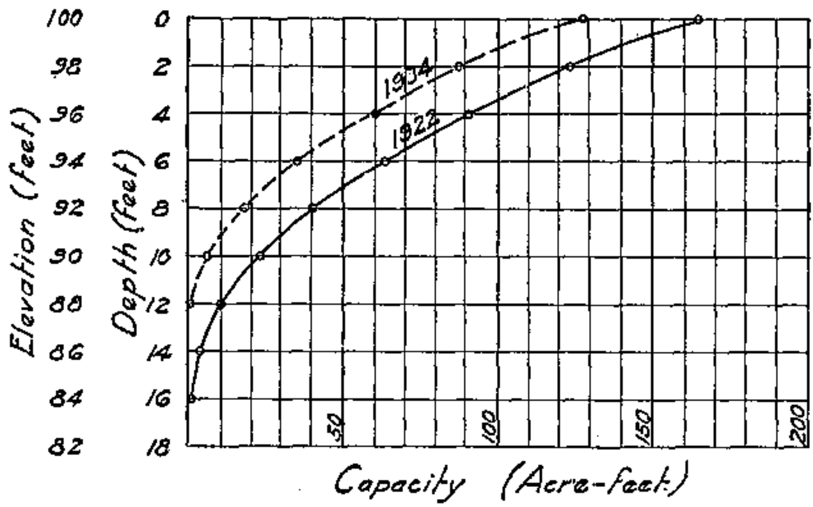

FIGURE 8.—Capacity distribution of Rogers Municipal Reservoir, Tex., 1922–34.

It has been widely held, and with obvious reason, that greater depths of water should deposit greater depths of sediment, and, therefore, that plotted ratios of sediment and original water depths should

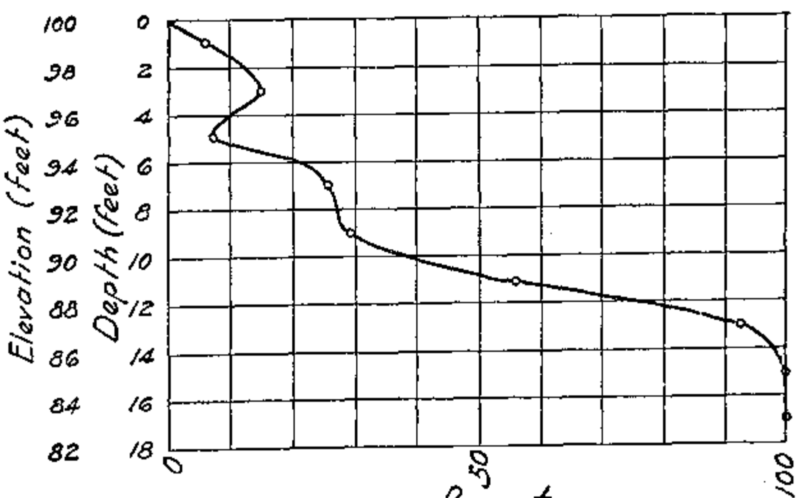

FIGURE 9.—Ratio of fill to original storage volume at various levels, Rogers Municipal Reservoir, Tex.

show more or less of a straight-line relation. Figure 10 shows these ratios for the Rogers Reservoir. This graph shows a rather limited range of variation of the sediment-water depth ratio, thus apparently reflecting a considerable dependence of rate of silting upon depth of water. The form of the graph, showing increase in ratios from a medial minimum toward both top and bottom, is undoubtedly significant of the play of additional factors.

The increase toward the top undoubtedly relates to selective deposition of coarser-grained fractions of stream load at higher levels in the delta area at the head of the reservoir. This is an easily observed and well-recognized factor of uneven sediment distribution in reservoirs generally, regardless of climate.

The increase of ratios with greater depths in this case is even more pronounced than the upward increase due to selective delta accumulation. It thus points to an equally important but less obvious causal factor.

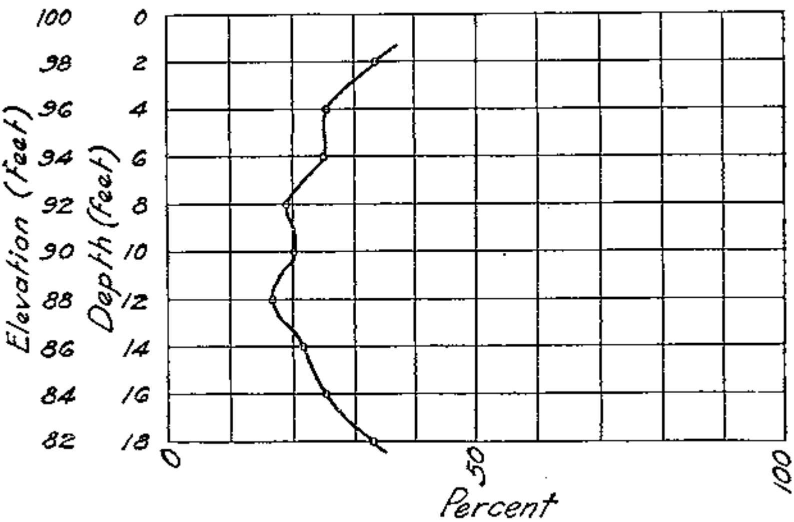

FIGURE 10.—Ratios of average sediment depth to original water depth over various levels of the original reservoir floor, Rogers Municipal Reservoir, Tex.

The cause of the downward increase of sedi ent-water depth ratios is rationally explained by underflow of muddy flood flows, heavier than the clear ponded waters on account of their charge of suspended sediment. This phenomenon is of more or less common occurrence in reservoirs of the Southwest that are fed by intermittent or highly variable streams. At Elephant Butte such flows from the Puerco River commonly flow or "tunnel" under the clear lake waters and appear in the outlet discharge well within 2 days, indicating velocities of underflow of more than a mile per hour. Instances of record show periods of as much as 17 days of muddy discharge from an apparently clear lake, with sediment load approaching 6 percent by weight of solid matter. The same phenomenon has been observed on many other southwestern reservoirs.

Rogers Lake appears to fulfill the conditions required for occurrence of selective underflow to an effective extent. However, owing to windy climate and strong wave action in relation to its depth, the surface as well as the bottom waters of the lake become somewhat turbid during stormy periods. Despite this interference with full effect of muddy-water underflow, the effects of its partial operation would appear to have been sufficient to give a very notable increase in sediment-water depth ratios in the vicinity of the dam. It is believed this points to a general phenomenon of sediment distribution in reservoirs in regions of low but concentrated rainfall, entailing a disproportionate accumulation of sediment in the reservoir depths adjacent to the dam. This is contrary to the usual conception that all reservoirs fill in earlier stages almost exclusively at their heads and that the deeper pool section near the dam remains open until head fill has advanced progressively through the full length of the pond. Early fill in the vicinity of the dam is naturally hidden from casual observation and is to be discerned only through definitely designed engineering measurements. If Rogers Lake is truly representative of reservoirs in semiarid regions, the fact that sediment-water ratios tend to increase in deeper areas toward the dam, in early as well as later stages of fill, should be recognized and taken into account in considering the expectancy of useful life and manner of filling of such reservoirs. Also, the phenomenon would appear to have possibly important bearing upon design of dams and dam operations intended to promote minimum rates of fill and longest life of reservoirs under naturally unfavorable semiarid climatic conditions.

The original capacity of Rogers Reservoir was equivalent to about 490 days' supply, or some 25 percent more than a full year's draft. The present capacity is little more than a year's draft. The average yearly loss of capacity is equivalent to a 9-day supply. At this rate only a few years will be required to bring capacity below yearly requirements.

As a matter of fact, the lake was drawn down near the end of September 1934 to 35 acre-feet of water in storage or to about 105 days' supply. Had there been no silting the lake would have had at that time some 72.5 acre-feet, or 217 days' supply. In other words, the silting of 23 percent of the original reservoir in the course of actual use was responsible for a more than 50-percent reduction in reserve-water supply. Considering the chances of continued dry weather through the early fall months in this section, it is clear that 12 years of silting has put this originally satisfactory water supply in a precarious position.

This illustrates the fact that from earliest stages reservoir silting represents encroachment upon margins of safety, and that the adequacy of a reservoir for given service is destroyed when loss through silting equals this marginal fraction of total capacity. Expectancy of useful life of a reservoir, in the sense of fully adequate service, is the time required for silting to eliminate this fraction of capacity. This emphasizes the need of recognizing the silting problem and applying corrective measures for sediment control concurrently with original reservoir construction.

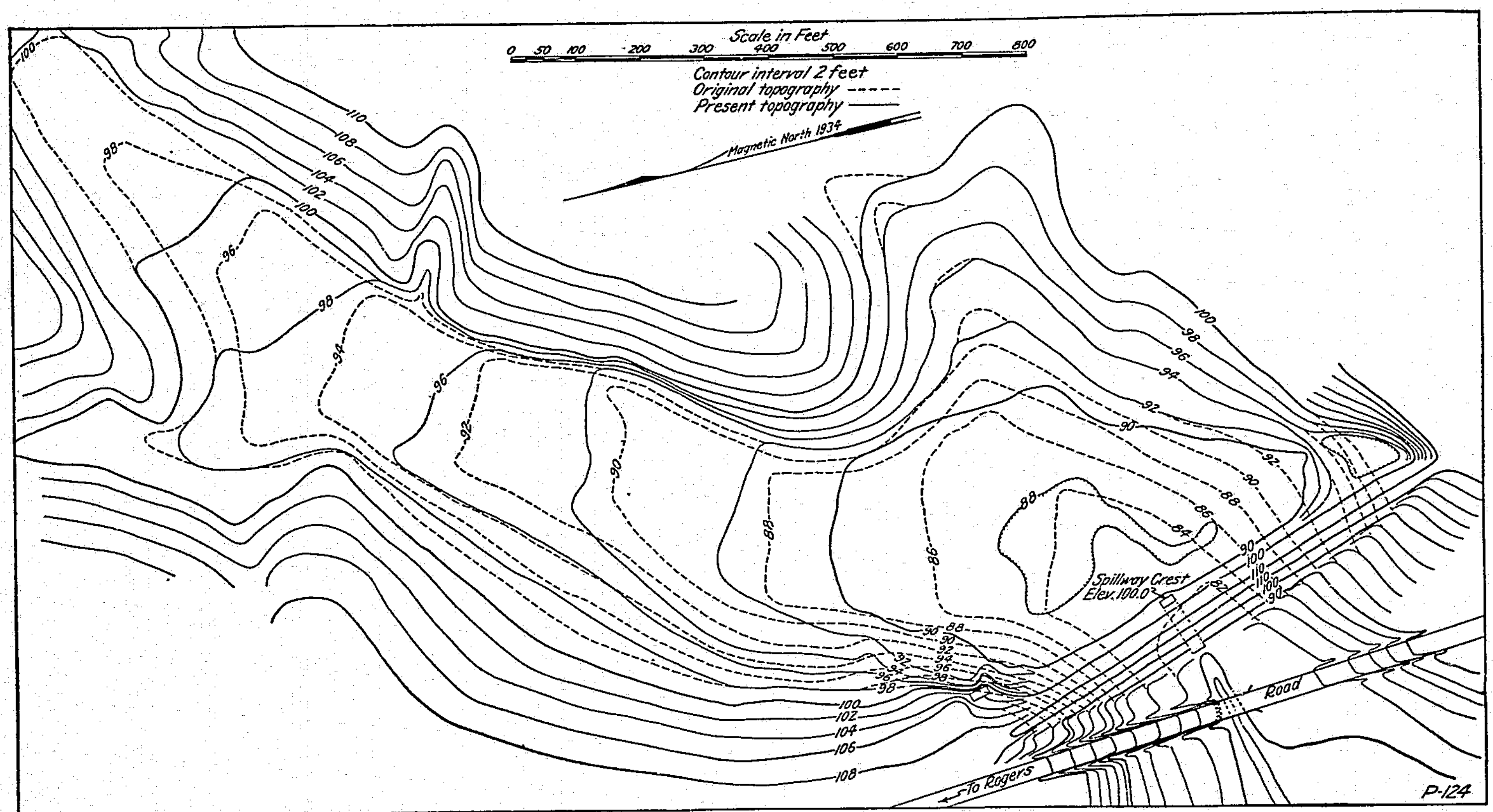

FIGURE 11.—Map of Rogers Municipal Reservoir, Rogers, Tex., showing sediment accumulations, 1922–34

A summary of pertinent data relative to Rogers Municipal Reservoir (fig. 11) is contained in the following tabulation:

Summary of data on Rogers Municipal Reservoir, Rogers, Tex.

Age [1]	years	12.0
Watershed area [2]	square mile	0.55
Reservoir:		
Original area at crest stage	acres	23.1
Area at crest stage at date of survey	do	21.8
Original storage capacity to crest level	acre-feet	164
Storage capacity at date of survey	do	126.5
Original storage per square mile of drainage area [3]	do	298.18
Storage per square mile of drainage area at date of survey [3]	do	230.00
Sedimentation:		
Total sediment	do	37.5
Average annual accumulation	do	3.13
Annual accumulation per 100 square miles of drainage area	do	[3] 608.0
Annual accumulation per acre of drainage area	cubic feet	[3] 413.80
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds	tons	[3] 12.41
Depletion of storage: [3]		
Loss of original capacity per year	percent	1.91
Loss of original capacity to date of survey	do	22.87

[1] Date storage began September 1922. Date of survey September 1934.
[2] Including reservoir area.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, which include the reservoir area, are 569 acre-feet, 387 cubic feet, and 19.35 tons, respectively.

LAKE WACO [21]

General Information

Location.—State—Texas. County—McLennan. Distance and direction from nearest city: 4½ miles west of Municipal Building, Waco, Tex. Drainage and backwater: The dam is 3,300 feet below the junction of the North and South Bosque Rivers.

Ownership.—City of Waco.

Purpose served.—Municipal water supply.

Description of dam.—The dam is of earth-fill type, constructed of the most suitable clays from the adjoining valley floor and slopes. The upstream slope of the dam is faced with 6 inches of concrete underlain by a 6-inch gravel blanket. From the upstream base, a 3:1 slope was laid up to elevation 430.0 (spillway crest), then a 2.5:1 slope up to elevation 440.0, and finally a 1.5:1 slope up to a paved road 25 feet wide extending across the dam at elevation 442.0. From the base on the downstream side, the slope is 3:1 up to an 8-foot berm designed for draining the 2:1 slope above. The thickness of the dam at its base varies with topography.

The greatest vertical dimension of the structure is at the spillway, where its height from apron to spillway crest is 57 feet, and from apron to top of roadway is 69 feet. The crest of the weir is at elevation 415. Upon it rest 16 taintor gates, each 15 feet high and 25 feet

[21] The Service wishes to express appreciation to George J. Rohan, superintendent of the Waco waterworks, for his close cooperation throughout the survey. The superintendent of Lake Waco, R. B. Petty, and his staff were constantly helpful in carrying on the work in an efficient manner. Office work was facilitated through use of the city engineer's office in Waco. J. L. Lockridge, of Dallas, furnished valuable information concerning the planning of the reservoir and building of the dam.

wide, forming the actual spillway. The gates are separated by 15 concrete piers, each 3 feet in width.

Information has been obtained [22] that borings at the time of construction proved the existence of a gravel bed on the northwest side of the spillway and on the upstream side of the dam. The stratum was found 30 to 40 feet below the surface of the ground, and ranged from 2 to 8 feet in thickness. It was not encountered on the southeast side of the spillway. This gravel stratum, which crops out upstream in the now submerged river course, affords a subsurface channel with porosity sufficient for steady but minor leakage into the Bosque Valley below the dam. Since the spillway was not constructed over the original stream channel, an artificial channel was cut from the spillway base to join the old course a short distance below and to the north.

Date of completion.—April 1930. Surveyed March 1935. Resurveyed February 1936. Age at date of resurvey: 5.9 years.

Length of lake at crest stage.—Original—North Bosque arm, 7.01 miles; South Bosque arm, 6.63 miles. Neither arm of the lake has been shortened by sediment deposits at its head. Water seldom flows over the spillway, since it is customary under normal conditions to keep the lake 0.5 to 3 feet below crest stage by municipal draft and occasional use of sluice gates. As a result current action extends downstream for varying distances from the extreme upper end of the arms, and the portions thus subject to intermittent scour have remained practically free of sediment.

Area of lake at crest stage.—Original and at date of resurvey, 2.801 acres.

Storage capacity to crest level.—Original, 39,378 acre-feet (12,831,-321,300 gallons). At date of 1936 resurvey, 31,588 acre-feet (10,292,-949,800 gallons). Loss, 7,790 acre-feet (2,538,371,500 gallons).

Since the lake filled, no survey had been made up to January 1935 to determine loss of storage capacity through silting. Seven profiles of the lake were originally established at great intervals, but half the monuments have been subsequently destroyed. These ranges had been spaced at intervals too great to make them of material assistance in the present work.

Area of watershed.—1,662 square miles, according to the original dam-site survey.

General character of watershed.—The watershed of Lake Waco includes parts of McLennan, Coryell, Bosque, Hamilton, Erath, and Somervell Counties. The topography and soils of this area have, in general, uniform characteristics over the area as a whole, in keeping with the uniformity of the underlying rock formations (*13*). The entire watershed of the lake is underlain by the Washita, Fredericksburg, and Trinity formations of the Comanche series (Cretaceous). The Trinity is very sandy, but, since it occupies the uppermost portion of the drainage area, it has only a remote effect on sedimentation in the lake. The Washita and the Fredericksburg, on the other hand, consist for the most part of fossiliferous limestones interbedded with shales, and are, therefore, chiefly responsible for the extremely fine calcareous silt of Lake Waco. Where it has been impossible for the soil to accumulate in thickness sufficient for agricultural purposes,

[22] Oral information from J. L. Lockridge, of Floyd & Lockridge, Dallas, Tex.

it supports grazing. In general, mature topography prevails in the valleys of both the North and South Bosque Rivers. Bluffs and steep banks occur where the streams have undercut or are undercutting the nearly horizontal limestone beds. A prominent erosional escarpment follows the southeastern side of the South Bosque for a considerable distance upstream.

In the South Bosque Valley most of the land is under cultivation, including practically the entire drainage area except wooded lands bordering the streams. Gullies are not infrequent, though nowhere were they found in an extreme state of development. Apparently the South Bosque watershed contributes much of its sediment through sheet erosion. Cotton is the principal crop, and abandoned land is practically unknown.

In the drainage area of the North Bosque, which includes the larger part of the watershed, grazing assumes importance, and in many sections of the area becomes predominant over farming. The limestone formations mentioned above are covered by only a moderately thick to thin veneer of soil where they are not actually exposed. Irregular areas of mesquite make up most of the larger vegetative growth, with the exception of occasional groves of live oak. Abandoned land is not in evidence, and, because of the widespread grasslands, erosion has rarely gone to extremes.

Mean annual rainfall.—35.26 inches at Waco. To the northwest, near the headwaters of the North Bosque, the mean annual rainfall is only 28 inches.

Draft on municipal reservoir.—The approximate average daily draft on the lake from April 1, 1934, to March 31, 1935, was 4,700,000 gallons. This amount, according to the superintendent of the waterworks, is a fairly constant average. The population of the city of Waco is about 55,000, in addition to which a large Government hospital and several industrial plants are supplied.

History of Surveys

The first sedimentation survey of Lake Waco was begun by the Great Plains party on January 15, 1935, and completed on March 30, 1935. During that period, however, the party was engaged on another assignment from February 26 to March 12, so that the actual field work covered only 6½ weeks. The survey was made by a party of six men under the direction of Thomas L. Kesler, chief of party.

The field work included establishing a triangulation net; setting up, sounding, and spudding 33 ranges; and mapping the crest line (elevation 430) contour and the contour 2 feet above crest over the entire lake. A mapping scale of 1,000 feet to the inch was used. This survey shows the extension of the crest contour somewhat farther up both the North and South Bosque Rivers than had been determined in previous surveys on a scale of 2,000 feet to the inch.

Little difficulty was experienced in penetrating through the sediment into old soil. Out of hundreds of spud measurements the spud failed to penetrate only seven times. It is possible that in some of these instances the poorly consolidated condition of the old soil made field distinction between it and the lake deposits impossible.

All survey stations, except those of minor importance, were marked by iron pipe bearing the station number or numbers stamped in the metal. The pipes were encased in cement-filled forms, so that the markings are permanent.

Computations were made in the field in accordance with standard practice, using the range formulas as given in the Appendix. In computing the volume of segment 1, bounded by range 1—2 and the dam, the average cross-section areas of ranges 1—2 and 3—4 were assumed to apply in segment 1 and were multiplied by the surface area between range 1—2 and the dam. The sediment cross section on range 3—4 was used because the irregular bottom on range 1—2, due to excavation at the time of building the dam, made the latter range unsatisfactory for spudding.

The second sedimentation survey of Lake Waco was begun on January 17, 1936, and completed February 20, by a field party under the direction of Louis M. Glymph, Jr. During this survey all ranges set in the first survey were resounded and respudded, and in addition two new ranges were established on bends in the midportions of segments 8 and 23 to allow more accurate calculation of volumes in these segments. Improved technique in spudding practice, including closer and more precise spacing of observation points, together with the additional ranges, permitted a more accurate determination of the original capacity. As a result of recalculations it was determined that the original capacity was larger by 895 acre-feet than previously recorded, that the volume of sediment deposited during the first 5 years was 5,661 acre-feet instead of 4,766 acre-feet, and that, correspondingly, the depletion of storage capacity in this period had been 14.38 percent instead of 12.38 percent.

Sediment Deposits

Sediment in the reservoir is composed largely of fine-textured silt, but at the heads of several arms the deposits become thicker and slightly coarser in texture.

Relatively large quantities of fragmental organic debris are washed into the reservoir after heavy rains. The material consists of leaves, twigs, branches, and bark ranging in size from minute particles to fragments several feet long. Huge cottonwood logs are sometimes brought in by floods. The debris tends to collect in the more sheltered water of embayments, there to become waterlogged and sink. While these embayments undoubtedly receive a substantial percentage of such debris in their total sediment, their combined area is only a small proportion of the total area of the lake, and their combined capacity of minor importance because of original shallow depth. Furthermore, hundreds of sediment samples taken from all parts of the main basin failed to show even a low proportion of similar debris.

In the lower part of the lake, as well as near the upper limit of backwater, depth ratios of sediment to water are not excessive. The highest ratios are found just below the extreme upper or narrow portions of the arms, in areas where the abrupt checking of flood currents, which determines the locus of most silting, results in concentrated deposition of bed load. On the North Bosque, the area of greatest silting extends from range 29—30 down to range 8—9, although ratios run rather high as far up as range 43—44. On the

South Bosque, the corresponding area extends from range 33—34 down to range 14—15.

In segment 16, bounded by one range, active silting was found to extend only halfway from the range to the head of the area. Segments 32 and 34 are subject to scour in the upper parts, and much of the sediment originally deposited therein has been swept below the bounding range. In segment 19, silting extended without diminution to the head of the arm. In segment 22, heavy silting has been continuous practically to crest level as a result of the entrance of a silt-laden tributary stream.

The results of this survey give a minimum figure on extent of erosion in the watershed. Some sediment, though the total quantity is believed to be small, has gone over the spillway and through the sluice gates in time of flood. A small amount of sediment is also banking up above the crest line of the lake on some arms.

In following the stream courses above the lake it may be observed that erosion of steep banks is a contributing factor in silting. Undercutting is common. The material thus removed consists of clay and fine to coarse limestone fragments. The clay is carried downstream in suspension, whereas the gravel tends to form bars which cause frequent lateral migration of the stream in its valley. A few bars of this type are below the head of the lake. Although they receive some additional gravel in time of flood, much the greater part of the coarse material normally lodges on the bars above crest level.

In the light of carefully obtained data, Lake Waco was found to have had, at full stage, an original storage capacity of 39,378 acre-feet, compared with 38,483 acre-feet as previously determined and a preconstruction estimate of 38,500 acre-feet. The crest-level area of the lake was determined to be 2,801 acres as against the 2,700 acres in the original estimate. In the first five years of its life, 5,661 acre-feet of sediment was deposited in the reservoir, leaving its 1935 storage capacity 33,717 acre-feet. This represented a loss in capacity of 14.38 percent. The resurvey made in 1936, when the reservoir was still less than 6 years old, showed a storage loss of 19.78 percent, an average loss of 3.34 percent a year, but an actual loss of 5.4 percent, or 694,000,000 gallons, of storage space in 11 months. Since this second survey in February 1936, the heaviest floods of record have occurred on the adjacent Brazos River, and the inflow into Lake Waco was greater during the year following the last survey than in the preceding year. The total storage loss to 1938 may therefore be well over 25 percent. If only the average 6-year rate of silting is assumed the reservoir capacity will be exhausted in another 24 years, but if the rate during 1935 should prevail as it probably did in 1936, storage capacity would be gone in another 19 years.

Sediment has been determined in volumes, and no attempt was made to determine the amount of actual solid matter devoid of water. However, the water content of the deposits does not constitute active storage (*5, p. 47*) and the volume of the deposits therefore represents an equal volume of lost water capacity.

The Brazos River Basin is considered to be representative of conditions in other drainage areas in Texas (*5, p. 52*). Inasmuch as the Bosque is a prominent tributary of the Brazos, and representative of conditions in a large part of central Texas, the results derived from the survey of Lake Waco may be applicable over a considerable region.

A summary of pertinent data relative to Lake Waco (fig. 12) is contained in the following tabulation:

Summary of data on Lake Waco, Waco, Tex.

Age (second survey)[1]	years	5.9
Watershed area[2]	square miles	1,662
Reservoir:		
Area at crest stage (original and at date of survey)	acres	2,801
Original storage capacity to crest level	acre-feet	39,378
Storage capacity 1935	do	33,717
Storage capacity 1936	do	31,588
Original storage per square mile of drainage area[2]	do	23.69
Storage per square mile of drainage area in 1936[2]	do	19.01
Sedimentation:		
Total sediment 1935	do	5,661
Total sediment 1936	do	7,790
Accumulation per year, average to 1936	do	1,316
Annual accumulation per 100 square miles drainage area to 1936	acre-feet	[3]79.6
Annual accumulation per acre of drainage area to 1936	cubic feet	[3]54.20
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds	tons	1.63
Depletion of storage:		
Loss of original capacity per year to 1936	percent	3.34
Loss of original capacity between surveys of March 1935 and February 1936, 11 months	percent	5.40
Loss of original capacity to 1935	do	14.38
Loss of original capacity to 1936	do	19.78

[1] Storage began in April 1930; second survey was made in February 1936.
[2] Including reservoir area.
[3] Excluding reservoir area.

WHITE ROCK RESERVOIR[23]

General Information

Location.—State—Texas. County—Dallas. Distance and direction from nearest city: 4 miles east of Dallas city hall. Drainage and backwater: White Rock Creek, a tributary of the Trinity River.

Ownership.—City of Dallas.

Purpose served.—Built in 1910, at a cost of approximately $765,000, as a municipal water-supply reservoir for Dallas. Since July 1930 this lake has been used as a recreational unit of the city.

Description of dam.—Height, 40 feet; width at base, 214 feet; width at top, 20 feet; length, 2,100 feet; length of spillway, 450 feet; earth in dam (final estimate), 333,680 cubic yards; concrete placed, 9,327 cubic yards; spillway elevation, 457.45 feet above sea level; slope (below-crest slope not identified), 2:1 and 3:1.

The dam is of the earth-fill type with a concrete facing on the upstream side. The spillway at the southeast end has below it a long, broad, concrete apron carrying the overflow to the valley several hundred feet below the dam. The State Reclamation Service has

[23] The Service wishes to thank the officials of the Dallas Water Department and the Dallas Park Board for their courtesy and cooperation in furnishing boats, materials, and information during the period of field work. The city engineer and his staff made available the full facilities of a drafting room and map files. Dean T. U. Taylor, of the University of Texas, kindly furnished a map of his 1928 survey. W. J. Powell, of Dallas, supplied valuable information on the 1923 survey.

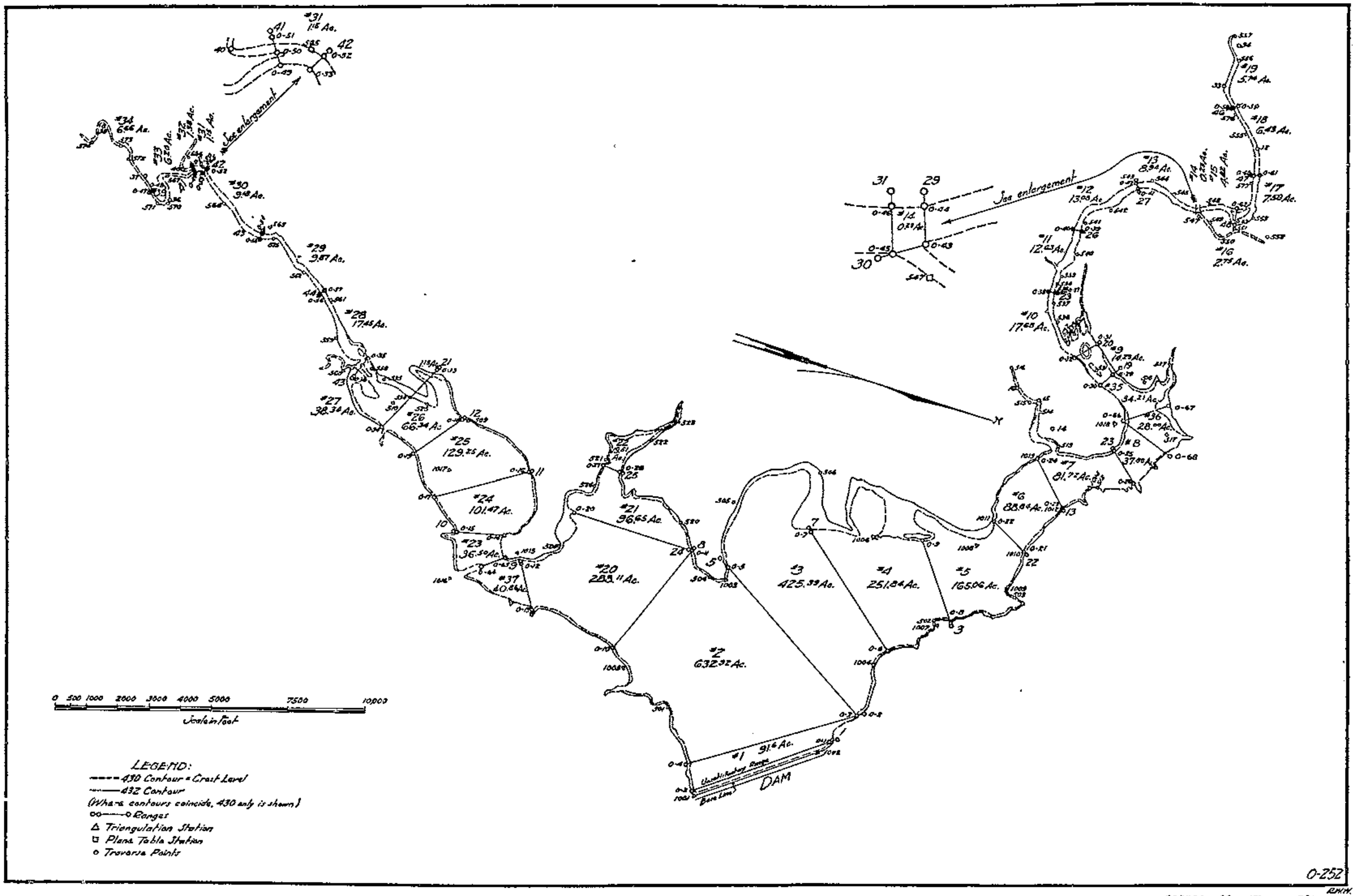

FIGURE 12.—Map of Lake Waco, Waco, Tex., resurveyed February 1936.

established a benchmark on the southeast concrete wall of the spillway. Its elevation is 466.2 feet above mean low tide, and checks 0.48 foot high with respect to spillway elevation of 457.45. The spillway datum was employed exclusively in the present work. It corresponds to the 138.5 contour (local datum).

Date of completion.—1910. Surveyed April 1935. Age at date of survey: 25 years.

Length of lake at crest stage.—Original, 5.09 miles. At date of survey, effective length 2.67 miles, but a heavy flood may at any time clear out blocking débris and restore full length.

Area at crest stage.—Original, 1,254 acres as measured by this survey. According to Taylor (*16*, pp. 87–90) the area was 1,279 acres at spillway crest stage and 1,360 acres with use of 2-foot flashboards. In 1935 the area was 1,150 acres.

Storage capacity to crest level.—Original, 18,158 acre-feet. (The capacity of the lake to the top of the 2-foot flashboards, elevation 140.5 local datum, was estimated in 1910 to be 21,500 acre-feet.) At date of survey, 14,276 acre-feet. Loss, 3,882 acre-feet.

Area of watershed.—99.1 square miles, lying in Dallas and Collin Counties, as determined from conservation survey maps.

General character of watershed.—The watershed of White Rock Reservoir is underlain by the Austin formation (*13*), a member of the Gulf series of Cretaceous age. It consists of alternate beds of white chalky limestone, limy marl, and shell marl, whose weathering has produced the deep fertile soils characteristic of the rich blackland of Texas. The watershed is gently rolling and has very few steep slopes, as shown by the following figures on slope classes. According to a recent conservation survey practically flat land having slopes of 0 to 1 percent occupies 45.3 percent of the drainage basin, whereas 49.2 percent, or nearly half, has slopes of only 1 to 6 percent. Slopes of 6 to 10 percent occur on only 5.4 percent of the watershed, mainly near the stream courses, and slopes of over 10 percent are mapped on only 0.1 percent of the area.

The most widespread soils belong to the Houston series, the very productive Houston black clay, covering 64.1 percent of the drainage area, being the most prominent, and the Houston shallow and colluvium phases, 14.1 percent, being next in importance. Other soils mapped in the watershed are, in percentage, Lewisville clay 6.8, Trinity clay 5.2, Bell clay 2.9, and Austin clay 5.6. Chalk outcrops occupy 1.3 percent of the area.

Despite the prevailingly gentle slopes, erosion has taken its toll in this drainage area, as revealed by the conservation survey. Slight erosion has affected 53.1 percent of the area; moderate erosion, representing losses of 25 to 75 percent of topsoil, 33.1 percent; severe erosion, representing losses of more than 75 percent topsoil, 4.2 percent; and very severe erosion, representing not only total topsoil loss but subsoil erosion, 2.6 percent. Areas of no erosion, including all alluvial and colluvial deposits, occupy only 7.0 percent of the drainage area.

Land use in the watershed includes 69.8 percent of cropland, 3.1 percent of idle land, 16.4 percent of pasture, 5.1 percent of woodland, and 5.6 percent of farmsteads and urban areas. Cotton is the principal crop, although truck farming is of considerable importance.

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Calculations based on a conservation survey made in the drainage area since 1935 show that 16,610 acre-feet of soil had been eroded within the area in approximately 75 years, from 1860 to 1935. In addition to the 3,882 acre-feet of sediment (equivalent to 2,569 acre-feet of eroded soil) accumulated in the reservoir in the 25 years from 1910 to 1935, it has been estimated with fair accuracy that 710 acre-feet of above-crest deposits were laid down in a 4¾-mile stretch of valley extending upstream from the reservoir. It has been estimated that during the entire 75-year period 50 acre-feet has accumulated in minor ponds and that 648 acre-feet of colluvial material more than 6 inches thick has accumulated at the base of slopes. From these data, including reservoir measurements which show that 15 percent of the total erosional debris was actually retained in the reservoir, it is estimated that 50 percent of the total erosional debris would have passed out of the drainage basin had no dam been built, although, because of the dam, 20 percent was held back; and that 50 percent was deposited as colluvium on the lower slopes, most of it too thin to map, and as alluvium in the valleys.

The large amount of land under cultivation, together with the prominence of cotton, a clean-tilled crop, and the lack of soil conservation measures, account for the prevalence of sheet erosion. The fact that almost 90 percent of the watershed has undergone and is still subject to slight to moderate erosion affords a poor outlook for downstream developments until soil conservation practices are introduced on a widespread scale.

Mean annual rainfall.—37.0 inches at Dallas during period 1898–1934. The Dallas Water Department has furnished the following rather significant record: Period of time: 12:30 a. m. December 2, 1913, to 8:30 a. m. December 5, 1913. Precipitation: 5.53 inches. Water impounded: 3,067,867,768 gallons. Run-off from drainage of 114 square miles (shown by later survey to be 99.1 square miles): 30 percent (approximate).

Draft on municipal reservoir.—From January 1927 to July 1930 the average monthly draft on the reservoir was 206,385,255 gallons.

History of Survey

The survey of White Rock Reservoir was made during the period April 1–25, 1935, by the Great Plains sedimentation party under the direction of Thomas L. Kesler, chief of party.

Field work involved establishing a triangulation net for primary control, locating ranges by stadia, and subsequent sounding and spudding of these ranges. All survey points were marked by numbered iron pipes set in concrete.

The surface map of the survey of 1923, on a scale of 200 feet to the inch, was used in the present survey. The same scale was used in the new work, and a number of corrections and modifications were made on the original maps. The extension of the lake above line A–B (fig. 13) was mapped for the first time.

Special variations in computation of original capacity and sediment volume were used in certain segments of the lake.

In segments 4, 10, and 16, all closed arms, the present surface was mapped with contours for comparison with future delta deposits.

Segment 9 is a wide, shallow basin largely filled by delta deposits and covered by shallow water and abundant vegetation. Range 18—19 is typical of this segment, in contrast to the little channel range 26—27 at the head of the delta. The volume was therefore computed as though this segment were a closed arm bounded by range 18—19, but an additional pyramidal volume was computed for the channel from range 26—27 for the length of the area. The delta surface was contoured for future comparison.

Segment 13 contains the greater part of the main delta. After considerable experimental sounding and spudding, range 14—15 was established just below the delta front, where it was possible to penetrate through the sediment. Range 16—17 was established over deposits which were largely above water at the time of survey. On the latter range borings were made with an auger to old soil, and surface elevations were determined by stadia and corrected to crest level.

The volume of the segment was then computed by the usual methods.

Segment 14, which was almost entirely filled with sediment, was treated as a closed segment. It was originally a shallow, sloping meadow or bottom land parallel with the channel of White Rock Creek.

Segments 13 and 14 together have undergone a reduction in surface area of approximately 100 acres, through silting. These tapering, above-crest deposits were roughly measured in the same manner as below-crest deposits in the closed arms, but were not added to total computations for the lake. They amount to 69 acre-feet.

Sediment Deposits

The record of the early history of White Rock Lake has been to a large extent lost. It is reported that a contour map of the basin was prepared before the dam was built, but neither the map nor the notes are now available. As a consequence, the volume of a spectacular delta developed at the upper end of the lake cannot be computed by the more accurate contour method.

A set of 2-foot flashboards was used intermittently on the spillway for a number of years, but the full set was not constantly in use. Lack of knowledge or record concerning the period and frequency of their service made it necessary to use the spillway crest level in the present survey. The superintendent of the water department believes that the flashboards have accounted for most of the delta deposits above crest contour, but such indefinite information does not afford a basis for including these deposits in the total fill. The original crest line at the upper end of the delta is no longer determinable, and in the present survey it was necessary to rely on the map prepared in 1923. In the present survey all the minor delta areas were mapped with 1-foot contours, to establish an accurate basis for future resurveys.

A prominent delta has formed where White Rock Creek channel enters the main body of the lake. A little storage would be available even over this delta were it not for the accumulation of debris on the surface of the delta after flood periods. Through this debris, seepage occurs into the main body of the lake. Damming by this debris is so superficial that a little ditching would render this storage fully available.

The smaller arms have correspondingly smaller delta areas. Over the main floor of the lake, there is a comparatively uniform blanket of very fine dark-brown silt or oozy mud. The delta is made up of light-gray to black clay. The deposits show a rather uniform increase in thickness from the dam to the delta front. Only small quantities of organic matter are present in the deposits of the lower lake basin, but in the delta areas there is a considerable amount of twigs, dead weeds, and larger limbs such as are found in most river-bottom deposits of this region.

A summary of pertinent data relative to White Rock Lake (fig. 13) is contained in the following tabulation:

Summary of data on White Rock Lake, Dallas, Tex.

Age [1]	years	25
Watershed area [2]	square miles	99.1
Reservoir:		
Original area at crest stage	acres	1,254
Area at crest stage at date of survey	do	1,150
Original storage capacity	acre-feet	18,158
Storage capacity at date of survey	do	14,276
Original storage per square mile of drainage area [3]	do	183.23
Storage per square mile of drainage area [3] at date of survey	do	144.06
Sedimentation:		
Delta deposits below crest level	do	1,256
Bottom-set beds	do	2,626
Total sediment below crest level	do	3,882
Average annual accumulation	do	155
Annual accumulation per 100 square miles of drainage area	do	[3] 160
Annual accumulation per acre of drainage area	cubic feet	[3] 108.84
Or, assuming 1 cubic foot of deposit weighs 60 pounds	tons	[3] 3.27
Depletion of storage:		
Loss of original capacity per year	percent	0.86
Loss of original capacity to date of survey	do	21.38

[1] Storage began in 1910; survey was made in April 1935.
[2] Including reservoir area.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin and to conform with a revision of the watershed area based on a new map made since the first edition of this bulletin was published. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, based on a total drainage area of 114 square miles, including reservoir, are 130.21 acre-feet, 92.71 cubic feet, and 4.64 tons, respectively.

GUTHRIE RESERVOIR [24]

General Information

Location: State—Oklahoma. County—Logan. Distance and direction from nearest city: 5 miles southwest of Guthrie, Okla. Drainage and backwater: Tributary of Cottonwood Creek, which flows into the Cimarron River.

Ownership: City of Guthrie.

Purpose served: Municipal water supply.

Description of dam: Guthrie Reservoir is impounded by an earth-fill dam, approximately 38 feet in maximum height and faced with riprap on the upstream 3:1 slope. The dam crosses the valley in a

[24] The cooperation of the Guthrie city manager, John T. Hamill, and the assistance of the city engineer and the caretaker of the lake were of material help in carrying out this survey.

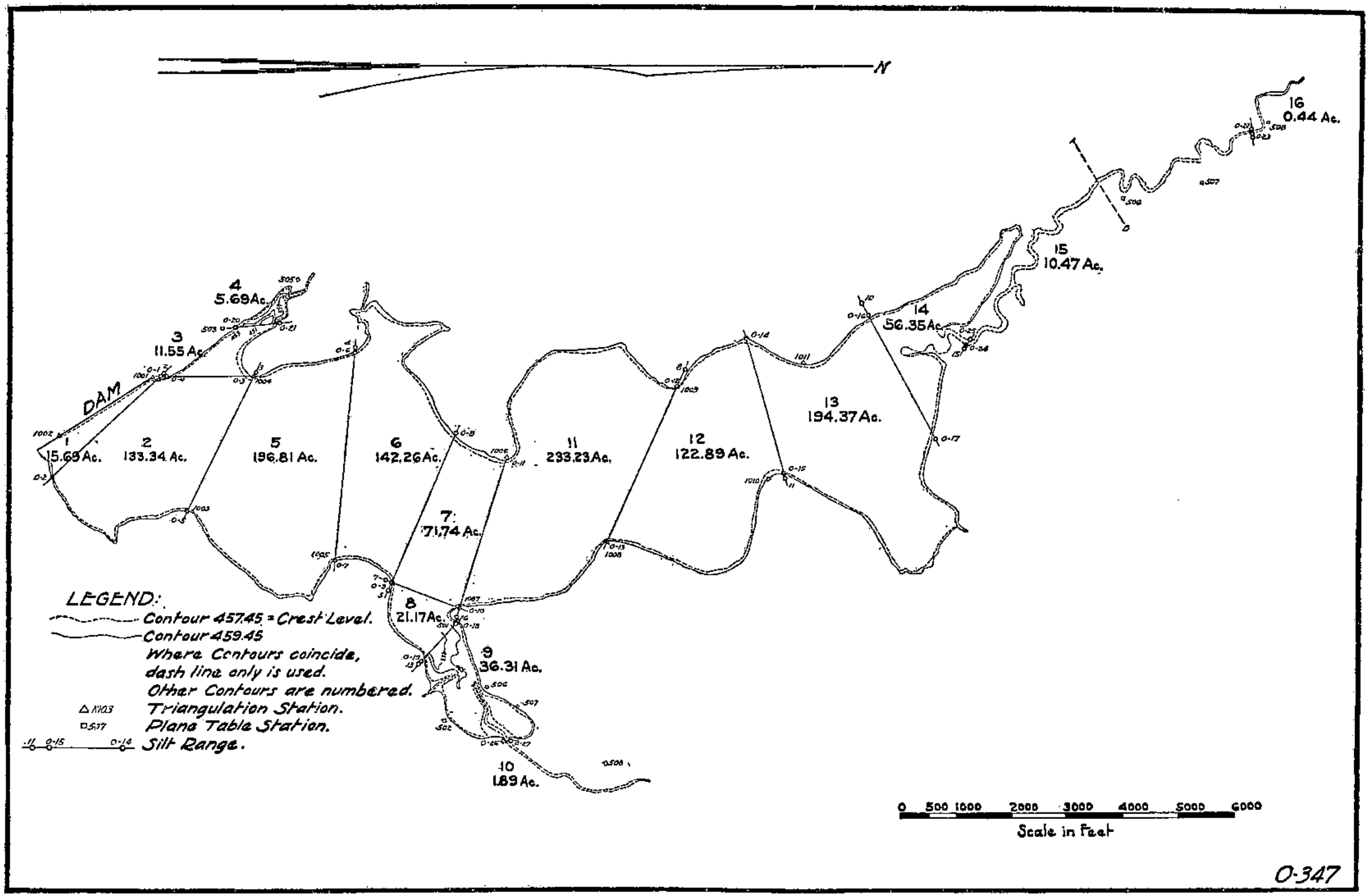

Figure 13.—Map of White Rock Lake, Dallas, Tex., surveyed April 1935.

northeast direction and is 1,540 feet long. The old stream channel lies a little southwest of the center of the dam.

The spillway is a circular concrete bowl built into the southwest end of the dam. Its elevation was determined in the original survey to be 980.0 feet (sea-level datum). The spillway elevation was found, however, to be 1.99 feet low when checked with a known elevation, determined by the State Highway Department, on a bridge crossing the delta. In this survey, the 980-foot crest elevation was retained because time would not permit running levels necessary to discover the source of this discrepancy. Water surface, which stood at crest level during this survey, was used as a datum from which all elevations were taken.

Date of completion.—October 1920. Surveyed May 1935. Age at date of survey: 14.5 years.

Length of lake at crest stage.—Original, 1.9 miles; at date of survey, 1.5 miles. The lake has been shortened 0.4 mile by delta deposits at its head.

Area of lake at crest stage.—Original, 226 acres; at date of survey, 217 acres. Loss, 9 acres.

Storage capacity to crest level.—3,064 acre-feet or 998,404,400 gallons. At date of survey, 2,608 acre-feet or 849,816,800 gallons. Loss, 456 acre-feet or 148,587,600 gallons.

Area of watershed.—13.3 square miles, according to original surveys.

General character of watershed.—The drainage area of Guthrie Reservoir lies mainly within the outcrop area of the Garber formation (*2, pp. 235–238; 7, pp. 88–89*) of Permian age, consisting of red shales and lenticular, cross-bedded red sandstones, all poorly consolidated and susceptible to rapid erosion when unprotected, as is well demonstrated by the large accumulation of relatively coarse deposits at the head of the lake.

Topographically the area is a nearly level to gently rolling plain, with slopes generally ranging from level to 8 percent but steepening to 15 percent or more near the larger streams. The soils are mainly residual from the underlying sandstones and shales, and belong predominantly to the Kirkland and Vernon series. The Kirkland soils are typical brown Prairie soils, rather high in organic matter, which in a virgin state support a good growth of grass. These soils generally prevail on slopes of less than 3 percent. The Vernon soils are generally lighter in color, more friable, and occur on the more rolling and steeper slopes.

Approximate percentages of land use in the drainage area are: Cultivated 40 percent, abandoned 12 to 15 percent, and grazing (with some timber) 45 to 48 percent. The percentage of abandoned land in the watershed slightly exceeds that of Logan County as a whole, which is 10 to 12 percent.

Mean annual rainfall.—33.39 inches for the period 1930–34, according to records of the Red Plains Soil Erosion Experiment Station, 4½ miles south of Guthrie and 1 mile east of the reservoir. The mean yearly average at Guthrie during the period 1893–1930 was 32.72 inches.

Draft on municipal reservoir.—The average daily treatment of water at Guthrie, equivalent to daily draft, was 751,364 gallons from March 1934–April 1935, inclusive. June, July, and August comprise the period of greatest use, with monthly draft reaching 25 million gallons or more. The city has a population of 9,500, in addition to which the reservoir supplies two commercial plants of fairly large year-round use.

History of Survey

The survey of Guthrie Reservoir was made in the period May 2–14, 1935, by the Great Plains sedimentation party under the direction of Thomas L. Kesler, chief of party. Drafting and computations were subsequently completed by the party in the Soil Conservation Service office at Stillwater, Okla.

The field work included establishing a primary triangulation net of 14 stations with base line on U. S. Highway 77 where it crosses the delta. The base line extends 500 feet south and 1,000 feet north from the common corner of sections 4, 5, 8, and 9. Triangulation stations were used insofar as possible as cut-in points for the ranges, which were tied by secondary control into the triangulation net.

Direct sediment depth measurements were made with spudding apparatus up to range 14–15 at the front of the delta area. Above this range the delta was mapped with 1-foot contours and the volume of fill was computed by the modified prismoidal formula based on the difference in area between present and original contours.

Road fills of considerable volume extend across the delta at the head of the recervoir and across the upper end of the arm nearest the dam on the west side. Allowance for these artificial fills was made in computing capacities and sediment volume.

The extent and volume of delta deposits above crest level of the lake, or the upper limit of backwater, were measured separately as a special problem. The contours of the original maps did not extend into this area, and it was therefore necessary to make borings at carefully chosen spots with an auger. From numerous well-distributed bore holes, the average thickness of the above-crest delta deposits was determined, and by mapping the surface area the volume was computed. In figure 14 the area is shaded to distinguish it from other delta deposits. The results are not shown in the tabulated summary as they do not enter into computation of sediment in the lake basin or depletion of storage. They do afford, however, valuable supplementary information on the total quantity of soil brought down from the watershed.

A contour map of the lake basin with a 5-foot contour interval was made in 1919. This map was somewhat generalized in places and a number of minor alterations had to be made in this survey. This generalization, together with the relatively small thickness of sediment, which was easily penetrated in the lower part of the basin, made the range method—based on direct silt measurement—preferable to recontouring the whole basin. It was necessary to map the delta area with contours, however, because of the impossibility of penetrating to old soil.

The original maps were on a scale of 300 feet to the inch, and the same scale was adopted for the 1935 survey.

Sediment Deposits

The sediment in the main body of the reservoir, below range 14—15, is predominantly chocolate-brown to reddish-brown silt but contains

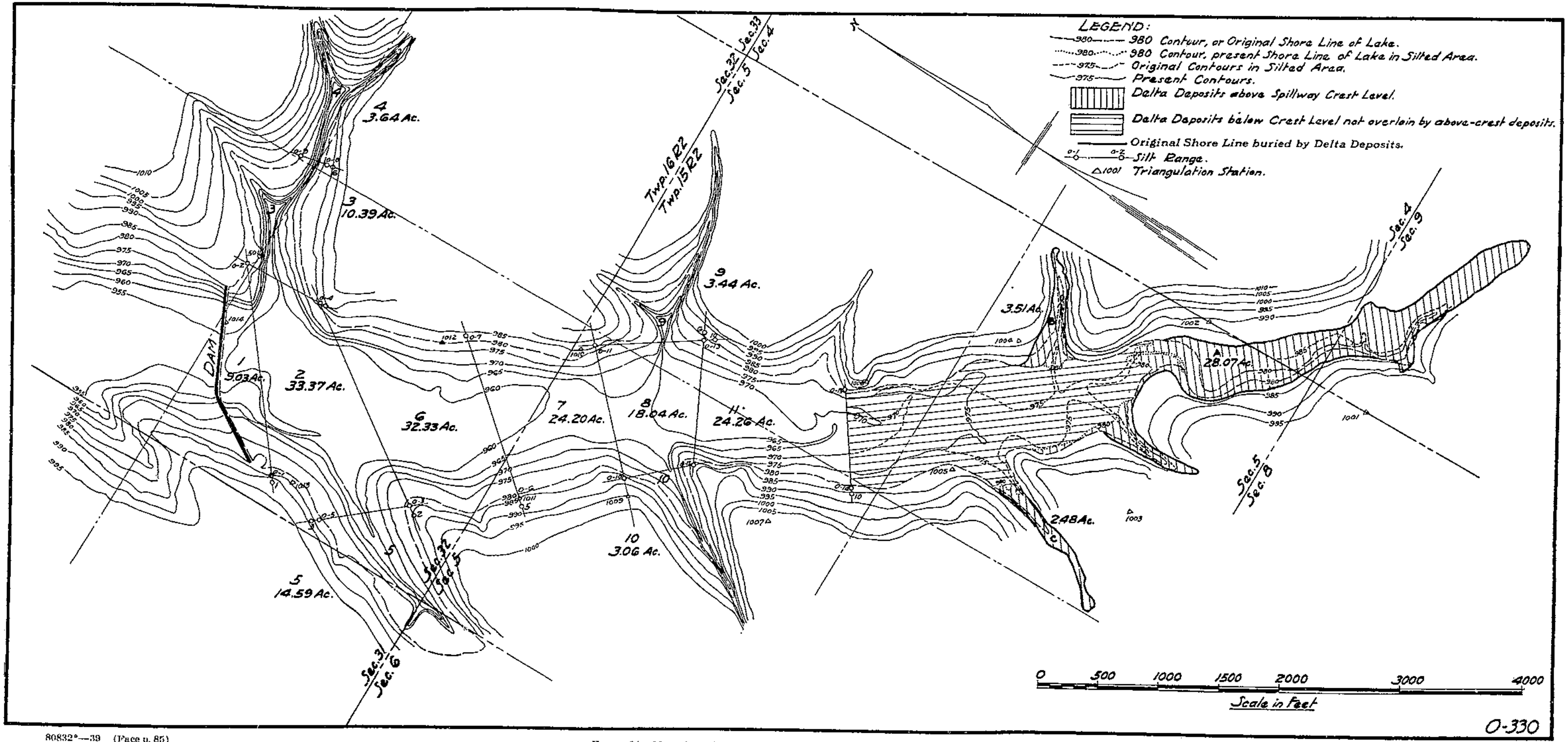

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FIGURE 14.—Map of Municipal Reservoir, Guthrie, Okla., surveyed May 1935.

an appreciable percentage of fine sand. The sand causes it to be less cohesive than the purer silts which characterize the central Texas reservoirs described above. The deposits below the delta area occur as a rather uniform blanket, the thickness of which at any place is roughly proportional to the water depth.

In several arms of the lower basin, bounded by one range across the mouth, the deposits were found to thin out gradually toward the head of the arm.

In the delta area, above range 14—15, the deposits are composed largely of fine to coarse sand. The surface of these deposits rises rapidly upstream, extending in places to as much as 8 feet above crest level. The above-crest deposits have shortened the lake by 0.4 mile, and are covered in most places by a dense growth of willows. The delta is gradually advancing its front down the reservoir, and the gradient upstream is being flattened by the banking up of top-set beds.

A summary of pertinent data relative to Guthrie Reservoir (fig. 14) is contained in the following tabulation:

Summary of data on Guthrie Reservoir, Guthrie, Okla.

Age [1]	years	14.5
Watershed area [2]	square miles	13.3
Reservoir:		
Original area at crest stage	acres	226
Area at crest stage at date of survey	do	217
Original storage capacity to crest level	acre-feet	3,064
Storage capacity to crest level at date of survey	do	2,608
Original storage per square mile drainage area [2]	do	230.38
Storage per square mile of drainage area at date of survey [2]	do	196.09
Sedimentation:		
Delta deposits	do	77
Bottom-set beds	do	379
Total sediment	do	456
Average annual accumulation	do	31.4
Annual accumulation per 100 square miles of drainage area	do	[3] 242
Annual accumulation per acre of drainage area	cubic feet	[3] 164.65
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds	tons	[3] 4.94
Delta deposits above crest	acre-feet	100
Total volume eroded material	do	556
Depletion of storage:		
Loss of original capacity per year	percent	1.03
Loss of original capacity to date of survey	do	14.88

[1] Storage began in October 1920; survey was made in May 1935.
[2] Including reservoir area.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, which include the lake area, are 236.47 acre-feet, 160.95 cubic feet, and 8 tons, respectively.

BOOMER LAKE [25]

General Information

Location.—State—Oklahoma. County—Payne (secs. 2 and 11, T. 19 N., R. 2 E., and secs. 26 and 35, T. 20 N., R. 2 E.). Distance and

[25] The generosity of the city water department and city engineer of Stillwater in providing data on the lake and materials used in the survey is acknowledged. The cooperation of R. G. Saxton, of Oklahoma Agricultural and Mechanical College was of much help in carrying on the field work. The triangulation system established by the engineering department of that institution was of material aid in expediting the survey.

direction from nearest city: 2 miles north of the center of Stillwater, Okla. Drainage and backwater: Boomer Creek, a tributary of Stillwater Creek which flows into the Cimarron River.

Ownership.—City of Stillwater.

Purpose served.—Municipal water supply.

Description of dam.—The dam is an earth-fill structure with riprap on the upstream face, which has a 3:1 slope. The total length of the dam is 8,300 feet, of which approximately 1,300 feet, or the main segment, extends east and west across the stream valley. The remaining portion was constructed as a dike over the shallow topography on the east side of the reservoir. The dam is approximately 23 feet high and is 20 feet thick at the top and 125 to 150 feet thick at the base. The spillway, a circular concrete bowl, is at the west end of the dam. It was originally built in 1925 at an elevation of 910 feet above sea level. In August 1933, 2 feet of concrete was added, bringing the elevation at the date of survey to 912 feet. This newer datum was used in the 1935 survey, elevations being taken from a temporary benchmark 6 inches west of the center line expansion joint on the spillway.

It is generally agreed by those familiar with the lake that, because of the usually low water stage, computations of capacity and volume of sediment might be made equally well on either the 910 or 912 datum. A complete set of computations was made for both elevations, however, in order, first, to check rates and volumes against original crest stage capacity, and, second, to bring the same series of data to present crest from which all future sediment measurements must be made. The quantitative data in this report are based on the 912-foot elevation except where otherwise noted.

Date of completion.—March 1, 1925. Surveyed June 1935. Age at date of survey: 10.25 years.

Length of lake at crest stage (original and at date of survey).—At elevation 910, 2.65 miles; at elevation 912, 2.74 miles.

Area of lake at crest stage.—Original, at elevation 910, 246 acres; at elevation 912, 292 acres.

Storage capacity to crest level.—Original, at 910 elevation, 2,246 acre-feet (731,859,100 gallons); at 912 elevation, 2,812 acre-feet (916,-290,200 gallons). At date of survey, at 912 elevation, 2,641 acre-feet (860,569,850 gallons). Loss, 171 acre-feet (55,720,350 gallons).

Area of watershed.—9.13 square miles.

General character of watershed.—The drainage area above Boomer Lake is underlain by "Red Beds" of Permian and Pennsylvanian age, consisting of thin-bedded shales and thin- to thick-bedded sandstones. This area lies within the transition zone between the prairies and the plains, although its soils and vegetation indicate a closer relation to the former. Topographically it is a more nearly level part of an undulating to gently rolling plain. The principal soils, in order of areal extent, are Vernon loam; Vernon loam, heavy subsoil phase; Kirkland silt loam; Yahola very fine sandy loam; and Kirkland loam. The most severe erosion has occurred on the Vernon soils which generally occupy the steeper slopes, and has been accentuated in some areas by cultivating the soil in the fall and leaving it bare through the winter.

In sec. 23, T. 20 N., R. 2. E., which is fairly representative of the watershed, the percentages of area devoted to various land uses in 1934 were as follows: Cultivated, 17; abandoned, 7; and grazing (with some timber), 76. Of the total area of grazing land in this section considerably more than half has been under cultivation in the past.

Mean annual rainfall.—Approximately 32 inches, according to records of a 36-year period.

Draft on municipal reservoir.—The average daily draft from July 1, 1933, to June 30, 1934, was 686,241 gallons. This quantity serves a population of approximately 8,000 the year round and, in addition, over a 9-month period in each year, about 4,000 students of Oklahoma Agricultural and Mechanical College. During the remaining 3 months of the year, the number of students is reduced to about 1,500. There is no marked variation in the daily or monthly draft, for the increase in normal town demand during the summer months is about offset by the decreased use of the college during this period. In addition to supplying the town and college, the reservoir also furnishes water for a Federal nursery, a State nursery, and three Civilian Conservation Corps camps, having a combined personnel of about 675 men. Members of the Stillwater Water Department stated that the town in 1935 was gravely concerned over the low stage of the lake and meager additions to storage during periods of heavy rain.

History of Survey

Field work of the Boomer Lake survey was done between May 16 and June 6, 1935, by the Great Plains sedimentation party under the direction of Thomas L. Kesler, chief of party.

The survey was based on a permanent triangulation system of seven stations which had been established and is now in use by the engineering department of Oklahoma Agricultural and Mechanical College for student practice.

The lake basin was mapped with considerable accuracy by plane table and stadia from triangulation control. Three contours, the old 910 crest level, the new 912 crest level, and a 914 contour, were mapped on a scale of 200 feet to the inch. A total of 20 ranges was established, sounded, and spudded. As a result of low water, a number of these were largely land profiles, established by levels from a plane table set up on a range end. Spud measurements were made with every sounding, or at intervals of 50 feet.

Sediment Deposits

The sediment in Boomer Lake is classified as entirely bottom-set silt and clay. It is extremely fine textured. No delta deposits were found in any portion of the basin.

Segments 1, 2, and 4, closest to the dam, contain the greatest thickness of silt, a reflection of the fact that the usual low-water stage of the reservoir permits transportation of sediment to the lower reaches of the basin.

The field and office work on the Boomer Lake survey was done with unusual care and fullness of detail in order to provide an exceptionally accurate basis for measuring past and future erosional activity in the erosion-control demonstration area.

It is believed that Boomer Lake will provide a convenient and adequate yardstick for comparing losses from erosion in the past with those in the future as modified by methods of soil conservation now being put in effect.

A summary of quantitative data on Boomer Lake (fig. 15) is contained in the following tabulation:

Summary of data on Boomer Lake, Stillwater, Okla.

Age [1] ....years..	10.25
Watershed area [2] ....square miles..	9.13
Reservoir:	
Area at crest (912) stage (original and at date of survey)....acres..	292
Original storage capacity (912)....acre-feet..	2,812
Storage capacity (912) at date of survey....do....	2,641
Original storage per square mile of drainage area [3]....do....	307.99
Sedimentation:	
Total sediment....do....	171
Average annual accumulation....do....	16.7
Annual accumulation per 100 square miles of drainage area acre-feet..	[3] 192
Annual accumulation per acre of drainage area....cubic feet..	[3] 130.91
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds....tons..	[3] 3.93
Depletion of storage:	
Annual loss of original capacity....percent..	0.59
Loss of original capacity to date of survey....do....	6.08

[1] Storage began on March 1, 1925; average date of survey, June 1, 1935.
[2] Including reservoir area.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, which include the lake area, are 182.69 acre-feet, 124.34 cubic feet, and 6.22 tons, respectively.

LAKES CROOK AND GIBBONS

Lake Crook is 4½ miles north of Paris, Tex., on Pine Creek, a tributary of the Red River. Lake Gibbons is on a small tributary of Pine Creek about 2 miles above and within the watershed of Lake Crook. Both lakes are owned by the city of Paris, Lake Crook being the present source and Lake Gibbons the former source of municipal water supply.

The dams of Lakes Crook and Gibbons are both earth-fill structures with concrete spillways 26 and 35 feet above stream bed, respectively. The Lake Gibbons spillway was originally 38 feet high but was lowered 3 feet in 1932 to an elevation of 599 feet above sea level. The elevation of the Lake Crook spillway is 476 feet. At the time of construction in 1900 the area of Lake Gibbons to the 35-foot level was 131 acres and the storage capacity was 1,414 acre-feet. At the time of survey in 1936 silting had not reduced the area appreciably but had decreased the capacity to 1,336 acre-feet. Corresponding reductions in Lake Crook from the time storage began in 1923 to the time of survey in 1936 were from 1,291 acres to 1,227 acres in area and from 11,487 acre-feet to 10,755 acre-feet in storage capacity.

The drainage basin above Lake Crook, including the 1.26 square miles tributary to Lake Gibbons, embraces nearly 53 square miles of

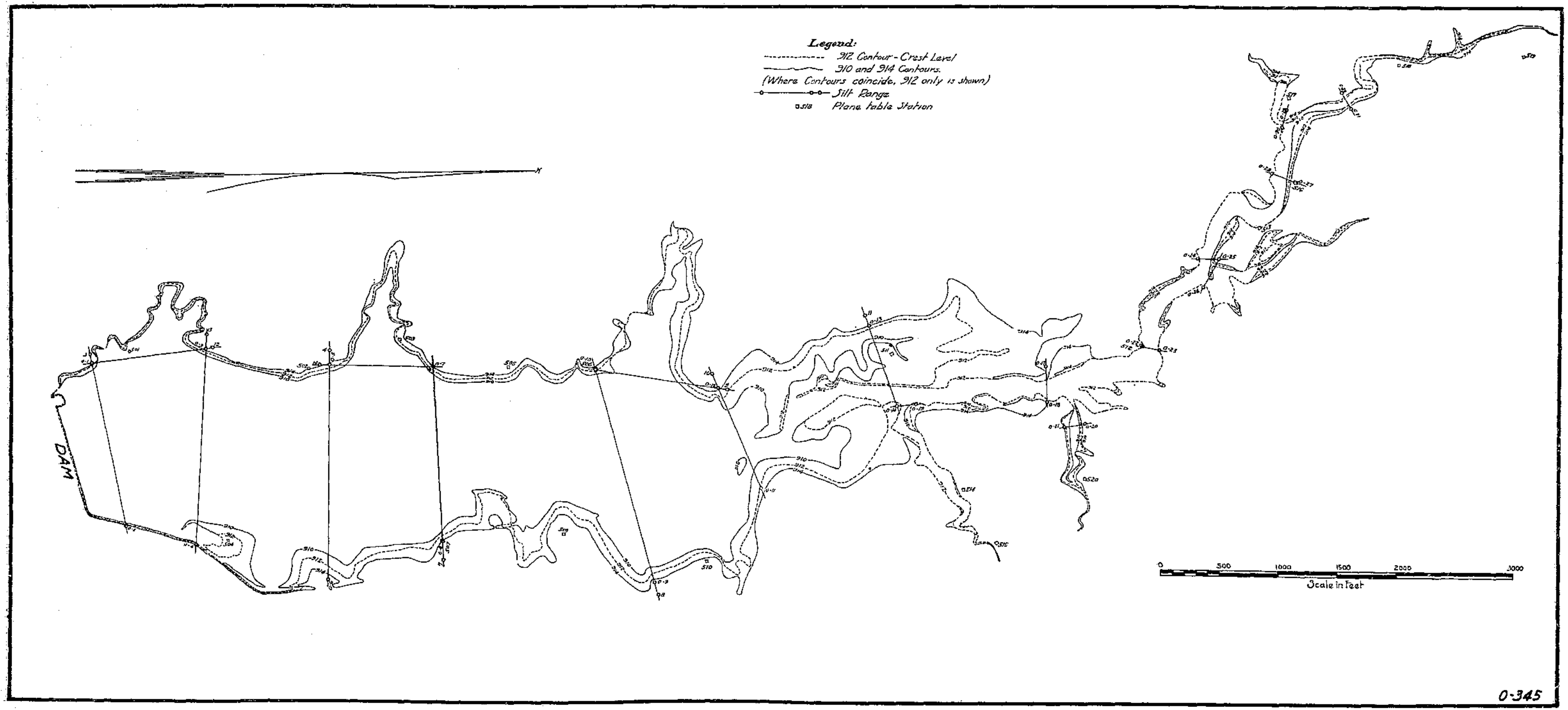

FIGURE 15.—Map of Boomer Lake, Stillwater, Okla., and tributary streams, surveyed June 1935.

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gently rolling prairie characterized by loose friable topsoils and heavy, slowly permeable subsoils, which are highly conducive to rapid run-off and serious soil losses. Moderate to severe erosion, however, has affected less than a third of the total area, limited largely to the steeper slopes on cultivated and idle land. The mean annual rainfall is 38.94 inches.

The sedimentation surveys of March 1936 revealed a 36-year accumulation of 78 acre-feet of sediment in Lake Gibbons and a 13-year accumulation of 732 acre-feet in Lake Crook. The deposits in both lakes are predominantly silt and clay, including only minor amounts of fine sand at the upper ends, uniformly distributed over each basin. The observed high turbidity of the overflow during periods of heavy run-off indicates that considerable quantities of sediment are carried past the dams. The volume of accumulated sediment therefore does not represent the entire erosional output of the watershed.

Comparison of the results of a detailed survey of the watershed, made by the Section of Conservation Surveys, with the sedimentation data on the two reservoirs revealed that although the Lake Crook watershed (exclusive of the area tributary to Lake Gibbons) has nearly twice as large a part of its area in cultivated and idle land as the smaller drainage area, the annual rate of accumulation per acre of drainage area in Lake Crook is little more than half that in Lake Gibbons. After careful study of all factors involved it was concluded that greater opportunity for upstream deposition on alluvial flood plains, together with the greater proportion of sediment bypassed through Lake Crook as a result of a smaller capacity-inflow ratio, accounted for the lower rate of sediment accumulation per unit of drainage area from the more severely eroding Lake Crook watershed.

The quantitative results of the sedimentation surveys of Lakes Crook and Gibbons are summarized in table 12.

TABLE 12.—*Summary of data on Lakes Crook and Gibbons, Paris, Tex.*

Item	Lake Crook	Lake Gibbons
Age ... years	[1] 13.1	[2] 36
Watershed area [3] ... square miles	[4] 51.0	1.26
Reservoir:		
Original area at crest stage ... acres	1,291	131.3
Area at crest stage at date of survey ... do	1,227	130.5
Original storage capacity ... acre-feet	11,487	1,414
Storage capacity at date of survey ... do	10,755	1,336
Original storage per square mile of drainage area [3] ... do	222.62	1,122.22
Storage per square mile of drainage area at date of survey [3] ... do	208.43	1,060.32
Sedimentation:		
Total sediment ... do	732	78
Average annual accumulation ... do	55.9	2.2
Annual accumulation per 100 square miles of drainage area [5] ... do	112	204
Annual accumulation per acre of drainage area [5] ... cubic feet	76.68	139.13
Or, assuming 1 cubic foot of deposit weighs 60 pounds ... tons	2.30	4.17
Depletion of storage:		
Loss of original capacity per year ... percent	0.49	0.15
Loss of original capacity to date of survey ... do	6.37	5.52

[1] Date storage began: February 1923. Date of this survey: March 1936.
[2] Date storage began: 1900 (month undetermined). Date of this survey: March 1936.
[3] Including reservoir area.
[4] Exclusive of Lake Gibbons drainage area.
[5] Excluding reservoir area.

SURVEYS IN SOUTHWESTERN UNITED STATES

ELEPHANT BUTTE RESERVOIR

General Information

Location.—State—New Mexico. Counties—Sierra and Socorro. Distance and direction from nearest city: The dam is 4 miles east of Hot Springs, N. Mex., 120 miles north of El Paso, Tex. The upper end of the reservoir is at San Marcial, N. Mex. Drainage and backwater: Rio Grande.

Ownership.—United States Government. Operated by United States Bureau of Reclamation.

Purpose served.—Irrigation of approximately 200,000 acres of the Rio Grande Valley in New Mexico, Texas, and Mexico extending 100 miles north and 90 miles southeast of the city of El Paso, Tex.

Description of dam.—The Elephant Butte Dam is one of the largest in the United States, and before construction of Boulder Dam impounded the largest reservoir in this country. The dam is a concrete gravity structure having a maximum height of 306 feet above its foundation, or 193 feet above river bed, and a total length of 1,674 feet. The spillway crest is at an elevation of 4,407.0 feet (project datum, which has been used in all calculations) or 4,450.3 feet above sea level.

Date of completion.—1916. Water storage began, however, on January 6, 1915. Surveyed March to June 1935. Age at time of survey, 20.25 years.

Length of lake at crest stage (original and at date of survey).—Approximately 41 miles.

Area of lake at crest stage.—Original, 40,096 acres; at date of survey, 38,309 acres.

Storage capacity to crest level.—Original, 2,638,860 acre-feet; at date of survey, 2,273,674 acre-feet. Loss, 365,186 acre-feet.

Area of watershed.—26,312 square miles, exclusive of all inland drainage.

General character of watershed.—The lower part of the watershed is underlain mostly by surficial deposits of alluvium, dune sand, the Gila conglomerate, and the Palomas gravel; and to a lesser extent by the Ogallala and Santa Fe formations. There are also extensive areas of Quaternary and Tertiary basalt and rhyolite and mixed Cretaceous and Tertiary volcanics of several types. On the headwaters and in the higher mountains Pennsylvanian and Permian limestones occupy broad areas.

That part of the drainage area south of Santa Fe consists of isolated ranges and mountain groups (largely dissected block mountains) separated by aggraded desert plains, and the broad valley of the Rio Grande itself. The valleys are 4,000 to 5,000 feet above sea level and the mountains are commonly 1,200 to 1,500 feet higher.

The entire lower section of the watershed is characterized by its aridity. The rocks decompose slowly, and most of the finer particles are carried away by wind and sheet floods, leaving the surface covered with a coarse rubble. Away from the river course, creosotebush, sagebrush, greasewood, and cactus constitute the principal vegetation. Some cedar is found between 5,000 and 7,000 feet; above this elevation pine and fir cover the mountain slopes.

Considerable portions of the drainage area were formerly range lands, but overgrazing has seriously depleted their value. Consequent destruction of the natural grasses has exposed large areas to sheet wash and wind erosion; and in some sections, comprising a very considerable aggregate area, strong arroyo and gully development is in progress. This action, for the most part, has begun since the advent of domestic grazing. At present it is extending over widespread areas at alarming rates, and in many places, particularly in soft shale and alluvial formations at the foot of the mountains, has produced considerable areas of typical badlands topography.

Mean annual rainfall.—10 to 15 inches over most of the lower drainage area. In the higher mountainous region around the headwaters it is 25 inches or more.

Inflow.—The average total annual inflow into the reservoir is 1,000,000 acre-feet. Normally about 800,000 acre-feet come in during the first 6 months of the year.

Evaporation.—Losses by evaporation, including seepage, range from 150,000 to 250,000 acre-feet annually, depending on the stage of the reservoir.

Draft for irrigation.—The mean annual draft is about 750,000 acre-feet.

History of Survey

The survey of sediment deposits in the main basin of Elephant Butte Reservoir was made between March 2 and May 15, 1935, by a special party under direction of Herbert W. Yeo. This party was assisted from March 3 to March 12 by the Great Plains sedimentation party under the direction of Thomas L. Kesler, and from March 3 to April 20 by the southwestern party under the direction of Raymond C. Becker.

A triangulation system and benchmarks had previously been established in surveys by the Bureau of Reclamation in 1903, 1908, and 1916–17. Most of these old stations were reoccupied or flagged during the present work. Additional level lines were run to correct elevations on certain stations established during the 1916–17 survey. Accurate leveling showed that primary stations were in adjustment, but certain intermediate stations that had been established by vertical angle and stadia work, had to be corrected. A few new stations and numerous additional level lines were established.

The southwestern party is responsible for having mapped most of the western edge of the reservoir from Silver Canyon to San Marcial, for the entire San Marcial sheet and most of the Paraje sheet. Grove C. Traylor, attached to Mr. Yeo's party as a special surveyor, completed topographic mapping on the Paraje sheet and mapped the section from that sheet to the lower end of the Narrows sheet and the extreme upper end of the Alamosa Canyon sheet. Work of the Great Plains party was confined largely to leveling. The lower basin, as well as remaining portions of the area above the Narrows, was surveyed by Mr. Yeo's party.

The survey consisted, in addition to adjusting the control network, of mapping with 1-foot contours approximately 21,600 acres of the present silt surface, more than 90 percent of which was covered either with closely spaced stadia shots, or with carefully located soundings.

A mapping scale of 1,000 feet to the inch was used, this being the scale of the original maps which were used for comparison. The original maps show only 10-foot contours, so necessarily only the 10-foot contours of the present survey could be used for comparative capacity computations. The 1-foot contours will afford, however, an extremely accurate basis for future resurvey.

The upper basin was mapped by traverse lines tied into the triangulation net and stadia shots taken at frequent intervals. The dense vegetation of the upper basin was a severe obstacle to rapid progress. Near San Marcial, cottonwood and willow trees and small brush, including some saltcedar, prevail. Near Paraje saltcedar is the principal vegetation along the east side and small willows prevail along the west side of the basin. Near the mouth of Nogal Canyon saltcedar 2 to 6 feet high predominates. Near San Alvino and San Jose the vegetation consists mostly of water anemones. Near River Bend and Toby the only vegetation is cattails and tules, while the extreme lower half-mile of unsubmerged area is devoid of plant growth.

During this survey water stage was at an extremely low level, so that all the area above the Narrows except small isolated ponds could be mapped by plane table and stadia despite the soft character of the sediment which made precautions necessary to prevent bogging down. The area below the Narrows was sounded from a boat, soundings being accurately located by intersection from instruments on adjacent triangulation stations.

On completion of contour mapping of the deposits over the floor of the main valley, a map of the entire reservoir was compiled from the plane-table sheets on a scale of 1,000 feet to the inch. This map shows the original 10-foot contours and the present 5-foot contours on top of the deposits. The map reproduced in this report (in pocket) is a pantographed reduction of the original. Preparation of the final map, planimeter measurements, and capacity computations were made by the United States Bureau of Reclamation in its El Paso, Tex., office, the work being done by A. B. Cundell under the direction of L. R. Fiock, project superintendent.

The 1935 capacity computations were made by the modified prismoidal formula which was used in computing the original capacity following the 1903–8 surveys. This formula is:

$$Vx=\frac{2H}{6}(A+4B+C)-Vy$$

where

Vx=volume between contours at B and C
H=contour interval
A=area bottom surface
B=area midsurface
C=area top surface
Vy=volume between contours A and B, previously determined.

The volume below the lowest 10-foot contour was computed by the average end-area method which provided Vy. The above formula was then used progressively for each succeeding higher contour. This method was used to determine the original capacity of 2,638,860 acre-feet which has been carried in the literature for some 20 years.

SEDIMENT DEPOSITS (6)

The Rio Grande carries the largest sediment burden, both in absolute maximum percentage of suspended load to discharge during any particular flood, and in ratio of total suspended load to total discharge, of any major stream of the Southwest on which measurements are available. Records and observations of the suspended load of the Rio Grande, which are available for a longer continuous period than for any other stream in the Southwest, show that the principal sources of sediment are the Rio Puerco and Rio Salado, tributaries which enter between Albuquerque and Socorro.

The headwaters of the Rio Grande in north central New Mexico and south central Colorado, draining a mountainous area of 11,028 square miles, are fed largely by melting snow, springs, and normal run-off. The waters carry little or no suspended load, and are commonly filled with mountain trout, which thrive only in clear water. It is this source of supply that is relied on to replenish the storage during the late spring floods originating from melting snow. In contrast, the Puerco, Salado, and other smaller streams, draining 13,621 square miles of the generally barren, broken, central part of New Mexico, supply floods of heavily sediment-laden water derived from the erratic and often spectacular cloudbursts that occur during summer and early fall (pl. 9, *A*). The waters of these flashy summer floods usually carry 4 to 10 percent, and occasionally as high as 26 percent, by weight of sediment which is characterized by a high percentage of very fine-grained material. On the other hand, the spring floods coming from the headwater drainage and normally supplying the greater part of the total annual inflow carry only 0.5 percent or less of sediment.

A large part of the sediment from tributaries has been derived as a result of incision and lateral widening of valley trenches. In an unpublished report, Bryan and Post have estimated that the channel of the Rio Puerco was deepened 18 feet and widened 185 feet on the average during the period 1885 to 1927. The debris removed from the main and tributary channels during this period is estimated to have been 9,400 acre-feet per year. This is equivalent to about half of the average annual accumulation in the reservoir.

All the material from the tributaries of the Rio Grande is not transported directly into the reservoir. The spasmodic summer floods commonly transport far more sediment into the Rio Grande Valley than the diffused flood flows are able to carry downstream to the reservoir. The difference in gradient between the relatively steep tributary valleys and the much flatter trunk channel has been responsible for much of the aggrading of the valley level, which was in progress even before construction of the reservoir. Such a feature of aggradation is notable at the mouth of the Rio Puerco 55 miles above the head of the reservoir, and has been locally referred to as a "plug." The sediment thus deposited along the course of the valley is picked up in part, however, by the normal spring floods which would otherwise enter the reservoir nearly devoid of sediment. This condition, together with deposition of sediment at the head of the reservoir where carrying power is destroyed, have forced the stream to readjust its profile of equilibrium to a much flatter gradient. It is known that sediment is now being deposited in the

Rio Grande Valley as much as 50 miles above San Marcial at the head of the reservoir. This sediment is probably somewhat coarser in texture than the reservoir deposits because of the sorting action of the river water. The finer material transported as suspended load is carried downstream farther and more rapidly than the coarser debris which is transported as bed load.

Sediment deposits, considerably above original crest elevation of the lake, are found at San Marcial and for some distance down the reservoir (pl. 9, *B*). A large amount of the sediment was deposited in September 1929, when the largest flood of recent years occurred. At this date a flow of 29,000 second-feet was recorded and a possible peak of 48,000 second-feet was indicated. By way of contrast, the normal food flow in the spring is only 6,000 to 12,000 second-feet. This record flood deposited 3 feet of sediment, mostly above crest level, over much of the valley around San Marcial. Some striking observations made during this survey showed old fence posts projecting only 6 inches above the present surface. A United States Geological Survey benchmark has recently been unearthed under 4 feet of sediment and reestablished on the present surface. The upper part of the reservoir basin is filled and covered by above-crest deposits (pl. 10).

It now supports a dense growth of willows and brush, which has the effect of retarding the deposition of sediment in the lower basin by causing the above-crest deposits to bank up to higher levels.

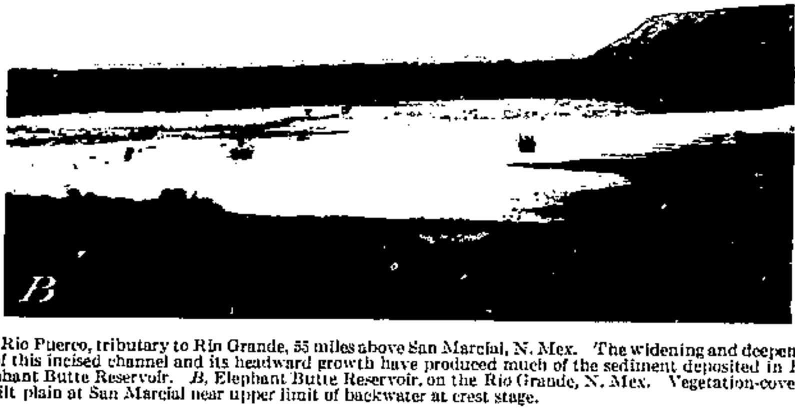
The surface sediment deposits below San Marcial are characteristically very fine textured, containing a high percentage of true clay and colloidal matter. Much of the sediment is so fine that no grit can be discovered by rubbing it between the teeth.

Arroyo deposits being carried into the storage basin below crest-level are, on the other hand, characteristically coarse boulders (pl. 11, *A*). The surface of the Nogal Canyon is covered across its full width of 1,000 feet with this coarse debris, in which boulders as much as 1 foot in diameter are common. Parts of this debris are moved by floods from each recurring cloudburst. The erratic floods flow first through one channel and then another over the braided drainage slope of the arroyo bottom (pl. 11, *B*), so that in the course of a decade or two all the debris has been moved once or perhaps several times.

During low-water stages in the average year, most of the reservoir basin above the Narrows is uncovered. Sediment deposits dropped here during floods are exposed to air and hardened. Below the Narrows sediment remains, under water, in a comparatively soft and uncompacted condition. In this section of the reservoir the singular and striking phenomenon of "underflow" occurs.

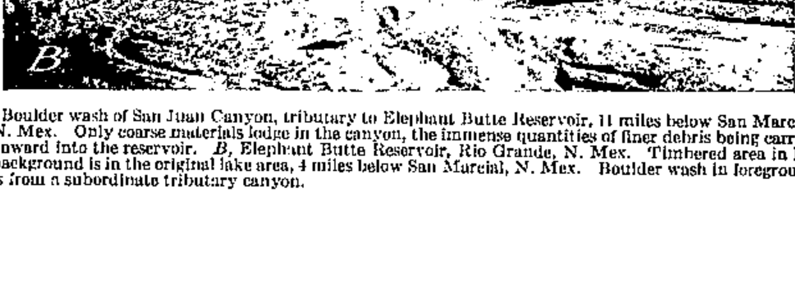
Following by several days the entrance of heavily sediment-laden flood waters into the upper end of the reservoir basin, extremely muddy water is discharged through outlet gates in the dam. During this time, however, surface water near the dam retains its usual crystal clear, blue color. Fiock (*6, pp. 472–473*) explains this phenomenon as follows:

> Observations have revealed that the silt-laden water flows along the bottom of the lake in a very thin sheet (less than 5-foot depth), or through the lowest portions of the floor of the Reservoir much as water itself flows under air, and apparently does this without diffusing into the water already in the lake, as it



A, Rio Puerco, tributary to Rio Grande, 55 miles above San Marcial, N. Mex. The widening and deepening of this incised channel and its headward growth have produced much of the sediment deposited in Elephant Butte Reservoir. B, Elephant Butte Reservoir, on the Rio Grande, N. Mex. Vegetation-covered silt plain at San Marcial near upper limit of backwater at crest stage.

Elephant Butte Reservoir, Rio Grande, N. Mex.: *A*, Vast silt plain covered with vegetation between San Marcial and the "Narrows." Silt ranges from 15 to 30 feet in thickness over this whole expanse of valley. *B*, Reservoir below Alamosa Canyon. Note wave-cut terraces in foreground. *C*, At mouth of Alamosa Canyon. Entrance to reservoir as viewed from south showing the vast quantity of debris and delta front.



A, Boulder wash of San Juan Canyon, tributary to Elephant Butte Reservoir, 11 miles below San Marcial, N. Mex. Only coarse materials lodge in the canyon, the immense quantities of finer debris being carried onward into the reservoir. *B*, Elephant Butte Reservoir, Rio Grande, N. Mex. Timbered area in left background is in the original lake area, 4 miles below San Marcial, N. Mex. Boulder wash in foreground is from a subordinate tributary canyon.

retains certain distinct characteristics which are evident and have been observed as it is discharged from the outlets. There may occur some modifications of these characteristics of the silt-laden water during its passage through the Reservoir, but it even retains a temperature higher than that of Reservoir water as it flows along beneath the clear water. When the silt-laden water is being discharged from the outlet-gates it carries a silt load up to 6 percent by weight. The temperature of the outflow immediately rises about 6° and the soluble salt-content increases materially. With the clearing up of the outflow-water which usually occurs quite rapidly the temperature of the outflow drops back to the normal temperature of the Reservoir outflow for that particular season of the year and the soluble salt-content also drops off to that of the ordinary Reservoir water. The character of the silt in the Reservoir discharge is almost pure finely divided clay with all particles of grit or heavier silts completely removed, these having been deposited within the Reservoir area.

The conditions productive of a silt-flow through the Reservoir may be observed to be as follows: They occur when heavily silt-laden floods, usually carrying from four per cent to ten per cent of silt by weight, originating from rains on the Rio Grande watershed in central New Mexico enter the Reservoir. The silty outflows, carrying from two per cent to six per cent of silt, usually continue for only a few days, the duration depending upon the volume and duration of the flood-inflow and the quantity being released from the Reservoir. With the head-waters of the lake between 30 to 35 miles above the dam the silty water makes its appearance in the outflow in from two to five days after entering the Reservoir. The silt-load in the outflow reaches its maximum quite rapidly and clears up at the end of the run with equal dispatch. No observations have been made to determine the depth to which the silt-laden water accumulates just above the dam but it is planned to make such a determination.

The reason for this phenomenon has caused some wonderment but it is undoubtedly explained by the fact that the silt-laden water as it is discharged from the Reservoir weighs up to two or three pounds more per cubic foot than clear water. Its flow along the bottom of the lake is, therefore, undoubtedly explained by its higher specific gravity, but why it does not diffuse or mix more than it does with the Reservoir water and why it retains its own particular characteristics, including a higher temperature, may be a matter for further scientific analysis.

Its economic significance is of somewhat doubtful importance. The total volume of the silt passing through the Reservoir with these flows is so relatively small compared to the total volume of silt entering the Reservoir and being deposited there that it is of little consequence in prolonging the useful life of the Reservoir. The total volume carried through the Reservoir in this manner to date is estimated to be only about 5,000 acre-feet. As the storage capacity of the Reservoir is more and more encroached upon by accumulated silt-deposits, silt-flows through the Reservoir may be expected with progressively increasing frequency and duration.

Not only does the occurrence of muddy water discharge at the dam show the existence of a sediment underflow, but the fact that more than 30 feet of sediment has accumulated at the dam, where the water is constantly clear at the surface, conclusively proves the existence of this phenomenon which has been generally neglected heretofore in discussions of reservoir silting. Far more storage depletion appears to be taking place in the lower end of many reservoirs than has been generally suspected, and it has in fact been a common feature of previous sedimentation surveys to omit measurements of the lower part of the reservoir as having negligible silting.

The sinking of the sediment-laden water below desilted water of the lower basin may be noted, at times strikingly, in the area a mile or two below the Narrows. The line of demarcation between muddy water from above the Narrows and clear water of the lower basin is very sharp, being distinguishable within a space of less than 5 feet. The front of the muddy water is lobate in shape, the extreme front of the lobe near the center of the lake being about half a mile below the flanks of the lobe where they join the shore. Apparently, during low-water stages the denser water settles at a fairly definite point, where the horizontal velocity head, which diminishes rapidly after passing

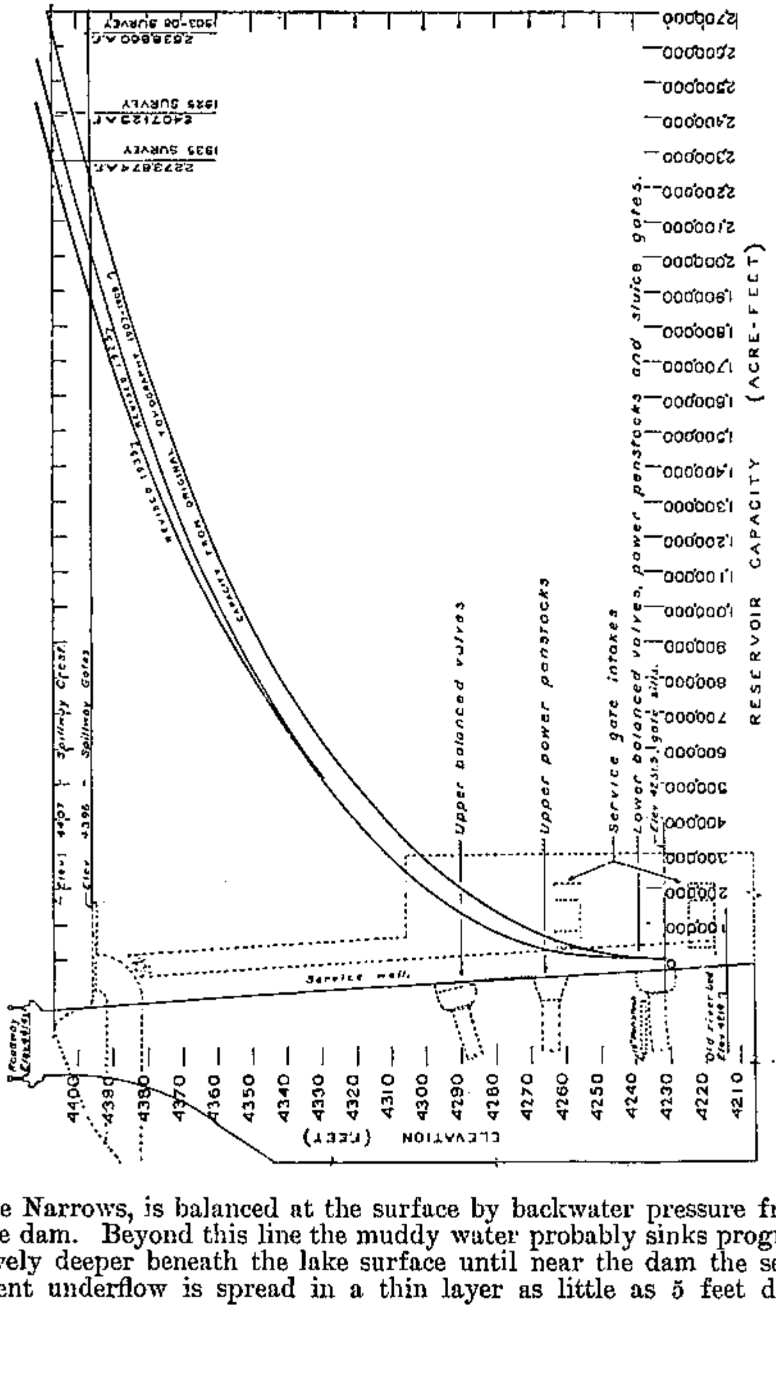


FIGURE 16.—Storage capacity of Elephant Butte Reservoir.

the Narrows, is balanced at the surface by backwater pressure from the dam. Beyond this line the muddy water probably sinks progressively deeper beneath the lake surface until near the dam the sediment underflow is spread in a thin layer as little as 5 feet deep across the flatter section of the reservoir floor, generally extending from valley wall to valley wall.

The accompanying charts (figs. 16 and 17) show that practically all (98.8 percent) of the capacity below the 4,240 contour is gone.

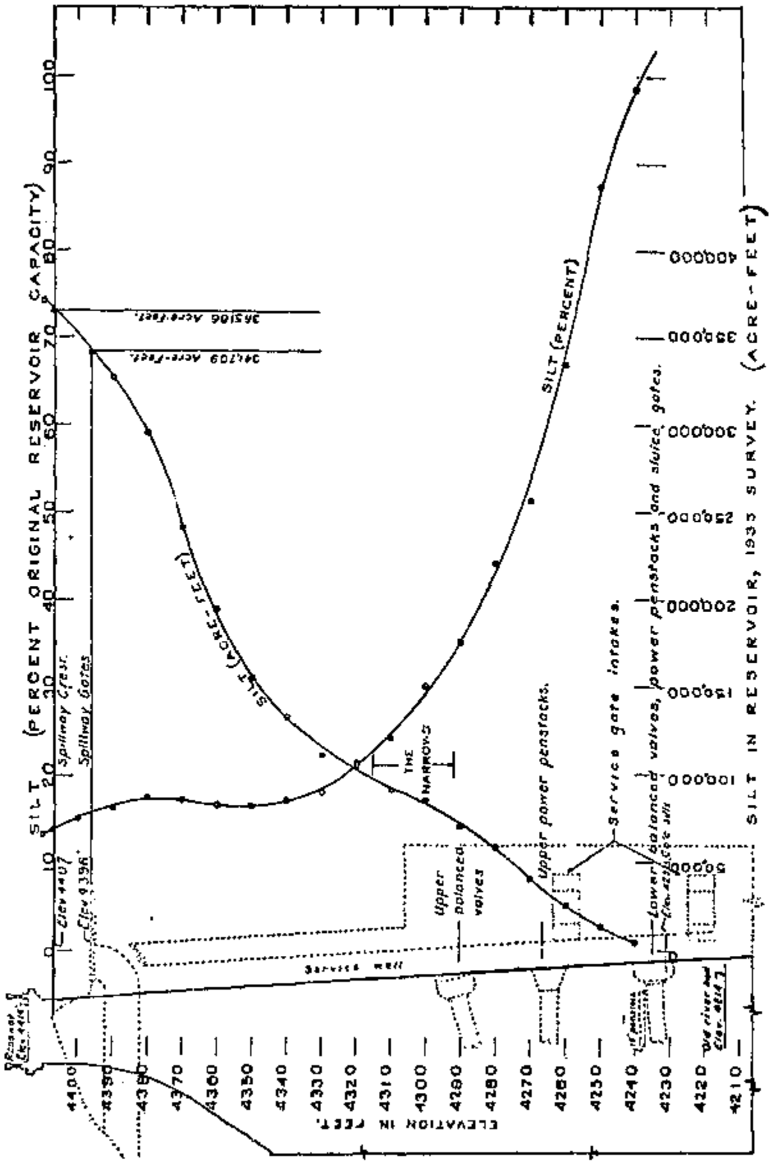


FIGURE 17.—Distribution of sediment deposits in Elephant Butte Reservoir.

Depletion of capacity ranges from 87.2 percent at the 4,250 contour down to 30 percent at the 4,300 contour. Above 4,350 the depletion remains fairly constant at 15 to 18 percent.

Water-surface area curves of Elephant Butte Reservoir are shown in figure 18.

Profiles of the original valley floor and sediment deposits of various dates are shown in figure 19.

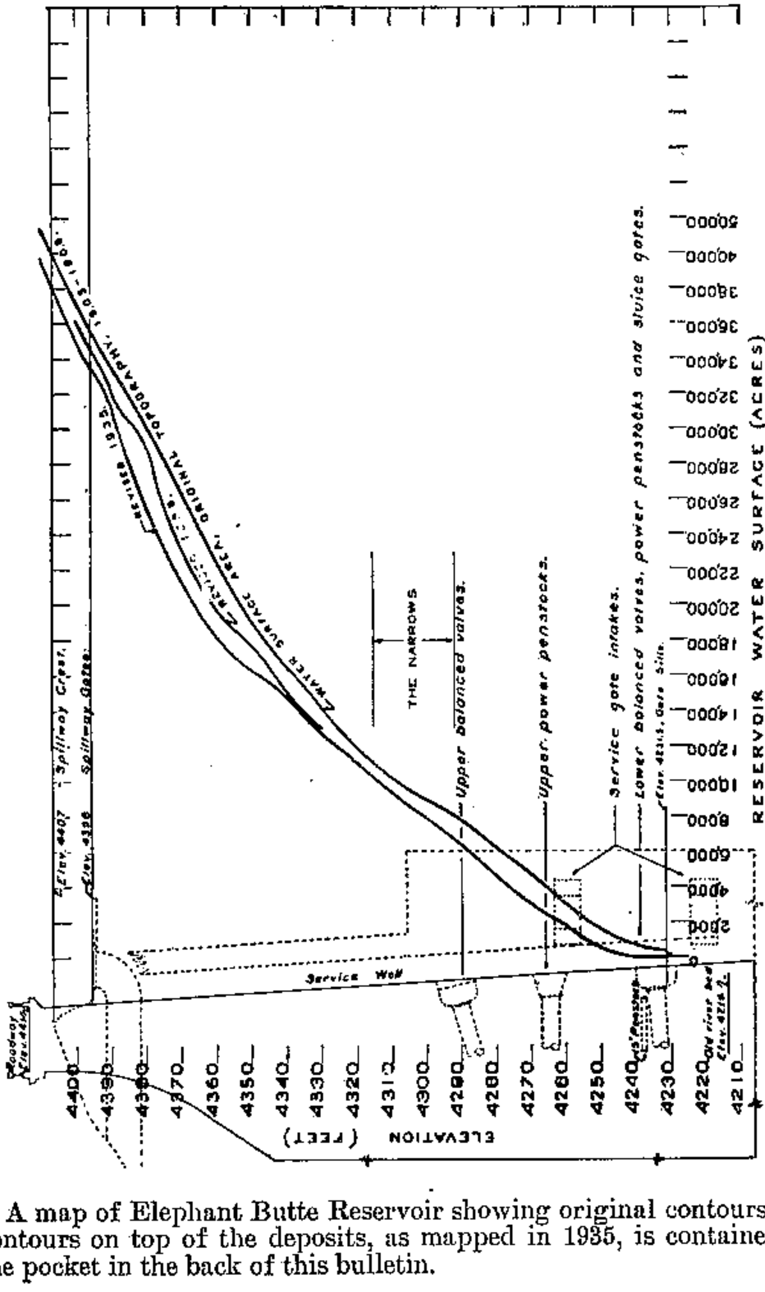


FIGURE 18.—Water-surface-area curves of Elephant Butte Reservoir.

A map of Elephant Butte Reservoir showing original contours and contours on top of the deposits, as mapped in 1935, is contained in the pocket in the back of this bulletin.

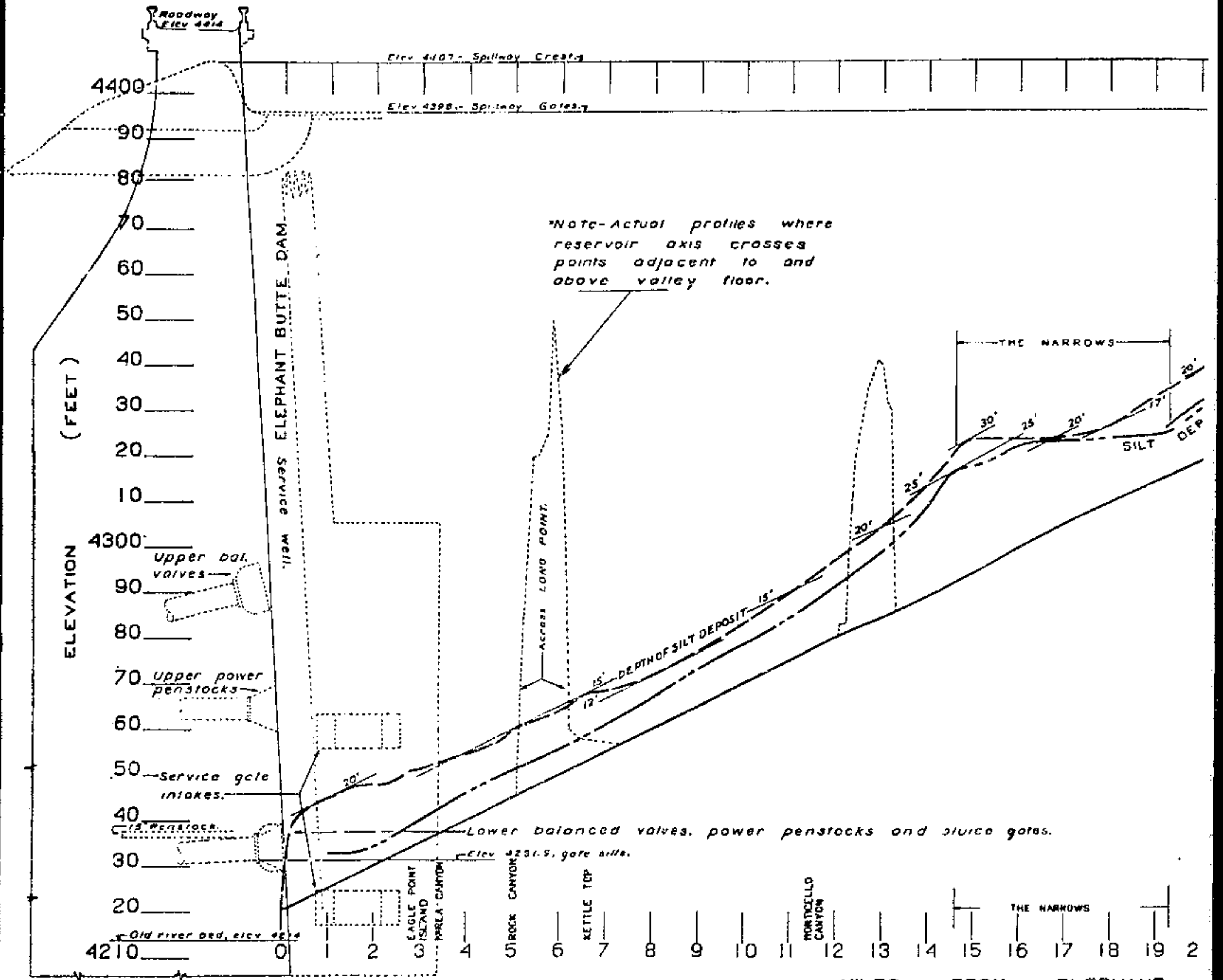


FIGURE 19.—Profiles of the original valley floor and

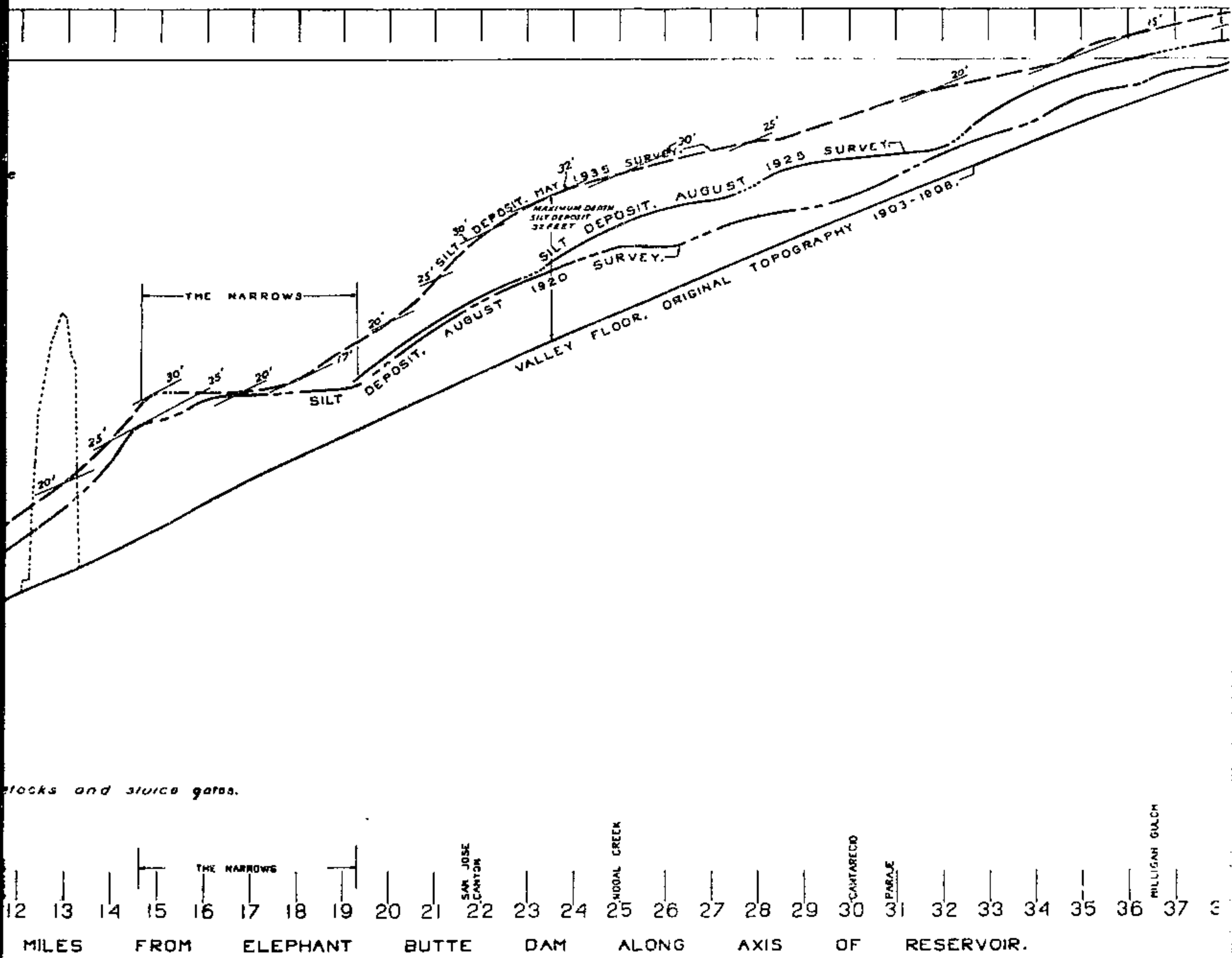
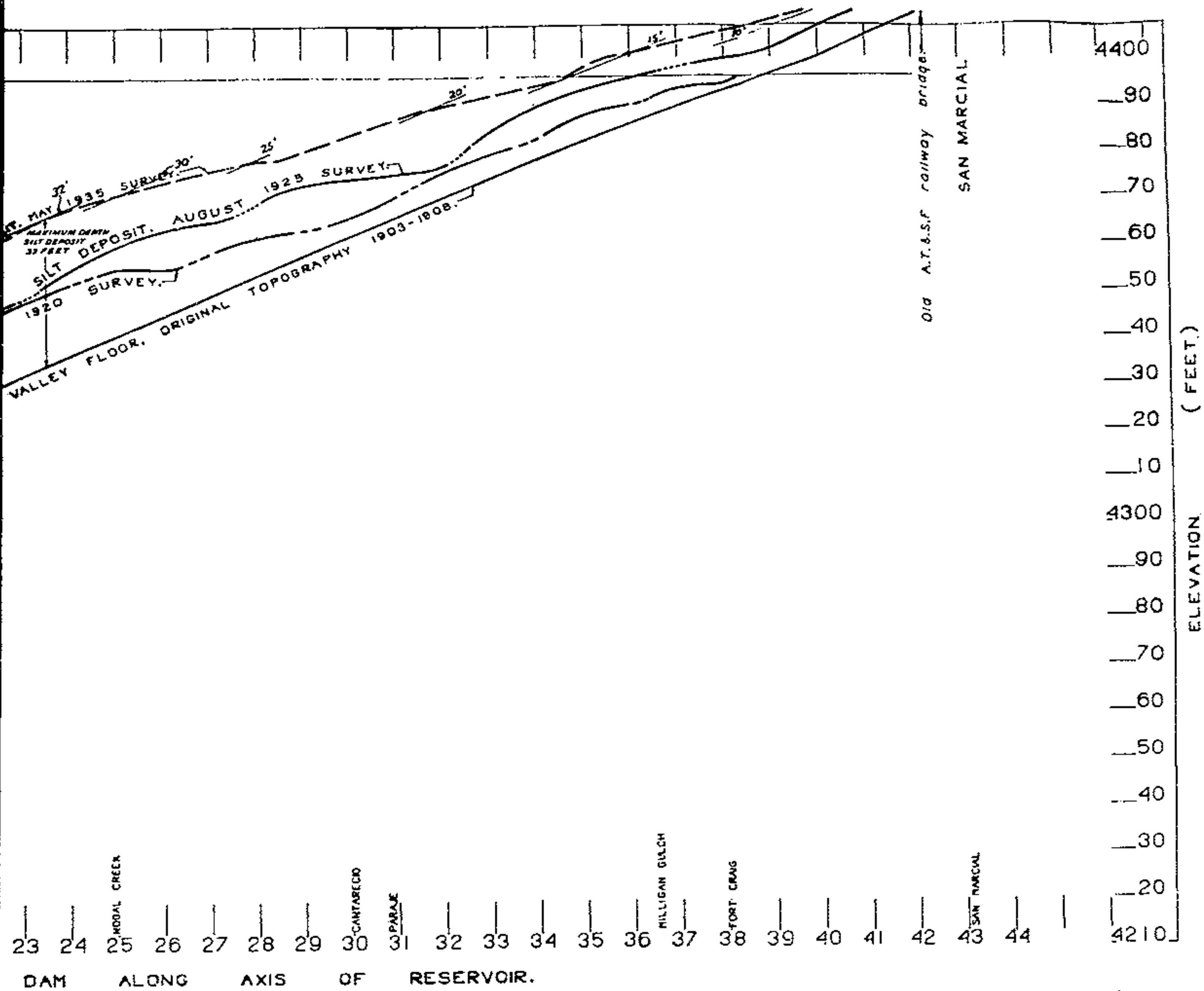


FIGURE 19.—Profiles of the original valley floor and sediment deposits of Elephant Butte Reservoir at various dates.



ts of Elephant Butte Reservoir at various dates.

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A comparison of rates of silting during the different periods of the reservoir's life, for which data are available, is given in an earlier part of this report (pp. 11–13) and does not require repetition here. The total volume of sediment and the annual rate of accumulation in respect to drainage area are shown in the following tabulation, which contains a summary of pertinent data relative to Elephant Butte Reservoir:

Summary of pertinent data relative to Elephant Butte Reservoir, N. Mex.

Age [1] ____ years	20.25
Watershed area ____ square miles	[2] 26,312
Reservoir:	
Area at crest stage:	
Original ____ acres	40,096
At date of survey ____ do	38,300
Storage capacity to crest level:	
Original ____ acre-feet	2,638,860
At date of survey ____ do	2,273,674
Storage per square mile of drainage area: [3]	
Original ____ do	100.29
At date of survey ____ do	86.41
Sedimentation:	
Total sediment (exclusive of arroyo deposits and above-crest deposits) ____ acre-feet	365,186
Average annual accumulation ____ do	18,034
Annual accumulation per 100 square miles of drainage area ____ acre-feet	[4] 68.7
Annual accumulation per acre of drainage area ____ cubic feet	[4] 46.76
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds ____	[4] 1.40
Depletion of storage:	
Loss of original capacity per year ____ percent	0.68
Loss of original capacity to date of survey ____ do	13.84

[1] Storage began on Jan. 6, 1915; average date of survey, April 1935.
[2] This represents the Rio Grande drainage area in Colorado and New Mexico, not including 2,900 square miles in the San Luis Valley closed basin, but including 1,663 square miles draining directly into the reservoir.
[3] Including area of reservoir.
[4] These figures are revised to exclude the lake area from the total area of the drainage basin. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, which include lake area, are 68.5 acre-feet, 46.65 cubic feet, and 2.33 tons, respectively.

SAN CARLOS RESERVOIR [20]

General Information

Location: State.—Arizona. Counties: The Dam is on the boundary line dividing Gila and Pinal Counties. The upper part of the reservoir extends also into Graham County. Distance and direction from nearest city: 28 miles southeast of Globe, Ariz. Drainage and backwater: Gila River, and its tributary, San Carlos River, which enters the reservoir 8 miles above the dam.

Ownership: United States Government. Under supervision of the Indian Irrigation Service.

Purpose served: (1) Irrigation of the Coolidge project of approximately 100,000 acres; (2) hydroelectric power development.

[20] The aid extended by C. J. Moody, project engineer of the Indian Irrigation Service at Coolidge Dam, in furnishing original maps of the reservoir, is acknowledged. D. G. Butler, superintendent of Coolidge Dam, generously extended the courtesies of his camp and office for use of the field party. The work was also facilitated by the advice and cooperation of the late B. P. Fleming, director of the Gila project of the Soil Conservation Service.

Description of dam: The dam is a concrete structure of the multiple-dome type, the largest of its kind in the United States. Each of its three domes has a span of 180 feet, is 28 feet thick at the base and 4 feet thick at the top. On each side of the dam at elevation 2,511 are spillways 150 feet wide. Three gates, 12½ feet high and 50 feet wide on each spillway raise the crest level to 2,523.5 feet above sea level. The river bed at the dam is at elevation 2,308. The total height of the dam from bedrock to spillway is 203 feet, and to the roadway on top, 250 feet. Its length, including spillway, is 850 feet.

Date of completion: October 25, 1928. (Construction was begun in January 1927.) Date of survey, February 1935. Age at date of survey, 6.33 years.

Length of lake at crest stage: Original and at date of survey, 22 miles in Gila Valley.

Area at crest stage: Original and at date of survey 18.847 acres, planimetered from original maps of 1916.

Storage capacity to crest level: Original (1916 survey) 1,247.999 acre-feet; at date of survey 1,211,103 acre-feet; loss 36,896 acre-feet.

Area of watershed: 13,540 square miles, embracing portions of Cochise, Greenlee, Graham, and Gila Counties, Ariz.; and Catron, Grant, and Hidalgo Counties, N. Mex.

General character of watershed: San Carlos Reservoir lies in an intermontane basin, drained by the Gila River, which is joined by the San Carlos Basin some 8 miles above Coolidge Dam, where the southward-flowing San Carlos River joins the Gila River. The Gila Basin is enclosed by the Turnbull Range on the south, the Pinal and Mescal Ranges on the west, and the Gila Range on the north. The southern range rises gradually from the Gila River terraces and the eroded remnants of old alluvial slopes into the foothills of Mount Turnbull. On the west the Pinal Range rises precipitously from the gorge in which the dam is located. Lava-capped mesas and plateaus lead northwest to the Gila Range.

The Gila River drains all the watershed except a portion of Gila County north of the reservoir, extending eastward from Globe to the Bonita Creek Divide, which drains directly into the San Carlos River.

The drainage area of the Gila River is so vast that it is beyond the scope of this report to even outline its geology in detail. In a general way the whole stratigraphic column from pre-Cambrian metamorphics to Tertiary volcanics is well represented.

The Gila River drains a region composed largely of mountains and plateaus, wide areas of which in both Arizona and New Mexico are composed of Tertiary and Quaternary volcanics. These formations include young basalt flows and older dacite, latite, rhyolite, andesite, basalt, and other extrusives, as well as tuff, ash, and agglomerate.[27]

The San Simon Valley and portions of the Gila Valley are covered by bolson deposits of sand and gravel, and the Gila conglomerate. Lake deposits of gray, yellow, and greenish-blue clay, and gray and reddish sand are also exposed in many places. Overlying them are younger stream deposits which mantle the older valley alluvium.

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[27] Geologic map of the State of Arizona. Ariz. Bur. Mines and U. S. Geol. Survey. 1924.

The reservoir basin is underlain successively by dissected alluvium beds, Gila conglomerate, and pre-Quaternary igneous and sedimentary rocks (*12*).

At the dam site the Gila River flows in a gorge 2,000 feet deep, cut through the Mescal Range.

Darton (*3*, p. 252) described the geology of the immediate region as follows:

> The rocks in the higher parts of the range are mainly pre-Cambrian granite, diorite, and schist, the formations of the Apache group, and the Martin and Tornado limestones. On the flanks are Gila conglomerate, and various Cretaceous and Quaternary volcanic rocks * * *.

According to Ransome (*11*) the Apache group includes the Troy quartzite, a vesicular basalt flow, the Mescal limestone, Dripping Spring quartzite, Barnes conglomerate, Pioneer shale, and Scanlon conglomerate. The Tornado limestone is early Pennsylvanian and Mississippian and the Martin is upper Devonian.

Vegetation.—Range studies of the Gila project by specialists of the Soil Conservation Service disclosed that only a relatively few vegetative types dominate the area. In a recent report Anderson [28] states:

> Several broad vegetative types dominate the area; coniferous forest at the higher elevations, an oak-juniper woodland below, running into oak-chaparral. Below this a mixed browse-grass type with mesquite and catclaw in the canyons and curly mesquite, tobosa, and grama grasses on the ridges. Below this a browse type, either dominated by mesquite and chamiza, or predominantly creosote bush. This type does not extend farther than Red Rock on the Gila, but does cover the Gila Valley proper below Red Rock, and takes in nearly all of the San Simon and San Pedro Valleys.
>
> At the foot of the Mogollon Mountains the oak-chaparral gives way to a grass type composed of curly mesquite, tobosa, and blue, hairy, and black grama grasses. On the Burro and Mule Mountains the chaparral to yellow pine types occur and below Red Rock the browse types predominate.

Erosion conditions.—Several vegetative-type areas, varying in erosion conditions, have been recognized in the progress of range studies in the Gila project. The San Simon Valley is normally a browse and grassland type, but serious gully erosion has reduced the grassland area, so that the valley bottom now supports only small stands of overgrazed grass and saltbush, mesquite, and chamiza. On the ridges creosotebush, mesquite, cactus, and burroweed are common. The Clifton-Duncan area, formerly abused by overgrazing, is severely eroded. It now supports a creosote-tobosa type of vegetation with Indian-wheat and filaree. The Lordsburg Plain is covered by a scattered browse type. Overstocking and drought have placed it in a critical condition.

Severe overgrazing has also been common in the Burro and Mule Mountains where oak-chaparral and yellow pine predominate, and as a result abnormal erosion has developed.

Below the oak-chaparral are the grass areas of Eagle, Mangus, Duck, Mule, and Bear Creeks, and the upper Gila and San Francisco Rivers. A mixed grass type, including tobosa, blue grama, hairy grama, side-oats grama, black grama, and curly mesquite covers this

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[28] ANDERSON, H. L. PROGRESS REPORT TO MAY 1, 1935, FOR RANGE STUDIES, GILA PROJECT. U. S. Dept. Agr., Soil Erosion Serv.

area. Overgrazing has likewise resulted here in the development of gullies on many hillsides.

In the higher altitudes of the Gila headwaters oak-chaparral, juniper, and yellow pine are found. Reduction of stock to prevent ex-

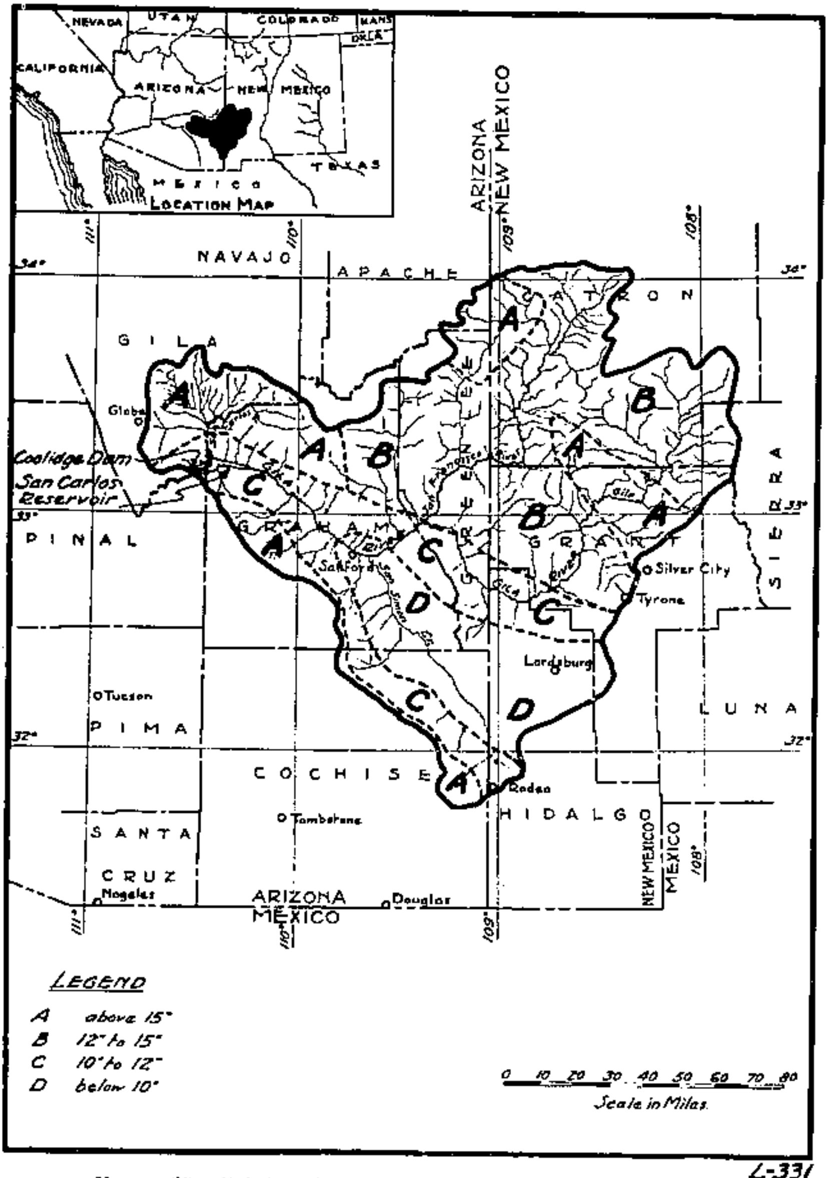

FIGURE 20.—Rainfall distribution in Upper Gila River watershed.

cessive grazing even in this rugged country has recently been urged by Soil Conservation Service specialists.

Mean annual rainfall.—The map in figure 20 shows the distribution of mean annual rainfall in the Gila River watershed. It was compiled from the data of 26 gaging stations by members of the staff of the Gila project. The watershed is divided into four sections as follows:[29]

(1) Below 10 inches; (2) from 10 to 12 inches; (3) from 12 to 15 inches; (4) above 15 inches.

Under the first division (see attached map) is included the San Simon Valley and the Gila River Valley, from the mouth of the San Simon to the town of Pima. The Lordsburg Plain is also included in this division. The total area is about 3,000 square miles, being approximately 30 miles wide and 100 miles long.

Division 2 includes an area which surrounds and is adjacent to the San Simon Valley and Lordsburg Plain; also under this division comes a part of the San Pedro River. This division may be generally described as about 15 miles wide in the San Pedro and Gila Valleys and lying on each side of the two rivers. Where it surrounds the San Simon Valley its width is about 10 miles. The approximate area under this division is 4,000 square miles.

Division 3 includes the largest area of any of the 4 divisions. All of the country which is generally spoken of as the headwaters of the Gila River, is included in this division. In this area is a large part of Greenlee County, Ariz., and Catron and Grant Counties, N. Mex. The approximate area is 7,000 square miles.

Areas where the rainfall is over 15 inches per year and which we are classifying under division 4, are not confined to any one part of the watershed, but include all the areas of higher elevation and are to be found in the extreme southern part of the watershed, as well as in the extreme northern part. Elevation is the controlling factor rather than location. The approximate area under this division is 4,000 square miles.

Inflow.—Of the rain falling on the upper Gila watershed, an average of 25,443 acre-feet per month eventually flows into San Carlos Reservoir. The water-distribution chart, figure 21, however, shows a mean annual fluctuation of inflow over a period of 4 years of 78,250 acre-feet.

Melting snow in the headwaters of both the Gila and San Carlos Rivers swell the streams to torrential proportions in the spring, whereas early summer droughts may reduce the San Carlos to a mere trickle or dry it up entirely.

The reservoir has never been completely filled. The highest stage to date was to elevation 2,471.56, on April 5, 1932, when the reservoir held 469,164 acre-feet of water (fig. 22), less the volume of silt accumulated to that date. This stage was 52 feet below gate level and the unoccupied storage capacity was then 778,835 acre-feet. In other words, the reservoir at maximum storage to date has been about one-third full.

Two periods of maximum inflow normally occur each year, one in the winter months, the other in late summer. Fortunately, these peaks of maximum inflow generally precede or are coincident with the irrigation season, May, June, and July, when the heaviest demands are made on the reservoir, and when the Gila and San Carlos Rivers are frequently lowest. However, the failure of the customary winter rains in 1934 reduced the average inflow of 70,500 acre-feet for the month of February to 7,000 acre-feet. The following irrigation season brought the water-level elevation to the lowest point since the reservoir began filling—2,387 feet above sea level, or only 23 feet above the level of the deposits at the dam. Actual water storage was therefore reduced to 18,134 acre-feet, which is only 7,366 acre-feet more than the dead-storage requirements. During July of

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[29] See footnote 28, p. 101.

that year, evaporation alone was responsible for lowering the water level 3.85 feet.

In view of the uncertainty of periodic rains and the extreme fluctuation of inflow within a year, it is obvious that the coincidence

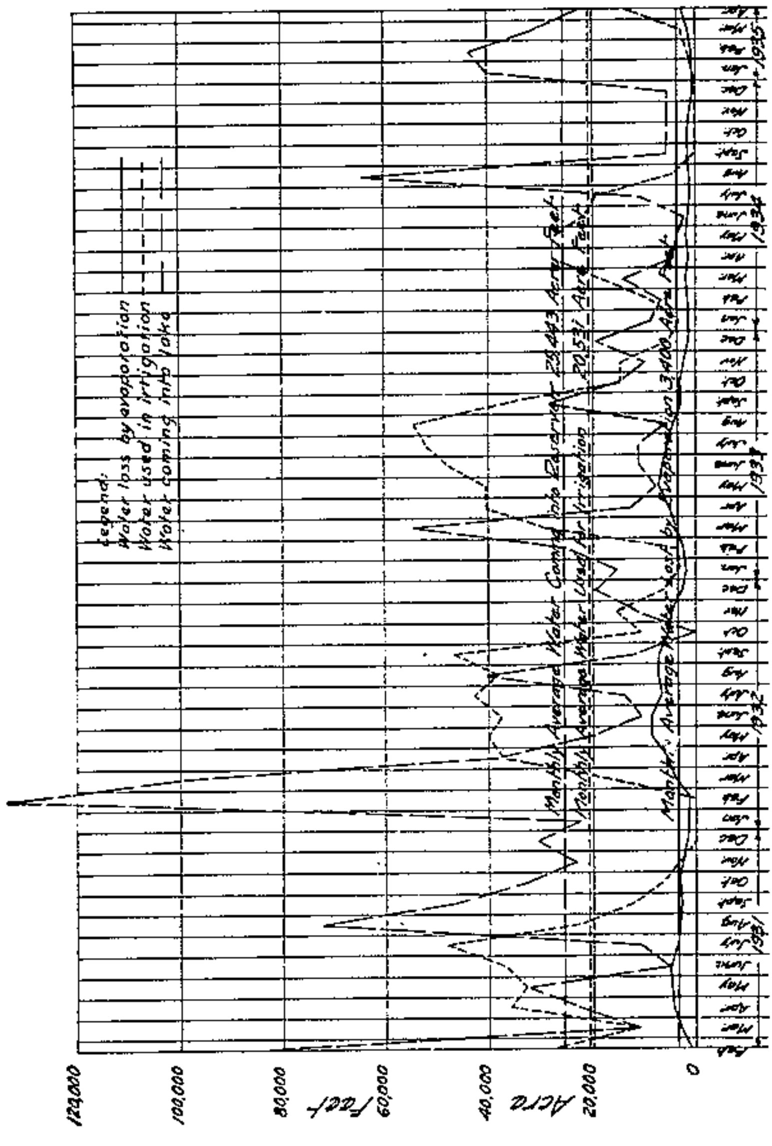


FIGURE 21.—Water-distribution chart derived from 1935 sedimentation survey of San Carlos Reservoir, Coolidge Dam, Ariz.

of the irrigation season with a period of minimum inflow will practically deplete the reservoir's storage, as happened in the spring of 1934, at a season of year when evaporation is also at a maximum.

Evaporation.—Loss of water by evaporation, for the period from February 1931 to April 1935, has amounted to a general monthly mean of 3,400 acre-feet. Periods of maximum evaporation per unit area generally occur in spring and early summer months when strong winds and high temperatures are most frequently combined. Total volume of evaporation depends also upon variations of lake stage and consequent changes in area of exposed water surface.

The effects of these different factors are illustrated in the records of 1932, when the maximum stage in the history of the reservoir was reached in April and was sustained with but little change through the ensuing months by generous inflow. Owing to the exceptional expanse of the lake area the volume of evaporation rose in April to 4,000 acre-feet. The following month, with lake area practically the same, the rate increased to 9,000 acre-feet, the increase being

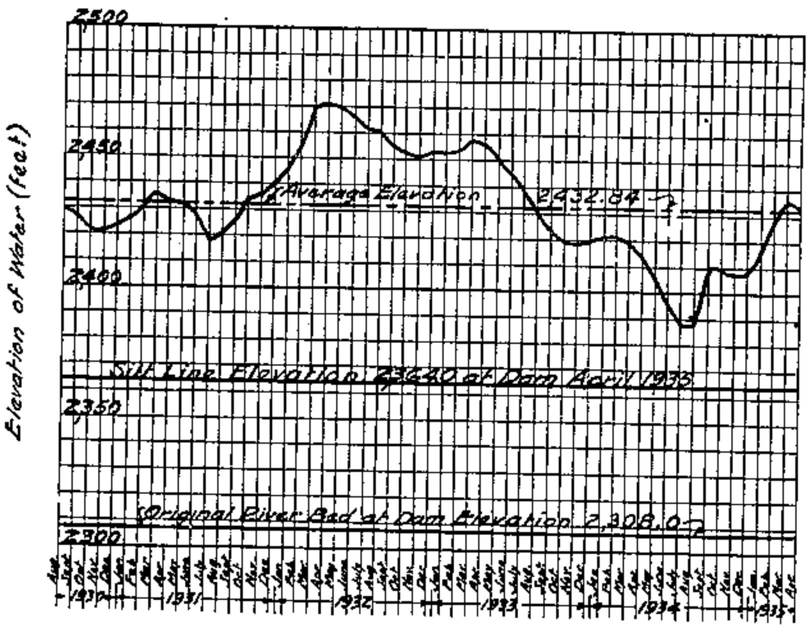


FIGURE 22.—Water-surface elevation chart of San Carlos Reservoir, Coolidge Dam, Ariz., from 1935 sedimentation survey.

attributable entirely to the stronger winds and higher temperatures of the later season. The depths of water represented by these volumes were 0.37 and 0.83 foot, respectively, for the two monthly periods of record.

Power development.—The power plant contains two generating units rated at 6,250 kilovolt-amperes each, and is capable of developing 2,400 kilowatts. The operating head with full reservoir is 207 feet. Under full plant operation the draft is 800 cubic feet per second.

Irrigation draft.—The water-distribution chart in figure 21 shows that the draft for irrigation averages 246,372 acre-feet per year.

HISTORY OF SURVEYS

The sedimentation survey of San Carlos Reservoir was made by the southwestern party under the direction of Raymond C. Becker, chief of party. Field work covered 8½ weeks divided into two periods, January 24 to February 26, and April 16 to May 22, 1935, between which the party was engaged on another assignment.

Field work involved establishing a triangulation net of 31 stations, expanded from 7,300-foot base line, and secondary control by stadia, tied to the triangulation system. In the lower flooded section of the reservoir 40 ranges were established across the lake at intervals of approximately 1,000 feet, along which systematic soundings were taken on top of the sediment deposits.

In the upper reaches of the flooded area contours were mapped on the surface of the sediment deposits from numerous elevations established by accurately located soundings. Location of soundings were obtained by setting up a plane table and a transit on adjacent triangulation stations where with each sounding a direction line could be drawn on the oriented plane table and a bearing read on the transit. Bearings later platted on the plane table established intersections as points of sounding. By use of this system the boat was permitted to move in zigzag lines across the lake until the surface of each lake segment was thoroughly covered with soundings.

In the upper part of the basin above backwater stage at the time of survey, contours were mapped by stadia traverse tied to triangulation stations.

Both the underwater mapping based on sounding and the exposed-surface mapping of this survey were confined to the surface of the sediment deposits and did not extend to the valley walls. The original capacity of the reservoir was determined from the Indian Irrigation Service maps made prior to construction of the reservoir. Contours mapped on the surface of the sediment deposits in 1935 were tied into contours of the old maps along the valley walls. Field checking of the old maps at that date revealed errors and generalizations in the original contours, but it was considered that the task of resurveying the steep and rugged valley walls to spillway contour 2,523.5 was not possible, considering the time and funds then available.

At the request of local agencies a resurvey of the storage capacity of the reservoir up to contour 2,460 was carried out between December 1, 1936, and January 22, 1937, by a field party under the direction of Louis M. Seavy of the Section of Sedimentation Studies. This survey, using the 1935 triangulation system as a base, involved resounding all portions of the reservoir below the then existing water level (about contour 2,395) and plane-table mapping of exposed sediment deposits and valley walls up to contour 2,460. This survey showed considerable differences in areas enclosed by contours above elevation 2,435, the prevailing upper limit of mapping in 1935. These differences, due to errors and generalizations in the original maps, showed that the reservoir capacity below elevation 2,460 was actually greater in January 1937 than it was determined to be in 1935 by the previous survey, which depended on original maps for computations between contours 2,435 and 2,460.

The 1937 survey showed an accumulation of 3,032 acre-feet of sediment below contour 2,395 since 1935. The area below this elevation was completely mapped in both 1935 and 1937, and the results are therefore strictly comparable. Between elevations 2,395 and 2,460 the surface of the sediment deposits at various places was shown either to have changed little or not at all, or to have undergone some scouring action due to the exceptionally low lake level during the entire period between surveys. Inspection and rough checking indicated, however, that the scour between contours 2,395 and 2,460 was probably at least equalled by deposition in the upper reaches of the reservoir basin. Therefore, the net sediment accumulation in the 20 months between surveys is believed to be essentially the 3,032 acre-feet measured below contour 2,395.

It is estimated that the sediment deposits in the reservoir in January 1937 amounted, in round figures, to 40,000 acre-feet.

Sediment Deposits

The deposits that have accumulated below crest level in San Carlos Reservoir comprise a variety of formations, including bottom-set clays in the deeper parts of the flooded basin above the dam, delta and alluvial fan deposits in front of local tributary canyons and dry washes, delta deposits in the Gila and San Carlos Valleys where submergence has occurred, and alluvial deposits in these valleys above levels of past submergence but below the spillway crest level.

The general bottom-set clay deposits have accumulated to a maximum depth of about 45 feet overlying the original channel bottom in the vicinity of the dam, and have formed a remarkably even-surfaced plain, obliterating original irregularities of channel and bottom-land topography, throughout the deeper parts of the lake area. This plain rises gradually upstream but is nearly level from side to side on any given range. On some of the ranges 6,000 to 7,000 feet in length across the silted area, less than 0.5 foot difference in elevation of the sediment surface was recorded. On other ranges the surface of the deposits was found to curve down from the margins toward the center, but in no case did this depression amount to more than 3 feet in the entire width of the section.

This regularity of the sediment surface and increase in depth of sediment toward the dam are undoubtedly due to the phenomenon of tunneling or underflow of heavily sediment-charged flood flows of the Gila and San Carlos Rivers beneath the lighter desilted waters already in storage.

The bottom-set beds are impalpable clays with high colloidal content. Where they have been continuously submerged they have retained a remarkably high water content and were found to be soft and yielding to penetration with the sampling spud. Penetrations of as much as 27 feet of sediment were obtained in the course of the survey.

The deltas and fans in front of directly tributary canyons and dry washes are composed typically of sand and gravel. Some 24 major dry washes enter the reservoir proper from the south and nearly as many from the north above and below the mouth of the San Carlos River. They are typically flat-bottomed, straight-sided troughs, 20 to 100 feet or more in width, floored with loose sand, gravel, or boulders. Their slopes commonly range from 1 to 4 percent. Although floods on these intermittent tributaries are infrequent and of short duration, the streams carry during such periods extraordinary loads of debris which is delivered very rapidly and in large aggregate volume.

The deltas in the main Gila and San Carlos Valleys are composite features, representing successive deposits at various lake levels, subject to subsequent scour and dissection of the higher-level deposits during lower lake stages. The larger delta features are composed mostly of sediment laid down in relatively quiet waters at the head of the lake. In places such deposits are overlain by ridges of sand, particularly in the lee of clumps of trees and bushes or piles of drift, representing sand overwash deposited above lake level by extraordinary river floods.

Similar overbank deposits of silt and sand extend up valley above the usual lake level to the limit of backwater of the highest lake stage that has been reached to date, or approximately to contour 2,475. The processes of valley sedimentation have been accentuated by the general development of a dense growth of vegetation over the flood-plain area. This very effective vegetative screen is made up predominantly of two species, seepwillow (*Baccharis glutinosa*) and saltcedar (*Tamarix gallica*).[30] The form of the valley deposits has been greatly complicated by scour as well as deposition, both the Gila and San Carlos Rivers being of meandering habit and subject to continuous change in channel position in the lower reaches of their valleys above reservoir level.

The surface area, water-storage capacity, and sediment accumulation of the San Carlos Reservoir are indicated in figure 23.

Figure 24 indicates the percentages of sediment below each contour.

A summary of pertinent data relative to San Carlos Reservoir (fig. 25) is contained in the following tabulation:

Summary of data on San Carlos Reservoir, Coolidge Dam, Ariz.

Age[1] ... years	6.33
Watershed area[2] ... square miles	13,540
Reservoir:	
Area at crest stage, original and at date of survey ... acres	18,847
Original storage capacity ... acre-feet	1,247,999
Storage capacity at date of survey ... do	1,211,103
Original storage per square mile of drainage area[2] ... do	92.17
Storage per square mile of drainage area at date of survey[2] ... acre-feet	89.45
Sedimentation:	
Delta deposits ... do	11,896
Bottom-set beds ... do	25,000
Total sediment ... do	36,896
Average annual accumulation ... do	5,829
Annual accumulation per 100 square miles of drainage area ... acre-feet	[3] 43.1
Annual accumulation per acre of drainage area ... cubic feet	[3] 29.36
Or, assuming average weight of 1 cubic foot of deposit is 60 pounds ... tons	[3] 0.88
Depletion of storage:	
Loss of original capacity per year ... percent	0.47
Loss of original capacity to date of survey ... do	2.96

[1] Storage began on Oct. 25, 1928; average date of survey Feb. 25, 1935.
[2] Including area of reservoir.
[3] These figures are revised to exclude the lake area from the total area of the drainage basin. Also, laboratory tests on numerous sediment samples have shown that, in general, the average dry weight of reservoir sediment is closer to 60 than to 100 pounds per cubic foot. Corresponding figures given in the first edition, computed by including the lake area, are 43.05 acre-feet, 29.30 cubic feet, and 1.47 tons, respectively.

[30] Identified by C. J. Whitfield, chief of range studies of the Gila project.

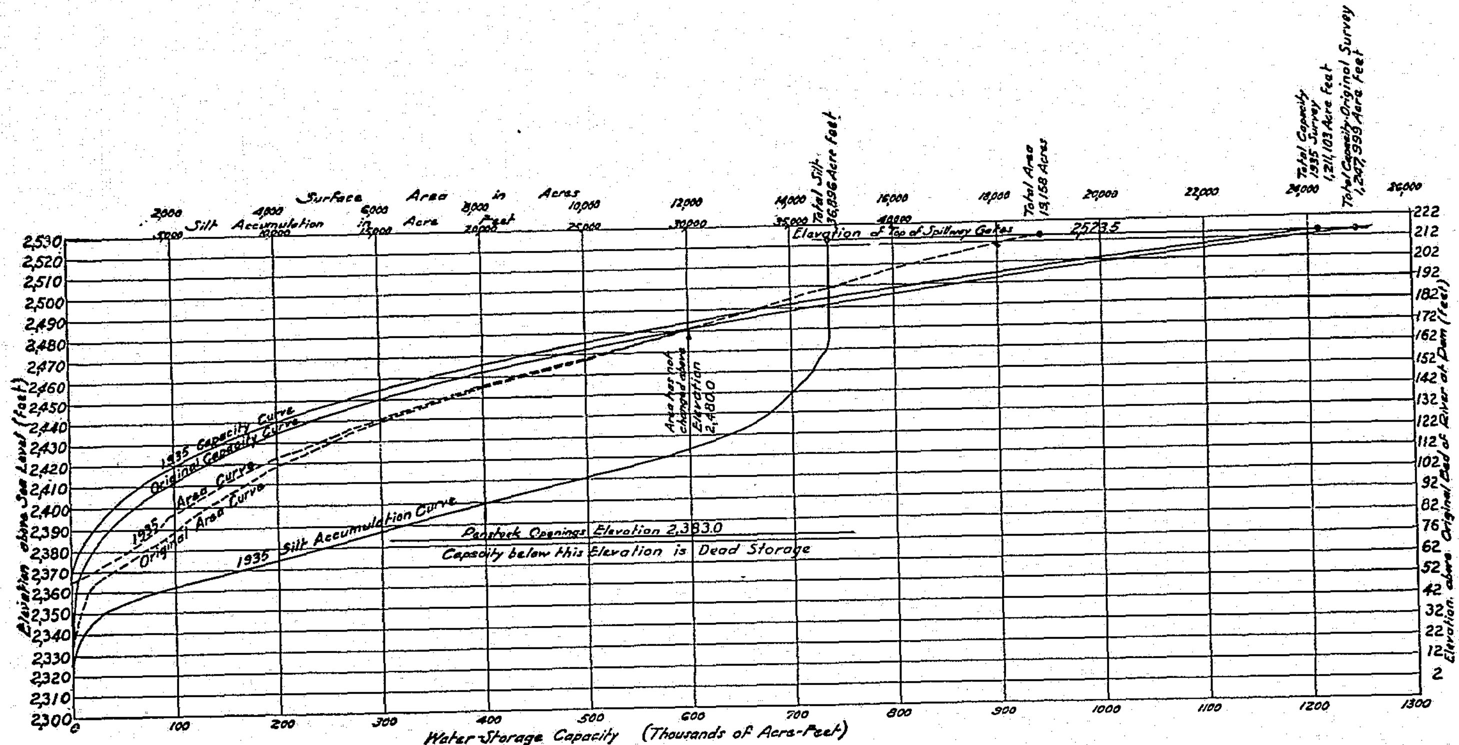


FIGURE 23.—Surface area, water-storage capacity, and sediment-accumulation curves of San Carlos Reservoir, Coolidge Dam, Ariz.

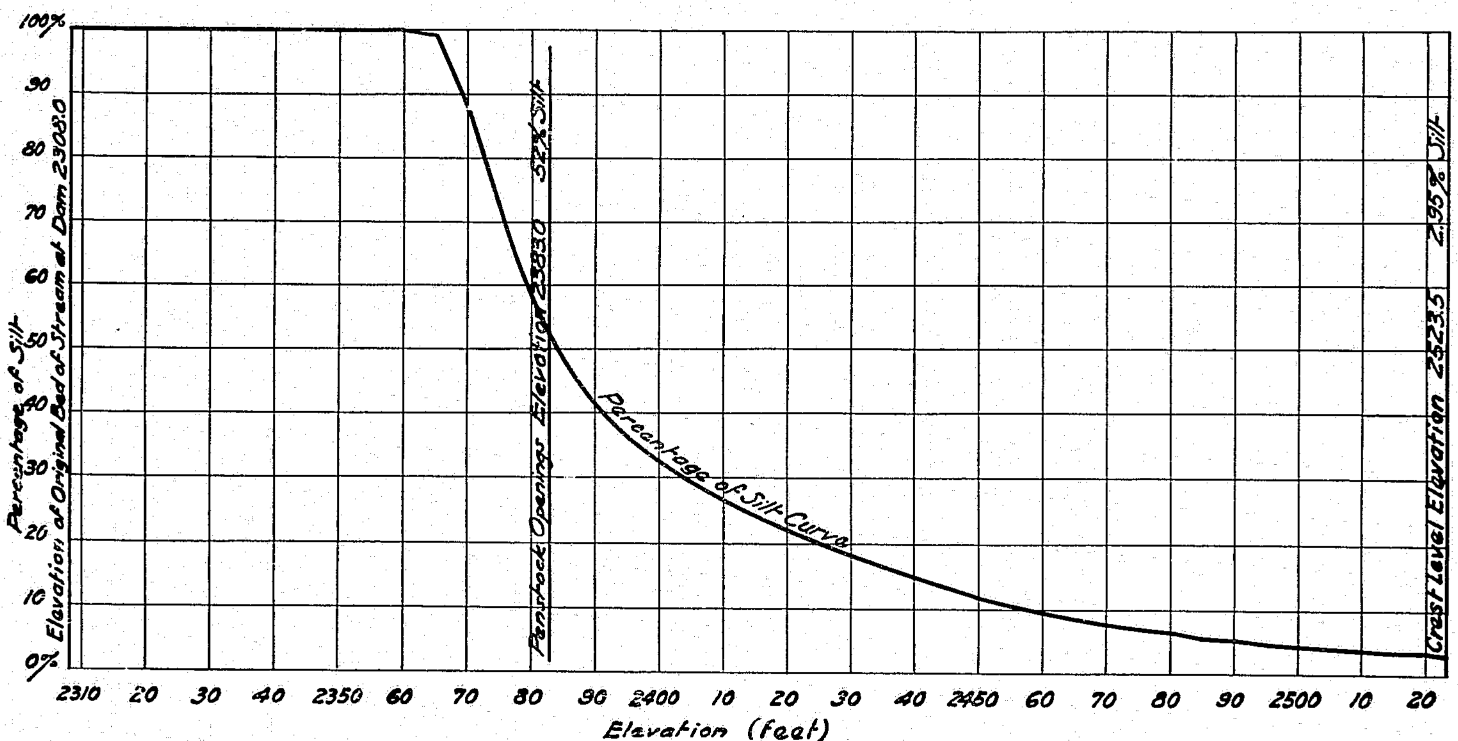


FIGURE 24.—Diagram showing percentage of sediment, June 7, 1935. San Carlos Reservoir, Coolidge Dam, Ariz.

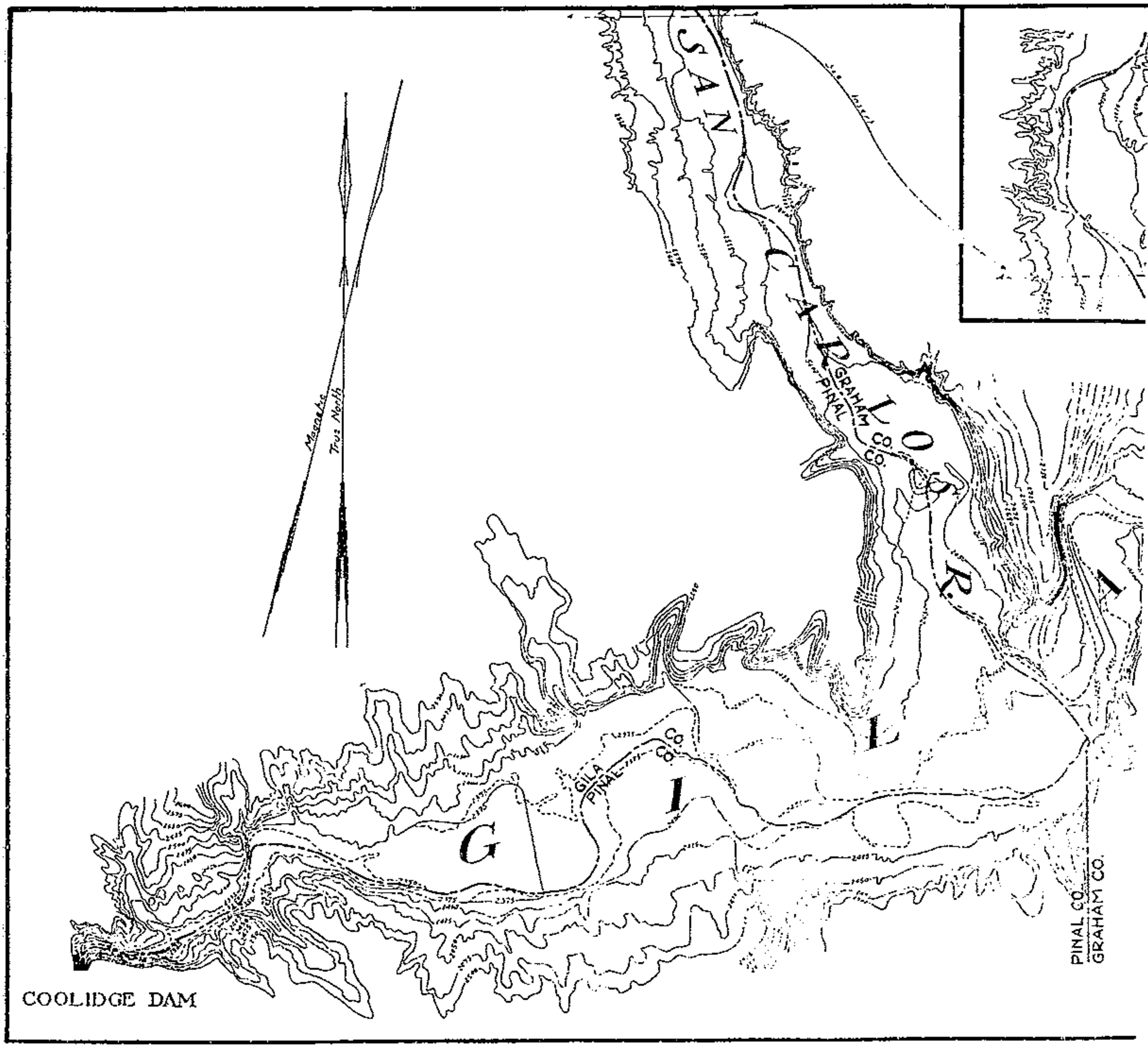

SAN CARLOS R.
GILA
GRAHAM CO.
PINAL CO.
GILA CO.
PINAL CO.
Magnetic
True North
PINAL CO.
GRAHAM CO.
COOLIDGE DAM

FIGURE 2.

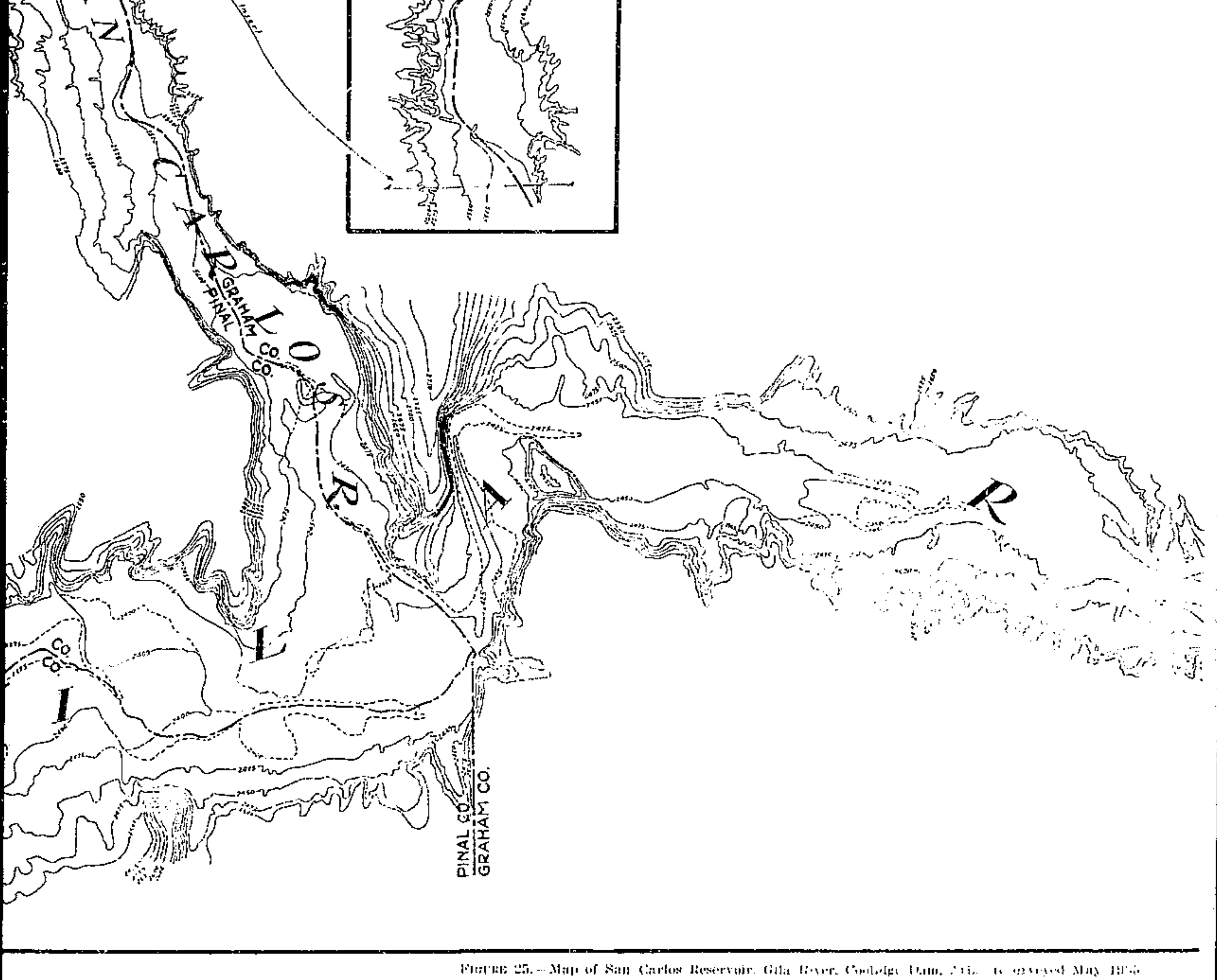
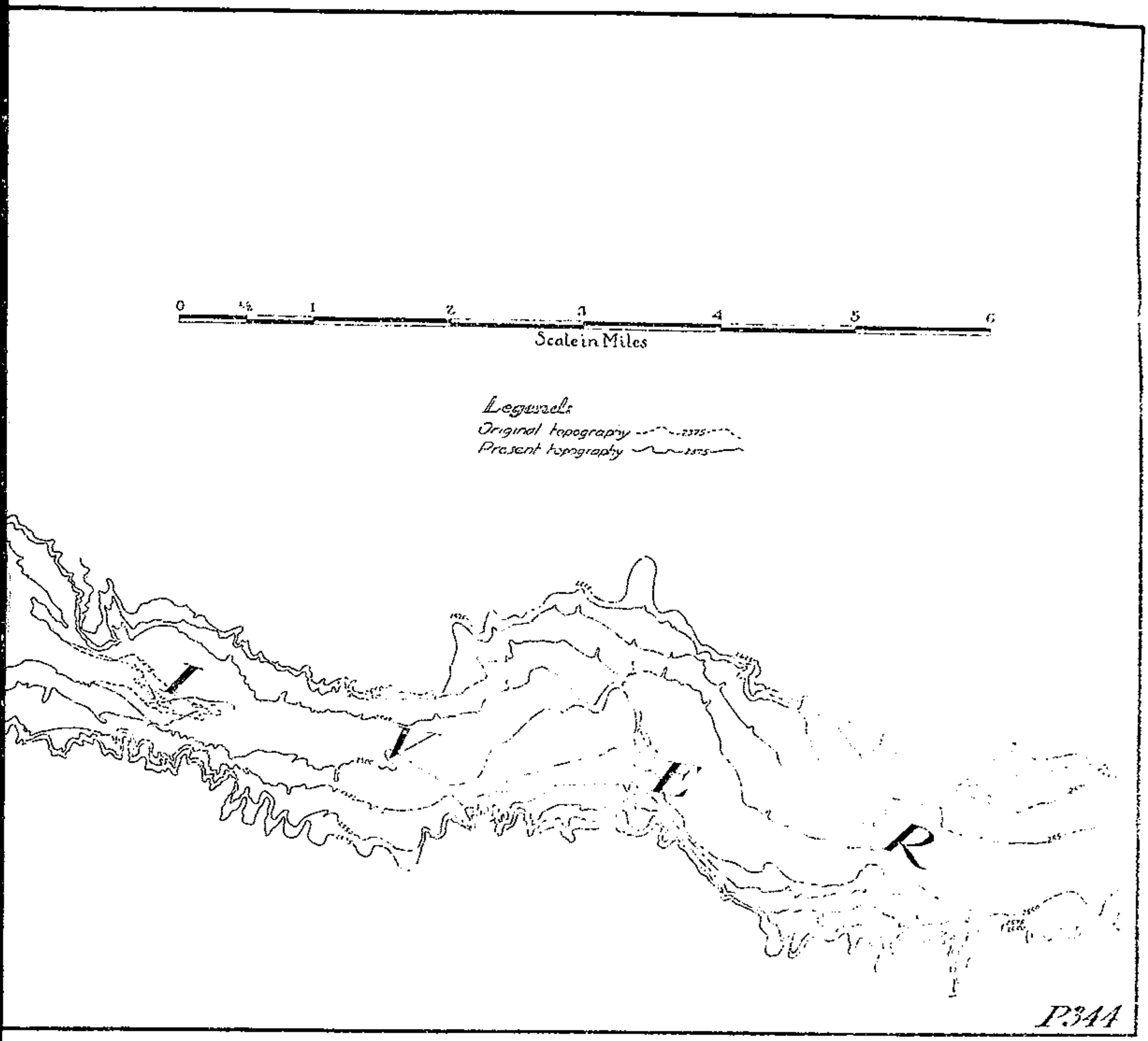


FIGURE 25.—Map of San Carlos Reservoir, Gila River, Coolidge Dam, Ariz. [illegible] surveyed May [illegible]



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HODGES RESERVOIR

Hodges Reservoir is on the San Dieguito River about 20 miles north of San Diego, Calif. It is owned by the city of San Diego and forms an important part of the municipal water-supply system. In addition about one-third of the water is used to irrigate the lower San Dieguito Valley.

The dam is a multiple-arch concrete structure 750 feet long and 130 feet in height above the stream bed. The spillway is 343 feet long and 115 feet above stream bed, or 315 feet above sea level. At the time storage began early in 1919 the lake area at crest stage was 1,368 acres and the storage capacity was 37,450 acre-feet, but at the time of survey in 1935 silting had reduced the area to 1,248 acres, a loss of 120 acres, and the capacity to 35,628 acre-feet.

The drainage basin, 303 square miles in area, is characterized by steep-sided but locally wide valleys cut into a more gently sloping upland on granitic rocks. These rocks weather to loose granitic soils that erode seriously when denuded of vegetative cover by fire or put under cultivation. About 15 to 20 percent of the area is cultivated, and the remainder is chaparral-covered slopes and bottom-land pasture. Considerable gullying has occurred on sloping land near the reservoir. The average annual rainfall over the watershed is about 22 inches.

The sedimentation survey of Hodges Reservoir, made during the period July 8 to July 30, 1935, revealed a 16½-year accumulation of 1,822 acre-feet of sediment. More than 80 percent of the sediment is coarse granitic sand lying within 25 feet of crest level near the head of the reservoir. The balance is made up of fine dark silt and clay deposits in the lower part of the basin. The exceptionally high proportion of coarse sediment in the reservoir deposits is apparently the result of (1) the predominance of coarse material in the watershed soils, and (2) a combination of steep slopes and high run-off which results in both coarse and fine components being carried rapidly to the reservoir with little sorting.

The quantitative results of the survey of Hodges Reservoir are summarized in the following tabulation:

Summary of data on Hodges Reservoir, San Diego, Calif.

Age[1] ……years	16.5
Watershed area[2] ……square miles	303
Reservoir:	
Original area at crest stage ……acres	1,368
Area at crest stage at date of survey ……do	1,248
Original storage capacity ……acre-feet	37,450
Storage capacity at date of survey ……do	35,628
Original storage per square mile of drainage area[2] ……do	123.60
Storage per square mile of drainage area[2] at date of survey ……do	117.58
Sedimentation:	
Total sediment ……do	1,822
Average annual accumulation ……do	110
Annual accumulation per 100 square miles of drainage area[3] ……do	36.7
Annual accumulation per acre of drainage area[3] ……cubic feet	24.97
Or, assuming 1 cubic foot of deposit weighs 60 pounds ……tons	0.75
Depletion of storage:	
Loss of original capacity per year ……percent	0.29
Loss of original capacity to date of survey ……do	4.87

[1] Storage began: January 1919; average date of survey, July 1935.
[2] Including area of reservoir.
[3] Excluding area of reservoir.

MORENA RESERVOIR

Morena Reservoir is on Cottonwood Creek, 35 miles east of San Diego, Calif. It is owned by the city of San Diego and serves as a reserve storage unit of the municipal water-supply system.

The dam is a loose rock-fill structure with masonry water face and an independent concrete spillway. The spillway was 146 feet above stream bed at the time of construction in 1910, but in 1923 it was raised to its present height of 155 feet. Crest level, determined by the tops of 7½-foot steel flashgates, is 162.5 feet above stream bed, or 3,044.9 feet above mean sea level. When storage began in 1910 the lake area at the present crest level would have been 1,687 acres and the storage capacity 68,388 acre-feet, but at the time of the survey in 1935 silting had reduced the area at this level to 1,669 acres, a loss of 18 acres, and the capacity to 61,204 acre-feet.

The drainage area embraces 112 square miles of rough mountainous country, characterized by highly erodible granitic soils on the slopes and deep unconsolidated alluvial deposits in many of the valleys. These alluvial deposits are highly susceptible to erosion, and deep gullying or trenching has occurred wherever the protective grass cover has been impaired by overgrazing. Over most of the area the slope soils are protected by a good vegetative cover, chiefly chaparral, but in local burned-over areas gullying and sheet erosion are severe. The mean annual rainfall ranges from 22 inches at the dam to 30 inches in the high mountains.

The sedimentation survey of Morena Reservoir, made during the period October 25 to December 31, 1935, revealed a 26-year accumulation of 7,184 acre-feet of sediment, one-third of which consisted of fine dark-gray to brown silt and clay and was distributed over the entire lake basin but tended to increase in thickness toward the dam. The remaining two-thirds consisted of coarse sandy deposits accumulated to maximum depths of 30 feet or more at the heads of the principal arms. Delta deposits had shortened the length of the Cottonwood arm by nearly half a mile at the time of the survey.

The average sediment depth increases gradually from less than 2 feet just below the deltas to 10 feet at the dam. The surface of the deposit in the lower mile of reservoir is remarkably level, being nearly flat in cross section and having a downstream slope of less than 0.2 percent. This distribution, characterized by a concentration of sediment toward the dam, is strikingly similar, on a smaller scale, to that found in Elephant Butte and San Carlos Reservoirs and suggests that here, as in those reservoirs, underflow may be an important factor influencing the distribution of reservoir sediment.

The quantitative results of the survey of Morena Reservoir are summarized in the following tabulation:

Summary of data on Morena Reservoir, San Diego County, Calif.

Age [1]	years	25.7
Watershed area [2]	square miles	112.0
Reservoir:		
Original (1910) area at present crest level	acres	1,687
Area at crest stage at date of survey	do	1,669
Original (1910) storage capacity to present crest level	acre-feet	68,388
Storage capacity to crest level at date of survey	do	61,204

See footnotes at end of summary.

Reservoir—Continued.	
Original storage to present crest per square mile of drainage area [2] ....acre-feet..	610.61
Storage per square mile of drainage area at date of survey [2]..do....	546.46
Sedimentation:	
Total sediment........do....	7,184
Delta deposits........do....	4,538
Bottom-set beds........do....	2,646
Average annual accumulation........do....	280
Annual accumulation per 100 square miles of drainage area [3]..do....	256
Annual accumulation per acre of drainage area [3]........cubic feet..	173.91
Or, assuming 1 cubic foot of deposit weighs 60 pounds..tons....	5.22
Depletion of storage:	
Loss of original capacity per year........percent..	0.41
Loss of original capacity to date of survey........do....	10.50

[1] Storage began March 1910; average date of survey, December 1935.
[2] Including area of reservoir.
[3] Excluding area of reservoir.

GIBRALTAR RESERVOIR

Gibraltar Reservoir is on the Santa Ynez River 4 miles north of Santa Barbara, Calif. It is owned by the city of Santa Barbara and forms an important part of the municipal water-supply system.

The dam is an arch-type concrete structure 984 feet long and 157 feet in height above stream bed. The spillway crest is 147 feet above stream bed and 1,355 feet above sea level. At the time of construction in 1920 the lake area at crest stage was 325 acres and the storage capacity was 14,500 acre-feet, but at the time of the 1936 survey silting had reduced the area to 256 acres, a loss of 69 acres, and the capacity to 10,186 acre-feet. Results of surveys made in 1925, 1931, and 1934 by the city of Santa Barbara are given on page 15.

The drainage basin above Gibraltar Dam embraces 215.4 square miles of steep, mountainous country characterized by loose, friable soils, developed chiefly from easily weathered shales and sandstones, which are highly susceptible to sheet wash. Erosion has been aggravated by forest fires, which have denuded more than 80 percent of the normally chaparral-covered watershed since 1922. The mean annual rainfall is 22.14 inches.

The 1936 survey, made during the period April 1 to May 9, revealed a total deposit of 4.314 acre-feet of sediment accumulated in the 16-year period since completion of the dam in 1920, of which 470 acre-feet had been deposited since the 1934 survey. The sediment ranged in texture from fine silt and clay near the dam through coarse silt to sand at the upper end.

The distribution of the sediment was characterized by gradual increase in thickness both ways from a point midway from the dam to the upper end; downstream to the dam as a result of underflow, and upstream to crest level through progressively coarser delta deposits. Sediment thickness over the channel was 74 feet near the dam, 22 feet at midlength, and 40 feet in the main delta.

Shortly after the flood of March 2, 1938, a few well-distributed soundings were taken in Gibraltar Reservoir to determine in a general way the changes in the topography on the sediment surface since the 1936 survey. These soundings were plotted on the detailed map of the 1936 survey, and from them approximate contours showing changes in topography were drawn. From these contours it was calculated that 1,269 acre-feet of sediment, equal to 8.75 percent of the original capacity, had been deposited since the 1936 survey. It is believed that most of this accumulation took place during the flood of March 2, 1938. Based on this approximate figure, the total volume of sediment in 1938 was 5,582 acre-feet, which represents a total capacity loss of 38.5 percent.

The quantitative results of the 1936 survey of Gibraltar Reservoir are summarized in the following tabulation:

Summary of data on Gibraltar Reservoir, Santa Barbara County, Calif.

Age [1] ... years	16.25
Watershed area [2] ... square miles	215.4
Reservoir:	
Original area at crest stage ... acres	325
Area at crest stage at date of survey ... do	256
Original storage capacity to crest level ... acre-feet	[3] 14,500
Storage capacity to crest level at date of survey ... do	10,186
Original storage per square mile of drainage area [2] ... do	67.32
Storage per square mile of drainage area at time of survey [2] ... do	47.29
Sedimentation:	
Total sediment ... do	4,314
Average annual accumulation ... do	265
Annual accumulation per 100 square miles of drainage area [4] ... do	124
Annual accumulation per acre of drainage area [4] ... cubic feet	84.08
Or, assuming 1 cubic foot of sediment weighs 60 pounds ... tons	2.52
Depletion of storage:	
Loss of original capacity per year ... percent	1.83
Loss of original capacity to date of survey ... do	29.75

[1] Storage began in January 1920; average date of survey, April 1936.
[2] Including area of reservoir. The effective watershed area was reduced to about 200 square miles in 1930 by the construction of Juncal Reservoir upstream on the Santa Ynez River. However, as this reduction was in effect during only 6 of the total 16 years of storage, the drainage area above Juncal Dam was included in all computations.
[3] Approximate figure based on original survey by city of Santa Barbara.
[4] Excluding area of reservoir.

UPPER CRYSTAL SPRINGS RESERVOIR

Upper Crystal Springs Reservoir is on Laguna Creek, about 5 miles south of San Mateo, Calif., on the southwest side of San Francisco Bay. It is owned jointly by San Francisco County and the city of San Francisco, and forms an important part of the municipal water-supply system.

The reservoir is impounded by a rolled-earth-fill dam with a puddled core wall and a concrete-lined tunnel spillway. The dam is 520 feet long and 92 feet in maximum height above the stream bed. The spillway is 58 feet above the stream bed and 258 feet above mean sea level. At the time of construction, in 1877, the lake area at crest stage was about 800 acres and the storage capacity was 29.138 acre-feet. At the time of survey in 1935 the lake area was the same, but the capacity had been reduced by silting to 28.159 acre-feet.

The drainage basin, 9 square miles in area, lies entirely within the trough of the San Andreas fault, characterized by many approximately parallel small ridges and hollows. The slopes are steep and rounded and are generally covered with fine-textured highly absorptive soils. About half of the area is woodland and the remainder is grassland. The entire area, which is controlled by the city and county, is closed to grazing and cultivation. Some sheet erosion and minor gullying occur on the limited upland areas where the soil is coarse and the vegetation is sparse, but in the area as a whole erosion appears to be slight.

In October 1934, one year prior to the sedimentation survey, water from the Hetch Hetchy Reservoir on the Tuolumne River was diverted by pipe-line into Upper Crystal Springs Reservoir and is adding about 45 million gallons daily, or about 50,400 acre-feet per year. This is equal to about 25 times the natural inflow (estimated at 2,300 acre-feet per year). No information on the amount of sediment that may be entering the reservoir through the pipe line is available, but, as the pipe line had been in operation during only 1 of the 58 years of storage preceding the 1935 survey, its effect on the average rate of silting for the period was at most very slight.

The sedimentation survey made in October 1935 revealed a 58-year accumulation of 979 acre-feet of sediment, consisting predominantly of fine silt and clay but including some coarse silt and sand near the prevailing head of backwater (12 feet below spillway crest).

The average sediment depth on successive cross sections increased almost uniformly from a few tenths of a foot 2 miles above the dam—or about one-fourth mile below the crest-stage head of backwater—to more than 3 feet one-fourth mile above the dam. Very little sediment was found immediately above the dam.

The average annual accumulation amounted to more than 2 acre-feet per square mile of drainage area (217 acre-feet per 100 square miles), which is large in comparison with drainage areas of other reservoirs on which similar studies have been made—this despite the generally well-vegetated condition of the drainage area. Two factors may account, at least in part, for the high rate thus indicated: (1) Little sediment is deposited in the watershed above the reservoir, and (2) the extremely large capacity-inflow ratio indicates unusually complete desilting of all inflow. The rate of storage depletion, on the other hand, is extremely low, amounting to only 0.06 percent of the original capacity per year. This low rate is attributed to the exceptionally large capacity-inflow ratio.

The quantitative results of the 1935 survey of Upper Crystal Springs Reservoir are summarized in the following tabulation:

Summary of data on Upper Crystal Springs Reservoir, San Mateo County, Calif.

Age [1]	years	57.8
Watershed area [2]	square miles	9
Reservoir:		
Area at spillway stage (original and at date of survey)	acres	799
Original storage capacity to spillway level	acre-feet	29,138
Storage capacity at date of survey	do	28,159
Original storage per square mile of drainage area [2]	do	3,237.56
Storage per square mile at date of survey	do	3,128.78
Sedimentation:		
Total sediment	do	979
Delta deposits	do	57
Bottom-set beds	do	922
Average annual accumulation	do	16.9
Annual accumulation per 100 square miles of drainage area [2]	acre-feet	217
Annual accumulation per acre of drainage area [2]	cubic feet	147.76
	tons [4]	4.43

See footnotes at end of summary.

Depletion of storage:	
Loss of original capacity per year .... percent ..	0.06
Loss of original capacity to date of survey .... do	3.36

[1] Storage began January 1878; average date of survey, October 1935.
[2] Including area of reservoir.
[3] Excluding area of reservoir.
[4] Based on an assumed average dry weight of 60 pounds per cubic foot.

UPPER SAN LEANDRO RESERVOIR

Upper San Leandro Reservoir is on San Leandro Creek about 8 miles southeast of Oakland, Calif., and 2 miles above Lake Chabot. It is owned by the East Bay Municipal Utility District and serves as a domestic water supply for the metropolitan area around Oakland.

The reservoir is impounded by a hydraulic-earth-fill dam whose crest is 656 feet long and 190 feet above the stream bed. A concrete spillway around the southeast end of the fill is 170 feet above stream bed and 460 feet above mean sea level. A bypass tunnel 9 feet in diameter under the spillway permits complete draw-down of the reservoir to fill Lake Chabot below. Water enters the distributing system directly through a tunnel from an outlet tower in the Redwood Creek arm about 2 miles above the dam. At spillway stage backwater extends about 5 miles up San Leandro Creek from the dam and for distances ranging from 1,600 to 9,000 feet up six tributary arms.

When storage began in March 1927 the area of the reservoir at spillway stage was 771 acres and the storage capacity was 43,460 acre-feet. At the time of survey in August 1935 silting had not changed the area but had reduced the capacity to 43,290 acre-feet.

The drainage basin, 30.3 square miles in area, has extremely rugged topography, characterized by V-shaped valleys separating narrow ridges with steep sides and rounded summits. It is underlain largely by shales, sandstones, and associated thin-bedded limestones and cherts ranging in age from Jurassic to Tertiary, and to a lesser extent by Pliocene volcanic rocks. The soils are predominantly fine-textured dark-gray to black compact clays, but include some lighter sandy soils. The area is about 50 percent in range, 30 percent cultivated, and 20 percent wooded. There is practically no gullying, but moderate sheet erosion has occurred on some overgrazed slopes and in the cultivated areas, chiefly orchards.

A sedimentation survey [31] of the reservoir, made in August 1935 by the Soil Conservation Service, revealed an 8.4-year accumulation of 170 acre-feet of sediment, consisting entirely of fine dark-gray sticky silt and clay. The deposits were confined to the lower levels of the basin and had a maximum depth of 6 feet near the dam, from which they gradually thinned out upstream within a distance of 2 miles.

[31] This survey involved remapping the reservoir basin with 10-foot contours for comparison with the original topography. The resurvey revealed errors in the original map—above the silted area—which account for an original capacity figure of 41,461 acre-feet, previously computed from these maps, instead of 43,460 acre-feet as determined by the resurvey. This discrepancy was probably due to generalization of contours on the original map, which was drawn in the office from transit notes. In the lower part of the basin—where all the measurable deposits in the reservoir are concentrated—determinations of the elevation of the original bottom, by direct measurement of the sediment thickness at selected points, showed the original map to be sufficiently accurate to warrant its use in determining the volume of sediment accumulated between the two surveys.

The average annual accumulation amounted to about ⅔ acre-foot for each square mile of drainage area (69.5 acre-feet per 100 square miles) but to only 0.05 percent of the original capacity. This exceptionally low rate of storage depletion is believed to be due mainly to the very large capacity-inflow ratio.

The quantitative results of the 1935 survey are summarized in the following tabulation:

Summary of data on Upper San Leandro Reservoir, Oakland, Calif.

Age[1]	years	8.4
Watershed area[2]	square miles	30.3
Reservoir:		
Area at spillway stage (original and at date of survey)	acres	771
Original storage capacity to spillway level	acre-feet	43,460
Storage capacity at date of survey	do	43,290
Original storage per square mile of drainage area[2]	acre-feet	1,434.32
Storage per square mile of drainage area[2] at date of survey	do	1,428.71
Sedimentation:		
Total sediment	acre-feet	170
Average annual accumulation	do	20.2
Annual accumulation per 100 square miles of drainage area[3]	acre-feet	69.5
Annual accumulation per acre of drainage area[3]	cubic feet	47.35
	tons[4]	1.42
Depletion of storage:		
Loss of original capacity per year	percent	0.05
Loss of original capacity to date of survey	do	0.39

[1] Storage began in March 1927; average date of survey, August 1935.
[2] Including area of reservoir.
[3] Excluding area of reservoir.
[4] Based on an assumed average dry weight of 60 pounds per cubic foot.

ORIGINAL CAPACITY SURVEY OF LAKE MEAD

Lake Mead, created by Boulder Dam and situated in the upper Black Canyon of the Colorado River at the Arizona-Nevada State boundary 25 miles by air southeast of Las Vegas, Nev., is by far the largest and most important completed water-storage development in the world. The dam itself rises 726 feet in maximum height from foundation rock to the roadway on its crest and contains somewhat more than 3,000,000 cubic yards of concrete. The water in the reservoir at full stage will stand 584 feet higher than the original river level, forming a lake 115 miles long, with a surface area of 230 square miles and a volume of some 30,500,000 acre-feet of stored water.

The immense storage of the reservoir has been created at a direct cost of about $2.50 per acre-foot for the dam structure and flowage rights. Appurtenant developments of power plant and the All-American Canal will bring the total Federal outlay to about $165,000,000. Water and power facilities of the metropolitan district of Los Angeles will comprise an added investment of some $240,000,000. The ultimate economic values dependent upon conservation of water-storage capacity in the reservoir will include not only these major initial investments but also vast cooperative and private-property values represented in water-supply and power-distribution facilities, industrial establishments, and the homesteads, plantings, and general improvements of immense areas of irrigated land, easily running in all to a billion dollars or more.

In order to have an accurate factual basis for future planning of policy and practice with respect to conservation of these immense resources against loss due to silting, it will be necessary to determine the actual volumes of erosional debris produced in the watershed and destined, in the absence of adequate protective measures, to find lodgment within the original reservoir cavity. To make these determinations by future resurveys of the reservoir it was essential to have an accurate detailed survey of the reservoir basin in its original condition. To this end the Soil Conservation Service, in cooperation with the Bureau of Reclamation and the Coast and Geodetic Survey, undertook the work of mapping in greatest detail the topography of the 230 square miles to be inundated behind Boulder Dam.

The map has been made on a horizontal scale of 1,000 feet to the inch, which gives an assembled map somewhat more than 50 feet in length. This has been prepared for reproduction as a folio of individual sheets, each 30 inches square. Contour intervals of 10 feet for areas of stronger relief and 5 feet for flatter river bottoms and alluvial slopes have been used.

Horizontal and vertical control were based upon first-order triangulation and traverse systems of the Coast and Geodetic Survey, supplemented by special second- and third-order expansions into intervening territory as necessary to extend accurate control to every section of the area.

The contouring of the more rugged areas of the basin was done by stereoplanigraph from the complete set of aerial photographs taken before the reservoir had filled to any material extent. As a further check on contour form, aerial photographic traverses of shore lines were made with each 20-foot rise in reservoir stage during the first year of filling. As an aid to accurate use of the shore-line photographic data, systematic observations of variations of water level under variable conditions of discharge and wind were maintained for an extended period at four stations: At the dam, at the upper end of Boulder Canyon, at Greggs Ferry, and at Pierces Ferry.

For detailed mapping of the Colorado River channel and valley bottom a method of sounding in the advancing head of the reservoir was adopted. Under this method horizontal control, for locating ranges and cut-in stations used in sounding operations, was taken from the aerial photographs covering the river and adjacent topography. Vertical control was afforded by water-surface elevation determined from hour to hour at the four observation stations mentioned.

Detailed contouring of the flatter upland valleys and slopes of the Virgin River and Muddy Creek arms of the reservoir was done by usual land-survey methods by United States Bureau of Reclamation personnel temporarily assigned to the project. In this work control was extended from Coast and Geodetic Survey stations by transit and level traverse, and contouring was done by plane-table and stadia survey. Monumented stations of the local plane-table survey were tied in to both the primary and secondary systems of control that extend over the reservoir region as a whole.

As indicated by the foregoing description of methods and standards of work the general project of mapping Lake Mead has been designed to leave nothing undone that could contribute to practical development of a most refined and accurate record of its original form and capacity. Future surveys made from time to time with similar accuracy will show precisely the topographic changes that will result from continuous deposition of sediment. From these changes in topography the actual volumes of erosional debris delivered from the watershed area in definite periods can be computed. It is only upon the basis of such information as to actual rates of storage depletion, coupled with accurate knowledge of erosion conditions throughout the drainage basin, that future conservation policy and practice of erosion and sediment control can be properly planned.

GENERAL SUMMARY OF RESULTS OF THE 1934–38 SURVEYS

Table 13 is a summary of the most significant statistical information from the detailed reservoir surveys completed to July 1, 1938. It brings together the quantitative data essential for analyzing silting rates as a reflection of erosional debris productivity in various geographic subdivisions of the country:

TABLE 13.—*Reservoirs surveyed by the Soil Conservation Service, 1934–38*

Region, use, and name	Location	Age at time of survey	Original capacity	Sediment volume at date of survey	Area of watershed [1]	Sediment accumulation per acre per year	Dry weight of sediment per cubic foot	Sediment accumulation per acre per year [2]	Original storage per square mile of drainage area	Annual sediment accumulation per 100 square miles of drainage area [3]	Annual depletion of storage	Total depletion of storage to date of survey
Southeastern States:												
Water Supply:		*Years*	*Acre-feet*	*Acre-feet*	*Square miles*	*Cubic feet*	*Pounds*	*Tons*	*Acre-feet*	*Acre-feet*	*Percent*	*Percent*
Barcroft Reservoir [4]	Alexandria, Va.	23.1	1,847	85	14.5	17.49		0.52	127.38	25.7	0.20	4.60
Bayview Reservoir [5]	Birmingham, Ala.	24.6	11,866	2,352	72.3	90.95		2.73	164.11	134	.81	19.82
Burlington Reservoir [6]	Burlington, N. C.	10	1,488	163	105.2	10.57	63	.33	14.14	15.5	1.10	10.95
Burnt Mills Reservoir [7]	Silver Spring, Md.	7.8	170	79	27.0	25.53		.77	6.30	37.5	5.96	46.47
Franklinton Reservoir [8]	Franklinton, N. C.	13.33	34.7	7.4	1.13	34.57	67	1.16	30.71	50.9	1.60	21.33
Greensboro Reservoir	Greensboro, N. C.	11.5	2,870	260	74.1	22.46		.67	38.86	32.3	.79	9.06
High Point Reservoir	High Point, N. C.	6.5	4,354	247	62.8	41.51	50.6	1.05	69.33	61.0	.87	5.67
High Point Res. (1938 resurvey).	do.	10.25	4,354	316	62.8	33.68	50.6	.85	69.33	49.5	.71	7.26
Lake Concord	Kannapolis, N. C.	10.2	1,201	79	4.7	117.14		3.51	255.53	172	.65	6.59
Lake Harris [9]	Tuscaloosa, Ala.	6.75	2,421	48	30.0	16.26		.49	80.70	23.9	.29	1.98
Lake Lee	Monroe, N. C.	11.1	821	169	50.5	20.59	61.8	.64	16.26	30.3	1.85	20.58
Lake Michie	Durham, N. C.	8.75	12,671	395	167.5	18.43		.55	75.65	27.1	.36	3.12
Lake Purdy [10]	Birmingham, Ala.	25.2	19,080	486	41.74	32.64		.98	457.12	48.0	.10	2.55
Lancaster Reservoir	Lancaster, S. C.	13.4	242	52	9.4	28.27		.85	25.74	41.7	1.60	21.49
Spartanburg Reservoir	Spartanburg, S. C.	8.2	2,700	463	91.0	42.23		1.27	29.67	62.0	2.09	17.15
University Lake	Chapel Hill, N. C.	2.9	1,915	64	30.6	49.23		1.48	62.58	72.3	1.14	3.34
Power Development:												
High Rock Reservoir [11]	Salisbury, N. C.	7.8	289,432	13,916	3,930	31.10		.93	73.65	45.7	.62	4.81
Lay Reservoir [12]	Sylacauga, Ala.	22.3	156,525	18,005	9,087	6.05		.18	17.23	8.9	.52	11.50
Lloyd Shoals Reservoir	Jackson, Ga.	24.3	112,538	13,960	1,414	27.76		.83	79.59	40.8	.51	12.40
New River Reservoirs [13]		33.5	13,255	8,155	1,320	12.56		.38	10.04	18.5	1.84	61.52
Buck Reservoir	Ivanhoe, Va.	23.7	1,225	284							.98	23.18
Byllesby Reservoir	Byllesby, Va.	23.7	8,892	5,354							2.54	60.21
Fields Reservoir	Mouth of Wilson, Va.	5.7	184	75							7.15	40.76
Washington Mills Reservoir.	Fries, Va.	33.5	2,954	2,443							2.47	82.69
Recreation:												
Greenbelt Lake [14]	Greenbelt, Md.	1.6	196	10	.83	538.04		16.14	236.14	791	3.19	5.10
South Central States:												
Water Supply:												
Boomer Lake	Stillwater, Okla.	10.25	2,812	171	9.13	130.91		3.93	307.99	192	.59	6.08
Clinton Reservoir	Clinton, Okla.	7.4	4,415	434	23.0	177.57	63.36	5.63	191.96	261	1.33	9.83
Grand Saline Reservoir	Grand Saline, Tex.	13.25	531	22	2.12	55.94		1.68	250.47	82.2	.31	4.14
Guthrie Reservoir	Guthrie, Okla.	14.5	3,064	456	13.3	164.65		4.94	230.38	242	1.03	14.88
Lake Booneville [15]	Booneville, Ark.	6.7	289	8	2.6	31.58		.95	111.15	46.0	.40	2.77
Lake Crook [16]	Paris, Tex.	13.1	11,487	732	51.6	76.68		2.30	222.62	112	.49	6.37
Lake Gibbons [16]	do.	36.0	1,414	78	1.26	139.13		4.17	1,122.22	204	.15	5.52
Lake Sapulpa [17]	Sapulpa, Okla.	22.5	1,094	183	8.72	64.59		1.94	125.46	94.9	.74	16.73

Lake Spavinaw [18]	Spavinaw, Okla	11.0	31,686	1,177	400	46.16	----------	1.38	79.22	26.9	.34	3.71
Lake Waco (1935 survey)	Waco, Tex	5.0	39,378	5,661	1,662	46.49	----------	1.39	23.69	68.1	2.88	14.38
Lake Waco (1936 survey)	do	5.9	39,378	7,790	1,662	54.20	----------	1.63	23.69	79.6	3.34	19.78
Rogers Municipal Reservoir.	Rogers, Tex	12.0	164	37.5	.55	413.80	----------	12.41	298.18	608	1.91	22.87
White Rock Lake	Dallas, Tex	25.0	18,158	3,882	99.1	108.84	----------	3.27	183.23	160	.86	21.38
Wills Point Reservoir	Wills Point, Tex	23.6	396	121	1.83	198.88	----------	5.97	216.39	293	1.29	30.56
Power Development:												
Lake Taneycomo [19]	Branson, Mo	22.4	43,980	20,266	4,610	13.37	----------	.40	9.54	19.6	2.06	46.08
Recreation:												
Ardmore Club Lake	Ardmore, Okla	15.5	1,797	153	4.15	171.72	----------	5.15	433.01	252	.55	8.51
Lake Bennett [20]	Conway, Ark	.37	492	4	4.16	179.47	----------	5.38	118.27	264	2.20	.81
Irrigation:												
Lake Medina	San Antonio, Tex	23.8	318,703	6,265	587	30.52	----------	.92	542.94	45.4	.08	1.97

[1] Area of watershed is taken from best available maps and other sources of data, but should not be considered exact in all cases. This figure is subject to revision when more accurate watershed maps become available, thereby changing figures in succeeding columns on original storage per square mile of drainage area and annual sediment accumulation per 100 square miles of drainage area.

[2] Where no dry weight is given in the preceding column an approximate weight of 60 pounds per cubic foot of sediment was used in computing the annual accumulation in tons per acre.

[3] Excluding area of reservoir. In the first edition of this bulletin and in the earlier mimeographed reports the lake area was not excluded, thus accounting for slight discrepancies between these figures and those published previously.

[4] Barnes, F. F. Advance Report on the Sedimentation Survey of Barcroft Reservoir, Alexandria, Va. U. S. Soil Conserv. Serv. SCS-SS-29, 13 pp., illus. 1939. (Mimeographed.)

[5] Eargle, D. H., and Barnes, F. F. Advance Report on the Sedimentation Survey of Bayview Reservoir, Birmingham, Ala. U. S. Soil Conserv. Serv. SCS-11, 12 pp., illus. 1937. (Mimeographed.)

[6] Connaughton, M. P., and Hough, J. L. Advance Report on the Sedimentation Survey of Burlington Reservoir, Burlington, N. C. U. S. Soil Conserv. Serv. SCS-SS-28, 25 pp., illus. 1939. (Mimeographed.)

[7] Barnes, F. F., and Brown, C. B. Advance Report on the Sedimentation Survey of Burnt Mills Reservoir, Silver Spring, Md. U. S. Soil Conserv. Serv. SCS-SS-31, 14 pp., illus. 1939. (Mimeographed.)

[8] Connaughton, M. P., and Barnes, L. H. Advance Report on the Sedimentation Survey of Franklinton Reservoir, Franklinton, N. C. U. S. Soil Conserv. Serv. SCS-SS-30, 15 pp., illus. 1939. (Mimeographed.)

[9] Eargle, D. H. Advance Report on the Sedimentation Survey of Lake Harris, Tuscaloosa, Ala. U. S. Soil Conserv. Serv. SCS-SS-4, 7 pp., illus. 1936. (Mimeographed.)

[10] Eargle, D. H. Advance Report on the Sedimentation Survey of Lake Purdy, Birmingham, Ala. U. S. Soil Conserv. Serv. SCS-SS-5, 11 pp., illus. 1936. (Mimeographed.)

[11] Eargle, D. H. Advance Report on the Sedimentation Survey of High Rock Reservoir, Salisbury, N. C. U. S. Soil Conserv. Serv. SCS-SS-10, 23 pp., illus. 1937. (Mimeographed.)

[12] Barnes, F. F. Advance Report on the Sedimentation Survey of Lay Reservoir, Clanton, Ala. U. S. Soil Conserv. Serv. SCS-SS-13, 13 pp., illus. 1937. (Mimeographed.)

[13] The data opposite this heading are composite figures obtained from the sums of original capacities, sediment volumes, and drainage areas of the four New River reservoirs. Brown, C. B., and Barnes, F. F. Advance Report on the Sedimentation Investigations of Reservoirs and Navigation Improvements on the New River, Va. and W. Va. U. S. Soil Conserv. Serv. SCS-SS-6, 24 pp., illus. 1936. (Mimeographed.)

[14] Barnes, F. F., and Brown, C. B. Advance Report on the Sedimentation Survey of Greenbelt Lake, Greenbelt, Md. U. S. Soil Conserv. Serv. SCS-SS-33, 12 pp., illus. 1939. (Mimeographed.)

[15] Glymph, L. M., Jr., and Jones, V. H. Advance Report on the Sedimentation Survey of Lake Booneville, Booneville, Ark. U. S. Soil Conserv. Serv. SCS-SS-3, 7 pp., illus. 1936. (Mimeographed.)

[16] Glymph, L. M., Jr., and Jones, V. H. Advance Report on the Sedimentation Survey of Lakes Crook and Gibbons, Paris, Tex. U. S. Soil Conserv. Serv. SCS-SS-17, 15 pp., illus. 1937. (Mimeographed.)

[17] Glymph, L. M., Jr., and Jones, V. H. Advance Report on the Sedimentation Survey of Lake Sapulpa, Sapulpa, Okla. U. S. Soil Conserv. Serv. SCS-SS-7, 9 pp., illus. 1936. (Mimeographed.)

[18] Kesler, T. L. Advance Report on the Sedimentation Survey of Lake Spavinaw, Okla. U. S. Soil Conserv. Serv. SCS-SS-1, 5 pp., illus. 1936. (Mimeographed.)

[19] Kesler, T. L. Advance Report on the Sedimentation Survey of Lake Taneycomo, Taney County, Mo. U. S. Soil Conserv. Serv. SCS-SS-8, 8 pp., illus. 1936. (Mimeographed.)

[20] Glymph, L. M., Jr., and Jones, V. H. Advance Report on the Sedimentation Survey of Lake Bennett, Conway, Ark. U. S. Soil Conserv. Serv. SCS-SS-9, 5 pp., illus. 1936. (Mimeographed.)

TABLE 13.—*Reservoirs surveyed by the Soil Conservation Service, 1934–38*—Continued

Region, use, and name	Location	Age at time of survey	Original capacity	Sediment volume at date of survey	Area of watershed	Sediment accumulation per acre per year	Dry weight of sediment per cubic foot	Sediment accumulation per acre per year	Original storage per square mile of drainage area	Annual sediment accumulation per 100 square miles of drainage area	Annual depletion of storage	Total depletion of storage to date of survey
Southwestern States:												
Irrigation:		*Years*	*Acre-feet*	*Acre-feet*	*Square miles*	*Cubic feet*	*Pounds*	*Tons*	*Acre-feet*	*Acre-feet*	*Percent*	*Percent*
Elephant Butte Reservoir.	Hot Springs, N. Mex.	20.25	2,038,860	365,186	26,312	46.76	....	1.40	100.29	68.7	.08	13.84
San Carlos Reservoir	Coolidge Dam, Ariz.	6.33	1,247,999	36,896	13,540	29.36	....	.88	92.17	43.1	.47	2.96
California:												
Water Supply:												
Gibraltar Reservoir	Santa Barbara, Calif.	16.25	14,500	4,314	215.4	84.68	....	2.52	67.32	124	1.83	29.75
Hodges Reservoir	Escondido, Calif.	16.5	37,450	1,822	303	24.07	....	.75	123.60	36.7	.29	4.87
Morena Reservoir	Campo, Calif.	25.7	68,388	7,184	112	173.91	....	5.22	610.61	256	.41	10.50
Upper Crystal Springs Reservoir.	San Mateo, Calif.	57.8	29,138	979	9	147.76	....	4.43	3,237.56	217	.06	3.36
Upper San Leandro Reservoir.	Oakland, Calif.	8.4	43,460	170	30.3	47.35	....	1.42	1,434.32	69.5	.05	.39
Recreation:												
Lake Sherwood	Oxnard, Calif.	31.0	2,870	78	16	10.91	....	.33	179.38	16.0	.09	2.72
Irrigation:												
Little Rock Reservoir	Palmdale, Calif.	11.75	5,300	83	68	7.09	[21] 85	.30	77.94	10.4	.13	1.57
Flood Control:												
Live Oak Reservoir	La Verne, Calif.	[22] 2.2	242	13	2.34	....	....	....	103.42	560	....	5.37
Santa Anita Reservoir (1936 survey).	Monrovia, Calif.	7.9	1,043	33	10.8	....	....	....	96.57	....	.40	3.17
Santa Anita Reservoir (1938 survey).	do	10.2	1,043	360	10.8	222.88	....	6.69	96.57	327	....	34.52
Northwestern States:												
Irrigation:												
Black Canyon Reservoir [23]	Emmett, Idaho	12.0	37,659	4,037	2,540	9.02	....	.27	14.83	13.3	.89	10.72
North Central States:												
Water Supply:												
Lake Brackon [24]	Galesburg, Ill.	12.7	2,881	221	8.91	137.47	....	4.12	323.34	202	.60	7.67
Lake Decatur [25]	Decatur, Ill.	14.2	19,738	2,808	906	15.46	....	.46	21.79	21.9	1.00	14.23
West Frankfort Reservoir.[26]	West Frankfort, Ill.	10.0	1,175	95	3.79	102.46	....	5.47	310.03	268	.81	8.09
Recreation:												
Lake Calhoun [27]	Galva, Ill.	11.9	286	149	13.1	65.29	....	1.96	21.53	95.9	4.37	52.10

Northern Great Plains States:												
Recreation:												
Baker Reservoir [25]	Baker, Mont.	29.1	756	254	5.2	118.58	39	2.31	145.38	174	1.15	33.60
Hayes Lake [29]	Hayes, S. Dak.	4.2	629	49	40.0	19.92	[30] 41.7 [31] 32.7	.39	15.73	29.3	1.86	7.79
Lake Hurley [32]	Gettysburg, S. Dak.	4.5	1,226	37	70.0	8.02	40.9	.16	17.51	11.8	.67	3.02
Meade County State Lake	Meade, Kans.	8.8	891	72	18	31.26	----------	.04	49.50	46.1	.92	5.98
Ottawa County State Lake.[33]	Bennington, Kans.	8.0	1,001	71	20.5	30.05	----------	.90	48.83	44.2	.89	7.09
Santa Fe Reservoir	Augusta, Kans.	8.6	1,741	146	40.0	30.36	----------	.91	43.53	44.6	.98	8.39
Wellfleet Reservoir [34]	Wellfleet, Nebr.	5.6	519	55	43.0	44.86	[21] 65	1.46	34.60	65.9	1.89	10.60
Water Supply.												
Lake Eldorado [35]	Eldorado, Kans.	9.0	3,213	131	33.0	30.54	66	1.01	97.36	44.9	.45	4.08
Lake Olathe [36]	Olathe, Kans.	4.9	532	55	6.2	125.05	60.4	3.78	85.81	184	2.11	10.34
Mission Lake [37]	Horton, Kans.	13.0	1,852	289	11.4	135.87	62.2	4.23	162.46	200	1.20	15.60

[21] Estimated.

[22] Length of period between the capacity survey of March 1936 and the sedimentation survey of May 1938.

[23] Hough, J. L., and Flaxman, E. M. Advance Report on the Sedimentation Survey of Black Canyon Reservoir, Emmett, Idaho. U. S. Soil Conserv. Serv. SCS-SS-19, 20 pp., illus. 1937. (Mimeographed.)

[24] Jones, V. H. Advance Report on the Sedimentation Survey of Lake Bracken, Galesburg, Ill. U. S. Soil Conserv. Serv. SCS-SS-14, 10 pp., illus. 1937. (Mimeographed.)

[25] Glymph, L. M., Jr., and Jones, V. H. Advance Report on the Sedimentation Survey of Lake Decatur, Decatur, Ill. U. S. Soil Conserv. Serv. SCS-SS-12, 23 pp., illus. 1937. (Mimeographed.)

[26] Jones, V. H. Advance Report on the Sedimentation Survey of West Frankfort Reservoir, West Frankfort, Ill. U. S. Soil Conserv. Serv. SCS-SS-15, 9 pp., illus. 1937. (Mimeographed.)

[27] Glymph, L. M., Jr., and Jones, V. H. Advance Report on the Sedimentation Survey of Lake Calhoun, Galva, Ill. U. S. Soil Conserv. Serv. SCS-SS-16, 9 pp., illus. 1937. (Mimeographed.)

[28] Jones, V. H. Advance Report on the Sedimentation Survey of Baker Reservoir, Baker, Mont. U. S. Soil Conserv. Serv. SCS-SS-21, 15 pp., illus. 1938. (Mimeographed.)

[29] Connaughton, M. P. Advance Report on the Sedimentation Survey of Hayes Lake, Hayes, S. Dak. U. S. Soil Conserv. Serv. SCS-SS-20, 28 pp., illus. 1938. (Mimeographed.)

[30] Older lake sediment.

[31] Sample of new sediment collected soon after deposition by a heavy flood flow.

[32] Glymph, L. M., Jr. Advance Report on the Sedimentation Survey of Hurley Lake, Gettysburg, S. Dak. U. S. Soil Conserv. Serv. SCS-SS-26, 17 pp., illus. 1938. (Mimeographed.)

[33] Flaxman, E. M., and Barnes, L. H. Advance Report on the Sedimentation Survey of Ottawa County State Lake, Bennington, Kans. U. S. Soil Conserv. Serv. SCS-SS-18, 10 pp., illus. 1937. (Mimeographed.)

[34] Jones, V. H. Advance Report on the Sedimentation Survey of Wellfleet Reservoir, Wellfleet, Nebr. U. S. Soil Conserv. Serv. SCS-SS-23, 16 pp., illus. 1938. (Mimeographed.)

[35] Jones, V. H. Advance Report on the Sedimentation Survey of Lake Eldorado, Eldorado, Kans. U. S. Soil Conserv. Serv. SCS-SS-25, 14 pp., illus. 1938. (Mimeographed.)

[36] Jones, V. H. Advance Report on the Sedimentation Survey of Lake Olathe, Olathe, Kans. U. S. Soil Conserv. Serv. SCS-SS-24, 14 pp., illus. 1938. (Mimeographed.)

[37] Jones, V. H. Advance Report on the Sedimentation Survey of Mission Lake, Horton, Kans. U. S. Soil Conserv. Serv. SCS-SS-22, 15 pp., illus. 1938. (Mimeographed.)

The period of years in each case, with one exception, is the total life of the reservoir. It is a factor of considerable importance inasmuch as the rate of silting is known to follow certain cycles which bear a definite relation to increasing age of the reservoir.

Original capacity in acre-feet has been used as the best expression of comparative size of the reservoirs surveyed, while storage per square mile of drainage area shows the relation of capacity to size of the tributary watershed. The annual sediment accumulation per hundred square miles of drainage area is the standard of comparison of silting rates which has been used in the engineering literature for a number of years. It does not, of course, give the total volume of debris eroded from the watershed but only that portion which has at the time of survey been transported into the reservoir basin and deposited below crest level of the lake.

The annual depletion of storage is an average rate derived from the total depletion to date of survey. Such a figure does not, in fact, imply that this average was true for any year in the past nor may it be actually expected for any year in the future. It is apparent from a study of the few available earlier silting records given in table 1, and from general information secured in the last few years, that silting rates are subject to definite cycles of acceleration and retardation, depending on such variable factors as percentage of watershed unprotected by vegetative mantle, methods of land utilization, climatic variation, upstream alluviation, growth of vegetation on deltas, and probably others as yet little understood.

The number of reservoirs thus far surveyed does not represent an adequate sampling of conditions over the entire United States. A minimum of 150 surveys on the most significantly located reservoirs is needed to include the major variations of reservoir type and watershed characteristics. To determine variations, trends, and cycles in silting rates these surveys should be repeated at intervals, preferably every five years.

Of the 66 reservoirs surveyed by the Soil Conservation Service to July 1, 1938, about 90 percent depend almost solely upon storage capacity for their continued usefulness. It is well known that the useful life of most reservoirs terminates long before their measured storage capacity is all occupied by sediment. In fact, every reservoir, when it is "completely silted", still has a "residual capacity" equal to the volume of the adjusted alluvial channel required to carry normal stream flow through the original reservoir area. This fraction of the measured original capacity may vary from 1 or 2 percent in reservoirs of extremely high capacity-inflow ratio to 20 or 30 percent or even more in channel-type reservoirs of very small capacity-inflow ratio. There is an additional percentage of the capacity over and above the "residual capacity" which is required for minimum service requirements of the reservoir. This may be equal to the normal draft for a week, for several months, or for several years, but in any case represents a portion of the capacity which, when seriously encroached upon by silting, determines the end of the useful life of the reservoir in its existing form.

If three assumptions are made to clarify the picture, first, that decrease of reservoir capacity to 20 percent of that originally provided will on an average terminate the useful life of a reservoir, secondly, that the rate of silting will remain generally uniform until

80 percent of the storage capacity is gone, and, thirdly, that data on 98 reservoirs—64 surveyed by the Soil Conservation Service (included in table 13) and 34 by other agencies—represent an adequate sampling of the total number in the United States, then these data indicate that 39 percent of existing reservoirs will have a useful life of less than 50 years, 25 percent a life of 50 to 100 years, 21 percent a life of 100 to 200 years, and only 15 percent a life of more than 200 years. If this picture is even substantially correct, it shows an urgent need for remedial measures of soil conservation and sediment control to protect existing developments, along with more considered planning of future water-storage projects in the light of watershed conditions.

RESERVOIR RECONNAISSANCE INVESTIGATIONS, 1934–37

SEDIMENT MEASUREMENTS IN OTHER SOUTHEASTERN RESERVOIRS

In a general reconnaissance of the Southeast during the summer of 1934, it was impossible in the limited time available to make extensive sediment measurements on more than the few reservoirs selected for special study. Some measurements were made, however, in a considerable number of other reservoirs throughout the Piedmont, wherever boats were readily obtainable or bridges or routes of travel offered favorable opportunity. In addition to this reconnaissance, more extensive observations were made by the southeastern party in the winter and spring of 1935 on four reservoirs which lie in or on the border of the southeastern Coastal Plain province. Warwick Reservoir, near Cordele, Ga., and Emporia Reservoir, Emporia, Va., were scheduled for detailed survey, but certain conditions that were discovered only after field work began made more extended surveys infeasible. Therefore, such data as were collected are treated in this section as reconnaissance information. The southeastern party also spent 1 day on Flint River and Muckafoone Reservoirs near Albany, Ga., to investigate sedimentation conditions in Coastal Plain lakes.

The reservoirs are treated in geographic order from north to south, regardless of relative size, importance, or the amount of silt measurement done, largely because most of them were visited in this order. Water measurements are corrected in all cases to spillway crest level.

EMPORIA RESERVOIR, EMPORIA, VA.

Emporia Reservoir is on the Meherrin River, 1¼ miles northwest of Emporia, Va. The dam is located exactly on the Fall Line dividing the Coastal Plain province on the east from the Piedmont Plateau on the west. The dam is built on shoals of hard crystalline rock, although all the country below it, as well as the bordering ridges, is covered with unconsolidated sands and clays of the Coastal Plain. The reservoir itself is surrounded and underlain by granite and ancient volcanic rocks of the Piedmont. The entire watershed of approximately 800 square miles is likewise in the Piedmont, which in this section is in a severely eroding condition.

The gently undulating upland plain on both sides of the lake has an average altitude of 240 feet above sea level and approximately 105 feet above the lake valley. The upland plain is being dissected only to a slight degree, but near the main streams gullying is pronounced.

The dam is of concrete masonry, 41 feet high, and was built in 1908 by a local power company. In recent years it was acquired by the Virginia Public Service Co. The lake is used for water supply of Emporia and North Emporia as well as for power development. Backwater extends approximately 6¼ miles up the river.

The southeastern party, between April 18 and 22, 1935, established 10 ranges, at intervals across the lower third of the lake, which were tied together by stadia traverse on a scale of 200 feet to the inch. The uppermost range is about 10,000 feet above the dam. Profiles along all the ranges were obtained from soundings.

Soundings made on the first range, approximately 300 feet above the dam, showed a much flatter cross section than is indicated by topography below the dam. The water depth over most of the range averaged 18 feet which, with 1 foot of water flowing over the 41-foot dam, shows a sediment depth at this place of 24 feet. Near the middle of the range, however, a distinct channel was found, in which only 7 feet of sediment had been deposited. This channel may have been cut out during extreme draw-down which occurs at intervals of several years. On range 7–8, 1,500 feet above the dam, all traces of the channel had disappeared, which suggests that deposition of bottom load, possibly accompanied by underflow, during periods without extreme draw-down had subsequently filled the channel to this distance down the lake. The average water depth became less on each succeeding range above 7–8, and the water depth on the upper two ranges nowhere exceeded 11 feet and averaged much less. Another notable feature appearing on the upper two ranges was the banking up of sediment as bars or levees along the stream channel near the center of the lake. These above-crest deposits, having a considerable aggregate volume, were laid down during flood stages.

Penetration to old soil with the sediment-sampling spud could not be attained at any point more than 50 feet from shore. This is a result of several conditions; namely, the thickness of the deposits; the fact that alternate excessive draw-down and flood stages have caused advance and recession of the delta front to such an extent that the deposits nearly everywhere consist of alternate layers of sand and silt difficult to penetrate; and lastly, the fact that reservoir deposits, having been exposed to the air at intervals, are compacted to such a degree that the spud will enter for only a foot or two.

The upper two-thirds of the lake is completely silted, that is, the present storage capacity is virtually equal only to the storage capacity available in a channel of the original size. The upper portions of the lake basin contain a channel lined with banks or natural levees of sand and mud, which are frequently several feet above high-water mark and were obviously deposited during flood stages. The levees are now covered with a thick growth of willows, which stabilize the deposits and prevent their being moved into the lower reaches of the lake. Despite this, additional floods are extending the levees farther down the lake, largely with new sediment eroded from the watershed.

Between the levees and the valley sides are lagoonlike bodies of water, many of them several hundred yards in width, filled with swampy material and usually covered by growing vegetation. Fine silt, together with much decaying vegetal matter, is settling from the muddy water in these bays.

The cross sections on Emporia Reservoir show conclusively that it is in an advanced stage of silting, and that a large proportion of the original storage capacity is gone. Lack of contour maps of the original basin and inability to penetrate through the deposits with sampling devices prevented computation of the exact quantity of sediment and rate of fill.

Undoubtedly a large aggregate quantity of sediment is going over the dam in turbid water, especially during flood stages, when little opportunity is afforded for desilting. During a flood that occurred just prior to the time this work was done, it is reported that 4 to 5 feet of water was passing over the dam. This must have created a fairly rapid current through the reservoir. During the course of this work more than a foot of water was still passing over the dam.

WATEREE RESERVOIR NEAR CAMDEN, S. C.

Wateree Reservoir, on the Wateree River 8 miles northwest of Camden, S. C., was completed in 1919 and was 15 years old at the time of these measurements. The dam is 78 feet high. Table 14 shows measurements on ranges across Wateree Reservoir.

TABLE 14.—*Measurements on ranges across Wateree Reservoir*

Range location and observation No.	Water depth	Sediment thickness	Relation of average sediment depth to original depth (sediment+water)
	Feet	*Feet*	*Percent*
1,000 feet above dam, region of least deposit, west to east:			
1	40.4	0.2	
2	44.1	.7	
3	63.3	1.0	
4	64.6	1.4	
5	67.7	1.7	
6	69.0	1.3	
7	71.0	1.6	
8	71.8	1.4	
Total	491.9	9.3	1.9
7 miles above dam. Westerly arm, Colonel's Creek Bridge:			
1	19.0	1.2	
2	18.5	.9	
3	18.0	.9	
4	18.0	.7	
Total	73.5	3.7	4.8
10 miles above dam. Westerly arm, Dutchman Creek Bridge:			
1	24.0	.9	
2	23.0	.8	
3	24.5	.5	
4	23.5	.6	
5	21.5	.6	
Total	116.5	3.2	2.7
18 miles above dam. Westerly arm, Taylor Creek Bridge:			
1	23.0	1.0	
2	22.5	.7	
3	22.5	1.0	
4	19.0	.8	
Total	87.0	3.5	3.9
20 miles above dam. Westerly arm, Wateree Creek Bridge:			
1	22.0	1.2	
2	28.0	3.5	
3	27.0	1.7	
Total	77.0	6.4	7.7

Difference in turbidity of waters entering Wateree Reservoir at the head and discharging through the tailrace of the power plant was very noticeable at the time of inspection, and is reported to be so most of the time. Apparently the main river contributes materially to the silting of Wateree Reservoir, despite the desilting influence of the eight other reservoirs of major size upstream from it on the Catawba River.

If sediment distribution in Wateree Reservoir is generally similar to that of the reservoirs surveyed in greater detail, the total accumulation would be 15,000 acre-feet or more (pl. 12, *A*). Certainly, it is not zero as has been previously reported (*17*).

LAKE MURRAY, SALUDA RIVER, ABOVE COLUMBIA, S. C.

Lake Murray is the largest reservoir in the Southeast and among the six largest in the United States. It is impounded by Saluda Dam, at the time of its construction the largest earth dam, in cubical content, for power purposes in the world. The dam has a maximum height of 208 feet and is more than 8,000 feet long. It was completed and storage began August 31, 1929. The storage reservoir extends 41 miles up the Saluda River and is 14 miles wide at the broadest point. It covers 50,000 acres and impounds 2,341,590 acre-feet of water. The generating capacity of the power plant is 222,600 horsepower.

Table 15 shows measurements made in September 1934.

TABLE 15.—*Measurements at State Highway 391 Bridge, south of Prosperity, S. C.*

Observation No.	Water depth	Sediment thickness	Observation No.	Water depth	Sediment thickness
	Feet	*Feet*		*Feet*	*Feet*
1	19.5	0.2	5	35.0	(1)
2	28.5	3.2	6	36.0	(1)
3	22.0	2.5			
4	22.0	2.0	Total	92.0	[2] 7.9

[1] Sand.
[2] The relation of average sediment depth to average total original depth (water plus sediment) is 7.9 percent, disregarding observations Nos. 5 and 6.

The absence of sediment in the deeper channel part of the section is probably due to scour of river currents that are in force here when the reservoir is drawn down toward the usual operating limit. The silt thus removed is largely redeposited farther down.

The sediment in this part of Lake Murray should represent about the greatest, rather than least, fill.

Additional measurements, extending over the full width of the reservoir within 3 miles of the dam, were made in October 1937. Although extremely rough water and water depths of more than 100 feet made accurate sampling difficult, the results of 12 measurements indicated a maximum sediment thickness of 1.2 feet in the channel and an average thickness across the lake of 0.3 foot.

APPALACHIE RESERVOIR, GREER, S. C.

Appalachie Reservoir is 2 miles north of Greer, S. C., on the South Tiger River, and is used for power development to operate the Ap-

B

A, Wateree Reservoir, Wateree River, Camden, S. C. Typical delta at mouth of westerly tributary of reservoir. *B*, Appalachie Reservoir, South Tiger River, Greer, S. C. Sand delta at head of reservoir and shoal stream channels where original lake had depths of as much as 35 feet.

FIGURE 26.—Map of Appalachie Reservoir, South Tiger River, Greer, S. C., surveyed September 1934.

palachie Mills. It was mapped by H. M. Eakin during July 1934 with plane table and stadia on a scale of 200 feet to the inch, including location and sounding of 12 representative cross-section ranges.

The dam, 38 feet in height, was completed in 1904 and has stored water continuously since. The drainage area is 63 square miles, 51 percent forested, 44 percent cultivated, and 5 percent pasture and idle land.

Complete data on the original levels of the reservoir bottom are not available. The depths at the dam, however, necessarily equaled the height of the dam crest above the original rock bed of the river at the shoal, or 38 feet. Depths were greater by several feet in the pool area above the shoal and a mile above the dam were 35 feet at the beginning of storage, according to the report of a mill employee who farmed part of the flooded area before the dam was built.

Maximum depths in the vicinity of the dam and in the pool area above it are now only 30 to 33 feet. A mile upstream, where former depths of 35 feet were reported, there is now a sand flat, nearly level from shore to shore, with water depths of 9 to 10 feet at crest-level stage.

It thus appears that filling has occurred in the upper delta region of the reservoir to maximum depths of about 25 feet (pl. 12, *B*). The silt and clay fill in the arms and main body of the reservoir would appear to range from 5 to about 15 feet. Such depths of fill would accord with the fact that it proved impossible to penetrate the sediment to the old soil level at any point although sections of new sediment 5 to 7 feet thick were brought up with the sampling apparatus.

The original reservoir flooded an area of about 80 acres at crest level stage. Of this the main delta comprised some 13 acres and three local tributary deltas about 7 acres, making 20 acres of delta area in all. These areas are filled to depths below crest level, ranging from zero, perhaps, to 25 feet and averaging for the 20 acres about 15 feet. If so, the deltas should contain an aggregate volume of about 300 acre-feet.

Of the remaining 60 acres the fill in the upper half would appear to range from about 10 to 15 feet and in the lower from 5 to 10 feet. Averaging these probable limits and applying them to the acreage involved gives a volume of some 600 acre-feet of general bottom deposits. This, added to the delta deposits, would give 900 acre-feet of total reservoir accumulation in 30 years. The annual rate would be 30 acre-feet from the actual drainage area of 63 square miles, or about 50 acre-feet a year per 100 square miles of drainage area.

A map of Appalachie Reservoir is shown in figure 26.

STEVENS CREEK RESERVOIR, AUGUSTA, GA.

Stevens Creek Reservoir, 9 miles north of Augusta, Ga., on the Savannah River, was completed in 1914. The dam is 27 feet high and impounds water 14 miles up the Savannah River and 13 miles up Stevens Creek.

Table 16 shows sediment-depth measurements on a range 1,000 feet above the dam at estimated equal intervals over a 5,000-foot width, made in 1934 when the dam was 20 years old.

TABLE 16.—*Sediment measurements on Stevens Creek Reservoir, Augusta, Ga.*

Range location and observation No.	Water depth	Sediment thickness	Range location and observation No.	Water depth	Sediment thickness
1,000 feet above dam; made at estimated even intervals over a 5,000-foot width:	*Feet*	*Feet*	1,000 feet above dam; made at estimated even intervals over a 5,000-foot width—Con.	*Feet*	*Feet*
1	10.3	6.3+	10	13.9	7.5+
2	21.2	6.1+	11	12.8	6.3+
3	13.0	3.9	12	10.7	6.2+
4	13.5	3.8	13	16.8	5.1+
5	7.0	3.3	14	15.1	4.7+
6	5.9	3.3	15	22.6	6.1+
7	6.7	3.0	16	15.5	3.9+
8	7.3	5.4			
9	7.6	6.4+	Total	199.9	[1] 81.3

[1] The relation of average sediment depth to average total original depth (water plus sediment) is in excess of 28.9 percent.

Additional measurements made in November 1937, from the highway bridge 5 miles above the dam where backwater is confined to the original river channel, revealed a rocky bottom free of sediment except for narrow belts 2 to 3 feet in depth along each bank. It thus seems improbable that any extensive delta deposits have formed in this reservoir.

WARWICK RESERVOIR, NEAR CORDELE, GA.[32]

GENERAL INFORMATION

Location: State—Georgia. Counties—Lee and Worth. Distance and direction from nearest city: 15 miles southwest of Cordele, Ga. Drainage and backwater: Flint River.

Ownership: Crisp County, operated by Crisp County Power Commission.

Purpose served: Hydroelectric power, developed and distributed by Crisp County.

Description of dam: The dam is a gravity-type reinforced-concrete structure, 400 feet long and 30 feet high, including 12- by 25-foot taintor gates on top. Earth embankments on either side of the concrete section extend to the valley sides.

Date of completion: August 1930.

Length of lake at crest stage: Original, approximately 30 miles at the 530-foot contour level.

Area of lake at crest stage: Original, 7,000 acres.

Storage capacity to crest level: Original undetermined. Loss of storage not determined but relatively slight. See remarks on silting conditions.

Area of watershed: Approximately 3,500 square miles.

General character of watershed: Of the total watershed, approximately 1,500 square miles lie in the Coastal Plain and 2,000 square miles in the Piedmont. This section is the center of the Georgia agricultural country, where the principal crop is cotton, although

[32] Acknowledgments are gratefully made to the Crisp County Power Commission for providing boats and outboard motor, and to E. S. Killebrew, chief engineer for the commission, for his generous cooperation during this work.

peach and pecan orchards are now of considerable importance. The country is rolling dissected Piedmont and more gently undulating Coastal Plain. Much of the watershed is in an advanced stage of erosion due to intensive cultivation and depletion of the natural forest cover.

Mean annual rainfall: Approximately 50 inches.

Installed power equipment: Two generators with a total capacity of 8,000 kilovolt-amperes. No. 1 generator has a capacity of 3,000 kilovolt-amperes and No. 2, 5,000 kilovolt-amperes. The present operating head is 23 feet.

History of investigations: Tests of silting conditions on Warwick Reservoir were carried on during a period of 6 days between January 24 and 31, 1935, by the southeastern party under the direction of Carl B. Brown, chief of party.

A complete quantitative survey of this reservoir had been anticipated before field work was begun, but the peculiar conditions described below made this impracticable. However, tests made with the sampling spud at more or less regular intervals in the channel and bordering swamps over the entire length of the lake proved interesting and significant in showing factors affecting silting and future expectations of silting.

The first few spud tests showed that the bottom deposits of this lake contain so little bonding material that they either will not adhere to the spud at all or only for a space of 1 or 2 inches where some mud is present in the layers of sand. To satisfactorily retain a sample, one side of the spud was smeared with ordinary automobile cup grease; this proved efficient in bringing up a continuous columnar record of the deposits penetrated, while the opposite (clean) side of the spud retained only such layers of silty material as might be present. Soundings to determine the depth of water were taken at most of the test points simultaneously with spuddings.

In all, 78 spud tests were made between the dam and head of backwater. Near Cox's Ferry two ranges were established and sounded to obtain average cross-section profiles of the lake. At Cox's Ferry, level readings were obtained on several high-water lines as shown by mud on nearby trees and buildings. These elevations were established by plane table and stadia using water surface as a datum, the elevation of which is continuously recorded at the dam.

Conditions affecting silting: Warwick Reservoir is in the Coastal Plain of southeastern United States, 60 miles south of the Fall Line which passes through Macon, Ga.

The dam has its foundation on Vicksburg limestone (Oligocene) (*19*, pp. 314–316), which also underlies most of the reservoir, at least as far up as the Seaboard Air Line Railway trestle. Good exposures are found at the dam, in numerous bluffs where the river swings against its banks, and in an abandoned quarry just east of the reservoir. In several spuddings in the old channel soft marly limestone of this formation was the only material penetrated.

On the uplands away from the reservoir the surface formation consists of reddish sands or sandy clays in which chert is abundant. Much of this clay appears to be residual from the underlying limestone, whereas the sand, at least in part, is derived from Pleistocene terrace formations, the youngest deposits of the Coastal Plain.

The Flint River south of the Fall Line is bordered by swampy flood plains which increase in width southward as the river flows into flatter, less rolling country nearer the coast. In the section covered by this reservoir the original swamps varied from one-half to three-quarters of a mile wide, including the river which meandered from bank to bank. The original swamp growth consisted of cypress, gum, and other water-loving trees and plants characteristic of coastal swamps.

Most of the original swamp growth, especially the larger trees, was left standing when the reservoir was flooded. This makes it virtually impossible, except in a few selected spots, to navigate even a small boat through the swamps from channel to bank. Water over the swamp areas is rarely more than 10 feet deep, and in many places is less than 5 feet. This condition, fully as much as the character of the deposits, made it impracticable to carry out a quantitative sedimentation survey.

Of the 78 spuddings taken between the dam and the upper limit of backwater, 59 were taken in the old river channel and 19 in the bordering swamps. Of the 59 in the channel, 26 showed no silt or insufficient silt to act as a binder for the sand. In these spuddings no sample would have been obtained without the use of grease to make the sand adhere to the spud. The sand is coarse textured, the grains ranging from less than ½ to 2 millimeters or more in diameter, and is composed chiefly of quartz, but includes some accessory minerals such as garnet and magnetite as well as occasional fragments of calcareous and siliceous fossils. It is light to dark gray in color when free of mud. Most of the sand is believed to have been derived from the surface formations of the uplands adjacent to the reservoir or in the country between the reservoir and the Fall Line. It is of a type more characteristic of the coastal-terrace formations than of the coarser, unassorted, residual sand derived from the Piedmont crystalline rocks.

No silt or finer material whatever was found in the upper 2 miles of the reservoir. A slight current moves through this part of the lake, becoming stronger toward the head even under normal water conditions. During high water this area is subject to extensive scour and shifting of sand bars.

Of the remaining 33 spuddings in the channel, 31 showed 0.1 to 0.5 foot of fill, which in most instances varied from sandy to very sandy silt. In many places the material was actually muddy sand, but has been classified as silt when the bonding content of mud was sufficient to cause the sample to adhere to the clean side of the spud. The muddy sand or sandy mud was usually found as a layer 0.1 to 0.3 foot thick on top of clean, fine-textured white or gray sand. Occasionally a layer of sand-free mud 0.1 foot or less in thickness occurs on the extreme top of the column. In other cases a layer of sandy silt as much as 0.3 foot thick occurs below the top of the column, being overlain by clean sand. In still other instances the entire column of sand is muddy though without sufficient mud to cause adherence to the clean spud. The probable explanation for occurrences of this type is found in the recurrence of periodic floods.

Two spuddings showed more than 0.5 foot of silt in the channel. Test 28 was made on a big bend in the river where it swings sharply against and has undercut its banks. At this point the maximum depth of water (50.2 feet) in the whole lake was recorded. It is apparent that a deep hole (probably an eddy hole) was scoured out on this bend before the area was inundated. The silt (1.6 feet plus) has subsequently settled or flowed into this depression where it has remained below the depth of effective currents of later floods, which have periodically stirred up the bottom deposits at shallower places. In test 44, 1.4 feet of silt was found, apparently in another eddy hole.

Of the 19 tests made in the swamp area in water 0.5 to 12 feet deep at distances of 100 to 300 feet from the channel, all but 5 showed less than 0.5 foot of silt, and these showed only 0.5 or 0.6 foot. The new deposits are less compacted, lighter in color, and lack the amount of organic matter found in the old swamp sediment on which it has been deposited. In other ways the two types of material are very similar in composition, were derived from the same sources, and deposited in the same manner, except that later sediment has generally settled from somewhat deeper water. There were several old lakes in the original swamps, notably Lake Cannon, which probably originated when cut off from the channel by natural levees and normal meandering of the river.

The Flint River is subject to periodic floods which profoundly affect silting in the reservoir and disturb the bottom deposits to such an extent as to prevent accurate quantitative measurements of the amount or rate of silting.

During a large flood in 1925, when the dam was under construction, the water level rose 40 feet above normal, washing out one cofferdam and seriously damaging the construction work. The water is reported to have risen to the level of the floor of the Seaboard Air Line Railway trestle (elevation 540.32).

The level of the lake is now held between 520 and 521 feet. In March 1934 the water rose to 532.2 and for a period of 2 weeks stood about 528 feet. In April 1932, high water reached 530.4 feet. These elevations were determined from mud lines on trees and buildings at Cox's Ferry, 7 miles above the dam. The respective dates that mud lines formed were obtained from local residents.

During the April 1932 and March 1934 floods, all taintor gates on the dam were opened to their maximum, yet for a period of 2 weeks in 1934 the water level remained more than 8 feet higher than normal. During these floods a strong current is reported to have flowed through the entire reservoir, putting the ferry out of commission for several weeks. Undoubtedly the current must have been of equal or greater magnitude than that normally found in the river above or below the reservoir. Even in periods of normal flow one or two gates are usually raised about 2 feet to drain excess water that cannot be used through the turbines. It is noteworthy that only half the equipment for which the powerhouse was designed has been installed, and that while the dam is designed to impound water to the 530-foot contour, the present level is held at 520 to 521 feet.

These facts lead to the conclusion that during flood periods, in particular, and to a lesser extent constantly, the bottom deposits in the reservoir are picked up, shifted, and redeposited; and much silt that would settle under other conditions is carried past the dam in suspension. Some of the silt resettles in mixture with sand to form a muddy sand layer a foot or more thick. In the few places, where layers of sandy silt were found below clean sand, or two layers of sandy silt were separated by clean sand, it seems likely that the lower layer represents a deposit which settled after an earlier flood, and was not subsequently disturbed by later flood currents because it was in a more favorably sheltered position or had received enough clean sand on top to serve as a protection. In a few deeps or eddy holes fine silt is accumulating where it will be protected from future floods. All the sandy silt now generally present as a layer 0.1 to 0.5 foot thick is believed to have settled entirely since the last flood in March 1934, and therefore does not give a true measure of total silting since the reservoir was impounded.

Deposits at the head of the lake are identical with those in the lower reaches, and, in the absence of original contour maps, delta areas cannot be distinguished. Probably little or none of the coarser sediment now being deposited comes from erosion in the Piedmont portion of the watershed. Only the finer sediment, carried mostly in suspension, seems to be coming from above the Fall Line, and this type of material is being largely carried through the reservoir, with at most only a temporary halt. As long as present conditions persist, including periodic floods, sedimentation will be confined largely to coarser bottom-load material carried by traction. Filling should thus take place to an appreciable extent only at the head of the lake.

FLINT RIVER AND MUCKAFOONE RESERVOIRS, ALBANY, GA.

Flint River Reservoir is on the Flint River, 2 miles north of Albany, Ga. It was completed in 1920 as a hydroelectric power development, and is owned by the Georgia Power Co. The lake covers approximately 2,500 acres and drains about 5,000 square miles. The reinforced-concrete hollow dam is 464 feet long and 26 feet high and is capped by 16 taintor gates 25 feet wide and 10 feet high, which give the dam a total height of 36 feet. An earth embankment 250 feet long connects the concrete dam to the valley side on the east. On the west, an earth embankment, 5 to 12 feet high, extends for 2,600 feet to a concrete spillway, 12 feet high and 500 feet long, which was constructed as an extension of the old Muckafoone Dam, 22 feet high.

The Muckafoone Dam was constructed in 1905 and impounded a reservoir on Muckafoone Creek and its tributaries, Muckalee and Kinchafoone Creeks. After completion of Flint River Reservoir a canal was cut to divert water of the old reservoir into the Flint River, entering 1,000 feet above the latter dam. The drainage area of Muckafoone Creek adds about 300 square miles to the 5,000 square miles above Flint River Dam. The Flint River power plant develops 8,250 horsepower.

The southeastern party spent 1 day, January 30, 1935, measuring sediment depths on Flint River Reservoir between the dam and a point 2½ miles up the lake, and in the lower mile of old Muckafoone Reservoir. The results showed that silting conditions are similar in all respects to those encountered in Warwick Reservoir 25 miles upstream. The two dams are of like construction with reservoirs of comparable size and on the same river.

Periodic floods have the same effect on sedimentation in each reservoir, inasmuch as no surplus storage is available in Warwick Reservoir as long as its present lake level is maintained. Probably as much suspended matter comes into Flint River Reservoir as into Warwick Reservoir during flood stages when virtually no desilting takes place in the upper reservoir, although it does retain sand carried as a bed load in Flint River. Neither reservoir basin was cleared of swamp timber before impounding of the lake.

A notable difference between Muckafoone and Flint River Reservoirs is the turbidity of the water, which is strikingly shown where the Muckafoone Canal enters the Flint River 1,000 feet above the dam. A sharp boundary line divides the milky to muddy water of the Flint River from the almost crystal-clear water of Muckafoone Creek. Muckafoone Lake is so clear that the outline of objects under 6 feet of water may be recognized easily in bright sunlight. The water has the slightly brownish color characteristic of natural coastal lakes.

The difference in turbidity results from the fact that the 300-square-mile watershed of Muckafoone Creek lies wholly in the Coastal Plain whereas part of the drainage area of the Flint River is in the Piedmont. Spud tests show that the bottom deposits of Muckafoone Reservoir consist either of sand alone or sand with only a slight admixture of fine grayish-white mud.

Tests on these reservoirs have led to the conclusion that no satisfactory measurements by direct sediment sampling can be made on southeastern Coastal Plain lakes because of inability to distinguish new deposits from old. Only in lakes where accurate contour maps of the original basin are available can the volume of accumulated sediment be determined within the degree of precision demanded by the present standards of accuracy.

LAKE MARTIN, DADEVILLE, ALA.

Lake Martin, on the Tallapoosa River, is impounded by a dam 168 feet high which backs water 31 miles up the main valley to form a lake 40,000 acres in area. It was completed in 1927 and was 7 years old at the time of the following measurements.

Measurements on five ranges across the main lake and a series of measurements in the Sandy Creek arm are shown in table 17.

TABLE 17.—*Measurements on ranges across Lake Martin, Dadeville, Ala.*

Range location and observation No.	Water depth	Sediment thickness	Relation of average sediment depth to average original depth (water+sediment)
7 miles below head of reservoir, United States Highway 241 Bridge, west of Dadeville:	*Feet*	*Feet*	*Percent*
1	48.5	5.4+	
2	52.8	5.0+	
3	52.8	6.3+	
4	46.5	5.5+	
5	27.9	4.4	
Total	228.5	26.0	10.4
7 to 10 miles below head of reservoir, between Highway 241 Bridge and Old Walker Ferry line:			
1	44.9	1.3	
2	34.2	.7	
3	53.6	5.0	
4	27.3	.7	
5	59.1	6.4+	
6	39.6	1.0	
7	69.2	2.6	
8	70.5	5.0+	
9	63.5	6.7+	
10	57.3	3.0	
11	43.5	.9	
12	59.7	2.3	
13	32.2	.5	
14	20.2	.6	
15	62.4	2.2	
16	57.1	1.4	
Total	790.3	40.9	4.9
10 to 14 miles below head of reservoir, between Old Walker Ferry and mouth of Sandy Creek Arm:			
1	65.8	2.6	
2	77.0	6.4+	
3	67.7	2.0	
4	80.0	2.5	
5	67.2	2.0	
6	43.5	.5	
7	94.2	2.4	
8	87.0	3.0	
9	98.0	2.6	
10	86.0	2.3	
11	78.9	1.5	
12	71.9	1.5	
13	86.2	1.8	
14	61.0	1.0	
15	42.0	.4	
16	91.0	1.2	
17	87.0	.8	
18	82.3	1.6	
19	85.0	.9	
20	90.0	.8	
21	91.0	1.4	
22	95.4	1.3	
Total	1,728.1	40.5	2.3
14 to 19 miles below head of reservoir, or 4 to 9 miles above dam, south of Sandy Creek arm to mouth of Blue Creek arm:			
1	54.5	.8	
2	97.3	1.1	
3	90.2	1.3	
4	69.8	.5	
5	82.6	1.0	
6	104.6	1.7	
7	49.6	.2	
8	123.5	1.3	
9	112.0	.7	
10	127.0	1.3	
11	125.7	1.0	
Total	1,044.6	10.9	1.0

TABLE 17.—*Measurements on ranges across Lake Martin, Dadeville, Ala.*—Con.

Range location and observation No.	Water depth	Sediment thickness	Relation of average sediment depth to average original depth (water+sediment)
2 to 4 miles above dam, main valley:	*Feet*	*Feet*	*Percent*
1	106.3	.5	
2	126.6	.8	
3	153.0	1.1	
Total	385.9	2.4	.6
Measurements in Sandy Creek arm, going up valley:			
1	84.7	1.1	
2	63.0	.6	
3	69.2	.6	
4	68.8	1.2	
5	57.7	1.4	
6	58.5	1.0	
7	52.8	1.7	
8	54.9	1.0	
9	50.7	.8	
10	47.5	.8	
11	39.5	.5	
12	43.9	.7	
13	39.3	1.8	
14	36.2	2.2+	
15	32.6	2.5+	
Total	799.3	17.9	2.2
Grand total	4,976.7	139.2	2.7

Farther up Sandy Creek Valley a large delta was built during high water from 1932 to early 1934. This is reported to have measured 600 yards in length. The valley is about 100 yards in average width. Checked against a known profile of the original valley bottom, the average depth is said to have been about 10 yards, giving a total volume of some 600,000 cubic yards or roughly 360 acre-feet of sand discharged from Sandy and Buck Creek basins in 2 years. This would be at a rate of 180 acre-feet a year from the drainage area of 180 square miles or 100 acre-feet a year per 100 square miles of drainage area.

This delta was largely scoured and carried farther down the arm during the low-water season of 1934.

In contrast with the Sandy Creek arm, the arms on Elkahatchee, Blue, Kowaliga, and other creeks have relatively small delta deposits. Measurements of general bottom deposit in them showed very small ratios of sediment thickness to original depth. Furthermore, wherever the draw-downs of 50 to 60 feet have exposed banks to wave action, sediment deposits have been largely removed and carried out to lower parts of the reservoir.

The following additional data on silting in Lake Martin are based on a survey made by the Alabama Power Co. in November 1935, in which 15 cross-section ranges, established before the basin was flooded in 1926, were resounded to the lower limit of draw-down, or 60 feet below crest. As all but three of the cross sections across the main lake extend below the limit of sounding the maximum depths of sediment were not determined in most cases. Table 18 includes data only for the ranges on which a complete record was obtained.

TABLE 18.—*Sediment depths in Lake Martin, Dadeville, Ala., based on the 1935 sedimentation survey by the Alabama Power Co.*

Range location	Maximum original water depth	Sediment thickness	
		Maximum	Average
Tallapoosa River:	*Feet*	*Feet*	*Feet*
9 miles below head of lake	72	18.5	7.2
5 miles below head of lake	43	13.0	5.3
4½ miles below head of lake	47	15.0	7.1
Blue Creek	60	1.0	1.0
Sandy Creek 1½ miles above mouth	60	1.0	1.0
Kowaliga Creek 0.7 mile above mouth	60	2.0	1.0
Small tributary near head of lake	31	2.5	1.6

COMPLETELY FILLED PIEDMONT RESERVOIRS

Practically all small reservoirs in the Piedmont and many others of major size that are more than a few decades old were found to be completely filled, except for a normal alluvial stream channel through the region of the original pond (pls. 13 and 14).

Typical of the smaller reservoirs are those of the Deep River, downstream from the municipal reservoir of High Point, N. C.; Gil Reath's Mill on a tributary of the South Tiger River, near Greer, S. C.; Jenkins Mill on Glade Creek northeast of Gainesville, Ga.; and Barrett Mill Dam on East Sandy Creek (pl. 15, *A*), Athens, Ga. In all the Piedmont there are literally scores of such smaller reservoirs, with dams 10 to 20 feet high, equipped to generate various amounts of power running generally from 15 or 20 upwards to 75 or 80 horsepower. Altogether, these smaller plants generate a really important aggregate power. Their intimate distribution and service among the rural communities of the Southern States for gristmill and other local uses makes their gradual deterioration particularly grievous to a considerable part of the population.

Detailed description of individual plants of this class would be tedious repetition for the most part of complex histories of small dams having been constructed, filled, raised, and filled again. At the present time most of these small dams are practically without useful storage and, consequently, reduced in power capacity during low-water season to the ordinary discharge from small drainage basins.

Larger reservoirs filled to the point of practically complete elimination of storage as a factor of power production, are those of the Broad River at Gaston Shoals near Gaffney, Ninety-nine Islands, south of Blacksburg, and Parr Shoals, north of Columbia, S. C.; those of the Enoree River at Van Patton Shoals near Woodruff, and at the Riverdale Mill near Enoree, S. C.; those of the Saluda River at the Saluda Dam near Greenville, Ware Shoals at Ware Shoals and Holiday Dam near Belton, S. C.; those of the Savannah River basin at Portman Shoals, the Seneca River near Anderson, and Gregg Shoals, the Savannah River near Iva, S. C.; those of the Oconee River at Tallassee Shoals (pl. 15, *B*), Mitchell's Bridge, and Barnett Shoals near Athens, Ga.; that of the Yellow River at the Millstead Dam, near Conyers, Ga.; and those of the Chattahoochee River at the Dunlap

Dam near Gainesville (pl. 16); at Morgan Falls near Roswell and at Langdale and Riverview Dams near West Point, Ga.

An appreciation of the magnitude and rapidity of loss of storage-capacity assets of these power plants can be conveyed better, perhaps, by table 19 than by detailed description of each individual case. The height of dam relates rather closely in most cases to original size of reservoir. The age given is the maximum time required for complete filling. In several instances the reservoir has been filled in shorter time, and stream-borne materials, including sand, have been passing over the dams for several years.

TABLE 19.—*Completely silted reservoirs in various sections of South Carolina and Georgia*

Reservoir	Height of dam	Age (1934)	Reservoir	Height of dam	Age (1934)
	Feet	*Years*		*Feet*	*Years*
Gaston Shoals	39	28	Ware Shoals	20	30
Van Patton Shoals	14	26	Barnett Shoals	45	23
Saluda	44	29	Dunlap	36	30
Holiday	37	29	Morgan Falls	50	30
Portman Shoals	42	38	Langdale	14.5	28
Gregg Shoals	14	27	Riverview	9	29
Tallassee	30	32			
Mitchell's Bridge	15	36	Average	32.0	29.1
Ninety-nine Islands	70	24			

All these dams are first-class concrete or masonry structures, and represent large initial investments. More than half are 30 to 50 feet in height and impound water for distances of 4 to 7 miles upstream. The fate of these dams indicates clearly the serious inroads already made upon developed power resources of the southern industrial region by accumulation of erosional waste, and the magnitude of the continuing menace to other power developments that have been or may be made in the erodible Piedmont region. This situation in the Piedmont would appear to present one of the major problems of erosion control.

SILTING OF SOUTHERN APPALACHIAN MOUNTAIN RESERVOIRS

LITTLE RIVER RESERVOIR, NEAR BREVARD, N. C.

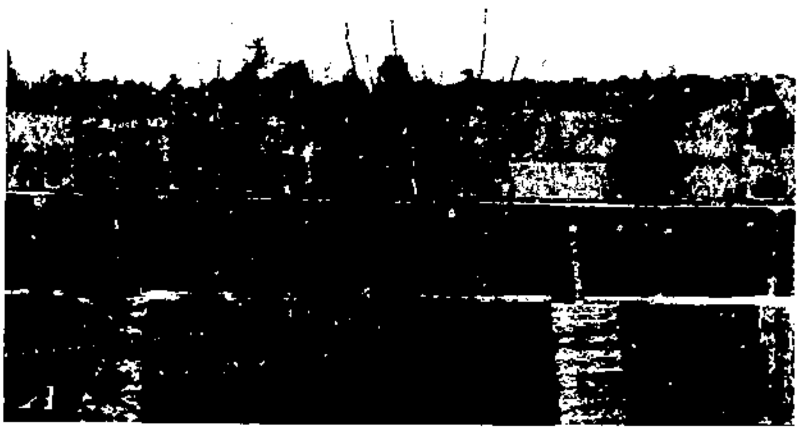
The drainage basin of the Little River, some 60 square miles in area above the reservoir, heads on the northerly slopes of the Blue Ridge. It has been logged off to a considerable extent in the past, but natural reforestation occurs very rapidly in this area and the basin is generally well covered, cleared land being limited to a few agricultural plots near Cedar Mountain, perhaps 50 acres in all.

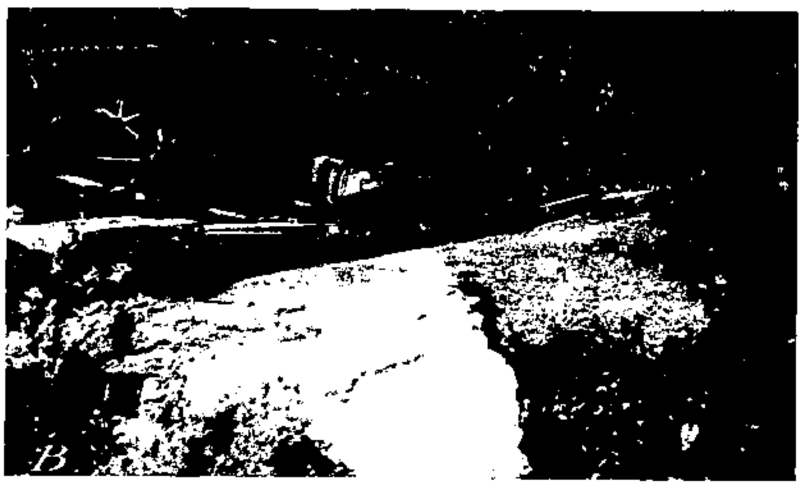
The soils are derived from granite and gneiss that differ little in depth of decay and erodibility from the same formations in the Piedmont. The slopes on the whole are longer and somewhat steeper than in the Piedmont.

Little River Reservoir is about 3½ miles long in the main valley and extends in minor bays into the valleys of several small tributaries.

Silt and sand deposits behind mill dam, Pacolet River, near Spartanburg, S. C.

Silting in reservoir near Spartanburg, S. C. The efficiency of this reservoir has been practically ruined by collection of sediment above the dam. Only the stream channel is open. View from bridge just above dam.





A, Barrett Dam, East Sandy Creek, Athens, Ga.; original dam completely filled, raised, and filled again. This illustrates the common history of many small dams throughout the southern Piedmont region. *B*, Tallassee Dam, Oconee River, west of Athens, Ga.; reservoir filled and covered with trees, excepting stream channel through the original lake area. Power plant closed down and dismantled because of elimination of storage.

Dunlap Reservoir, Chattahoochee River, Gainesville, Ga. New stream channel nearly completed by general silting and deposition of a natural levee through the center of the original reservoir.

At the time of examination, July 25, 1934, it was raining and there had been rather heavy thundershowers during the previous week. The river itself and the reservoir waters were both very clear. This was stated by the plant operator, a man of 12 years' service, to be their common condition under all ordinary rainfall. Only after a week of extraordinary rainfall does any turbidity appear in the tail water.

The stream enters the reservoir in a well-formed rock-bottom channel. Although the dam has been built 25 years this has not been filled at the edge of the lake and no delta is in evidence.

GREEN RIVER RESERVOIR, NEAR TUXEDO, N. C.

The Green River drainage basin, like that of the Little River farther west, is generally well forested. In areas cleared and in cultivation the soils, where observed, seem fully as erodible as those of the Piedmont.

This reservoir also was observed on July 25, 1934. Except for the muddy waters which showers brought into the bays along the northerly side of the reservoir, from cleared land and the drains of a newly graded road, the reservoir waters were beautifully clear. The plant foreman, familiar with the reservoir since it was constructed in 1918, stated that the water at the dam has been turbid only a few times since that date.

The river has not developed any extensive mud flats at the head of the reservoir, 7 miles above the dam; a little sand is said to appear there when the reservoir is drawn well down. The total accumulation must be relatively small, however, in the absence of characteristic delta features.

BRIDGEWATER RESERVOIR (LAKE JAMES), UPPER CATAWBA RIVER, WEST OF MORGANTON, N. C.

Bridgewater Reservoir, impounded by three earthen dams completed in 1919, has a total storage capacity of 292,341 acre-feet. An earthen dam with a concrete spillway ac oss the Catawba River diverts water through a canal into Paddy Creek Valley, from which it is again diverted across a low saddle into the Linville River Valley by a second earth and concrete dam. The third earthen dam, on the Linville River, has no spillway but contains the outlets to the power plant at its base. The Linville dam has a maximum height of 150 feet, 10 feet of which is above spillway crest level.

The drainage basin embraces 380 square miles of rugged mountainous country on the east slope of the Blue Ridge, of which 75 percent is forested, 10 percent is in pasture, and 15 percent, largely in the valley bottoms, is cultivated.

The depth measurements shown in table 20 were made in the fall of 1937.

TABLE 20.—*Sediment and water-depth measurements in Bridgewater Reservoir, upper Catawba River, west of Morganton, N. C.*

Location and observation No.	Original depth (water + sediment)	Sediment thickness	Relation of average sediment thickness to average original depth
Linville River arm near dam:	*Feet*	*Feet*	*Percent*
1	118	2.5	
2	121	1.1	
3	68	.2	
4	116	.8	
5	106	1.1	
6	91	.3	
7	71	.5	
8	121	.4	
9	131	1.3	
10	121	1.2	
Total	1,004	9.4	0.9
Catawba River arm from dam to point 2 miles above:			
1	98	.8	
2	97	.7	
3	103	2.0	
4	104	3.2	
5	100	1.6	
6	97	1.1	
7	91	.4	
8	110	2.8	
9	85	.4	
10	88	1.8	
11	107	.2	
12	91	.9	
13	92	.8	
14	102	2.8	
15	104	1.0	
Total	1,469	21.2	1.4
Paddy Creek arm opposite canal from Catawba arm:			
1	47	0	
2	48	0	
3	47	0	
Total	142	0	0

BURTON, RABUN, NACOOCHEE, AND TALLULAH RESERVOIRS, UPPER TUGALOO RIVER BASIN NEAR TALLULAH FALLS, GA.

These reservoirs were all clear at the time visited, August 28, 1934, except near the heads of tributary bays that were receiving discharge from road drains and from small cultivated patches under heavy showers throughout most of the day. The heavy discharges of streams from undisturbed forest tracts at the same time were perfectly clear.

Confirming these observations was the statement of a resident, that during recent complete draw-down of Lake Rabun only a few inches of mud were seen generally over the lake bottom. In view of this statement and the great predominance of clear run-off over the limited discharge from road drains and small cleared patches, it appears certain that the rate of silting in these mountain reservoirs is practically negligible.

Considerable new road work has been done recently under Civilian Conservation Corps auspices along the east side of Lake Rabun. The depths and erodible qualities of the clays exposed by this work, and demonstrated by thick muddy waters in the drains, show conclusively that it is due mainly, if not altogether, to the forested conditions of the area that the southern Appalachian mountain reservoirs are silted so slowly in comparison with those of the Piedmont agricultural region.

SEDIMENT MEASUREMENTS IN OTHER SOUTH-CENTRAL RESERVOIRS

LAKE DALLAS NEAR DENTON, TEX.

Lake Dallas is about 23 miles northwest of Dallas, Tex., on Elm Fork of the Trinity River. The dam is an earth embankment slightly more than 2 miles in length and 20 to 45 feet in height above original land level. The spillway is a concrete structure 520 feet long with crest level 525 feet above sea level, and 67 feet above original stream level. A main highway traverses the dam from end to end, passing over the spillway on a steel bridge which surmounts the concrete structure.

Backwater at crest stage extends about 10½ miles up the valley. The area of the lake at this level is 10,900 acres and the original capacity 180,750 acre-feet. The drainage basin is 1,174 square miles in area, of moderate relief and covered in part with sandy soil. The vegetative cover is for the most part seasonal cultivated crops, scattered mesquite, and pasture grasses. Sheet erosion generally, and moderate gully development locally, are in evidence. Erosional waste includes much sand but flood flows are generally turbid with considerable charges of suspended silt and clay. Annual rainfall is about 35 inches.

The dam was completed in February 1928 and stored nearly all of the basin run-off for the first 6 years.

Sediment measurements made on ranges across Lake Dallas on September 21, 1937, gave the results shown in table 21.

TABLE 21.—*Sediment measurements on Lake Dallas, Denton, Tex.*

Range location and observation No.	Original depth (water + sediment)	Sediment thickness	Relation of average sediment thickness to average original depth
Range No. 1, from southwest to northeast, approximately 2,000 feet above main dam:	*Feet*	*Feet*	*Percent*
1	25.3	0	
2	35.9	.7	
3	38.0	1.2	
4	38.5	.6	
5	30.0	.8	
6	30.6	.3	
7	50.3	6.5	
8	25.5	.0	
Total	280.7	10.1	3.5
Range No 2, from east to west across main lake, approximately 1 mile above dam:			
1	31.3	.2	
2	34.3	1.2	
3	32.9	.8	
4	48.3	3.1	
5	34.7	1.8	
6	34.9	1.1	
7	35.3	1.1	
8	38.2	1.3	
9	30.9	1.9	
Total	320.8	12.3	3.8

TABLE 21.—*Sediment measurements on Lake Dallas, Denton, Tex.*—Continued

Range location and observation No.	Original depth (water + sediment)	Sediment thickness	Relation of average sediment thickness to average original depth
Range No. 3, from south to north across large embankment, 1½ miles north of main dam:	*Feet*	*Feet*	*Percent*
1	30.0	.6	
2	25.3	.3	
3	19.0	.0	
Total	74.9	.9	1.2
Range No. 4, from southwest to northeast across main lake, 3 miles above main dam:			
1	25.4	.3	
2	25.8	1.3	
3	26.0	1.5	
4	27.5	1.7	
5	25.8	1.5	
6	40.9	5.0	
7	23.4	1.1	
8	26.1	1.6	
9	24.8	.9	
Total	245.7	14.9	6.1
Range No. 5, from north to south across mouth of Pecan Bayou, about 5 miles above main dam:			
1	13.9	.2	
2	15.4	.6	
3	15.9	.7	
4	16.9	.8	
5	17.1	.8	
6	15.5	1.0	
Total	94.7	4.1	4.3
Range No. 6, from west to east just north of old McKinney highway, about 5 miles above main dam:			
1	18.1	1.5	
2	18.9	2.1	
3	18.9	1.6	
4	18.9	2.0	
5	18.3	1.7	
6	16.5	.2	
7	15.5	.2	
8	18.3	2.0	
9	19.1	2.5	
10	20.1	2.8	
11	21.3	3.4	
12	20.6	3.0	
13	19.2	2.6	
14	19.5	2.0	
15	18.4	2.1	
Total	281.6	29.7	10.5
Range No. 7, across arm about 6 miles above main dam:			
1	15.0	.2	
2	14.4	.1	
Total	29.4	.3	1.0
Range No. 8, across main lake about 8 miles above main dam:			
1	12.4	1.9	
2	11.6	1.7	
3	12.0	1.5	
4	16.5	5.0	
5	14.5	3.0	
6	15.6	2.7	
7	17.7	3.9	
8	17.9	3.5	
Total	118.2	23.2	19.6
Grand total	1,458.0	95.5	6.5

The marked increase in sediment thickness below water depths of 40 feet is probably significant of underflow of heavy sediment-charged waters along the reservoir bottom. If so, the sediment-water depth ratio may be somewhat less in the intermediate region of the reservoir. No observations have been made of delta conditions at the head of the lake, but it is reported locally that a great expanse of sediment is exposed for 4 miles down the reservoir when lake level is 18 feet below crest.

On the basis of the data in table 21 and other observations, it is estimated that the total volume of reservoir sediment at the time of the measurements was 13,000 acre-feet.

LAKE WORTH, FORT WORTH, TEX.

Lake Worth is on the West Fork of the Trinity River about 5 miles northwest of Fort Worth, Tex. The dam is an earth structure with concrete spillway, one-half mile long and 36 feet in maximum height above the old stream channel. Backwater at spillway crest level extends about 10 miles up the valley. The original lake area at this stage was 3,770 acres, and the capacity 47,177 acre-feet. The drainage area is 1,969 [33] square miles. Mean annual rainfall is about 31 inches.

The dam was completed in 1915 and has functioned for 23 years.

A resurvey of Lake Worth in 1928 reported by Taylor (*16*, p. 85) gave a capacity of 33,340 acre-feet, indicating a total accumulation of 13,837 acre-feet of sediment in 13 years. This amounts to 54 acre-feet a year per 100 square miles of drainage area, and to an average storage depletion of 2.26 percent a year.

Table 22 gives the results of measurements made on September 24, 1934. These data indicate an average sediment depth near the dam of 2.3 feet, compared with a depth of 2 feet shown by the 1928 survey.

In 1933 the effective drainage area above Lake Worth had been reduced to 94 square miles by the construction of Bridgeport and Eagle Mountain Reservoirs upstream on the West Fork. By projecting the rate of silting determined by the 1928 survey and allowing for the reduction in effective drainage area, the total amount of sediment accumulated to the end of 1937 has been computed as 18,371 acre-feet, or 39 percent of the original capacity.

If it is assumed that the rate of sediment output per unit of drainage area indicated by the 1928 survey is now the same on the remaining 94 square miles of effective drainage area as in the whole drainage basin, and that no sediment passes the first dam upstream, the average rate of storage depletion in Lake Worth since the completion of Bridgeport and Eagle Mountain Reservoirs should be only about 0.11 percent a year.

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[33] This figure, at variance with the 1,865 square miles given by Taylor (*16*, p. 82), is based on recent planimeter measurements of the most accurate maps now available. A still more accurate determination of the area will be possible on the completion of aerial mapping of the Trinity watershed now in progress.

TABLE 22.—*Sediment measurements in Lake Worth, near Fort Worth, Tex.*

Range location and observation No.	Water depth	Sediment thickness	Range location and observation No.	Water depth	Sediment thickness
Range 1, 1,500 feet above dam. City boathouse on north shore:	*Feet*	*Feet*	Range 1, 1,500 feet above dam. City boathouse on north shore—Continued.	*Feet*	*Feet*
1	7.7	0.0	6	26.2	3.1
2	9.8	.3	7	20.0	1.2
3	28.3	2.3	Total	133.9	[1] 16.2
4	29.7	5.0			
5	17.2	3.1			

[1] The relation of average sediment thickness to average original depth (sediment plus water) is 10.4 percent.

LAKE PENICK NEAR LUEDERS, TEX.

Lake Penick is near Lueders, Tex., on the Clear Fork of the Brazos River. The dam is of earth construction in overbank areas and of concrete for a section of 900 feet in the old channel area, the latter serving as spillway. The spillway crest is about 40 feet above the lowest point of the old bedrock channel.

Backwater originally extended about 7 miles above the dam in Clear Fork Valley and 2½ miles in the valley of Cottonwood Creek which joins the former three-quarters of a mile above the dam. The original capacity of the reservoir was 3,096 acre-feet. The direct drainage area, according to Taylor, is 2,500 square miles for the whole basin of Clear Fork above Lueders, less 250 square miles tributary to headwater reservoirs, or 2,250 square miles net (*16*, p. 101). The soils, according to the same authority, are dominantly sandy clay loam, about 30 percent cultivated and 70 percent in pasture with mesquite growth at lower and scrub oak at higher elevations. Both sheet and gully erosion are pronounced in many parts of the basin. The mean annual rainfall is a little more than 23 inches. The dam was completed in 1920.

The present reservoir floods an older dam, 4½ miles up Clear Fork Valley, behind which considerable sediment had accumulated before it was flooded. Gravel and sand bars have extended down the head of the present reservoir over this fill nearly to its lower end. Widespread deposits farther down have reduced depths so that flood flows maintain effective velocities and carry much sediment through the length of the reservoir and over the dam.

Measurements just above the dam gave water depths of only 8 to 10 feet where original depths approached 34 feet. At the railroad bridge one-half mile above the dam, measurements gave a maximum depth of 13.4 feet and an average of 12.4 feet. Penetrations of 6 to 10 feet in the sediment were obtained with the sampling spud without reaching its bottom. The soft condition of the deposit thus indicated suggests that much of it is scoured out by each flood and the space refilled during subsiding stages. In other words, the reservoir has been converted essentially into an alluvial channel with low grade, large cross-section area, and subject to readjustment, according to stage, to the fixed base level determined by the spillway.

A resurvey of Lake Penick in 1927 showed a capacity of 2,126 acre-feet, a reduction from original capacity of 970 acre-feet, or an annual rate of 6.2 acre-feet per 100 square miles of drainage area. The very low rate of silting per unit of drainage area compared with Lake Worth and other Texas reservoirs would appear to have little significance, except as an indication that perhaps a much larger part of the sediment carried into the reservoir had continued to travel through its length and over the dam.

LAKE HENRYETTA, HENRYETTA, OKLA.

Lake Henryetta is approximately 10 miles east of Henryetta, Okla., which it serves for municipal water supply. The dam is of earth-fill construction with a concrete spillway and has a maximum height of 42 feet. It was completed in January 1929. The lake covers 500 acres and stores approximately 21,000 acre-feet (6.8 billion gallons) on which there is an average daily draft of 800,000 gallons. The drainage area of the lake is 23 square miles.

Measurements made in the lower part of the lake showed 1.0 foot of sediment in the old channel and 0.1 to 0.2 foot on the adjacent submerged flood plains.

LAKE OKMULGEE, OKMULGEE, OKLA.

Lake Okmulgee is about 6 miles west of Okmulgee, Okla., which it serves for municipal water supply. The dam is of earth-fill construction with a concrete spillway and has a maximum height of 65 feet. It was completed in 1927. The lake is 6½ miles long and has 25 miles of shore line. It covers 710 acres and stores approximately 13,000 acre-feet (4.3 billion gallons). The average daily draft is about 2.5 million gallons.

Measurements made at the dam in 60 feet of water showed 0.7 foot of sediment. The sediment thickness increases progressively to 3 feet at the upper end of the wide body of the lake at the rim of the delta.

LAKE McALESTER, McALESTER, OKLA.

Lake McAlester is 8 miles northwest of McAlester, Okla., and is owned by that city, which it serves for municipal water supply. The lake was completed in 1923 and had an original length of 4.6 miles and 22 miles of shore line. It covers 1,645 acres, drains 33 square miles, and stores approximately 20,000 acre-feet (6.5 billion gallons) of water.

Measurements over many parts of the lake showed only 0.1 to 0.3 foot of sediment, although in the extreme upper end 3.3 feet was measured in the old channel. The winding channel and dense vegetation at the upper end are responsible for holding back much sediment from the main body of the lake.

SEDIMENT MEASUREMENTS IN RESERVOIRS OF THE PACIFIC SOUTHWEST

SANTIAGO CREEK RESERVOIR, SANTA ANA, CALIF.

Santiago Creek Reservoir is on Santiago Creek, an easterly tributary of the Santa Ana River, about 11 miles east of the city of Santa Ana, Calif.

The dam is of earth- and rock-fill construction, 110 feet high and 1,400 feet long, with concrete pavement on the reservoir slope and a concrete spillway 20 feet lower than the top of the dam. Backwater, at spillway level, extends 2 miles up the valley and forms a lake of 590 acres with a maximum depth of about 95 feet and a storage capacity of about 25,000 acre-feet. The drainage area is 62.8 square miles.

The dam was completed in 1931; its age in October 1934, was a little under 3 years.

Owing to subnormal rainfall in the area the past several years the reservoir has not yet been completely filled. The stage on October 7, 1934, when the measurements shown in table 23 were taken, was 62 feet below spillway level.

TABLE 23.—*Sediment measurements on Santiago Creek Reservoir, near Santa Ana, Calif.*

Range location and observation No.	Water depth (below crest)	Sediment thickness	Range location and observation No.	Water depth (below crest)	Sediment thickness
Range 1, east to west, 900 feet above dam:	*Feet*	*Feet*	Range 1, east to west, 900 feet above dam—Continued.	*Feet*	*Feet*
1	80.2	0.1	6	94.0	0.6
2	81.1	.3	7	75.8	0
3	81.5	.5			
4	91.0	.9	Total	598.8	[1] 3.4
5	95.2	1.0			

[1] The relation of average sediment thickness to average original (sediment+water) depth is 0.56 percent.

In June 1938, direct measurement of the sediment thickness at 45 well-distributed points in the reservoir showed an average deposit of 1.3 feet. By applying this thickness to the 590 acres of surface area, a volume of 767 acre-feet, or 3 percent of the original capacity, is obtained as the volume of sediment accumulated in the 7-year period of storage. The average rate of storage depletion thus indicated is only about 0.04 percent a year.

This very low rate of silting relates in part to subnormal inflow into the reservoir but also reflects the generally intact condition of vegetal cover over the drainage basin. The only burn of any consequence in the basin was the few square miles of Harding Canyon drainage about 6 miles up the valley from the Santiago Creek Reservoir. The sediment production from this area has been reduced in considerable measure by regrowth of vegetation on the slopes and treatment of gullies by extensive use of check dams. The sediment now finds an effective screen in the thickly vegetated area at and above the old Harding Reservoir, where most of it settles.

HARDING RESERVOIR, NEAR SANTA ANA, CALIF.

Harding Reservoir is in Harding Canyon, an easterly tributary of Santiago Creek about 6 miles above Santiago Creek Reservoir.

The original dam was built shortly after 1900. This was raised in 1924 to a height of about 40 feet, forming a reservoir half a mile long, mostly in the narrow canyon section.

The watershed is a mountain basin about 5 miles long and largely floored with disintegrated granite soils. Practically all the basin above the reservoir was burned over in the late summer of 1926. The reservoir is said to have silted but little prior to this fire. Following the fire, in February 1927, a series of heavy rains caused drastic erosion of the denuded soils and practically filled the reservoir within a single month.

In subsequent years the filled area of the reservoir and section of valley immediately above has grown up with a heavy stand of willows or "water anemones," which has provided an effective screen for settlement of debris that has come from later stages of gully erosion. Also, in view of construction of the new and larger reservoir below on Santiago Creek, considerable control work has been done on the larger gullies of the Harding Canyon burned area. Hundreds of check dams have been built which have not only arrested much sediment but are said also to reduce the size of flood crests and to delay arrival of crest discharge into Santiago Creek by a space of about 3 hours.

The fate of the Harding Reservoir demonstrates the erodible character of local soils and the importance of fire prevention elsewhere in the Santiago Creek basin if the indicated slow rate of silting in the new reservoir is to be long continued.

BARRETT RESERVOIR, 26 MILES EAST OF SAN DIEGO, CALIF.

Barrett Reservoir is on Cottonwood Creek, 26 miles east of San Diego, Calif., by air line. It is a part of the San Diego city water supply system.

The dam is a gravity-arch type constructed of large aggregate concrete masonry and was completed in 1922. Its total height above river bed is approximately 179 feet. The spillway is integral with the dam and is controlled by automatic flashgates which give a maximum storage level 169 feet above stream bed or at elevation 1,615 above sea level. The lake at crest stage originally had an area of 862 acres and a capacity of 42,765 acre-feet.

The watershed comprises 130 square miles of generally high mountain country, not including the 112 square miles of the Cottonwood Creek drainage basin above Morena Dam, 8 miles upstream from Barrett Dam. The granitic rocks that underlie the district have weathered deeply in places to produce sandy soils. These are generally well covered with brush and other vegetation, but locally are subject to considerable sheet wash and gully erosion. The debris thus produced is mainly sand, which has accumulated in well-developed deltas at the heads of the principal arms of the lake. Smaller amounts of finer materials have settled farther down the lake all the way to the dam. The average annual rainfall at the dam is about 18 inches.

Measurements of sediment in the lower end of the lake made on October 10, 1934, are given in table 24.

TABLE 24.—*Sediment observations, Barrett Reservoir, near Dulzura, Calif.*

Range location and observation No.	Water depth	Sediment thickness	Relation of average sediment thickness to average original depth (water+sediment)	Range location and observation No.	Water depth	Sediment thickness	Relation of average sediment thickness to average original depth (water+sediment)
Range 1, west to east, 700 feet above dam:	*Feet*	*Feet*	*Percent*	Range 2, east to west, 1,200 feet above dam:	*Feet*	*Feet*	*Percent*
1	93.1	0.3		1	125.4	1.3	
2	115.2	.8		2	143.3	1.6	
3	139.9	1.9		3	135.5	1.8	
4	131.1	2.1		4	122.0	1.2	
5	100.9	1.5		5	122.6	.9	
				6	122.3	.7	
Total	580.2	6.6	1.1	Total	771.0	7.5	0.96

The foregoing depths of sediment apply only to the true bottom-set clays that have accumulated in the lower part of the reservoirs subsequent to deep flooding of the basin. A considerable depth of sediment, mostly sand, was deposited against the dam by a flood that occurred with the reservoir almost empty when the gates were first closed. The soundings indicate a maximum depth of these earlier deposits of about 27 feet.

The low ratios of sediment to water depth shown in table 24 relate in part to a smaller production of fine silts and clays than of sands in weathering and erosion in granite areas. They would appear to be due in part also to a rather low rate of silting of the reservoir as a whole.

SUMMARY

The foregoing data on significant reservoirs in the southeastern, south-central, and southwestern type areas of the United States show that silting of reservoirs is a practical problem of the first order of importance in all three regions, wherever accelerated erosion occurs. Observations made on many other reservoirs visited but not yet surveyed, and on erosion conditions along all routes traveled, emphasize the dependence of high rates of silting upon man-induced erosion and the general prevalence of these conditions over broad areas of the country.

In the Southeast, reservoir silting results chiefly from accelerated erosion of deep residual soils induced by human occupation. Lower rates prevail in mountainous and other sections wherever the natural forest cover is largely intact. Higher rates go with agricultural practices in the lower Piedmont country—practices which, by general consent, can be greatly improved upon from the standpoint of erosion prevention. Organized cooperation of the agricultural population toward better terrace and crop practices, and rededication of oversteep lands to noncultivated crops or forest is eminently in order. There is no doubt that large benefits to downstream investments can come from structural and vegetational gully control and treatment of highways and country roads.

In the southern Great Plains higher rates of silting relate to accelerated erosion of soils from sedimentary rocks under agricultural and grazing practices. Greater attention to terrace and contour cultivation, cover and strip cropping, and control of incipient gullies can effect material improvement. Range restoration and more restricted grazing are needed in many places. Detention of sediment above reservoir level in broad tributary valleys in many reservoir drainage basins also can be effectively and profitably employed.

In the Southwest higher rates of silting are in considerable measure the result of overgrazing and its consequence of extraordinary sheet and gully erosion. Sheet erosion, perhaps, can be reduced in time through further restriction of grazing beyond that already imposed by the sparseness of remaining grasses. Arroyo and gully cutting and attendant excessive production of sediment can be reduced, or even prevented from increasing, in many cases only by direct engineering methods. Sediment detention above reservoir level in broad tributary valleys by earth barriers and by growth of vegetative screens in delta areas is practicable in many cases.

It would also appear, in view of the indications of underflow and concentration of muddy flood waters against the dams in this region, that important reduction of rate of silting is probably feasible through selective wastage of these more heavily sediment-charged waters through properly placed outlet gates. Such sediment-and-water mixtures remain fluid after considerable settling and concentration of the mud charge and are capable of selective movement toward a lower outlet. Sludges carrying 20 to perhaps 30 percent of solid matter should be subject to such selective movement, under laws of stratification of liquids of different densities, for long distances above dams, provided selective evacuation be practiced from the start to maintain bottom slope and deep sludge pockets near the dam. Sediment deposits against the dam and in adjacent deeps of the reservoir reduce the forces of selective flow and the thickness of muddy water accumulation at the dam, and thus preclude the possibility of deferred development of optimum mud-evacuation practice.

Without such practice it is not an unknown occurrence for clear waters which have deposited their load in the reservoir to be wasted over the spillway, thus making room at the bottom for a new body of very muddy water. This would appear to be the most favorable arrangement for shortening reservoir life. On the other hand, since most of the solid matter that encroaches upon the storage capacity of these Southwestern reservoirs is composed of finer-grained silt and clay, long held in suspension before final settlement and compaction, it appears that a very notable lengthening of useful life of present and future reservoirs in this region should follow successful development of a practical system of mud evacuation. The question of disposal of mud thus passed through the dam would probably be the crux of the problem in most cases and positively preclude adoption of such a practice where continuous clear-water discharge is imperative.

In California higher rates of reservoir silting relate, for the most part, to fires in tributary drainage areas. Fire prevention, quick reseeding of burned-over areas, and treatment of gullies in their incipient stage would appear to be generally in order to keep rates in nonagricultural areas at a minimum. When erosion of cultivated lands is involved, as at Lake Hodges and other reservoirs of the lower foothills, modern erosion-control methods are applicable.

In broad national view, it appears with unmistakable clearness that exorbitant rates of depletion of reservoir storage by silting are widely prevalent and that the problem of protection of reservoirs from this menace goes hand in hand with that of saving farm and range lands from impairment and destruction by uncontrolled erosion. While some supplementary practices of debris disposal may be employed to conserve storage from sediment encroachment, they are generally subject to special difficulties and limitations.

Main reliance for material and permanent conservation of reservoir resources therefore must rest upon control of sediment production at primary sources through more widespread and effective application of established methods of erosion control.

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APPENDIX

The following instructions are now in effect for reservoir surveys made by the Soil Conservation Service.

INSTRUCTIONS FOR RESERVOIR SEDIMENTATION SURVEYS

PURPOSE

The immediate objective of each survey will be the determination of the volume and distribution of sediment accumulated within the storage basin during a specific period of time, either the entire period of the reservoir's existence or a shorter period between an earlier and the current survey.

The ultimate objectives are (1) to establish information on the factors involved in reservoir silting, the rates of silting, the effects of different soil, slope, and climatic conditions and to correlate these results with land use in the drainage area, and (2) to develop new methods of sediment control supplementary to existing erosion-control practices.

GENERAL PLAN OF SURVEY

Survey operations, in all cases, will be designed to establish accurate basic data and field lay-out, to facilitate future resurveys as well as to check previous surveys and indicate past rates of silting.

The nature of field work will depend upon choice of surveying methods, but will include under different conditions triangulation control, areal and topographic mapping, range location, sounding and leveling range cross sections, and direct measurement of sediment deposits.

Office work will include preparation of a reservoir map, showing results of field work, plotting and planimetering cross sections, computation of original capacity and sediment volumes, and preparation of a project report.

CHOICE OF RESERVOIRS

Choice of reservoirs for survey will be based on a Nation-wide reconnaissance now in progress. Factors to be considered are original storage capacity per square mile of drainage area in relation to annual rainfall, distinctiveness and character of drainage area, amount of sediment, availability of previous base maps, and cooperation of owners.

Recommendations of reservoirs for detailed survey and recommendation of a program to be followed will be submitted by the field specialists in charge of reconnaissance, but final choice and approval will be made by the Washington office.

CHOICE OF SURVEY METHODS

Choice of methods to be followed in making the detailed survey will depend on the amount and distribution of sediment as indicated by reconnaissance, and on the availability and character of previous base maps.

Sediment volume and distribution may be derived by mapping contours—for comparison with older maps—on the surface of the deposits over the entire lake, by establising, sounding, and measuring sediment depth on ranges, or by a combination of the two methods. Choice of methods will depend on the conditions indicated below.

Contour Method

The principal advantage of the contour method is that it shows both the vertical and horizontal distribution of sediment and allows plotting of capacity curves. On the other hand, it generally necessitates a longer period of survey and increases the chance of error unless the original basin maps are of a high standard of accuracy.

The contour method can be used only where accurate base maps on suitable scale with contour interval not over 10 feet are available. Contouring should not be resorted to on those parts of the lake where penetration with the spud may be universally obtained, providing these areas amount to 50 percent or more of the total area of the original basin.

Range Method

The range method has the advantage of shortening the time of survey and of allowing actual sediment-thickness measurements. It is to be used where more than 50 percent of the lake area is covered by deposits that can be penetrated with the sampling spud. In the absence of contour maps, it may be used on the deltas if original cross sections can be established by borings or from known elevations in the old valley.

Combination of Ranges and Contours

A combination of the two methods will be applicable to many of the reservoirs surveyed. It will consist of setting up and measuring ranges over the lower part of the lake where penetrations are generally obtainable, and mapping contours on the delta portions of the lake, provided previous contour maps are available for comparison. Previous maps will be checked by well-distributed borings wherever possible.

RANGE METHOD

Triangulation Control

Triangulation control is to be established on lakes where adequate previous base maps are not available. Where maps of suitable scale and accuracy can be obtained ranges may be tied together by stadia control with frequent reference lines to prominent points shown on the maps, such as benchmarks, property corners, bridges, houses, junction of streams or conspicuous irregularities of contours. Observed errors in previous maps, especially in shore line, should, however, be corrected by remapping, using adjacent correct points for control.

Triangulation control may be used for establishing ranges where distances are so great that stadia readings cannot be made.

Triangulation control, where it is necessary, will be established by plane-table methods, starting from a chained and rechecked base line, and will be further checked by chain measurement between located points in the outer reaches of each major extension of the main network.

Mapping scales will be adjusted to the size of the reservoir with a view to facilitating progress and keeping the number of field sheets within practical limits. On reservoirs a mile or two long, scales of 1 inch=100 feet to 1 inch=400 feet will serve. On larger reservoirs scales of 1 inch=500 feet to 1 inch=1,000 feet should be used.

Base lines 2,000 to 5,000 feet long, according to the scale of the map, are preferable to shorter lines. In general, base lines should be as long as the greatest distance between any two adjacent or opposite triangulation stations.

Supplementary Control

Supplementary control will be tied to triangulation stations where they have been established; otherwise, to well-located features shown on the map. It will be extended by stadia traverse, depending on foresight and backsight orientation of the plane table. In small bays or narrow winding lake arms that involve no great distances, magnetic orientation may be substituted locally, using a magnetic line drawn at the last backsight control station.

The principal use of supplementary control in the range method will be for mapping shore line.

RANGE LOCATION

Where the range method is applicable, the main body of the lake and its principal arms will be subdivided by cross ranges so that the silted condition of each subdivision will be represented, insofar as possible, by the average of conditions on the bordering ranges.

The ranges should extend rather directly across the lake from shore to shore where it is practicable, but of greater importance is the need for having the upstream and downstream ranges approximately parallel. A divergence of not more than 10° may be tolerated for convenience in locating the ranges, but not more than 30° should be permitted in any case except as stated below. The series of ranges should begin with an initial range just above the dam on the main body of the lake, or directly across the mouth on the arms, and should extend upstream to its head or to a final cross range below the delta area to be mapped in detail by contours.

Frequently there will be bends or curves in the reservoir that will render the maintenance of the above limit of divergence for the entire series impracticable. In such cases the series is to be broken up into sets where the limit of divergence is maintained within each set. In the segment between the sets the ranges may have any divergence not greater than 90°. In these transition segments it is desirable to have the end ranges set very close together, or starting from a common point, the purpose being to concentrate the irregularity into the smallest area so that it will have the least effect.

Where a tributary enters or an arm of the lake is cut off, a new series of ranges is started without regard to the direction of the two main ranges of the segment. The first range should be across the mouth of the tributary and perpendicular to its general direction or as near to this position as practical considerations will permit.

RANGE ELEVATION

The elevation of each end point of a range must be established. Where the end point of the range is not more than 500 feet from the water's edge, the plane table may be used as a level in establishing this elevation. The elevation of the range end on the opposite side of the lake may be established by level or plane table, provided the shots to the end point and to the water's edge are neither more than 1,000 feet long, and the difference in the length of these two shots is not more than 200 feet. The difference between the two rod readings is added to the lake level to give the elevation of the range end.

If range ends are far removed from water surface, a level should be used to carry elevations to the range ends; and if an entire section of the reservoir basin is above backwater at the time of survey, level lines must be carried either from accurately determined water surface below the lower zone of flowage into the reservoir or from established benchmarks known to be correct with respect to water-elevation gages used for other parts of the lake.

Where water surface is used for elevations, the height of water should be obtained hourly to the nearest tenth of a foot. In most power reservoirs, a gage is located on the dam or power-house.

In such cases arrangements should be made in advance with the operators in charge to furnish hourly water-level readings during field hours. In other cases, on many smaller lakes, it will be necessary to establish a temporary water gage. A simple type for field use can be made by graduating a long piece of lumber in feet and tenths and driving it into the bottom of the lake near the dam or pier where the depth of water is greater than the probable draw-down in the lake during the course of survey. The gage should be tied by levels to a permanent benchmark if one is available within reasonable distance. Otherwise assume a datum for height of water at the beginning of the survey. With a temporary gage it may be necessary to employ a local resident to take water readings hourly.

RANGE PROFILES

Elevations on top of the sediment deposits will be taken along each range below water level at regular intervals by soundings. Elevations above water will be taken by levels up to the range-end monument, which must be set above spillway level.

Sounding intervals of about 20 feet are suitable on ranges up to 500 feet in length. On longer ranges with generally regular profile, intervals of 50 to 100 feet may be used without material increase in error.

Direct Measurement of Sediment

Direct measurement of sediment with the sampling spud (fig. 27) to the nearest tenth of a foot is to be made at intervals on all ranges wherever penetrations to the underlying basin soil can be obtained.

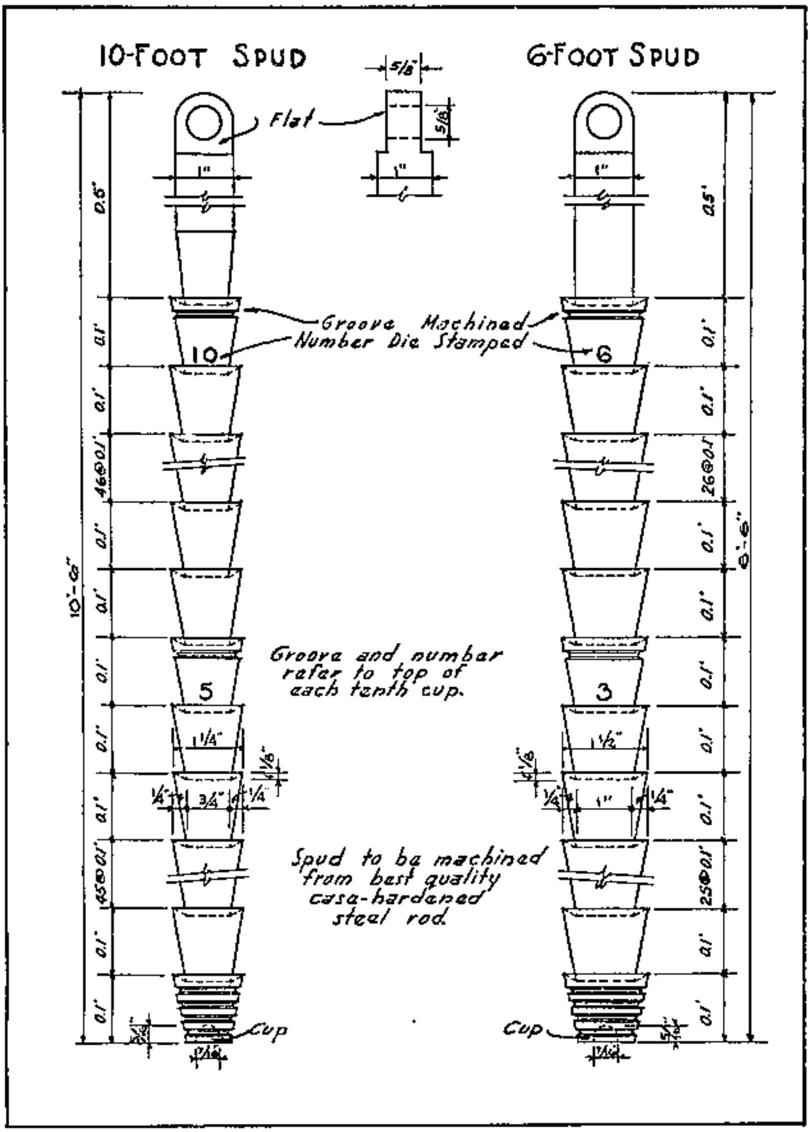

Figure 27.—Sediment-sampling spuds.

Water depths are to be measured and recorded at each point of direct sediment measurement. The elevation of old soil surface is to be computed from this depth and the determined sediment thickness, both below water and on exposed shore if the lake is drawn down below crest level.

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Spud observations on ranges 500 feet or less in length should be taken at intervals of 20 to 50 feet, or with each second sounding. On ranges 500 to 1,000 feet long, spuddings should be taken every 50 feet, or with every second sounding. On ranges from 1,000 to 2,000 feet long, spuddings should be taken every 100 feet, or with every third sounding. On longer ranges spuddings may be 200 feet or more apart. Spacing of spuddings will depend on silting conditions, and rigid rules need not be followed. The main object is to obtain a measurement with each appreciable change of sediment depth. Thus spuddings should be closer together where the range crosses the original stream channel, and may be farther apart over broad flat areas. The edge of the sediment toward each range end should be determined and located on the map either by probing with the spud or by search between the water's edge and range monument.

Spuddings should be taken simultaneously with soundings on one trip across the range.

Use of Sediment Sampler or Spud

The sediment sampler or spud will be used on range or elsewhere only when the boat is held stationary either by the boatman or by anchor.

The spud will be plunged from sufficient height to give penetration through the sediment and slightly into the underlying original soil. The longer more slender spud will be used where deeper penetration is required.

Distinction between old soil and lake deposits generally depends upon comparative softness and lack of grit in the deposits. Often there is a marked difference in color. Where old soil is clayey it generally clings to the spud more stiffly than the sediment; where sandy, it may fail to come up on the spud, in which case a clean section of spud marks the lower limit of the deposit.

In many places the sediment contains leaf fragments that are absent in the old soil, or the old soil may contain roots and rootlets that are absent in the sediment.

In very deep water or where the deposits are gritty and the spud sample tends to wash off on the way to the surface, it may be advantageous to smear one side of the spud with ordinary automobile cup grease. This has been found efficient in retaining a sample of sand.

Measurement of Volume of Delta Deposits

Where deltas are present and original contour maps of the basin are available, the contour method described below is to be followed in surveying that portion of the lake or lake arm between the last range where sediment penetration can be obtained and a point where backwater is confined entirely to the original channel.

Between the point where backwater is confined entirely to the original channel and the actual upper limit of backwater, ranges from bank to bank along the channel will give the present cross section. The original cross sections may be reconstructed from such data as are available, particularly original river profiles and borings.

Plotting and Planimetering

Range profiles are to be plotted on cross-section paper ruled 10 squares to the inch. For most ranges a horizontal scale of 50 feet to the inch and a vertical scale of 5 feet to the inch will be satisfactory. In some more detailed work or with small sediment thickness it may be necessary to use a vertical scale of 2 feet to the inch. In special cases, scales may be varied to fit a particular problem at hand.

The elevation of the sediment surface, or of the original bottom where sediment is absent, should be calculated for each point of sounding by subtracting the depth of water from the elevation of water surface during the hour of sounding, as obtained from gage readings.

The elevations calculated for each sounding are to be plotted as a profile cross section of the range. Distances of soundings from one end of the range are scaled from the plane-table sheet, read to the nearest foot by using magnifying glass, and recorded in the notebook. Distances and elevations being determined, the points are plotted and are joined by straight-line segments to form the range cross section.

The elevation of the old soil at each point of spudding may be plotted easily after the sediment surface cross section is completed by plotting a point directly below the sounding equal to the sediment thickness recorded. The thickness of sediment at each point of sounding between spud measurements should be plotted by interpolation.

Where the thickness of sediment requires boring by auger for penetration, the present surface may have little relation to the original surface, now buried, and in such cases interpolation should not be done by rule of thumb, but rather in the light of circumstances, using all available data on original valley slopes and profiles to supplement boring data.

The cross-section area enclosed by the old-soil or bottom curve below crest level is to be obtained by planimeter in square feet. The cross-section area enclosed by the sediment surface or upper curve below crest level is measured in the same way. The difference between these two quantities represents the cross-section area of sediment. Results on the above scale should be accurate to within 1 percent and should be recorded on each cross section.

Range lengths for use in calculations are to be scaled from the cross sections between shore lines which are taken as the points where the old soil curve crosses the spillway elevation contour. Ranges are to be drafted on the base map. Where the range lengths do not agree with the distances between shore lines, the shore lines are to be adjusted, on the basis of field data, preferably by remapping.

The total area enclosed by all the ranges and intervening shore line bounding each segment of the lake is to be planimetered. The quadrilateral area, which is formed by the two main ranges and straight lines connecting the points where they intersect the shore lines, is then obtained by planimetering or scaling and computation. These areas, total and quadrilateral, will be converted into acres to the second decimal place, recorded on the base map, and labeled A and A', respectively.

The planimeter work must be carefully done. At least four separate measurements within 1 percent variation must be made and averaged on each curve and segment for correct results.

COMPUTATION OF ORIGINAL CAPACITY AND SILT VOLUME

The segments, or subdivisions, of the lake may be bounded by any number of ranges and intervening stretches of shore line. Areas with two ranges may have one or two stretches of shore line and areas with three or more ranges may be closed figures with no shore line or may have any number of stretches up to the number of ranges.

The original capacity and sediment volume for all segments except the one next to the dam will be computed by the following general formula:

$$V=\frac{A'}{3}\left(\frac{E_1+E_2}{W_1+W_2}\right)+\frac{A}{3}\left(\frac{E_1}{W_1}+\frac{E_2}{W_2}\right)+\frac{h_3E_3+h_4E_4+\ .\ .\ .}{130{,}680}$$

where: V=Original capacity or sediment volume, in acre-feet.

A'=The quadrilateral area, i. e., the area in acres of the quadrilateral formed by connecting the points of range intersection with crest contour between the two principal or most nearly parallel ranges.

A=The lake area of the segment in acres.

E=The cross-sectional area, in square feet, of original capacity or sediment volume cut by a bounding range.

W=Width (length of bounding range) at crest elevation in feet.

h=The perpendicular distance from the range on a tributary to the junction of the tributary with the main stream, or if this junction is outside the segment, to the point where the thalweg of the tributary intersects the downstream range.

The subscripts of E, W, and h identify these quantities with the respective ranges of the segment.

The formula is general and covers all cases except the special case of the segment next to the dam where the effect of the shape of the dam does not lend itself to inclusion in the formula. The application of the formula is exactly the same for sediment volume as for original capacity and all quantities used, except those for E, will have the same values.

For each segment, the numbers of the ranges, which are the subscripts in the formula, will generally be taken so that No. 1 is the downstream range, No. 2 the upstream, and Nos. 3 and higher are ranges on tributaries or arms of the lake. In cases where the range on a tributary, or arm of the lake, is nearer parallel to range No. 1 than the upstream range it is taken as No. 2 and the upstream range as No. 3.

It will be seen from the derivation of the general formula, as given below, that, theoretically, there must be at least two ranges in a segment. Where only one appears, as on a tributary or lake arm, No. 2 must be considered as a point at the extreme upper end of the arm. Here then, is a range with zero cross-sectional area, $E_2=0$, and zero width, $W_2=0$, although A' is not zero. The quadrilateral area, A', in this case has one side, W_2, that is zero and has the shape of a triangle with W_1 as the base and the point of hypothetical range No. 2, as its apex. In this case the formula reduces to:

$$V=\frac{A'}{3}\left(\frac{E_1}{W_1}\right)+\frac{A}{3}\left(\frac{E_1}{W_1}\right)=\frac{A'+A}{3}\left(\frac{E_1}{W_1}\right)$$

The use of the formula for segments having two or more ranges is obvious; the quantities bearing subscripts greater than the number of ranges are equal to zero and vanish.

The original capacity and sediment volume for the segment next to the dam, which has only one range, will be computed by the formula,

$$V=A\frac{E}{W}-V_0$$

where the values of V, A, E, and W, are the same as above and V_0 is the volume, in acre-feet, displaced by the upstream face of the dam. For concrete dams with vertical or nearly vertical upstream face, $V_0=0$. For dams with an upstream slope, V_0 is computed, as follows:

For original capacity,

$$V_0=\frac{HBL}{174{,}240}$$

and for sediment volume,

$$V_0=\frac{L\left(2B-\frac{E}{W}s\right)\frac{E}{W}}{130{,}680}$$

where L=Length of dam in feet.
B=Width of base of dam at original bottom of reservoir.
H=Height of dam, original bottom of reservoir to crestline.
s=Slope of upstream face of dam.

Derivation of the Formula

A formula is desired that will give the most probable values for original capacity and sediment volume when the available data consist of: (1) The lake area of the subdivision; (2) the width and cross-sectional areas of the ranges and (3) the points where the thalweg of the streams intersect the ranges. These represent in most cases the extent of data available where the range method is used. In using the general formula, the values of the quantities h, for ranges Nos. 3 and higher, must be known in addition to the given data. Wherever possible these are to be obtained by plotting original channels from previous maps on present survey maps. Where the location of old channels is not shown on previous maps the points of junction of the tributaries and the main stream must be plotted from judgment, using as guides the shape of the shore line and the points where the thalwegs intersect the ranges as plotted from the range cross sections. These values of h may not be as accurate as desired but they represent the most probable from the available data.

When an engineer wants the most accurate value of the yardage in a cut, fill or levee from cross sections, he uses the prismoidal formula. This formula gives exact results when the figure is a true prismoid, and for many figures that are prismoids only by liberal definition. In the problem at hand, the figure is never a true prismoid, but the formula makes a good point of beginning.

Consider, first, an imaginary segment with two parallel ranges and shore lines that are straight lines connecting the ends of the ranges. The most probable capacity of this segment can be represented by a prismoid having either rectangles or triangles, with areas equal to the actual areas, for end faces.

The width, W, and the depth, $\frac{E}{W}$ or $\frac{2E}{W}$ vary uniformly from one end face to the other. These prismoids are shown in figure 28, A, B, and C.

Using the notation of the general formula, h', for the perpendicular distance between the ranges, and the subscript, m, for the computed midrange, the volume of either of these prismoids can be computed as follows by the prismoidal formula:

$$V' = \frac{h'}{6}(E_1 + 4E_m + E_2)$$

where

$$E_m = \frac{1}{4}(W_1 + W_2)\left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right)$$

which gives

$$V' = \frac{h'}{6}\left[E_1 + (W_1 + W_2)\left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right) + E_2\right]$$

but

$$A' = \frac{h'}{2}(W_1 + W_2)$$

so that

$$V' = \frac{A'}{3}\left[\left(\frac{E_1 + E_2}{W_1 + W_2}\right) + \left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right)\right].$$

It will be seen from this equation that the average depth of this segment is $\frac{1}{3}\left[\left(\frac{E_1 + E_2}{W_1 + W_2}\right) + \left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right)\right]$. This volume can be obtained, in the case of figure 27, A, by breaking the prismoid down into prisms, wedges, and pyramids and taking the sum of their volumes; but in the case of figure 28, B, this method

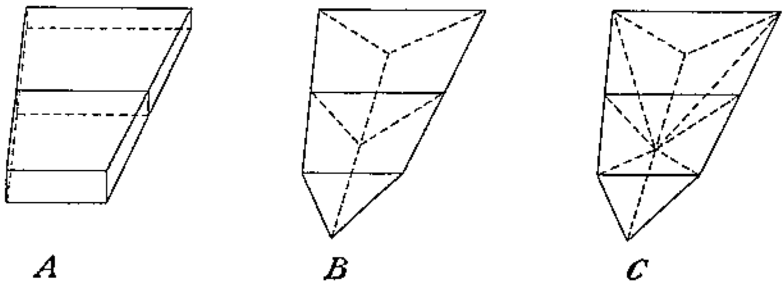

Figure 28.—Equivalent prismoids: A, rectangular; B, triangular with warped surfaces; C, composed of three pyramids.

cannot be used because the slope faces are warped surfaces. By resorting to calculus the volume can be proved correct in the latter case.

If the prismoid shown in figure 28, B, is changed to the one in figure 28, C, it will be bounded by eight triangular and one quadrilateral plane surfaces and by the prismoidal formula will have the same volume. That this volume is correct for the new prismoid can readily be proved by breaking it down into three pyramids.

In building up the formula so far, only straight shore lines have been considered and the area used, A', is the quadrilateral area of the general formula. The width of the lake is usually greater between the ranges than at the ranges. This is to be expected because the narrow places are the most practical places to locate ranges. In the large majority of cases, this makes the lake area, the A in the formula, greater than the quadrilateral area, A'. The total volume can be regarded as made up of the volume already established for straight shore lines (fig. 28, C) plus the volume contributed by the excess area, $A—A'$. This latter volume might be regarded as equivalent to a wedgelike figure having the maximum depth line as its edge, or a pyramid having the depth to the midpoint of the maximum depth line as its altitude. If we consider figure 28, *C*, as the most probable equivalent of the volume for straight shore line and picture the shore line as bent outward in curves the added volume takes the form of the pyramid. A study of the shape of contours in natural reservoirs provides convincing evidence that the pyramid is the form to use rather than the wedge for the excess volume. This gives for the excess volume,

$$V''=\frac{1}{3}(A-A')\left(\frac{E_1}{W_1}+\frac{E_2}{W_2}\right)$$

This volume added to the volume for straight shore line gives,

$$V=V'+V''=\frac{A'}{3}\left(\frac{E_1+E_2}{W_1+W_2}\right)+\frac{A}{3}\left(\frac{E_1}{W_1}+\frac{E_2}{W_2}\right)$$

From the form of this equation and from the shape of the figure developed as the equivalent of the most probable volume, it will be seen that, had it been self-evident that this was the shape to use, the above formula could have been derived by taking the sum of the volumes of three simple pyramids.

When tributaries enter the subdivision, or arms of the lake are cut off by ranges, there will be more than two ranges to consider. The formula developed for two ranges is the sum of the volumes of three pyramids with bases equal to the lake area and the two end areas. The altitude of the latter two are automatically cared for in the quadrilateral area, A'. The third and higher numbered ranges will also enter as pyramids with the range end-areas as bases and with altitudes to be determined. Bearing in mind that the shape used in obtaining the most probable volume was an equivalent shape and not the actual shape, a study of natural conditions indicates that the altitude should be the perpendicular distance from the range to the junction of the streams if the junction is inside the subdivision or, if not, to the point where the thalweg of the tributary intersects the lower range.

All the foregoing assumes that ranges Nos. 1 and 2 are parallel, a condition seldom encountered in practice. The only part of the formula affected by diverging ranges is the expression involving A' as a direct factor. The computation of the error caused by this condition for any segment is impractical because it involves the unknown location of the intersection of the thalweg with an imaginary midrange. Careful investigation indicates, however, that this error is insignificant up to a 10° divergence of ranges and that it tends to compensate in the sum of the volumes of the segments.

CONTOUR METHOD

Triangulation Control

Triangulation control is to be established on lakes where adequate previous base maps are not available. Where maps of suitable scale and accuracy can be obtained, surface or subsurface contour mapping should be controlled by frequent reference shots to prominent points shown on the original maps. It is essential that the crest contour as previously mapped should be used, with corrections if necessary, in order that the remapped surface may correspond with the original surface at a level above sediment deposits. The original and present contours below crest will both be shown on one final map by different symbols.

Triangulation may be used where it is deemed necessary as a base for random or radial soundings used to plot subsurface contours. Because of the time required, however, it should be dispensed with wherever the original maps afford a satisfactory base for accurate location of points.

Surface Contour Mapping

Surface contour mapping is to be used on delta areas where the lower portions of the lake are surveyed by the range method, and on all sediment deposits above water at the time of survey where the contour method is used over the entire lake.

Contours must be mapped at not more than 5-foot intervals. On the flatter portions of the sediment deposits, elevations should be obtained at sufficiently frequent intervals to map 1-foot contours which should be drawn on the plane-

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table sheets. On the final map, only those contours which correspond to the original contours need be shown. That is, if the original maps show 5-foot contours, then the same contours on the present surface should be drawn, although on the plane-table sheets the 1-foot contours are also shown.

In surface mapping, stadia traverse and intersection should be used, tying to established locations. Stadia shots should be taken in all the visible area from each traverse station, and separate traverses, each frequently tied to control points, should be made in sufficient number to thoroughly cover the surface.

Three-point location should not be resorted to except in special cases where time required for traverse would be excessive. No traverse should be run from a three-point location.

Subsurface Contour Mapping

Several methods may be used for obtaining accurate location in subsurface contour mapping. Each will doubtless be found of advantage at one time or another during the course of subsequent surveys. It is a prime requisite, of course, that an adequate number of accurately located soundings be taken to afford a sure basis for interpolating contours on an invisible surface. Naturally, the more irregular the sediment surface, the more soundings required, and, conversely, the flatter the fewer.

(1) A radial fan of lines covering a section of the lake may be drawn on the plane table at any previously established station at suitable angle-intervals of 10° or 15°. A cut-in station is established by stadia and so located that suitable intersections may be obtained on all radial lines. A transit is set up over the pivotal station and the angles turned as plotted on the plane-table sheets. The boat moves along the lines directed by signals from the transitman. Soundings are located on the plane table at a cut-in station by a direction line drawn to cross the radial line on which the boat is moving.

(2) A control network of stations covering both banks of the lake may be established. From alternating stations on each bank radial lines are plotted on the plane-table sheets at suitable angle-intervals, usually 10°, beginning with the orientation line toward another station in the previously established net. Adjacent stations in the net may serve as cut-in points. A transit is set up at the apex of a set of radial lines and oriented on one end station of the radial pattern. The boat moves along this initial line directed by signals from the transitman. The plane-table operator at the cut-in station signals for soundings. As this subrange is complete the transit is turned 10° and the boat directed along the second subrange. The process is continued until this radial pattern of subranges is completed, whereupon the transit is moved to the apex of an adjoining radial pattern on the opposite shore to continue the soundings.

(3) The system of transit and plane table operated at adjacent stations in a previously established net may be used without establishing a radial pattern of ranges. In this case, the boatman may direct progress of his movements, and on his signals an angle is read on the transit with each sounding and a direction line drawn on the plane table. This permits boat movements in a zigzag course under conditions that permit entry only along certain channels.

(4) The underwater surface may be contoured by establishing ranges sufficiently close together in the same manner as in normal range work. This is sometimes advisable and time-saving where the sediment surface is especially flat and even.

(5) Under unusual conditions and in quiet water, sounding positions may be located from a stadia rod held firmly in the center of the boat. This method should be used only in emergencies, however, as it is especially susceptible to error.

Computation of Original Capacity and Sediment Volume

Where an original contour map is available and the sediment surface has subsequently been remapped on the same scale and contour interval, the following modified prismoidal formula will be used for computing the original capacity and sediment volume between two adjoining contours. The formula may be used for either a segment of the lake bounded by one or more ranges and intervening stretches of shore line, or for the lake as a whole bounded only by the dam and shore line.

$V = L/3 \ (A + \sqrt{AB} + B)$ acre-feet.

where V=Original capacity or sediment volume in acre-feet.

L=Contour interval in feet. In the lowest prismoid, L is the vertical distance between the lowest contour and the lowest point in the bottom of the reservoir.

A=Area, in acres, of the original lower contour for original capacity, or difference between the areas of the original lower contour and the present lower contour for sediment volume. In the lowest prismoid A equals zero for both original capacity and sediment volume.

B=Area, in acres, of the original upper contour for original capacity, or difference between the areas of the original upper contour and the present upper contour for sediment volume.

The formula is applied progressively to the prismoids, or volumes between the contours, beginning with the prismoid between the lowest contour and the bottom of the reservoir. The sum of these volumes will give the desired total.

This method of computation has the advantage of establishing distribution of original capacity and total sediment in the vertical as well as areal plan of the reservoir, which is of great practical importance from the viewpoint of reservoir utility.

FURTHER COMPUTATIONS

The following additional computations should be made and the results tabulated, as shown in the tabular summary at the end of the following section on preparation of final reports.

1. Original area at crest stage. (Sum of all surface areas planimetered from original base maps or remapped original crestline contour. (Acres.)
2. Area at crest stage at date of survey. (Sum of all surface areas to present crestline contour. Should be less by the amount of delta fill to and above crest, and greater by the amount of bank erosion.) (Acres.)
3. Original storage capacity. (In range method, sum of capacities of various segments. In contour method, obtained by planimetering original base maps.) (Acre-feet.)
4. Storage capacity at date of survey. (In range method, sum of original capacities of various segments less sum of sediment deposited. (Acre-feet.)
5. Storage per square mile of drainage area.

$$\text{Original} = \frac{\text{acre-feet of original storage}}{\text{square miles of drainage area}} \text{ (Acre-feet)}$$

$$\text{At date of survey} = \frac{\text{acre-feet of remaining storage}}{\text{square miles of drainage area}} \text{ (Acre-feet)}$$

Compute to second decimal place.

6. Delta deposits. (Sum of all volume computations of delta deposits in various segments.) (Acre-feet.)
7. Bottom-set beds. (Sum of all volume computations of bottom-set beds in various segments.) (Acre-feet.)
8. Total sediment. (Sum of 6 and 7.) (Acre-feet.)

9. Average annual accumulation$= \dfrac{\text{total sediment}}{\text{years}}$ (Acre-feet).

Compute to second decimal place. Years should be determined to a fraction representing nearest month when filling began.

10. Annual accumulation per 100 square miles of drainage area=

$$\frac{\text{Annual accumulation (determined in 9)} \times 100}{\text{Square miles of drainage area}} \text{ (Acre-feet)}$$

Compute to second decimal place.

11. Annual accumulation per acre of drainage area=

$$\frac{\text{Annual accumulation (determined in 9)} \times 43560}{\text{Square miles of drainage area} \times 640} \text{ (Cubic feet)}$$

Compute to second decimal place.

12. Also,
where n=Average dry weight of sediment in pounds per cubic foot, as determined from undisturbed samples.

$$\frac{\text{Cubic feet (determined in 11)} \times n}{2000} \text{(Tons)}$$

13. Loss of original capacity per year=

$$\frac{\text{Accumulation per year (acre-feet determined in 9)} \times 100}{\text{Original capacity (acre-feet determined in 3)}} \textit{(Percent)}$$

Compute to second decimal place.
14. Loss of original capacity to date of survey.

$$\frac{\text{Total sediment (acre-feet determined in 8)} \times 100}{\text{Original capacity (acre-feet determined in 3)}} \text{(Percent)}$$

NOTE KEEPING

Field notes should be kept in standard engineering field books which may be obtained on requisition from the Washington office. All notes should be neatly and uniformly printed. The flyleaf in the front of each notebook should contain a legend after the following pattern:

SEDIMENTATION SURVEY

of

Boomer Lake

Stillwater, Oklahoma

June 4–18, 1935

Sedimentation Studies

Soil Conservation Service

U. S. Department of Agriculture

Field Book No. 1 of 3 — Thomas L. Kesler, Chief of party.

The same legend should appear on the front cover of the notebook.

Immediately following the flyleaf should be a complete index of all notebooks of the survey if more than one book is used. There should follow a separate index of the first notebook, and each succeeding notebook should have an individual index.

Following the last index of the first notebook, all general description of the reservoir, namely, the information required in the reservoir inventory report, should be given. Also any additional information of importance regarding the survey.

Notes of various types such as triangulation, stadia traverse, range sounding, etc., shall be segregated on separate pages but may be given in any order in a properly indexed notebook. Notes shall conform to standard engineering practice, care being taken that sounding and spud notes contain adequate legend for use by engineers unfamiliar with this type of survey. Weather conditions and duties of each engineer should be recorded daily.

Planimeter measurements and computations of areas and capacities should be recorded in the last notebook following field notes. All factors scaled from maps and sections, such as range widths and lengths of lines erected for height of pyramid in side arm computations, must be recorded.

No field book should contain notes on more than one lake.

Tabulations

RANGE SURVEYS

Ranges

Range No.	Length (feet)	Original cross-section area (water plus sediment)	Cross-section area at time of survey (water)	Sediment cross-section area

Surface areas

Segment No.	Square feet	Acres	Ranges bounding segment
Total			

Segment volumes

Segment No.	Original capacity (acre-feet)	Capacity at date of survey (acre-feet)	Sediment (acre-feet)
Total			

CONTOUR SURVEYS

Areas enclosed by contours

Contour elevation	Original area (acres)	Area at date of survey (acres)	Difference (acres)

Capacities by contour intervals

Bounding contours	Original capacity (acre-feet)	Capacity at date of survey (acre-feet)	Sediment (acre-feet)
Total			

Capacities to each contour

Elevation	Original capacity (acre-feet)	Capacity at date of survey (acre-feet)

SURVEY MONUMENTS

All triangulation stations, range ends, and other important survey points will be marked by substantial concrete monuments set 2 to 6 feet in the ground, depending on the depth of freezing. Elevations will be determined on the top center of each monument, which will be marked with the station number and properly recorded in the field book.

PREPARATION OF REPORTS

In the preparation of reports on each reservoir survey, the following outline should be followed as rigidly as possible in order to insure uniformity of treatment in the several parts. It will not, of course, be possible to obtain all the information suggested here for each report, nor will a place be found in this outline for every class of information that may be of local importance. It should be borne in mind that the principal objective in these reports is to present a systematic, clear, and concise arrangement of data and observations in uniform style. Tabulations should be used as much as possible, so long as they are readily understandable even to casual inspection.

OUTLINE OF REPORT

Abstract

A concise summary, in four or five paragraphs, of the important facts contained in the report, including short descriptions of the reservoir, drainage basin, and sediment deposits; the more significant quantitative results of the survey; and a brief statement of the principal conclusions expressed.

Introduction

A brief statement of the project of which this survey is a part; dates of survey period; names of party and of party chief and other personnel; and acknowledgments of all assistance and cooperation received in making the survey.

General Information

Location.

State.—

County (or counties).—(Give also sections, townships, and ranges where possible.)

Distance and direction from nearest city.—

Drainage and backwater.—(Give drainage on which dam is located and all important tributary streams on which backwater is impounded.)

Ownership.—

Purpose served.—(If dual purpose, as water supply and power, compare use for the two purposes.)

Description of dam.—(Give type, material of construction, length, height, thickness, elevation of spillway, and any special features such as floodgates, mud gates, character of foundation, etc.)

Date of completion.—(To nearest month, also average date of survey and total age to date of survey.)

Length of lake.—(From dam to head of backwater along axis of reservoir. Give also length of major arms.)

	Miles (or feet)
Original	
At time of survey	
Amount shortened	
(When unchanged write: Original and at time of survey)	

Area of lake at spillway stage.—

	Acres
Original	
At time of survey	
Reduction	

Storage capacity to spillway level.—(If a water-supply reservoir give gallons also. Show whether original capacity determined by this or earlier survey.)

	Acre-feet
Original	
At time of survey	
Loss due to silting	

General character of reservoir basin.—(General discussion of physical characteristics of reservoir basin.)

Former sedimentation surveys.—(Give in detail all information obtainable on former surveys, including type of survey, date, name of persons or agency making survey, and results obtained.)

Area of drainage basin.—(Square miles or acres.)

General character of drainage basin.—(Brief description, usually to be confined to one or two paragraphs on each of the following topics, in order):

(1) Geology.
(2) Topography and drainage.
(3) Soils.
(4) Land use.
(5) Erosion conditions.

Mean annual rainfall.—(Weather Bureau reports, Soil Survey reports, Soil Conservation Service regional office data.)

Inflow into reservoir.—(U. S. Geological Survey gaging records where available.)

Evaporation.—(Available only in certain places. Often determined by owners of reservoir.)

Draft on municipal reservoir.—(Usual daily or monthly draft. Season of greatest use and draft during this period.)

Power development.—(Installed power equipment; number of units, rating of each and of plant as a whole, in horsepower, kilowatts, or kilovolt-amperes; operating head under full reservoir; average daily or seasonal draw-down of reservoir below spillway crest level; draft in cubic feet per second under full plant operation with full reservoir.)

Irrigation.—(Annual draft or amount of water used during the whole growing season, in acre-feet; either from records or from number of acres irrigated multiplied by usual depth in feet of water applied to typical crops during a full season.)

Method of Survey

Summarize work done, as the number of triangulation stations, number of ranges, miles of shore line mapped, acres contoured. Refer to general method used in survey. Give mapping scale and description of previous base maps available.

Description of any local peculiarities that necessitated methods not covered in general instructions. Complete description of any methods used that did not conform to general standards.

Sediment Deposits

Character of sediment.—Describe the sediment as to texture, color, and consistence in various parts of the lake. Include results of laboratory studies.

Distribution of sediment.—Discuss the general distribution of sediment, illustrating where feasible with tables and graphs (longitudinal profiles, capacity curves, sediment curves, etc.) the average and specific sediment depths in various parts of the basin, actual and percentage volumes by natural units, and by contour intervals where the contour method was used.

This section should include a discussion of factors influencing distribution, such as configuration of basin, nature of incoming sediment, underflow, history of reservoir operation (draw-down, change in dam height, etc.), wave action, mass movements of sediment, and other factors whose effects are evident. Where laboratory studies bearing on distribution have been made these should also be included.

Origin of sediment.—Interpret the character and distribution of sediment in terms of source material, slope, climate, land use, erosion conditions, etc. Discuss the relative importance of specific areas and soils of the drainage basin as sources of reservoir sediment.

CONCLUSIONS

All interpretations, conclusions, and recommendations based on the completed study and digest of silting and watershed conditions (unless adequately brought out under the preceding headings) should be presented in a final section. This section will always include the tabular summary of quantitative results of the survey.

Treatment of special field studies, as of wave erosion, upstream deposition induced by the reservoir, and mass movement of sediment, may be placed under separate headings where this seems desirable for emphasis. Otherwise they will be included under one of the preceding headings.

Summary of data on ____________, ____________, ____________
(Reservoir) (City or county) (State)

Age [1]	years	----------
Watershed area [2]	square miles	----------
Reservoir:		
Area at spillway stage:		
Original	acres	----------
At time of survey	do	----------
Storage capacity to spillway level:		
Original	acre-feet	----------
At time of survey	do	----------
Capacity per square mile of drainage area: [3]		
Original	do	----------
At time of survey	do	----------
Sedimentation:		
Total sediment	do	----------
Delta deposits	do	----------
Bottom-set beds	do	----------
Average annual accumulation:		
From entire drainage area	do	----------
Per 100 square miles of drainage area [3]	acre-feet	----------
Per acre of drainage area [3]	cubic feet	----------
	tons [4]	----------
Depletion of storage:		
Loss of original capacity:		
Per year	percent	----------
To date of survey	do	----------

[1] Storage began in__________ ______ (Month) (Year); average date of survey, __________ ______ (Month) (Year)
[2] Including area of reservoir.
[3] Excluding area of reservoir.
[4] Based on an average dry weight of ____ pounds per cubic foot, as determined from ____ undisturbed samples.

PREPARATION OF MAPS, ILLUSTRATIONS, AND SUPPLEMENTAL MATERIAL

(1) A general map of the lake showing shore line and other contours, all triangulation and supplementary control stations, ranges, and range ends should be prepared for planimeter measurements. This map should be labeled with range widths and acreage within segments. Where original maps of suitable accuracy are available all surveying data and legend may be drafted on these providing no confusion will arise from crowding of lines. Where only plane-table sheets are available, a single composite map must be drafted.

All maps will be redrafted in the Washington office. Therefore, maps submitted from the field need follow only the requirement that all information thereon be accurate, legible, and subject to no confusion of detail.

(2) A compact systematic folio, preferably bound in covers, of range cross sections and other graphs shall be submitted.

(3) Field notebooks properly prepared as outlined above shall be submitted with the final report.

(4) Plane-table sheets properly numbered and labeled for identification shall be forwarded to the Washington office.

(5) All film exposed in the field will be developed in the Washington office and a set of prints supplied to the field for inclusion in reports. (Additional prints available on request.) All exposed features of sedimentation should be amply illustrated with photographs in the final report.

U. S. GOVERNMENT PRINTING OFFICE: 1939


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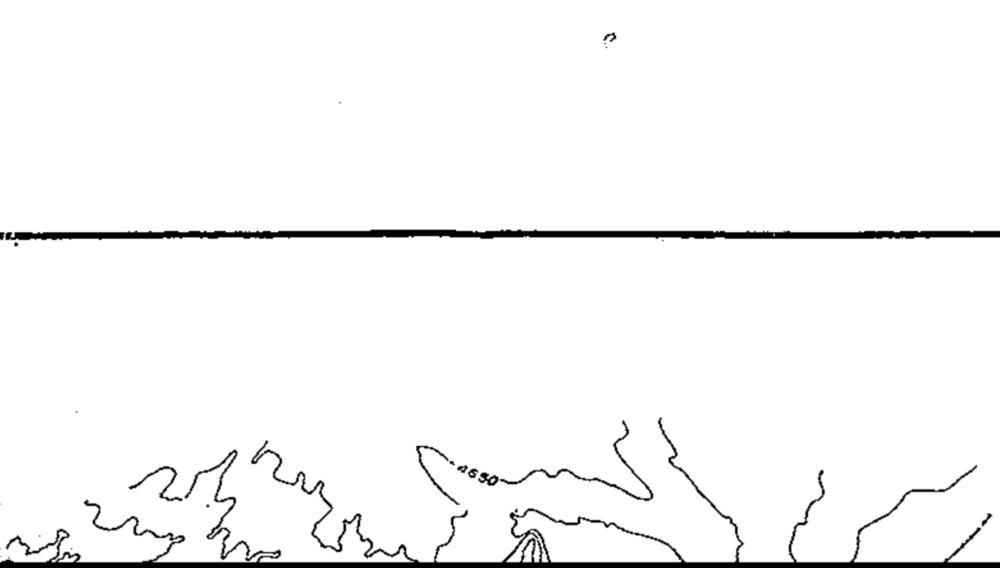
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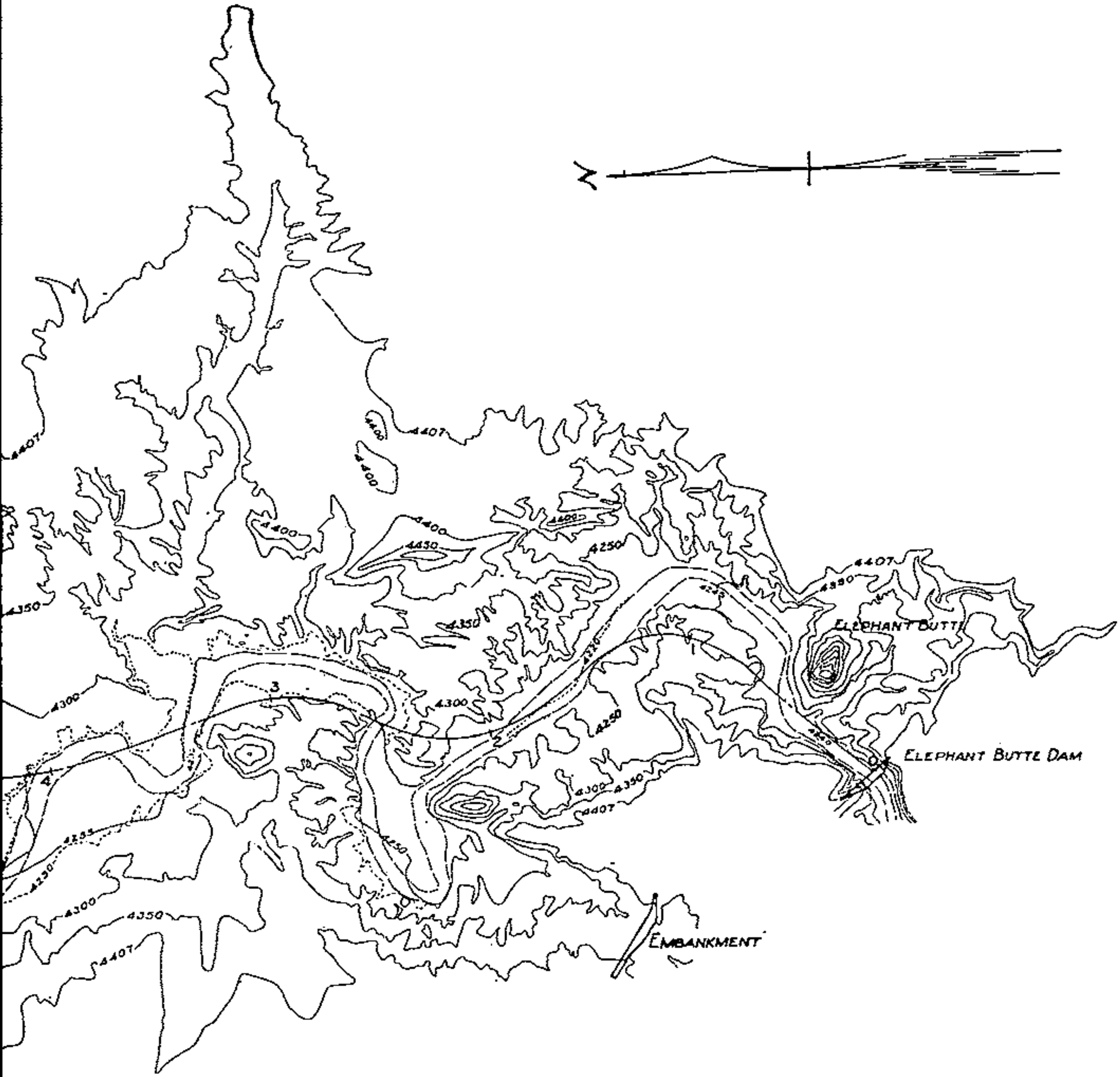


Notes:

Original surveys by Bureau of Reclamation 1903-1908

Elevations based on Rio Grande Irrigation Project Datum

For sea level datum add 43.3 feet

Present contours

Original contours

Original river bed

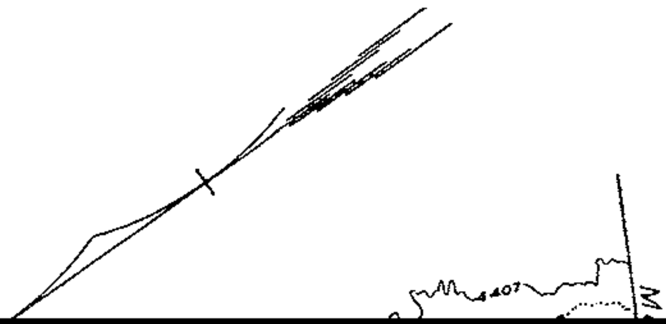
Scale in Feet

3000 0 3000 6000

Sheet 1 of 2

S-623

J.T.F.

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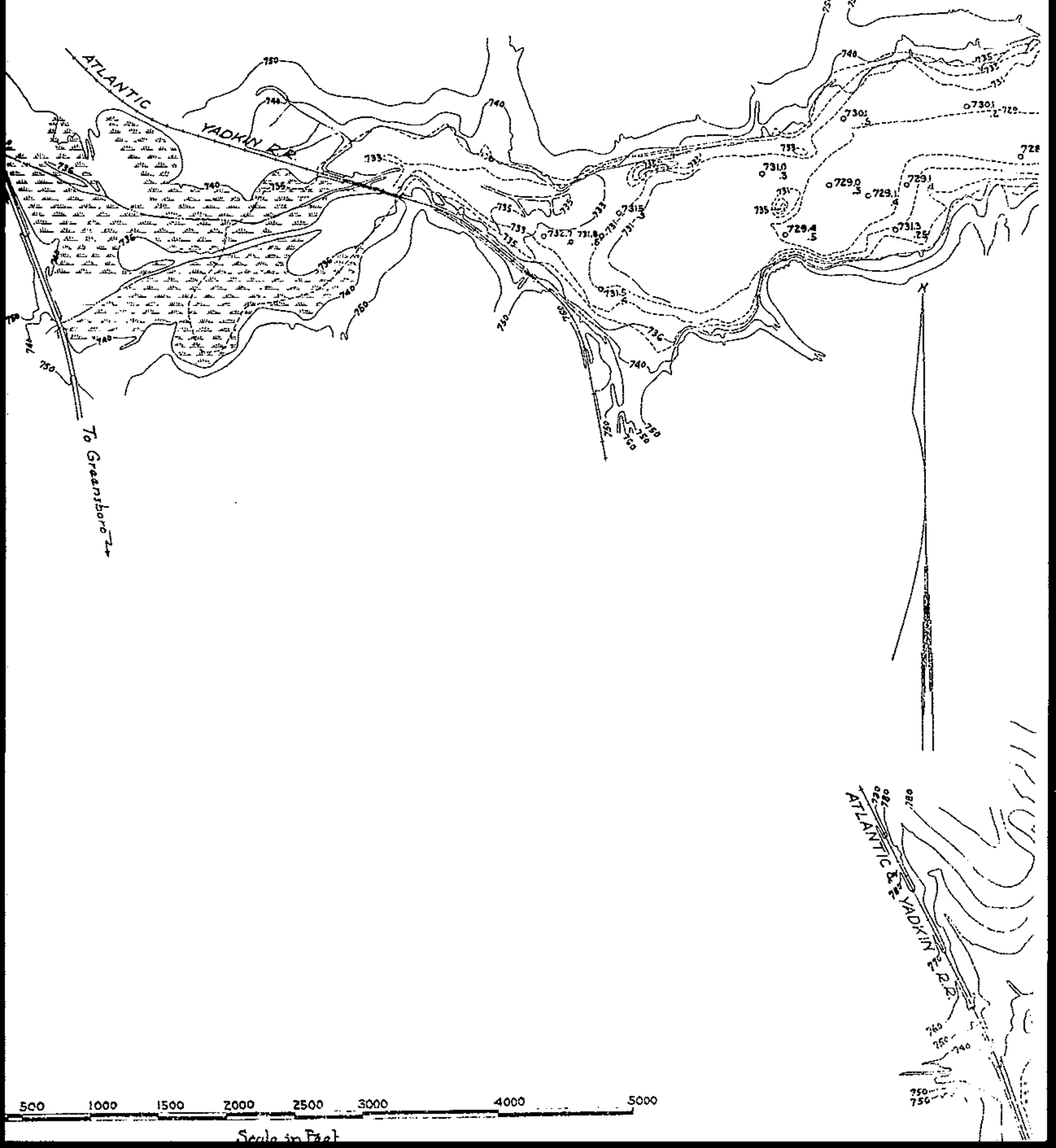
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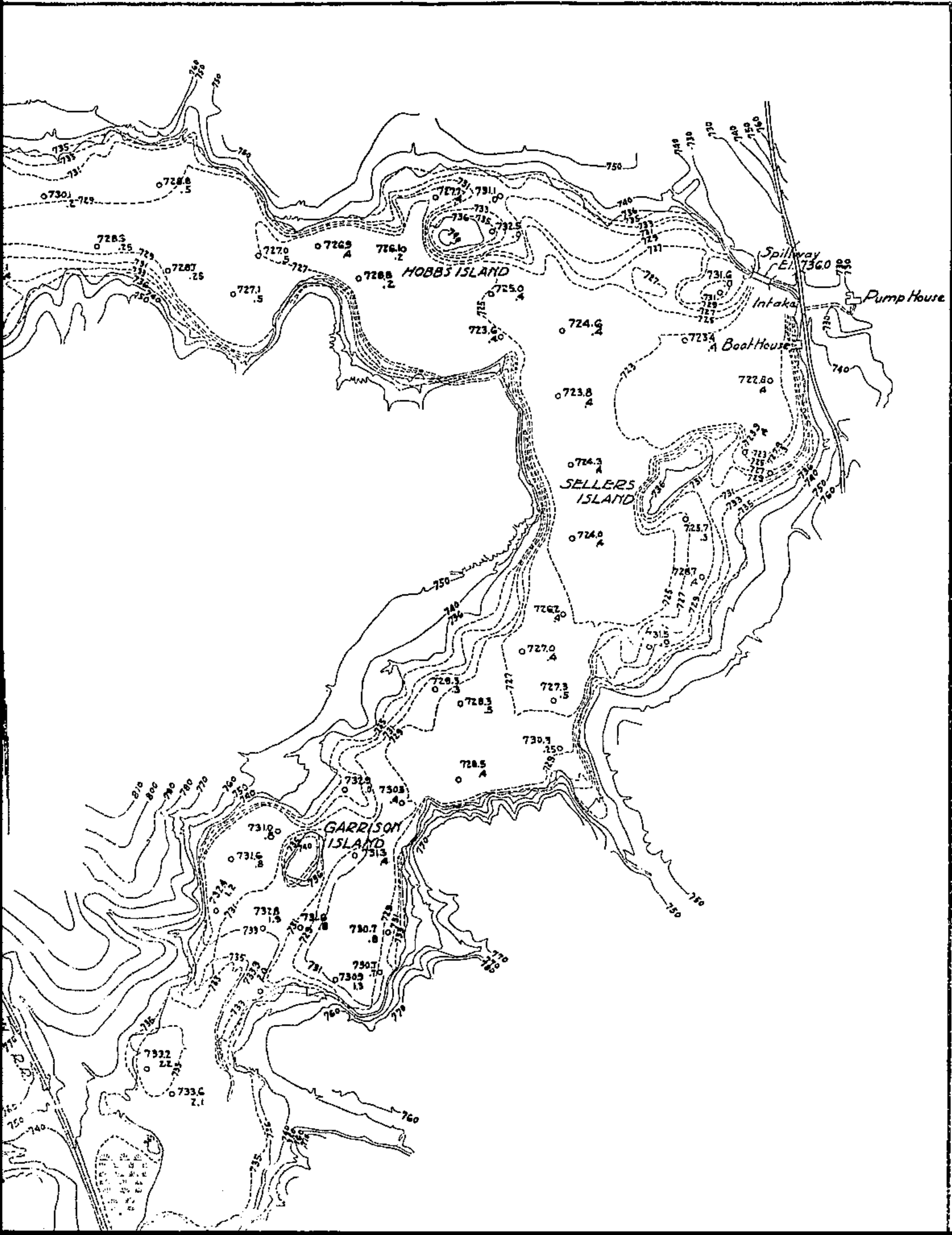
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SELLERS ISLAND
GARRISON ISLAND
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Intake
Pump House
Boat House

MARY FOSTER BRIDGE
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SR.
MUD
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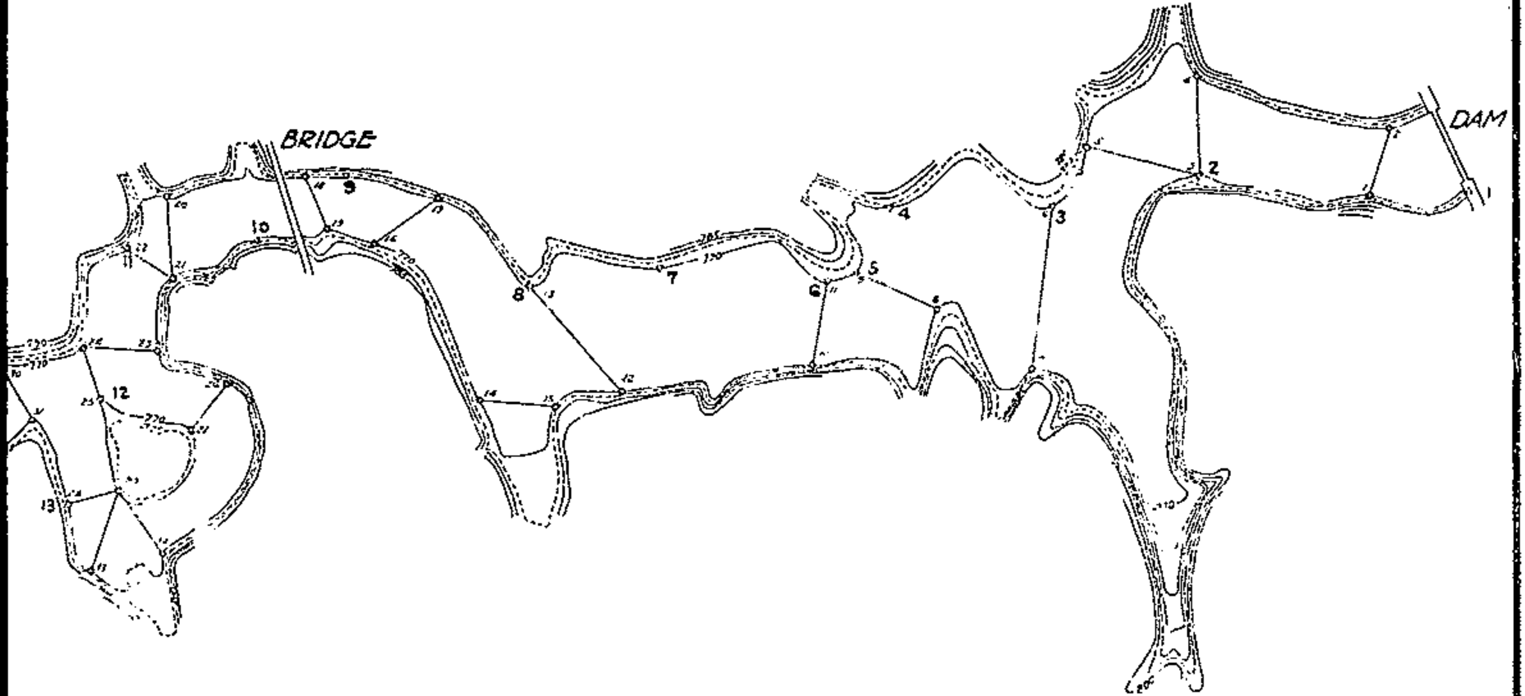

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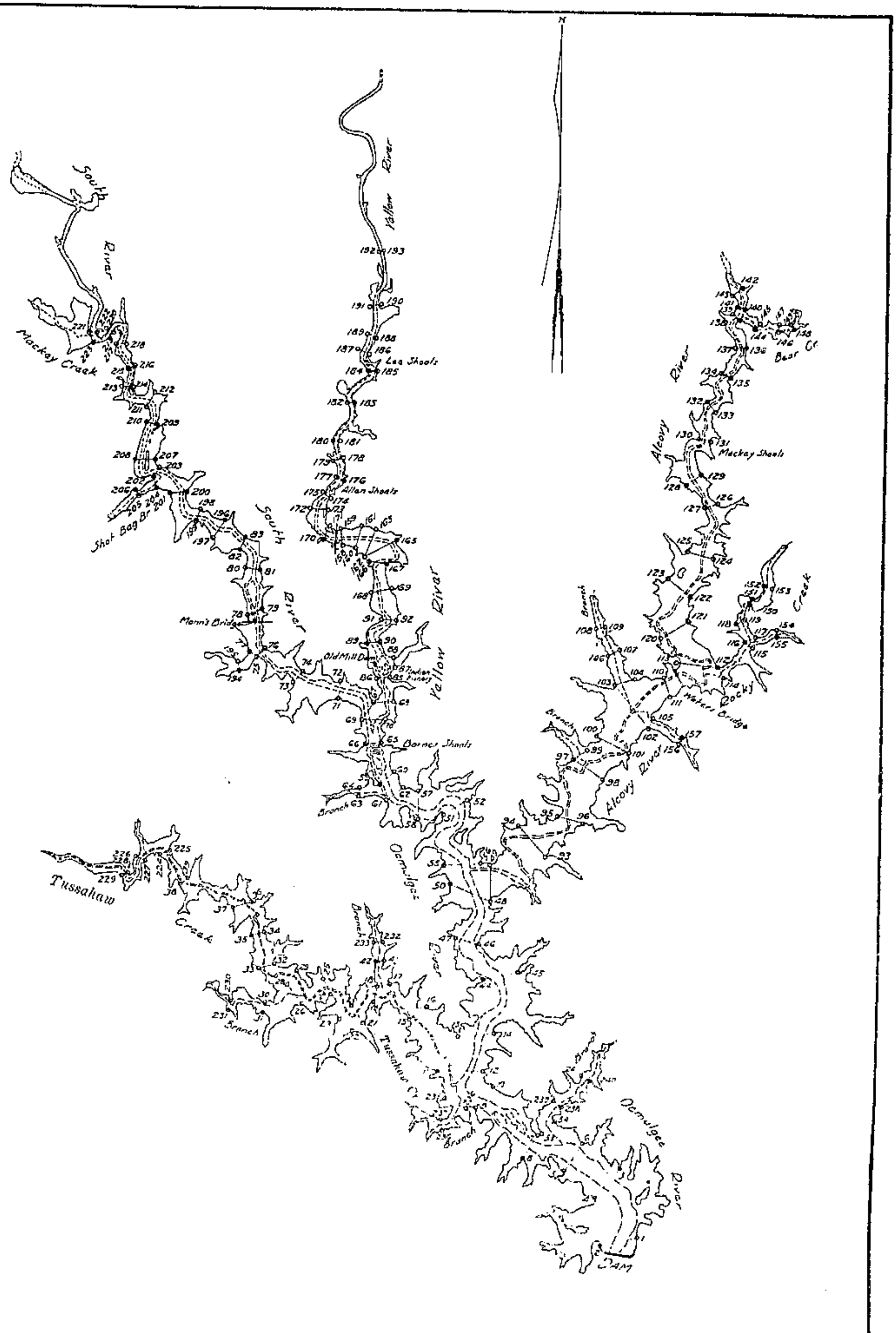
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Yellow River
Mackay Creek
Shot Bag Br
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Mann's Bridge
Old Mill Dam
Indian Fishery
Allen Shoals
Lea Shoals
Barnes Shoals
Branch
Ocmulgee River
Tussahaw Creek
Branch
Tussahaw Cr
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Mackay Shoals
Bear Cr
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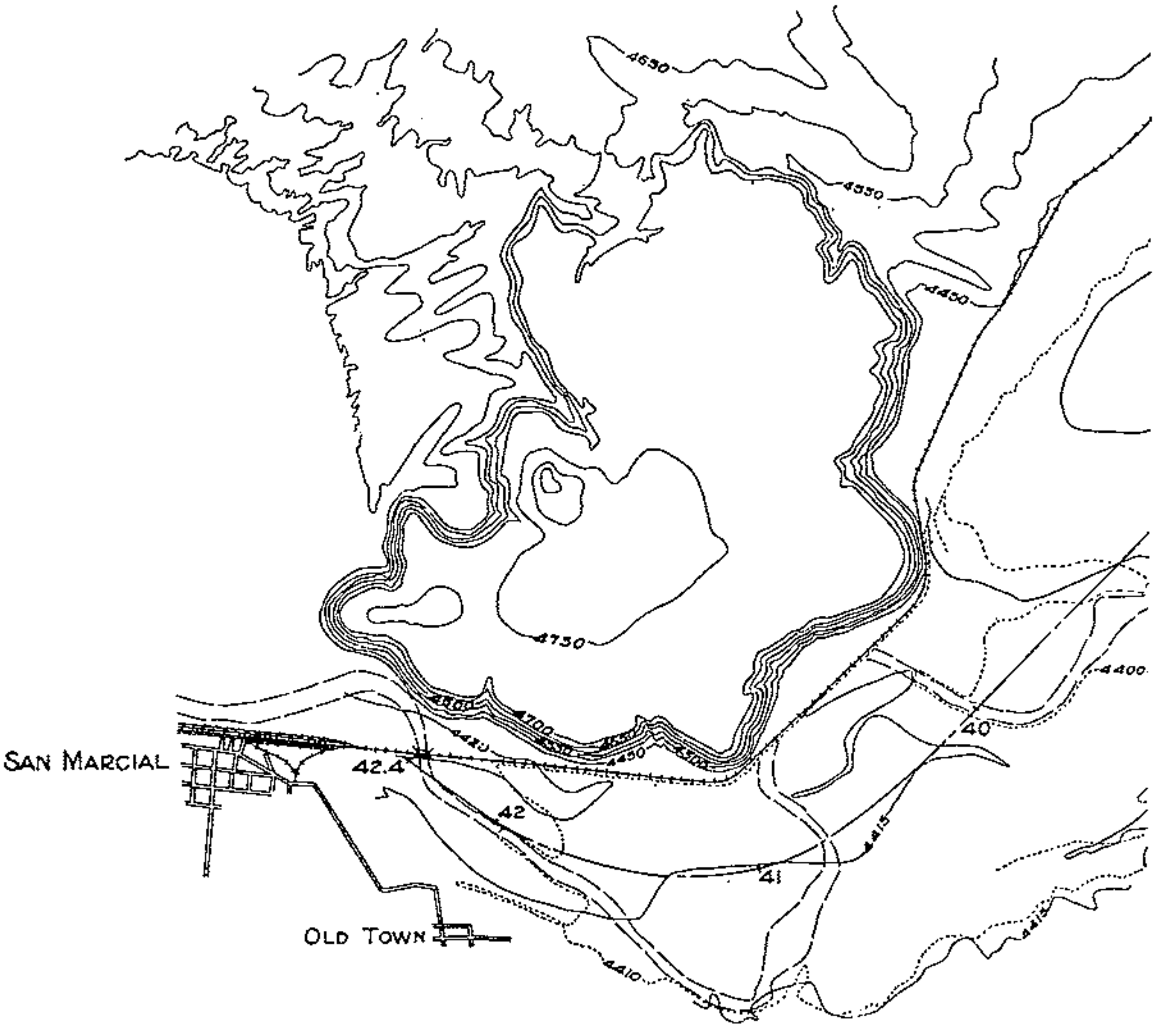
Waters Bridge
Rocky Creek
Alcovy River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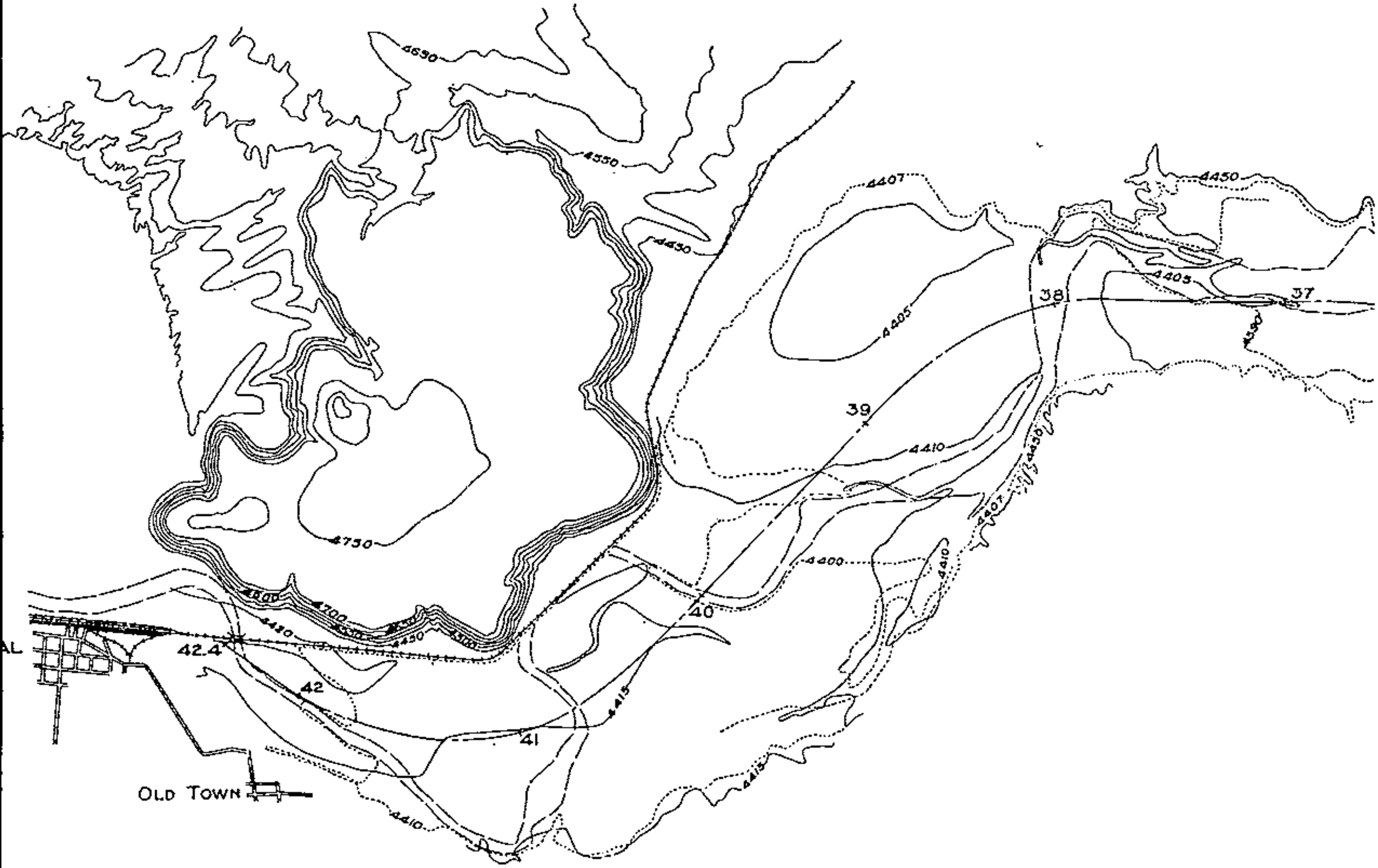

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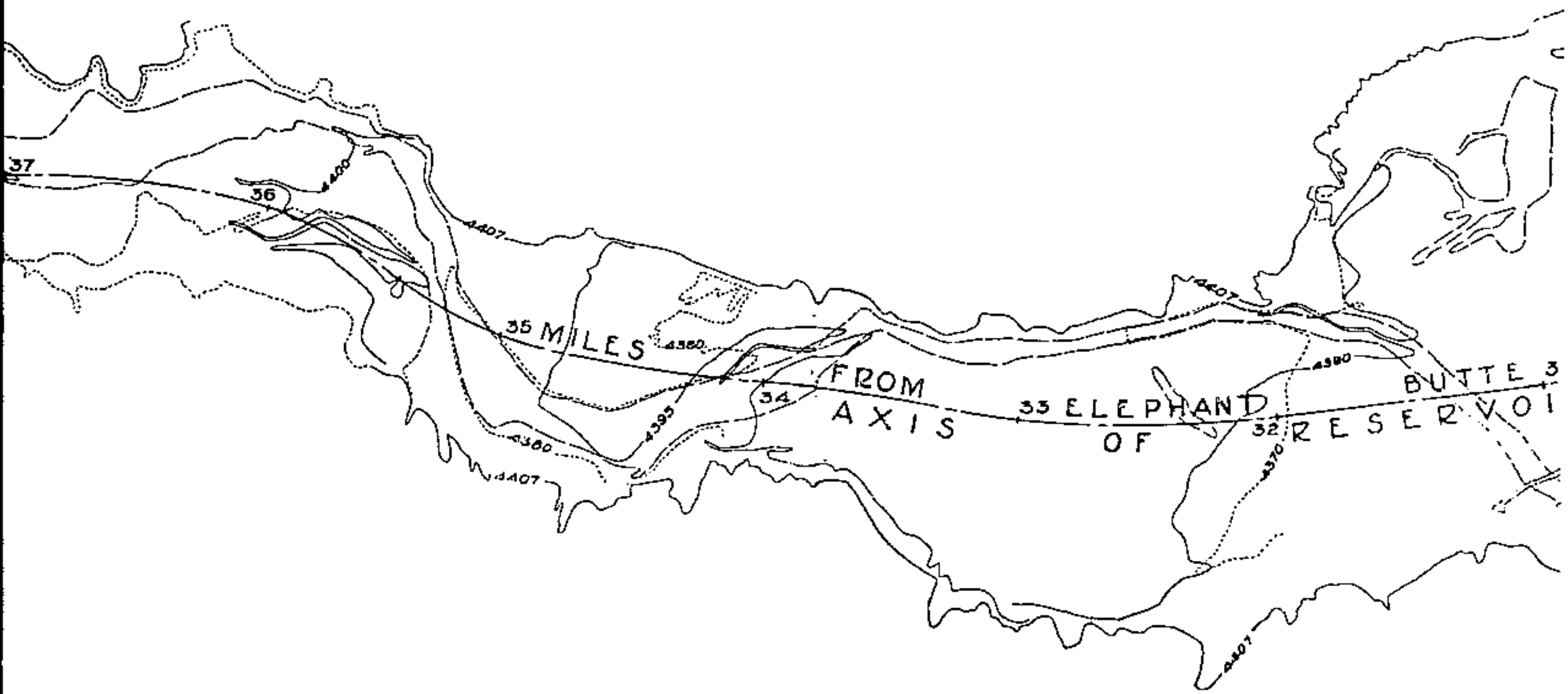

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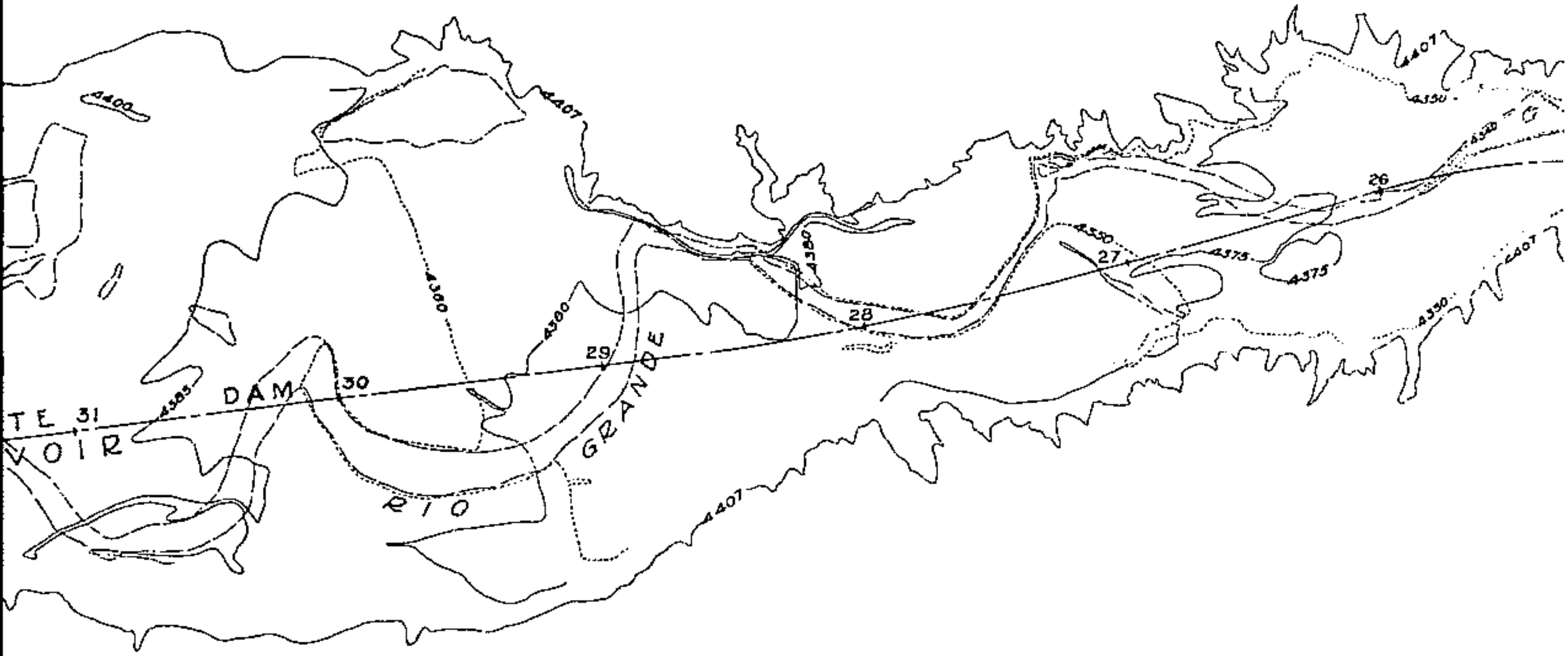

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Elevations based on Rio Grande Irrigation Project Datum
For sea level datum add 43.3 feet
Present contours
Original contours
Original river bed

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Sheet 1 of 2

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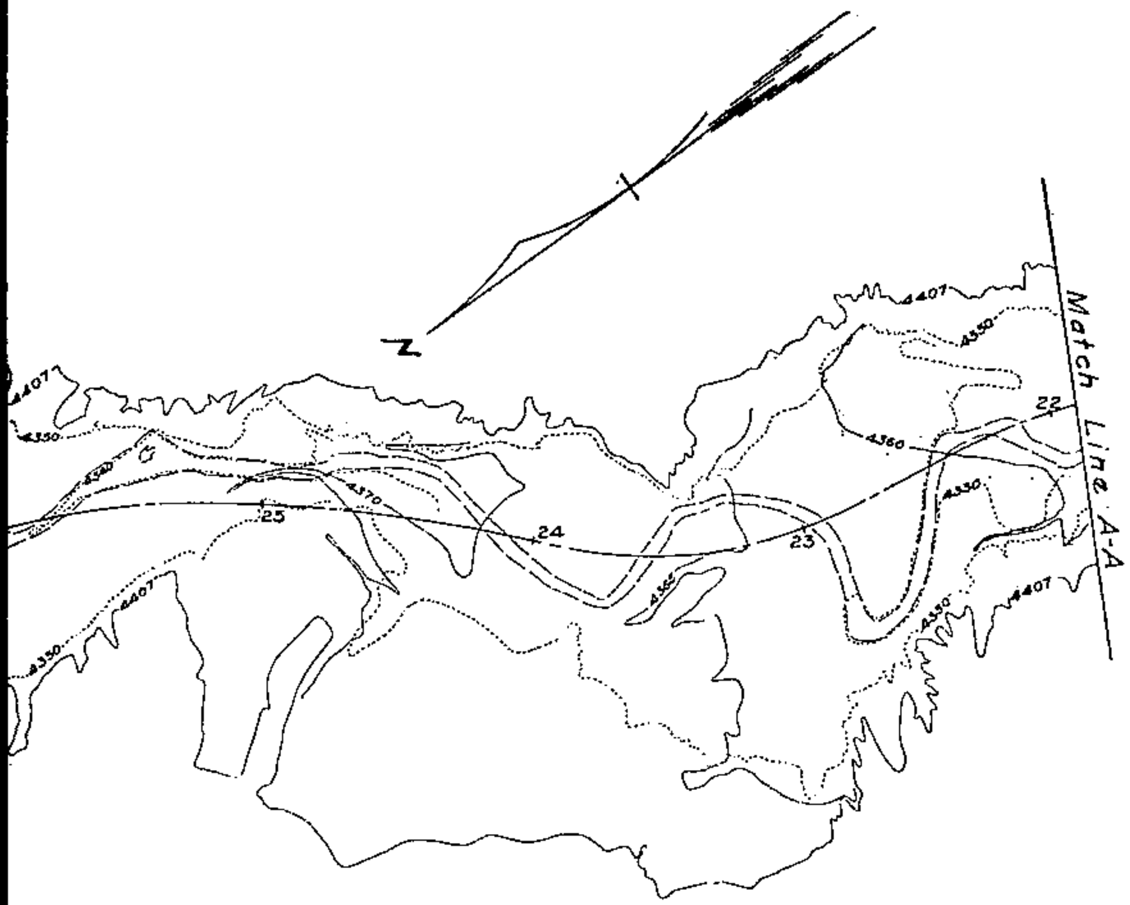


ELEPHANT BUTTE RESERVOIR
RIO GRANDE
NEW MEXICO

Resurvey Feb.-Apr. 1935

SOIL CONSERVATION SERVICE
U. S. DEPARTMENT OF AGRICULTURE
in cooperation with
BUREAU OF RECLAMATION
U. S. DEPARTMENT OF INTERIOR

Scale in Feet
3000 0 3000 6000

Prepared by
SOIL CONSERVATION SERVICE
DRAFTING SECTION
Dec. 11, 1935

Notes:

Original surveys by Bureau of Reclamation 1903-1908
Elevations based on Rio Grande Irrigation Project Datum
For sea level datum add 43.3 feet
Present contours
Original contours
Original river bed

Sheet 2 of 2

S-623

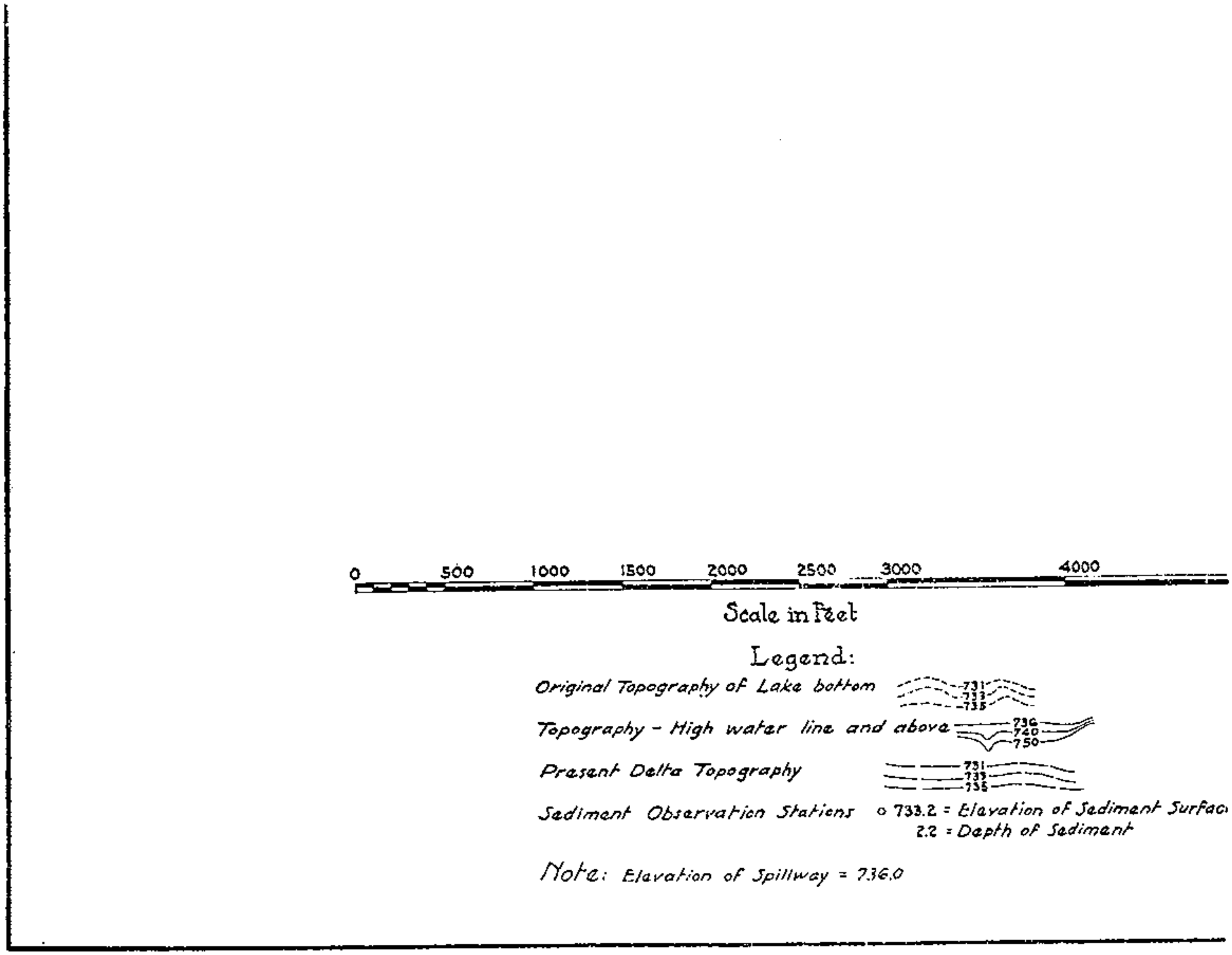


FIGURE 3.—Map of Greens

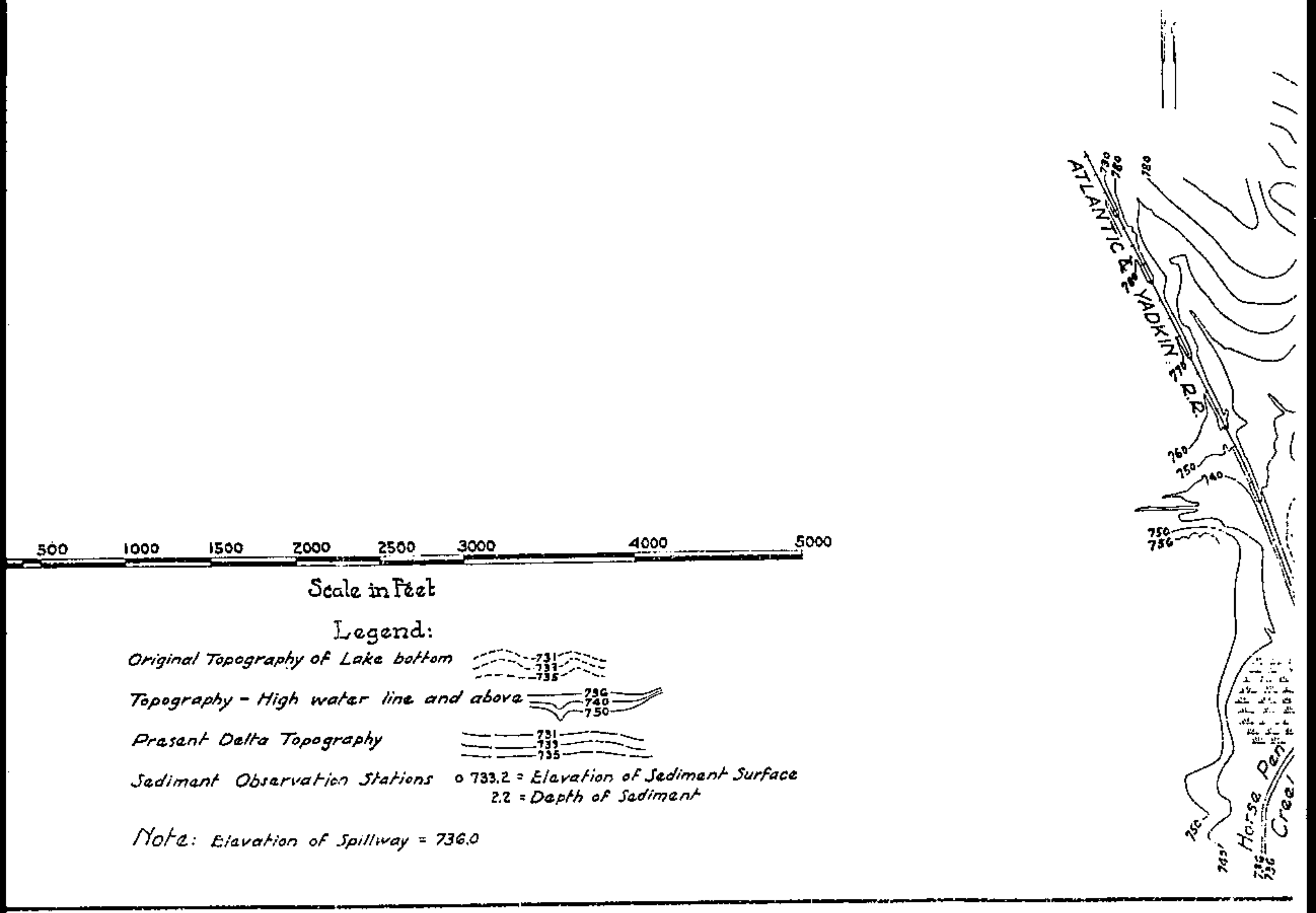
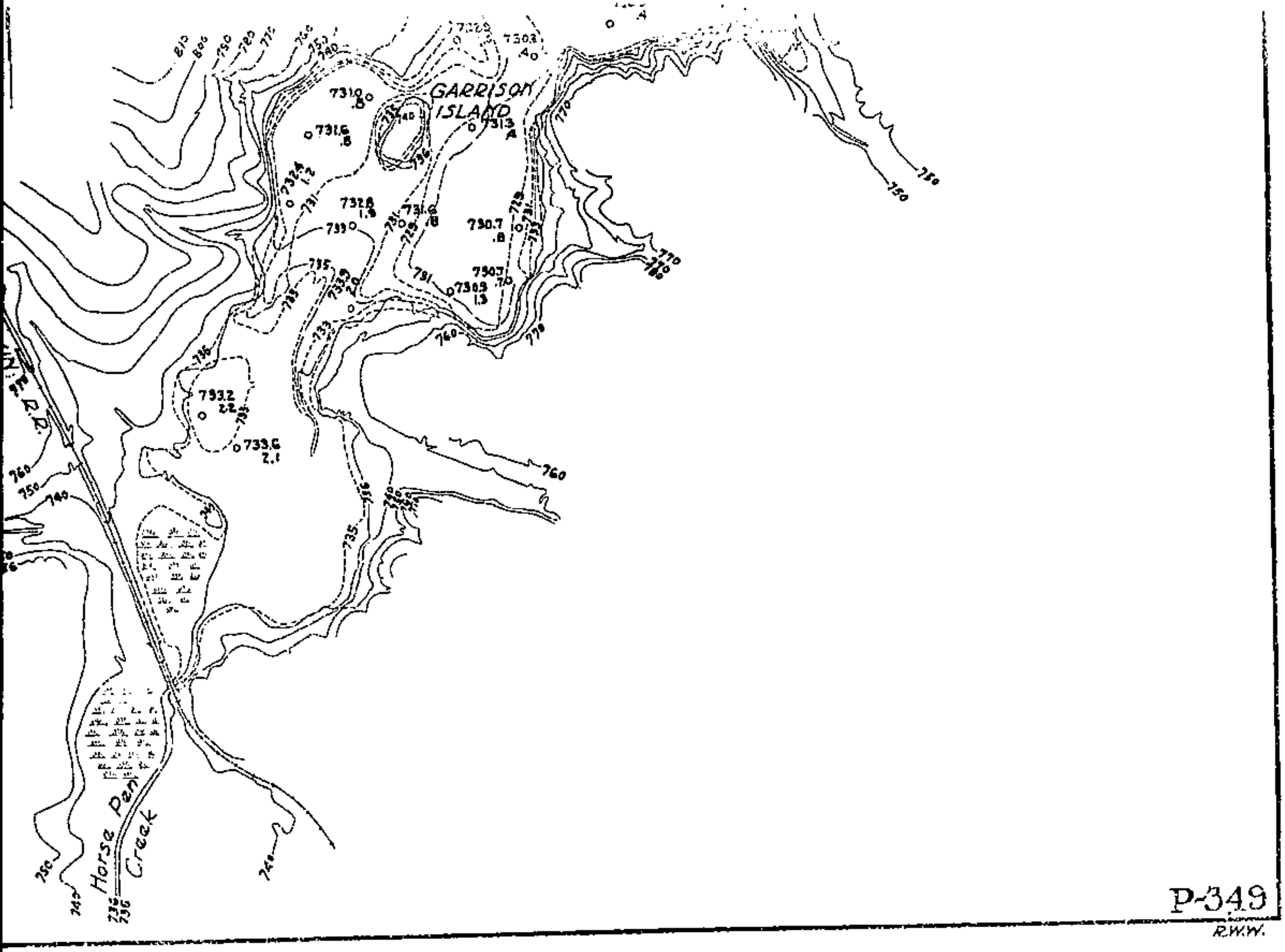


FIGURE 3.—Map of Greensboro, N. C., Municipal Reservoir and tributary streams, resurveyed



eams, resurveyed August [illegible]

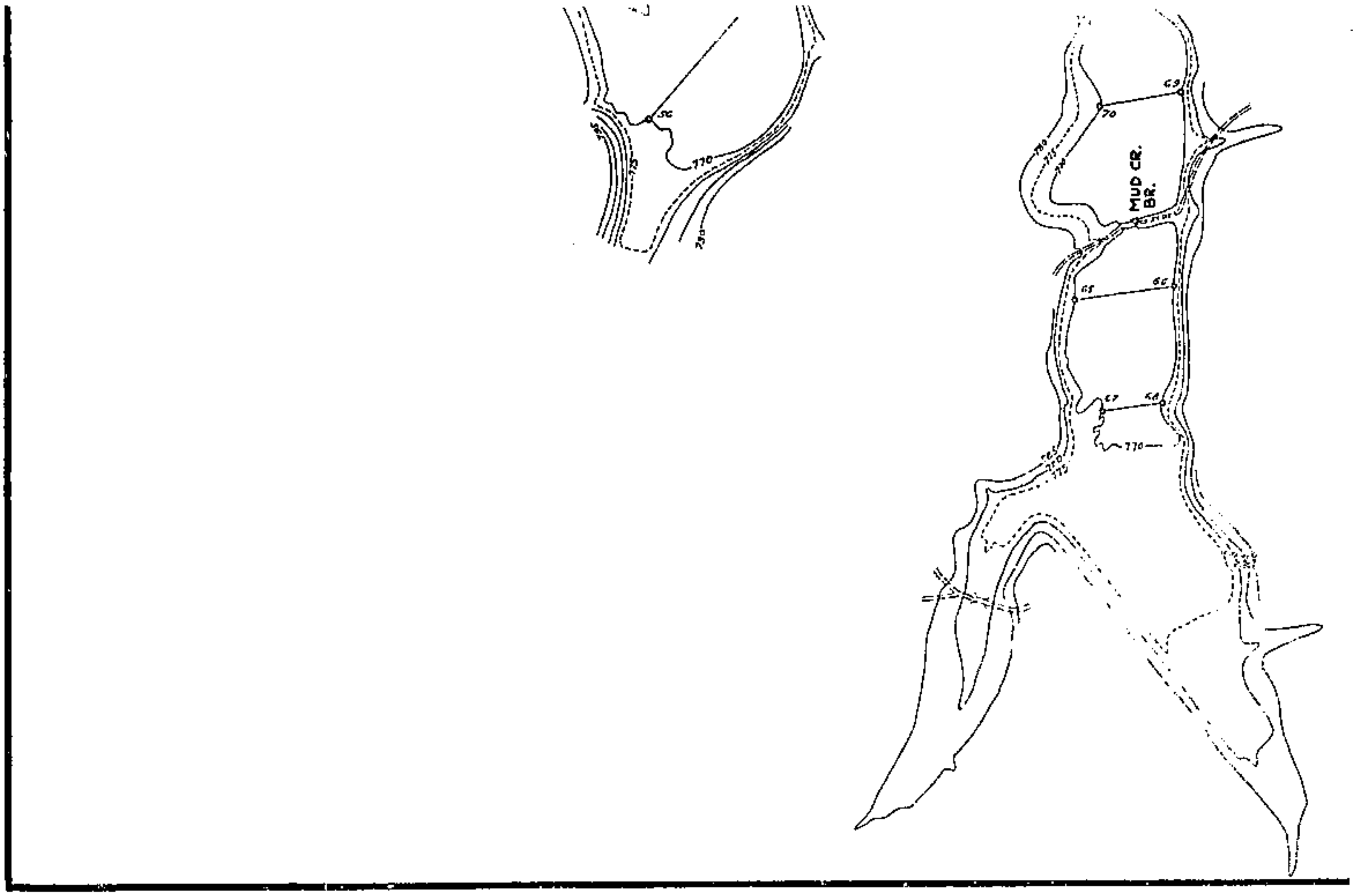
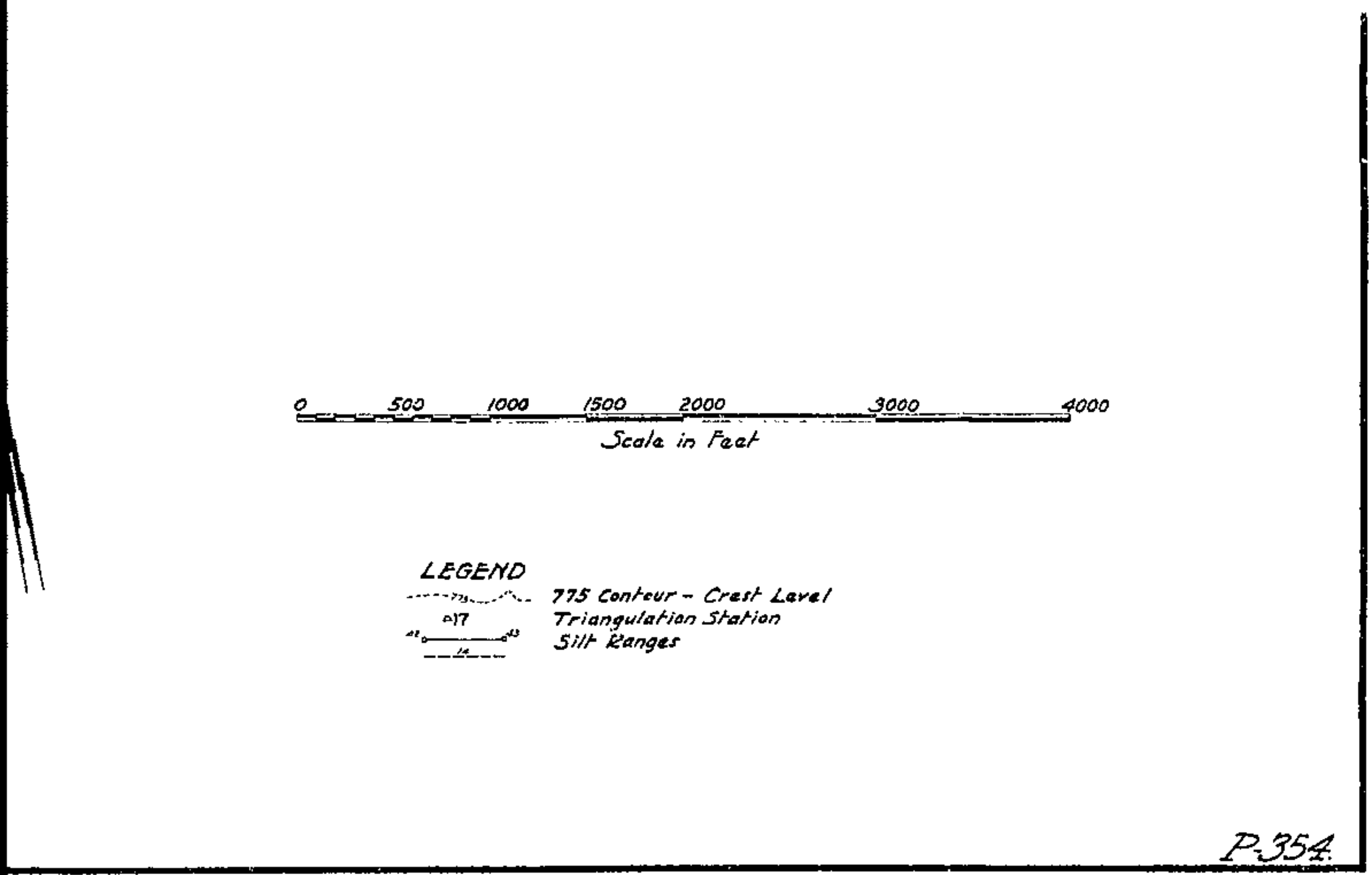


FIGURE 6—Map of Spartanburg, S. C.



l Reservoir, surveyed July August 1934.

80832°—39 (Face p. 56)

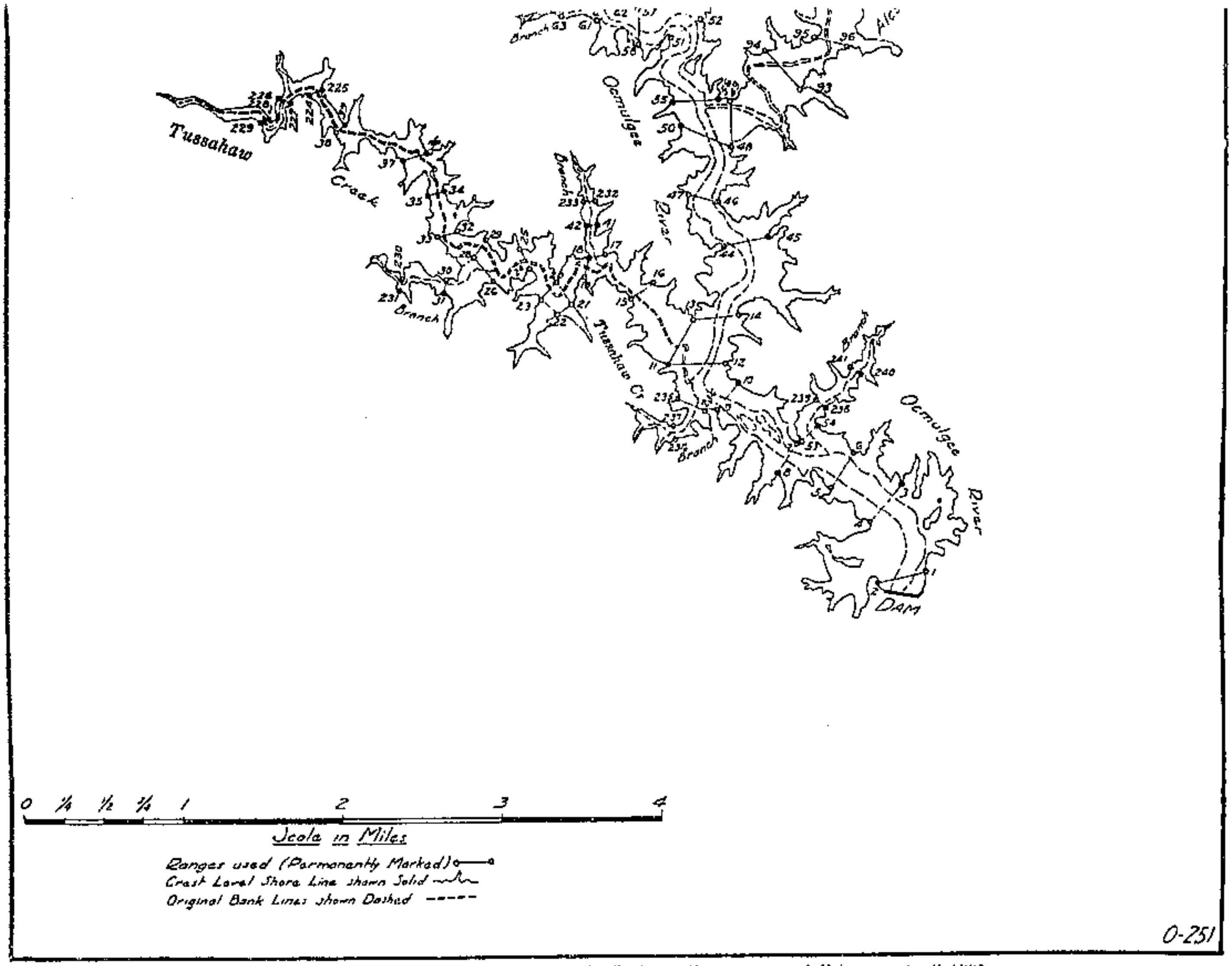


FIGURE 7.—Map of Lloyd Shoals Reservoir, Jackson, Ga., resurveyed February–April 1935

80832°—39 (Face p. 64)

END